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<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
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</thead>
<tbody>
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<td>Adil Sharag-Eldin</td>
<td>United States</td>
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<td>Turkey</td>
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<td>Veronica Soebarto</td>
<td>Australia</td>
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<td>Germany</td>
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<td>Korea</td>
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# Table of Contents

## Poster Session (Day3, December 18, 09:25 - 10:10)

### Session PA: Cities and neighbourhood development
- Study on the Sustainable Renewal of Poor Rural Communities of Southwest China .......................................................... 1
- Urban Biophilic Theories upon Reconstructions process for Basrah City in Iraq ................................................................. 9
- Design Science to Improve Air Quality in High-Density Cities .............................................................................................................. 17
- Green Space Factor In Modifying The Microclimates In A Neighbourhood: Theory And Guidelines ....................................................... 26
- The UK’s experience in mitigating climate change: a planned strategy or a learning curve? ......................................................... 35
- Energetic expenses of walls and roofs used in the metropolitan zone of Tampico, Madero and Altamira ........................................ 43
- Urban Physics for tomorrow’s Urban Design ........................................................................................................................................ 51
- Assessment of Solar Access in different urban space configurations in two southern latitude cities with mild climates .................. 61

### Session PB: Vernacular Architecture
- An Analysis of the Potentialities of Portuguese Vernacular Architecture to Improve Energy Efficiency .............................................. 69
- The influence of culture on energy consumption in Aboriginal housing in arid regions of Australia ......................................................... 77
- Evaluation of Environmental Control of Transitional Microclimatic Spaces in Temperate Mediterranean climate ......... 85
- The Cross Socio-cultural and Climatic Adaptation Aspects of the Peranakan Chinese House in Kelantan ........................................ 93
- Traditional Sustainability: Environmental Designs in the Traditional Buildings of the Middle East ............................................. 101
- Thermal Characteristics of a Vernacular Building Envelope ............................................................................................................................. 109
- Daylighting Analysis of Vernacular Architecture in Guizhou Province, China ................................................................. 117
- Changes in Culture and Architecture from Vernacular to Modern: M.P., India ........................................................................................................ 125
- Vernacular Ecology: Environmental Recreation of Ancient Dwellings in Southeastern Turkey .............................................. 133

### Session PC: Passive Design
- Morphological Variation Impact on Heating and Cooling Energy Consumption in Buildings .......................................................... 142
- Digital Process: environment analysis of intermediary spaces in the context of Brazilian modern dwelling ............................................. 149
- Zero Energy Solar-House Model for Isolated and Environmental Protection Areas in Brazil ......................................................... 156
- Development of Single Parameter to Rate Architectural Design for Green Building Certifications ............................................. 166
- Towards new design tools for integrating environmental criteria in the design process of architectural and urban projects in developing countries ......................................................... 174
- Eco building schools in remote places | Case study: Cunene, Angola ................................................................................................................. 182

### Session PD: Thermal comfort
- Integrating User Awareness and Behavior into Building and Product Design for India: Survey in Eight Giant Cities in India ............................................................................................................. 191
- Perception of Indoor Temperature of Naturally Ventilated Classroom Environments during Warm Periods in a Tropical City .................................................................................................................................... 199
- Thermal Perception of Users of Different Age Groups in Urban Parks in Warm Weather Conditions ................................ 207
- Environmental sustainability in scholastic facilities: an integrated assessment of building and food ........................................... 215
- Towards Sustainable Modular Housing: A Case Study of Thermal Performance Optimisation for Australia ........................................ 223
- Sustainable Habitat for Developing Societies: Learning from European Experiences ................................................................. 231
- "LEED-Oriented" Projects in Mainland China and the Indication to Sustainable Practice in Developing Countries .................. 239

### Session PE: Materials
- Survey on electrical energy use in Asia office facility and economic analysis through the application of Battery Energy Storage system (BESS) ................................................................. 247
- Performance of Phase Change Materials for Cooling of Buildings in Mild Climates ............................................................. 255
- Proposal of a Methodology for the Architectural Design of Timber Houses ..................................................................................................................... 262
- Window Components’ Heat Control versus Orientation under the Extreme Hot Climate of the UAE ........................................... 270
- Investigation of thermal resistance and bridging in examples of contemporary and vernacular solid wall architecture ................ 278

### Session PF: Vernacular architecture
- Diurnal Radiative Cooling of Spaces in Mediterranean Climate ......................................................................................................................... 286
- Measurement of Thermal Radiation Properties of Large Heating Equipment Using Infrared Thermography .............................................. 292
- Phantom Loads in Residential Projects in Medellin, Colombia ......................................................................................................................... 300
- Renewable Energy Application in Floating Architecture ......................................................................................................................... 308
- Analysis of daylight performance in classrooms in humid and hot climate ................................................................................................. 316

### Session PG: Passive Design
- Energy codes for Mediterranean Climates: comparing the energy efficiency of High and Low Mass residential buildings in California and Cyprus .......................................................... 326
- Architectural Design: Form follows sustainability? ........................................................................................................................................ 334
Session PA: Cities and neighbourhood development

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Auditorium - Knowledge Consortium of Gujarat
Study on the Sustainable Renewal of Poor Rural Communities of Southwest China

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ABSTRACT
Cities and counties in China experience unbalanced development as well as vulnerable economies and environments despite the rapid country-level progress. These poor villages thus face the enormous challenge of sustainable development. The government’s attempt of improving the situation through its “urban–rural integration” policy to promote the development of rural areas has helped achieve short-term objectives in building construction and some other aspects. However, this policy is a disaster for long-term development in rural areas. Specifically, only 5% of the rural areas in Southwest China, especially those located near cities, are suitable to the government’s policy; the remaining 95% of villages, especially those in remote areas, need to find their own ways to realize sustainable development.

This study combines the theories of sustainable development in China and other countries and proposes the use of the “endogenous development” concept to meet the development needs of poor rural areas. Under this model, the villagers can use the modified “traditional ways” to improve their housing conditions (i.e., space, materials, daylighting, and ventilation), public health circumstances, and financial and cultural situations. This study tests the theory using two case studies of the Yangliu and Ma’angqiao reconstruction projects and provides strategies for the sustainable renewal of poor rural areas of Southwest China.

Keywords: sustainable renewal, Endogenous development, poor rural communities, Southwest China

1. INTRODUCTION
The Chinese government invests in and provides preferential policies for rural areas. However, several of these policies are unsuitable for Southwest China, a multi-ethnic area with a considerably diverse and complex natural environment, which remains undeveloped despite the country’s rapid development. This study combines the sustainable development theories in China and other countries to introduce the concept of “endogenous development” that could solve the problem. The study likewise establishes a sustainable development framework for poor rural areas in Southwest China.

2. BACKGROUND AND PROBLEMS
The scope of the study includes Sichuan, Yunnan, Guizhou, and Chongqing in Southwest China (Figure 1). These four provinces have a total land area of 1,134,400 square kilometers (Wan, 2013). Southwest China is home to ethnic groups and minority nationalities, many of whom have a low educational level. This mountainous area with complex topography and bad transportation is frequented by natural disasters; such characteristics seriously impede the development of both its society and its economy.
2.1 Poverty Problems

The mountainous Southwest China has inconvenient transportation and low land-use efficiency. Its productivity level is relatively backward, and its agricultural structure is unbalanced. The villagers lack the ability to abandon the traditional agricultural model. Therefore, an increasing number of villagers go to large cities to seek jobs to feed their families; this phenomenon has caused villages to become empty and lifeless. The per capita net income of rural households of Southwest China is less than the average level of China (Figure 2).

![Figure 1: the scope of Southwest China](image1)

![Figure 2: Per capita net income of rural households by region in China](image2)

2.2 Environmental Problems

Villagers cannot determine an appropriate method for waste management in poor rural areas because of deficient knowledge on public health. As a result, solid and liquid wastes pollute land and water resources. The so-called solid white waste pollutes both soil and water. Non-treated waste can produce toxic substances that attend to the top of the food chain. This environmental problem seriously damages the liver and the nervous system of humans (Zhang & Yu, 2007).

2.3 Public Health Problems

Lack of consideration for health issues is a common problem across the poor rural areas in Southwest China. Villagers do not fully understand the importance of health, and this situation adversely affects people’s health and lives. For instance, burning firewood is the principal source of indoor air pollution; high indoor levels of PM10 in rural areas lead to several diseases, such as upper respiratory tract infection and asthma (Guo, 2005). Moreover, dry latrines that are extensively used in poor rural areas typically cause infectious diseases and zoonoses (Hu, 2009).

2.4 Building Renewal Problems

Various architectural forms follow unique regional conditions, such as those in the rural areas of Southwest China. However, traditional architecture lacks systematic ecological strategies and has technical problems with regard to anti-seismic design. At present, rural communities lack proper infrastructure and public service facilities; therefore, a suitable strategy for building renewal must be developed by comprehensively considering community planning and building design.

2.5 Government Policy Problems

Several important policies for rural development have been implemented in China, such as the 11th Five-Year Plan, which puts forward new countryside construction in 2005, and the Third Plenary Session of the 18th Central Committee, which emphasizes urban–rural integration as the fundamental
solution to rural issues in China. However, these policies insufficiently focus on poor rural areas with complex topography and deficient transportation and have thus failed to produce the desired effects.

3. A SUITABLE MODEL FOR RURAL DEVELOPMENT

Cities and counties of Southwest China have unbalanced development and extremely sensitive economic, environmental, and public health situations. Therefore, these areas face an enormous challenge in terms of sustainable development. The government has implemented the urban–rural policy to promote the development of rural areas and thus improve their situation. This policy is a means for officers to achieve the short-term objective in building construction and other aspects. However, this policy is a disaster for long-term development of rural areas because only 5% of villages, especially those counties near cities, are suitable for urban–rural integration; the remaining 95% of villages, especially those in remote areas, should determine their own means of realizing sustainable development (Qiu, 2007). Thus, endogenous development may be the appropriate model for poor rural areas in Southwest China.

Endogenous development entails “respect for the cultural identity, [wherein] people have the right to own their culture. . . . Humans are the power [and] also the purpose of development. In form, development should be generated internally; in purpose, development should serve the people” (Huang, 1988). Compared with the old rural development model, the theory of endogenous development is defined by three key points (Table 1): first, the shift in emphasis from inward investment to endogenous development, which promotes the development of resources found within the region instead of attracting investment from external sources; second, the shift in delivery mode for rural development from a top–down to a bottom–up approach; and third, the shift in the structure of rural development policy from sectoral modernization to a territory-based integrated rural development (Michael, 2011).

<table>
<thead>
<tr>
<th>Modernization</th>
<th>New rural development paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inward investment</td>
<td>Endogenous development</td>
</tr>
<tr>
<td>Top-down planning</td>
<td>Bottom-up innovation</td>
</tr>
<tr>
<td>Sectoral modernization</td>
<td>Territorially based integrated development</td>
</tr>
<tr>
<td>Financial capital</td>
<td>Social capital</td>
</tr>
<tr>
<td>Exploitation and control of nature</td>
<td>Sustainable development</td>
</tr>
<tr>
<td>Transport infrastructure</td>
<td>Information infrastructure</td>
</tr>
<tr>
<td>Production</td>
<td>Consumption</td>
</tr>
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<td>Industrialization</td>
<td>Small-scale niche industries</td>
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4. STRATEGIES FOR RENEWING POOR RURAL COMMUNITIES

Sustainability comprises three dimensions, namely, environment, economic, and social dimensions. Social sustainable development covers several issues, such as peace, security, social justice, and human settlement. A sustainable social environment focuses on health and education, and sustainable societies provide high levels of health and wellbeing to their members (Jeremy, 2003). The strategies for renewing poor rural communities are expounded in this paper from the social, environmental, and economic aspects according to the practical application.

4.1 Fully Respect the Autonomy of Villagers

In 2005, the Central Committee of the Communist Party officially launched the “construction of a new socialist countryside” policy as “a major historic task [that] relates to the Chinese modernization process in the future” (Xinhua News Agency, 2005). The local government has used unified management, as well as unified planning and designs, to merge smaller villages or to move them to another site. A “rural house standard atlas” was used for reference in building apartments, which were not easily changed according to the opinions and the difficult-to-meet needs of villagers. However, the endogenous development model suggests that designers actively listen to the villagers’ viewpoint and
follow their actual needs. Furthermore, in this model, the completed construction is evaluated through value orientation of villager groups. This approach provides an effective way to enhance public participation in architectural design and to improve the design quality of new residential communities.

4.2 Provide More Public Space

In the traditional development model, the local government prefers to support the construction of infrastructure, such as roads and bridges, and a “village center” serves as a venue for village leaders to hold their meetings. In endogenous development, more attention is paid to communication infrastructure than physical infrastructure. However, very few public spaces in most rural communities of Southwest China are available for interflow or for educating villagers of all ages.

4.3 Make Use of Local Material and Resource

In the pursuit of rapid economic development, the traditional development model often overlooks the effect of development on the environment. By contrast, endogenous development finds ways to increase the value of natural resources in rural areas through prescriptions. For instance, a regional climate analysis is conducted prior to the architectural design to find the most suitable passive design to minimize energy consumption of buildings. Local natural materials should be used during construction. Furthermore, construction wastes generated during the project should be recycled. Natural energy sources, such as solar energy and wind energy, are good alternatives to non-renewable energy sources. Architectural strategies that follow local conditions can reduce the negative effect of construction and development on the environment.

4.4 Develop Traditional Construction Techniques

Large-scale intensive house construction is difficult in poor rural areas with a complicated mountainous terrain. This terrain results in traffic inconvenience, which means that the transportation cost of industrial construction materials will be high. Meanwhile, low education level villagers are not easy to accept the specialized construction techniques. Traditional construction techniques have an irreplaceable regional advantage in rural areas. Thus, architects should investigate local traditional techniques and combine them with modern technology by using the “high science and low technology” concept for innovation and improvement, while preserving the technical mastery of the farmers.

4.5 Villagers Participation and Cooperative Construction

Local villagers are the main targets and movers of efforts toward the renewal of rural communities. During the period of house construction, villagers help each other by way of “labor exchange” and exert effort to build their own homes. Participation and cooperation enhance the cohesion of villagers; such relationship can be used as motivation for people to remain on their own lands and not fall for labor migration. On that basis, the semi-self-construction system and regional cooperatives were also established.

4.6 Proper Economic Strategies

The use of indigenous technology and local materials greatly reduces the purchasing and transportation costs in projects for the renewal of rural communities. The participation of the local workforce not only improves labor skills but also maximizes the value of labor because it encourages “labor exchange” and “volunteer work.” Therefore, local resources are effectively utilized by the most appropriate configuration in this region.

4.7 Environment-Friendly Strategies

The effect of the rural community development process on the environment should be reduced. Household wastes and those generated from production should be properly classified, and small-scale
landfills should be available for the disposal of such garbage. Sewage needs treatment before being discharged to rivers so that the water could be fit for everyday household use after sedimentation and purification processes. These strategies will help improve the ecological carrying capacity of the environment.

4.8 Public Health Strategies

Implementing ecological toilets and separating livestock are important aspects of public health strategies. In Southwest China, animals and humans share very limited land, especially in residential areas, because of economic and land conditions. By optimizing the residential design, rational space can be designed to separate animals from humans in rural communities. In addition, the establishment of eco-toilets will eliminate the “dirty and messy” status of traditional toilets and will significantly improve public health. People’s awareness of public health could also be enhanced by the promotion and popularization of related knowledge.

Generally speaking, the sustainable renewal of poor rural communities of Southwest China could follow the below steps:

1. Before the start of the design process, local climate, culture, and traditional techniques should be analyzed systematically.
2. During the design period, the practical needs of the villagers should be considered. Local materials and resource should be used, and traditional techniques should be improved by the “high science and low technology” concept.
3. During the construction period, villagers should participate and learn the modified techniques, which will be the ways to make their living.
4. After the construction period, the modified techniques and the renewal model should be publicized and promoted to improve the endogenous development of these areas.

5. CASE STUDY

5.1 RECONSTRUCTION OF YANGLIU VILLAGE

Yangliu Village has suffered a major geological damage in the 5/12 Wenchuan earthquake in 2008 when more than 85% of the rural houses were damaged. To avoid further geological damage, the village government decided to relocate the entire village to an open area near the Minjiang River. Architect Hsieh Ying-chun and his team carried out the overall planning and architectural design for the new site based on traditional customs and lifestyle. The construction work was successfully completed with good use of “collaborative construction” (Figure 3) and sustainable ecological strategies. The cost of per square meter is less than brick-concrete building in the same region (Figure 4).

![Figure 3: collaborative construction](image)

![Figure 4: cost comparison of reconstruction house and brick-concrete building](image)
The framework in the reconstruction of houses mainly used cold-formed steel, which has good seismic performance. The entire framework was connected by bolts, and the villagers were able to build it themselves after a one-time demonstration. The walls were filled according to traditional ways by using local materials. The houses looked identical because of the recycled old materials (Figure 5).

The framework has these other features:
1. Large-scale standardized production. The period of construction was short, which was very suitable for reconstruction;
2. Direct molding of the framework depending on the level of construction skills. This feature was suitable for villagers who built houses by themselves.
3. The openness of the structure. Villagers could easily add a room to the original building because of structural flexibility.
4. Similarity of this architectural framework to the traditional “through type timber frame.” Such similarity helped steer the reconstruction of houses toward having the same spatial form as that of traditional houses.

![Figure 5: framework of reconstruction house](image1)
![Figure 6: a double-sided hot-dip galvanized network](image2)

Architect Hsieh Ying-chun was also concerned about a building’s energy efficiency and sustainable development. Given that Maoxian is in the hot-summer-and-cold-winter area, the thermal performance of a building during winter should be considered. The main envelope of a house is composed of three layers of exterior walls: the first layer is made of local stone, which has strong local characteristics; the second layer is a double-sided hot-dip galvanized network with concrete-filled gap to effectively reduce the weight of the wall and to increase the strength of the structure to resist horizontal forces (Figure 6); and the third layer mainly uses insulating form board with grass soil, which is likewise used in the main structure of the roof. In this way, the house has good thermal performance. Compared with traditional houses, the roof and three layers of exterior walls can save 45.61% and 39.45% of construction energy consumption, respectively (Du, 2010).

Furthermore, the lesser energy consumption of cold-formed steel compared with clay bricks and the local availability of stones lead to effective control of CO$_2$ emissions.

5.2 Ma’anqiao Reconstruction Project

Ma’anqiao is a small and poor village located in the impoverished mountainous area of Southwest China, in the southernmost side of Sichuan Province near the Jinsha River and close to Yunnan Province. An earthquake in August 2008 severely damaged most of the village houses. Rebuilding materials (e.g., bricks) are too expensive for the villagers and are also difficult to be transported across the river. The remote location, poor accessibility, and resource limitations hampered the rebuilding efforts of the villagers. Considering that many other remote villages in Southwest China are similarly situated as Ma’anqiao, the challenge for development workers and rebuilders was “how to make use of local materials to create an anti-seismic, comfortable, and cheap [but sustainable] house.” The post-earthquake village reconstruction project in Ma’anqiao Village is the first comprehensive village...
demonstration project in the poor rural areas of Southwest China after the 2008 Wenchuan earthquake. Professor Edward Ng of the Chinese University of Hong Kong and his team from the Wuzhiquiao Foundation worked on the project for three years.

Before the initiation of the design work, the team conducted a series of survey and investigation in the village, communicated with the villagers to define the key problems, and conducted research to find an appropriate solution (Figure 7). This project provided several designs suitable to the needs of different family sizes. Villagers could choose the appropriate design according to their own needs.

The old rammed earth building has poor seismic performance because the building’s foundation is not solid enough, and the tensile strength of mud wall is insufficient. After a series of investigations, the team invented and proposed a series of anti-seismic designs and strategies. Timber frame inside the mud wall became an important part of an effective anti-seismic design, and a building’s foundation with appropriate size and correct cement mortar enhanced the integrity of houses. Bamboo strips, which are embedded into the mud wall, can bond the frame with the walls; some concrete belts were added into the wall to improve structural integrity and to avoid vertical cracking. Light lime and cement were added into the mud to strengthen the wall. Ramming tools were improved to pound the mud better by fitting them with iron heads (Wan, 2013). The resulting anti-seismic rammed earth building could satisfy the demand of seismic fortification in the area (Figure 8). The cost of per square meter is $32 which is only 20% of brick-concrete building in nearby village.

The traditional rammed earth houses in this village were ill ventilated and dark. Therefore, windows of proper sizes and cross ventilation were provided to improve daylight and natural ventilation (Figure 9). Biogas has since then been used to turn waste into fuel for lighting and cooking. Water cellars were built to supply clean water from the nearby spring instead of people directly collecting “dirty” water from the river. In addition, storm water was naturally channeled to the land.

After the rural houses have been reconstructed for basic living needs, a village center with a clinic,
reading room, kindergarten school, shops, and other facilities was built to provide public space and to make its facilities available to the villagers. The village center could also function as an ethnic cultural exhibition center and was built in a round yard because Dai and Yi people prefer dancing together in a circle to celebrate festivals or for entertainment (Figure 10). This yard has become a public communication space and could maintain the minority culture of the village.

As in the Yangliu Village, the villagers of Ma’anqiao were employed in the reconstruction process. Given the effective, economical, and easy-to-learn anti-seismic strategies, the villagers were able to build their homes by themselves without hiring a contractor and without using complex technology. The occupied houses were also inexpensive and easy to build and repair. In this way, the villagers built anti-seismic rammed earth houses and learned an economical way to make their living. The idea of the project was to transfer knowledge and skills during the construction process rather than merely teaching the villagers using drawings.

5.3 Discussion

The case studies show that both of reconstruction projects fully respected the traditional cultures and the autonomy of villagers and also made rational use of local materials and local technology to rebuild the rural communities. The concept “collaborative construction” not only provided an opportunity for the local labor force to learn new skills but also reduced the economic pressure on house construction. The two cases also considered the reduction of environmental and ecological damage in the entire process. Case 2, in particular, was an overall reconstruction project of a community, and its supporting facilities (i.e., construction of village center, setting up ecological toilets, and promoting public health awareness) have good social effects. The sustainable practices of Village level (i.e. the orientation of houses should respect to climate, rain water harvesting system and water supply etc) and settlement level are also important aspects for this study. Due to the space constraints, the related strategies will be discussed in the further study.

6. CONCLUSION

Endogenous development emphasizes the concept of sustainability and focuses on the importance of humans living in rural areas. Endogenous development suggests a self-sufficient, regional characteristics-based model that is suitable to the situation of poor rural communities in Southwest China, which have poor transportation and backward economy. This model can also reduce the communities’ dependence on inward investment by emphasizing the use of local resource and traditional core values. The discussed strategies could provide a systemic way to further study sustainable renewal in the poor rural communities of Southwest China.

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Urban Biophilic Theories
upon Reconstructions process for Basrah City in Iraq

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ABSTRACT
Basrah is the most beautiful part of Iraq. In terms of size, it is the second largest city after Baghdad. For more than 25 years, Basrah has almost constantly been at war or been in an aggressive situation. Three major conflicts have dominated, from 1980 to 2003. The wars have brought great suffering to the Basrah population and city. The bombing caused great material damage. Today with reconstruction process the city require to take a stable process of reconstruction by using environmental codes in urban planning and design which offer an exciting opportunity to achieve environmental, social and economic benefits. The concept of biophilia deserves a deeper explanation. The hypothesis is that this affiliation leads to positive responses in terms of human performance and health even emotional states. The new movement aims to create environmentally friendly, energy-efficient buildings and developments by effectively managing natural resources. This path will discover a far deeper integration of nature with the built environment and the potential synergies in exchanging energy and nutrients across the human-nature interface. The research will take in reading different experiences from 1980 until now, in which we will try to put all practical consideration necessary to be able to select competent urban and architectural elements adequate to Basrah condition.

INTRODUCTION
An urban settlement, town or city, is one of the primordial and predominant expressions of human sociability on a territorial basis. The outward, visually perceptible manifestation of the complex, multiform social structure that constitutes a town is the three-dimensional plastic townscape [Acta Tongressus madviciani 1958]. A sustainable city is organized so as to enable all its citizens to meet their own needs and to enhance their well-being without damaging the natural world or endangering the living conditions of other people, now or in the future [Herbert Girardet 1999]. Arid zones are characterized by various conditions that can be affected by different combinations of physical determinants. Planners must decide which conditions are desirable and adopt criteria designed to maximize them in selecting the best site for a new settlement [Gideon Golany 1977]. The region of Basrah, the city of Sinbad, is, some would say, the most beautiful part of Iraq. It is Iraq’s second largest city and principal port. Its commercially advantageous location, localize near oil field. In 1948 many oil refineries have been built in the city. It is an area of countless birds and a variety of animals, full of trees and gardens and canoes.
gliding on the mirror-surfaces of calm lagoons [Amjad Almusaed 2004:14]. The human being entered the third millennium without the hope of achieving permanent peace on our beautiful earth, sustainable development and equality for all. We must seek what we have in common, namely, codes of understanding [Amjad Almusaed 2004:11]. A biophilic city is a healthy city, a city with abundant nature and natural systems that are visible and accessible to urbanities. It is certainly about the physical conditions and urban design parks, green features, urban wildlife, walkable environments, but it is also about the spirit of a place, its emotional commitment and concern about nature and other forms of life, its interest in and curiosity about nature, which can be expressed in the budget priorities of a local government as well as in the lifestyles and life patterns of its citizens. [Timothy Beatley 2011:13]. Natural and biophilic elements require being significant in everything and anything we design and build, from habitations, schools and hospitals to neighborhoods and urban configuration, to street and road structures and larger urban- and regional-scale design and planning. One of the classics of town and country planning is a garden city movement which it founded and inspired, has had a profound influence on town planning throughout the world, though its essential proposals are only now beginning to be properly understood and applied. Garden City history is that it carried further than Letchworth the technique of civic design and architectural harmony, and in the organization of its shopping center and factory area, it conducted interesting experiments which merit careful study by all who are concerned with the economics of large-scale development [Ebenzer Howard 1918:2]. Garden City is a Town designed for healthy living and industry; of a size that makes possible a full measure of social life, but not larger; surrounded by a rural belt; the whole of the land being in public ownership or held in trust for the community [Ebenzer Howard 1918:5].

There are several obstacles prevent us to achieve a biophilic city and/or neighborhood, and many interruptions in contemporary life navigate as far afield from nature. Such technological interruptions as digital communications devices are often seen as substantial permanent factors in our rising interruption with the natural ecosphere. Biophilic cities reflect a humility that understands the wisdom of nature and natural systems and the need to learn from them and model design and planning after them. McDonough is famous for imploring us to design “buildings like trees, cities like forests.” A city the functions like a tree is a model for our time, as we imagine cities that are carbon neutral and energy-balanced (that produce as much power as they need and live within the limits of current solar income), that are zero-waste, and that integrate and celebrate diversity (from which cities will become more resilient in the face of climate change and a highly dynamic world) [Timothy Beatley 2011:49].

**CLIMTE CONDITIONS IN ACTING THEATER**

The average temperatures in Basrah range from higher than 48 degree ºC in July and August to below freezing in January [Gideon Golany 1977:6]. The summer months are marked by two kinds of wind phenomena: the south and southeast, a dry, dusty wind with occasional gusts to eighty kilometers an hour, occurs from April to early June and again from late September through November. Basra climate is hot, dry summer, cold winter, and a pleasant spring and fall [Daniel E. Williams 2007:32]. Roughly 90% of the annual rainfall occur between November and April, most of it in the winter months from December through March [Amjad Almusaed 2004:12]. The remaining six months, particularly the hottest ones of June, July, and August, at approximately 32 ºC, air dry. The influence of the Arabic Gulf on the climate of Basrah is limited. But near the gulf the relative humidity is higher than in other parts of the country. Most nights are clear in the summer, and about one third of the nights are cloudy in the winter [Amjad Almusaed 2004:13].

**PROBLEM PROPOSED**

There were two major catastrophic actions caused a great environmental catastrophe over Basrah
city from 1980 until now. The first starts after the terrible consequence of the Iraq–Iran war and recently USA attack over Iraq the urban green covering disappeared from large areas of the city, beside the extension of the city development axes over the green areas. The negative effect of the heat island phenomenon over the city area, consequently the human’s thermal comfort becomes more perceptive [Amjad Almusaeed 2004:176]. Other action was after the decision of the Iraqi regime over the south Iraqi marshes, which is located in the north part of Basrah city. The Mesopotamian Marshlands, nearly destroyed in the 1990s, have been partially restored but remain at risk. The Mesopotamian Marshlands are the largest wetland ecosystem in the Middle East [William J. Mitsch et al 2010]. Construction of numerous dams, water diversions and hydropower facilities on the Tigris and Euphrates Rivers over the past century and the deliberate draining of the marshes by the Iraqi regime in the early 1990s had almost destroyed the wetlands by 2000 [Aoki, C. and Kugaprasatham, S. (2009)]. Iraq’s southern marshes were a historic area, which had been a traditional hideaway for rebels. They were the largest wetlands in the Middle East, and some believed they were where the first human civilization began.

![Image of the southern marshes before and after Saddam's campaign of destruction](Herbert Girardet 1999)

Ecosystem recovery, however, has been seriously undermined by a severe drought (2008-2010) and uncoordinated water-related developments in the Tigris-Euphrates basin [Garsteck and Amr 2011]. The lack of a water sharing agreement between riparian countries and potential declines in Euphrates flows are a major threat to the wetlands’ survival [Herbert Girardet 1999]. Today we can observe clearly the negative effect of urban heat island in the center of Basrah city, precisely in physical frameworks of the city, where we can detect a typical phenomenon with a large negative effect for the period of summer heating that is a natural thermodynamic phenomenon. International sanctions are supposed Iraq in 1990 prevented the development process of the civil city requirements. Therefore the city requires many civil elements. The major negative acting is:

- Basrah is a rich petroleum city; therefore city development axes are under governor petroleum minister control.
- A bad city zoning after 1989’s reforming
- The city today is in a bad condition, where the main urgent requirements are:
  - A huge requirement for residential units for more than 1.5 million inhabitants
  - Efficient social and cultural zones
  - Additional open green areas
• Efficient management of vernacular buildings existent
• Competent and suitable civic centers and arteries

Sustainable cities are created by people who are knowledgeable about sustainable solutions. Decisions about sustainable development made by people whose have knowledge of the opportunities and implications inherent in sustainable choices. Decision makers can only choose sustainable solutions if they know they exist. Arid settlement and development in virgin areas require, as we noted, vision and pioneering spirit or ideological motives in the young, dynamic settlers for quite a long time after its initiation [Golany, Gideon S. 1995:4].

DISCUSSIONS AND RECOMMENDATIONS

Good stories and narratives are crucial to change in the future. Key questions are therefore:
• How town’s functions do is that we make a difference in the city?
• What visions they have for how they can and will contribute to the city in the future?

We are looking to condense and in outline form / imagery to translate into a strategy proposal [UNITED NATIONS CONFERENCE ON HUMAN SETTLEMENTS (HABITAT II)]. Understanding the natural history of a city helps us to see cities as ever-changing, ever-evolving palettes of life [Timothy Beatley 2011:14]. The study aims to achieve an overall development strategy with the following strategies:

Activation of vernacular concepts of urban texture structure

Where vernacular habitat units are compact with interior courtyard; the streets are sinuous and pass through houses volumes. The shady interior courtyard has the effect that the rooms do not communicate directly with the overheated air outside, but through intermediate buffer spaces. Windows are often protected from the appalling [Amjad Almusaed 2004:23].

Moving towards a compact urban city

A compact form can reduce the length of utility networks, the maintenance they require, and the expenditures of energy and thereby prove economical. However, such a form mandates special designs that may increase construction cost [Golany, Gideon S. 1995:16]. It is necessary to create a more judicious urban microclimate than that dominant in the neighborhoods. They have to reflect the requirement for verticality (as opposed to horizontally) in the conceptual process of urban structures; this could involve some subterranean construction.

Implementation of a Linear City model

In old regions of the city we can implicitly, the concept of the linear city to rebuild and recover the deteriorate regions of the city, in a new ecological one that can go beyond the laws and restrictions of Iraqi petroleum ministers, where the main feature of the linear urban form is its ability to deal with the rapid and efficient mass movement of people and goods within and between cities. A further quality of the linear structure is its ability to deal, in theory, with infinite growth. Fig. 2 shows the possible extension in linear of the city by axes and the positioning of civic centers.
In this context, it be required to respect the following parametric factors:

- Divide Basrah in a great main center includes all private and public buildings, and many other small centers. The centers can be connected through a large classified transport network.
- A better organization of the Basrah has to divided city in many different levels
- The city has to be built by determining an urban point called 0 zone. Development process and city orientation start on this form.
- The city's borders have to be Determined through roads and streets.
- City district and development process can be arises by redefinition of the streets and buildings with sustainable vision
- Divide the city in many environmental zones can help in improving the macro- climate
- The city has to give city coherence through a clear road and transport networks.
- Conversion of Basrah marsh has to be built in an optimal way.

**Application of bioclimatic architecture policy**

The building design likewise should be governed by the climatic realities. The architecture itself is important, as are the shading devices, the landscaping, the shielding that a designer provides against adverse conditions, and the ventilation. The heating and air-conditioning plants of a structure must be designed with the climate in mind. Another very important element in arid-zone building design is insulation, because it is the one thing that tempers extreme outside variations in climatic factors. The easiest way to reduce the variations between daytime and nighttime temperatures is to put something between the inside and outside worlds: insulation does just this [Golany, Gideon S. 1995:32].

**Initiated the concept of biophilic city and healthy environmental concept**

The biophilic structure of the earth is a valued and appreciated part of life, where areas and human carrier green is not only an excellent synthesis of both qualitative and quantitative research that documents the bond between people and plants, it is a synthesis of the life's work and thinking of one of the most important figures in people-plant relationships. A biophilic community is a place where residents can easily get outside, where walking, strolling, and meandering is permissible, indeed encouraged, and evidence suggests that these qualities now carry an economic premium [Timothy Beatley 2011:3]. A green building uses considerably less energy and water than a conventional building, has fewer site impacts and generally higher levels of indoor air quality [New York City Department of Parks and Recreation]. It also accounts for some measure of the life-cycle impact of building materials,
furniture and furnishings. These benefits result from better site development practices; design and construction choices; and the cumulative effects of operation, maintenance, removal, and possible reuse of building materials and systems [Jerry Yudelson, 2006:19]. A biophilic city is one that is full of varied sights, sounds, smells, and textures, many, but not all of which are natural [Brian Burton 2009].

First of all, an urban area invariably absorbs more heat from the sun than does an undeveloped one because the building materials usually have an albedo lower than that of most natural land environment. Thus, they necessarily absorb more energy [Ken Yeang, 2006:294]. Second, an urban area rejects man-made heat because machinery, combustion processes, and a man in a city are heat rejecting [Gideon Golany 1977:33]. The urban heat island mitigation strategies, can support to diminish direct energy utilize in buildings, and if applied in a community-wide basis, can decrease generally ambient air temperature in a specified region [Gallo, K.P.; Tarpley, J.D (1996)]. There are many assumptions, average leaf, and average plant. Hospitals and health facilities utilize the therapeutic benefits of green areas [Wolf K. L. 2007]. These facilities sometimes use gardening as a tool to enhance the healing process for patients. In addition, the person can enjoy the comfort, fresh air, and landscape while restoring their health [Ismail Said (Jun 2003)].

**Reducing of CO2 emissions and increasing energy saving and efficiency concept**

We require to control the traffic-systems reduction, distraction and rerouting to reduce the production of air and noise pollution, and heat discharges. For parking the optimal solution is in building vehicular parking spaces underground or as covered structured parking. Use an open-grid pavement system (with impervious surfacing such as porous concrete) for the parking-lot areas [Ken Yeang, 2006:318]. Reducing carbon dioxide emissions from the building sector is critical to our ability to combat global warming. Green buildings are an important component in the effort to bring carbon dioxide emissions back to 1990 levels, as required by the Kyoto Protocol, so that we can begin to stabilize carbon dioxide concentrations in the atmosphere at levels no more than 20 percent above today's [Jerry Yudelson, 2006:41]. Topography by vertical variations in the landscape is helpful in creating potential energy saving idea. Gravity is one of the most significant sustainable forces. It can distribute water for free, and even stratification of microclimatic air temperature is related to its presence.

**Increasing of environmental, human thermal comfort**

Communities can take as many steps to lower the temperature of the environment. These temperature reduction strategies include: By means of the greater concept of biophilic city, vegetated green roofs, living green walls and planting trees and vegetation employ the evapotranspiration and evaporative-cooling procedures of vegetation on construction surfaces and integrate open green spaces. In addition, trees, shrubs, and other plants help reduce ambient air temperatures during a process known as "evapotranspiration." This happens when water absorbed by vegetation evaporates off of the leaves and surrounding soil to naturally cool the surrounding air. Trees also insert oxygen to the atmosphere, break down a quantity of pollutants and diminish dust [Amjad Almusaed 2004:231].

**Decreasing the level of heat-absorbing surfaces**

Adjust current and new urban city block layouts and configurations with explain patterns, materials and surfaces that absorb a small amount of solar energy [Berdahl, P. Bretz, S., 1997:25, 149-158]. Building materials and finishes appropriate to the impacts from the climate and the weather. Earth building can achieve great heights of structural and aesthetic achievement [J.C. Moughtin 1985:21]. Earth can be used in a variety of ways which encompasses a wide range of architectural styles and aesthetic appeal [Peter Shirley, J. C. Moughtin 2006: 30].

Facade cladding systems is a most popular building material uses for façade in Basrah today. It's
made of different materials such as steel, aluminum, Cor-Ten and glass. The material absorbs a huge amount of heat in the day at summer period and its release it at night. It works such as thermal mass. The montage of this material in Basra is without thermal insulation. This contributes in amelioration of the heat island phenomenon. Application of other environmental material is essential today. [Myer, W. B (1991)]. The current surfaces (roofs, infrastructure, pavements, etc.) with vegetated surfaces such as green roofs or green gardens and open - network road surface or specify cool materials to decrease the heat absorption. In other hand, we need to employ the well reflective and high emissivity building surfaces, materials upon walls and roofs, or by installing of a green roof or walls. Therefore, we have to increase the reflectivity of building surfaces such as rooftops and using frequently of light colors to create a highly reflective building climatic surface to keep buildings cooler in summer season to reduce energy consumption

**CONCLUSION**

Planning and architecture must work together to be sustainable. To design sustainable is to integrate the design into the ecology of the place the flows of materials and energy residing in the community [William D. Solecki, et al,2005]. One of the major problems facing us is how to establish and maintain environments that support human health and at the same time are ecologically sustainable. Green areas seem too important to people. Most people today believe that the green world is beautiful. Biophilic habitats are still often seen as an unadulterated esthetical element in architecture, as a spleen of some “Greenies”. In fact, green areas by now contribute, some extent, to a better microclimate through evaporation, filtering of dust from the air and reduce inside temperatures at the building's surface. Besides improving the microclimate and the indoor climate, the retention of rainwater is another important advantage. The aesthetic form requires, escalating the value of the possessions and the marketability of the building as a complete, mainly for accessible green areas. Urban and regional planners should view the world's arid zones as potential locations for future urban expansion and for food production, and as energy resources. No matter what function these areas serve, the construction of settlements of different forms and functions which respond to the unique nature of a desert climate will be needed. Generating more biophilic cities will also necessitate political governance, of course, and there are currently strong suggestions that politicians are capable to gain political benefits from sustenance for green developments. The green areas can take a differ places in relation to the non-greenly areas where the green area appearance aim to be synchronized by means of another area in concordance with architectural perception upon biophilic habitat.

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Design Science to Improve Air Quality in High-Density Cities

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ABSTRACT
In high-density mega cities, air pollution has a higher impact on public health than cities of lower population density. Apart from higher pollution emissions due to human activies in densely populated street canyons, stagnated airflow due to closely packed tall buildings means lower dispersion potential. The coupled result leads to frequent reports of high air pollution indexes at street-side stations in Hong Kong. Therefore, high-density urban morphology design science is needed to lessen the ill effects of high density urban living. This study addresses the knowledge-gap between planning and design principles and air pollution dispersion potential in high density cities. The air ventilation assessment for projects in high-density Hong Kong is advanced to include air pollutant dispersion issues. The methods in this study are CFD simulation and parametric study. The SST κ-ω turbulence model is adopted after balancing the accuracy and computational cost in the validation study. Urban-scale parametric studies are conducted to clarify the effects of urban permeability and building geometries on air pollution dispersion. Given the finite land resources in high-density cities and the numerous planning and design restrictions for development projects, the effectiveness of mitigation strategies is evaluated to optimize the benefits. A real urban case study is finally conducted to demonstrate that the suggested design principles from the parametric study are feasible in the practical design of high-density urban areas.

INTRODUCTION
Emissions from motor vehicles contribute to air pollution in urban areas, particularly at street canyon level. The European Environment Agency (EEA) (2012) has reported seven types of pollutants that urban dwellers are exposed to. All of these pollutants are primarily or secondarily related to road traffic emission (fossil fuel combustion). The World Health Organization (WHO) (2008) has therefore explicitly recommended the concentration limits for various air pollutants such as O₃ and NO₂. The risks associated with exposure to air pollution are relatively low for individuals but are a significant public health concern (Kunzli et al., 2000). Understanding the problem in densely populated urban areas from the urban and city scales is therefore paramount.

To decrease traffic pollution, an improved vehicle emission control program has been implemented in Hong Kong by the Hong Kong SAR Government. Nonetheless, the roadside concentration of NO₂ continues to increase (Environmental Protection Department, 2011). Similar findings are also being reported in Europe by EEA (European Environment Agency, 2012). High hourly, daily, and annual average concentrations of NO₂ have been recorded at the road-side stations in the Central, Causeway Bay, and Mong Kok in Hong Kong. Air pollution far exceeds the limits recommended by the WHO (Environmental Protection Department, 2011). These three areas are high-density metropolitan areas and traffic hotspots. As shown in Figure 1, vehicles crowd the streets of these high-density urban areas. The reported higher concentration of NO₂ is the result of the larger NO₂ percentage in total traffic emissions (European Environment Agency, 2012; Grice et al., 2009) and of poorer urban air ventilation in high-
density urban areas (Ng et al., 2011). The bulky building blocks, compacted urban volumes and very limited open spaces seriously block the pollutant dispersion in these deep street canyons (Tominaga & Stathopoulos, 2012). Therefore, apart from having control measures to decrease vehicle emissions, understanding pollutant dispersion as related to the urban planning and design mechanism is necessary in order to guide policymakers, planners, and architects in making better evidence-based decisions.

Figure 1 Vehicle fleets in the deep street canyons of Mong Kok and Wan Chai in Hong Kong; high concentration of NO\textsubscript{2} is frequently measured at the roadside stations in the areas.

The Severe Acute Respiratory Syndrome (SARS) episode in 2003 triggered the Air Ventilation Assessment (AVA) study in Hong Kong. Since 2006, AVA has been implemented as a prerequisite for urban development and old-district redevelopment (Ng, 2009). The Sustainable Building Design (SBD) Guidelines (APP-152) have also been drawn up by the Hong Kong Government. These guidelines allow architects to evaluate the effects of their proposed building designs on the surrounding wind environments, and then to enhance urban environmental design (Hong Kong Building Department, 2006). This study builds on the previous work (Yuan & Ng, 2012) by conducting parametric studies to statistically evaluate and further develop the efficacy of the AVA TC-1/06 guidelines and the SBD's APP-152 guidelines with regard to air pollutant dispersion. This study aims to provide significant and sufficiently accurate insights on the air pollutant issue at the beginning stage of the design practice. These insights are helpful to avoid the mistakes that cannot be easily corrected at the late stages of the design process. The result of this study, as a piece of design science, is intended to facilitate a paradigm shift from the typical experience-based ways of designing and planning to a more scientific, evidence-based process of decision making.

METHOD AND VALIDATION

This study used the Eulerian method to model the air pollutant dispersion. Compared with the Lagrangian method, which considers the species as a discrete phase, the Eulerian method considers phases as continuum and is solved based on a control volume, which is similar in form to that for the fluid phase (Wang, Lin, & Chen, 2012; Zhang & Chen 2006). Wang, Lin and Chen (2012) compared the performance of Reynolds-averaged Navier-Stokes (RANS) model with Eulerian method and Large Eddy Simulation (LES) model with Lagrangian methods. The later one is more accurate but also with higher computational cost. Zhang and Chen (2006) used a user-defined function in Fluent to calculate the pollutant concentration, because the lagrangian method does not directly output the concentration value. Therefore, the Eulerian method is more convenient for calculating the air pollutant concentration, which was the index that this study used to evaluate air pollutant dispersion.

In this study, the wind tunnel data provided by Niigata Institute of Technology (Tominaga & Stathopoulos, 2011) was used to validate the Eulerian method. The effects of the different turbulence models on air pollutant dispersion simulation were also investigated in this validation study. RANS and
LES models were included in the validation study. In RANS models, the standard and realizable $k$-$\varepsilon$ model, Reynolds stress model (RSM), shear-stress transport (SST) $k$-$\omega$ model were used, in which approaches of dealing with Reynolds stresses are different (Murakami 2006).

Ethylene ($C_4H_4$) was used as tracer gas, and the tracer concentration was set at 1000 ppm, duplicating the setting in the wind tunnel experiment (Tominaga & Stathopoulos, 2011). The tracer gas was released from the point source in the model with a wind velocity $W_s$ ($W_s/U_b = 0.12$, $U_b$ is the input wind velocity at the building height, 3.8 m/s).

The model configurations were set to match those in the wind tunnel experiment too (Tominaga & Stathopoulos, 2011). The H/W and H/L aspect ratios were set to 1.0 and 0.5, respectively, where H is the building height, W is the width of the street, and L is the length of the canopy. All modeling settings followed the Architectural Institute of Japan (AIJ) guidelines. The input wind direction was perpendicular to the street canyon. Input wind velocity ($U_i$) and turbulence kinetic energy (TKE) profiles were set by a user-defined function.

The simulation results of the different turbulence models were collected at two test lines and cross-compared in Figure 2. The simulation results were closer to the experiment data particularly near ground ($X/H=0.1$, X is the height of the test line). However, compared with LES model with best accuracy, all RANS models overestimated the concentrations at upper lines ($X/H=0.5$, for example), particularly at the windward side of the street canyon. Among the RANS models, the SST $k$-$\omega$ model best performed in terms of air pollutant modeling at the windward side. The special near-wall region (the shear layer) treatment by the standard $k$-$\omega$ model (Menter, Kuntz, & Langtry, 2003) was considered helpful for estimating the air pollutant concentration near surface regions. Balancing the computational cost and accuracy, for this study, the SST $k$-$\omega$ model was selected as the preferred turbulence model to simulate the air pollutant dispersion in the parametric study.

![Figure 2 Cross-comparisons of time-averaged concentrations $<c>$ at the street canyon between the wind tunnel experiment and different turbulent models: a) $<c>$ at the bottom line; b) $<c>$ at the middle line. Error bars: standard deviations of the measurements in the wind tunnel experiments.](#)
PARAMETRIC STUDY

The parametric model was at the urban scale and established from urban conditions in Mong Kok (Figure 3), a high-density downtown area in Hong Kong, using a regular street grid. As shown in Figure 3, eight strategy cases were designed to create their corresponding parametric models, establishing a total of eight simulation scenarios with different building geometries and urban permeabilities. Their details were tabulated in Table 1. Plot ratios of Case 3 to 8 were set to be same to that of Case 2.

Given the different building geometries, the corresponding urban permeability of the eight cases were different, as shown in Table 1. The permeability of buildings (P) (Hong Kong Building Department, 2006) and site area ratio (λ_p), which respectively represent the vertical and horizontal permeability, were calculated. High values of P and λ_p indicate low permeability.

![Figure 3 Actual urban area located at Mong Kok, the corresponding parametric model and eight strategy cases.](image)

Table 1 Eight simulation scenarios with different building geometries and permeabilities.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Building geometry</th>
<th>Land use</th>
<th>Urban permeability</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameters</td>
<td>H (m)</td>
<td>Plot ratio</td>
<td>P</td>
</tr>
<tr>
<td>1</td>
<td>Current urban form</td>
<td>60</td>
<td>8.9</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>Future urban form</td>
<td>95</td>
<td>14</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>Building setback</td>
<td>105</td>
<td>14</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>Building separation</td>
<td>137</td>
<td>14</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>Stepped podium void</td>
<td>109</td>
<td>14</td>
<td>0.8</td>
</tr>
<tr>
<td>6</td>
<td>Building porosity</td>
<td>133</td>
<td>14</td>
<td>0.7</td>
</tr>
<tr>
<td>7</td>
<td>Building separation &amp; Build setback</td>
<td>146</td>
<td>14</td>
<td>0.7</td>
</tr>
<tr>
<td>8</td>
<td>Building separation &amp; Stepped building void</td>
<td>150</td>
<td>14</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Note: H: building height; P: permeability of buildings (P = sum of projected building areas/Area of the assessment zone); λ_p: site coverage ratio; λ_i: integrated permeability.

RESULT ANALYSIS AND DISCUSSION

This study used the normalized concentration (\(\bar{c}\)) as the index to analyze the effects of different urban permeability and building geometries on air pollutant dispersion in the street canyon. This was
given by:

\[
\bar{c} = \frac{< c >}{< c_0 >} \quad (1)
\]

Where \(< c >\) is the modeling result of the time-averaged concentration of NO\(_2\) and \(< c_0 >\) is the reference emission concentration, the norm of \(< c >\). Given the definition of \(\bar{c}\), the threshold value of \(\bar{c}\) was set to 1.0. When the value of \(\bar{c}\) is less than 1.0, air pollutants disperse away and do not concentrate in the street canyon.

**Building scale analysis**

The simulation results, contours of \(\bar{c}\) at the vertical sections (Figure 4), firstly indicated that mitigation strategies for the air pollutant dispersion are necessary in the high-density urban planning and design. In current urban conditions (Case 1), air pollutants are seriously concentrated in the deep street canyon. Most values of pedestrian-level normalized concentration (\(\bar{c}\)) in the street with emission sources were larger than 1.0, indicating that air pollutant does not disperse but concentrate in the street canyon. If current planning and design activities do not change, the air quality will worsen with future urban development (Case 2). Given the negative effects of air pollution on public health and that of the high population density in Hong Kong, mitigation strategies are necessary to alleviate this negative impact.

![Figure 4 Contour of \(\bar{c}\) at the vertical sections in Cases 1-8.](image)

Secondly, the modeling results indicated that the air pollutant dispersion in high-density cities can
occur if strategies which promote convection effects, such as building separation (Case 4), stepped podium void (Case 5), and porosity (Case 6), are implemented and could be more efficient than strategies for larger turbulence diffusion, such as building setback (Case 3). Unlike what the AVA knowledge indicates, pedestrian-level pollutant concentration depends on the permeability of the entire street canyon. Although a high building porosity off ground level cannot increase the wind speed at pedestrian level, it can decrease pedestrian-level air pollutant concentrations as Case 6 did in the parametric study. In the design and planning process, appropriate strategies need to be chosen based on the particular concerns in different projects. The performances of various mitigation strategies were quantitatively investigated and tabulated in Table 1, as the practical design reference. Consequently policy maker can determine what and how much needs to be modified in the practical design. Strategies recommended in this study can be applied into both the new project design and the urban redevelopment.

**Urban scale analysis**

Furthermore, this study conducted a linear regression analysis to statistically weight the effect of permeability of buildings (P) and $\lambda_p$ (Table 1) on the spatially averaged pollutant concentration at the street with emission. Based on the results plotted in Figure 5, it is clear that the spatially-averaged normalized concentration depends on the permeability of buildings (P) more than on the site coverage ratio ($\lambda_p$), as the $R^2$ for P, 0.78, is larger than the $R^2$ for $\lambda_p$, 0.47.

![Figure 5 Linear relationships between pedestrian level air pollutant concentration and permeability indexes, P, $\lambda_p$, $\lambda_i$ (Table 1). The values of two real urban Cases, Case A and B, were also plotted. (significant level: 95%)](image)

To better predict spatially-averaged $\bar{c}$ in high-density urban areas, the integrated permeability ($\lambda_i$) was calculated based on Counihan's roughness model (Grimmond & Oke, 1999) for estimating urban permeability as following:

$$\lambda_i = (C_1 \cdot \lambda_P - C_2) \cdot P \quad (2)$$

The coefficients $C_1$ (1.4352) and $C_2$ (0.0463) were for the contribution of $\lambda_P$, considering that $\lambda_P$, as the horizontal permeability, is less important than P, as the vertical permeability. The values of $\lambda_i$ in all eight cases were given in Table 1. As shown in Figure 5, a strong relationship between $\lambda_i$ and spatially-averaged $\bar{c}$ ($R^2=0.83$) indicated that $\lambda_i$ is a better urban permeability index than P and $\lambda_p$ to estimate traffic air pollutant dispersion. This analysis result makes possible to map traffic air pollutant dispersion.
concentrations in urban areas by using urban morphological indexes in GIS.

**URBAN IMPLEMENTATION BASED ON THE REAL CASE STUDY**

A real case study at Mong Kok was conducted to demonstrate that suggested design principles and knowledge are feasible in real urban design practice. As shown in Figure 6, based on the current urban morphology (Case A), an urban design was produced (Case B) to improve the local air quality. Based on the characteristic of existing buildings, different mitigation design strategies in Table 1 were employed in street blocks. To avoid reducing the land use efficiency, the plot ratio in these two cases were same, 8.3. The site coverage ratio in Case A and B were 0.51 and 0.42, respectively. The averaged building permeability (P) of the total area was estimated at 0-60m above the ground and was 0.7 in Case A and 0.5 in Case B, as shown in Figure 6.

For comparison purpose, a CFD simulation study was conducted to model air flows and traffic air pollutant dispersion in the above two cases. The simulations were constructed in accordance with the methodology in the parametric study. The comparing results in Figure 7 demonstrated that the wind permeability in the entire area significantly increased in Case B. Therefore, Case B significantly increased the local dispersion. The normalized concentration data was collected at the street with emission and cross-compared in Figure 8. It is clear that the probability of high concentration ($c > 1.0$) in Case B was far less than the one in Case A. This result validated the suggested mitigation measures suggested by this study.
Figure 8 Normal distribution fit of the normalized concentrations in Cases A and B. The probability of high concentration ($\bar{c} > 1.0$) in Case B is far less than the one in Case A.

Based on the Equation 2, the urban permeability $\lambda_i$ at two real cases was also calculated, which was 0.48 in Case A and 0.27 in Case B. Correspondingly, the spatially averaged normalized concentration ($\bar{c}$) at the street with the emission source decreased from 0.79 in Case A to 0.59 in Case B. These results were plotted in Figure 5. It is clear that these results coincided well with the linear relationship and validated that the supposed knowledge of urban permeability for air pollutant dispersion is feasible in the practical urban design.

CONCLUSION AND THE WAY FORWARD

The planning guidelines for air quality in Hong Kong Planning Standards and Guidelines (HKPSG) point out that 'In the preparation of land use plans, due consideration should be given to the location of major polluting uses with a view to improving the regional air quality.' and ‘Concentrations of NO$_2$ and particulates are high, particularly at the older urban areas where motor vehicle usage is intense and vehicle exhausts are trapped between narrow roads and tall buildings’ (Chapter 9, Hong Kong Planning Department, 2011). It is clear that the ‘due consideration’ is needed especially at the existing urban areas. But, meanwhile, the major factors in these guidelines are too rough to make ‘due consideration’, using only the topography factor. No urban development factors are included. This study clarified the effect of urban development factors on outdoor air quality and provides the practical design knowledge. The architect can choose the corresponding design strategy based on the particular design concerns. The outcomes mainly focused on the building design strategies but urban scale analysis was also included, so that the research has the great potential to be extended for the urban planning implementation.

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Green Space Factor In Modifying The Microclimates In A Neighbourhood: Theory And Guidelines

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ABSTRACT
Cities and rural environments differ substantially in their land surface temperature, which leads to urban heat island effect (UHI). Cities have a dynamic relationship with the microclimate. Landscaping is one of the most effective passive design strategy compared to other passive design strategies in mitigating the UHI effect. The degree of 'greenery' or 'greenness' (Green space factor) is usually defined and measured as the percentage of total urban area that is devoted to open green spaces. The higher the percentage of green cover, the greener that particular city becomes. National forest policy, India states that a 20% to 33% of green cover is considered to be fairly good. The green spaces help to alter the temperature, reduce the urban heat island effect and improve the air quality. In most cities, concentrated vegetation is seen only in parks or recreational spaces. This lowers temperatures on the microclimate of the park but does not have any effect on the microclimate of the neighbouring built environments. By placing vegetation within the built space of the urban fabric, the effect of UHI effect can be reduced where people live, work and spend most of their lives. Such approaches have been investigated in the fields of planning, urban design, landscape architecture, environmental engineering. Selection of right plant in the right place can be based on many aspects such as its thermal performance. It further depends on various plant typologies and their characteristics which will have significant role in urban heat balances by reducing the land surface temperature and reduce energy consumptions in the dense built up areas. It also helps to improve the microclimate performance in the built environment and also create a visually appealing environment compared to other passive techniques. This paper describes the importance of relationship between green space factor and microclimate and implementation of these guidelines in a neighbourhood with various case examples from research papers, literature and theories.

Keywords: urban heat island, green space factor, green spaces, Envimet

1. INTRODUCTION
Climate, buildings, and green spaces have been explored worldwide by many researchers due to their interesting interrelationships and significant impacts to the environment. In recent years, urban heat island effects(UHI), induced by urban form, anthropogenic heat from buildings and Air conditioning systems have been studied extensively in cities around the world (1). Since the mid twentieth century, the global surface temperature has increased by 0.7±0.18°C during the 100 years ended in 2005. Thus the increased temperature is connected with increase in UHI through expansion of built up areas and populated area. The heat island during daytime increases rapidly and takes 3-5 hours to reach the
maximum after sunset. These increased temperatures have implications on electricity, energy consumption and use of resources which in turn affect the environment. The most sustainable solution to these energy and environment problems is following more natural passive cooling techniques. Urban green spaces can directly or indirectly affect local and regional air quality by modifying the urban climates. Many studies have highlighted how landscape in urban design and planning can improve microclimate and thermal comfort (2). Plant processes such as photosynthesis, Evapotranspiration helps to reduce the Mean radiant temperature and anthropogenic heat generated from the buildings which leads to urban heat island effect. This in turn reduces the cooling load of the buildings. The environmental conditions of urban green space have significant impact on the comfort conditions experienced inside them especially in seasons of stressful climate and the development of sustainability in cities (6). Many researchers agreed that plants have an effect on the urban temperature and the cooling loads of building (6, 8). For instance the air temperature distribution was closely related to the distribution of greenery in the urban areas where for some large urban park, the ambient temperature was 2-3°C lower than surrounding built-up areas and it shapes a pleasant urban environment (14). Furthermore, the effects of plants density, plants species, plants distribution and large space of greenery give a large impact, where greenery reduce the surface temperature and urban heat effect (11). Green interventions in terms of trees, shrubs, ground covers, green roofs, bioswales or rain gardens, green walls, permeable pavement may be adopted to achieve comfort and reduce UHI in urban areas. These green interventions are to be quantified to achieve the specific green space factors. The main objective of this study is to find the effect of the green space factors in modifying the microclimate.

2. GREEN SPACE FACTOR CONCEPT

In the literature reviewed, the primary metric used to measure the percentage of green spaces under the land cover based on the plant types such as lawns, turfs, shrubs and trees are their biological parameters such as LAI – Leaf area intensity, LAD – Leaf area density. There are several benefits associated by incorporating plants in the neighbourhood. There are remarkable efforts being made at different scales for the different types of green space factors which are developed across the world. Table 1 shows the examples of such initiatives across the world; California’s attempt to reduce C02 emissions by 25% by 2020 (5); Vancouver’s Eco- Density initiative (7); Portland’s effort to reduce stormwater runoff (1); from an urban landscaping viewpoint, Biotope Area Factor (3), Seattle’s Green Factor (10) Green Plot Ratio (15), and Malmo Green Space Factor (9), which discusses the usefulness of various Green Factor. These green rating systems are designed to examine the relationship between the Green factors or the landscape elements and their performance in the built environment. The green factor systems are designed to increase the quantity and quality of planted areas while allowing the flexibility for developers and designers to meet development standards. These studies deal the metric of green spaces at the scales from one dimension to three dimensions but there is no evidence whether these metrics are climatically sound. This study analyses the performance of these green space factors.

3 METHODOLOGY

Methods to study the green space factor in modifying the microclimate include both numerical modeling and empirical analysis, such as using on site measurements using instruments and weather data obtained from nearest weather stations. With empirical data, the study can be more specific, but have limitations on time and space. Thus, to have a theoretical understanding of performance of different vegetation scenarios and their effects on the microclimate, numerical modeling with on site observations is required. The simulation has been carried out with the help of Envi-met models and simulated along with initial onsite observation which was conducted on 20.03.2014 for the climate monitoring and the plant distribution was accounted. In this paper, different scenario such as (i) with existing base case, (ii) nil vegetation, (iii) with turfs and (iv) with trees was selected to assess the air temperature. For the selected sites, the green plot ratio (15) has been applied and evaluated for its performance on the microclimate.
Table 1. Green metrics and policies used around the world

<table>
<thead>
<tr>
<th>Category of metric</th>
<th>Place</th>
<th>Green metric</th>
<th>Goals</th>
<th>Description and characteristics</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>One dimensional</td>
<td></td>
<td>Inventory of plants</td>
<td>To increase the number of plants</td>
<td>The number of plants being managed in an area. Simple to use for homogenous or heterogenous plant populations. Does not provide information on plant species</td>
<td></td>
</tr>
<tr>
<td>Two dimensional</td>
<td>Berlin</td>
<td>Biotope Area factor</td>
<td>Retain high densities of development, whilst also developing the city’s green infrastructure</td>
<td>Attempts to account for various types of ecologically effective or environmentally friendly green systems</td>
<td>1994</td>
</tr>
<tr>
<td></td>
<td>Malmo</td>
<td>Greenspace Factor</td>
<td>Increase of green space per inhabitant from 33m² to 48m² in the urban area and increase the area of accessible green space in the countryside from 2% to 33%</td>
<td>Quantifies the planting area. Does not account for vertical stacking.</td>
<td>2001</td>
</tr>
<tr>
<td></td>
<td>Portland</td>
<td>Portland’s Green Building Policy</td>
<td>All new City-owned facilities to include an eco-roof systems</td>
<td>Advancement in green roofs design to include an eco-roof with at least 70% coverage</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>Vancouver</td>
<td>Eco-Density</td>
<td>Building green liveable and affordable Communities</td>
<td>Cities’ densification systems</td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td>California</td>
<td>California Global Warming Solutions Act of 2006(5)</td>
<td>Reduce GHG emissions in the state to 1990 levels (25%) by 2020, and 80% below 1990 levels by 2050</td>
<td></td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td>Seattle</td>
<td>Green Factor</td>
<td>New developments in commercially zoned areas must commit 30% of the parcel area to urban landscaping</td>
<td>Attempts to account for various types of ecologically effective or environmentally friendly green systems</td>
<td>2007</td>
</tr>
<tr>
<td>Three dimensional</td>
<td>Singapore</td>
<td>Green Plot Ratio</td>
<td>Greening the buildings in cities</td>
<td>Sum of total leaf area developed in the site divided by the site area. Better correlation with the environmental performance of greenery</td>
<td>2003</td>
</tr>
</tbody>
</table>
3.1 AREA OF STUDY

Madurai is the oldest inhabited city in the Indian peninsula and is referred as Kadambavanam (forest filled with kadamba trees) at the banks of river vaigai. Madurai city has an area of 52 km², within an urban area now extending over as much as 130 km², and it is located from 9°56′N to 9.93°N Latitude and from 78°07′E to 78.12°E Longitude. It has an average elevation of 101 meters above mean sea level. The climate is hot and humid, with rains during October to December. Summer temperatures range between 40 and 26.3 degrees Celsius. Winter temperatures range between 29.6 and 18 degrees Celsius. The average rainfall is about 85 cm and the average humidity is 65%.

The impact of green spaces on the urban heat island is more comprehensive if supported by the appropriate green space factors. The urbanization in Madurai has rapidly increased and has also increased land surface temperature of Madurai since 1990 to 2001. To substantiate this, study has been done with Land use patterns for 1991 and 2001 (Figure 1&2) and land surface temperature maps (Figure 3&4) were prepared by using 1990 TM image and 2001 ETM+ image. Land surface temperature type indicates; “red and orange” with average temperature of 43.9°C and 41.9°C respectively for urbanized area a with a greater density of buildings and paved surfaces that absorb and retain heat from the sun, “yellow” with average temperature of 38.9°C for urbanized area a with a medium density of buildings and paved surfaces that absorb and retain heat from the sun, “green” with average temperature of 36.9°C for urban green areas, and “blue” with average temperature of 30.9°C for water bodies. This map shows that urbanization has spread rapidly from year 2001 especially in the central business district of Madurai. This rapid urbanization has contributed to the increase of urban temperature in Madurai. This map also shows how extremely green spaces are replaced by the grey spaces without considering the impact of huge loss of green space to the urban environment. Therefore, this study has examined the potential of green space factor in modifying the microclimate. Urban neighbourhoods was selected with dense (Study area 1 – Railway colony) and sparse vegetation (Study area 2 - Periyar) as shown in Figure 5 and compared with hypothetical conditions with mentioned scenarios and has been studied for their...
microclimatic performance is studied using micro scale model ENVIMET (4) due to its advanced approach on plant atmosphere interactions in cities. The numerical model simulates the complex urban structures with resolution between 0.5m and 10m according to the position of sun, urban geometry, vegetation, and soil by solving thermodynamic and plant physiological equations.

Figure 5 Study areas. Source: Google Images

3.2 Model and its validation

Envi-met Version 3.1 (Bruse 2013) has been employed to simulate the potential impact of urban form and vegetation on the urban microclimate for March 20, 2014, during mid summer day when peak temperature is experienced. Envi-met is a three dimensional computational fluid dynamics and energy balance model that simulates plant air interactions in urban environments with a typical horizontal resolution of 0.5m to 10m in space and 10 seconds in time for built environment from microclimate scale to local climate scale at any location. Although Envi-met mainly uses a 3D prognostic model, it also uses 1D models to transfer all data input for wind speed, wind direction, air temperature, relative humidity, specific humidity and turbulence quantities (Bruse 2004). In order to conduct the simulation, basic data about the location, cloud cover conditions, initial temperature, wind speed at 10m above ground level, specific humidity at 2500m and relative humidity at 2m are required. In addition, the initial temperature, soil temperature (at 0m-0.2m, 0.2m-0.5m, 0.5m-2m), heat transmission in walls and roofs of buildings can also be defined in the mentioned model. The model gives a large number of output data that include air temperature, surface temperature, wall temperature, long wave radiation, shortwave radiation, latent and sensible heat fluxes, PMV, PPD, and MRT as the indicators of outdoor thermal comfort. In order to achieve realistic results, a simulation of an existing urban area in Madurai was carried out and the results were compared with on-site measurement temperature (1300LST on 20th March 2014) as shown in Figure 6. Envi-met was carried out for a 24 hour period starting at 0600LST with model output for every 60 minutes, using the configuration parameters. The relationship of both results was found to be correlated with an R-squared value equal to 0.876 (Figure 6). The verification process further rationalizes the use of ENVI-met to study the microclimatic issues in Madurai with hot and humid climatic conditions.

4 RESULTS AND DISCUSSIONS

Envi-met simulation was conducted for both the selected areas and the results reveal that the green spaces play a major role in modifying the microclimate.
4.1 AVERAGE AIR TEMPERATURE

Figure 7 shows the average air temperature for different scenarios such as (i) with existing base case, (ii) nil vegetation, (iii) with turfs and (iv) with trees. Figure 8 shows the average air temperature for different scenarios such as (i) with existing base case, (ii) nil vegetation, (iii) with less number of trees and (iv) with increased number of trees since providing turf or lawns is not possible in this case as it has dense urban pattern with wall to wall construction.
4.2 APPLICATION OF GREEN SPACE FACTORS

Green plot ratio (GnPR) by Ong (2003) was known as an effective green assessment method to determine the ratio of green space distribution. According to Ong (2003), the GnPR has been defined as the average leaf area index (LAI) of the greenery on the site and also can be equivalently defined as the ratio of the total single-side leaf area of the planted landscape to the plot or site area. GnPR can be defined as the area-weighted average LAI of a site, which account for unequal amount of area occupied by different plants in a landscape. Leaf area index can be defined as one-sided area of leaf tissue per unit ground surface area where the green plot ratio is the only green assessment method that relies on LAI.

For the selected sites, the green plot ratio (15) has been applied and simulated along with initial onsite observation which was conducted on 20.03.2014 for the climate monitoring and the plant distribution was accounted. This on-site observation was only focused on the study areas, Madurai and during the observation the temperature found to be 31°C with clear sky conditions.

In this study the green plot ratio have been considered for all the scenarios as shown in equation 1. The green plot ratio have been carried out as following: existing base case, scenario (i) with no vegetation of 0 green area factor, scenario (ii) with lawn of green factor 0.304 and scenario (iii) only trees of green area factor 0.304 had impact on the reduction of temperatures. The calculations, assumptions, and results were given in Table 2 and 3.

Based on the understanding of the parametric study and Green space factor, the following key observations were found as given in Figure 7 and 8 which can be useful for urban planners.

First, greening is beneficial in cooling the urban environment and creating better urban microclimatic conditions for human activities at the ground level.

Second, tree planting is more beneficial than turfs or lawns (where trees provide shade for the lawns, to other vegetations and buildings) as evident from the study.

It also suggests that the green factor of above 0.45 is essential to reduce a maximum of 2°C in the built environment. Whereas in the study area 2 the temperature is reduced a maximum of only 1°C.
This also shows that the green factor of maximum 0.34 is not sufficient as it reduces about only 1°C and green factor of above 0.45 is as essential as to reduce a maximum of 2°C in the built environment.

5 CONCLUSION

Design strategies for open spaces and landscape in a site development not only require to accommodate their density in the site development standards, but also it plays an important role in modifying the microclimate and create thermal comfort since it controls the access of sun, light and wind. The microclimatic effect of the Green area factors were done with Envimet Numerical model. This has been done considering only the lawns and the trees. The results shows that trees perform better then the turfs or lawns. This lead to further investigate and develop green space factors for the thermal comfort conditions outdoors, based on the empirical data and numerical modeling. This Green space factor when included and applied in Madurai will help the Urban Designers, Planners and Landscape architects to decide on the percentage of green space to be included in the city which can create comfortable environment even in the urban neighbourhoods which is now available in the large urban open spaces such as parks alone. This further helps to reduce the UHI in the city which in reduce the energy consumption in the buildings.
6 REFERENCES

The UK’s experience in mitigating climate change: a planned strategy or a learning curve?

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ABSTRACT
Reducing the CO2 emission by 80% from 1990 level by 2050 is a challenging operation for the UK. This challenge has embarked the whole nation in a national exercise that involves professionals in all sectors, corporations, SMEs, families and individuals. The nation meets every day with new tasks, initiatives and incentives designed to meet that target. The built environment is one aspect of this multifaceted exercise and within the built environment itself many aspects are being tackled. This paper evaluates the current legislations, initiatives and incentives introduced in the UK to reduce the energy demand in the Built Environment and how they contribute to meeting the UK’s international obligation in cutting CO2 emission.

Incentives such as feeding tariff for renewable energy, Green Deal for upgrading buildings and many other initiatives; have been withdrawn, revised or replaced after their excessive success or unexpected failure. These actions reflect the lack of clear plan and strategy. This paper won’t examine the reasons of these success or failures but will use these disruptions as a call for the establishment of serious tools and mechanisms as a platform for discussion in mitigating climate change. Although the theme of this conference is dedicated to developing world, we believe that exchanging our experiences will benefit developing countries in avoiding our mistakes and follow successful steps. There is certainly no benefit in re-experiencing same failures as the world is embarked in the same climate change mitigating exercise.

INTRODUCTION
The climate change is monitored very closely by the IPCC (Intergovernmental Panel on Climate Change), whose main task is to review and assess scientific and socioeconomic data produced globally in order to understand climate change and in particular the effect of human activity on climate change (Ipcc.). Although there is evidence of the changes in global climate in the last 10.000 years, IPCC’s
reports show a significant rate of increase since 1750. A date that coincides with the industrial revolution (Pearson & Foxon, 2012) which has involved intensive use of fossil fuel to run ambitious industrial ideas and increase productivity (Antràs & Voth, 2003). Since then, an ever increasing large-scale production to satisfy booming economies and people’s desire to maintain a comfortable level of living standard has worsen the situation of the planet’s climate.

The global warming has entered the public domain after serious research undertaken in the 1950s when scientists began assessing the CO2 effect on climate change worldwide. The sad news resulted in the whole world engaging in long debates on how best to mitigate climate change. These debates took place between governments as well as nongovernmental organisations and resulted in solutions that were interpreted by each participating country, in different ways. The goal was to reach an optimum level of CO2 emission in the atmosphere while keeping industrial and socio-economical activities moving forward to meet people’s needs and expectations in a sustainable manner (Momtaz, 1996).

The aim of this paper is to present the various initiatives introduced in the UK to mitigate the effects of the built environment on climate change as well as to evaluate their effectiveness. This investigation will show that some of these initiatives are rushed which is evidenced by the fact that many of them were withdrawn or revised shortly after being introduced.

THE UK AND ITS COMMITMENT IN MITIGATING CLIMATE CHANGE

The UK as many nations started organising itself to deal with climate change throughout conventions, agendas, road maps and declarations. Le country took swift actions and made significant commitments in response to these climate change (Department of energy and climate change. May 2014).

We have to bear in mind that, despite the CO2 emission worldwide being multiplied by three since 1990, the UK are still referring to the 1990 levels in their commitment to reduce the CO2 emission by 80% by 2050. Nonetheless, even such commitments require legal and technical instruments to be honoured.

In the Built Environment, various instruments have been created to reach that goal; these instruments varied from legislations to personal initiatives where the awareness was a major driver in finding alternative solutions to tackle climate change.

THE UK MAJOR ENGAGEMENT ACTIONS IN MITIGATING CLIMATE CHANGE

The UK signed international agreements and reflected on them nationally put in place policies to reduce greenhouse gas emissions relatively early as part of the international efforts to limit global warming and other effects of human induced climate change. It now has a range of measures and targets in place, underpinned by statute, to achieve the reductions and in this regard has been one of the leaders internationally. As stated by the CCCEP (Centre for Climate Change Economics and Policy): “CO2 emissions are the main focus of climate change mitigation policies in the UK as they account for around 80% of total greenhouse gas emissions”.

However whilst the UK may claim, with some legitimacy, to have been at the forefront of measures and policies to tackle climate change it is less clear how effective those measures and policies have been, or indeed what the likelihood is of achieving the ambitious target of an 80% reduction in carbon emissions by 2050.

According to The Energy Saving Trust, in order to ‘achieve these goals the UK needs radical change’ (Energy saving trust, 2014). A report on the UK’s climate change policy, in 2011, by the CCCEP concluded that ‘a step-change in the pace of emission reductions is required to put the UK on
the path towards its ambitious 2050 target’ (Climate change policy in the United Kingdom, 2014).

Since the UK government passed the Climate Change Act in 2008 to impact positively on climate change, this long term legally binding framework requires the reduction of the UK annual carbon emissions to 154.2 million tonnes of CO2 by 2050.

To reach such level of CO2 reduction, the British Governments introduced a number of regulations and incentives at various levels. These regulations were not necessarily based on a quantitative analysis and scheduled intermediate aims based on capabilities to meet the set target. Selected regulations and incentives are shown next and vary between successful unchanged regulations to multi-updated incentives.

UK ACTIONS TOWARDS REDUCING CO2 IN BUILDINGS AND THEIR REVISIONS

1. The introduction of the Energy Performance of Buildings Directive (EPBD) in 2003 which influenced the construction industry and building renovation. However, this measure can be challenging given that the buildings’ actors need to look for different means to reduce the building energy consumption and require the exploration of a huge number of possible combinations of energy-saving measures. (Hamdy, Hasan, & Siren, 2013). A recast took place in 2010 followed in 2013 by a proposal from the Scottish Government to consult on the implementation. A new change took place in 2013 as a result and the green Deal took place (Scottish Government).

The Government introduced SAP (Standard Assessment Procedure), a method which aims to calculate and assess the overall energy use of buildings. Although this method of assessment didn’t go through revisions and changes, its formulation was not practical for all buildings. This method was criticised at various levels, it still has its importance in energy use assessment of dwelling, but still controversial (Kelly, Crawford-Brown, & Pollitt, 2012). SAP calculation is a requirement to demonstrate compliance with the energy performance requirements of Part L of the Building Regulations, as well as used to demonstrate achievement of the required performance levels for sustainability benchmarks such as the Code for Sustainable Homes.

2. Building Regulations Part L (Conservation of Fuel and Power). Provides guidance on the means to comply with the energy efficiency requirements of the Building Regulations. It deals with a number of areas including insulation requirements, heating and air permeability etc. but also sets out the requirements for SAP calculations and Carbon Emissions Targets for dwellings (Planning portal, 2014). The reinforcement of the existing Building Regulation in its Part L dedicated to the energy performance. This continuously updated regulation has seen a huge step forward in regards to the minimum energy performance requirement of new buildings and refurbished existing buildings. The requirements, expressed in U-Val, are not generic to the whole building but very specific to the building’s components such as the roof, wall, windows and floor.

3. The Building Regulations co-exist with other standards and recommendations that largely relate to best practice (Department for building innovation and skills, 2014), for example BREEAM and the Code for Sustainable Homes. BREEAM is an environmental assessment method and rating system for buildings which, amongst other key areas of environmental impact, addresses energy demand, consumption and CO2 emissions by promoting designs that minimise demand and consumption in buildings thus reducing carbon emissions. These instruments have been in place early enough to influence the building sector by reaching the whole building sector industry and achieve thereafter part of the goal.
4. The Code for Sustainable Homes is in effect the domestic version of BREEAM and there remains to date a mandatory requirement for new homes to be rated against the Code. However in an effort to reduce ‘red tape’ in the housing construction industry the government has confirmed, in March 2014, that it will be ‘winding down’ the Code and consolidating some of its requirements in the Building Regulations (Sustainable construction legislation, regulation and drivers, 2014).

5. The Feed-In-Tariff was announced in 2008 and introduced in 2010 to replace the UK Government grants as the main financial incentive to encourage uptake of renewable electricity generating technologies. Less than a year into the scheme, the new coalition Government announced that support for large-scale photovoltaic installations would be cut. From August 2011 the rate for installations changed. In October 2011a second review of the Feed in Tariffs for low carbon electricity generation was announced and was supposed to take an effect from 12th December 2011. In its second year, the government announced further cuts to the FIT scheme. On 5th March the tariff was cut done. This cut was originally scheduled for 12th December 2011 but was delayed. The latest cut came into effect on 1st November and this rate was set to remain until 1st February 2013). Another drop in the FIT is to take place in January 2015 to £0.13 that is a 1/3 of its original incentive of £0.43. This can’t come from a strategic approach unfortunately.

6. Energy Performance Certificates (EPC) is a Post construction monitoring tool, reporting on energy efficiency of building of small scale. The buildings are then classified into categories from A to G where A indicates the best rating. EPCs are mandatory for the sale and letting of properties but they provide only theoretical ratings on energy performance based on the design and construction in conjunction with assumed patterns of use and occupation. Such theoretical assessment doesn’t convey a full understanding of buildings and a more measurable approach are required to really have a clear perception of these buildings. Further collaboration between energy supply companies to provide buildings’ energy consumption might give a better understanding on where these building stands in regards to their CO2 emission but not on their heating need therefore separated meter for heating and cooking where possible will narrow the potential misleading analyses given by the EPC.

7. The Display Energy Certificate (DEC) (Display energy certificates, 2014) is more of a permanent document to display. They are far more informative with regards to energy performance as they are based on actual consumption but despite the fact that there is evidence that their use can help achieve substantial reductions in energy use they are currently only a requirement for buildings that are over 500m² and occupied by the public sector (Fuerst & McAllister, 2011). There is more of a psychological influence on occupants to save energy but might not be effective in long term if actions are not taken forward.

8. The compulsory inspection of equipments, such as boilers, to insure their performance. This is an important measure given that 57% of energy use in the UK goes towards space heating. However, the guidelines did not insist on the best performance at this stage but a new future enforcement is due to take effect where buildings will be assessed to that level. As a consequence, many landlords might find themselves not able to rent out their properties if they don’t meet certain levels of performance. (Hamilton, Steadman, Bruhns, Summerfield, & Lowe, 2013). This level of performance, although known, is still unclear on how to be reach in efficient way.
9. The Green Deal was included in the Energy Act 2011 and came into force in 2012. In 2014 a second green deal would be launched, as grants rather than the loans which underpinned the original Green Deal scheme. The initial Green Deal didn’t take into account a socio economical and behaviour of home buyers since the deal consisted on a loan to be granted and remain with the property rather than with the initial owner, hence its failure. The Green Deal is a government initiative to try and incentivise building owners and occupiers to invest in improving the energy efficiency of existing properties by offering ‘green finance’ for the installation of energy efficiency measures. Taken at face value a scheme that offers the chance to fund improvements to the energy efficiency of property with the promise that the savings will outweigh the cost of the finance (the so-called ‘Golden Rule’) appears attractive and an effective way of targeting a big contributor, housing, of carbon emissions.

The reality has been somewhat different with doubts over value for money (uncompetitive interest rates for the loans offered) as well as little, and often conflicting, evidence to support the government’s assertion that the investment is financially worthwhile (for the occupier). Uptake to date has been very low and the initiative is plagued by the perception that neither energy companies nor the government are committed to the scheme.

The Green Deal is an attempt to deal with the retrofit of energy efficiency measures in existing homes which is clearly is a key area to target but its apparent failure suggests the strategy is not working in its current form.

10. The GCB was set up to provide leadership to the sector on reducing carbon emissions and capitalising on low carbon growth opportunities, as well as monitoring the implementation of, actions in the Low Carbon Construction Action Plan. It was announced in February 2014 that the Green Construction Board (GCB) will continue its work on reducing carbon emissions for a further two years. The focus of the GCB over the next two years will be working towards delivering the ‘ambition of a 50% reduction of greenhouse gas emissions by 2025’. It will be interesting to see what recommendations are made to achieve the ‘ambition target’ of 2025 that will act as benchmark for the 2050 commitment.

The above list can be extended to other actions and strategies however the message is conveyed through these actions and showing the country’s ‘rush’ to demonstrate many actions towards 2050 target. Although all actions are positive in their contents, the wider vision doesn’t seem to be that positive. The fact that these actions were addressed short after their applications and this reflects a quick response and therefore a close monitoring of the outcomes. Were these actions put in place for just testes? Something we won’t know from diferent governements in place since?

**BUILT ENVIRONMENT AND CLIMATE CHANGE**

The Royal Institute of British Architects (RIBA) describes the UK government’s overall strategy as ‘encouraging organisations to reduce their emissions and embrace opportunities through setting regulations, establishing market-based mechanisms, providing incentives and ensuring the provision of information, advice and support’. It [the government] hopes that in doing this it will ‘help to stimulate development of low carbon solutions and services and promote their uptake within the UK’ (Willars, 2014).

The UK Green Building Council quotes: Construction and Sustainable Development report that states that ‘energy from fossil fuels consumed in the construction and operation of buildings accounts for approximately half of the UK’s emissions of carbon dioxide’ and ‘housing alone generates 27% of UK emissions, of which 73% is used for space and water heating’ (Constructing Excellence, 2008). This
means that space and water heating in UK homes is responsible for nearly 20% of the UK’s carbon emissions.

Further evidence is found in the UK Government Department for Business Innovation and Skills 2010 report that estimated the amount of CO2 emissions that the construction industry can influence. It considered the life cycle of buildings from design, through operation to refurbishment/demolition. It concluded that the industry could influence almost 47% of all the UK’s emissions and in-use building emissions accounted for 80% of this figure (Department for building innovation and skills, 2014). Therefore building emissions in-use alone is estimated to account for over 37% of all of the UK’s CO2 emissions.

It is not disputed that the built environment and the construction industry are major contributors to the UK’s carbon emissions and therefore required to play a significant role in actions and strategies to meet the reduction targets. In the UK the means of doing this is largely through the Building Regulations. The Building Regulations are the statutory instruments that are used to try and ensure that legislated policies are acted upon.

The UK has highly ambitious targets for ‘zero carbon’ standards but it remains unclear as to exactly what the definition of ‘zero carbon’ is or how it will be reached. The Code was introduced in 2006 to help achieve the pledge that all new homes would be ‘zero carbon’ from 2016 but its ‘winding down’ is part of a wider review and plans to ‘rationalise all building regulations and national and local housing standards’ (UK Green Building Council, 2014). The UK Green Building Council claims that not only was the 2016 Zero Carbon target instrumental in achieving improved environmental standards and innovation in building (UK green building council, new built, 2014), but also that the changes now being made will ‘almost certainly result in poorer quality homes, built to lower environmental and social standards’ (UK green building council-government shake-up of housing regulations likely to cause confusion, affect quality and slow down delivery warns UK-GBC, 2014).

Inevitably, opinions differ on the motivations and likely impact on sustainability of the decision to phase out the Code. The decision is based on a desire to reduce ‘red tape’, and in the process help to invigorate the housing construction industry. This raises an interesting point that is a basic problem for governments in tackling carbon reductions. One of the biggest reductions in carbon emissions recently followed the 2007 recession and downturn in the economy and conversely a growing economy sees an increase in output and carbon emissions. A challenge for government is to stimulate and grow economies without sacrificing climate change targets. It begs the question of whether governments can be relied upon to balance long term climate change policies over other issues such as economic growth.

One of the key issues of this study is the energy performance gap: that is the difference between the designed performance and the actual in-use performance with regards to energy efficiency and consequently operational carbon emissions. It is interesting to note that the mandatory requirements for assessing energy performance prior to construction are based on theoretical performance and that reporting on the energy efficiency of the vast majority of buildings once completed and in use is also based on theoretical assumptions rather than actual performance. A 2012 report that analysed actual energy use in commercial properties found ‘little or no correlation between EPC ratings and actual energy performance’ (Jones Lang Lasalle & Better Buildings Partnership, 2014).

THE ECONOMICAL IMPACT OF MITIGATING CLIMATE CHANGE

The move to the low carbon economy cannot be without an impact as stated by Sir Nicolas Stern, who highlighted, in a world renowned report, the dramatic consequences of not acting and insisting that the economical impact of not acting is worse than acting: “The costs of stabilising the climate are significant but manageable; delay would be dangerous and much more costly.” (STERN, 2007). We should emphasise that the economical aspect of mitigating the climate change was of concern at an early
stage of the climate change debate. Although nations have different financial capabilities, they, nonetheless, face the same challenge. Such financial disparities were addressed in later climate change discussions and encouraging solutions where found to make it less challenging for developing countries. This was introduced in the form of CO2 trading mechanisms involving developed and developing nations as stated by the United Nation Framework Convention on Climate Change (UNFCCC) 2014.

**DISCUSSION AND CONCLUSION**

The concerns raised in this paper appear to be fairly consistent in saying that:

- There is a lack of clear understanding of the mechanisms and their capabilities in mitigating climate change in the UK. The withdrawn of certain initiatives based on their excessive success such as FIT was not particularly welcomed.
- Current legislation and strategies are insufficient, inconsistent and unclear from the operational perspective.
- The rate of progress needs to change radically if the UK is to have any chance of meeting its legally binding commitments by 2050. Meeting the target in advance is also problematic since this will be achieved against other needed development in the country.

In consideration of current observations and research it seems that some of the key areas of focus in order to achieve the government targets of CO2 reduction that require further investigation are:

1. Making DECs mandatory for all buildings so that the actual performance is measured rather than theoretical (predicted). DECs are also accompanied by an advisory report that identifies measures to improve the buildings’ energy rating as currently there is no obligation to act on the advice in the report.
2. Legislation tends to focus primarily on new build properties. The biggest single contributor to carbon emissions from the built environment and construction is operational carbon from residential property (space and water heating) and the vast majority of dwellings (around 80%) that will be in use in 2050 have already been built. Therefore retrofit should be the main focus to reduce in-use operational carbon emissions.
3. The way the building occupiers behave and use their buildings is hugely significant in terms of energy consumption (and therefore carbon emissions), yet existing assessment methods such as SAP ratings and EPCs are not able to account for the complexities and variations that accurately reflect how significant occupant’s behaviour is.
4. The government needs to increase its efforts to incentivise people and organisations to want to make their buildings more energy efficient. A small percentage will pursue a low or zero carbon building because of an ideology or ethos but the majority will respond more to legislation and/or financial incentives.
5. The revisions of many initiatives including legislations and incentives the UK saw in the last decade reflects a clear uncertainty in regards to the effectiveness of what is made in place to mitigate climate change.
6. There is still a lack of strategy to quantify and measure the potential outcomes of these initiatives hence their suspension or revision.
7. There is not enough measuring of the actual performance and too great an emphasis is placed on the theoretical or predicted performance based on design assumptions.
8. Not enough is done by the government to make it easy and cost effective for building owners and occupiers to implement energy efficiency measures in existing buildings with an over reliance on ‘encouragement’ and ‘hope’ that the market will develop low carbon solutions that are taken up to ‘solve’ the problem.

It is understandable that a start needed to happen to mitigate climate change but the lack of expertise worldwide has led to a period of trial and error. This period lasted for more than it should and the time has come for actions based on strategies and undertaken by experts in consultation with all stakeholders. Actions should be seen in a wider context and overseen by multidisciplinary teams to anticipate dysfunctions that can happen along the way as was stated in this paper.

This period of trial and error was certainly costly, time and cost wise. This lost won’t be passed on to other nations who joined lately the mitigating climate change actions. PLEA is certainly the hub where experiences are exchanged to move on from trials actions to planned strategies.
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Acknowledgment:

This paper has benefited from students’ input in my distance learning “Sustainable Development” course where students feed into it worldwide, by exploring their countries’ actions in mitigating climate change. I realised that countries are undertaking similar actions sometimes and commit same errors. I found it important to share awareness of the benefit of exchanging experiences between nations.
Energetic expenses of walls and roofs used in the metropolitan zone of Tampico, Madero and Altamira

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ABSTRACT
This is a presentation showing the procedures and results obtained from the analysis of the energy transmitted in walls and roofs of the selected homes in the south zone of the state of Tamaulipas, one of the five zones established in the “Development and validating of a methodology to estimate the impacts in the saving of energy for the use of passive-constructive systems in the edification for different climates in México” project, which third stage of execution’s objective consisted in making use of the Ener-Habitat software, developed during the project’s second phase. This research was sponsored by the Energy Sector Sustainability Fund SENER - CONACYT S0019 - 2009-01 call log under the project No. 118665. With this software the comparative energy expenses of four constructive systems for walls and three constructive systems for roofs were determined. With the acquired information and through the use of the methodology developed to estimate the impacts on energy saving, the energetic price of each of the constructive systems was evaluated. With the acquired results it was determined which were the walls and roofs of less energy expense for the study zone.

INTRODUCTION

It is essential in locations which have high solar insolation and large temperature variations through the day to evaluate the thermal performance of building systems. This emphasizes G. Barrios, P. Elias, G. Huelsz and J. Rojas (2010) who state that "in climates where solar radiation is significant and the daily temperature swing is important, as in most of Mexico, the heat transferred through walls and roofs must be analyzed as a function of time. For these climates, the steady state heat transfer model from a period of time can lead to the improper selection of materials”.

The objective of this project is to provide guidance for the selection of suitable constructive systems for the warm-humid climate of the southern part of the state of Tamaulipas to help improve the thermal comfort inside the home without using air-conditioning systems.

The study was divided into three parts:

A. Apply the methodology established in the project protocol.

B. Analyze the results derived from the Ener-Habitat program construction systems of the}

1 For further information consult: http://www.enerhabitat.unam.mx/Cie2/

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selected walls and roofs, comparing energy costs.

C. Get the conclusions of the investigation in the study area.

This also implied a review of climatic factors existing in the study area formed by the municipalities of Tampico, Madero and Altamira, prevailing therein a warm-humid climate with average summer temperatures of 29°C in summer and 21°C in winter. The variations of weather through the year fluctuate in summer ± 10°C and in winter ± 8°C.

METHODOLOGY

As part of the established objective, the following steps to define the selection of constructive systems for the warm-humid climate of the study zone were generated.

A. Twenty five housing buildings were selected in the south zone of Tamaulipas for investigation.

B. A data sheet designed to provide the information of each of these homes on their behavior with regard to the thermal comfort inside, provided the m2 of property, the square meters of construction, typology, orientation, vegetation and exterior colors.

C. Determine which passive systems impact on each housing building.

D. Analyze the constructive systems of walls and roofs using the software. Ener-Habitat solves the time dependent one dimensional heat transfer equation using the sol-air temperature at the exterior. At the inside, the indoor air temperature can be assumed constant (air-conditioned) or as a function of the heat transferred through the constructive system (free running).

E. Compare, using the Ener-Habitat software, the two most widely used construction systems in the area which transmit less energy for walls and roofs.

F. Suggest other systems of walls and roofs in different layers, so as to establish the best benefit cost.

G. Different layers of walls and roofs were proposed which were analysed for their energy-cost with the information provided by the Ener-Habitat software.

H. Determine which were the final layers of walls and roofs of lower expense and energy-cost of the climatic zone of study.

RESULTS

With the information gathered in the data sheets of the 25 homes tested, it was determined how passive systems impacted in each of these homes.

It was shown on a study which were the constructive materials for walls and roofs more widely used. This information was used to feed the Ener-Habitat software which steps are:

I. Select the construction system (wall or roof). Determine whether the layers are homogeneous or not and understanding that homogeneous are those with a single material and no air gaps.

II. The following information is selected from the database:
   a) The city where the calculation will be made: in this case Tampico.
   b) The time period analyzed: annual or a specific month.
c) Use of air-conditioning: yes or no.
d) Select the type of construction element: roof or wall.
e) Number of building elements to compare: 1 to 5.

III. Determine the amount of building elements to be analyzed, for all the following (Image 3):
   a) Orientation: north, south, east, west, other.
   b) Tilt angle: 0° to 90°.

IV. The layers of the construction system from 1 to 7 are introduced to be analyzed.

V. Determine the absorptance, the thickness and the material of the outer layer of this system. And subsequently, determine the thickness and the material of the following layers. Because the time dependent heat transfer equations are solved, being the thermal properties needed for the evaluation the thermal conductivity, the density and heat capacity, as well as the width of each layer.

VI. Finally, after entering all the data, the software shows the results from the Ener-Habitat through tables and graphics.

Image 1. Selection of layer material.
The calculation of the energy transferred to the two different wall construction systems to compare the walls and roofs of the building envelope used in the area of Tampico was made considering that all the walls are west facing. This was done in order to compare them regardless of orientation.

In Table 1, the two types of walls most used in the zone are shown. Percentages of the construction systems used in homes as well as the transmitted energy values are included. Each system has two extreme values of transmitted power; the minimum value corresponds to the wall that transfers the least amount of energy and the maximum value corresponds to the wall that transfers more energy, classified within the same type.

Furthermore, the values of energy transmitted in the same type of construction system presented in Table 1 are associated with walls with clear exterior colors, which have low solar absorptance (A). Without air conditioning, it is observed that the energy transmitted by the walls with no homogeneous layer (wall of hollow concrete block) is 2.56Wh/m² day. This allows us to affirm that the walls with no homogeneous layers and more space between their inner sides are more suitable for homes without air-conditioning operating in southern Tamaulipas.

The calculation of energy transmitted in the walls north, south, east and west to find the best orientation and also using white colors with absorptance 0.1 was found to be the most used in the building systems in the area.

The most energy transmitted is from the wall facing west with an average of 4.80Wh/m² per day and the wall with less energy is facing east with an average of 3.62Wh/m² per day and therefore being the best orientation for the zone.

Table 1. Result rates of transmitted energy in the wall construction systems.

<table>
<thead>
<tr>
<th>Wall construction system</th>
<th>Label</th>
<th>% Construction systems</th>
<th>Without air conditioning Energy transmitted warmest month (Wh/m² day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollow concrete block 10cm</td>
<td>BH_acay_10</td>
<td>36.0</td>
<td>19.12</td>
</tr>
<tr>
<td>Hollow concrete block 15cm</td>
<td>BH_acay_15</td>
<td>64.0</td>
<td>2.56</td>
</tr>
<tr>
<td>Total non homogeneous construction systems</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Total housing represented</td>
<td></td>
<td>1325</td>
<td></td>
</tr>
</tbody>
</table>

The best wall construction systems without air conditioning is using hollow blocks of 15cm with 2.56Wh/m² per day, in second place, with a bigger difference, is using hollow blocks of 10cm with 19.12Wh/m² per day.

The wall construction system non homogeneous to analyze the effect of color is shown in Table 2.

Table 2. Specification wall construction system used to study the effect of color.

<table>
<thead>
<tr>
<th>Construction system components (outer layer → inner layer)</th>
<th>Thickness (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand-cement mortar</td>
<td>1.50</td>
</tr>
<tr>
<td>Hollow concrete block</td>
<td>15.00</td>
</tr>
<tr>
<td>Plaster</td>
<td>1.50</td>
</tr>
</tbody>
</table>

With the Ener-Habitat software solar absorptance varied from 0.1 to 0.7 without air conditioning during...
the critical summer month of August. The transmitted energy increases linearly with solar absorptance 0.4kWh/m² per year for each 0.1 of solar absorptance, is shown in graphic 2.

The average interior temperature in the warmest month also increases linearly with the increase of solar absorptance as shown in figure 3. For A = 0.1 the average temperature is 27.5°C, while for A = 0.3 is 29.6°C. In this case, the increase is 1°C for every 0.1 increase in solar absorptance. For this reason light colors are recommended in the outside of the walls, especially the west and eastern walls, which receive more solar radiation is shown in graphic 3.

The evaluation of energy cost, using the Ener-Habitat software, was conducted using horizontal roofs. Two types of homogeneous roofs were used, concrete ribs and polystyrene blocks of 10cm and 15 cm. The systems were evaluated without air conditioning.

Table 3 shows the percentages of each type of construction systems used in homes as well as the transmitted energy values. The best rated roof construction system shows that the transmitted energy is of 8.55 Wh/m² per day.

<table>
<thead>
<tr>
<th>Roof construction systems</th>
<th>Label</th>
<th>% Construction system</th>
<th>Without air condition Energy transmitted warmest month (Wh/m² day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete rib slab and polystyrene block 10cm</td>
<td>NeCa_cfy_10</td>
<td>16.0</td>
<td>9.31</td>
</tr>
<tr>
<td>Concrete rib slab and polystyrene block 15cm</td>
<td>NeCa_cfy_15</td>
<td>84.0</td>
<td>8.55</td>
</tr>
<tr>
<td>Total non homogeneous roof construction systems</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total housing represented</td>
<td>1325</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Result Rates of transmitted energy in roof constructive system. Source: Created by researchers with Ener-Habitat software (2012).

To calculate the cost-benefit of wall construction systems, three systems were used: the first system is a brick wall with an exterior and interior finish of sand-cement mortar of 1.5cm, the outer surface being white with a solar absorptance of 0.1; the second being a wall of compressed earth block 14cm thick, with an interior and exterior finish of sand-lime mortar 1.5cm with solar absorptance of 0.10; which mechanical behavior is shown in table 4. The third is a set of five layers, two layers of compressed earth block joined by a sand-lime mortar being the same used for the interior and exterior layers.
### Dry condition | Resistance Kg/cm | Humid condition | Resistance Kg/cm
---|---|---|---
6% | 41.40 | 6% | 41.40
8% | 77.72 | 8% | 44.63
10% | 120.74 | 10% | 44.63

**Tabla 4. Mechanical behavior, compressed earth block.**

*Fuente: Roux (2010).*

The analysis for the proposed wall construction system is to compare the cost-benefit factor that obtained from the product of the energy (E) for the cost (C) of the 3 proposed systems, taking care that the standard cost (Cu) is not too high.

Table 5 shows that “Wall One” transmits more energy (E=1.20) than the “Basic Wall”, its cost is equal to the “Basis Wall” (C01.0), so that a cost- benefit factor is E*C=1.20. “Wall Two” transmits a fraction of energy E= 0.70, and has less cost than the “Basic Wall” (C=0.70) and the cost- benefit factor is E*C=0.49. “Wall Three” transmits less energy than the “Basic Wall” (E=0.10), the standard cost is C=1.10 and its cost- benefit factor is E*C=0.11.

“Wall 3” is the one with the lowest cost-benefit factor E*C = 0.11 and this cost is even higher than the basic system. Note that this type of construction system with double compressed earth block 32cm thick is not currently on the market in the area.

For the proposed roof construction system, the same methodology for walls is used.

“Roof One” is a conventional slab of reinforced concrete; while “Roof Two” has in addition a layer of polyurethane foam of 2.5cm of thickness. The two systems have an exterior finish of white acrylic waterproofing (absorptance of 0.20) and an internal plaster finish.
Table 5. Comparison of wall construction systems in Tampico.
Source: Created by researchers (2013).

Table 6 shows that “Roof One” transmits more than twice the energy value of the “Basic Roof”, with $E = 2.4$ which has a standard cost of $C = 0.9$ and a cost-benefit factor $E \cdot C = 2.16$. “Roof Two” transmits a normalized energy $E = 0.1$, and has a cost of $C = 1.0$ as the “Basic Roof” with a cost-benefit factor $E \cdot C = 0.10$.

### Table 6. Comparison of roof construction systems in Tampico.
Source: Created by researchers (2013).

<table>
<thead>
<tr>
<th>Roof construction system</th>
<th>$\alpha$ [-]</th>
<th>Layers</th>
<th>$e$ [m]</th>
<th>$Eu$ [Wh/m$^2$ day]</th>
<th>$Cu$ [$/m^2$]</th>
<th>$E^*$ [-]</th>
<th>$C^*$ [-]</th>
<th>$E^<em>C^</em>$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Roof</td>
<td>0.10</td>
<td>acrylic waterproofing</td>
<td>0.001</td>
<td>70.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>compression layer</td>
<td>0.035</td>
<td></td>
<td>650.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>polystyrene block</td>
<td>0.150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>plaster</td>
<td>0.015</td>
<td></td>
<td>180.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Basic Roof</td>
<td></td>
<td></td>
<td>0.201</td>
<td>5.52</td>
<td>900.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Roof One</td>
<td>0.10</td>
<td>acrylic waterproofing</td>
<td>0.001</td>
<td>70.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>reinforced concrete</td>
<td>0.120</td>
<td></td>
<td>540.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>plaster</td>
<td>0.015</td>
<td></td>
<td>180.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Roof One</td>
<td></td>
<td></td>
<td>0.136</td>
<td>13.06</td>
<td>790.1</td>
<td>2.4</td>
<td>0.9</td>
<td>2.07</td>
</tr>
<tr>
<td>Roof Two</td>
<td>0.20</td>
<td>acrylic waterproofing</td>
<td>0.001</td>
<td></td>
<td>170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>polyurethane foam</td>
<td>0.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>reinforced concrete</td>
<td>0.120</td>
<td></td>
<td>540.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>plaster</td>
<td>0.010</td>
<td></td>
<td>180.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Roof Two</td>
<td></td>
<td></td>
<td>0.156</td>
<td>0.791</td>
<td>890.0</td>
<td>0.1</td>
<td>1.0</td>
<td>0.142</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The thermal performance of a house depends on many variables; most of them derive from the architectural design, especially, the morphology rather than the materials and construction systems; however the knowledge and use of thermophysical properties of materials is an aspect that can more easily be subjected to regulation. Some decisions regarding the selection of materials can contribute to the better performance of the building, particularly if the materials are appropriate to the environmental conditions of a region.

The study in the area has shown in its initial stages that the construction processes used for architectural housing envelop are not the most appropriate. So to continue analyzing and comparing these processes, it has been established that in the case of the walls, the compressed-earth block has a better thermal performance than the traditional hollow-concrete block used for building walls. For roofs, the results of the analysis showed that the lightened layers (polystyrene foam and reinforced concrete) are less efficient than the reinforced concrete with polystyrene foam.
For the south zone of Tamaulipas, where a warm humid climate prevails, the construction systems recommended without air conditioning are:

For walls, a double compressed earth block with a thickness of 29 cm and an outside and inside finish of sand-lime mortar 1.5cm thick using white exterior colors and a solar absorptance of 0.1 are proposed. The energy transferred from this construction system is 0.10 used and its cost is 76% of the value of the most used in the zone, with a value of the cost-benefit factor of $E\times C=0.11$

For roofs, a reinforced concrete slab of 12 cm with a layer of polyurethane foam 2.5cm on the top and a finish of acrylic waterproofing 1cm thick using white colors with a solar absorptance of 0.10 and in the interior a plaster of 1cm thick is proposed. The energy transferred from this construction system is 0.1% of the value of the most widely used in the area with a cost-benefit factor of $E\times C=0.10$

For the south zone of Tamaulipas, where a warm-humid climate prevails, the dwellers usually have mechanical ventilation, like air-conditioning, to improve the thermal confort.

The study showed that the construction systems proposed and mentioned above were efficient for thermal comfort even without using air conditioning.

REFERENCES


ROSAS Lusett, Mireya Alicia; Roux Gutiérrez Salvador Rubén; Espuna Mújica, José Adán; García Izaguirre, Víctor Manuel, (2013b) “Propuestas de sistemas constructivos para la envolvente de edificación en la zona de Tampico, estudio técnico- económico” Informe Técnico entregado al CONACYT-SENER de la etapa 3. Febrero 2013.


ABSTRACT

The quality of urban life and urban experience is being compromised regularly in urban areas; one primary aspect being continuous urban climate degradation because of concentrated anthropogenic intervention in natural climate. As a result of rapid urban sprawl, drastic modification of the natural setup are common all around; like transformation of surface cover, alteration of watersheds and natural drainage, devastative destruction of natural flora and fauna, which in turn deteriorates the overall urban experience. On the other hand, urbanization is the necessity to sustain the economic growth and overall prosperity of the population in the present global scenario. Maintaining the quality of urban experience is one of the toughest challenges to the planners, urban designers and architects.

The researchers are investigating on the impacts of modified urban climate in terms of degraded air quality, thermal discomfort, unbalanced hydrological cycle, and various socio economic impacts as a result of the same. Urban physics is increasingly gaining importance in the research world as a tool to mitigate the urban climate and improve the overall living experience in urban areas. Urban physics is basically an inter-disciplinary approach combining physics, environmental chemistry, aerodynamics, climatology, mathematics and statistics, and most importantly urban morphology. But the real-life application of the knowledge acquired is limited. The pattern of urbanization and the main trend of building our cities remained primarily unchanged.

This paper will focus on different types of researches carried out so far in this Urban Physics domain, and their findings. This state of the art review will also provide a scope for the present authors to identify application potential of different researches in real life scenario. This can bring out scope for further research extensions on the basis of gaps found in research findings.

INTRODUCTION

The planning and designing of urban areas has taken a radical paradigm shift in the last few decades in the developed nations regarding the environmental sustainability. The change transcends from the early energy efficient buildings to the present net positive energy, intelligent buildings, which is really a big step towards the mitigation of the problem of climate change issues and global warming. The awareness of the people, encouragement from the government and social motivators played a great role to bring the wind of change.

The 20th century tendency of “design whatever the client wants, mostly on the basis of cost or aesthetics” (Butler, 2008) is an anomaly and hardly ever leaves much impact in our ‘ecological age’ (Head, 2008). Presently most of the buildings and urban settlements are designed in a much sustainable way remembering their context and subsequent environmental impact. But, climate-responsive design is becoming more and more difficult due to rapidly changing urban climate and the buildings are depending more and more on artificial cooling, mechanical ventilation and artificial lighting even at daytime. This problem becomes more traumatic in the urban areas of developing nations because of their high density and higher insolation which is further deteriorated due to tremendous population pressure, lack of financial support, political ill-will and ignorance of common mass to retrofit the urban growth pattern for a more
positive outcome. The deteriorating urban climate casts doubt on the efficiency of traditional Indian design philosophy of open buildings with fuzzy demarcation between the inside and the out.

This rapid urbanization demands sprawl of the city boundaries and densification of the urban tissues as well. The latter frequently results in the erection of tall structures along narrow streets and complete eradication of green spaces. As a result of the altered climatic balance, the air temperature, humidity, air pollutants and concentration of Suspended Particulate Matters (SPM) in air rises, worsening the quality of life in urban areas by the decreased thermal comfort, acute air pollution, frequent urban floods and increased energy consumption.

In order to apprehend all the problems of urban areas, it is essential to look into the physical properties of the various elements of urban climate. Urban physics is the engineering discipline that establishes the interrelationship of the transfer of heat, wind flow, moisture, pollutants, light and sound in urban areas to have a better understanding on urban climate. The aim of the study of urban physics is to provide an outdoor and indoor built environment that is healthy and comfortable taking into account of existing and future economical, ecological and climatic constraints.

Presently most of the researches in urban physics focus on environmental degradation in urban areas taking into account the Urban Heat Island, evapotranspiration, wind driven rain, pollutant dispersion, wind turbulence etc. Techniques like advance measurement of climatic parameters in boundary layer, sophisticated modelling tools based on Computational Fluid Dynamics (CFD) and wind tunnel simulations are combined together to obtain knowledge about heat, moisture and air flow starting from individual building scale to neighbourhood and entire city scale. The study of urban physics is helping the researchers a lot to understand the urban climate and finding out solution for better urban experience.

OVERVIEW OF URBAN PROBLEMS

Urban areas are plagued with various issues like outdoor thermal discomfort, extreme air Pollution, Urban flood, Low water table, loss of natural vegetation etc. These are basically a result of the interaction between some more fundamental inherent and external factors. If these fundamental issues are understood first, it will be easier to formulate some streamlined mitigation strategies in order to make cities a better place for living. Issues related to the design of urban areas like the materials used to cover the surfaces, placement of plazas and courts, alignment of trees and vegetation etc. play a vital role in urban thermal dynamics. Based on the principles of urban physics high performance computers analyze huge data sets collected by the instruments and help to understand various responsible factors and the interrelationship between them. The most important issues and their impact on urban climate are described below stating their causal relationship with other factors.

Transformation of Urban Surface:

The urbanization of the natural landscape through the replacement of vegetation with roads, bridges, houses, and commercial buildings has dramatically altered the temperature profile of cities. In fact, even within a city, different zones have different temperature profiles, dependent on their surroundings, type of surfaces, and characteristics of ground cover. Urban areas are characterized by dry, impervious surfaces, such as conventional roads, roofs, sidewalks, and parking areas. As cities grow, more greenery is vanished, and more surfaces are either paved or covered with buildings. The transformation in ground cover consequences in less shade and evapo-transpiration to keep urban areas cool. Lesser evapo-transpiration from paved and built up areas contributes to the rise of ground and air temperatures. These transformations affect the natural hydrological cycle within the urban area, leading to extreme surface runoff, reduced baseflows and infiltration, greater amounts of non-point source pollution when compared to areas of a more rural nature, and especially forested areas.

The surface transformation brings in consequential changes in urban hydrologic cycle that contributes to greater localized flooding potential, water bodies that harbour more nutrients and other chemicals, resulting in a greater growth of algae and reduced diversity of fish and wildlife, and a general overall decline in the aesthetics of urban water resources.
Formation of Urban Heat Islands:

In most cities, urban air temperatures are generally greater than their corresponding rural counterparts. This occurrence, the urban heat island (UHI), has been known since the turn of this century and has been well documented (T.J. Chandler, 1960), (T.R. Oke, 1987), (T.R. Oke, 1988). The fluxes of heat, moisture, and momentum are significantly altered by the urban landscape and the contrast between the urban and 'undisturbed' climates is further enhanced by the input of anthropogenic heat, moisture, and pollutants into the atmosphere. It has been observed that the heat island intensities can go up to 10°C in Indian cities (Pune) (Santamouris, 2001). The probable causes of the formation of UHI as suggested by Oke (1982) are as follows:

i. Trapped short and long radiation between the buildings.
ii. Reduced Sky View Factor (SVF) resulting in decreased long wave radiative heat loss
iii. Increased heat storage in urban construction materials
iv. Abundant anthropogenic sources of heat and moisture from fuel combustion
v. Reduced evapo-transpiration
vi. Reduced wind speed resulting in reduced convective heat removal

Though UHIs are not always unfavorable for cold climatic regions (Erell et al., 2011), it substantially increases the cooling load in warm climate and causes serious effects on inhabitants regarding the comfort and health issues. The increased urban temperature not only creates acute heat stress, but it also leads to psychological and behavioural changes along with the reduction of human physical and mental performance which leads to lesser productivity (Evans, 1982).

Increased Energy Demand:-Increased energy demand costs the consumers and municipalities more energy related expenses to maintain the desired comfort levels. The heating and cooling load of a building depends on the climate to which the building is exposed. Buildings located in the same area can have entirely dissimilar energy consumption pattern due to altered local microclimates. High ambient temperature increases the cooling load and energy consumption as well. It has been stated that for US cities the peak electricity loads increase by 1.5–2 % for a temperature increase of 1 °F (Akbari et al. 1992). A number of studies has been carried out using urban physics to look into the effects of urban heat island on various cities like Athens (Santamouris et al.2001), London (Kolokotroni et al. 2010) (Kolokotroni et al. 2006), Kassel (Schneider & Maas, 2010), Tokyo (Hirano & Ohashi, 2009) etc. All studies indicate a substantial impact of the increased urban temperature on the energy consumption of buildings.

Wind movement:

Wind movement in urban areas is much restricted due to the high building density. It results in low air exchange and lower the potential of air circulation in and around the buildings (Hirano & Ohashi, 2009) (Ghiaus et al. 2010).

Convective heat transfer and evapo-transpiration is also affected by lower wind speed. This reduced heat exchange results in excess heat storage in the urban built environment and raises the temperature of urban microclimate which again increases the cooling demand of indoor spaces. As a result of the entrapped solar radiation, the building skin temperature is always higher than the ambient air temperature (Allegrini et al. 2011).

Air Pollution: -

Generation of more electricity by power plants leads to higher emissions of sulfur dioxide, nitrous oxide, carbon monoxide, and suspended particulate matters, along with carbon dioxide. Development of urban heat islands often escalates the formation of photochemical smog, as ozone precursors like nitrous oxides (NOx) and volatile organic compounds (VOCs) reacts photochemically to form ground level ozone.

As the intrinsic characteristics of the natural landcover is transformed in the urbanization process, the energy exchange which takes place within the boundary layer are highly affected. Transformation of the natural ground cover influences the local (microscale), mesoscale, and the macroscale climate and disrupts the natural route of energy flow through the land, atmospheric and water cycles.
Planning Issues:

A number of planning related issues are responsible for continuous degradation of urban climate. In most of the cities, urban growth happens in a haphazard way without proper planning. Though the urban development guidelines tell some sort of indirect guidelines, the planners and urban designers often neglect the issues. In most of the cases they only visualize the space but fail to apprehend impact of the proposed development after their construction on urban climate. The climatic data that are taken into account, mostly collected by the weather stations which are placed at a much higher height. The actual ground level climatic parameter and the impact of local anthropogenic factors like mutual shading and reflected heat from surroundings, very often remain unnoticed.

Absence of mandatory energy efficiency codes and the resulting energy wastage from buildings also play a vital role in deterioration of urban climate. Building energy efficiency policies and programs are mostly in an active design stage with limited implementation to date. Decision-making authority at the national level is spread between several agencies and program design and implementation responsibilities are spread across a large number of state and municipal agencies, resulting in a diversity of implementation regimes and little coordination. This micro level reduction in energy use can cumulatively make a great impact on improvement of urban climate.

The role of urban physics in better appreciation of the problems of urban climate is indisputable. A lot of researchers are working in this field presently in order to solve the problems generated by rapid urbanization in various parts in the world. For an in depth appraisal of urban climate in urban neighbourhoods and street canyons, the combined effect of solar radiation, wind flow and evapotranspiration is studied. Modelling and simulation of various cases are performed using computational fluid dynamics (CFD), Radiation simulation and whole building simulation tools. Wind tunnel simulations are often carried out to validate the CFD simulation. By varying the various parameters of the model (like building density, green plot ratio etc.) the impact on microclimatic variables like outdoor temperature, wind speed etc. are observed and optimum solution can be proposed.

APPLICATION OF URBAN PHYSICS

Urban physics not only helps a lot to identify the problems of urban areas but also has the capability to suggest the optimum solutions of the problems.

A substantial amount research has been done to reduce the detrimental impact of urban climate change which suggests various measures like the use of evaporative cooling from ground level (Kruger and Pearlmutter, 2008) and rooftop water bodies (Runsheng et al.,2003; Tiwari et al.,1982) or make use of evapo-transpiration from wetted ground. Alternatively the design of the buildings with lesser exposed flat surfaces to control the direct solar access and aerodynamic design of the building can facilitate wind movement in and around it to improve the urban microclimate.

Considering the context of cities where the high humidity level, acute shortage of land is a burning issue, the solutions mentioned above are not feasible. As of today, most of the buildings in cities of the developing nations are built without any professional input and custom made passive design solution for every single building is a farfetched dream. Rather the protection of existing landscape by facilitating urban forestry, increasing the surface albedo by applying reflective materials especially on horizontal surface and plantation of shade providing trees along the road and around the buildings seem to be a more implementable solution. Among all known strategies of urban climate mitigation, a few, befitting the present context are discussed below.

Implementation of Urban Green Infrastructure:

‘Green infrastructure’ (GI) is a term used to delineate a network of greenways, parks, and untransformed open spaces, which are basic modules of urban environments (Benedict and McMahon 2006). (Kambites and Owen 2006, 484) specified that green infrastructure denotes “connected networks of multifunctional, predominately unbuilt, space that supports both ecological and social activities and processes”. These systems provide assorted psychological, economic, social, and environmental benefits
to urban individuals and communities (Forest Research 2010); (Manning 2011), and are essential in city planning and design (Walmsley 2006). Green infrastructure focuses on strategic planning to identify and protect wetlands, forests, and other natural components that deliver crucial ecosystem services.

GI includes the community “greening,” in which trees and plants are used tactically for stormwater management and other functions in urban areas. Urban greening ranges from planting streetside trees, installation of high albedo surfaces and rain gardens to installation of green roofs and planters on high-rise building balconies. Urban greening is very important to mitigate the extremities of urban climate and it provides several types of additional benefits to the urban community including richer biodiversity, pleasant visual experience, reduction of stormwater runoff and more groundwater recharge.

**Green roofs:**

Installation of green roof can passively cool the air above it and the indoor space below, (Köhler, 2004) (Teemusk and Mander, 2009) reduces the stormwater runoff, tackles air pollution by absorbing the pollutants and Suspended Particulate Matters (SPMs) and so on. The higher reflectivity of the foliage of the trees compared to common roof materials results in lesser absorption of radiated heat. Their higher emissivity also facilitate long-wave radiation and so radiat cooling (Gaffin et al., 2005) (Gaffin et al., 2006). Green-roof shades the roof slab by obstructing solar radiation. It offers thermal insulation to obstruct heat absorbed at the upper surface toward the roof slab (Lazzarin et al., 2005) (Getter et al., 2011).

**Use of High Albedo Surface:**

Roofs and pavements constitute around 60% of urban surfaces in many urban areas (Akbari et al., 2003) (Rose et al., 2003) (Akbari and Rose 2001). It is also demonstrated in many studies that an increase of roof reflectivity from 10-20% to 60% can generate energy savings excess of 20% in many cities. Increase of albedo of roofs and pavements can improve the air quality and reduce the summertime temperature in urban areas (Taha 2001) (Taha et al. 2000) (Rosenfeld et al. 1998). Due to the increased reflectance of urban surfaces some amount of incoming solar radiation can be reflected back and can counter global warming also (Kaarsberg and Akbari, 2006). but this strategy can only work in the case where the solar radiation is reflected back to the space and not entrapped between the building due to multiple reflections.

**Promotion of Urban Forestry:**

Urban forests can ameliorate the urban climate by restricting direct solar radiation, facilitating wind movement, removing SPMs and pollutants by the means of bioretention. It can lower the overall temperature of the surrounding by at least 2 °C-8 °C by the means of increased evapo-transpiration (Oke, T.R., 1987), (Taha et al, 1989). The shade provided by urban trees can be the single most important parameter to increase the overall thermal comfort as the direct solar radiation has the maximum impact on the surface energy balance (Taylor and Guthrie, 2008). The most favourable design solution is a layout where the buildings and trees together mutually shade the open spaces and roads (Emmanuel and Johansson, 2006), (Erell, 2008).

**Policy Level Mitigation Strategies**

Planning policies, guidelines and development control regulations actually determines the urban geometry. Though there is a subtle linkage between policy framing and urban physics, appropriate planning and development control regulations can facilitate the solutions that came out from simulation of various city models. At the same time, proper implementation of those guidelines should also be ensured.

Urban geometry has a strong influence on urban climate and the comfort level. It has been observed that a compact urban form with very deep street canyons and lower sky view factor (SVF) can create lower temperature (Cool Island) providing shade to the pedestrians in hot dry climate (Pearlmutter et.al. 1999) (Givoni,1998). On the contrary, dispersed urban forms create an extremely uncomfortable environment in the summer. So urban physics can indirectly guide the framing of building bylaws of a city depending
upon its climate.

From the above discussion it is understood that urban physics not only gives the researchers an in
depth knowledge of the problems regarding urban climate but also helps to find out the solutions for the
same. The advancements in this field of research will certainly help to build better cities with better living
experience.

**INTEGRATION IN URBAN DESIGN**

The comfort level of cities are highly compromised due to their high pollution level, formation of
UHI, and reduced thermal comfort. Framing the Urban design guidelines according to the findings of the
researches following the principles of urban physics can can lead to the optimum urban setup. Taking the
case of a city in warm humid climate, it can be observed that the stagnant air mass inside the city helps to
form UHI, rises the humidity level and concentrating the pollutants and SPMs which altogether
deteriorates the urban experience. But improvement of wind movement inside the city can substantially
improve the scenario. Strategic placement of the tall buildings in the urban fabric can extensively improve
the wind flow in the city. But placing the tall building in a dense pattern restricting the wind penetration
inside the city is not recommend in this particular case. So setting the building bylaws in favour of higher
FAR and lower ground coverage in some strategic plots and designing the urban area in accordance with
it can be very helpful to improve the outdoor comfort and reduce the outdoor temperature which results in
substantial energy savings.

But this same urban setup can become incompatible in the case of cold and windy cities. The opposite
approach, i.e. clustering of tall building in the path of prevailing wind restricting the wind flow can reduce
the pedestrian level wind movement to a comfortable level and prevent the conduction heat loss from
building skin. Appropriate and contextual urban design guidelines understanding the principle of urban
physics can thus improve the urban experience and reduce the energy demand as well.

In the case of a number of tropical and subtropical coastal cities, moist air comes from the seaside.
The hot urban area underneath heats up the moist air and it rapidly goes up followed by sudden
cooling and formation of dense clouds. But the wind drives the clouds on the other side and heavy rainfall
happens in the opposite side of the city of the direction of that incoming moist air from the sea. This
unequal heavy sudden rainfall results in unprecedented high intensity urban flooding in those cities. Cities
like Kolkata, Mumbai, Puri, Kochi, Surat are some common example of this incident in India. The urban
poor or those who live in slums are mainly affected by urban flood especially in cities like Kolkata and
Mumbai where the slums are located in low lying ecologically fragile areas.

There is a need to access the probability and extents of occurrences of these incidents and design the
urban area accordingly facilitating prolonged runoff time using urban green infrastructure, more permeable
surfaces, more urban greenery and improving the efficiency of stormwater drainage. This can reduce the
chances of vulnerability of the services and the inhabitants as well. Therefore many of the urban design
principles for sustainable and climate resilient development of the cities require the inputs from urban
physics for betterment of their performance.

**THE INDIAN SCENARIO**

Since the economic reforms started in 1991, Indian economy is growing at a fast pace. Due to
migration from rural to urban areas, India’s urban population is expected to reach 472 million in 2020 and
611 million in 2030 compared to 325 million in 2005 reaching a share of 41% of the total population
resulting in urban sprawl and densification (MGI 2010). To accommodate the migrating population, the
construction industry is also growing at a fast rate contributing an average 6.5% of GDP (JLLM 2007).

Indian cities grow in a ridiculous way by inclusion of urban fringes in the municipal areas. When a
city starts to grow, the land price of its surrounding village areas go up and development of the rural areas
start according to the rules and regulation of the rural areas having narrow roads and lack of public
amenities. It does not support any future improvement due to high built up areas and virtually no open
space. When these peri-urban settlements are included in the urban municipal areas, the problem increases
many fold due to the further increased population pressure. These areas may be retrofitted with some basic services and amenities, but the situation remains the same. These densely packed buildings (mostly without mandatory open spaces) creates a havoc impact on the urban climate because of complete extinction of greenery, extensive hard paved surfaces and the least space for wind movement.

In most of the cases, Indian cities only have municipal building byelaws which only deals with one individual building but they do not have any comprehensive strategy or guidelines for developing the public spaces considering the outdoor comfort and convenience in the urban realm. The existing building bylaws are often disobeyed which creates problems in wind movement, water percolation etc. Even the buildings in the National Capital Territory of New Delhi, comply with building codes less than 35% of the time (WB & IFC, 2009). Considering the unsustainable growth of the urban areas in India, a number of policies are introduced to facilitate the energy efficiency and green building as a control and regulatory measures including appliance ratings and certifications. But almost all the measures deal with an individual building. No visionary guideline has not been developed considering a neighbourhood level or city level.

Though in March 2011, BEE asked for the compulsory enactment of ECBC at the local level in eight states starting in 2012: Delhi, Maharashtra, Uttar Pradesh, Haryana, Tamil Nadu, Andhra Pradesh, Karnataka, and West Bengal (PTI, 2011).

The data on existing building stock in India are incomplete and estimates about the total floor space, number of units and typology of building (commercial, residential or industrial) vary considerably. With this limitation, the following facts and figures should be viewed as approximation. The total building stock in India has experienced an annual average growth of 6% between 1990 and 2005 resulting the doubling of floor space from 4 to 8 billion m². From 2005 to 2030, the average growth is expected to be 6.6% resulting 22 billion m² in 2020 and 41 billion m² in 2030. The growth pattern represents that almost 70% of the buildings that will exist in 2030 have not been built yet which actually leaves a window of opportunity to make substantial improvement of urban climate. (The World Bank, 2010). There is an urgent need to develop an urban development guidelines with a strong emphasis on the mitigation strategies of climatological and environmental impacts of urban development.

It is an agreed upon fact that Indian cities need much more attention for their extreme and as well as diverse character and as most of the future cities are yet to be built, there is a great scope of implementation of urban physics in designing Indian cities. Though a lot of researches has been carried out but the real life implementation of urban physics in urban design is yet to gain its momentum in the subcontinent.

CONCLUSION

The amelioration strategies discussed above came only through the research of urban physics and gives a direction to improve the experience of urban areas and explore new areas for improvement. It is evident that most cities suffer due to their air quality (pollution), thermophysical quality (thermal comfort) and water related issues (urban flood, low water table, etc.) (Campbell-Lendrum & Corvalan, 2007). In most of the case they are linked with one another in the urban ecosystem. So, the architects, urban designers and planners need to use urban physics to understand their interrelation for a practically implementable, streamlined and unified approach to start the development of mitigation strategies to deal with the unintended urban climate change.

The development route of world civilization till date has made it very clear that the population growth and urbanization will continue at a very rapid pace. Development of a number of new cities and expansion of the existing ones is a necessity. Therefore, there is an urgent need to develop new sets of urban design guidelines that comply with the research outcomes of urban physics to ensure that the upcoming buildings and the corresponding urban areas go along with today’s most efficient, climate resilient design and planning strategies.

Though the subject, urban physics, comes with a world of opportunities, it has some downside too. The correlation between various factors of urban climate, huge data sets and highly complex mathematical calculation demands profound knowledge of the subject and substantial amount of computational resource to run the simulations. Supply of resources and availability of experienced professionals and a streamlined
networking among all the stakeholders is necessary for its success.

Though urban physics mainly deals with a group of buildings, neighbourhoods, urban canyons etc. special emphasis has to be given on the design of individual buildings also as they cumulatively contribute to the overall urban experience. Considering the common trend of having very less building designs with professional inputs in most of the urban areas, the situation is going to deteriorate much more in the foreseeable future. It is very important to get the urban fabric right so that every single building have the capability to extract the maximum environmental potential with or without professional interventions echoing the ethos of traditional Indian design with a fuzzy demarcation of indoor and outdoor.

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Assessment of Solar Access in different urban space configurations in two southern latitude cities with mild climates.

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ABSTRACT
One of the characteristics of passive low energy architecture is the dependence of its facades on solar access. However, this aspect is little considered by law or in the practice of real estate development. On the one hand, urban space configurations such as streets are defined in planning guidelines by law to safeguard the common good, but on the other, real estate activity puts pressures on land and creates large buildings occupying maximum plot ratio. This is particularly the case in developing societies and emerging economies. One of the direct effects of this process is solar obstructions on the urban space, i.e., facades, ground, and sky. This means that indirect passive low energy opportunities which affect the possibility to capture energy for passive or active systems are lost with new high-rise developments creating inequitable environments. Therefore, the design of urban space which considers solar access to facades becomes an important issue as a means to avoid these problems.

This paper seeks to explore designs which permit solar access within the context of urban practice which permits large building volumes. Here, different street configurations are examined to evaluate to what extent it is possible to balance solar access and plot ratio criteria in planning guidelines. This investigation examines four urban space configurations from lower to higher density to discover the range in which both criteria present compatibility. Two cities located at two different latitudes are compared to assess solar irradiation availability on the surfaces of facades, the ground, the roof, and the urban space. A simulation was carried out on winter and summer solstices with two urban orientations: east-west and north-south axes. Results show an inflection point in the curve of irradiance according to geometrical profile. These findings help to orientate planning guidelines in the consideration of passive low energy architecture to promote a more sustainable habitat in developing societies.

INTRODUCTION
Contemporary cities in the context of emerging economies tend to experience growth both outwards on the periphery and upwards in high-density central areas with planning guidelines trying to control development. Whether in horizontal or vertical expansion, the built environment is shaped by economic forces that try to maximize plot ratio and building floor-space. One of the effects of these developments is the creation of towering high-rise blocks which shadow streets and surroundings impacting on solar access for urban spaces, facades, and buildings in cities as shown in Figure 1.

On the other hand, the Chilean urban regulations try to order urban morphology and spatial arrangements through morphological constraints such as; distance to boundary (“rasante”), plot ratio,
built floor coefficient, shadows above plot, amongst others. These parameters are useful to shape urban form for individual buildings on a single plot but not necessarily achieve a coherent morphology at city-block level. The emphasis on individual buildings in the urban regulations results in the poor design of three dimensional spatial surroundings. Regulations determine parameters which are concerned with architectural built form which theoretically allow the access of sunlight but in practice shadows are really only taken into account as a spatial limit to the height of buildings rather than any concern for energy use in passive and low energy architecture.

![Figure 1](image1.png) (a) dark street from shadowing and high rise buildings and (b) panoramic view of Santiago city to the East side.

Nonetheless, from a solar perspective planning guidance should consider the shading effects of buildings on their surroundings because this has an impact on the opportunity of daylighting and passive or active heating. Equity is put at risk when solar obstructions from high buildings fall on a neighborhood regardless of a minimum solar access to sunlight or daylight. The question is how to protect solar resources for every neighbour within cities? This is particularly important in cities which belong to the world’s ‘sun belt’ which have extremely high irradiance and opportunities to benefit from this resource, such as in the case of Chilean cities. As an example the southern German city of Freiburg is known as the “solar city” with enormous solar PV cells and solar thermal investment integrated to the architecture. It is located at latitude 45°N which is considerably further north and therefore receives less radiation, than Chile’s southerly cities, for example Puerto Montt at latitude 41°S. Therefore there is enough radiation to justify exploring solar options in Chilean cities not only in the north but also in the southern territory. Therefore it is argued that urban planning instruments should recognise the potential of solar access throughout the whole of Chile whilst considering the different contexts which may create different opportunities.

International institutions have stated that traditional approaches to urban planning have failed to promote equitable, efficient and sustainable human settlements for addressing twenty first century cities in developing countries (UNHS, 2009). However, there are many authors studying specific issue such as solar access on buildings and cities to deal with energy and spatial conditions to save urban morphology. (Capeluto, 2001; Košir et al., 2014; Lau et al., 2011; Benoit, 2012)

The general objective of this paper is to explore urban design which allows solar access within the context of urban development which permits large building volumes regardless of energy capture on urban surroundings. Cross-section of streets with different configurations (width/height ratio) are examined to evaluate to what extend it is possible to balance solar access and plot ratio criteria in urban planning guidelines.

Amado et al (2013) state that solar urban planning is a complex process that requires interplay between many factors related to urban form and solar energy inputs. The authors use a parametric approach to quantify solar energy from photovoltaic systems in the urban context (Amado, 2013). They argue that solar power plays a strategic role in improving the energy efficiency of cities because it could be used to generate clean energy for consumption and perhaps match demand. Both these functions are key indicators to understand the balance of energy performance in city neighbourhoods.

In the city of Oeiras, Portugal, an algorithm has been developed to estimate the annual energy production for PV systems. This has been applied to specific urban configurations such as the cellular unit called the “warped parallel”. Three factors were used to classify the city into different cellular units;
year/period of construction, population density and representative morphological patterns. The element of ‘roof surface’ was the mean element used to study the PV solar electricity potential. Here they compared energy demand and solar supply in the urban system with existing typologies of building block and street pattern. This appears to be a useful tool for consolidated urban areas but the question arises as how to plan the future urban configuration with a huge diverse morphological pattern.

With this in mind, we propose that a simple cross section analysis might support planning guidance in the future to control height of buildings considering both interests of maximizing urban densities and providing solar access to neighbouring buildings.

Current controls and guidance on urban morphology include “Site Layout Planning” of the Building Research Establishment (BRE) of Great Britain which has been in use since 1991 (Littlefair, 2011). This document advocates access to skylight and sunlight because these contribute to building energy efficiency. Daylight will reduce the need for electric light, while solar gain can help meet heating requirements in winter.

Additionally ‘Development Advice Notes’ exist at local municipal level in the UK to help applicants in submitting their planning applications. For example, Stirling Council in Scotland has produced a document to give general advice on daylight, sunlight and privacy on new development or extensions. Here they look for a balance between expectations of the homeowners and the effect of that development on the locality. The discretion of the Council is relevant to give permission for any changes in the built environment and daylight in this case is a guiding principle rather than sunlight.

These guidelines are set out to minimize the overshadowing of neighbouring properties for the majority of the day where the design should confine shadow projection to the applicant’s own land. The factors considered in the design are height, distance to boundary, size of plot, orientation and topography on plan. A “degree approach” refers to the angle allows daylight at the “centre of the closest ground floor habitable room window of neighbouring properties” (Stirling Council, 2002).

Finally, urban canyon has been analyzed as an element used to characterize the street in relation to the climate, meteorology and urban design by many authors (Oke, 1986; Mills, 1993; Pearlmutter et al., 1999; Venegas y Maceo, 2012; Andreou, 2014; Botillo et al., 2014). In this paper urban canyon was chosen to create a conceptual model for studying available solar direct radiation.

RESEARCH METHODOLOGY

In order to analyse effects of different urban configurations on solar access a parametric approach was applied. To achieve this objective a digital model was constructed considering a typical cross section of a street found in central areas of the city as shown in Figure 2. Two parameters were tested: irradiation (Wh/m2) and ratio height/width (1:1, 1:3, 1:5, and 1:7) where the heights of buildings were changed while maintaining a constant street width as shown in Figure 3 for each city and Table 1. This model was chosen because it represents urban spatial configuration that involves a topological relationship between facades and urban space. This means that analysis is not only of single buildings, as is traditional, but of two buildings which interact with the urban spaces and hence the human habitat.

![Figure 2 A cross section model of urban street canyon](image)
Table 1. Parameters of the model based on Cross section of streets

<table>
<thead>
<tr>
<th>Width of street between official line</th>
<th>ID</th>
<th>Height of building (N° of floor)</th>
<th>Proportion of urban space (W/H)</th>
<th>Factor of constructibility (ratio: floor surface / site surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>A</td>
<td>4</td>
<td>1:1</td>
<td>0.99</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>12</td>
<td>3:1</td>
<td>1.98</td>
</tr>
<tr>
<td>11</td>
<td>C</td>
<td>20</td>
<td>5:1</td>
<td>3.96</td>
</tr>
<tr>
<td>11</td>
<td>D</td>
<td>28</td>
<td>7:1</td>
<td>7.92</td>
</tr>
</tbody>
</table>

Two cities which have witnessed rapid growth and urbanization located in different latitudes and climates were selected to examine incident radiation on facades and urban space. To achieve this, the same cross section model was analyzed to compare how spatial configuration works in different climates. Four configurations were chosen according to proportion of urban space and two street axis orientations: North-South and East-West. The criterion for urban spatial configuration was a growing density from a lower to a higher extent to discover the range in which both objectives present compatibility: solar access and density. The questions were; To what extend it is possible to raise the height of buildings and have available solar radiation? and, How to balance both objectives to get a maximum solar energy on facades and a maximum high rise buildings?

Figure 3  Urban spatial configuration proposed for analyses pointing out solstice angle.
Table 2. Simulated value of solar incidence on facades and urban space in two cities: Puerto Montt and Santiago as a daily average on solstices: 21Jun and 21 Dic.

RESULTS AND CONCLUSIONS

First of all energy simulation has carried out by using Heliodon™ software to measure irradiation on facades and urban space assembled on two axes: North-South (N-S) and East-West (E-W). Total direct radiation incidence on both facades in front of the urban canyon was calculated which was divided by available surface on building in square meters to give the average energy. Masking has been...
considered in calculations during one whole day: summer and winter solstice, as shown in Figure 4. The same method was used for ground as horizontal data and all those values were registered in Table 2. In Figure 5 the chart shows curves energy performance according to proportion of street expressed through ratio H/W (height/width) such as 1:1, 3:1, 5:1, and 7:1.

Figure 5. Solar irradiation available on facades and urban space considering mask from buildings in front during solstice and growing density.

Results from Figure 5 show an inflexion point of facades curve at 3:1 proportion of the canyon in both cities of Santiago and Puerto Montt. After that radiation curves continue to slowly descend as density increases (higher buildings). Energy available on facades also changes according to the orientation of street axis and climate. If direct radiation is compared between the two cities the maximum values are observed in East-West facades during summer solstice (21 Dec). Similar values are observed in East-West facades during winter solstice as well (21 Jun). However values (kWh/m²) in North-South facades present differences in both cities whether summer or winter solstice. For instance, Puerto Montt registers almost twice the amount of solar energy values in summer and same situation as in Santiago but in winter. A conclusion might be that North-South facades within an urban canyon are relevant to assembled grid on urban design project and hence planning guidance.

In Figure 5 (a) it is also observed that the proportion of urban canyon becomes another relevant parameter for similar values. Given 3:1 in winter solstice in Santiago city is of a similar energy value to 1:1 in winter solstice in Puerto Montt city. So a conclusion for planning guidance is high rise buildings should be allowed in latitude closer to the equator (Santiago) rather than far from them (Puerto Montt). If the width of street is enlarged it would capture solar energy. A balance between solar gains in front urban facades is possible when a proportional magnitude of streets is managed by town planners at local government level.

Following this conclusion it is relevant to find out that some different orientations and different solstices in the same city of Santiago deliver equivalent solar direct radiation on facades. Values obtained from East West facades in winter are equivalent to North-South facades in summer solstice. By contrast, in the city of Puerto Montt different orientation in the same climate delivers equivalent values. Therefore a conclusion is that each city has equivalent values combining orientation of the street and weather (solstice). These findings might be useful for urban planning guidance which wants to consider solar energy as input for the architectural envelope in the urban context rather limited to the isolated
In Figure 5 (b) solar irradiation on urban spaces presents a higher value in Santiago than in Puerto Montt as expected, at the summer solstice there is a 1kWh/m2 difference in value. However values tend to be similar when approaching winter with a similar curve at the solstice of June 21th. An inflexion point occurred at the 3:1 proportion of urban space in both cities. The north-south axis presents more dispersion in respect to the east-west. The proportion of 7:1 in Santiago is equivalent to 3:1 in Puerto Montt therefore high-rise building might be managed to have a similar potential of solar access.

Finally a comparison of irradiation performance on facades and ground surface regarding the proportion of urban space has been analysed with simulation modeling. Solar energy performance changes significantly if facades or ground surfaces are analyzed considering masking. A balance between both initial objectives, highlighted at the beginning as solar access and urban density, is possible to achieve when analysing values from simulation as this paper demonstrated. Decision making might be taken by local planners through physical parameters such as proportion of street canyon. It is interesting to discover that similar solar energy values can be obtained depending on the height of buildings in two cities with different latitudes. More specifically, it is possible to manage the proportion of urban space through finding out the relationship between ground width and building height. These parameters would help urban design and planning guidance at local government.

![Figure 6](image)

**Figure 6** New arrangement buildings are placed on land plots varying the width of the street.

To evaluate more complex changes in building geometry the model is rebuilt with different heights for both cities during the day of least favorable solar radiation, the Winter solstice (June 21). In this new arrangement buildings of different heights are placed on land plots as an alternative to the continuous urban canyon and this time varying the width of the street. **Figure 6** shows a simulation of solar flux intensity (kWh/m2) falling on the façade of a building on a street of 20m (top) and 30m (bottom). An inverse relationship was discovered; as the width of the street becomes greater the direct solar radiation available on the north façade facing a solar obstruction is slightly lower for Santiago. However the model for Puerto Montt shows a direct relationship; as the width of the street increases the direct solar radiation available on the north façade increases. Since Puerto Montt is at a lower latitude than Santiago it could be inferred that high latitude cities, increasing the width of the street optimizes solar energy in northern facades, but in cities of a lower latitude this spatial parameter works the opposite way.
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An Analysis of the Potentialities of Portuguese Vernacular Architecture to Improve Energy Efficiency

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ABSTRACT

Vernacular architecture is characterised by a type of formal expression that has been developed in response to a number of factors – climatic, lithologic, cultural and economic – characterising the local area or region. In its various forms, a range of techniques has been employed in different regions to mitigate the effects of climate. Despite the fact that Portugal is a small country, it has a territory full of contrasts, which gave origin to many different architectural manifestations. The approaches adopted in the design and construction of vernacular buildings have the potential for further development and could be adapted in response to contemporary needs. In the future, a blend of tradition and modernity should be aimed at in order to develop a new form of aesthetics and functional construction. Portuguese vernacular architecture is associated with a fund of valuable knowledge that should be studied and aligned with the principles of sustainability. In this paper, is presented the climatic contrast between the northern and southern parts of Portugal and the relation with the purpose of different passive solar techniques used in vernacular architecture to provide comfort. The focus is on the effectiveness of passive cooling techniques (e.g. high thermal inertia, the use of light colours and patios), and the findings of a case study in which the thermal performance during the summer of a vernacular residential building located in the south of Portugal are presented. In the context of the current global drive for clean energy and sustainable buildings, much can be learned from a review of past experience in order to provide an understanding of such forms of construction, which are an intrinsic feature of specific places and have evolved over time in the face of a lack of resources.

INTRODUCTION

Nowadays, sustainability and energy efficiency are inevitable discussion topics for building industry. This industry is one of the largest raw materials and energy-consuming sectors of the economy and responsible for almost a third of all carbon emissions (Ürge-Vorsatz, Danny Harvey, Mirasgedis, & Levine, 2007). In order to address this problem various bodies have set medium and long-term targets for improving efficiency in construction, such the European Union that has outlined a path of 70% of reuse/recycling/recovery of construction and demolition waste by 2020 (European Comission, 2012) and an 80-95% reduction in CO2 emissions by 2050 (EEA, 2012).
In order to achieve the above-mentioned objectives, there is an urgent need to rethink the ways of building. In an era of globalization that led to the homogenization of the different ways to build, according to some authors we should reflect on past experience, since traditional buildings are an example of a more sustainable construction and so they could have an important role to play in the future of construction (Foruzanmehr & Vellinga, 2011; Oliver, 2006). Intrinsically bound up with the local conditions, vernacular architecture could contribute towards reducing waste and energy consumption through the use of passive solar design, traditional techniques and local materials, which were developed in accordance with a specific territory and climate (Fernandes, Mateus, & Bragança, 2013; Kimura, 1994; Singh, Mahapatra, & Atreya, 2011).

This paper is focused on energy efficiency (other sustainability categories are not discussed), since this issue is particularly relevant in the contribution of vernacular architecture towards sustainable building. This is because vernacular buildings gave prime importance to passive climate control for ensuring indoor conditions of comfort. Additionally, the strategies used to mitigate the effects of climate are usually low-tech and not very dependent on non-renewable energy, while they do not require special technical equipment, which makes them suitable for contemporary construction, especially passive building design. In this sense it is important to highlight that a passive houses provide the lowest contribution in terms of such equipment as far as LCA results are concerned, mainly due to the fact that there is little need for conventional ventilation and air-conditioning equipment (HVAC) (Passer, Kreiner, & Maydl, 2012).

Although “Energy” is just one of the sustainability categories, several comparative studies (Forsberg & von Malmborg, 2004; Haapio & Viitaniemi, 2008) about Building Sustainability Assessment (BSA) tools have shown that energy efficiency is a relevant aspect of the overall sustainability of a building. For example, according to the Portuguese assessment and rating system (SBTool PT), the “Energy Efficiency” category has the highest weighting (32%) in the assessment of environmental performance and the third highest weighting in the assessment of the global sustainability of a building (Mateus & Bragança, 2011). Energy consumption is also a key issue in terms of the environmental life-cycle impacts of buildings, mainly during the operation stage, and is related to the provision of healthy and comfortable conditions for occupants (Passer et al., 2012)

Nevertheless, some studies have been carried on the passive strategies used in Portuguese vernacular architecture, the state of the art is that there are no results available from in situ measurements that can demonstrate the contribution of these different approaches to improve energy efficiency. Therefore, this paper attempts to provide a contribution in this field by presenting both: an overview of the climatic contrast between the northern and southern parts of Portugal and its influence on the type of approaches adopted by vernacular architecture; their potential contribution to passive building design; and the results of a study on the effects of passive cooling strategies on the control of indoor temperature and humidity of a building during summer.

THE CONTRIBUTION OF VERNACULAR TECHNIQUES TOWARDS ENERGY EFFICIENCY

In the past, due to the lack of advanced technological systems for the maximization of comfort, buildings were built using passive systems. While simple and clever, these were based only on the available endogenous resources and on a range of criteria such as: geographical characteristics; insolation; orientation; geometry; form; and materials, among others (Coch, 1998; Oliveira & Galhano, 1992).

The relationship between the built environment and the natural environment is well described by the Roman mythological concept of the Genius Loci and has primal importance on buildings’ conception and thermal performance. The significant differences between the way house-construction developed in northern Africa and northern Europe, for example, demonstrates that this was not a random process; similarly, in Portugal, there is a considerably difference between the houses from north and south.

Several quantitative studies on the thermal performance of vernacular buildings conducted in different parts of the world have shown that vernacular buildings achieved acceptable comfort standards throughout much of the year just using passive strategies, in some cases indoor temperatures remaining almost constant (Cardinale, Rospì, & Stefanìzzi, 2013; Martin, Mazarrón, & Cañas, 2010; Shanthi Priya, Sundarrajaa, Radhakrishnan, & Vijayaralakshmi, 2012; Singh, Mahapatra, & Atreya, 2010). The results
support the idea that passive strategies are in many cases feasible for use in contemporary buildings and that they could contribute to reduce buildings’s energy demands for HVAC.

**VERNACULAR ARCHITECTURE IN NORTHERN AND SOUTHERN PORTUGAL: STRATEGIES TO SUIT THE CLIMATE**

Vernacular architecture in Portugal, as in other countries all over the world, is influenced to a great extent by geographical location. Climate and other geographical features account for differences between the various types of vernacular constructions found in the different regions of this country.

Continental Portugal is located between latitudes 37° and 42°N in the transitional region between the sub-tropical anticyclone zone and sub-polar depression zone. Beside latitude, the most important features affecting the climate of the territory are orography and the influence of the Atlantic Ocean (Santos, Forbes, & Moita, 2002). With regard to relief, the highest peaks rise to a height of 1,000m to 1,500m, except for the Estrela Mountains, whose highest point is just under 2,000m.

Even though it is a small country, Portugal is a territory of contrasts. In spite of the fact that the variation in climate factors be rather small, it is sufficient to justify significant variations in air temperature and precipitation, such as (Santos et al., 2002):

- **Air temperature** – in winter the average minimum temperature varies between 2°C in the mountainous interior zone and 12°C in the south zone of Algarve; in summer the mean maximum temperature vary between 16°C in Serra da Estrela and 34°C in inner central region and eastern Alentejo.

- **Precipitation** – in the highlands of the northwest region the mean annual accumulated precipitation is above 3000 mm, one of the wettest zones in Europe; in southern coast and in the eastern part of the territory: the average amount of rainfall is in the order of just 500 mm; southern interior has a Mediterranean climate, well known for its vulnerability to climate variability, namely to droughts and desertification.

To suit different climate conditions Portuguese vernacular architecture developed specific mitigation strategies. In a general form, as shown in Figure 1, it is possible to verify that in the northern part of the country the adopted strategies aim to increase heat gains and to reduce indoor heat losses during winter, while in the south the strategies are more focused on passive cooling during summer.

In order to respond to cold winters, reducing heat losses and taking advantage of solar radiation, vernacular buildings from the north frequently used thatched roofs – due to their insulating properties – to reduce heat losses, and south-facing balconies to take advantage of solar radiation. The glazed-balconies are a feature of the architectonic identity of the Beira Alta region and, due to the advantages they bring many are still in use today. They are usually facing between south and west so that they receive the highest number of hours of sunshine and a high level of radiation during the winter, while affording the best shelter from the prevailing winds, as shown in Figure 1 (a). The use of this kind of structures is feasible in refurbishment projects with energy efficiency purposes, as demonstrated at the Residential complex in Dornbirn, Austria, where residents' heating bills have been significantly reduced (Küess, Koller, & Hammerer, 2011).

In the south of the country, in order to minimise heat gain, several techniques were developed, such as (Figure 1 (b)): reducing the size of doors and windows; the use of a high thermal inertia building systems; the use of courtyards (patios); and the use of light colours in order to reflect the excess solar radiation. The effect of these passive cooling strategies on the thermal performance of buildings is described in the case study in the following section.

The abovementioned strategies are relevant to the debate on energy efficiency in buildings because they are aimed at reducing energy consumption and increase the comfort level for occupants by passive means. Despite the advantages of the presented passive strategies, for the Portuguese context there is a lack of quantitative data on the effectiveness of these approaches on the thermal performance of vernacular buildings in different climate zones. Nevertheless, the interpretation of the results of studies conducted in other European countries points to some techniques of Portuguese vernacular architecture
being effective and having the potential for use in contemporary buildings.

Figure 1 Winter / summer mean temperature maps (IGEO, n.d.) and vernacular strategies distribution; (a) glazed-balcony building; (b) building with a courtyard (patio).

PASSIVE COOLING STRATEGIES EFFECT IN THERMAL PERFORMANCE OF A CASE STUDY

Aim and description of the case study

The study presented in this paper is aimed at a quantitative analysis of the contribution of passive cooling strategies, a vernacular approach used mainly in the south of Portugal (Figure 1), in the control of indoor temperature and humidity during the summer to achieve comfort conditions.

The case-study is situated in the historic city centre of Évora, a city located in southern interior Portugal (latitude 38°34’N, longitude 7°54’W). The climate in Évora is Mediterranean temperate (Csa – according to the Köppen climate classification), with hot and dry summers and high temperatures during July and August (with maximum temperatures of 30°C to 40°C, occasionally reaching 45°C) (AEMET & IM, 2011). In July and August severe drought is normal and rainfall is rare, with an average total precipitation of 8,6 and 6,6 mm, respectively (AEMET & IM, 2011).

The monitored building has an L shape, with the façades facing the courtyard oriented to SE and SW, as shown in Figure 2a-b. The courtyard has plenty of vegetation and in which two trees offer considerable shade for the building. The building has two storeys and a total area of approximately 900m²: the ground floor houses the kitchen, a bedroom, and various storage spaces; on the upper floor there are living rooms and other bedrooms.

The in situ measurements were carried out in the ground floor (Figure 2a), which have the following construction features: traditional brick vaulted ceilings, ceramic tile finished floors, lime mortar finished walls and single glazed wooden windows. The average wall thickness of the building is about 100 cm. It was not possible to rigorously determine the composition of the walls but, so taking into consideration that this kind of buildings were usually built with rammed earth or massive brick masonry, it was estimated that the heat transfer coefficient (U-value) is of about 1,00 W/m2.ºC. The floor area of the monitored spaces is approximately of: kitchen – 33m²; bedroom - 17m²; courtyard - 600m².
Methodology and equipments

The effect of passive cooling strategies in the control of the indoor temperature and humidity of the building was quantified through in situ experimental measurements. Two physical parameters were quantified: air temperature (ºC) and relative humidity (RH %). For this purpose, were used three equipment with an internal sensor to measure temperature and relative humidity of the air. It has a measuring range between -35 to 70ºC and an accuracy of ±0.9ºC. Readings recorded can be downloaded to a PC.

Field measurement involved the positioning of units inside and outside the house: one in the courtyard and two inside, in the ground floor: one in the room adjacent to the courtyard (the kitchen) and the other in the bedroom (Figure 2a). Data was recorded continuously over the period from 17th to 26th July 2007; data from the different sensors was recorded at 30-minute intervals. Secondary data for the study was collected at the Geophysics Centre of Évora for the same time period.

![Figure 2](image_url)

**Figure 2**  a) Ground floor plan showing the position of measuring instruments; b) View of the courtyard (patio).

Analysis of results

Indoor air temperature, both in kitchen and bedroom, varied slightly, remaining nearly constant, while in the courtyard there were great fluctuations in air temperature throughout the day (Figure 3). The high thermal inertia of the building is the most probably reason for this, but the presence of abundant vegetation in the courtyard also contributed towards reducing direct heat gain through the envelope by providing shade. In order to provide an understanding of the effectiveness of different passive cooling techniques used in the building, these results were compared with the data recorded in the city centre during the same period. This showed not only the importance of the thermal inertia for reducing variations in indoor temperature but also the role of the courtyard in substantially reducing air temperature around the building. An analysis of recorded data shows that air temperatures in the courtyard always remained lower than those recorded for the city centre, especially during peak periods of heat, with a maximum difference of around 9ºC, as shown in Figure 3. It may also be concluded that this vernacular approach also allows for a delay of approximately 90 to 150 minutes between the moment at which the temperature in the courtyard starts to rise and that at which peak temperatures are reached in the city centre. An analysis of the chart in Figure 3 shows that during daytime, in the city centre, outdoor relative humidity reaches a minimum of about 20% whereas the maximum temperature is nearly 40ºC. For the same period, in the courtyard, minimum relative humidity is nearly 30% and the maximum temperature is about 30ºC. A possible reason to explain the lower air temperature in the courtyard is that the existing vegetation does not allows that this area contributes for the local heat-island effect (Figure 2b). Additionally, both the abundance of vegetation and the presence of a water fountain contribute to the evaporative cooling of the courtyard, thus raising the relative humidity and diminishing the air temperature. Another plausible reason for this difference is that cool humid air, which is consequently dense, remains in the courtyard during the early hours of the morning, until is warmed by the sun. In this confined space, the air takes longer to gain heat than the air in the city centre, thus its temperature remains lower and its relative humidity higher than the air in the city centre during warm periods.

Indoor relative humidity shows slight fluctuations throughout the day with an average of around 50%, the most suitable level for human health and comfort (Morton, 2008). This difference between indoor and
outdoor relative humidity can be explained by the use of materials that contribute to the regulation of indoor humidity. Indoor wall surfaces and ceilings are covered with lime plaster, with a thickness of about 3cm. This material regulates the quality of the indoor environment, as it is not only permeable to water vapour but also contributes towards moisture buffering (Berge, 2009), i.e. it moderates changes in relative humidity by absorbing moisture from the surrounding air and, when the air is less humid, giving off absorbed moisture.

In what concerns the assessment of the thermal comfort conditions indoors, was applied an adaptive model of thermal comfort, since this is the most adequate model for naturally conditioned areas, and used a psychrometric chart representing Évora’s climate conditions and the adaptive comfort range for July. Due to high fluctuations in outdoor temperature and humidity between night and day, the thermal conditions for each indoor space were represented separately for day and night. Analysing the results it is possible to conclude that both kitchen and bedroom spaces have thermal conditions within the limits of the adaptive thermal comfort range for summer in the majority of the days without any mechanical cooling system, as shown in Figure 4. Only the bedroom did not reach the comfort conditions in two days. However, is very close to the comfort limit.

![Indoor and outdoor temperature and relative humidity profiles.](image1)

**Figure 3** Indoor and outdoor temperature and relative humidity profiles.

![Psychrometric chart for Évora representing the indoor comfort conditions in the case-](image2)

**Figure 4** Psychrometric chart for Évora representing the indoor comfort conditions in the case-
DISCUSSION AND CONCLUSIONS

Vernacular architecture is the paradigm of the interaction between architecture and climatic conditions. The techniques presented in this paper, due to their simplicity and pragmatism, have great potential for use both in the design of refurbishment projects and the construction of new buildings. For example, the passive cooling strategies employed in the south of the country, as shown in the case study in Évora, are simple to implement and can improve indoor comfort conditions in buildings during the summer season. Our findings show a difference of 7ºC and 16ºC between indoor temperatures and the peak outdoor temperatures (recorded in the courtyard and in the city centre, respectively) and the psychrometric chart showed indoor spaces within the thermal comfort limits during all the monitoring period, which means that such a vernacular approach has great potential for decreasing energy consumption by means of active cooling systems. These results are achieved by combining several passive-cooling strategies, such as: whitewashed walls; small exterior doors/windows; high thermal inertia walls; and courtyards or patios. In these strategies, the two last have considerable influence in indoor climate. The courtyard revealed to have a large influence on the creation of a microclimate near the building, with air temperatures remaining lower than those recorded for the city centre, with a maximum difference of around 9ºC. It is likely that these features affect the thermal performance of the building during the winter. However, taking into consideration the regional climate classification considered in the Portuguese Regulation for Energy Performance of Buildings (DL118/2013, 2013), the most difficult issue to solve in this region is the hot summer period.

With an opposite purpose, the balconies in Beira Alta provide an efficient mean of increasing solar gains and preventing heat loss, are easy to install and play an important role in minimising heating requirements. It may also be concluded that these strategies are perfectly adapted to the local area in which they were developed and there is no negative aesthetic impact on buildings.

Vernacular knowledge on passive strategies is relevant when current buildings are known to have a high level of energy consumption for providing air conditioning. It is imperative that priority is given to building design that adopts passive methods for controlling the indoor climate, limiting mechanical systems no more than a backup role, to be used only when the passive strategies are not sufficient for meeting the comfort needs of occupants. This paper assesses in holistic terms this architectural manifestation in the light of current knowledge in order to seek scientific justification for the principles of vernacular architecture and validate its use in the future. However, there are limitations to this study and some aspects are only discussed qualitatively. Further studies are required to provide quantitative assessments in order to generate specific scientific information about the thermal performance of vernacular buildings in Portugal. More accurate information about the contribution of passive vernacular solar strategies would be useful for architects and engineers concerned with climate-responsive and energy efficient buildings and therefore could provide a contribution to the sustainability of buildings.

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The influence of culture on energy consumption in Aboriginal housing in arid regions of Australia

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ABSTRACT
This paper examines both the technical and sociocultural aspects of Aboriginal housing in hot dry climates, posing the question: can domestic living patterns and preferences be harnessed to reduce domestic energy consumption? The colonial history of housing Aboriginal people in Australia is rife with precedents that are unsuccessful on multiple levels. Research has highlighted the frequent mismatch between modern housing types and the sociocultural traditions of Aboriginal households. In arid and semi-arid regions, the majority of Aboriginal housing is poorly designed for the climate, yet this aspect of shelter has received limited scholarly attention. The design of bioclimatic houses that support cultural patterns is still an architectural challenge, complicated by diverse historical and economic conditions. Additionally, the increasing cost of energy causes economic stresses for public housing occupants. Current climate change models for Australian arid regions predict increasing temperatures and less predictable rainfall patterns, which provide further challenges for low-energy housing design. Using recent survey data on Aboriginal housing in Northwest Queensland, this paper examines the design implications of using both sociocultural and technical factors to improve living environments and reduce energy consumption. The integrated design of buildings in landscaped yards can both mitigate overheating and support socio-cultural practices that affect overall residential energy consumption. Despite a general consensus on the significance of external living environments in the literature, there is lack of evidence from research that measures culturally derived adaptive strategies to reduce residential energy consumption in Aboriginal housing.

INTRODUCTION
In the arid and semi-arid regions of Australia, a large proportion of the Aboriginal population face problems associated with socio-economic disadvantage, the high cost of domestic electricity supply, high energy demand, and predicted changes to the climate. These problems are compounded by housing and yards that are poorly designed for the current climatic conditions. In the remote regions, within the last century, the transition to sedentary Western style housing has disrupted and transformed social and cultural practices related to Aboriginal domestic living patterns. Since the 1970s, when housing Aboriginal people became a political concern for Australian governments, researchers have documented the dilemmas and difficulties of designing culturally appropriate housing (Heppell 1979; Memmott 2004; Reser 1979; Ross 1987). This area, and Aboriginal housing generally, remains under-researched (Long, Memmott & Selig 2007), partly due to the diversity of Aboriginal groups, demographic change
and significant socio-cultural changes influenced by multiple factors. Only recently has research attended to questions of thermal performance of Aboriginal housing and energy use, partly as a result to climate change studies (Duel et al. 2006; Martel et al. 2012; Horne et al. 2013). There is a need for further studies that pursue an integrated approach to research that attempts to measure housing quality and performance, and record and analyze behaviours that affect energy use. This aligns in one of the gaps in data identified by the IPCC (2014:67), which recognized the need for “Improved and more comprehensive databases on real, measured building energy use, and capturing behaviour and lifestyles are necessary to develop exemplary practices from niches to standard.”

![Figure 1. Map of the upper Georgina River Region showing settlements Dajarra, Urundangi, Camooweal and Wunara examined in the research on climate change.](image)

Using data from different sources, this paper examines the potential for synergies between low-energy housing design and Aboriginal cultural practices. It also identifies behaviours and external factors that challenge sustainable domestic architecture in remote semi-arid and arid regions. This raises the primary question: once identified, can socio-cultural patterns and preferences be used in design strategies for low-energy domestic living environments? This question is particularly pressing given the added challenge of climate change in the arid regions of Australia, where new approaches to housing design are necessary for mitigation strategies in both Aboriginal and mainstream housing (Wang et al. 2011).

**METHODS**

This paper draws on research that examined climate change Aboriginal people and in the Georgina River Basin, a semi-arid region in northwestern Queensland, extending across the Northern Territory boarder (Figure 1.). In 2011 and 2012, an interdisciplinary study of Aboriginal adaptation to climate change was conducted in four towns in the region (Memmott et al. 2013). Surveys were used to ask 32 questions (quantitative and qualitative) about the informant’s experience and use of the built environment and utilities. This included housing, domestic behaviour patterns and preferences, water supply and electricity, with some questions related to climate. These data and observations of Aboriginal
houses and yards are compared with the literature on Aboriginal housing design, complemented by evidence from architectural practitioners working in the field. Data on the planning, construction and performance of Aboriginal housing in remote areas draws on post-occupancy evaluations, housing assessments and the collective observations and records of an interdisciplinary research centre with four decades of experience in the field. A number of researchers have conducted research in the upper Georgina River Region for over a decade with a particular focus on the built environment and the delivery of services (Long & Memmott 2007; O’Rourke 2011). In the small town of Dajarra, Long (2005) documented socio-cultural practices in an extended ethnographic study of Aboriginal people’s living environments in the settlement.

CLIMATE AND HOUSE CONSTRUCTION

The upper Georgina River Region is characterized by a hot dry climate with mild winters, although toward the north of region the summers are more humid. The rainfall varies across the region, with a general decrease in precipitation moving south away from the influence of the northern summer monsoon: from wet summer/dry winter (mean annual rainfall of 401 mm in Cammoweal) to an arid climate (264 mm/annum in Bouila). Landscapes are predominantly grasslands in the north with deserts in the south. In Cammoweal, the annual mean maximum temperature is 32°C and in mean minimum is 17.6°C.

Climate change models for the region predict temperatures to increase in arid regions with a greater frequency of extreme heat events (CSIRO 2007). A recent review of the Australian climate data (CSIRO 2014) describes a significant warming trend across the arid and semi-arid regions of the continent. This includes increases in the duration, frequency and intensity of heatwaves since 1950. Seven of the ten warmest years on record have occurred since 1998. In 2013, the region experienced its warmest spring on record. Overheating is the main challenge with housing in the region, with mean maximum temperatures averaging around 38°C across the four summer months. Winter temperatures require heating for thermal comfort, and Aboriginal people in the arid regions are sometimes more concerned about cold conditions that hot weather (Thorne et al. 2013).

In his analysis of the regional climate and housing design, Szokolay (1990) advised that cross-ventilation cannot be relied on for cooling; insulated thermal mass walls are able to exploit the relatively high diurnal variation with nocturnal ventilation, and benefits from either passive or mechanical evaporative cooling. He also recommended slab-on-ground construction with full shading of walls all-year-round. Deep verandahs are generally recommended for cultural reasons, although fixed shading can

![Figure 2. Climate profile for Cammoweal. (Source Memmott et al. 2013)](image-url)
limit the use of thermal mass for heating in the regions with colder winters (Duel et al. 2006:45). Recent studies (Wang et al. 2010, 2011) of heating and cooling energy requirements for residential buildings across different Australian climatic zones predict that, under current models, climate change will significantly increase the cooling loads in arid zone housing.

In our survey of housing in four settlements in the Georgina River region, 72% of the participants (N=68) agreed that their house was too hot in summer and similar numbers agreed that their houses were too cold in winter. Over 70% used air conditioning to ‘get through summer’, although the preference to live in an air-conditioned house was less than 50%. In Dajarra, about one third of the houses had evaporative air conditioners and one third had refrigerated air-conditioners—all were retrofitted to the housing. The state-wide use of residential refrigerated and evaporative air conditioners has increased significantly in the past 20 years, with only one third of Queensland households not using air conditioners in 2009 (ABS 2010).

ENERGY PRICE AND POVERTY

Electrical energy is the primary source of domestic energy in the study region with all but a few houses connected to a distribution network. Between 2003 and 2013 in Australia, household electricity costs increased on average by 72% in real terms (Swobada 2014). The increase in the study region was 73%, with additional price increases of 20.4% in 2013-2014 and 13.6% announced in May 2014 (AER 2013:131). This increasing cost in electricity supply has placed considerable financial burden on Aboriginal households in the remote regions where low rates of employment limit disposable income. In a 2008 survey, expenditure on electricity in Dajarra ranged from AUS $2,400 to $6,000 per annum for Aboriginal households of varying size in one settlement (O’Rourke 2011). For many Aboriginal people occupying remote public housing, price rises in electricity increase vulnerability to climatic extremes, and particularly during heatwaves (PWC 2012).

In remote settlements, Aboriginal people have increased dependency on electrical energy although surveys of housing show that refrigerators, air-conditioners and electric heaters are at the lower end of energy efficiency. In our survey, 55% worried about paying bills and the same number of participants had changed the way they used household appliances to reduce electricity usage. A significant number (37%) had changed the way they lived in their house and yard due to extreme weather events.

HOUSING BACKGROUND

The change from mobile hunter-gather patterns of dwelling to more sedentary living conditions in remote regions of Australia varied with the history and circumstances of the colonial frontier. Aboriginal dwelling practices follow three historical phases that were often overlapping and uneven across the last 150 years: 1. In traditional or pre-colonial campsites a repertoire of shelters largely related to seasons were structured around spatial practices: windbreak and shade structures were used for most of year, with thatched domical dwellings used during cold and wet weather; 2. Adaptation of building traditions to more sedentary settlements often on the margins of colonial towns, pastoral properties, and government or missionary reserves; and, 3. The first substantive investment in state-supplied Aboriginal housing began in the late 1960s.

Although the involvement of architects in housing was initially promising in the 1970s (Heppell & Wigley 1981), direct participation in design has been marginal. In remote settlements, the housing stock varies in age and type, ranging from transportable homes, prefabricated housing, to a variety of mainstream housing, often standardized designs. A substantial proportion of Aboriginal housing in remote areas is of poor quality and requires either significant upgrade or replacement (Hall & Berry 2006; Pholeros et al. 1993). Remoteness—defined by distance to a service centre—is a significant factor in the design, delivery and maintenance of housing (Hall & Berry 2006:100). Transportation to remote or settlements limits construction choices and the cost of both labour and building materials escalates with distance from major coastal cities. A correlation between remoteness and continuities of pre-colonial Aboriginal socio-cultural practices adds to complexity of housing design in remote settlements.
Memmott (2003) identified three approaches to Aboriginal housing design that vary in their primary objectives: culturally appropriate factors, design for environmental health, and building procurement and delivery methods. These overlap but design for environmental health has had the largest influence on design standards (FACSIA 2007). There are notable exceptions of housing that provides architecture responsive to socio-cultural practices in remote regions of Australia (Dillon & Savage 2003; Memmott 2001, 2004). But within the literature, low-energy housing, for either socio-economic reasons or concerns about climate change, has received less emphasis than housing for cultural or health factors. There are few empirical studies of the thermal performance or energy use in Aboriginal housing: Duel et al. (2006) modeled thermal comfort of standardized designs in desert communities and Martel and Horne (2013) examined house designs in hot/humid area of northern Australia.

Settlement morphology and conventional housing in arid regions of Australia are not derived from historical or vernacular building traditions suited to hot/dry climates. Residential building types are largely detached suburban housing (variations on the bungalow), which continue to establish patterns and expectations for mainstream residential buildings. Courtyard type housing, for example, has few precedents in arid Australia for either Aboriginal or mainstream housing. Two examples by architects in the 1970s failed for a number of cultural and functional reasons (Heppell 1979; Heppell & Wigley 1981:157). Remote Aboriginal clients are wary of experimental housing design and preferences for conservative, mainstream architecture can conflict with preferred living patterns (Memmott 2003).

**SOCIO-CULTURAL FACTORS AND IMPLICATIONS FOR HOUSING ENERGY USE.**

Research and evaluation of both mainstream and self-constructed Aboriginal housing has identified a range of behaviours and social practices that are relatively consistent across remote settlements in semi-arid regions (Memmott 2003). We need to be cautious about accepting generalizations for diverse groups and changing demographic profiles, but the following factors either directly or indirectly influence residential energy use.

**Mobility and the use of houses**

High intraregional mobility is a consistent and common practice of people Aboriginal in remote and regional areas across the country and this factor directly affects the occupation of housing with implications for domestic energy use. Research on mobility in three towns in the study region in 2006 found that about one third of Aboriginal households contained visitors, a proportion consistent with other studies (Long & Memmott 2007:3). Cultural and social factors (the maintenance of kinship relationships) and service needs are main reasons for the high mobility.

Across Australia, Aboriginal household numbers are significantly higher than the mainstream household. High household numbers are related to general housing shortage in remote areas, population growth, socioeconomic disadvantage and cultural preferences (Memmott et al. 2012). High mobility also causes household numbers to fluctuate. There is a growing literature on overcrowding Aboriginal households yet there is little direct evidence of the relationship between numbers and energy use. High and fluctuating household numbers present challenges to designers and need to be considered in the assumptions required for thermal modeling of Aboriginal housing.

Unconventional use of housing by Aboriginal people is common in remote and urban settlements. Living rooms are used at night for sleeping (Long2005:223) and bedrooms can be occupied by relatively large numbers (2013). Social and technological change has also increased energy intensive activities such as television and computers, particularly for younger generations, yet the effects on housing use is underexplored. Surveillance of the community and environment was a determinant in the architecture and spatial arrangement of traditional camps yet it is common for windows to be closed and heavily screened. This may relate to privacy but in remote communities the practice may also relate to a fear of the supernatural and sorcery (Dillon & Savage 2003). In areas where this practice is prevalent, the use of windows for either diurnal or nocturnal ventilation needs to be reconsidered—occlusion of windows renders them ineffective for either daylighting or ventilation (per. comm. Finn Pederson 2014).
External living

The literature on Aboriginal housing indicates a strong preference living outdoors during the day, and sleeping outside the house has shown to been common in remote settlements (Long 2005; Memmott 2003; Musharbash 2008; Pholeros et al. 1993). Both socio-cultural practices and thermal comfort influence these behaviours. In summer, shaded areas outside the house, mostly from trees but also purpose built shade structures, are used in preference to the house interior (Dillon & Savage 2003). External living environments, which include verandahs, also enable social and environmental surveillance, including the monitoring of weather and seasonal indices.

In remote areas, adapted forms of pre-colonial shelter types continue to be constructed in yards to support socio-cultural practices. Variations on the windbreak are used extensively in yards and often associated with fires for warmth or cooking purposes: firewood piles are common in yards in the study area with the elderly often supplied by family. In the study region, and arid-zone settlements generally, traditional thatching materials are used on shade structures, but certified uses of such materials are limited.

![Figure 3. Housing in Dajarra that show little modification of the yard and a self-constructed windbreak used for cooking and other activities. June 2013. (Photographs author).](image)

Aboriginal residents use conventional (mainstream) internal kitchens but a range of traditional cooking activities occur outside the house in open fires and wood-fueled stoves (Long 2005). Long has traced the continuity of these traditions in the study area, recording the additions and alterations to rental housing to make external cooking areas. Thermal comfort was an additional reason for external cooking. In survey questions about adapting to increasing energy costs (Memmot et al. 2013), almost of quarter of respondents preferred to cook outside on wood fires.

Design guides (FACSIA 2007) and good architectural practice (Dillon & Savage 2003) recognize the use of external living environments but exemplars of yard design are rare and not recorded in the study region. Our research shows that gardening practices vary and landscaping around housing for shade depends on the householder. In Dajarra, comparisons of aerial photographs show an increase in vegetation cover over the last three decades. Garden irrigation is also used for evaporative cooling effects in summer but garden maintenance results in very high residential water use in settlements with unreliable water supplies (O’Rourke 20110).

With limited empirical data, it is difficult to gauge whether outdoor living activities are diminishing as people adapt more to houses and become accustomed to air-conditioning. In survey questions on adaptation of living environments to increasing hot weather, the most common answer was to use trees and landscaping. A recent post occupancy evaluation of Aboriginal housing in Alice Springs (CAT 2013), suggested that improvements to yards were more desirable for tenants than alterations to the house. Although the potential of landscape elements to improve thermal performance of residential buildings has long been recognized in arid region design in Australia (Aitchison 1962), there is a wide
gap in studies of the actual and potential contribution of microclimates to low-energy housing, particularly in the reduction of cooling loads. Selection, testing and evaluation of xerophytic plants are also necessary given climate change and problems with water supply in arid regions.

With the high cost of construction, landscaping of yards is rarely delivered in remote public housing projects. Cost, household mobility and resources limit ability of the tenants to improve landscapes around remote public housing. Despite these impediments, a range of gardening practices can be identified in the study region. Design improvements to residential landscapes benefit from the participation of household, in both maintenance and involvement in the design process.

CONCLUSION

Studies in the Georgina River Region found that vulnerability to climate change was related to poor quality housing and increasing energy prices. Low-energy housing is required for socio-economic reasons and the viability of remote Aboriginal settlements, in addition to low carbon imperatives. In the semi-arid and arid regions of Australia, modeling software demonstrates that both existing and new residential buildings will need substantial changes to building envelopes to achieve existing levels of thermal comfort without large increases in energy intensity (Wang et al. 2011). Harvey’s review of low-energy buildings (2013:303) suggests that high performance housing requires “significant additional investment costs, with simple payback times of 20–30 years or more.” His survey shows that high levels of skill, from integrated design processes to construction, can produce economical low-energy buildings.

Although integrated design and technologies can inform approaches to Aboriginal housing, the literature emphasizes knowledge of domestic social and cultural behaviours as a prerequisite for cross-cultural design. Limited but relatively consistent evidence presented in this paper suggests that certain socio-cultural practices provide a level of passive thermal comfort. This is particularly the case with the use of external living environments. These practices present opportunities for synergies between behaviour and passive or low-energy design. Landscape design for residential microclimates in the arid region supports current cultural practices and has potential to reduce the energy intensity of housing. In contrast, mainstream housing, reliant on air-conditioning, can work to undermine domestic cultural practices that are inherently sustainable.

It is a challenge for researchers to devise methods to record behaviours and preferred practices that influence the use of housing and yards over different seasons in remote areas. This does require an ethnographic strand to the research. In different settings, social and cultural change affects the currency and relevance of existing data. Data is also deficient in the measurement of energy use and the thermal performance of existing housing and yards as well as data on new approaches to design of both the internal and external living environments in arid regions.

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Evaluation of Environmental Control of Transitional Microclimatic Spaces in Temperate Mediterranean climate

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ABSTRACT

Mediterranean architecture is characterised by the presence of transitional spaces in which thermal conditions are intermediate between the inside and the outside ones. It is important to analyse these spaces because they act as climatic moderators with a strong social role at the micro scale level.

This study focuses on a particular type of transitional space that morphologically is located at the border of a building, usually called porch. The geometry of this space influences the effect of solar radiation as a source of heat in the space and for the building facing on it. However, their potential in terms of thermal comfort especially in summer season is in contrast with the need of solar gains in winter, daylighting and visual contact to the outside. The importance of integrating these aspects is generally underestimated by designers.

Aim of this study is to define the potential of environmental control of these transitional spaces and, in particular, how they can balance the requirement of a shaded area and the need of natural lighting inside the building. The effects of a porch orientation and proportions are analysed to compare how different configurations modify the transitional space performances. These evaluations are performed with simple tools, which take into account the impact of direct and diffuse solar radiation.

The analysis is still in progress but the most important finding of this paper is to present a method of evaluation that enables the architect to do early stage considerations according to the user requirements and the external constraints of the context.

INTRODUCTION

Mediterranean architecture is characterized by a great diffusion of transitional spaces (called also intermediate or semi-open spaces) that have intermediate thermal conditions between the indoor and outdoor environment. Historically their role as climatic moderators makes them an extension of living space and a place that favour social relations.

These spaces have always existed in different countries with specific features according to the culture and the climate. The benefits they provide make them interesting to investigate.

Intermediate spaces were largely used in the history of the Mediterranean countries where they originated and developed different configurations as porches, patios, loggias etc. especially in the
northern latitudes where the climate is more temperate and variable through the year (presence of hot summers, cold winters and middle seasons). These intermediate conditions imply the necessity of adapting the building to variable external dynamic stresses, combining the necessity of summer cooling and winter heating. For these reasons, transitional spaces are considered very important passive strategies, especially for their role in moderating the effect of direct solar radiation at a microscale level.

Since a complex network of different public spaces constitutes the structure of Mediterranean cities, the presence of intermediate spaces such as covered streets creates semi-public environments that act as unifying elements and promote a gradual transition between areas with different functions and levels of privacy. The potentially comfortable area they provide makes possible to experience protected zones where to sit, relax and enjoy the surroundings.

They are still built today but often using new materials and formal solutions with the only aim of enhancing the building exterior appearance. In fact, the advent of mechanical systems to control climate in modern buildings led to a standardized architecture with little use of passive strategies. Thus, the results often demonstrate a lack of environmental consciousness. This paper tries to clarify the environmental impact of these traditional forms and explains a method that enables the architect to do first conscious design considerations balancing the different needs required by a specific project.

**TRANSITIONAL SPACES**

Although transitional spaces have always played a significant role in moderating climate, it’s difficult to completely define their use because of their nature of being always “in between” different conditions (external/internal, public/private etc.). However, they can be classified in categories depending on their relation to the building.

From literature review (Chun et al., 2004; Coch, 2008; Maragno, 2010) there are: the “central type” totally enclosed by building’s walls and opened to the sky such as courtyards, patios and atria and the “perimeter type” covered and located at the border of a building such as porches, loggias and balconies.

Their value in climatic control is recognized from the Greek and Roman architecture mostly because they provide protection from undesired sun radiation, wind and rain, creating habitable semi-open spaces. The two types are sometimes integrated or used in a sequence increasing their value. For example, the Roman “domus”, the most typical Mediterranean residential housing type, is constituted by these different types of space: the impluvium and the court (central) and the peristilium (perimeter).

![Diagram of transitional spaces](image)

*Figure 1 (a) “central type”, (b) “perimeter type” and (c) the Roman “domus”.*

The advent of the glass in the modern architecture made possible the transformation of these two traditional types of transitional spaces in real “thermal buffer spaces”: the central type became an atrium and the perimeter type a greenhouse. The glazed solution increases the thermal effect but loses partially the relation to the outside that remains only visual. This is an example of how the new technology transforms traditional architectural elements in a way that potentially increases the climatic control but more specific knowledge and a more conscious design is required to avoid undesiderated effects of overheating.
The shading effect

This work is based on the hypothesis that the microclimatic characteristics of transitional spaces influence people’s behaviour and their propensity to use such spaces (Dessì, 2007). The qualities of these spaces are visible at a micro-urban level because they create microclimatic environments that enhance activities and provide social interaction. They can be seen as a comfortable extension of the private living space and a passive strategy of building envelope protection in overheated period. Their “ability” to protect from external environmental factors like sun, wind, rain and the amount of natural light inside the building depends on their configurations (horizontal and vertical limits) and on the materials that constitute them.

Although it is demonstrated that the presence of shaded spaces reduces the temperature fluctuation producing a more liveable environment (Chun et al., 2004), current comfort standards are not appropriate to evaluate well-being conditions in spaces that are neither interior nor exterior.

In this sense, it is necessary to assume a different approach to demonstrate their effectiveness. According to Potvin (2000), the presence of urban transitional spaces as porches provide a progressive adaptation of the body to a new environment. Even though this phenomenon cannot be clearly evaluated, there are researches that deeply investigate the perceived thermal comfort related to the psychological effects (Nikolopoulou and Steemers, 2003). In transitional spaces, the adaptive behaviour of people is demonstrated by the positive feeling resulting from the experience of passing through gradual conditions between the interior and the exterior. Moreover, the vision of a shaded space that anticipates the coolness sensation is a form of thermal “gestalt” which defines the richness of sensations that associate the multisensory perception to the metabolic and behavioural mechanisms of thermal regulations.

Thus, not only the physical effect of shading, but also psychological aspects related to multisensory experience are important issues that induce social use of transitional spaces.

THE PORCH AS A TRADITIONAL CLIMATIC MODERATOR

This research focuses on a particular transitional space usually called “porch” in Mediterranean countries. It is a “perimeter type” that in another part of the world has different cultural or climatic values. In traditional Japanese house where it is named “engawa”, it is a house extension that creates a continuum with the interior, while in tropical countries it has a stronger climatic impact and it is called “verandah” (Maragno, 2010).

In temperate countries, the porch is present both in its introvert and extrovert expression, along the streets and inside the courtyards. It has its origins in classical civilizations but its configuration has changed through the history to meet specific functional and aesthetic requirements.

The term “porch” derives from the Latin word “porticus” referring to a covered, columned space facing to a religious or civil building. On one side with a very symbolic value in relation to the concept of access to the sacred area of the temple, while in its public meaning with the name of “stoloi” as place of philosophical, political and commercial meeting. In the private roman house the “peristyle” defined a certain internal realm around a courtyard. During medieval times it has been used in the monastic architecture inside cloisters as a space for meditation, than in the Renaissance it was a recurrent element in palaces courtyards or at upper floors named “loggia”. In modern architecture, it appears in the form of modular balcony or delimited by Le Corbusier “pilotis”. Today the porches are built with new technologies and materials often with bad results in terms of climatic control, as previously mentioned.

The morphology of a porch is defined through spatial characteristics that are useful also to analyse other configurations of “perimeter spaces”. These spatial characteristics are: the “degree of enclosure” (enclosed or attached) in the building volume, the “proportions” respect to the façade (punctual or linear) and the “level” at which is located (ground or upper floor).

According to these variables, the porch can be defined as “enclosed”, positioned at the ground level and “linear” since normally its length is much more than the other dimensions.
The position on ground floor makes the porch a space with a strong link with the surrounding open space with a potential high level of social interaction and, for this reason, the permeability of the open side (e.g. distance between columns if any, presence of shading elements etc.) acquires great importance. Then the characteristic of being “enclosed” means that the upper horizontal limit is not exposed to the solar radiation but it only makes shade. Finally, the fact that the porch is linear allows its analysis in section, considering only the depth and the height: if it has the proportions of a corridor, it is only a space of circulation while if it is wider it can become a place for static activities.

In the perspective of a new project or a renewal, each of these variables assumes the role of a design strategy with a functional, environmental and aesthetic impact.

Environmental potential

Especially in temperate latitudes, the porch has a great climatic importance because of its good response to the variability of the climate: it protects from direct sunlight in summer but allows sun penetration in winter.

From a thermal point of view it enlarges the perimeter “potentially passive zone” (Baker and Steemers 2000) of the building in which the climate can be moderated without mechanical control systems. In relation to natural light, the porch works as an “intermediate light space” which permits the entry of daylight in the adjacent building through wall openings. Thus if it is designed so as not to reduce too much the daylight availability, it can provide a decreased and less contrasting light level to the interior zones facing the porch.

The effectiveness of a porch in relation to thermal and visual comfort depends primarily on its geometrical configuration, the orientation and the materials that constitutes its limits.

The solar radiation is the most critical environmental factor because it needs a contradictory architectural response according to the season and to its direct and diffuse components. Preventing direct sunlight creating shadows means to reduce also the infrared re-emitted radiation. Diffuse radiation is reduced as well affecting the daylight levels inside. The reduction of direct sunlight has positive effects because it increases illuminance uniformity and reduces contrasts preventing glare. It also creates pleasant effects of “penumbra” but you have to be careful in order not to go below the threshold of visibility. It’s worth noting that the amount of daylight inside should be considered togheter with the wall openings size and position.

All these issues refer to the importance of integrating different (and sometimes contrasting) environmental aspects in the design process in order to balance the effects primarily in relation to the user needs.

METHODOLOGY TO EVALUATE THE ENVIRONMENTAL CONTROL OF A PORCH

Many works have contributed to the quantitative evaluation of daylighting and sunlight control with energy simulations but few researches have explored the combined visual and thermal aspects related to solar radiation. The aim of this work is to propose a methodology based on an integrated approach that takes into account the requirements of a shaded area with the need of daylighting inside the building. In this way, architects can be helped to solve the problem of associating aesthetic qualities to environmental issues and functional needs.

Evaluation process

In order to evaluate the environmental potential of a transitional space configured as a porch (as described before) it is important to individuate the main parameters which represent its behaviour at micro-urban level.

A configuration comprehends the building surfaces that define the limits of the porch and the urban surrounding space. It is defined in terms of latitude, orientation, proportions and materials. In a preliminary design stage, the geometric parameters are more important than the material’s effect. Later, to have a more detailed analysis, it is useful to introduce the physical properties of the materials.
key issue is to balance the requirement of shading with the need of opening to the sky. Thus the first step is to evaluate solar accessibility in different seasons. The influence of external obstructions is assessed in terms of “aspect ratio” (H/W, the height of the building to the width of the open space) during the winter solstice when the sun is lower in the sky and the direct radiation is desirable. It is possible to define the two opposite urban scenes in relation to the solar access: a street canyon completely shaded or a wide open space (as a square) without influence of obstructions.

![Figure 2. Solar accessibility in winter solstice at 45°N latitude in two urban contexts with the aspect ratio of a square (a) or of a street canyon (b)](image)

On solar access and urban geometry, Oke observes that an “H/W of approximately 0.6 seems to be a suitable upper limit to maintain solar access in a city at a latitude of 45°N” (Oke, 1988). The need of opening to the sky is not only related to the thermal aspect but also to the daylight issue. In previous studies (Littlefair, 2001) it is suggested a spacing angle for temperate climate, that is nearly 35°. In fact, a transitional space in a street canyon tend to lower the sky component of daylight but at the same time the reflective properties of materials could increase illuminance levels due to the diffuse light reflection within the canyon.

<table>
<thead>
<tr>
<th>Sunlight</th>
<th>Daylight</th>
<th>View</th>
</tr>
</thead>
<tbody>
<tr>
<td>on ground (central point)</td>
<td>on workplane (h=0.80 m)</td>
<td>at view level (h=1.50 m)</td>
</tr>
<tr>
<td><img src="image" alt="Sunlight projection" /></td>
<td><img src="image" alt="Daylight overcast sky" /></td>
<td><img src="image" alt="View uniform sky" /></td>
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![Figure 3. Evaluations and related representations. (e.g. H/D=1 and facade completely glazed)](image)
After the context analysis, the evaluation should focus on the geometrical effect of the porch defined in terms of aspect ratio H/D, since it is assumed of infinite length (Fig. 4). The prediction of the sunlight and daylight distribution in the transitional space and in the adjacent interior rooms can be performed using different procedures (e.g. algorithms, nomographs, prediction tools, scale model-measurements and simulation programmes).

A simple graphic way to assess the direct sunlight impact in a point consists in overlaying a sun path diagram of the selected latitude to an obstruction mask properly oriented in a plane projection of the sky vault. Thus, it is immediately visible if the point meets the requirement of being shadowed in summer and not in winter. The unobstructed part of the mask gives also information on visual comfort (changing the reference point height above the ground), evaluating two aspects. On one side, it provides directly the percentage of visible sky from that point as Sky Factor (SF) measured considering a uniform distribution of the sky vault. This parameter is related to the pleasant effect of having a visual link to the exterior and for this reason it is interesting to evaluate it at the eye level of a standing person (1.50 m).

On the other side, overlaying a dot chart representing the illuminance distribution of an overcast sky (worst-case scenario) it is evaluated the Daylight Factor (DF, the ratio of interior horizontal illumination to exterior unobstructed horizontal illumination) as a first approximation. In fact, actually, the number of dots in the opening area represent the sky component of the DF, the illuminance received directly from the sky (neglecting in this first stage the reflected light from surrounding surfaces). In this way, for Mediterranean countries, sometimes the amount of natural light can be underestimated because in the southern latitudes there is a high frequency of clear sky conditions and that increases the contribution of radiation reflected from ground. In our case, considering the northern Mediterranean areas with temperate climate (latitude of about 45°N) it is reasonable to consider an overcast sky (in a first stage). Moreover, there are many design parameters, such as surfaces reflectances, window shape and size, and optical properties of the glazing that are unknown by the designer at the early design stages. For reference, a room that has a DF of less than 2% is considered poorly lit while rooms with DF between 2% and 5% are considered ideal for activities that commonly occur indoors.

Using different representation techniques, it is possible to have a more comprehensive description of the parameters values in the space. Especially at the early stages it is very useful for a designer to have simultaneous views (plan, section etc.) of the same object (Fig. 3).

In this study the parameters described are calculated with the help of Heliodon 2 (Beckers, 2009), a simple simulation software that allows faster evaluations and multiple view of the same geometry. Other more sophisticated tools (e.g. Radiance) enable more precise assessments but they are much more complex to use and the computation takes longer time, thus they may be of help in a further step of the design process to verify the choices made.

The study model

![Figure 4. Configuration of the study model.](image-url)
The effect of proportions and orientation of the porch on the luminous and thermal performances is evaluated through a study model (Fig. 4) considered representative of possible real cases. The model is located at a 45°N latitude, in an urban context in which external obstructions does not affect solar accessibility (Fig. 2, case a).

It is tested in different hours of the day and in the two seasons with conflicting requirements (summer and winter). The proportions tested are based on the observation of different existing porches and ranges from 0.5 to 2 H/D.

The evaluations are performed using indexes that allow comparisons among different configurations. The percentage of shaded area in summer is evaluated on the ground surface (on the 21st of June at noon) as Shading Factor, while the ratio of sunlite area in winter winter (on the 21st of December at noon) is assessed on the building wall as Sun Factor. The Daylight Factor (actually its sky component as previously explained) is evaluated at a work plane height (0.80 m) while the Sky Factor at the eye level of a standing person (1.50 m).

The building wall is the critical limit on which to evaluate the porch and the effect on the interior space depends on the porch’s geometry and the wall configuration, in particular in terms of both windows size and position in the wall.

Results

Regarding the porch orientation: the more the angle deviates from the east-west axis the more the porch becomes useless for all tested proportions. If the porch is very deep (H/D < 0.5) there is a lack of daylight inside and at least 50% loss of solar gains in winter. This first observation highlights the importance of integrating different aspects in the evaluation process.

Fig. 5 shows the comparison between different aspects ratio integrating the thermal and luminous aspect. Therefore, DF and SF are considered as punctual values on the building façade, the physical boundary that separates the inside to the outside.

Observing the graph, it seems that the aspect ratio of 1 offers the best balance between protection and openness to the sky, with the same percentage of shaded ground in summer and wall exposure to solar gains in winter, with a medium value of daylight and view factor on the building envelope. On the contrary, the extreme cases show that: if the depth is double than the height the only benefit is to have a wide shaded space in summer, while if the porch is too narrow it does not provide a usable space and it is only a solar protection for the building envelope. Of course, as it mentioned before, these analysis do not pretend to give accurate results but they are first evaluations to be integrated with other design features.

Figure 5. Effect of different aspect ratio on thermal and visual parameters.

Fig. 5 shows the comparison between different aspects ratio integrating the thermal and luminous aspect. Therefore, DF and SF are considered as punctual values on the building façade, the physical boundary that separates the inside to the outside.

Observing the graph, it seems that the aspect ratio of 1 offers the best balance between protection and openness to the sky, with the same percentage of shaded ground in summer and wall exposure to solar gains in winter, with a medium value of daylight and view factor on the building envelope. On the contrary, the extreme cases show that: if the depth is double than the height the only benefit is to have a wide shaded space in summer, while if the porch is too narrow it does not provide a usable space and it is only a solar protection for the building envelope. Of course, as it mentioned before, these analysis do not pretend to give accurate results but they are first evaluations to be integrated with other design features.
CONCLUSION AND FUTURE DEVELOPMENTS

The partial findings presented in this paper are part of a wider research that investigates transitional spaces in relation to human well being with the aim of providing guidelines for an architect in the early design stages. In particular, the importance of the porch as a climatic moderator in temperate Mediterranean latitudes has been clarified. Since environmental potential is well exploited only if it anticipates the human expectations, the method presented makes the effort to integrate different and sometimes contrasting needs especially in terms of daylight and sunlight.

Further evaluations can be performed taking in account other design features. In particular, the material effect is to be investigated: on one side in terms of exterior finishing, taking in account the surfaces’ multi-reflectances for a more precise assessment of the illuminance levels and eventually the occurrence of glare; on the other side the thermal effect due to reemission of long-wave radiation.

All the design choices modify the building exterior appearance with consequent effects on multisensory perception and on the integration within the surrounding context, especially in the case of building renewal or in an extremely dense urban context. Resolving all of these questions is a complex issue; therefore, the priorities of a project should be defined in relation to the specific user needs and balanced with the external constraints in order to reach a satisfactory compromise.

REFERENCES

The Cross Socio-cultural and Climatic Adaptation Aspects of the Peranakan Chinese House in Kelantan

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ABSTRACT
This study unveils PCK house by revealing its sustainable architectural features in both cross-cultural and climatic adaptation aspects. The Kelantan Peranakan Chinese (KPC) are a group of Chinese-Malay-Siamese mixed-race community living in the state of Kelantan, Malaysia bordered with south Thailand, a Malay-Muslim majority region. The KPC’s ancestors were Chinese from Min Nan, the southern Fujian province who migrated to and settled down in Kelantan in the last 300 years. Throughout these periods, KPC have socio-culturally assimilated into Malay-Thai native identity and adapted into the local tropical environment. One of the most noticeable features of these cross-cultural and cross-regional climatic adjustments is their unique domestic architecture. Ritually, the layout of a KPC house strictly inherits the basic Chinese domestic house planning, where the ancestral hall is positioned in the central and both sides of the hall are bedrooms. Externally, the style of the KPC house resembles typical Malay-Thai timber stilt houses. These amalgamations are required in order for KPC to fulfill their spiritual needs, and at the same time to harmoniously sustain in a new socio-cultural and nature environment. This study unveils the KPC’s creativity in modifying the architecture of their domestic house by regulating certain socio-cultural and ritual-religious variables to suit local climate and contexts. The purpose is, certainly, towards creating a more socially and environmentally sustainable residence. The methodology of this study is based on contents analyses of five measured drawings and observations on more than 400 visited houses. Simple temperature, humidity and illuminance measurements have been taken to provide some quantifiable figures. These analyses suggest that in adapting into a new local context, KPC are more concerned on how to achieve and maintain their ritual needs and identity over climatic aspects.

INTRODUCTION
In the quest of energy conservation and visioning the low carbon developments, investigation on how vernacular houses sustain naturally by their passive energy mechanism is getting more attention in environmental science researches recent years. Undeniably, vernacular architecture has been highly cited by scholars as one of the established archetypes evolving over the time through the processes of intertwining and adapting nature and socio-cultural aspects. The purpose is to achieve a balance living condition for humans to sustain harmoniously in their domestic sphere and surrounding contexts.
Vernacular house is the metaphor of these nature and socio-cultural symbiosis reflecting on its house form, spatial layout, site planning, material selection, etc. In searching for the lessons of sustainability aspects of vernacular architecture, however, most researchers focus on quantifiable climatic aspects than human or socio-cultural aspects. Albeit climatic architecture features are important supportive mechanisms to help providing climatically comfortable living to the residents, it is not always the main choice for vernacular houses where socio-cultural contexts, inherited rituals and identity aspects may play decisive factors over the climatic aspects.

So far, most environmental researches on vernacular architecture focus on homogeneous setting. The outcomes might not offer diverse and alternative lessons which are very useful in hypothesising the way of sustaining the growing plural and cross-cultural living environment in today’s world. Hybrid vernacular architecture, or fusion of two or more cultures, perhaps is one of the best subjects to be examined. KPC’s vernacular architecture offers great research exploration on how cross-cultural and cross-regional climatic adaptations could happen, particularly when involving different socio-cultural and environmental contexts; for example adapting sub-tropical climate into tropical climate or from a Min Nan Chinese culture into Muslim-majority context. The study shows the KPC are adaptable to their external architecture identity by adapting local influences in materials, design elements, and styles in order to sustain ecologically in the new environment. However, these amalgamations do not prevent their strong instinct to inherit their Chinese cultural identity, ritual and spiritual needs by remaining the Chinese architectural principal in spatial organizations in their house layouts by scarifying some climatic quality aspects.

The methodology of this study is based on contents analyses and observations on five measured drawings from KALAM (Center for the Study of Built Environment in the Malay World), UTM, and more than 400 identified houses from five fieldworks. In the aspects of climatic adaptations and socio-cultural assimilations, analyses are made from the comparisons between KPC houses and their vernacular houses in Min Nan, China as well as Malay houses in Kelantan. In the aspect of climatic adaptations, aspect of ventilation, lighting, materials, etc. are discussed and supported by some simple quantifiable measurements. Socio-cultural amalgamations such as factors which influence the adaptations and changes in KPC architecture were gathered through observations, interviews and literature reviews.

GEOGRAPHY AND CLIMATE

The Peninsula Malaysia, strategically located between West and East Asia, has been an important melting pot of commercial and cultural exchange since six hundred years ago. Today the diverse multi-racial demographic, comprising 60% Malays, 27% Chinese, 10% Indians and others, in the Peninsula is the result of these historical consequences. Kelantan, the most north-eastern state of Malay Peninsula, shares its border with Southern Thailand. Covering the area of 15,099 km2, Kelantan is the sixth biggest state in Malaysia. With a population of 1.5 million, the density of the state is about 100 where the concentration of population can be found in Kelantan Plain, a fertile agriculture plain dominated by the main river system, Kelantan River, and other smaller river systems.

Generally, the climate of Malaysia is tropical rainforest, having hot and humid ambience and no distinct rain and dry seasons year round. With the latitude and longitude slightly north from the equator 5.2500° N, 102.0000° E, Kelantan has clearer dry and wet seasons compared to southern part of Peninsula Malaysia. The wettest period is from end of October to early January when the Northeast Monsoon brings heavy rain to the state, whereas the driest period is from February to May. The average
yearly rainfall and temperature in Kota Bharu, the state capital, is about 2600mm and 26.7°C.

HISTORY

Facing the South China Sea, the Northeast Monsoon does not only bring heavy downpours to Kelantan, but historically it had been shipping the Chinese immigrants to the east coast of Peninsula Malaysia. The coming of the Chinese into the Southeast Asia can be traced back to 3rd century A.D. There are very rare academic records on the history of the Kelantan Chinese in the early period, but the existence of a 300-year old Chinese temple at Kampung Tok’ kong proves that a small group of Chinese had already established their community in Kelantan in 18th century.

The early Chinese immigrants who landed in Kelantan were mainly from Min Nan, Fujian province, China. Most of them settled down in rural areas along Kelantan rivers’ basins to find livelihood. Their comings were much earlier and small in numbers compared to those Chinese immigrants who migrated massively into the British Malaya in 19th to 20th century. Due to separation by the central mountain range and limited infrastructures, social contacts and economic exchanges between Kelantan Chinese and Chinese from other Malayan states have been scant. Having long been away and disconnected from their Chinese roots has resulted in that the Kelantan Chinese gradually assimilated to the natives’ way of life by acquiring local Malay language as their mother tongue, adapting to local food, costume and others. One of the most obvious assimilated features is their fusion domestic house which shows interesting cross-cultural and cross-regional climatic adaptations. This community is widely known as Cina Kampung or village Chinese by the local Malay and Siamese natives, but the community prefer to be called as Kelantan Peranakan Chinese (KPC), means local born Chinese or the Peranakan in short.

KELANTAN PERANAKAN CHINESE VILLAGES AND STILT HOUSES

Almost all KPC villages can be found along the fertile river basins of Kelantan, Pengkalan Datu and Kemasin rivers. Alike native Malay and Siamese traditional villages, their houses are usually located near to the source of their livelihoods such as paddy fields and rivers (Chen, 1998). River fish provides important source of protein to the KPC. Besides, rivers were the main highway for the KPC to communicate from one village to another and ferry their livestock, goods and crops to towns for trades. Although the rivers have not been actively used as in former days, the rivers are an important symbol of how the community sustained their living in the new environment. This could be deduced from the practical way on how most of the KPC orientated their houses facing the rivers, significant to their source of livelihood, economy, transport and communication.

Traditionally, the orientation of Chinese house is facing south (坐北朝南) following the Chinese geomancy principals, while to climatically avoid cold northern winds during the winter months. Nevertheless, extreme weather is not part of issues in the hot-humid climate of Kelantan and the principal of orientating the house facing south is impractical for KPC to conduct their daily activities with rivers.

Most KPC houses are sparsely located from each other on linear grid pattern by facing rivers or roads. The KPC village pattern is obviously disparate from Min Nan traditional village pattern, as Min
Nan villages are arranged in cluster group patterns. Two reasons could be hypothesized; least concern of security and climate in Kelantan. In Min Nan, traditional houses are closely grouped together to form a big cluster. The purpose is to create a strong surveillance network to defend the villages from bandit attacks. Secondly is to keep the villages warm during colder months. Since security is not part of the concerns in Kelantan, KPC houses are not densely planned or arranged in cluster manner, which allows greater wind velocity and penetrations to help discharge contained humidity. Besides, the practice of opening new lands after the existing villages have reached certain levels help to maintain the villages in low density, which is critical to help KPC village to sustain its micro-climatic aspects. To maintain the social networking and kinships, normally the new villages are opened opposite the rivers or adjacent to the existing villages. Therefore, many KPC villages can be found located side by side or facing each other along the rivers in Kelantan. Due to small number of population, KPC villages’ public facilities such as schools, markets, public spaces, etc. are shared with surrounding Malay and Siamese native villages. Sharing these facilities enhances the interactions between the natives and the KPC, which it is very important for the KPC to mutually and socio-culturally sustain as a minority in the natives’ socio-cultural landscape.

THE HOUSE UNIT

Figure 4 (left) The KPC house plan comprises two units: main unit and kitchen unit. Figure 5 (right) shows the façade of KPC house with large curvy roof to help discharge rain water and reduce the velocity of strong wind.

Basically, a KPC house consists of two units, which are the main house (unit) and kitchen house (unit). The main unit has an ancestral hall and bedrooms. The kitchen unit is where kitchen, dining area and bathroom are located. Similarly to a Malay house, a KPC house also comprises of rumah ibu (main house) and rumah dapur (kitchen unit). In Min Nan, China, the house unit can be repeated and expanded to form a big enclosed complex to accommodate bigger family members of few generations. From climatic point of view, the enclosed complex is not suitable in hot-humid climate where accumulating humid and high air temperature will make residents feel uncomfortable. In Malay village, extended families normally will establish their own houses adjacent to or in the nearby areas to their parent houses. Several Malay houses form a family cluster and several family clusters form a Malay village. This trend also applies to the KPC house where a village normally comprises of several family clusters. Besides, the reason why the KPC and Malay houses are small may be due to the limited spans of timber material. Most of KPC house structure is about 9 x 6 m (main unit). Technically, it might be difficult for timber structure to hold a large span without established construction skills. Another interesting sustainable feature of Malay and KPC houses is these houses can be dismantled and reinstalled from one location to another location.

The House

Western scholar Kohl (1984), who studied on the development of Chinese architecture in West Malaysia and Singapore, observed that the Chinese community is pretty practical in dealing with their domestic houses, signifying that “satisfied with their fitness of purpose, serviceability and aesthetics, the Chinese have not altered their architecture forms, with architecture becoming more a rule of thumb than ‘art’
after the Tang dynasty.” Even the Chinese immigrants who have settled down in foreign lands for few hundred years would stick with the basic house plans. This is suggested by Chua (1997), stating that the principal of Chinese house is “not only cut across time, but also ‘survived transplantation’ from its origin to a new environment.” This principle has been reflected in KPC house.

The KPC house basically can be divided into three parts: the body, lower floor, and roof. The body is the main house where rooms are located. The lower floor is the area below the elevated timber floor of the main house. The roof is the upper level of the main house. This configuration provides a natural mechanism for KPC house to adapt into its environment.

The Body

As mentioned above, in term of spatial arrangement, Chinese domestic houses are rarely seen having much of regional differences. The internal layout of the Chinese house strictly follows the Chinese architectural concept of “one bright, two darks.” (一明两暗). The bright zone is where the ancestral hall is located in the middle of the house facing the main door. The dark zones are the bedrooms located at both left and right sides of the ancestral hall.

To achieve brightness in the ancestral hall, two small windows can be found at two sides of the main door of the ancestral hall. Above the main door are timber lattices to allow further penetration of light and air into the hall. Sometimes, small openings covered by transparent glasses can be found on the roof over the ancestral hall to enhance the brightness of the hall. According to the Chinese architectural principal, the dark zones are the bedrooms located at both left and right sides of the ancestral hall. Normally in the bedroom, no window is placed on the wall facing the front part of the house. Only a small window can be found at the side wall of each bedroom. Therefore, the bedrooms are darker than the ancestral hall. Usually, native Malay and KPC houses have low lighting ambience in indoor spaces. According to the simple indoor lighting measurements on a KPC house (refer Graph 1), most of the internal rooms hardly receive 100 lux. However, it creates a more relaxing indoor atmosphere for occupants to rest since most of the daily works are conducted outside of the house or in the kitchen. However, the method of using smaller windows is not due to native influences but the KPC’s intention to maintain the origin identity of the Min Nan architecture. The purpose of smaller windows in Min Nan
house functions for security reasons and minimizes the effect of northern cold wind. Nevertheless, the atmosphere of Min Nan house is much brighter than KPC house because there is a big central courtyard in the enclosed compound of Min Nan house. In KPC house, in the quest of achieving its ritual needs and architectural identity, the spatial arrangement of “one bright, two darks” with minimum opening makes the indoor lighting extremely low. The long and large overhanged roof at veranda further reduces the light penetration into the house. This situation is worsened by the main door and windows of the ancestral hall being closed in the most of the time. The rational of this incomprehensible practice perhaps is due to the feeling of insecurity and sensitivity being in the majority Muslim social setting. As Teo (2003) suggested, the attitude of the KPC is vividly reflected in their way of life where they practice native behaviour (local costume, culinary, sociolinguistic, etc.) in the frontage, while keeping their own Chinese religion and ritual in the backstage, which are usually contained in their own houses and domestic spheres. It shows that maintaining good ethnic relationships and sustaining a mutual-respect living environment with the local natives are given the priority by the KPC and the external factors such as climate and thermal comforts are relegated as secondary aspects.

Indoor ventilation and lighting are interrelated. Both are determined by the size and position of openings. Cross ventilation, particularly at body level, is critically important to achieve thermal comfort in hot-humid climates. The airflow will evaporate heat from the human skin allowing the occupants to feel cooler (Lim, 1987). In a Malay house, even though the indoor spaces are considered private to family members, usually windows and doors are open widely to allow natural ventilation occur. Furthermore, the concept of open plan where there is less or no partition is used to divide indoor spaces allows greater cross ventilation to happen in Malay house. In contrast, the concept of indoor space in KPC house is obviously more private, perhaps sacred, than that of Malay house. As mentioned previously, the main door and windows of the ancestral hall are remained closed to prevent direct contact of passer-by to the ancestral hall. Besides, the internal spaces, bedrooms and the ancestral hall are divided by walls which will definitely slow down or block the wind entering the house. However, the problem of limited body level ventilation in the indoor spaces is reduced by roof level ventilation. The steep pitch roofs provide higher roof attics which allow accumulated indoor hot temperature release at the roof level and keep the lower part of rooms cooler. However, this is not sufficient to reduce the indoor air temperature to comfort level.

Graph 1 (left) and 2(right): Sample air temperature and daylight measurements taken from a KPC house (Chan Awang’s house, Kampung Sering). The house has an extended living room in front of the ancestral hall. The thermal comfort temperature ranged from 23.5 - 28.5 deg C with neutral temperature (feel neither cold nor hot) = 26 deg C. Generally, all the spaces yielded temperature higher than the comfort zone starting from 11.00am to 11.30pm (except day 2, it was a raining day). For daylight, the living hall only yielded > 100 lux during 1030am to 330pm on the 1st and 3rd day (except second day).
Although the indoor air temperature and lighting are poor, KPC rarely use indoor spaces at daytime. KPC men preferred spending their daytime and doing domestic tasks in the open veranda, while women and children spend most of their time in the dining area and kitchen where Ratio Humidity (RH%) and air temperature are relatively lower due to better openings. Guests are usually entertained in the open veranda area, and the indoor spaces are only generally being used at night when the air temperature and RH% decrease to the comfort level. The roof level’s fenestrations and the thin clay roof tiles easily release hot heat, making the indoor area comfortable to relax at night. This suggests that in maintaining the ancestral ritual and identity, KPC choose not to change their spatial layouts and opening for better lighting and indoor temperature but choose to change their living behaviour by assimilating native’s way of life and alter its domestic architecture.

The Lower Floor and Roof

Either on lower plains or higher ground, KPC houses are usually elevated on timber stilts, like those of Malay, Siamese and many Southeast Asian traditional houses. Formerly, the underneath of elevated floor was used for storage and to rear domestic livestock. This space allows for a buffer zone between elevated timber floor and the ground. This gap prevents the humidity and moistures from the ground sip into timber and damage its strength and make the residents feel uncomfortable when touching or sitting on it. The elevated floors are very important for the KPC, since most of their daily household activities such as eating, sitting, relaxing, and sleeping are conducted on the elevated timber floors. This shows that KPC has changed their Chinese way of life from using furniture to sitting on the floor as Malay native. From the climatic aspects, the higher the house is elevated, the greater wind velocity can penetrate into the house. This helps to reduce the KPC house’s RH level.

Once, the roof of KPC house was made from thatch. Since 1960s, the roofs have been covered by a type of clay roof called atap Singgora, imported from Songkhla, Thailand (Winzeler. 1985). The roof is pretty thin and easily broken but it looks closer to the roof tiles in Min Nan house. Like those of Kelantan Malay house, the roof tiles are loosely hanged on the batten to allow breeze to slip inside the house, compared to Min Nan houses whose roof tiles are cemented onto each other to prevent blowing up by typhoons. The curvy tapering roof form is the most expressive part of the KPC house. It symbolizes the Chinese Min Nan architecture identity and their origin. The typical Min Nan house’s roof curves into two directions – the ridge and hip rafter, making the roof having greater velocity to discharge water and redirect wind; particularly during the typhoon seasons. In response to higher precipitation average 2600mm in Kelantan, the KPC design the roof steeper in the angle at about 45 degrees. The purpose is to discharge the rain water more smoothly, particularly during the heavy downpour in monsoon seasons from November to January. The pitch of the Min Nan house roof is at about 30 degrees, making the depth of roof lower than that of KPC house. With shallower roof depth, Min Nan house is able to allow greater daylight penetrating into the building and to make the building interiorly and exteriorly brighter. In contrast, the KPC house has steeper pitch and longer roof overhang to shade excessive sunshine. Therefore, the proportion of the roof is much greater than the body of the house, which provides deeper shades to the open veranda. It also helps to reduce excessive glare. The effect of glare provides some security protection to the house owners, particularly in sunny days where one at the veranda can easily recognise any passer-by, but the passer-by having difficulty to figure out whether anyone is inside the house due to glare effect.
CONCLUSION

Having been migrated from sub-tropical region of south China into the tropical region of Malaysia, KPC have to judge what aspects that they can retain and what aspects they should adjust, accept and change in order to sustain environmentally and socio-culturally with the new native environment. These negotiations are illustrated in their domestic house design. Most obviously, KPC ancestors had chosen to follow the local Malay and Siamese natives in using local natural material to build their homes. The lightweight natural material with low thermal capacity such as wood and bamboo provide the house better thermal comfort in tropical climate, besides being visually and contextually harmoniously with the native villages’ surrounding environment. To get rid the problem of contained humidity in tropical climate, KPC houses are kept in small units, with the houses being sparsely arranged and the floors are elevated. The purpose is to allow better wind velocity to penetrate into the house compounds and units for reducing the level of humidity. This illustrates that KPC have no longer follow their ancestor’s norm of expanding their houses into a big complex to accommodate generations of family members, which it is not suitable in tropical climate where humidity will be difficult to be discharged. Besides, KPC has got rid their Chinese ancestor’s furniture culture by adapting Malay natives’ way of life by utilizing elevated timber floor as a living platform to conduct their daily activities. Judging from the KPC house’s stilt house architecture, the KPC seem to have adapted into Southeast Asia native architecture tradition and further dissociated with their ancestral traditional house typology in Min Nan, China, where most of the houses are made from masonry and placed on stone platforms (Else Glahn, 1982).

However, the domestic sphere of KPC house is still ruled by the concept of Chinese ritual. Descending from Chinese origin, the practice of ancestral veneration is one of their cultural pillars which have to be performed in the ancestral hall. At two sides of the ancestral hall, the norm of placing male’s bedroom at the left side and female’s bedroom at the right of ancestral hall has further determined the concept of spatial planning inherited from their Chinese origin. Due to sensitivity to the Muslim-majority communities, the main door of the house where ancestral hall is located is always in closed condition. The smaller-size windows further restricts the penetration of light and air into the buildings, making the level of luminance low and air temperature hardly achieve comfortable level. To solve the problem, KPC have adjusted the use of these spaces. To avoid uncomfortable air temperature and low luminance level, these interior spaces are rarely used during the daytime but only at night when both aspects achieve comfortable levels. To substitute the interior spaces, KPC houses, like native houses, have wide veranda for men to rest and do their daily tasks during the daytime and women and children do their activities in kitchen unit where dining and extended family rooms are located.

These architectural adjustments are needed in order for them to fulfill their daily activities and spiritual needs and at the same time to harmoniously sustain in a new socio-cultural and natural environments. The KPC architecture reveals how certain socio-cultural and ritual-religious variables could be adjusted architecturally towards creating a more socially and environmentally sustainable habitat.

References and Notes
Traditional Sustainability: Environmental Designs in the Traditional Buildings of the Middle East

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Keywords:
Traditional, architecture, sustainable, environmental strategies, comfort.

ABSTRACT

The traditional mud buildings present throughout the hot dry countries of the Middle East provide excellent references to the sustainable elements of architecture. This paper presents the results of the research of a few buildings in Saudi Arabia, Qatar, Bahrain and United Arab Emirates in terms of architectural problems due to climate, and the environmental elements as their solutions. The buildings studied ranges from mud houses, mud palaces to souks or bazars. These are, Shaikh Issa House in Muharraq, Kingdom of Bahrain, Al-Mulla House in Al-Ahsa, Saudi Arabia (K.S.A), Souk Waqif in Doha, Qatar, and Shaikh Saeed Al Maktoum House in Dubai, United Arab Emirates (U.A.E). Measurements were taken of air temperature, relative humidity, and airflow. Observations were made on the various aspects such as plan, form, orientation, sections, elevations, materials and methods of construction and details of the buildings. Comfort survey was conducted among the occupants. The paper shows that the traditional architectural solutions to the climatic problems of the Middle Eastern countries such as thick walls, small openings, shaded courtyards, use of local materials and a few special strategies work very well in the context in terms of providing comfortable environment indoors. The measurements of temperature, relative humidity and airflow compared to the comfort ranges of the region, reinforce the sustainable design of these buildings.

INTRODUCTION

The case studies for this research are located in Kingdom of Saudi Arabia, Kingdom of Bahrain, United Arab Emirates and Qatar, all of which fall under the broader umbrella of tropical hot-dry climate (Ragette, 2012). The buildings range from market or Souk, small single courtyard house, to large multiple courtyard houses. The masons used local materials and methods in these buildings. An in-depth pilot research on the environmental behavior and related climate modifying elements and strategies of these buildings were conducted recently. These traditional building in the Middle Eastern hot-dry tropical climate is of mud. Whether made of poured in mud, or sun-dried mud blocks, they are good in making indoors cooler than outside (Bekleyen & Dalkılıç, 2011). The thicknesses of the earth walls help keep the indoors considerably cool (Vincent, 2008). With walls of high thermal mass and other environmental strategies, these buildings are able to keep the interiors much cooler than outdoors. Courtyards in these buildings meet environmental and privacy requirement well (Laffah, 2006)(Awadhi & Hasan, 2011).

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CASE STUDIES

Location, Plan, Section, and Elevation

Table 1. Plan, Section and Elevation

<table>
<thead>
<tr>
<th>Locations</th>
<th>Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doha, Qatar</td>
<td>Souk Waqif</td>
</tr>
<tr>
<td>Al-Ahsa, K.S.A.</td>
<td>Al-Mulla House</td>
</tr>
<tr>
<td>Muharraq, Bahrain</td>
<td>Shaikh Isa House</td>
</tr>
<tr>
<td>Dubai, U.A.E.</td>
<td>Al-Maktoum House</td>
</tr>
</tbody>
</table>

(1) Elevation | (2) Elevation | (3) 3D view | (4) Site plan |
(5) Main façade | (6) Gr. floor | (7) 1st floor |
(8) Main façade | (10) Gr. floor | (11) 1st floor |
(9) Elevation | (12) Section |
(13) Southern façade | (14) Gr.floor | (15) 1st floor | (16) Elevation |

Location, Climate and Building Description

Table 2. Location, Climate, Building and View

<table>
<thead>
<tr>
<th>Location</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doha, Qatar 25.2867°N Coastal city.</td>
<td>(1) Hot-dry tropical.</td>
</tr>
</tbody>
</table>
Building

Market complex. Narrow shaded roads, with wind tower-buildings.

Irregular shaped 3-courtyard building.

2 storied house with 4 courtyards & wind tower.

2 storied courtyard house with wind tower and liwans.

View

(5) Wind tower house, Doha

(6) Central courtyard, Al-Ahsa

(7) Central courtyard, Muharraq

(8) Central courtyard, Dubai.

FINDINGS: CLIMATE MODIFYING ELEMENTS/STRATEGIES

The Findings of the research is given in the following chart for ease of comparison of the architecture of the four countries. This also shows the environmental strategies, which are common in some of the buildings, as well as strategies that are unique to a single building.

Table 3. Environmental Strategies

<table>
<thead>
<tr>
<th>Environmental Elements/Strategies</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compactness</td>
<td>(1) Doha (2) S Arabia (3) Bahrain (4) Dubai</td>
</tr>
<tr>
<td>Orientation</td>
<td>(5) Doha (6,7) Dubai</td>
</tr>
<tr>
<td>Walkways/Alleys</td>
<td>(8,9) Bahrain</td>
</tr>
<tr>
<td>Plantation</td>
<td>(10) Doha</td>
</tr>
<tr>
<td>Shaded Walkways/Alleys</td>
<td>(11,12) Dubai (13) Dubai (14) Doha</td>
</tr>
<tr>
<td>Façade</td>
<td>(15) Dubai (16) Dubai (17) S Arabia</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
</tr>
</tbody>
</table>

FINDINGS

Compactness

Compact urban form, building shading building, shaded walkways. Protection from direct solar radiation & hot wind (fig 1, 2, 3, 4).

Orientation

Building oriented N-S for min. solar radiation and max. exposure to wind & cross ventilation (fig 5). Evaporative cooling from creek (fig 6, 7). Openings in north façade. Tilted east façade for northeast breeze (fig 8, 9).

Walkways/Alleys

Double & triple height buildings, narrow roads, various angles of winding roads, building orientation create shade in the alleys (fig 10).

Plantation

The photosynthesis strategy of plants reduces the heat gain on the roads, which reduces the temperature of immediate microclimate (fig 11, 12).

Shaded Walkways/Alleys

The alleys in many cases are covered with fabric to provide shade, thereby cooler alleys (Al-Eidi, L., 2013) (fig 14).

Façade

Solid walls & minimum openings on the western and southern façades to delay & reduce solar gain (fig 15).

Windows

Small recessed windows & clerestory, few in number, bring controlled & indirect natural light, thus less heat gain. Wooden frame and shutters (fig 16,17).
### Parapet Detailing

Roof parapet consists of hidden openings which allow air movement and privacy (fig 18, 19, 20).

![Parapet Detailing](image)

### Courtyards

Courtyards, generally small & partially shaded most of the time, help air cool down before entering indoors (fig 21, 22). Wells in courtyard help evaporative cooling (fig 23).

![Courtyards](image)

### Space Layering

Space sequence is from outdoors to wide shaded corridor or liwan, then to room. Layering of space makes rooms cooler than outdoors. Breeze gets cooler by passing through this shaded space, before entering the room (fig 24, 25).

![Space Layering](image)

### Corridor/Arcade or Liwans

Courtyards have surrounding arcades or liwans. These shaded semi-outdoor spaces block direct sunlight from penetrating indoors and provide shade to rooms; provide passage for occupants without being exposed to direct sun (fig 26, 27). Covered liwan, used for sitting, with thick roof and arcaded walls is cooler than outdoors in summer. As found in the study, liwan - 35°C, outdoor - 37 to 39°C. Arcaded corridors guide the breeze well.

![Corridor/Arcade or Liwans](image)

### Shading

Shading of walls, openings, courtyards, liwans is the most effective strategy to keep interiors cooler. (Batterjee, 2010). This also helps in circulation of warmer air outwards (fig 30, 31).

![Shading](image)

### Wind Towers or Badjir

Common in this region. Brings in cooler air from higher up which circulates through interior spaces; sometimes water is sprinkled in the surrounding walls to cool the air more (fig 32, 33). House in Moharraq has a large badjir, in Majlis or women’s living room. Temperature below the tower was 1°C cooler than rest of the room.

![Wind Towers or Badjir](image)

### High Windows

High windows work as air fan, since lighter warm air rises up and escapes through high openings, allowing cooler air to enter the room from below (fig 34, 35, 36).

![High Windows](image)

### Roshan, Perforated Screen Openings

Perforated screen or ventilator or roshan very effective in reducing room temp; warm air rises up and escapes through it. The screen diffuses the direct sunlight and reduces heat gain (fig 37).

![Roshan, Perforated Screen Openings](image)
3 layers of perforated openings let air escape more frequently, depending on its temp. (fig 38, 39, 40).

**Monsoon Window/Horizontal Slit Window**
The monsoon windows are small horizontal openings in the walls, which provide natural ventilation, indirect sunlight and privacy. It is mainly used on the exterior walls of 1st floor (fig 41).

**Roof Material**
Roof consisting of mud, palm trunks, bamboo, mangrove wood and palm leaves provide good thermal insulation (fig 42, 43).

**Roof Thermal Mass**
Thermal mass of thick roof aid in delaying and reducing solar gain inside. Roof thickness is between 0.30m to 0.70m.

**Wall Material**
Walls of mud blocks, coral stone, palm trunks and straws act as very good insulators. Poured in mud, or sun-dried mud blocks of rough texture. A variety of interior materials help diffuse sunlight (fig 44, 45).

**Wall Thermal Mass**
All four case study buildings have thick mud walls, typical of Middle Eastern architecture; wall thickness is from 0.40m to 1.00m. This gives high thermal mass to the building; thereby reducing and delaying heat gain inside (fig 48). Fursh coral, 0.07 m thick, was used with mud for infill panels between piers and for partitions. Dubai house had a difference of 2.7°C between outer and inner surfaces of exterior wall: •1-outer 35°C, •2-inner 32.3°C (fig 49).

**Floor**
Mostly earth over compacted sand. Some exterior ones were of rough cut stone. Mud kept floor cool (fig 50, 51). In Dubai, surface temperatures of floors at various spaces were: •1-unshaded area 37.8°C, •2 shaded liwan 34.0°C, •3 -room 31°C (fig 52).
FINDINGS: ANALYSIS OF DATA ON TEMPERATURE, RELATIVE HUMIDITY AND AIRFLOW

Comfort Zone

Figure 1 Application of Comfort Zone in Riyadh, Saudi Arabia
Source: (S. A. ALAJLAN, M. S. SMIAI, U. A. ELANI, 1997)

The comfort zones are similar for the hot-dry climates of these four adjacent countries, varying slightly from each other. The comfort zone of Saudi Arabia, which has the lower average temperatures among the four countries, has been taken as a standard for all countries.

The comfort values for different climatic elements can be considered as standard for Saudi Arabia as established by ALAJLAN, SMIAI, ELANI. According to Fig.1 summer temperature range is from 28°C to 33°C and Relative humidity ranges from 42% to 55%. With mass effect, and evaporative cooling, both of which is present and practiced in these buildings at a high level, the upper limit of the comfort temperature can be above 40°C, and humidity can range from 15% to 58%.

Table 4. Temperature, Relative Humidity and Airflow

<table>
<thead>
<tr>
<th>Market/Souk</th>
<th>Space</th>
<th>°C</th>
<th>RH %</th>
<th>Air m/s</th>
<th>Al-Mulla House</th>
<th>Space</th>
<th>°C</th>
<th>RH %</th>
<th>Air m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waqif Doha, Qatar</td>
<td>Nov</td>
<td>A</td>
<td>22</td>
<td>59</td>
<td>0.9</td>
<td>1</td>
<td>29</td>
<td>39</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>24</td>
<td>48.9</td>
<td>0.4</td>
<td>1</td>
<td>26.1</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>24</td>
<td>59</td>
<td>0.5</td>
<td>2</td>
<td>24.4</td>
<td>35.9</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D</td>
<td>26.1</td>
<td>52.6</td>
<td>0.4</td>
<td>3</td>
<td>25.9</td>
<td>38</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E</td>
<td>24.9</td>
<td>57.2</td>
<td>1.2</td>
<td>3</td>
<td>25.6</td>
<td>44</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>25.3</td>
<td>53.4</td>
<td>0.4</td>
<td>4</td>
<td>23</td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G</td>
<td>25.8</td>
<td>52.7</td>
<td>0.4</td>
<td>5</td>
<td>25</td>
<td>36</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H</td>
<td>26.9</td>
<td>46.6</td>
<td>0.4</td>
<td>7</td>
<td>27</td>
<td>39</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I</td>
<td>27.8</td>
<td>46.6</td>
<td>0.5</td>
<td>8</td>
<td>24.6</td>
<td>35</td>
<td>57</td>
</tr>
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<td></td>
<td></td>
<td>I</td>
<td>26</td>
<td>45</td>
<td>1.3</td>
<td>9</td>
<td>28</td>
<td>38</td>
<td>47</td>
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<tr>
<td></td>
<td></td>
<td>I</td>
<td>32</td>
<td>40.9</td>
<td>0.9</td>
<td>10</td>
<td>25.5</td>
<td>38.8</td>
<td>56.4</td>
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<tr>
<td></td>
<td></td>
<td>I</td>
<td>29</td>
<td>43</td>
<td>1.5</td>
<td>11</td>
<td>25.8</td>
<td>39</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 5. Temperature and Relative Humidity

<table>
<thead>
<tr>
<th>Shaikh Issa House, Muharrq, Bahrain</th>
<th>Space Name</th>
<th>°C</th>
<th>RH %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td>1</td>
<td>24</td>
<td>35.7</td>
</tr>
<tr>
<td>Family Courtyard</td>
<td>2</td>
<td>30.1</td>
<td>38</td>
</tr>
<tr>
<td>Family majles</td>
<td>4</td>
<td>27</td>
<td>35</td>
</tr>
<tr>
<td>Under the badger</td>
<td>11</td>
<td>27</td>
<td>35</td>
</tr>
<tr>
<td>Family majles</td>
<td>12</td>
<td>26.2</td>
<td>35</td>
</tr>
<tr>
<td>Children living room</td>
<td>13</td>
<td>28.4</td>
<td>35.6</td>
</tr>
<tr>
<td>Room for married son</td>
<td>14</td>
<td>28.6</td>
<td>35.8</td>
</tr>
<tr>
<td>Sheikh courtyard</td>
<td>15</td>
<td>32.2</td>
<td>34.5</td>
</tr>
<tr>
<td>Sheikh room</td>
<td>19</td>
<td>29.3</td>
<td>32.6</td>
</tr>
<tr>
<td>The sheikh son room</td>
<td>21</td>
<td>27.9</td>
<td>33.3</td>
</tr>
</tbody>
</table>

30th INTERNATIONAL PLEA CONFERENCE
16-18 December 2014, CEPT University, Ahmedabad
The analysis of data in Tables 4, 5 and 6 is presented below.

**Market or Souk, Doha, Qatar**

It is a semi-outdoor space. As average temperature of Qatar is higher than Saudi Arabia, the comfort zone of Saudi Arabia well served the function of comfort assessment here, as in Figure 1. Data in market spaces met the comfort values in the beginning of winter. Market spaces’ temperature range was 22-27.8°C and relative humidity 46.6-59%. Both the values are within the comfort range as shown in Figure 1. As the Comfort chart suggested, in Figure 1, high thermal mass, night ventilation and evaporative cooling, all of which existed in the buildings, effectively helped the spaces be comfortable in summer and winter.

**Al Mulla House, Al-Ahsa, K.S.A.**

In winter, when the exterior temperature was low, the interior temperature was warmer and the reverse was observed for summer. Roofs of the house is made of wooden beams, palm trunks and leaves, palm leaf or bamboo mat which, topped by earth, acted as insulating material against the summer heat and the cold of winter. The measurements in various rooms show that internal temperature remains nearly constant around the day on a typical summer or winter day, while the ambient temperature has a large diurnal variation. House has no trees inside the courtyard now. It originally had some in the courtyard, which helped in more comfortable performance of the building. Relative humidity indoors was found to be lower than outdoors, which added to the comfort conditions.

**Shiekh Issa House, Muharraq, Bahrain**

It is seen that there are variations in data of different spaces depending on the orientation, proximity to courtyard, level of floor, liwan location, number and types of openings, etc. Indoor spaces are warmer in winter and quite cooler in summer than the outdoor readings. Temperature and relative humidity are within the comfort range.

**Shaikh Saeed Al Maktoum House, Dubai, U.A.E.**

Dubai was relatively more humid in both seasons, compared to other countries. In terms of comfort conditions, the building performance in summer was better than winter. In winter, temperature and

### Table 6. Temperature, Relative Humidity and Airflow

<table>
<thead>
<tr>
<th>Space Name</th>
<th>°C</th>
<th>RH %</th>
<th>Air m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nov</td>
<td>May</td>
<td>Nov</td>
</tr>
<tr>
<td>Shaded side street</td>
<td>25.4</td>
<td>34.2</td>
<td>62.1</td>
</tr>
<tr>
<td>Unshaded side street</td>
<td>27.5</td>
<td>36.5</td>
<td>62.1</td>
</tr>
<tr>
<td>Open courtyard/plaza</td>
<td>30.6</td>
<td>36.3</td>
<td>42.2</td>
</tr>
<tr>
<td>(A) Shaded</td>
<td>26.7</td>
<td>35.2</td>
<td>52.4</td>
</tr>
<tr>
<td>(B) Unshaded</td>
<td>28</td>
<td>36.6</td>
<td>49.5</td>
</tr>
<tr>
<td>Summer room</td>
<td>27.5</td>
<td>34</td>
<td>48.1</td>
</tr>
<tr>
<td>Open roof, partly shaded</td>
<td>28.3</td>
<td>34</td>
<td>47.7</td>
</tr>
</tbody>
</table>
humidity were almost within the comfort zone. The cooler breeze that was cooling the indoors was due to the presence of the creek nearby. As a result, relative humidity was within the comfort zone. In winter, airflow was almost nil in some spaces which were warmer than the breezier spaces.

Summer had higher airflow in the spaces of all case study buildings. Measurements of temperature and Relative Humidity were within comfort ranges. Comfort survey among the users of the buildings revealed that most of the users were comfortable within the shaded interiors of the buildings, in all four cases. As the survey revealed, only 5% to 10% of the present users preferred air-conditioning in these spaces in summer.

CONCLUSIONS

The traditional wisdom of how to solve architectural problems due to climate lying beneath the various architectural elements was to be unearthed through this research. The paper establishes that the traditional buildings of the hot-dry climate of the Middle East were and are still, able to function as very good examples of sustainable architecture, in terms of passive cooling. The study shows that the hygrothermal performance in these mud buildings is very good, both in summer and in winter. It points out the various environmental strategies, materials and methods of construction of these buildings in question. Not much has been done in the research of this topic and hence this research is one of the few pioneering researches in Saudi Arabia. It is thus an important step towards rediscovering the traditional architecture of the Middle East from a new angle, the environmental point of view. Modern buildings of these countries are highly dependent on air conditioning that consumes massive amounts of electricity, and nearly 80% of household electricity is used for air conditioning (Taleb & Sharples, 2011).

The traditional strategies could easily be adopted for newer buildings that will help cool passively and thus save energy. The many towns that were sculpted with mud architecture in these places were, and some still are, in a ruined state. The respective governments are now restoring these. These examples of sustainable architecture will thus be sources for academic researches, professional inspiration as well as tourism, for years to come.

ACKNOWLEDGMENTS

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ABSTRACT
Climate responsive building design is determined by the local micro-climate and the ability of the building envelope to regulate the indoor thermal environment. The building envelope characteristics are based on the available/accessible building materials and technology. Studies on vernacular architecture across the world showed that wall configurations and the thermo-physical properties of the building materials are used intelligently to maintain comfortable indoor comfort across the seasonal weather variations. Vernacular buildings of North-East India are naturally ventilated. Hence, it is important to find out the optimum wall configuration which will provide enough time lag, reduced discomfort hours as well as optimum thermal performance of these buildings. Various studies on building simulation/modelling show that building dynamic simulation tool can be effectively used to study the building envelope characteristics. In this study, a typical vernacular building in warm and humid climatic zone of North-East India has been considered to study the effect of thermo-physical properties of wall, thickness and material assembly on the indoor environment. Solar energy modular simulation tool TRNSYS 16 is used to carry out the simulations of this building with an objective to improve the indoor thermal environment. Building model is generated in TRNSYS and parametric simulations for different wall characteristics by varying thermo-physical properties and thickness of wall, and insulation thickness on external wall are carried out. Simulation results are obtained in terms of temperature profiles inside the different zones of the buildings. Indoor temperature profile of the building with best suggested wall configuration shows reduction in indoor temperature compared to the base case. In this study, it is also found that other climate oriented features such as shading mechanism like over hangs (very common feature in vernacular buildings) significantly influence the thermal performance of walls.

INTRODUCTION
Thermal performance study is one of the critical aspects of vernacular houses. These structures are evolved through generations, addressing the microclimate variations and also satisfy the needs of habitats (Singh et al., 2009a). Thermal performance of a building refers primarily to how well a building is insulated from the external weather conditions in order to achieve a comfortable indoor temperature. This can be achieved by keeping the internal temperature higher or lower than the external temperature.
as per the requirement of comfort temperature. Building design is greatly influenced by the severity and climatic variations leading to the need for integrating the building thermal design with the overall design process, helping the designer to decide at the beginning of the design process to bring the built space into comfort conditions (Al-Homound, 1997; Liu et al., 2010). The important parameters required for the design of energy efficient buildings are walls, roof, placement and size of openings, and shading devices (Charde and Gupta, 2013). Building envelope like walls and roofs have important role to play in the heat transfer process between the indoor and outdoor environment of the building. Due to the quest for achieving better thermal comfort standard inside the building leads to higher heating and cooling energy requirements. Borah et al. reported that energy consumption for heating will be higher at higher base temperature and the energy consumption due to cooling of the buildings will be higher at lower base temperatures in the buildings of North-East India (Borah et al., 2015). The components of the building envelope can be used as the most effective way of controlling the indoor temperature of the building (Dutta, 2001). Simulation tools such as TRNSYS can be used effectively to study the effect of building envelope characteristics on indoor thermal environments. Singh et al. have done thermal performance simulation of three vernacular buildings at different bioclimatic zones of the north-eastern region by using TRNSYS simulation tool (Singh et al., 2009b). Simulation results concluded that the houses are fairly comfortable in pre-winter and pre-summer months compared to winter and summer months and successfully compared with the experimental results. Kalogirou et al. investigated the effects of the application of building thermal mass in Cyprus by modeling and simulating a typical house with the TRNSYS simulation program (Kalogirou et al., 2002). Jindal et al. analyzed the thermal performance of non-conditioned building of cold regions by using various insulation thicknesses at different positions of walls and roof. It is found that the thermal comfort for the three cold stations i.e. Srinagar, Shimla and Shillong cannot be ensured in the month of January if the building is not insulated (Jindal et al., 2013). The effect of insulation thickness on external walls in different seasons of the year in different climatic zones suggests that optimization of insulation thickness on external walls with respect to cooling loads is found to be more appropriate for energy savings compared to the heating loads (Bolatturk, 2008; Ozel, 2011; Yu et al., 2009). Al-Sanea et al. investigated the effects of location of thermal mass in insulated building walls on total and peak transmission loads, time lag, decrement factor, and dynamic resistance under the steady periodic conditions using climatic data of Riyadh. It is found that for a given thermal mass, a wall with outside insulation provides better overall performance than a wall with inside insulation (Al-Sanea et al., 2013). Asan investigated the effects of wall’s insulation thickness and position on time lag and decrement factor. It is found that insulation thickness and position have intense effect on time lag and decrement factor (Asan, 1998). Axaopoulos et al. analyzed the thermal behavior of external walls using TRNSYS and determined the optimum insulation thickness for the external walls of a residential building in Athens, Greece, considering wall construction, orientation, wind direction and the position of insulation (Axaopoulos, 2014). Huang et al. found that the variation in the window to wall ratio for different orientation results into different economical thermal insulation thicknesses of building envelope (Huang et al., 2014). It is also found that the optimum performance can be achieved by considering the windows-to-wall ratio, house orientation, types of insulating materials and windows in addition to the impact of the windows and walls.

Building energy simulation tools are widely used for thermal performance study of building. In this study, a building model generated in TRNSYS 16 is used to analyze the indoor thermal environment of a typical vernacular building at Tezpur, in warm and humid climatic zone of North-East India. Most of the houses of the region are constructed in direct response to the climatic constraints and are naturally ventilated (Singh et al., 2010). A building model is prepared based on the inputs like building construction details, thermo-physical properties of building materials, wall thickness and insulation thickness on external wall using TRNSYS simulation tool. The layout of the building considered for the base case is shown in Figure 1. Windows on the house are distributed on all the facades. It is a single zone house with flat roof and single glazed windows. Since the vernacular house is naturally ventilated, so auxiliary heating, cooling and mechanical ventilation are kept off for all the simulations and the zone air temperature is considered as the primary output parameter. The simulation provides the results in terms of hourly temperature profile inside the zone of the building. Indoor temperature variation for all the simulations is compared with the base case and the results are analyzed to obtain the optimum design parameters. An optimum thermal performance of the building has been achieved by integrating the building optimum design parameters.
METHODOLOGY

Vernacular buildings are constructed across the world based on the local climatic condition. Vernacular buildings are the structures built by local people using locally available material and affordable technology to deal with the local and day-to-day needs (Singh et al., 2009a; Singh et al., 2010). Studies on vernacular architecture reveal that wall configurations and the thermo-physical properties of building materials have a great influence on indoor temperature. In recent times due to quest for achieving better thermal comfort; energy consumption is increasing in buildings. So, it is important to study thermal performance of vernacular buildings with varying building elements which will provide maximum comfortable hours inside the building. In this study, a typical vernacular building of warm and humid climatic zone of North East India is modeled in TRNSYS. Figure 2 represents the methodology followed to carry out this study. Table 1 represents the thermo-physical properties of the materials used for the simulation and Table 2 represents the wall configurations considered for the simulations. First a base case model of the vernacular house is selected to carry out the simulation.

![2D layout of the house with single zone](image)

**Table 1 Thermo physical properties of the materials used for simulation**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Conductivity (W/m-K)</th>
<th>Thermal capacity (kJ/kg-K)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick</td>
<td>1.301</td>
<td>0.84</td>
<td>2000</td>
</tr>
<tr>
<td>Aerated concrete (floor 0.127m thick)</td>
<td>0.289</td>
<td>0.84</td>
<td>1000</td>
</tr>
<tr>
<td>Light concrete (roof 0.127m thick)</td>
<td>0.120</td>
<td>0.84</td>
<td>400</td>
</tr>
<tr>
<td>Plaster</td>
<td>1.390</td>
<td>1.00</td>
<td>2000</td>
</tr>
<tr>
<td>Extruded Polystyrene, Insulation1</td>
<td>0.0278</td>
<td>1.47</td>
<td>30</td>
</tr>
<tr>
<td>Cell Glass (High density), Insulation 2</td>
<td>0.061</td>
<td>0.84</td>
<td>250</td>
</tr>
<tr>
<td>Polyurethane, Insulation 3</td>
<td>0.022</td>
<td>1.47</td>
<td>35</td>
</tr>
</tbody>
</table>

Parametric simulation studies are carried out by using TRNSYS 16 simulation tool. The standard building subroutine TYPE 56 has been used for the simulation (Singh et al., 2009b). The material properties listed in Table 1 and 2 are used as input parameters to generate the building model. For carrying out further simulations, base case model is used with various design modifications. Figure 3 shows the different scenarios for which the base case model is carried out. The different scenarios considered for the simulation are (i) increasing the wall thickness of the base case (ii) adding three different insulations on the wall of the base case (iii) placing the insulation at three different positions of the wall of the base case (iv) replacing the single glazed windows of the base case with double glazing and providing overhang on the windows (v) increasing the window to wall ratio (vi) providing insulation to the roof of the base case and (vii) considering four different orientations of the house. The infiltration
for this house is kept at 3 ACH (air changes per hour) for all the simulations. Since the house considered for the simulation is naturally ventilated so the zone temperature is considered as the main output parameter. The surface temperatures of the wall are also obtained as output parameter.

### Table 2 Wall configuration considered for the simulation

<table>
<thead>
<tr>
<th>Case</th>
<th>External wall configuration (from inside to outside)</th>
<th>Overall heat transfer coefficient (U) (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>Plaster (0.01m) + brick (0.127m) + plaster (0.01m)</td>
<td>3.545</td>
</tr>
<tr>
<td>Base case + A1 (increased thickness)</td>
<td>Plaster (0.01m) + brick (0.254m) + plaster (0.01m)</td>
<td>2.633</td>
</tr>
<tr>
<td>Base case + A2 (increased thickness)</td>
<td>Plaster (0.01m) + brick (0.381m) + plaster (0.01m)</td>
<td>2.094</td>
</tr>
<tr>
<td>Base case + A3 (increased thickness)</td>
<td>Plaster (0.01m) + brick (0.508m) + plaster (0.01m)</td>
<td>1.739</td>
</tr>
<tr>
<td>Base case + B1 (wall with insulation 1)</td>
<td>Plaster (0.01m) + brick (0.127m) + insulation 1 (0.05m) + plaster (0.01m)</td>
<td>2.164</td>
</tr>
<tr>
<td>Base case + B2 (wall with insulation 2)</td>
<td>Plaster (0.01m) + brick (0.127m) + insulation 2 (0.05m) + plaster (0.01m)</td>
<td>2.748</td>
</tr>
<tr>
<td>Base case + B2 (wall with insulation 3)</td>
<td>Plaster (0.01m) + brick (0.127m) + insulation 3 (0.05m) + plaster (0.01m)</td>
<td>1.972</td>
</tr>
<tr>
<td>Base case + increased window area</td>
<td>Plaster (0.01m) + brick (0.127m) + plaster (0.01m)</td>
<td>3.545</td>
</tr>
<tr>
<td>Base case + double glazed windows</td>
<td>Plaster (0.01m) + brick (0.127m) + plaster (0.01m)</td>
<td>3.545</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

The vernacular house in warm and humid climatic zone is constructed with different wall configurations and various parametric evaluations have been done to analyze the effect of different wall configurations on the zone temperature. Analysis on the effect of window glazing, window to wall area ratio, providing roof with insulation on the zone temperature is carried out. Simulations are also carried out for different orientations of the building. The two very important characteristics, i.e., time lag and decrement factor, which determine the heat storage capabilities of any material, are also calculated. Simulation data for entire 8760 hours (i.e., one year) is obtained and the results in terms of temperature profiles are analyzed for January and July as the representative month for winter and summer seasons respectively. In this study, zone temperature is the main parameter around which analysis has been done. Figure 3(a) represents the variation of daily minimum zone temperature for all the days in the month of January. It is observed from the profile that variation in overall heat transfer coefficient (U value) depends on thickness and also the zone air temperature is higher in case of the wall with lower U-value, i.e., with decreasing U value, the daily minimum temperature of the zone increases which is desirable in winter. As we know that lower U value provides maximum resistance to the heat flow, hence, reducing the heat loss from inside the room to the outside air. So, it can be concluded from the Figure 3(a) that with the increase in thickness of wall, thermal inertia comes into play and consequently increases the time over which heat gain and loss takes place. This has also effect on the comfort conditions as occupants feel minimum thermal shock with noticeably varying outdoor thermal environment. So, for naturally ventilated buildings due consideration must be given to thermal inertia. Figure 3(b) represents the variation of daily maximum zone temperature for all the days in the month of July. It is observed from the profile that the temperature is lower in case of the wall with lower U-value (maximum thickness), i.e., with decreasing U value, the daily maximum temperature of the zone decreases which is reverse in the case of winter. With lower U value, heat gain from the outside air is reduced and thus the maximum temperature inside the room is low. Thus, from both the figures, it can be concluded that, the wall needs to be selected with U value as low as possible (with optimum thickness to maximize the effect of thermal inertia) to reduce the heat loss from inside the room in winter and heat gain from outside to the inside of the room in summer.

Figure 4(a) and 4(b) represent the daily minimum and daily maximum zone temperatures for each day of the month of January and July respectively. It is observed from the figures that 0° and 45° and 90° and 135° orientation shows similar temperature profile. For orientation 0° and 45°, minimum and
maximum indoor temperature decreases leading to decreased indoor temperature swing. This happens because with change in orientations of the building the surface area of the external wall exposed to sun varies and so the heat gain. Since, the selected building is rectangular in shape and of single zone the effect observed here is low. It is found from literature that in the case of multi-zone building with different shapes (L, U, C and H etc.) the variation in indoor temperature is significant. Hence, it is suggested to decide the building orientation wisely before construction to maximize the use of solar passive techniques in the building thus improving energy efficiency and thermal comfort. Figure 5(a) and 5(b) represent the minimum and maximum inner surface temperatures for each day of January and July month respectively. Here, insulation is added to the base case and placed in three different positions (i.e., inside, middle and outside) of the wall. Figure 5(a) shows that in January (i.e., in winter) when insulation is placed at the outside surface of the wall, the minimum surface temperature of the wall has increased compared to the wall when insulation is placed at the middle and inside position because of thermal inertia plays its role. It is observed from figure 5(b) that in July (i.e., in summer) also when insulation is placed at the outside of the wall, the maximum temperature is lower compared to the insulation at middle and inside wall surface. Thus, it is observed that both in summer and winter months, placing insulation at the outside of the wall, shows better thermal performance, out of all the three cases (combined effect of thermal inertia and insulation). Furthermore, it is also observed that there is not much difference when insulation is placed at the middle position of the wall.

Figure 3(a) Daily minimum zone temperatures for different wall thicknesses

Figure 3(b) Daily maximum zone temperatures for different wall thicknesses

Figure 4(a) Daily minimum zone temperatures in January for the four orientations

Figure 4(b) Daily maximum zone temperatures in July for the four orientations

Figure 6(a) and 6(b) represent the daily minimum and maximum zone temperatures in January and July respectively for different window to wall ratios. The windows are single glazed and window to wall ratio increases from 20 to 80%. It is observed from figure 6(a) that in January with the increasing window to wall ratio, the zone temperature is decreasing. This happens because with the increase in glazing area heat loss increase from inside to the outside environment. It is observed from figure 6(b), that the zone temperature increases with increasing window to wall ratio because heat gain is more from the outside environment. These two observations clearly indicate that both in summer and winter higher
window to wall ratio leads to uncomfortable conditions inside the room. Hence, optimum window to wall ratio needs to be chosen so that in summer there is minimum heat gain and minimum heat loss in winter. Figure 7(a) and 7(b) represent the daily minimum and daily maximum zone temperature for January and July months respectively, when single glazing on windows have changed to double glazing. It is observed from both the figures that the increase in temperature is more prominent in winter because low altitude of the sun allows direct sunlight to enter into the room and increases the thermal gain thus temperature of the indoor environment. Moreover, both the overall heat transfer coefficient and solar heat gain coefficient comes into consideration for glazing. Though, for double glazing, the SHGC (solar heat gain coefficient) is lowered by only 10% in comparison to single glazing but the effect due to low SHGC is compensated by low U value (U value of single glazing is 4.8 and for double glazing is 2.7). So, in winter the double glazed windows perform better by trapping the absorbed heat inside the room. However, in summer, the solar heat gain coefficient allows the direct sunlight to enter the room through the window and make the room hotter. Hence, in summer it is advised to have appropriate overhang on the window to block the direct sunlight to enter inside the room.
Figure 8 represents the effect on the zone temperature when the roof is provided with insulation. It is observed from the figure that the effect of insulation on the roof is negligible on the indoor temperature profile of the zone. This may be due to high infiltration in naturally ventilated buildings leading to negligible effect on the indoor temperature swing. Figure 9 represents the variation of time lag and decrement factor for different thicknesses of the wall. The variation of time lag and decrement factor is shown for two different materials. It is observed from figure 9 that the time lag increases with the thickness of the wall, whereas decrement factor decreases with the wall thickness. Moreover, both the materials are exhibiting different time lag and decrement factor. This indicates that time lag and decrement factor not only vary with the thickness of the wall but also with the material properties. For better thermal performance, time lag should be high and decrement factor should be minimum.

The effect of different insulation materials on inner wall surface temperature for a period of 24 hours (i.e., 1 day) in the month of January and July respectively has also been carried out. Three different insulation materials - extruded polystyrene, cell glass of high density and polyurethane are added with the base case and the inner surface temperatures of the wall are obtained. It is observed that in January (i.e., winter) month, the peak of minimum temperature is less in case of polyurethane as the insulation material, in comparison to cell glass and extruded polystyrene. It is also observed that in July (i.e., summer) month, the peak of maximum temperature for the wall with polyurethane as insulation material is lower than the wall with other two insulation materials. Moreover, the 24 hour swing in temperature throughout the day is less in case of polyurethane as insulation material. Hence, it can be concluded that with polyurethane as the wall insulation material shows better thermal performance both in summer and winter months. It is also observed that there is an increase in the temperature for the month of January (winter) when the windows are provided with overhangs. It is also observed that the maximum temperature in the month of July (summer) month is decreasing, clearly indicates that windows with overhang have a significant role to play by blocking direct sun light to enter the room in summer leading to decrease in indoor air temperature but in winter it allows sunlight to enter room thus increases the indoor air temperature.

**CONCLUSIONS**

Thermal performance analysis of building envelope is very important to evaluate indoor thermal environment of naturally ventilated buildings. The building envelope constitutes the major portion of the building through which maximum heat gain and loss occurs in both the extreme seasons respectively. In this study, a typical vernacular building of warm and humid climatic zone of North East India is considered. This study made an attempt to carry out the thermal performance analysis by varying building material parameters and their effect on the indoor environment. It can be concluded from the study that, with the increase in the wall thickness, the overall heat transfer coefficient reduces and also the overall heat transfer coefficient changes, when the thermo-physical properties of the material changes. It has been found that orientation has an important effect on the indoor temperature; because of different orientations, different area of external area is exposed to direct solar radiation leading to heat gain. It is also found that location of insulation on the wall have significant effect on the thermal...
performance, showing that insulation applied on the outside surface have less temperature swing. The
effect of different insulation material on the wall surface temperature has also been studied and
polyurethane has been found showing the best performance. This study also reveals that windows with
double glazing have maximum effect in winter when the sun’s altitude is less. Hence, if the window is
replaced by proper shading mechanism then overall performance can be improved. It is found that
increase in the window to wall ratio has significant effect on the indoor temperature swing. Increase in
the window area leads to maximum hours of discomfort inside the building in both January and July
months. It can also be concluded that providing insulation to the roof has negligible effect on the indoor
temperature profile. Time lag and decrement factor are also calculated for different wall thicknesses. It is
found that thermal mass of the wall and thermo-physical properties of the wall have a profound impact
on time lag and decrement factor. The findings of this study also relate to the policy intervention and
best practice needs to be followed in these types of building design. North-Eastern region is in
development process and the construction sector is rising in unprecedented way. These types of
buildings are well suited to the climatic factors as well as social requirements of the people of the region.
Hence, the findings of this study could be useful to the policy makers, architects, and local people for
designing better thermally comfortable buildings.

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Daylighting Analysis of Vernacular Architecture in Guizhou Province, China

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ABSTRACT
China has 55 minorities, most of whom have their own unique architecture. Due to urbanization these traditions are in danger and traditional dwellings are replaced with modern houses in the hope of better living conditions. By understanding and finding solutions to the problems emerging in these traditional dwellings and by using their features in a more sustainable and more adaptive way to local climate, living conditions could be improved without losing this unique culture. Due to its substantial minority population and varied terrain, Guizhou province in China has a rich source of different types of traditional dwellings. Dwellings representing the typical architecture of three different ethnic groups Han, Miao, and Dong were selected to conduct daylighting analysis. Measurements made during a field work helped to explore how the different building ways, folk customs, topography and other factors impact on architectural daylighting. With the help of the results, suggestions are made on how to reform existing dwellings under the corresponding architectural language and lifestyle, and what modifications should be made to meet the modern daylighting needs of occupants. Different scenarios are simulated using ECOTECT 2011 software (Ecotect, 2011) to show the positive results of the changes suggested.

INTRODUCTION
China is a multi-ethnic country with a long history and a vast territory, during the thousands of years of its history a vast amount of varied residential building types have evolved. Different regions have different natural conditions and cultural background, which is reflected by vernacular dwellings all over the country. Over the recent decades, due to the acceleration of urbanization, modern architecture became more widespread. Modern architecture promises to accomplish a better living environment, but it contributes to the destruction of traditional vernacular dwellings. Traditional vernacular dwellings represent a valuable heritage and help to preserve the habits and folk-custom of ancient people. More importantly the ecological thinking and technical solutions of vernacular buildings are a significant knowledge source for the sustainable development of new settlements and an indispensable reference on terrain adaptation, climate adaptation and construction of passive energy-saving measures. To renew the vitality of a traditional vernacular dwelling, its adaptability to modern life and comfort must be improved. Daylighting is an important measure of building comfort. Because of limited building and technical resources available at the time they were constructed, traditional houses typically take advantage of natural light. However with changes in living habits and the improvement of living standards, original daylighting conditions are not able to meet the demands of the present. Improvements of vernacular dwellings’ should also focus on enhancing daylighting condition, an area which needs to be researched in more detail. Few studies already have been conducted on architectural daylighting of Chinese traditional vernacular dwellings (Wang, Zhuo and Dac’y 2008, Duan, Lau and Ford, 2012, Lin, Li, and Chen, 2013), but it is a generally a neglected area of research to which this paper tries to contribute. There are many types of dwellings in different regions that have not been researched yet, from which this study is focusing on three typical types of dwelling characteristic of three ethnicities, a special group of the Han, the Dong and the Miao, all of which are characteristic to Guizhou Province,
which due to its less developed infrastructure and economy was especially neglected. The principle aim of this research is to investigate the daylighting performance of three traditional vernacular dwellings and the factors influencing it, by means of on the spot data collection, analysis, software simulation, in order to suggest viable modifications of the original dwellings, to meet the occupants’ lighting needs better. After introducing the characteristics of the locations of the field research, research methodology is explained. Results and analysis will then be presented, together with simulation, finally conclusions are made and suggestions for future improvements are given.

ETHNIC ARCHITECTURE AND LOCAL CLIMATE

The vernacular dwellings selected for the research are located in Guizhou province, in the village of Jiangchang, SanBao and Xijiang (Figure 1). The dwelling in Jiangchang is a typical example of Han Chinese vernacular architecture and the ‘tunpu’ culture retained locally. The dwelling in Xijiang reflects the local architecture of Miao minority and is part of the world’s largest Miao settlement while the dwelling in SanBao is typical of the Dong minority. All of the three ethnic groups have a history of hundreds of years and rich cultural traditions, which are reflected in architecture, clothes, food, folk beliefs and entertainment. Guizhou has a typical subtropical monsoon climate, where summer is hot, humid, and sunny and winters are relatively warm.

![Figure 1: Location of Jiangchang, SanBao Dong and Xijiang Miao in Guizhou province, China](image)

Each of the three dwellings chosen carry the main characteristics of the local traditional architecture. The main structure of the dwellings in Jiangchang consist of a wood structure and the building envelope is made of stone blocks. This is coupled with the most distinctive feature of these buildings, the thin slab stone roof, stacked layer upon layer. (Figure 2 (a)) The Dong minority’s dwellings in SanBao Dong are almost solely constructed from wood, from the load bearing structure, through the inner envelope and wooden stairs. Only the kitchen is made of brick, which is usually attached to the main building. (Figure 2 (b)) Both the Han and Dong dwellings usually consist of two storeys, with living areas located on the ground floor and storage places on the first floor. In the Xijiang Miao village local houses are typical mountain buildings, wooden houses on stilts located mainly on a hillside, built row upon row. A unique feature of these dwellings is the semi opened balcony located outside of the living room with railings locally called as ‘beauty’s leaning’. Buildings usually consist of two to three storeys. The ground level is used for storage or for livestock, accommodation and main living spaces are on the first floor while upstairs is used for storage. (Figure 2 (c))

![Figure 2: Traditional Dwelling in Jiangchang (a), SanBao Dong (b) and Xijiang Miao (c)](image)
FIELD SURVEY METHODOLOGY

The field research was conducted during the summer, data collection took place from 4th and 9th July 2013, over two days in each location. Daylighting data were collected through spot measurements using Digital LUX METER (TES 1330A) illuminometers. Data collection focused on the floor where main living spaces were located, in the Jiangchang and Sanbao Dong on the whole ground floor, while for the dwelling in Xijiang on the first floor, as for places used for storage or livestock daylighting is not of crucial interest and thus was omitted in this research. In the collection of illuminance values, the researcher took account of individual rooms and functions to determine the number of measuring points. A grid was drawn on the floor plan of each room, with intersection points not further apart than 1 meter, illuminance values were collected at each intersection at 800 mm above floor level, according to the reference working surface level suggested by the Standard for daylighting design of buildings (China, 2013). Inside and outside illuminance data were collected simultaneously by a pair of field researchers. To reduce error and to ensure the accuracy of the data, three complete sets of illuminance measurements were taken in each room under overcast conditions. No additional artificial lighting was used during measurement times. Outdoor illuminance values have drastic fluctuations, even under overcast conditions, resulting in change of indoor illuminance, but for the same test points, the ratio between the indoor and outdoor illumination value should remain stable. Ratio of outdoor and indoor illumination is called the daylight factor (DF), and it will be used as a basis for research daylighting performance in this research.

DATA ANALYSIS

Indoor daylighting condition is influenced by various factors, such as the proportion of the space (depth and width), presence of shading device or outside structures providing shading, the area ratio of windows to floor, the presence of grilles or wooden decoration on the windows and the reflectivity of the walls. The analysis of data focused on these factors.

The first step was to obtain the plan of the dwellings through measurements taken with Leica Disto™ D2 laser ruler and tape measures, layouts and section plans were drawn. Details of the size, position and form of the daylight openings in the house and the presence of shading devices were also recorded.

The vernacular dwelling in Jiangchang village has a simple rectangular layout (Figure 3 (a)). The dwelling is surrounded by a stone wall forming a courtyard. Building layout is simple, only consisting of three rooms arranged next to each other in a linear fashion, with the living room located in the middle facing south. The shape of the bedrooms is long and narrow, the depth reaching 7.5 meters, and the rooms have windows on both of their south and north wall. A bungalow was later built on the southeast corner of the main building. The windows are all the same size of 1300mm (w) *1000mm (h) decorated with grid patterns and with window sills’ height at about 1.1 meters. The layout of the dwelling in SanBao Dong is also symmetrical with the total of three bays, the main living area is located in the middle with the main entrance facing south. (Figure 3 (b)) The living room is surrounded by two-two bedrooms on both sides. Each bedroom has only one window the size of 850mm (width) * 900mm (height) and are equipped with safety grilles. Windowsill is relatively high, reaching 1.4 meters. The dwelling selected in Xijiang is a three floor pillar supported building, the back side of the building is connected to the mountain, while the front of it is facing south. The whole design embraces the mountain terrain specifications. The plan is long with an axis from east to west and symmetrical layout. (Figure 3 (c)) In the middle is the main living room area opened on the south side with the ‘beauty’s leaning’, which is connected to the rooms on its sides through a corridor. The kitchen is located on the west side. Window sizes vary on the first floor, with a width between 650 to 750mm and heights between 600 to 900mm. Window sills are at the height at 1 meter.

The three layouts are different and represent the local culture and adaptation to terrain, however there are some features which are present in all the three dwellings. The local subtropical climate of
Guizhou is quite wet, annual rainfall is around 1360 mm. In these wet conditions wood structures need to be protected, thus the presence of a roof overhang was observed at all the dwellings. In Jiangchang the building has a double pitch roof with 1.4-metres overhang on both south and north sides. In Sanbao Dong the south side of the building also has a 1.1 meter roof overhang while the overhang on the north side reaches the kitchen's outer wall. In Xijinag it reaches 1.3 meter on both south and north sides. Inside separation walls are made of wood, with a quite dark colour due to the aging of the material. The size and shape of the windows vary but, in each case the glass has a decorative wooden pattern. In Jiangchang this has decorative function, while in the other two dwellings it is a simple pattern and is more part of the traditional way of window construction than a decorative function. Next the area ratio of windows to floor \( \frac{A_w}{A_R} \) was calculated, by dividing the total area of the windows \( A_w \) present in a room by the area of the room \( A_R \). As the national standard minimum requirement are given in fractions, results in decimals were rounded to fractions. (Table 1)

Illuminance data collected was processed first by getting the ratio between the indoor and outdoor illumination value of every test point, and then by taking the average of the three measurements as the measuring points on the daylight factor (DF) values. Based on the data obtained in this way daylighting contours for all the rooms tested were generated using the software package Surfer 8 (2004) and daylighting situation in all the three dwellings was analysed based on the DF isolux contours obtained with Surfer. Results are shown on Figure 3.
Table 1. Area Ratio of Windows to Floor

<table>
<thead>
<tr>
<th>Place</th>
<th>Room area (m²)</th>
<th>(A_{W}/A_{R})</th>
<th>(A_{W}/A_{R}) in Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jiangchang</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living room</td>
<td>15.0</td>
<td>0.17</td>
<td>1/6</td>
</tr>
<tr>
<td>East Bedroom</td>
<td>18.5</td>
<td>0.15</td>
<td>1/7</td>
</tr>
<tr>
<td>West bedroom</td>
<td>18.5</td>
<td>0.15</td>
<td>1/7</td>
</tr>
<tr>
<td>Kitchen</td>
<td>4.2</td>
<td>0.38</td>
<td>1/3</td>
</tr>
<tr>
<td>Bungalow</td>
<td>9.0</td>
<td>0.33</td>
<td>1/3</td>
</tr>
<tr>
<td><strong>Sanbao Dong</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living room</td>
<td>24.8</td>
<td>0.08</td>
<td>1/12</td>
</tr>
<tr>
<td>East Bedroom</td>
<td>13.0</td>
<td>0.06</td>
<td>1/16</td>
</tr>
<tr>
<td>West bedroom</td>
<td>13.0</td>
<td>0.09</td>
<td>1/11</td>
</tr>
<tr>
<td>Kitchen</td>
<td>28.4</td>
<td>0.07</td>
<td>1/14</td>
</tr>
<tr>
<td><strong>Xijiang Miao</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living room</td>
<td>23.5</td>
<td>0.34</td>
<td>1/3</td>
</tr>
<tr>
<td>East Bedroom</td>
<td>7.6</td>
<td>0.08</td>
<td>1/12</td>
</tr>
<tr>
<td>West bedroom</td>
<td>10.6</td>
<td>0.06</td>
<td>1/16</td>
</tr>
</tbody>
</table>

**FINDINGS**

The analysis showed that daylighting of these dwellings has the following problem:

The minimum daylight factor (\(DF_{min}\)) cannot meet the residential building standard

The architectural lighting design standards for residential buildings (China, 2013) sets the minimum value of daylight factor at \(DF_{min}=1\%\). From the data analysis, it can be seen that, the minimum value of daylight factor of the three dwellings do not meet the specification above in none of the rooms, with \(DF_{min}\) values ranging from 0.01\% to 0.26\%. Living rooms in all the three dwellings have a better daylighting performance than bedrooms, where daylighting conditions are not favourable.

Concluding from the analysis of the data, the following factors have negative effects on daylighting in the three traditional dwellings:

1) **The size and proportions of the rooms.** The face width of the rooms can be considered normal according to modern building standards, however great depth, reaching even 7.5 meters in Jiangchang, results in not good daylighting condition and areas with almost no light. Great depth is especially characteristic and thus problematic for the living rooms, which are the main living area and such should have the best daylighting performance.

2) **The colour of the interior wall.** Internal partition walls are made of wood, which darkened after prolonged use. The dark colour of the partition walls makes the reflection of natural light more difficult, while also contributing to a feeling of darkness.

3) **The size and construction of the daylight openings.** According to the National standard minimum requirement of the area ratio of window to floor (GB50096-2011, 2011) needs to reach 1/7 in general. Normal values for bedrooms are considered to be between 1/6-1/8, and 1/4-1/6 for living rooms. Looking only at this value the situation in Jiangchang dwelling is quite favourable, with all rooms meeting national minimum requirements, however the great depth of the rooms disturbs the daylighting effect. The values are a lot below the standards, ranging from 1/11-1/16, only in one case is the value in the acceptable range, for the living room in Xijiang Miao dwelling. Besides the size, the presence of a wood pattern on windows, reduces the daylight effect even further, by reducing the area of the window.

**COMPUTER SIMULATION**

**Simulation description**

To show the effect of the identified problems and to find the best solutions for improving daylighting conditions in the dwellings, simulations were carried out using ECOTECT 2011 software.
During simulation, factors identified before to cause problems were improved compared to original measurements and the positive effect of these changes were evaluated. Three factors were selected to be variable in the experiment, the depth of the room, the colour of the interior wall and the presence of the grid on the window. (Table 3) The layout and original filed measurements of the Jiangchang dwelling were used as the control group for the simulation, as many of the factors causing daylighting problems were prominent. However simulation was only carried out on this one dwelling, findings should also reflect the other two dwellings, due to the similarity of the emerging problems, the similarity of outside conditions and the same orientation. All the simulations were done under the conditions summarized in Table 2.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>26.14 degrees north, latitude 105.55 degrees east</td>
</tr>
<tr>
<td>Daylight Climate zone</td>
<td>IV Daylight Climate zone</td>
</tr>
<tr>
<td>Critical illuminance value</td>
<td>4500lux</td>
</tr>
<tr>
<td>Illumination sky model</td>
<td>CIE cloudy sky</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Variable changed</th>
<th>Change compared to original situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>None</td>
<td>Variables are the same as in original conditions: bedroom depth 7.5m, living room depth 5.1m, walls are dark stone with dark wood, reflectivity rate is 0.16, grid is present on the window shown by transmission rate of 0.5, doors open</td>
</tr>
<tr>
<td>A</td>
<td>Room depth</td>
<td>Bedrooms’ depth is reduced to 6 m, livingroom’s depth is reduced to 3.6m</td>
</tr>
<tr>
<td>B</td>
<td>Indoor wall color</td>
<td>Indoor walls are set as painted a light wood color, the light reflectivity increases to 0.4</td>
</tr>
<tr>
<td>C</td>
<td>Window grid</td>
<td>No grid on the windows, transmittance rate increases to 0.7</td>
</tr>
<tr>
<td>D</td>
<td>All the above</td>
<td>All the above variables are present at the same time</td>
</tr>
</tbody>
</table>

Analysis of the different models resulted in five situations showing the impact of each variable on the indoor daylighting condition. Compared to Figure 3 (a), the indoor distribution curve of daylight factor of the control group has a similar distribution trend of the original dwelling (Figure 4 (a)). Although there are still some deviations in the data, the pattern of DF in the simulation experiments can be considered consistent with the existing situation. To show the effect of the different variables on the daylighting condition, average DF and the percentage of all values between DF 0-1% (under standard), DF 1-2% (gloomy but acceptable conditions) and DF 2% (reasonably good) were calculated and compared. When a higher percentage of the values are in the higher DF range the effect of the change of the variable can be considered stronger. (Table 4)

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Average DF</th>
<th>DF between 0-1%</th>
<th>DF between 1-2%</th>
<th>DF above 2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.77%</td>
<td>47.79%</td>
<td>24.64%</td>
<td>27.56%</td>
</tr>
<tr>
<td>A</td>
<td>2.26%</td>
<td>23.05%</td>
<td>39.78%</td>
<td>37.16%</td>
</tr>
<tr>
<td>B</td>
<td>2.00%</td>
<td>33.03%</td>
<td>36.04%</td>
<td>30.93%</td>
</tr>
<tr>
<td>C</td>
<td>2.27%</td>
<td>31.59%</td>
<td>32.33%</td>
<td>36.08%</td>
</tr>
<tr>
<td>D</td>
<td>3.67%</td>
<td>6.3%</td>
<td>32.76%</td>
<td>60.94%</td>
</tr>
</tbody>
</table>
The impact of room depth on daylighting: The change of the room depth affected the distance between the north window and the south window, and thus the area ratios of window to floor. From all the variables changing the room depth has the most positive effect on daylighting. The percentage of DF values between 0-1%, values, under the accepted standard, reduced to 23% while the percentage in the range of above 2% increased to 37.16%. Reducing the depth allows the same amount of light to be able to meet the needs of indoor better. Lighting distance on both sides also reflects the advantages of two-sided lighting.

The impact of interior wall surface reflectivity on daylighting: After the colour of the interior walls is changed to a light colour, their reflectivity increases from 0.16 to 0.4 resulting in the increase of the area with a value of DF in the range of 1% to 2%, however it’s a smaller increase than in the case of the other two factors. The increase of the interior walls’ reflectivity allows better diffuse reflection of the light entering through the windows and the doors.

The impact of grids on the window on daylighting: The grid on the window reduces the area of the window, but since its area is difficult to calculate, it was simulated by altering the transmittance rate for testing purposes. Simulation results showed that when there is no grid present, DF values near the windows increased and only 31.59% of DF values are under the standard compared to the original 47.79%. Removing the grid can increase the injection of indoor natural light and thus can positively affect daylighting condition.

Figure 4 (b) shows the cumulated effect of all changes. It can be seen that daylighting situation improved significantly. When applying all the changes together only 6.3% of DF values are under the standard and more than 60% of the DF values are reasonably good range. Considering the above results suggestions are given for future improvements.

Suggestions for improvement

By analysing the results, it can be concluded that both the large depth and dark interior wall of the traditional dwellings in the three villages have a negative effect on daylighting conditions of the residential living areas. Also, the traditional carved wood decoration and safety grills on the windows increase the self-shading of these houses and decrease the amount of light penetrating the rooms even in the case of an appropriate window area ratio in Jiangchang village. Not to mention in the other two cases, where the ratio of window to floor is much lower than suggested by modern building standards. These dwellings cannot guarantee even the basic lighting requirements of daily life.

Based on the data analysis and the results of the simulation future refurbishment or new build projects should be carried out including measures to increase the amount of sunlight and to improve the natural daylighting condition. To increase the comfort of occupants the following measures can be taken:

The amount of sunlight is most influenced by the area ratio of window to floor. The easiest measure would be to increase the window size. In the case of rebuilding traditional houses, this can be done to an extent when the appearance of the traditional dwellings doesn’t lose its originality. However when old dwellings are refurbished this could be problematic.
Another solution can be to replace the original glass of the window with high transmission glass and to replace the fixed carved wooden grilles with ones that can be opened at times, thus daylighting in the rooms can be improved without changes that influence local building style.

Under modern living conditions too large depth of the rooms is not useful anymore for the occupants of these dwellings. It was observed that due to shortage of daylighting the opposite end of the room is usually used as storage only and is not part of the active living space. The most hands on solution would be to reduce the depth of the room, as this is the factor having the biggest positive influence on daylighting condition, but it is a very difficult and complicated job to carry out as part of the refurbishment. Therefore, this modification is generally possible in case of new built dwellings following the traditional design style, but there it should be the primary consideration.

The change in the surface of indoor wall is a more feasible suggestion during refurbishment. In terms of traditional wood building material and stone, plastering on all walls seems too simple and rude, and it would destroy the native beauty of these residential dwellings. Despite painting the walls white would have a stronger positive effect on daylighting, taking in consideration the consistency of the traditional style, the solution suggested here is to clean the wooden walls and repaint them with wood protective paint. Such a change may not only improve the indoor lighting, but also protect the building components.

CONCLUSION

This research consisted of two parts. In the first part lighting data of the traditional dwellings in Jiang Chang Village, SanBao Dong and Xijiang Miao was collected during a field research. Based on the data collected features and influential factors of lighting were studied in detail. The other part was to study the lighting variables of the vernacular dwellings. A simulation experiment was carried out using ECOTECT software, which verified futures assumptions of influencing factors of daylighting. Renovation suggestions, such as cleaning and treatment of wood walls, movable grilles and replacement of the window glass, were given, which measures will improve daylighting situation. In case of new built dwellings using the traditional style, primary focus should be on reducing room depth. All these measures will have a positive effect on occupant comfort and thus contribute to the protection and preservation of these traditional dwellings, and could also be on dwellings in other parts of China. However, further research is needed in this area, to understand daylighting conditions in different dwellings and to explore more possible solutions to improve it.

ACKNOWLEDGEMENTS

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Changes in Culture and Architecture from Vernacular to Modern: M.P., India

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ABSTRACT

India is known for its rich cultural heritage. The culture plays an important role in defining the architecture of a place or people with time. Madhya Pradesh is one of the states of India. The objective of the paper is to study the changes in culture and architecture from vernacular to modern of Madhya Pradesh. Vernacular architecture has been evolved through a process of trial and error for ages. In Methodology the vernacular and urban dwellings are documented and analyzed on various parameters of culture and architecture. The dwelling of potters and bamboo workers are selected from vernacular and urban settlement. The two typical dwelling from BHEL, Bhopal is selected from an urban settlement. The result focuses on influences of urbanization and globalization which brought threat to cultural identity. The urban settlements are designed according to the economic status of the residents without considering their culture. The analysis is to adapt the appropriate technology using locally available material and construction techniques for a sustainable development. It requires an innovative and creative approach to integrate vernacular into the modern architecture. The paper concludes by learning and appreciating the principles of vernacular architecture and integrating them with the contemporary knowledge and technology.

Keywords: culture, architecture, vernacular, modern, sustainable development

INTRODUCTION

Madhya Pradesh is one of the states in India which is centrally located. It is also known as heart of India due to its geographical location. Bhopal is the capital of Madhya Pradesh was formed in 1956. The border of this state touches five states: Gujarat, Rajasthan, Uttar Pradesh, Chhattisgarh and Maharashtra. The influences of these states are prominent in zones and architecture of Madhya Pradesh. Its culture can be divided in four zones such as Bundalkhand, Baghelkhand, Malwa and Nimar. Each zone has its own cultural identity such as language, dialects, customs, rituals and beliefs. The state is famous for its tribal arts and crafts. As per 2011 census of the state the population was 72 million and the tribal population is approximately 20 % of the total population.

Figure1 Map of India  
Figure 2 Map of Madhya Pradesh  
Figure 3 Map of Bhopal city
CULTURE AND ARCHITECTURE OF MADHYA PRADESH

The tribal and folk traditions of Madhya Pradesh are reflected in the vernacular architecture. The state is known for its visual and performing arts, these art forms are closely associated with their beliefs, customs, religion and values. The singing and dancing are part of their day to day life. It is a community activity performed each day after the work to relax and enjoy. These activities have evolved the necessity of a community space like a courtyard or chaupal in their settlement pattern. These patterns resulted in a strong social binding within the community. Each tribe has its own way of settlement pattern on the basis of their culture and lifestyle like Saharia has circular, Bhil has scattered and Korku has linear. The central space in Saharia is ‘chaupal’ where grandparents chat and look after grandchildren while the parents are working on fields.

Madhya Pradesh is famous for its traditional crafts like bamboo, wood, pottery, painting, metal casting, terracotta and textiles. The sarees from Mahaeshwar and Chanderi are famous for weaving whereas Bagh and Ujjain are famous for printing. The designs are evolved and inspired from the surrounding environment. The weaving pattern in Maheshwari sarees ‘Laharia’ is most dominating which is inspired from the holy river Narmada. These patterns of textiles are also reflected in the vernacular architecture. The sculpture and murals in the houses are not simply for decoration but are part of their rituals and beliefs. During the festivals and rituals the murals depicted on the walls are Pithora, Sanjha and designs on the floors are Mandana, Alpana and Rangoli. The tribals adorn their roof tiles with animals, human images and some figure which have something to do with witch-craft and evil spirits. Horses occupy a significant status in tribal life as symbol of power and force. It is depicted in different forms in murals, sculpture and even in the structural members of the built form. The bas relief figure of birds, flowers, trees and animals are depicted on the interior walls of houses. The clay figures are prevalent to mark both auspicious as well as inauspicious occasions. The paneled doors of single plank and wooden pillars are carved with the motifs of flora, funa and geometry designs. The Bas relief figure of animals, birds, trees, flowers and god-goddess are depicted on the interior walls. The trees are integral part of a house like a Tulsi chura in middle of a Hindu house, they also have medicinal values.

REFLECTION OF CULTURE IN ARCHITECTURE

The communities of potters, textiles, printer, weavers and bamboo workers are well placed in their native places like textile printers in Bagh; weavers in Mahaeshwar, they have their own settlement pattern as per their trade. When they come to a city in search of employment they have to adopt a new trade or either continues with their own. There cultural identities are well defined in the traditional settlements in their built forms, decorations and lifestyle. The settlement of Bhil or Gond tribe can be easily identified through these identities.

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**Figure 4** Circular pattern, Saharia  **Figure 5** Scattered pattern, Bhil  **Figure 6** Linear pattern, Korku

**Figure 7** Tribal house  **Figure 8** Bamboo workers  **Figure 9** Gond painting
TRANSITION FROM RURAL TO URBAN

In Bhopal there is a planned urban settlement BHEL, a township developed for the workers. The planning of the settlement is done on the basis of economic status of the workers from one bedroom unit to four bedrooms unit. The township is designed with facilities like schools, colleges, sports complex, market places and other amenities. The spaces are provided for their religious and community activities although a township developed for the secular and democratic society as per Nehru’s vision. There is no such defined culture or identity of the settlement. It has a concept of global village which has a similar character of any other planned city of India. The cultural identities are vanishing from the modern cities. In the urban planning there is no place for traditional settlements and vernacular patterns. Parallel to this industrial development there are also traditional crafts and trades which are integral part of the society, for example a refrigerator could not replace an earthen pot in an Indian house. When a pot is brought in the house, a ritual is performed to fill the water. This shows that the potter is an integral part of the society and the tradition continues in this manner.

METHODOLOGY

The vernacular and urban dwellings are documented and analyzed on different parameters of culture and architecture. The dwellings of Potters and Bamboo workers are selected from vernacular and urban settlements. The dwellings of workers from BHEL Township, Bhopal are selected from an urban settlement. The parameters of changes in culture are characteristics, aesthetics, planning and community living. The parameters of changes in architecture are site planning, response to climate, material, construction method & techniques and cost effectiveness.

VERNACULAR SETTLEMENT OF POTTERS (KUMAHAR)

Potters community lives in separate clusters in village settlement due to their work culture. A traditional dwelling of potters at Damnod, District Dhar, Madhya Pradesh is selected for a case study. In the dwelling the spaces are required for storage of raw material and finished products, preparation of clay, creation of pots, roof tiles or bricks and firing. In the front there is an open space for working and selling and on the backyard for private space like washing, bathing and other household works. The enclosed spaces are used for sleeping, cooking and living. The toilets are not attached with the dwelling. A separate room for donkey is provided. These communities are associated with ceremonies of birth, marriage and death. The three to four generations live together which forms a strong social binding. The walls are constructed by rammed earth or brick masonry with mud mortar. The brick piers or wooden post are the vertical structural members. The attic is made of bamboo matting with mud mortar or wooden planks and is used as storage space. The stone slabs are rarely used because of site conditions. The roof consists of rafters, purlin with the covering of country tiles. The decorative figures of bird or animal are placed at the ridge. The tiles are moulded and casted or made on potter’s wheel. The plastering is done by mud plaster, red clay, white clay and yellow ochre. The flooring has rammed earth covered with cow dung. The wooden door and windows are double leaf. The niches are used for storage.

Figure 10 Plan

When they migrate to cities, they do not have space to settle down as per the work culture. Therefore, they are forced to live on the “eyeshores”, ‘Jhuggis’ or on the pavements. In the planned residential zones, the firing is not allowed where such living and working can be performed together.
The potter’s community residing on the pavements of Link Road No.3 in Bhopal is documented. There is a planning proposal for resettlement for these dwellers under JNNURM, which is a multistoried housing in the same locality. In the new dwellings they cannot live and work per their work culture. If they are not given an opportunity to work, they are forced to switch over to another trade. As a result this craft will slowly vanish from the society.

![Figure 12 Roadside settlement](image1)
![Figure 13 Living space](image2)
![Figure 14 Working space](image3)

![Figure 15 Selling space](image4)
![Figure 16 Interacting space](image5)
![Figure 17 By new settlement](image6)

VERNACULAR SETTLEMENT OF BAMBOO WORKERS (BASOR)

Bamboo workers community lives close to the forest. The Basods are the people belonging to community of bamboo craftsmen who are traditionally dependent on bamboo for their livelihood. They are mostly engaged in construction work like scaffolding or temporary structures. Variety utility items are made like furniture, basket, ornaments, musical instruments, effigies, totems etc. A traditional dwelling of bamboo worker at Churhat, District Satna, Madhya Pradesh is selected for a case study. They have living and sleeping spaces along the courtyard and the working space is outside the courtyard in front of the dwelling. The courtyard is used for household works, storage space for raw material and a pig house adjacent to the dwelling. This community is also closely associated with the society, when a girl is married; the essential utility items are given to her in a basket called ‘pitara’ or ‘dori’. It is very auspicious. The walls are made of thick bamboo matt covered with mud plaster, thick bamboos are used for vertical support. The attic floor is made of bamboo mating, covered with mud plaster. The roof consists of wooden trusses, rafters and purlins of bamboo and covering of country tile or thatch. The mud is used for plastering; flooring is done by rammed earth, covered with cow dung. The timber doors and window frames with bamboo shutters, bamboo jail used for lighting and ventilation.
This community is residing on the pavements of Link Road No.2 in Bhopal. In the similar way, for resettlement for these dwellers under JNNURM, a multistoried housing is provided in same locality, which is not as per their work culture and will result in vanishing of the craft from the society.

These communities have a tendency to calls his family members or relatives when one gets an employment in the city. They start living in close vicinity; form a community, quite similar to the village pattern. This result in the formation of basti’s (informal settlement) like potters basti, basoor basti, lohar basti etc. and are named after their trade. They face hardship in daily life; their biggest strength is social binding. Similarly the construction labors also form basti, named after their state as Chhattisgarhi basti, Orriya basti etc. There lives are challenging; even a birth or a death can take place at the site. Sometimes they come across serious incidences like Gas tragedy, Bhopal in 1984, the residents of Orriya basti were among the victims. It was one of the biggest industrial disasters; lakhs of people lost their life.

URBAN SETTLEMENT IN BHEL TOWNSHIP, BHOPAL

This township has been designed for an organized sector for industrial workers with modern amenities and facilities. It is a RCC framed structure, use of modern materials and construction techniques, technical experts, skilled labor were the prime concern. There is monotony in form and character which has similarity with any other planned urban settlement in India. The dwellings are designed as per the economic status of the worker. There is not a defined character and does not reflect a particular culture. Hence there is a change in living pattern and lifestyle. We have selected two type of dwelling units of the township, Type A and Type C. Type A is one bedroom unit with living room, kitchen, verandah, courtyard with bath and wc with an area of 454 sq ft. Type C two bedroom unit with two verandahs, kitchen, one common toilet and one attach toilet with an area of 883 sq ft.
## Table 1. Parameters of Changes in Culture and Architecture

<table>
<thead>
<tr>
<th>Parameters of changes</th>
<th>Details</th>
<th>Vernacular Architecture</th>
<th>Modern Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Culture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Characteristics</td>
<td>Different cultures of tribal and folk are well defined.</td>
<td></td>
<td>Universal characteristics, no reflection of local culture</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Murals, painting, sculpture are integral part of architecture.</td>
<td></td>
<td>Contemporary art is depicted.</td>
</tr>
<tr>
<td>Planning</td>
<td>Settlement planning as per their lifestyle like circular, squatter and linear.</td>
<td></td>
<td>People live in isolation, less interaction with others, no place for local arts and crafts.</td>
</tr>
<tr>
<td>Community living</td>
<td>Choupal, otla, chowk, courtyard for social interaction. Strong social binding.</td>
<td></td>
<td>Cultural hubs, sports complex are interaction spaces, intimate relationship and social binding is less.</td>
</tr>
<tr>
<td>Site planning</td>
<td>Planning as done as per topography and landscape.</td>
<td></td>
<td>Planning is as per the economic status of the user like HIG, MIG, LIG and EWS.</td>
</tr>
<tr>
<td>Response to climate</td>
<td>Plan form and built form are evolved as per the climatic conditions of the region.</td>
<td></td>
<td>Eco-friendly materials are in market but are expensive.</td>
</tr>
<tr>
<td>Materials</td>
<td>Locally available material like stone, mud, bamboo, timber and lime are used.</td>
<td></td>
<td>The market ones are given priority than local ones.</td>
</tr>
<tr>
<td>Stone</td>
<td>It is used in masonry, roof, flooring, in-built furniture, Chajjas and Jharakhos are provided for shading.</td>
<td></td>
<td>With modern techniques it’s used in a better way.</td>
</tr>
<tr>
<td>Mud</td>
<td>Rammed earth, adobe, mud mortar used in random rubble masonry, helps in acoustics and heat resistant.</td>
<td></td>
<td>Rammed earth, adobe are used in modern design.</td>
</tr>
<tr>
<td>Bamboo</td>
<td>Because of strength and flexibility widely used as structural skeleton, roofing structure, composite construction and utility items like jaails, baskets etc.</td>
<td></td>
<td>It is used as a new material in modern construction.</td>
</tr>
<tr>
<td>Timber</td>
<td>Used as a structural component, in the construction of beams, rafter, trusses, doors, windows and furniture.</td>
<td></td>
<td>Used for doors, windows and not as structural member</td>
</tr>
<tr>
<td>Lime</td>
<td>Used in brick masonry as a binding material, for plastering and fresco painting.</td>
<td></td>
<td>It is rarely used, limited to conservation</td>
</tr>
<tr>
<td>Brick and Terracotta</td>
<td>Brick is used for masonry walls, piers, jaalis, etc. Terracotta is used in roofing tiles, roof gutters, pottery.</td>
<td></td>
<td>Brick is used for masonry walls, piers, jaalis, etc.</td>
</tr>
<tr>
<td>New materials</td>
<td>Adaptability to new material.</td>
<td></td>
<td>Terracotta is used in roofing tiles, roof gutters, pottery.</td>
</tr>
<tr>
<td>Cost-effective</td>
<td>Because of locally available material, saves the cost of transportation</td>
<td></td>
<td>Adaptability to new materials is more</td>
</tr>
</tbody>
</table>

Source: Author
RESULTS AND FINDINGS

The vernacular dwellings have a special character that the spaces are multifunctional and each craft requires a different pattern of spaces. The dwellings are designed by keeping in mind the future expansion. The form of a building is evolved from its functions. Architectural characteristics are defined by their work culture. Pottery is a traditional craft which transfers from one generation to another. So it is continuously expanding as per their requirements hardly any change is seen in the living pattern and lifestyle. Some of the potters migrate to city for employment. Thus, migration is a major problem of urban settlement. The planned housing is defined by the economic status of the user. The modern material are used which are changing with new construction methods and techniques. In vernacular there is a subtle change in material and character. The acceptability of new material and technique is less. Therefore, they have a specific character and lifestyle. In urban settlements the changes are easily noticeable; acceptability to new material and techniques is high. A new character is coming up which has no relevance with the vernacular, it has a global character. The data collection and observations there is no space provided in the urban planning for traditional craft like potters, bamboo workers, blacksmith and weavers etc. which are an integral part of the society. Hence in the urban planning the provisions for these settlements should be provided. The research can give vision to policy makers, planner, architects to look into the traditional crafts and trades, understanding the vernacular traditions and incorporating them in the contemporary planning. The impact of globalization has threatened traditional and cultural values by the forces of economic, cultural and architectural homogenization. This has brought disregard for traditional environment and often considered as a symbol of poverty and backwardness. In the race of modernity, values, beliefs, culture are removed from the society. The steps towards sustainable cities are taken at various level such as Earth Summit, Agenda 21 at the international, JNNURM at national and other initiatives include National Habitat Mission, National Action Plan for Climate Change, Water Mission, Energy Efficiency Mission and so on. (Tipnis, 2012)

INTEGRATION OF VERNACULAR AND MODERN IN THE CONTEMPORARY DESIGN

Vernacular traditions lead a way towards the sustainable built environment. The valuable lessons from vernacular can be integrated with the modern to produce sustainable designs. Vernacular traditions can also be used as a design tool for slum re-developments. The designing of these settlements need understanding users' way of life, social and cultural values. LIC housing by Charles Correa, Anandgram by Kamath Design Studio in India are few examples of integration of vernacular and modern. Architects like Louis Kahn, Lourie Baker, B.V. Doshi, Shirish Beri, Revathi and Vasanth Kamath, Satprem Maini have incorporated the principles of vernacular traditions in their contemporary buildings (Tipnis, 2012).

Anandgram in Shadipur, Delhi is selected as an example of resettlement. It is designed by Kamath Design Studio, Delhi, India in 1983. Architect Revathi and Vasanth Kamath their work is a creative synthesis of attitudes and technologies into an aesthetic habitat and a way of life. They believe in using natural resources and utilize them to the most and are on a mission to substitute concrete, cement and energy-consuming systems with sun, water, wind and soil. Ecology must be understood to encompass both nature and culture (kamathdesign.org). The settlement is designed for traditional community of performing artists and craftsmen in their own traditional pattern by integrating values, customs, rituals, beliefs and lifestyle. The challenge was to provide the built-fabric in relation to the urban form. It is one of the best examples of reflection of culture in architecture in the contemporary design.

Figure 28 The change in unit after 30 years
Figure 29 The section through a cluster
CONCLUSION

The changes in culture and architecture are reciprocal. The impact of one is reflected on the other. India’s rich cultural heritage is vanishing due to the influence of urbanization and globalization. In order to protect and conserve our rich cultural and architectural heritage the elements of vernacular should be incorporated in the contemporary planning and architecture. The provision should be made to incorporate vernacular architecture and traditional knowledge in the policies. The policy makers, planners and architects should consider this in their work for betterment of society. The paper concludes by learning and appreciating the principles of vernacular architecture and integrating them with the contemporary knowledge and technology.

“Quality of life is enhanced through good architectural design which responds to the needs and wishes of users and use of natural materials and good urban design which allows creation of green spaces and reduction of noise and pollution.” Birkauser, (Tipnis, 2012).

ACKNOWLEDGMENTS

We are greatly thankful to Department of Culture, Archeology, Tribal Research Institute, Tribal Museum and State Archeological Museum of Madhya Pradesh.

GLOSSARY

Chaupal: denotes a common meeting place in a village which is owned by the community.
Bhil: one of the main tribes lining in the Jhabua and Dhar region.
Dwelling: is the name given to a house form or for living somewhere.
Jaali: lattices made of bamboo, grass and clay, used on mud houses in Sarguja, Raigarh.
Pithora: votive wall painting made by the Bhils, worshipped with sacrifices.
Sahariya: primitive tribe living in Gwalior, Shvpuri and Morena in the north-western part of Madhya Pradesh. The people of this tribe consider Sabari of Ramayana to their first ancestor.

REFERENCES


http://www.kamathdesign.org/project/anandgram
Vernacular Ecology: Environmental Recreation of Ancient Dwellings in Southeastern Turkey

Mina Hasman, LEED AP
Skidmore, Owings & Merrill, Inc.

ABSTRACT

“At the beginning of the 21st century, in a time of rapid ecological degradation, globalization and destruction of much vernacular architectural heritage, concerns for the maintenance of the local, cultural identities, and an awareness of the need to provide sustainable built environments are set to raise an interest in the vernacular traditions” (Asquith & Vellinga, 2006) for a culturally-embedded environmental design future. This paper investigates the Southeastern Turkey’s vernacular architecture with the aim to partake in the development of a New Hasankeyf proposal by investigating design guidelines for the new dwellings of the future city. The basis of the explored guidelines relies on the concept of ‘recreating the vernacular’ with the primary goal to enhance the environmental performance of the proposed dwellings; through passive means and without compromising the cultural/geographical premonitions that it originally derived from by implementing 1) compact form, 2) adapted space layout and 3) improved building elements.

INTRODUCTION

In an era, in which archeological sites are preserved with utmost diligence, Hasankeyf - a declared conservation area in Southeastern Turkey - is left at its destiny, which would be determined by the Turkish Government that attempts to flood the region with its Ilisu Dam along Tigris River as a part of an “integrated irrigation and agricultural project” (Demirbilek, 1997) called GAP.

It is not only the inconceivable truth of inundating such an ancient city which results in a homeless population and ever lost heritage, but also the insensibility of the government’s new construction proposal set forth that both encourage a need to offer construction and design guidance for a sustainable, long-lasting, culturally-familiar and aesthetically-amalgamated design approach.

Over the last century, the region has faced a “rapid and uncared growth” as observed by (Demirbilek, 1997) due to fast population increase, changes in the social context and economic restrictions. This has encouraged an incongruous, fast-pace construction without any considerations for (cultural) modern era notions. The main goal of the current research is, therefore, to understand and explore the limitations of the vernacular sustainable strategies in Hasankeyf and learn how the local approaches could be implemented in and further adapted to a new development within the region. Considering this, the paper at this stage, adamantly envisions the ‘recreation of the vernacular’ as an integral aspect of long-term sustainability by investigating potential passive measures, which could provide annual occupant comfort.

The recreation of the vernacular concentrates on exploring a design of mostly self-sustaining dwellings embedded within an environmentally-responsive enclosure without compromising elements that define the region’s unique architecture but enabling it to adapt to the contemporary family needs.
REGIONAL INFLUENCES

Climate & Topography

Hasankeyf is a hillside settlement with an altitude reaching up to 495m perched within a valley in the hot and dry Southeastern region of Turkey. The great temperature difference of about 32°C between the hot summer and relatively cold winter months made it “imperative to adopt to the natural forces from the early days” of the region’s history (Alioglu, 2000).

The climate analysis of the closest city of Batman obtained from the climate software, Meteonorm indicates that the area faces two annual extremes with a minimal amount of rainfall and a good amount of global radiation: fairly hot summers and cold winters with a large diurnal temperature difference. Based on this climate analysis, two different comfort bands can be determined by following de Dear’s formula calculations as outlined by (Szokolay, 2004): the resulting comfort band for summer ranges between 24°C and 29°C, and for winter, the band falls between the temperature range of 17°C and 22°C.

Culture & Architecture

The historical perspective reveals that in the vernacular architecture of Anatolia, human beings built dwellings based on a specific region’s geographic and climatic provisions along with the religious premonition of orienting the main façade towards Qibla - to Mecca, which is the direction of the Holy Land of Islam (Demirbilek, 1997).

Hasankeyf is an exceptional precedent to such a hypothesis: the city’s settlement on hillside topography with introverted house layouts, not only accentuates the region’s cultural privacy, but also represents the environmental benefits such a settlement and layout provide (Demirbilek, 1997). Moreover, the formation of semi-open (Eyvan & Revak) and open (courtyard & terrace) spaces along with enclosed areas forming the typical 2-level construction, differentiation of rooms for solely male and female occupancy, and small openings to outside mimic the characteristics of the area’s closed-in lifestyle (Alioglu, 2000).

The region houses three building typologies: the U-type (- most commonly encountered within the vernacular city fabric), the L-type and the Linear Type. The building forms portray the family status and size, ranging from the most prestigious house with the largest family in the U-type to medium size in the L-type and to the smallest building form of the Linear Type. Despite the difference in their size and form, all the building typologies have traditional flat roofs, same treatment of architectural features and closely related program allocation and space layouts.

CASE STUDY FIELDWORK & ANALYTIC STUDIES

A fieldwork is conducted and measurements are taken in a precedent dwelling - the Gozuoglu House - in Mardin (- a nearby city to Hasankeyf) with the aim to investigate the vernacular building’s performance.

The prestigious Gozuoglu House represents region’s emblematic, architectural features within its 2-level construction of 90cm-thick, non-insulated, locally-sourced stone walls with single-glazed, small windows and a U-type layout of varied open, semi-open and enclosed spaces.

The house consists of ‘living units’ as described by (Alioglu, 2000) which include bedroom areas (within Haremlik and Selamlik living rooms) and the most esteemed men (Selamlik) and women (Haremlik) living rooms at the upper level. These spaces are commonly occupied during the summer season due to their high volume with ceilings reaching up to 5m (Demirbilek, 1997). The external shutters supplement indoor comfort within these spaces by providing protection against (direct) sunlight during the peak hours of the day.

The winter season targeted lower level, on the other hand, embraces daily ‘service areas’ (Alioglu, 2000) including an office (live/work room) and a study room along with a kitchen across a storage space, and an earth-dug room, which is most commonly used during the summer season as it stabilizes the indoor temperature and maintains the space cooler.
Fieldwork

The fieldwork of the Gozuoglu House is completed using Tiny Tag data loggers (for room dry-bulb temperature) on the sunny days of 4th - 6th of July 2011, during which the average outdoor temperature ranged between 30.1°C and 31.2°C. The intent of the fieldwork is to understand the temperature performance of two similar spaces at different levels based on solar radiation impact. A living room - Haremlik and a live/work room - the office space are chosen due to their comparable layout and size (28m² of floor area in Haremlik and 25m² in the office) along with analogous window-to-floor ratios (13% in Haremlik and 11% in the office), occupancy pattern and ventilation rates. (Note: Both spaces were not occupied during the fieldwork period).

The obtained data logger results indicate that thermal mass maintains both spaces’ internal air temperatures at a fairly stable level (with a 2°C fluctuation) throughout the day despite the large 20°C diurnal fluctuation of the external temperature as seen on Figure 1.

Figure 1  Fieldwork measurements’ graph of two rooms in the vernacular Gozuoglu House

The 5°C internal air temperature difference between the upper level Haremlik and the lower level office highlights that solar radiation potentially plays an influential role in the increase of the internal air temperatures - a theory that needs to be confirmed by the subsequent analytic studies: the unobstructed Haremlik’s east and south facing windows increase solar access, whereas the lower level office’s only east facing, overshadowed (by terrace above) windows limit it.

Hypotheses

Analyzing the climatic characteristics of the city including S-SW wind flow pattern and high solar angles along with observing the case study fieldwork results, a series of strategies are formulated based on initial environmental hypotheses, which focus on passively improving the indoor comfort within such a vernacular enclosure:

- Increase of solar access into spaces
- Compact spaces of airtight, thermal mass construction
- Shading elements
- Night time ventilation (with additionally openable, upper pane windows and/or skylights)
- Maintenance of the vernacular’s semi-open and open spaces that further contribute to the indoor
comfort enhancement: during winter, these spaces provide buffer from the cold outdoor temperature while during summer, they offer a shaded microclimate environment (Fathy, 1986; Koch-Nielsen, 2002), extending the daily family life.

Analytic Studies

At the conclusion of the obtained fieldwork, analytic studies are conducted using Thermal Analysis Software (TAS) for calibration, understanding of the dwelling’s annual performance and confirmation of the proposed strategies in relation to the formulated environmental hypotheses.

The created base case model complies with the vernacular case study precedent in terms of building form, layout and inputs. The completed TAS model is examined for building’s performance of levels, orientation, solar radiation access and internal heat gains throughout a typical summer (7th - 13th of June) and a winter week (1st - 7th of December). The analysis and comparison of each simulation are evaluated against the comfort bands (24°C - 29°C for summer and 17°C - 22°C for winter) calculated according to de Dear’s formula.

Four rooms are selected for the simulations: Haremlik (the upper level living room with south and east facing windows), Selamlik (another upper level living room with south and west facing windows), office (the lower level live/work space with east facing windows) and Antre (a lower level living room with west facing windows). Both of the lower level rooms as well as the upper level ones are given the same window-to-floor ratios of the vernacular (13% on the upper level and 11% on the lower level) to minimize the parameters that would influence the outcome.

Similar to the fieldwork measurements, the summer simulation results for both orientations indicate that solar radiation has a valid influence on increasing spaces’ internal air temperatures: the more exposed upper level portrays approximately 4°C warmer temperatures (before the internal heat gains are applied) compared to the lower level rooms as indicated on Figure 2.

Despite the impact of solar radiation, the influence of orientation (East vs. West) is minimally observed due to the U-type building form that overshadows itself: two same level rooms portray a fairly close temperature range. Nonetheless, it can be clearly identified that the impact of internal heat gains is the most direct: the temperatures of both levels initially increase following the external temperature
pattern, however, with a time-lag due to the dwelling’s heavy-mass construction. Once the internal heat gains (i.e. mainly occupancy and some lighting) are applied into these spaces, the internal temperatures reach their peak approximately at a 1°C - 2°C higher level as highlighted with ☐ on Figure 3. When the internal heat gains are removed as spaces become unoccupied, the internal temperatures decrease following the pattern of the external temperature. Nevertheless, the internal temperature levels do not necessarily mimic the external temperature drop if the internal heat gains are continuously applied within these spaces as highlighted with ☐ on Figure 3.

Reassuring the previously formulated hypotheses, the free-running (without heating or cooling) Gozuoglu House Base Case exhibits a much poorer performance during the cold winter season with internal temperature levels falling below the calculated comfort band of 17°C - 22°C, following a fluctuation line of 7°C - 14°C as highlighted on Figure 4 (a) and (b).

Critical Review

The conducted fieldwork and current analytic studies confirm the initially formulated environmental performance hypotheses for the investigated vernacular dwelling, in which the heavy-mass stone construction and small window-to-floor ratio maintain the internal temperature levels stable during both winter and summer months, however, passively achieving indoor occupant comfort during the hot summer period, but not providing it for the cold winter season. Considering this, the focus of the future analytic studies in this paper is to enhance the vernacular building’s performance during winter while reducing the Annual Heating Load Demand and maintaining the summer indoor comfort.

Following the pattern of the previous section, a new hypothesis is formulated stating that the building scale manipulations such as improving the construction (i.e. implementing double-glazing and insulation) and increasing window-to-floor ratio along with defining a layout that is proportionate to the targeted occupants (in terms of floor area for the resulting internal heat gains) would increase the building’s performance during the winter season while also maintaining the desired summer comfort.
PROPOSAL & ANALYTIC STUDIES

Vernacular dwellings of the region (especially the U-type building form) were meant for large families because traditionally married males never left their family home (Alioglu, 2000). Nonetheless, current married generation prefers to privatize their individual, core family life from the extended relatives. Considering this, guidelines are presented for the ‘recreation of the ‘modern’ vernacular’ with the New Hasankeyf Base Case being created following the reiterated parameters:

- Compact dwelling size proportionate to a single family of 4 people, which corresponds to the Linear Type encountered within the vernacular fabric (Note: Per the previously completed analytic studies, the U-type building depicts the worst performance among all the typologies due to its form, which limits solar access and enables heat loss via large amount of exposed surface area. It is also due to this reason that the Linear Type is chosen to represent a new dwelling prototype for the future city of Hasankeyf).

- Reduced stone wall thickness from 90cm to 30cm for ease of transport, labor and cost reduction

- Adequate space layout to accommodate the modern era adaptation of programs (i.e. identification of programs for the vernacular model). (Note: Separate bedroom and bathroom spaces were not a part of the vernacular dwelling layout; instead they were a part of a ‘shared space’ system. However, with the increasing need of individual privacy within a dwelling, the locals of the region are encouraged to redefine some rooms to provide for the needs of those ‘unidentified’ programs. This ‘forced’ process often takes away from the function and the proposed layout of another vernacular space in the building, posing contradiction to the traditional occupancy pattern and space layout).

The created New Hasankeyf Base Case has the input values as shown on Figure 5, deriving from the region’s precedent characteristics.

![Figure 5](source: TAS)
The New Hasankeyf Base Case’s simulations conducted using TAS restate the previously encountered outcome: the model exhibits a good performance during the summer period with temperature patterns (for both levels) falling within the target comfort band, whereas it suffers throughout the cold winter season. As hypothesized earlier, the following building scale manipulations are additionally considered for the enhancement of the proposed dwelling’s annual performance:

- Addition of insulation along the exterior of structure (from the vernacular none to 5cm thickness)
- Change of glazing type (from the vernacular single to double-glazing)
- Increase of window-to-floor ratio (from the vernacular 11% (at lower level) and 13% (at upper level) to 15% (at lower level) and 25% (at upper level) both with insulated, external shutters)
- Reduction of terrace depth (from the vernacular 4m to 2m depth)

A architectural approach combining the considered parameters along with an optimum South (Qibla) orientation has been established based on a balance of Annual Heating Demand reduction and increase of Solar Gain, and it is reflected within the design prototype for the New Hasankeyf dwellings. To quantify the proposed prototype’s performance, a set of a typical summer and a winter week simulations has been completed comparing an upper level living room (Selamlik) to a lower level one (living room/office). The obtained summer simulation results of the free-running (without heating or cooling) New Hasankeyf Base Case as seen on Figure 6 (a), indicate a stable profile for the lower level living room/office, whereas it portrays a bigger fluctuation pattern for the upper level Selamlik due to increased ventilation strategy applied in order to maintain the internal temperature levels within the set comfort band with newly increased window-to-floor ratio.

The New Hasankeyf Base Case’s internal temperature profiles portray significant improvements of approximately 20-25% for the winter model performance when compared to the vernacular Gozuoglu House Base Case: both the upper level Selamlik and the lower level living room/office display a more regulated temperature pattern with a daily fluctuation reaching up to 4°C as indicated on Figure 6 (b). The obtained results highlight both levels’ potential for achieving comfort range with increased occupancy and/or minimal heating input: it has been observed that when there is constant solar radiation above 500 W/m² and the external temperature exceeds 10°C, the lower band of the comfort zone can be achieved during the occupation hours under free-running conditions. Moreover, there is an evident improvement in the lower level space’s internal temperature levels from the Gozuoglu House Base Case condition. The improvement also applies to the upper level Selamlik’s internal performance with a 3°C higher temperature range compared to the vernacular Gozuoglu House Base Case model. Considering this, the band in which the heating system would operate in order to reach the comfort range would be much smaller and therefore, significant savings can be achieved.
Despite the prototype dwelling passively not achieving a complete annual range within the calculated comfort bands, the proposed guidelines relay an achieved summer comfort and an enhanced winter performance without compromising the origins of the vernacular’s architectural existence: the primary focus of the research is to offer guidelines to design for inhabitants who are devoted to meticulously preserve their cultural traditions mirrored onto the region’s architecture and lifestyle.

The conducted research of the previously formulated hypotheses via supplementary analytic studies in this section, reassures the set theory in regards to the ‘recreated’ vernacular dwellings’ performance. More importantly, this research leads to an outcome that can provide guidelines for the New Hasankeyf dwellings’ passive design approach, through which not only current, but also future builders, designer and occupants can dwell upon, learn and grow, carrying on the precedents. The primary scope of this study has been to investigate the limits of the localized vernacular passive measures in order to enhance the environmental performance of dwellings within the Hasankeyf area. Nonetheless, further studies that are based on alternative performance metrics would explore useful measures that not only ‘recreate’, but also assist in achieving a more efficient and improved sustainable design by ‘redeveloping’ the vernacular lessons learned in this initial research.

ARCHITECTURAL DESIGN

The New Hasankeyf proposal derives from the architectural syntax of the vernacular, which is based on a 4mx4m grid layout (Ozbek, 2004). It represents housing units that achieve desirable indoor living conditions throughout varied seasons. The premise of the units’ design lies on maintaining the vernacular language based not only on its space layout, usage and building form, prolonging the roots of the cultural lifestyle and traditions, but also on its architectural aesthetic that smoothly amalgamates with the existing surrounding.

In addition to preserving the vernacular’s space layout and function, the bathroom and the bedroom spaces are compensated in the new proposal, all with either standard or high-level windows. Reiterating the transitional spaces, the New Hasankeyf proposal consists of terraces forming Revaks (semi-open spaces) below, which lead to a sheltered, private courtyard, in which comfort is enhanced with water elements and vegetation.

The varied façade treatment evident in materiality, scale and ornament application along with diverse opening sizes (15% on the lower level and 25% on the upper level) and ceiling heights (2.5m at the lower level and 5m at the upper level) visually contribute to the seasonally desired transition of the two levels: the linear patterned, local wood finish with smaller windows encapsulated with minimal, insulated, wood shutters on the lower level reflects the simplicity of the ‘service areas’ it encloses behind; whereas the elegant, local stone arrangement and the larger windows with ornate, insulated, wood shutters highlight the prestigious ‘living areas’ of the upper level.

The beneficial reconsideration from the vernacular example in the New Hasankeyf prototype is the secure extension of family life onto the flat rooftop enabled by the elaborate railing design, which, in addition to the terrace’s, defines the perforated, horizontal framing of the building’s overall façade.

CONCLUSION

The New Hasankeyf proposal depicts the pictogram of a vernacular ecology harmonized with the deeply rooted cultural texture of Hasankeyf in Southeastern Turkey. It presents an improved but closely paired to vernacular design that provides guidance for designers and builders who would partake in building dwellings for the soon-to-be-submerged city.

The proposed guidelines simply do not dwell upon a novel design; they instead focus on the ‘recreation of the vernacular’ with an enhanced environmental performance. It is nonetheless, acknowledged that the vernacular model faces constraints as passive design approaches are enforced. Considering this, design alterations to the vernacular model such as providing a glazed enclosure at terrace level to pre-heat the air to be supplied indoors and/or active systems would additionally need to be integrated to achieve full comfort.
All the unifying elements of the proposal are created to respond to the current family needs and environmental conditions for a building scale enhanced performance as discussed by (Yannas, 1994) along with finding a balance within the traditional composition of the area. It is through these considerations that the guidelines highlighted within this paper can be followed for a sustainable modern era adaptation of the new and soon-to-be emerging Hasankeyf dwellings.

REFERENCES

Session PC: Passive Design

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Grace - Knowledge Consortium of Gujarat
Morphological Variation Impact on Heating and Cooling Energy Consumption in Buildings

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ABSTRACT HEADING

This study quantified the impact of morphological variation on the heating and cooling energy consumption in buildings. Using the eQuest simulation program, a series of parametric simulations was conducted to derive the amount of heating and cooling energy consumptions for the numbers of floors, floor areas, and space volumes. Numerical tests were performed in a typical two-story single-family residential building located in the two different climate zones in the USA – the hot/humid and cold regions. Analysis revealed that the amount of heating energy in the cold climate was the most significant component in buildings: thus, an energy-efficient heating system and energy-conscious operation needs to be considered for saving energy. In addition, the amounts of heating and cooling energy were all proportional to the building’s number of floors, floor area, and volume of space. Therefore, the building is required to be planned based on the morphological impact on the building energy efficiency.

INTRODUCTION

The survey results conducted by the Ministry of Knowledge Economy of South Korea in 2009 indicated that almost quarter of the annually consumed energy in Korea was used in buildings (22.3%). Among this amount, 51.0% was used by residential buildings. In addition, 63% of the energy in residential buildings was consumed by single-family houses and 37.0% was used by multi-unit dwellings. Thus, single-family houses and multi-unit dwellings respectively accounted for 7.2% (=0.223*0.51*0.63*100) and 4.2% (=0.223*0.51*0.37*100) of the total national annual energy consumption. The heating and cooling systems consumed 58.1% of the total energy used in residential buildings. Therefore, it can be inferred that 6.6% (=7.2+4.2)*0.581) of the total national energy was consumed for heating and cooling in residential buildings (Moon, 2011a; Ministry of Knowledge Economy, 2009; Lee, 2006).

Numerous researches have been conducted regarding energy-efficient building thermal-control theories, systems and control technologies. The reinforced insulation level of building envelope was proved to be one of the most significant determinants for increasing building energy efficiency (Kim & Moon, 2009; Moon, Han, & Oh, 2011; Moon, 2011a), and the optimal controlled ventilation and infiltration was able to improve heating and cooling efficiency as well as to comfortably condition the indoor air quality (Moon, 2011b). In addition, the optimal control strategies for operating thermal-control systems have been widely investigated using state of the art control theories such as artificial intelligence (Moon & et al. 2014; Moon & Han, 2012; Moon, 2012; Moon & Kim, 2010). In particular, Kim has conducted a research on the relationship between the width-to-depth ratio (W/D), the surface-
to-volume ratio (S/V) and on the heating and cooling loads, in which heating and cooling loads were proportional to the W/D and S/V (Kim, 2013).

Energy savings and CO2 productions by the building is expected to be remarkably impacted by the building configuration. This study, thus, aimed to investigate the quantitative impact of morphological building variation on the amount of energy consumption for thermal conditioning. In order to accomplish the research objectives, the energy consumption pattern according to the changes in the number of floors, floor area, and space volume was analyzed for a single family house located in two different climate regions (cold climate: Detroit, Michigan, USA; hot and humid climate: Miami, Florida, USA). The numerical simulation method was applied for the tests and the findings of this study will be used as sound fundamentals for planning the energy-efficient and environment-friendly residential buildings.

RESEARCH METHODS

For calculating energy consumption by the morphological changes of building, a test building was modeled as shown in Figure 1, which has the typical features of a U.S. single-family house (U.S. Census Bureau, 2005). It is a two-story, south-facing, flat-roof building installed windows without shading devices and doors. An identical building was employed for the tests in two different climatic regions: hot/humid climate (Miami, Florida, USA) and cold climate (Detroit, Michigan, USA). The climatic conditions of Seoul, South Korea and of the two U.S. cities are summarized in Table 1. As Seoul, South Korea shows similar climatic conditions with Detroit, Michigan, USA, the outcomes for the cold climate will be more applicable to understand the Korean conditions.

The heat transfer coefficients of walls, roof, floor, windows and doors were 0.31, 0.16, 0.24, 1.64, and 2.00 W/m²K, respectively, which were lower value than standards for both Miami, Florida and Detroit, Michigan. Window-wall-ratio of envelopes was 0.15 in average with 0.20 for south, 0.10 for north, 0.15 for east and west. In addition, 0.30 ACH (air change per hour) was applied for ventilation and infiltration rate (Haysom & Reardon, 1998). As internal heat gains, four people and their hourly weighted heat and moisture gains (ASHRAE, 2004a; McArthur 2004), lighting fixtures with 5.38 W/m² for living area, 12.8 W/m² for storage, 13.8 W/m² for laundry, and miscellaneous with 3.2 W/m² for living area and 1.6 W/m² for laundry were applied.

For space heating and cooling, a furnace (26.70 KW for Miami, Florida; 31.67 KW for Detroit, Michigan) and DX colis (16.55 KW for Miami, Florida; 14.06 KW for Detroit, Michigan) were installed considering the normal and setback periods for energy saving based on the occupancy schedule. The set point temperatures in the normal and setback periods were 22.22°C (72.0°F) and 15.56°C (60°F), respectively, for the heating system, and 25.56°C (78°F) and 27.78°C (82°F) for the cooling system. The normal and setback periods were different among weekdays, Saturdays, and Sundays and holidays as shown in Table 2.

The eQuest3.63 numerical simulation tool, which is an acronym of the quick energy simulation tool and was based on the DOE-2.2 of by the U.S. Department of Energy (DOE) and Lawrence Berkeley National Laboratory, was applied for calculating the annual heating and cooling load and the energy consumptions according to the morphological building changes (eQuest, 2009). The validity of this program for further simulation has been confirmed in the previous studies (Kim & Moon, 2009; Moon & Han, 2011; Moon, Han, & Oh, 2011; Moon, 2011a; Moon, 2011b). The test period was the year 2012, and the TMY2 weather data were employed for the hot/humid and cold climates.

The test variable for analysing the energy consumption patterns were number of floors, the floor area, and the volume of space as summarized in Table 3-5. The basecase of the first variable was a two-story building as given in Table 3. Based on the base case, one- and three-story buildings were comparatively simulated. The total floor areas of three cases were identical while the areas of the walls, floor, and roof were changed. For example, compared to the basecase, the three-story building had a larger wall area but significantly smaller floor and roof areas while the one-story building had a reduced wall area but increased floor and roof areas.

The basecase of the second variable was a building with 224.5 m² (2,400 ft²) floor area as given in Table 4. With the basecase, five variations for the building area by the changes in width and depth were tested. No changes in the number of floors and in the building height were considered.
The basecase of the third variable was a building with a volume of space 303.0 m\(^3\) (21,600.0 ft\(^3\)) and five variable cases based on the change in building height were tested as given in Table 5. The other components such as building width, depth, and number of floors were not changed from the basecase.

![The test building.](image)

**Table 1. Comparison of Climate Conditions of Cities**

<table>
<thead>
<tr>
<th>Regional Factors</th>
<th>Seoul, Korea</th>
<th>Miami, Florida, USA</th>
<th>Detroit, Michigan, USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude (°)</td>
<td>37.55N</td>
<td>25.82N</td>
<td>42.23N</td>
</tr>
<tr>
<td>Longitude (°)</td>
<td>126.8E</td>
<td>80.28W</td>
<td>83.3W</td>
</tr>
<tr>
<td>Annual average temperature (°C)</td>
<td>12.2</td>
<td>24.4</td>
<td>9.2</td>
</tr>
<tr>
<td>Annual precipitation (mm)</td>
<td>1,344.3</td>
<td>1,419.9</td>
<td>828.0</td>
</tr>
<tr>
<td>Design temperature for heating-99% (°C)</td>
<td>-12.1</td>
<td>9.8</td>
<td>-15.1</td>
</tr>
<tr>
<td>Design temperature for cooling-1% (°C)</td>
<td>30.1</td>
<td>32.0</td>
<td>31.0</td>
</tr>
<tr>
<td>Heating degree day (°C*Day)</td>
<td>2,500–2,700</td>
<td>200</td>
<td>3,649</td>
</tr>
<tr>
<td>Cooling degree day (°C*Day)</td>
<td>600–800</td>
<td>4,198</td>
<td>626</td>
</tr>
</tbody>
</table>

**Table 2. Schedules for the heating and cooling System Operation**

<table>
<thead>
<tr>
<th>Days</th>
<th>Hours</th>
<th>Set-point temperatures (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Heating system</td>
</tr>
<tr>
<td>Weekdays</td>
<td>Normal 0:00–8:00, 18:00–24:00</td>
<td>22.22°C</td>
</tr>
<tr>
<td></td>
<td>Setback 8:00–18:00</td>
<td>15.56°C</td>
</tr>
<tr>
<td>Saturday</td>
<td>Normal 0:00–8:00, 14:00–24:00</td>
<td>22.22°C</td>
</tr>
<tr>
<td></td>
<td>Setback 8:00–14:00</td>
<td>15.56°C</td>
</tr>
<tr>
<td>Sunday &amp; holiday</td>
<td>Normal 0:00–24:00</td>
<td>22.22°C</td>
</tr>
<tr>
<td></td>
<td>Setback</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 3. Change of the Number of Floor**

<table>
<thead>
<tr>
<th>Number of Floor</th>
<th>Width (m)</th>
<th>Depth (m)</th>
<th>Walls (m(^2))</th>
<th>Floor (m(^2))</th>
<th>Roof (m(^2))</th>
<th>Total Envelope (m(^2))</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.3</td>
<td>12.9</td>
<td>163.1</td>
<td>223.2</td>
<td>223.2</td>
<td>609.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12.2</td>
<td>9.2</td>
<td>231.1</td>
<td>112.2</td>
<td>112.2</td>
<td>455.5</td>
<td>Basecase</td>
</tr>
<tr>
<td>3</td>
<td>10.0</td>
<td>7.5</td>
<td>283.5</td>
<td>75</td>
<td>75</td>
<td>433.5</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Change of the Building Area

<table>
<thead>
<tr>
<th>Floor Area (m²)</th>
<th>Width (m)</th>
<th>Depth (m)</th>
<th>Height (m)</th>
<th>Number of Floors</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>93.2</td>
<td>7.9</td>
<td>5.9</td>
<td>2.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>138.2</td>
<td>9.6</td>
<td>7.2</td>
<td>2.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>186.5</td>
<td>11.1</td>
<td>8.4</td>
<td>2.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>224.5</td>
<td>12.2</td>
<td>9.2</td>
<td>2.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>277.4</td>
<td>13.6</td>
<td>10.2</td>
<td>2.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>370.5</td>
<td>15.7</td>
<td>11.8</td>
<td>2.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Change of the Volume

<table>
<thead>
<tr>
<th>Volume (m³)</th>
<th>Width (m)</th>
<th>Depth (m)</th>
<th>Height (m)</th>
<th>Number of Floors</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>269.4</td>
<td>12.2</td>
<td>9.2</td>
<td>2.4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>303.0</td>
<td>12.2</td>
<td>9.2</td>
<td>2.7</td>
<td>2</td>
<td>Basecase</td>
</tr>
<tr>
<td>336.7</td>
<td>12.2</td>
<td>9.2</td>
<td>3.0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>381.6</td>
<td>12.2</td>
<td>9.2</td>
<td>3.4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>415.3</td>
<td>12.2</td>
<td>9.2</td>
<td>3.7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RESULT & ANALYSIS

Annual Heating and Cooling Loads

The annual heating and cooling loads were presented in Figure 2. In the hot/humid climate region, the cooling load (43,284 KWh) has taken most of the load (43,447 KWh). The heating load was just 164 KWh. On the other hand, the heating load (10,041 KWh) was significantly larger than the cooling load (1,910 KWh) in the cold climate region.

The total amount of heating and cooling loads was 4.3 times larger in the hot/humid climate compared to that in the cold climate. This is mainly due to the significantly larger cooling load in the hot/humid region. However, the total amount of annual heating and cooling energy will not differ as was the loads since the efficiency of the cooling system is normally higher than that of the heating system. That is, the increased heating load is directly proportional to the increased heating energy in the cold-climate region while the increased cooling load is relatively less effective for the increased cooling energy in the hot/humid-climate region.

![Annual heating and cooling loads for two climate regions.](image)

Figure 2

Amount of Heating and Cooling Energy Consumption According to the Morphological Variations

**Number of Floors.** The energy consumption pattern for different number of floors is compared in Figure 3. The amount of heating and cooling energy increased as the number of floors increased. This is due to the fact that as the number of floors increased, the roof and floor surface area, which had relatively smaller heat transfer coefficients, decreased while the wall area, which had a larger heat transfer coefficient, increased. The increasing ratio was 92.26 KWh/floor for heating and 1,010
KWh/floor for cooling in the hot/humid climate region. Compared to the basecase, which is two-story building, the one-story building saved 7.8% and 9.5% of heating and heating energy, respectively. On the other hand, the three-story building consumed 8.3% and 18.0% more energy for heating and cooling.

Identical to the hot/humid climate region, the amount of heating and cooling energy increase when the number of floors increased in cold climate region. Their amounts reached as much as 1,364.8 KWh/floor and 340.0 KWh/floor for heating and cooling energy, respectively. Compared to the base case, the one-story building saved 20.4% and 1.37% energy for heating and cooling while the three-story building used 15.2% and 5.8% more energy for heating and cooling. This analysis indicates that the low-rise building can be more energy efficient for a building with same area.

![Figure 3](image)

**Figure 3** Amount of heating and cooling energy by different building floor: (a) Miami, Florida, USA, (b) Detroit, Michigan, USA.

**Floor Area.** The energy consumption for the change of floor area is shown in Figure 4. The cooling energy significantly increased in the hot/humid-climate region as much as 41.83 KWh/m² while that of heating energy was 1.73 KWh/m². The case of the smallest building area saved 27.0% heating energy and 52.1% cooling energy. On the other hand, the case of the largest building area has consumed more energy by 40.2% for heating and by 50.5% for cooling. However, the amount of energy consumption per floor area was reduced as the floor area was increased. For example, the heating and cooling energy consumption was respectively 5.6 KWh/m² and 58.2 KWh/m² for the smallest building while those of the largest building were 2.7 KWh/m² and 45.94 KWh/m².

Similarly in the cold climate region, more heating and cooling consumed as the floor area increased. The increase ratio was 124.71 KWh/m² for heating and 6.61 KWh/m² for cooling. Compared to the base case, the smallest building saved 50.4% and 43.5% of heating and cooling energy, respectively while the largest building consumed 45.5% and 47.6% more energy for heating and cooling. However, similar to the hot/humid region, the amount of heating and cooling energy per floor area was decreased for the larger building. 230.21 KWh/m² and 10.17 KWh/m² were used in the smallest building while 151.25 KWh/m² and 7.50 KWh/m² were consumed in the largest building. Based on the analysis for the change of floor area, it can be concluded that the properly planned building area can be beneficial to improve building energy performance.

**Volume of Space.** Figure 5 compares the amount of heating and cooling energy for the change of space volume. Voluminal change was more related to the cooling energy increase in the hot/humid climate region as much as 14.6 KWh/m³. The amount of heating energy increase was 0.94 KWh/m³. Compared to the base case, the least-volume building saved 4.9% of heating energy and 4.5% of cooling energy while the largest-volume building used more energy as much as 14.0% for heating and 14.8% for cooling.

In the cold-climate region, the heating energy increase ratio was far more significant (37.7 KWh/m³) than that of the cooling energy (3.77 KWh/m³). In addition, the increase ratios were more significant than that in the hot/humid climate region. Compared to the basecase, changes in the heating...
and cooling energy for the least- and largest-volume buildings were 7.3% and 3.6% reductions and 21.5% and 10.9% increases, respectively.

However, similar to the analysis result for the floor area, the amount of heating and cooling energy consumption per space volume was reduced as the largest-volume building was applied. The amount of heating and cooling energy per spaced volume for the least-volume building was 2.53 KWh/m$^3$ and 39.94 KWh/m$^3$ for the hot/humid region and 135.91 KWh/m$^3$ and 6.57 KWh/m$^3$ for the cold region. Those of largest-volume building were reduced to 1.97 KWh/m$^3$ and 31.04 KWh/m$^3$ for the hot/humid region and 101.40 KWh/m$^3$ and 5.59 KWh/m$^3$ for the cold region.

![Figure 4](image1.png)  
**Figure 4** Amount of heating and cooling energy by different building area: (a) Miami, Florida, USA, (b) Detroit, Michigan, USA.

![Figure 5](image2.png)  
**Figure 5** Amount of heating and cooling energy by different building volume: (a) Miami, Florida, USA, (b) Detroit, Michigan, USA.

**IMPLICATIONS & CONCLUSIONS**

The objective of this study was to investigate the energy consumption pattern by the morphological variation of buildings. For this, typical U.S. single-family houses with different number of floors, floor area, and volume of space were numerically modeled and comparatively tested for two climatic regions; hot/humid climate and cold climate. Below is a summary of the study findings.

1. The cooling load was larger than the heating load in the hot/humid climate region while the heating load was larger than the cooling load in the cold climate region. The total amount of heating and cooling loads was 4.3 times larger in the hot/humid climate compared to that in the cold climate.

2. The amount of energy used for heating and cooling increased along with the number of floors since as the number of floors increased, the roof and floor surfaces having lower heat transfer coefficients became smaller while the wall area having a higher heat transfer coefficient became larger.

3. The heating and cooling energy increased as the floor area became larger. In particular, the cooling energy used in the hot/humid climate region and the heating energy used in the cold climate region predominantly increased.
(4) The amount of energy used for thermal conditioning was found to be proportional to the volume of a building. Identical to the change in the floor area, the cooling energy used in the hot/humid climate region and the heating energy used in the cold climate region remarkably increased. The increase ratio was larger in the cold climate region.

(5) The amount of energy per area or volume was reduced as the larger building was applied in both climate regions.

From the analysis, it can be concluded that the morphological variation in residential buildings has a direct impact on the amount of energy consumption for building thermal conditioning, and based on the findings, proper planning of floor numbers, size and volume need to be considered to advance the building energy efficiency. This study was conducted in only two cities in the U.S.; thus, performance tests for cities with other diverse climatic conditions and for Korean cities are warranted in the further studies. In addition, data analysis is required for the actual results from existing buildings.

ACKNOWLEDGEMENTS

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REFERENCES

Digital Process: environment analysis of intermediary spaces in the context of Brazilian modern dwelling.

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UFRGS, Brazil

Arnau Muñoz
Q_ARTS arquitetura

ABSTRACT HEADING

Europe of the beginning of the 20th Century: the desire to break away from the past and transform domestic spaces following the modern movement was clear. But there was a part of this production which sought to project the dwelling space based on traditional ideas. There are attributes of vernacular architecture, will be considered in the production of this time.

In this context we gave the focus of the study, looking at the veranda within the domestic environment of modern architecture in Brazil.

The veranda, as an intermediary space, was present in distinct eras of Brazilian housing, and together with this transformed itself of form, use and meaning.

The proposal of this investigation is to study the veranda as an architectural element, intermediary space and domestic living area, with the intention of identifying the distinct interpretations, from the formal and the principal elements from an environmental point of view. The analyses also look in which the domestic environment was incorporated into modern architectural production.

The second part of this investigation deals with the object of the study: the veranda as an intermediary space. This is undertaken by the presentation and analysis of case studies selected to represent the distinct compositional resolutions of the intermediary space in the modernism period (1930-1965). This study cases were also redraw, using digital tools which simulate incident solar radiation, thermal and lighting analysis. This helped to identify the solutions related to the comfort thermal and luminous of internal areas and observe the veranda as a step between interior and exterior, always considering different environments in this context.

INTRODUCTION

The Europe of the early twentieth century presented a panorama of major changes in different areas of life and knowledge, especially when it came to scientific and technological advances that eventually influenced, by new theories and concepts, the artistic production.

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Among other issues, modernity sought to change the way of think and project dwelling space, which in this research will be discussed from the point of view of the intermediary space of the veranda. At the same time, Brazil was looking to find their own ways in the artistic and architectural production.

Although it was clear the desire to break with the past and transform the domestic space guided by the ideals of the modern movement, there was a part of this production that wanted to design and build the living space based in tradition. There are a number of attributes of vernacular architecture, which will be taken into account in the architecture of this time.

**BASIC TYPES AND VARIATIONS**

Separate by typologies the intermediary space conforming by the veranda was appropriate from the beginning, when reduce to one type the complexities of an arquitectonic object it is not perceived yet. That is why the expression compositional resolution appears as a synonym for explaining these works, considering not only the intermediary space but other transition spaces from the home environment.

For this research, it was necessary to establish a selection criterion that could better represent each study case. Examples are sought in the major mass media of the time, looking at the theoretical and practical production of architects considering its importance for Brazilian architecture in this context. With this, it was proposed to look at these selected houses, from the point of view of the intermediary spaces.

Nine modern houses made between 1930-1965 are chosen to represent each compositional resolution.

After an initial reading and considering the before mentioned methodology, five basic formal design structures for the veranda in the context are established:

1. Veranda by Horizontal Plane extension
2. Veranda by Horizontal / Vertical Plane extension
3. Veranda by Subtraction
4. Veranda by Addition
5. Veranda by Pilotis

Identify and synthesize into five basic types allow us to separate case studies by groups of similar formal structures (with its variations).

With this, an understanding of the works is done, not only analyzing its formal qualities, but also the relations between the interior and the exterior, the permeability between these two environments and consequently the privacy levels.

Classify the works by typologies also help to identify when the veranda is designed with reference to tradition and (or) when is innovation.

At first, a look at the vast repertoire of modernity is done to find examples that accurately approach to the compositional resolution in its most essential form (or that could be "conceptually reduce" to one type). From this idea, the Mendes House by architect Oscar Niemeyer and Spartacus Vial by David Libeskind were selected to represent the way to design the veranda in their respective type.

On this same reflection, Osmar Gonçalves House by Oswaldo C. Gonçalves is chosen because of its formal simplicity and clarity to identify separately the volume of the main house and the intermediary space.

Guilherme Brandi House was a little different, because there were other houses that might better represent the idea of typology by extension of the horizontal and vertical plane. But although the house has a simple volume, some items such as the facade composition, awakened some curiosity to study.

Another reason for study this Sergio Bernardes house would be the variety of how this architect works the intermediary space in the domestic architecture.

It was slightly different the decision to choose Beira Mar residence. Being the typology that is closer to the traditional architecture (and this has never ceased to be part of the modern repertoire),
traces of modernity in both function and formal composition were sought to find in the examples. This work of Oswaldo Bratke was the most appropriate to represent the compositional resolution of the veranda, from a floping extension of the roof.

Trying to approximate (reduce) to one type, I realized that there were other reasons that led us to study these spaces, and is fot that, that other reasons were considered appropriate for the selection.

To represent the compositional resolution identified as horizontal plane extension, an easy reading was pretended. But looking at some Oscar Niemeyer works (both Canoas house and Dalva Simão house and another house build much later in France following the same concept), a different way to conform the intermediary space from the prolongation of the curved roof is perceived: the curve that characterizes the Brazilian architecture should be contemplated here.

Other reasons that led me to define the election were the different purposes of the veranda in the same house, like in Saavedra House, besides being clearly appropriate to represent the space generated through the inverted roof.

Magalhães Gouveia House would be the example more difficult to fit in a typology, but because of being a unusual roof design for the time (and that it is a proper addition) was choosed to do the analysis under this point of view.

Finally, we have the well known Carmen Portinho house by Reidy, for the way the architect incorpores (later) the veranda in the space liberated by the pilotis (without having the original function of pilotis).


STUDY CASES

In recent years, we have witnessed a technological revolution. The architecture is also a reflection of this situation, since there are new tools that have changed the way we work. Creation possibilities have increased, as well as accuracy. These new tools give new possibilities that allow more experimentation through simulation.

Using Ecotect software, we intend to analyze the works considered as representative of the different typologies for the varanda, pretending to find some answers related to both thermal and lighting, from the viewpoint of the presence of the intermediary space.

The analysis will be divided into five main points:

a) Shadow analysis

In this analysis we will proceed to simulate the cast shadow by the intermediary space in itself and
the adjacent room. With this analysis, it is intended to reach some conclusions as to verify if the situation of the veranda is determined by the solar orientation or because of terrain conditions.

### Figure 1. Saavedra house veranda shadow analysis

This house has 3 verandas (1-SO 2-SE, 3-NO). Each receives direct sunlight at different horaries due to its orientation, so each one can be enjoyed at its moment.

**Dalva Simão house** – The north facade is the only one that is connected to the exterior through big openings and it only receives direct sunlight during the winter, while in summer the roof extension that conform the veranda protects the interior from the direct sun.

**Guilherme Brandi house** - Receive the solar incidence relatively constant throughout the whole year, during the afternoon.

**Mendes house** - Receive morning sun, and is during the summer the highest exposure.

**Osmar Gonçalves house** – Incidence during the afternoon but the presence of the protection makes the veranda suitable to use.

**Carmen Portinho House**- The internal veranda receives the sun in the afternoon, and is in winter when the exposure is lower, while the external veranda (pilotis), that has the same orientation, receives direct sunlight in the early hours of the day too.

#### b) Solar radiation analysis

It will proceed to calculate the solar radiation in the intermediary space and the contiguous room, in the four year seasons between 7:00 and 18:00, expressed as average daily values. With these results we try to see the influence of the varanda on the adjacent rooms and its solar radiation.
We can observe that all of the houses receive more solar radiation during the spring and summer, except Dalva Simão house, that is because its orientation and roof design that makes autumn and winter when the higher levels of solar radiation (as we can see in the figure above).

c) Daylighting analysis

For the calculation of daylighting factors the Ecotect uses a geometric version of the Split Flux Method (BRE) and Design Sky values that are derived from a statistical analysis of outdoor illuminance levels. They offer a worst-case scenario that you can design to and be sure your building will meet the desired light levels at least 85% of the time.

This simulation will be made at 0,75m from the ground level, to see if the adjacent room to the veranda achieves the lighting levels established by the brazilian standard NB-57.
All of the residences achieve good levels of daylighting, making them suitable even for reading, except Osmar Gonçalves house, and Mendes house, because of the protection.

d) Sun incidence on facade analysis
With this analysis we try to see when the façade under the veranda receive the direct sun.

e) Sun protection on facades analysis
For this analysis, we propose to analyze the residences that have some kind of enclosure in the veranda to protect from the solar incidence. The simulation is done with the enclosure and without, so to compare the two situations, and verify the most efficient for each context.
Considering the Brazilian weather and the orientation of these spaces, we can see that the election of the architects about putting a protection is a good solution, achieving a solar radiation reduction between 60%-70%.

**CONCLUSIONS**

Being a quite extensive study, we can confirm that in the architectonic production of the modern Brasil there was a search for a design diversity of the intermediary space, as so the variety in functions. The design of this space was also to work with a second skin for the building, and in this way adapt the international language to the climatic context.

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Zero Energy Solar-House Model for Isolated and Environmental Protection Areas in Brazil

ABSTRACT
This study aims to analyze the benefits of applying a Zero Energy Building (ZEB) as an alternative to conventional buildings in isolated and environmental protected areas in Brazil as a hosting unit. A Zero Energy Solar-House (ZESH) is defined, considering its fabrication, assembly systems, use of natural resources and strategies for energy efficiency, leading to low environmental impact. A Brazilian scenery is described regarding energy feeding conditions in isolated areas, the occupation of protection areas, which are coveted by real estate market and touristic exploitation, and the consequent environmental impact. The ZESH harnesses sun's energy throughout a photovoltaic (PV) system for energy generation, solar collectors for water heating and passive environmental conditioning. Besides, it has local wastewater treatment and solid waste management systems, reducing the environmental impact arising from the occupants activities. To verify the ZESH model, this study takes the Ekó House Project, an efficient solar house prototype that meets the ZESH premises. This study results in accounting greenhouse gases (GHG) emissions reduction by the solar PV electricity generation instead of diesel generators. Results point out a potential to avoid up to 14.4 t of CO₂/year for one ZESH unit. It is observed that the ZESH contributes to enable the occupation of these areas by local communities or touristic exploitation with responsibility, low resources consumption and reducing the environmental impact when compared to conventional buildings, allowing these areas to develop on a sustainable way and benefiting local communities.

INTRODUCTION AND APPROACH
Brazils is a country known for its rich biodiversity, a coastline with almost 8000 km long and the world's largest tropical rainforest, the Amazon. Brazil is ranked fifth in the world in relation to territory and is the largest country in both South America and the southern hemisphere. Given the Brazilian territorial dimension, many communities are still living in isolated locations with restricted or no access to infrastructure such as electricity, sanitation, transport, health and education. To obtain minimum comfort conditions, these communities rely on isolated systems, when possible, mostly through diesel generators, which are very expensive, cause environmental impacts and affect population’s health (Di Lascio, 2009). Furthermore, the lack of infrastructure for sewage treatment and solid waste management
also cause environmental impacts such as contamination of soil and water courses (UNEP/UNWTO, 2005).

Besides the demand and impact of the native populations living in isolated areas, often these sites are targeted and exploited by tourism sector, which often causes similar impacts in environmentally sensitive areas. Some negative impacts can be associated with tourism, such as disordered development or inappropriate tourism scale to the area, causing degradation of the resource base and ecosystems; increasing pressure on the natural environment, with degradation or destruction of fragile ecosystems; impacts resulting from the implementation of roads, sanitation, airports, urbanization, and centers for final disposal of solid waste, that could cause negative environmental and social impacts (Brasil, 2009).

On the other hand, there are also positive impacts of tourism activities in isolated and environmental protection areas. Examples include the diversification of economic activities, employment generation and income for local communities; improvement in sanitation; proper handling and disposal of solid waste; improvement in water quality in water bodies and aquifers due to the installation of domestic wastewater treatment systems; possibility of expanding educational and environmental awareness programs (Brasil, 2009).

Many of mentioned impacts, positive and negative, have a direct correlation with the buildings for housing and lodging in remote locations and environmental protection areas. Thus, this study aims to analyze the contribution of a Zero Energy Solar-House (ZESH) model to reduce environmental impacts and improve the quality of life of local populations and in touristic areas, analyzing how architecture can respond to a demand for social and economic development with low environmental impact.

OCCUPATION AND ENERGY ACCESS IN ISOLATED AREAS IN BRAZIL

In Brazil the electric energy is provided almost entirely by the National Interconnected System - SIN a large hydrothermal system, with a strong predominance of hydroelectric plants. Only 3.4% of the country's electricity production capacity is out of SIN (ONS, 2013) mainly in small isolated systems located in the Amazon region. These isolated areas are almost entirely located in the Northern Region and are served by thermal generation (EPE 2013).

The regions without access to electricity are regions where enroll minors Human Development Index - HDI (Di Lascio, 2009). The lack of access to electricity limits the access of isolated populations to basic infrastructure. The power supply from the diesel is often unfeasible economically. With an intense demand for energy, the cost to universalize regions such as the Amazon under the current model, which is based in isolated fossil fuel thermal systems, supported by a strong allowance, can be very costly to the country. The cost of power generation from existing generation systems is made possible by the Fuel Consumption Account - CCC, which in 2006 reached R$ 4.5 billion, approximately 25% greater than the amount of R $ 3.6 billion approved for 2005 (Gonzalez, 2008). Is worth point out that in remote villages, away from the distribution grids, there is only power when the community itself manages a generator and a mini grid, with no public electricity service. Moreover, the diesel to power these engines is usually acquired at a very high price from traders (Di Lascio, 2009).

Besides the issue of economic viability, the diesel generators impact the health of communities supplied by this fuel. In many isolated communities lamps fueled by diesel oil or kerosene are used. This alternative, in addition to being inefficient (7.3 diesel lamps are needed to obtain the same luminance of a 9 watts compact fluorescent lamp) causes respiratory and ophthalmic diseases (Di Lascio, 2009).

The alternative of using overhead transmission and sub-transmission lines has a high rate of acceptance by planners. However, when observing the regional reality, is possible to realize that this type of infrastructure is too costly, or even ecologically unsustainable for many isolated areas (Di Lascio, 2009).

In Brazil, the Light for All (Luz para Todos) program was launched by the Federal Government in 2003 with the challenge of ending the electricity exclusion in the country and bring access to electricity to more than 10 million people (Programa Luz para Todos, 2009). In places where the electricity arrives, the population acquire consumer goods that they could not have when was relying on diesel generators.
Among those appliances, most families buy televisions, refrigerators, blenders, and water pumps (Seo, L. M.; Esteves, J. R., 2010). This also encourages these communities to diversify their economy. Some residents are opening their own business, sometimes associated with tourist activities, such as small hotels or restaurants. The access to electricity also favors public facilities such as health center and schools, improving the quality of life of these communities, allowing an improvement in healthcare services, education, and digital inclusion (Seo, L. M.; Esteves, J. R., 2010).

Many are the benefits obtained through the access to electricity. Thus, it is important to notice the suppressed demand for electricity in isolated areas and the importance of adopting energy efficiency measures together with the electricity access.

TOURISM IN ISOLATED AREAS

Considering initially mentioned positive influences that tourism can have on isolated areas, this study assumes the possibility to integrate environmental tourism activities with the native communities of such areas, collaboratively, looking toward a benefit to both parties. Naturally, this can only happen through a sustainable tourism way, which is the “tourism that takes full account of its current and future economic, social, and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities” (UNEP/UNWTO, 2005).

UNEP points out that tourism has the potential to contribute to local communities, especially the poor, through the development of local economy. The extent of the direct benefits to communities depend in large part on the percentage of tourism needs that are offered onsite, as product, labor, tourism services, and, increasingly, the "green services" on energy efficiency and water and waste management. UNEP also shows that over a third of travelers are in favor of eco-tourism and are willing to pay between 2% and 40% more for this experience. Tourists are interested in relevant social, cultural, and environmental issues for the destinations they visit, and are interested in supporting hotels committed to protecting the local environment (UNEP, 2011).

Programs of the Ministry of Tourism in Brazil define indicators of environmental sustainability for tourism in the country, this study assumes as relevant for a ZESH hosting unit the following indicators: water and energy consumption per guest, waste generation per guest and the percentage of solid waste recycled or sent to composting (Brasil, 2007). Furthermore, it is important to highlight the potential that such tourism development may represent with regard to education and environmental awareness, influencing its audience to adopt different habits to reduce consumption of natural resources and environmental impacts (Projeto Ekó House, 2012).

It is noticeable that the global tourism economy represents 5% of the Gross Domestic Product (GDP) and accounts for about 8% of total employment (UNEP, 2011). It is expected that the "greening" of tourism contribute to improvements in energy efficiency, water and waste systems, and enhance the potential for job creation in the sector with greater hiring and prospecting site and significant opportunities in tourism oriented to the local culture and the natural environment (UNEP, 2011). Thus, this study works with a scenario in which tourism projects focused on isolated and environmentally sensitive areas are developed along with local communities, promoting economic and social development, improving quality of life in an environmentally sustainable manner.

POTENTIAL OF SOLAR ENERGY IN BRAZIL

Brazil has favorable conditions for harnessing solar energy. Average annual irradiation varies between 1.200 e 2.400kWh/m²/year, values that are significantly higher than most European countries. As shown in Figure 1, the higher irradiation areas are the areas 5 to 8, in which the average productivity varies between 1.260 e 1.420Wh/Wp/year (EPE, 2012).
In addition to this, in locations without conventional electric service, photovoltaic (PV) systems constitute a viable alternative when compared with the extension of the power grid, diesel generation and other sources (Pinho, 2008). The problem lies in the economic conditions of people living in these isolated areas that cannot afford such systems. However, some kinds of subsidies may contribute on economic viability of PV systems in Brazil, such as reducing taxes on industrialized products, discount on income tax, specific lines of credit (EPE, 2012). Besides, the same way the government subsidizes diesel, subsidy for PV systems could increase, given the social and environmental benefits by the use of PV as an alternative to diesel. Subsidies could also be associated with sustainable tourism development.

ZERO ENERGY SOLAR-HOUSE BASED ON EKÓ HOUSE PROTOTYPE

A Zero Energy Building - ZEB is defined as a building that produces, through local sources – and preferably renewable ones – the energy it consumes, considering an annual balance (Torcellini et al, 2006). The ZESH modeled for this study integrates several systems to ensure its operation and functionality, comfort for the occupants, and low environmental impact. To verify this ZESH model it is adopted the Ekó House prototype. This prototype was developed by Team Brasil, a partnership between University of São Paulo and Federal University of Santa Catarina, and represented Brazil in Solar Decathlon Europe 2012 competition, held in Madrid.

Ekó House is taken as reference for this study because it meets the guidelines of a ZESH. In addition, the specific purpose for which the prototype was conceived is hosting in isolated environmentally sensitive areas in Brazil. The prototype can be connected to a local grid and could export the surplus energy to meet the demand of local facilities, like schools and healthy centers, or dwellings in these isolated locations. The ZESH strategies and systems are presented below.

Solar trajectory and orientation

The ZESH adopts a geometry that results in elongated facades facing north and south orientation, in order to obtain a better use of the sun throughout the year. In summer, when the sun is more directly overhead, radiation is less intense on north oriented facades than is east and west oriented facades (Southern Hemisphere). In winter the sun is lower, and radiation is more intense in north oriented facades than in east and west oriented facades, as shown in Figure 2. North oriented facades receive more direct solar gains in winter and less in summer than other facades.
Building envelope

Many strategies are possible to achieve environmental conditioning. The envelope elements of a ZESH have appropriate thermal performance, based on climate conditions of the location, through strategies such as insulation, the use of thermal mass and/or natural ventilation, among others. The Ekó House prototype has high thermal insulation levels and windows properly dimensioned and positioned, ensuring natural lighting and ventilation. This results in good comfort conditions with low energy consumption by integrating passive and active strategies. Simulation models indicate a Daylight Autonomy of 60% for the Ekó House prototype (Projeto Ekó House, 2012).

However, the climatic conditions vary widely, as well as the solutions to adapt the buildings to each climate. Considering this, a pre-fabricated structure made of modular panels is proposed to enables the use of different materials and, therefore, different strategies to the envelope, allowing an adaptation of the ZESH to different needs and conditions. Besides, the use of wooden pre-fabricated structural panels allows faster and cleaner assembly when compared to conventional constructions. Figure 3 shows this modular construction system.

Management and treatment of waste and sewage

Domestic waste, when correctly managed, can reduce significantly the volume of rejects to be discarded. Specific compartments for waste disposal can be integrated in the house design, both inside (for dry waste) and outside (composter). Adequate space for waste storage and organic material composting are essential and help the occupants to dispose wastes correctly.

In a ZESH there is a concern with the proper treatment and disposal of wastewater. Ekó House sewer system is decentralized. A composting toilet, which requires no water, is adopted. This technology accelerates the composting process to avoid odors and contribute to reduce fresh-water consumption (Projeto Ekó House, 2012). Through this system, it is possible to obtain an organic compound free of contaminants, avoiding the need for larger scale systems for treating such waste. The wastewater from shower, sink and washing machine, kitchen sink and dishwasher is treated by a natural system planted...
with hybrid filters macrophytes (wetlands). After this process the water can return to the environment without harming nature (Projeto Ekó House, 2012). Through such systems consumption of potable water is reduced. Furthermore, there is a system for collecting rainwater, which can be used as non-potable water or even be treated and consumed. Figure 4 illustrates such systems.

![Figure 4](image)

**Figure 4** (a) Systems for waste treatment and (b) composting toilet. (Projeto Ekó House, 2012)

Such systems for solid waste and wastewater management may waive the installation of large infrastructure for such purposes, and contribute to avoid contamination of soil and water bodies in areas where such infrastructure is often unfeasible.

**Structure for solar systems**

Architectural integration of solar system into ZESH is supposed to enable the profitable and advantageous use of solar energy into good quality architectural design. The architectural design can influence the performance of solar systems, allowing its integration into the envelope faces with higher levels of solar radiation and the proper arrangement of the system.

In Ekó House prototype, the roof surface is the suitable area for installing PV array due to its advantageous irradiation, is the face that gets higher incidence of radiation throughout the year, so it was used for the installation of solar systems. An aluminum frame, fastened to zipped metallic tiles supports PV systems and solar collectors. This structure is oriented to the North (considering the location in Brazil) and can be adjusted at different angles (10°, 15°, 20°, 25° and 30°). This ensures the efficiency of solar systems throughout the year and in different regions of the country, as shown in Figure 5.

![Figure 5](image)

**Figure 5** Structure for solar systems in the Ekó House prototype and adaptability to different Brazilian latitudes. (DIAS, 2014)

**Water heating system**

Heat water demand is associated to bathing, home appliances and in the thermal conditioning. Solar radiation can be harnessed to meet this demand in a ZESH. Solar collectors can be applied associated with electric shower, gas heating, electric boiler, among others. Flat plate solar collectors and evacuated tubes systems are examples of widely used collectors. The Ekó House prototype has four u-pipe solar collector (evacuated tubes) ensuring a high efficiency system.

The fastening system shall also be suitable to the envelope and it is important to provide appropriate space for reservoirs, passing pipes, and integration with other heating systems. Access for maintenance is also essential to ensure system performance.
**PV Solar System**

The solar PV generation on single houses can happen in two ways: with a system interconnected to the grid; or through a standalone system, and a storage system and/or additional generation is needed to ensure system's energy security. For the ZESH hosting unit is considered the adoption of a photovoltaic system associated to a battery bank and diesel generator set. It is important to notice that, in Brazil, the use of alternative fuels for electricity generation in autonomous systems has increased, as the use of biodiesel (Gonzalez, 2008) and even experimental processes such as gasification from the seed of the acai berry, which has a cost three times less than the cost of diesel per kWh generated (Freitas, 2006). Thus, it is possible to have a system that complements photovoltaic generation with a lower environmental impact.

The Ekó House prototype comprises 48 monocrystalline PV panels, with an 18.5% efficiency and 11 kWp of total installed capacity. Considering the location in Madrid, the PV system generates, on average, 1.790kWh/month, enough to meet the prototype energy demand, which is around 735 kWh/month, and still provide around 1.055kWh/month of clean energy to the grid (Projeto Ekó House, 2012).

In a ZESH the architectural design must contribute to a higher efficiency of the system, ensuring that PV modules are arranged on the sides of the envelope with better solar radiation, or even through the use of devices which adjust the tilt or track the sun, adapting the PV system for the orientation throughout the day and the year. Moreover, the architectural design should also provide suitable and safe conditions to place other equipment forming part of the solar PV system, as inverters spaces, in addition to providing space and appropriate protections for electrical wiring, terminals, fuses and circuit breakers. Cleaning and maintenance of the modules shall also be considered in the architectural design to ensure the best system performance throughout its lifetime. (Projeto Ekó House, 2012). ZESH solar systems are exemplified in **Figure 6**.

**Figure 6** Solar systems for a ZESH. (Projeto Ekó House, 2012)

The strategies adopted in ZESH confer a degree of adaptability, allowing the model to meet different demands. The full model, including all of its systems, responds to comfort standards of developed countries. However, the modular system allows beginning with the most basic systems to lower cost, and then install systems and expand square footage by attaching new modules. This modularity also provides flexibility in the final occupation, and this model can meet the demand for housing by local communities or units for hosting tourists.

**ENERGY CONSUMPTION IN A ZESH**

The data presented here are from the Ekó House prototype, which are fundamentally derived from computer simulations to estimate values of energy generation and consumption by this prototype over a year of operation. The energy consumption considers the prototype in Madrid. Is worth remembering that this prototype was designed to meet the standards for the use and comfort at developed countries due to the participation in the international competition Solar Decathlon Europe 2012. The project has been conditioned by the rules and requirements and does not represent the standard of living of the
largest part of Brazilian population, especially those living in isolated areas. Thus, it is possible to assume that the Ekó House average consumption, of 735 kWh/month, represents a situation of highest level of electricity consumption, even for hosting units in Brazil.

The energy generation was simulated on RETScreen® 4 software and consider both the prototype in Madrid and in some places in Brazil with potential to apply the prototype as a hosting unit in isolated areas. The PV system is the same of the prototype in all places, with 11 kWp. The slope and orientation of the system are changed in order to achieve better efficiency of the system for each location. These places are Manaus, in the Amazon region; Parati, touristic place located near Rio de Janeiro with some isolated communities; and Florianopolis, which is an island with some few isolated spots and less favorable solar radiation levels along Brazilian territory. Figure 7 brings energy balance data for the Ekó House prototype.

Figure 7    Ekó House energy balance considering different locations for energy generation. (Projeto Ekó House, 2012; RETScreen® 4)

It is possible to observe that even with a consumption that reflects standards of developed countries, the prototype proves more efficiency than homes in countries like the U.S., where the average consumption is 903 kWh/month for each residence (EIA, 2012). Besides, the PV system has a positive balance throughout the year. In addition, the modular structure favors the adoption of different materials for the envelope. This enables an adaptation to the climate of each region, providing appropriate comfort with lower energy consumption.

Regarding GHG emissions associated to energy generation, the emission factor for diesel oil generator set is 808 g CO₂/kWh (IPCC, 2007). When properly maintained, the generators have normal efficiency of 350 g/kWh, but most groups used in isolated areas in Brazil receives no adequate maintenance, increasing fuel consumption for about 500 g/kWh (Di Lascio, 2009). For the PV systems it is applied an average emission factor of 46 g CO₂/kWh (IPCC, 2012). Thus, avoided emissions by generating energy through PV system instead of diesel would be 762 g CO₂/kWh.

The table and graph in Figure 8 demonstrate energy generation and avoided emissions for one year of operation of a ZESH. It is worth noting that even a high energy consumption situation is compensated by the use of a clean source. Besides, the more efficient is the electricity consumption in ZESH units, more clean energy can be shared with local communities.

Figure 8    (a) Energy generation and (b) avoided emissions for one year of operation of a ZESH.

CONCLUSION

This study concludes that ZESH demonstrated and verified by the Ekó House prototype represents
an alternative to enable the occupation in remote and environmentally sensitive areas with low environmental impact, promoting access of local communities to a basic and autonomous infrastructure that can contribute to its socioeconomic development. This ZESH can be adopted both by local people and by tourist developments. It is a model that responds positively to environmental indicators set by the Brazilian government and to the concept of sustainable tourism defined by UNWTO.

The solutions proposed for this ZESH model, demonstrate the important role of architecture with regard to the use of the sun, both associated with passive strategies for greater energy efficiency, and for obtaining energy through active systems such as PV and water heating systems. In this way, it is possible to maintain comfortable levels for occupants without necessarily increasing energy consumption. The prototype also demonstrates that it is possible to associate to a housing unit some systems that ensure access to basic infrastructure for sewage treatment and solid waste, avoiding contamination of soil and water, and providing healthy and hygienic conditions for local and tourist populations.

Finally, the ZESH model presented in this study can be adopted and contribute to the mitigation of global warming by reducing GHG emissions, to an improvement in the quality of life of local populations in remote areas, to develop tourism in a sustainable way in environmentally sensitive areas, to promote socioeconomic development in remote communities, and also to educate different audiences (local and visitors) about how some appropriate systems and habits can reduce the impact of human activities on the environment.

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Development of Single Parameter to Rate Architectural Design for Green Building Certifications

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ABSTRACT

India is witnessing green building revolution. With rating schemes like LEED, IGBC and GRIHA in place and practice, building stakeholders are becoming more aware of sustainability issues. Issues under sustainability are clubbed under - Site, Energy, Water, Waste and materials and Environment. For most rating schemes across the world, Energy carries maximum number of points. High importance has been placed on energy because of current world energy scenario. Buildings are assuming critical role in energy dynamics. In India, building construction is taking place at a much higher rate than usual. Buildings consume tremendous amount of energy and this rate of energy consumption in buildings is also increasing. As per rating schemes, a comparison of energy consumption with base case or even an absolute figure of energy consumption is considered for ranking the energy efficiency of building. However, our traditional vernacular systems and passive features of building and design which impacted thermal comfort in response to climate are not accounted for in judgment criteria. At no place is the thermal comfort creation though spatial planning is emphasized, encouraged and rated. Therefore, in today’s time when relevance of energy efficiency is far larger than earlier, it becomes imperative that thermal comfort be achieved through spatial planning and efficiency of spatial planning be made judgment criteria for rating sustainability quotient of a building. Hence a common parameter needs to be evolved to quantify and judge achievement of thermal comfort through spatial planning and passive techniques in any building across the globe in context to the climate in which building is placed. This research is aimed at development of such parameter and its applicability in rating schemes. The paper details out the parameter, methodology to calculate it for any building and its relevance for building sustainability.

INTRODUCTION

India is a developing economy and building construction industry contributes substantially towards GDP, resource consumption, energy demand and pollution. (Tiwari P, 2001) Buildings therefore need to be constructed in a manner that they have least negative impact on the environment and maximize health and other benefits. (Arif M et. al, 2009) This fact has been duly recognized and that is the reason we have two successful Green Building Rating systems in our country – LEED-IGBC and GRIHA. (igbc.in, grihaindia.org) Both these rating systems are more or less similar to many other existing systems in the world. A green building is evaluated based upon certain themes which are almost the same; while
weightage of themes vary from one system to other. (Fowler K M et al, 2006) A comparative study has been done and the themes which are evaluated are- Site and transport, Energy, Indoor Environment, Materials and waste, Water and Operations and maintenance. (Liu G, 2010) Figure 1 clearly shows that maximum emphasis is laid on energy efficiency.

While credits are given for innovation and design, quantitative assessment of design for achieving energy efficiency doesn’t feature anywhere. (Happio A, 2008) For achieving a desired energy performance (whether prescriptive path is followed or performance rating method is followed) heads which are considered are- Building envelope, HVAC, Service Water Heating, Power, Lighting and other equipments. Building envelope focuses on Building Orientation, WWR, Fenestration design, type of glass being selected and opaque assemblies. (Fowler K M et al, 2006; Ballinger J A, 1988) Once mandatory requirements have been fulfilled, overall reduction in energy consumption is calculated and credits awarded. In all this, capability of architectural spatial planning in bringing in substantial reduction to energy consumption has totally been ignored. (Cole R J, 2012) It is like creating a problem through design and then solving it through employing better systems. The issue becomes more important for a country like India where we have a variety of climates. (ECBC, 2007) All our vernacular buildings present efficient examples where only with the help of spatial planning and materials (building envelope), thermally comfortable indoor environments have been created. This approach is a preventive approach and also affects the stakeholder behavior. (Plessis C et al, 2011) The need here is to develop a parameter by which we can judge the effectiveness of any architectural design in any climatic context (normalization) in bringing in energy efficiency. (Haas R, 1997)

THE CHALLENGE

Aim of this research is to develop a tool by which effectiveness of an architectural design in bringing in thermal comfort (which leads to energy efficiency) can be evaluated using a single parameter.

Taking a look at how energy efficiency of a project is determined through whole building simulation. A base case is established as per a standard document or code; say ASHRAE 90.1 in case of LEED or energy consumption baseline in case of GRIHA. (ASHRAE 90.1, ; ECBC, 2007) Architectural design remains same for base case and proposed case. Energy Conservation Measures (ECM’s) are then
added to proposed case (which mainly comprise of alternatives of building construction/ building envelope and mechanical systems) and performance of building is evaluated. In this entire process, potential of a better spatial design’s contribution towards energy efficiency is not being judged. Now if comparison of architectural design is to be done, what can be the base case? Since each building should respond to climate in which it is placed, the tool must have a tangible parameter through which effectiveness of architectural design can be evaluated.

**SOLUTION FINDING**

For evaluating effectiveness of architectural design towards creation of thermal comfort leading to energy efficiency, first solution that strikes is the use of thermal comfort indices for judging whether the design will be able to bring in thermal comfort.

**Existing attempts**

There are many thermal comfort indices which have been developed. To count a few popular ones- Effective Temperature, Corrected Effective Temperature, Operative Temperature, Equatorial Comfort Index, Bioclimatic Chart, Fanger’s PMV, Tropical Summer Index etc. (Koenigsberger et al, 1973). Each whole building simulation program is capable of generating thermal comfort data usually based upon PMV. But there are some problems with this assessment as it is not a clear indication of efficiency of architectural design-

1. The building design which is simulated includes all mechanical, electrical and other systems of thermal comfort creation. Thus a impact of only space design cannot be seen.
2. Even if simulation is intended to be done only for building (devoid of any mechanical/electrical installation), the results can be deceptive. For example in case of a building situated in a temperate climate like Bangalore; it would have more hours falling under comfort range as compared to a building (though efficiently designed) in an extreme climate like Jaisalmer.

Besides using thermal comfort indices, another factor called Degree Days is also being used. But Degree Days help to normalize the weather variation which are used for simulation rather than normalizing the building’s response to a climate (Eto J H, 1988).

Thus the issue is of normalization of building’s response to weather because a robust green building rating system has to be applicable to any part of the world. Hence thermal comfort indices cannot be used directly for assessing the effectiveness of space design for green building rating. A lot of efforts towards weather normalization has been made world wide. The prime objective however was to normalize weather to normalize variations in weather. The PRInceton Scorekeeping Method (PRISM)* which was initially created for calculating changes in energy consumption in a group of heated houses without cooling to individual houses (M. F. Fels et al. 1986), was developed to calculate energy consumption for individual house’s cooling and heating without integrating the two (C. L. Reynolds et al 1988). PRISM considers weather conditions as an important parameter while calculating energy consumption but does not regard architectural design as a parameter. Building Energy Analysis Consultant (BEACON) system was developed by Haberl et al (1988), which is capable of continuously monitoring and diagnosing the operation and maintenance problems identifying the causes of abnormal energy consumption. In most of the models it is considered that energy use in any other year is simply the product of the appropriate degree-days in this other year and the weather-invariant parameters (Joseph H. Eto, 1988). So, Joseph H. Eto (1988) developed a simulation model which accounts for temperature forecasting based on weather conditions of a decade. Radu Zmeureanu (1992) presented a new method for weather-normalization to be used for energy consumed from all types of energy sources and considers weather as a factor contributing to energy consumption but lacks consideration of architectural design.

None of the weather normalization techniques discuss the impact of architectural design on thermal
comfort normalized to the weather to which building is exposed. Hence a tool/parameter needs to be developed to evaluate thermal performance of building in response to climate it is being subject to.

THE PARAMETER

The parameter uses Tropical Summer Index as the selected thermal comfort index for assessing thermal comfort creation. TSI has been chosen as the parameter is initially developed to respond to Indian subcontinent and TSI is the accepted thermal comfort index in National Building Code. The parameter is based upon the ability of building to convert uncomfortable hours outside in a selected climate into comfortable hours inside. Similar attempt (not to create a parameter but in approach) was made to compare passively designed office buildings in Germany. (Jens U et al, 2007) More is the number of such hours, more is the efficiency of design. Also the design has to be able to retain outdoor thermal comfort (when possible) inside the building.

**Tropical Summer Index** (Sharma M R, 1986; SP 41; SP 07)

TSI is defined as “the temperature of calm air, at 50 percent relative humidity which imparts the same thermal sensation as the given environment.” The 50 percent level of relative humidity is chosen for this index as it is a reasonable intermediate value for the prevailing humidity conditions.”

Mathematically, TSI (°C) is expressed as

\[ TSI = 0.308T_w + 0.745T_g - 2.06\sqrt{V} + 0.841 \]  

(1)

Where: 
- \( T_w \) = Wet Bulb temperature in °C, 
- \( T_g \) = Globe Temperature in °C, 
- \( V \) = Air Velocity in m/s

For indoors, Globe temperature can be replaced with Dry-Bulb temperature. It is because Globe temperature takes into account Dry-Bulb temperature as well as effect of direct radiation also. Thus in the absence of radiation, globe temperature is almost the same as DBT. The environment was found comfortable between 25 to 30 TSI. It was tolerable up to 34 and down to 19. Lesser than 19, it was considered as too cold and beyond 34 it was considered as too hot. The TSI decreases further with increase in air velocity. (Table 1)

<table>
<thead>
<tr>
<th>Air Velocity m/s</th>
<th>Decrease in TSI in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>2.5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

THE PARAMETER – DUHOI

DUHOI – Difference in Uncomfortable Hours Outside vs Inside. As the title clearly states parameter is the difference of uncomfortable hours outside against inside in a given climate. The parameter compares thermal comfort achieved inside the building through design and construction to climate outside for all hours in a year. Each building design will have one single value for DUHOI. However DUHOI can be calculated for extreme seasons like summers in hot-dry climate, winters in cold climates depending upon the criticality. Calculation of DUHOI is demonstrated using analysis of hourly data obtained through whole building simulation of a traditional haveli residence in Sikar district of Shekhawati, Rajasthan, India (Agrawal A, 2006). Figure 2 shows typical ground floor plan of the case with open to sky courtyard in the centre and double layered rooms all around. All windows and walls are shaded by sun shades and thick walls are made up of brick set in lime mortar. Haveli is simulated for one year and hourly data (Dry Bulb temperature, Relative Humidity and air velocity inside) thus obtained is used to calculate TSI for all habitable spaces in the Haveli. Air velocity inside could not be obtained through simulation, therefore excel sheet was prepared as per NBC 2007 manually which were further
used to calculate TSI. After this DUHOI is calculated in the following manner-

DUHOI is calculated in a step wise manner as follows-

1. Calculate TSI for all habitable spaces and outside weather for entire year and all hours as per the formula of TSI stated above. (Table 2 – Because of limitation of space, calculations for only seven out of nineteen spaces have been demonstrated here)

2. Calculate the difference brought in TSI through design to each space. (When TSI inside is brought towards comfort it is counted as positive; if it is taken away from comfort it is taken as negative; based upon the comfort limits of TSI i.e. 25-30). (Table 3)

3. Overall difference brought in TSI (adding up positive and negative) is then averaged for the number of habitable spaces evaluated and number of hours for which evaluation is done. In case when TSI outside is already in comfort range say 29 and indoor TSI value also falls within comfort range say 25, such values will not be considered for calculations. (Table 3)

Table 2. Table showing Consolidated Thermal Comfort Data (TSI values) of Habitable Spaces in Simulated Haveli for few hours on one Typical Summer Day and TSI values Outside

<table>
<thead>
<tr>
<th>Time</th>
<th>Baithak</th>
<th>Rasodha</th>
<th>Chaughar a</th>
<th>Pauli</th>
<th>Sai T</th>
<th>Sai T</th>
<th>TSI o</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>31.8</td>
<td>32.1</td>
<td>32.1</td>
<td>32.5</td>
<td>31.1</td>
<td>32.6</td>
<td>34.3</td>
</tr>
<tr>
<td>1:00</td>
<td>31.6</td>
<td>31.9</td>
<td>31.8</td>
<td>32.2</td>
<td>30.9</td>
<td>32.3</td>
<td>33.6</td>
</tr>
<tr>
<td>2:00</td>
<td>31.3</td>
<td>31.6</td>
<td>31.5</td>
<td>32.0</td>
<td>30.6</td>
<td>32.1</td>
<td>32.8</td>
</tr>
<tr>
<td>3:00</td>
<td>30.9</td>
<td>31.3</td>
<td>31.2</td>
<td>31.7</td>
<td>30.4</td>
<td>31.8</td>
<td>31.0</td>
</tr>
<tr>
<td>4:00</td>
<td>30.7</td>
<td>31.1</td>
<td>30.9</td>
<td>31.5</td>
<td>30.3</td>
<td>31.7</td>
<td>30.2</td>
</tr>
<tr>
<td>5:00</td>
<td>30.4</td>
<td>30.9</td>
<td>30.7</td>
<td>31.3</td>
<td>30.1</td>
<td>31.5</td>
<td>29.4</td>
</tr>
<tr>
<td>6:00</td>
<td>30.5</td>
<td>31.0</td>
<td>30.8</td>
<td>31.4</td>
<td>30.3</td>
<td>31.6</td>
<td>30.4</td>
</tr>
<tr>
<td>7:00</td>
<td>30.9</td>
<td>31.3</td>
<td>31.2</td>
<td>31.7</td>
<td>30.6</td>
<td>32.0</td>
<td>31.2</td>
</tr>
</tbody>
</table>

Table continues for 8760 hours.
## Table 3. Table showing Difference of TSI Outdoors Vs Indoors for Uncomfortable Hours Outside

<table>
<thead>
<tr>
<th>Time</th>
<th>Baithak</th>
<th>Rasodha</th>
<th>Chaughara</th>
<th>Pauli</th>
<th>Sal 1</th>
<th>Sal T</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>2.5</td>
<td>2.2</td>
<td>2.2</td>
<td>1.8</td>
<td>3.2</td>
<td>1.7</td>
</tr>
<tr>
<td>1:00</td>
<td>2.0</td>
<td>1.7</td>
<td>1.8</td>
<td>1.4</td>
<td>2.7</td>
<td>1.3</td>
</tr>
<tr>
<td>2:00</td>
<td>1.5</td>
<td>1.2</td>
<td>1.3</td>
<td>0.8</td>
<td>2.2</td>
<td>0.7</td>
</tr>
<tr>
<td>3:00</td>
<td>0.1</td>
<td>-0.3</td>
<td>-0.2</td>
<td>-0.7</td>
<td>0.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>4:00</td>
<td>-0.5</td>
<td>-0.9</td>
<td>-0.7</td>
<td>-1.3</td>
<td>-0.1</td>
<td>-1.5</td>
</tr>
<tr>
<td>5:00</td>
<td>-1.0</td>
<td>-1.5</td>
<td>-1.3</td>
<td>-1.9</td>
<td>-0.7</td>
<td>-2.1</td>
</tr>
<tr>
<td>6:00</td>
<td>0.7</td>
<td>0.2</td>
<td>0.4</td>
<td>-0.2</td>
<td>0.9</td>
<td>-0.4</td>
</tr>
<tr>
<td>7:00</td>
<td>0.3</td>
<td>-0.1</td>
<td>0.0</td>
<td>-0.5</td>
<td>0.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>8:00</td>
<td>42.0</td>
<td>36.1</td>
<td>36.4</td>
<td>27.7</td>
<td>59.4</td>
<td>24.7</td>
</tr>
</tbody>
</table>

Table continues for 8760 hours.

\[
DUHOI = \left( \sum dT \right) / N * h
\]

Where
\[
\sum dT = \text{Summation of difference in TSI values of all habitable spaces to TSI Outside}
\]
\[
N = \text{Number of Habitable Spaces Analyzed}
\]
\[
H = \text{Number of Hours}
\]

### Conditions for calculation of DUHOI

Based upon logics and rationale, certain conditions have been set to calculate DUHOI.

1. Only habitable spaces are accounted for in this calculation. Service and ancillary areas such as circulation, toilets, machine rooms, kitchens etc are not included while calculating TSI and DUHOI.

2. If accessible open spaces have been provided in the building and schedule of activities suggests use of such a space during certain periods of the day, negative TSI difference values for those periods shall not be included in overall calculation of DUHOI. This is done in order to ensure that open spaces have been appropriately used. However for this option to be available, schedule has to be appropriately configured before simulating the building for its thermal comfort performance.

3. Building is assumed to be naturally ventilated without presence of any mechanical/electrical system in place. Natural ventilation schedule as per the practice of opening windows during summer nights and winter day has been included.

4. Energy consumption for lighting and heat gain due to lighting is neglected for calculation of thermal comfort.

5. In case of large building complexes, such as campuses, mutual shading and local wind pattern of building complex will be accounted for in simulation.

Graph 1 plots hourly thermal comfort data for a building. It can be seen that building is able to bring about positive changes in environmental conditions. Following the steps mentioned above to calculate DUHOI, difference brought is calculated using formula and the final value of DUHOI for the period simulated is calculated to be 1.41. This implies that building is able to convert uncomfortable hours into comfortable hours inside by 1.41 TSI on an average.

To know the performance of building in different seasons, seasonal DUHOI can also be found out and it can be ascertained that improvements are needed to bring down the temperature or to heat up a space. For the same building simulated here, DUHOI (summer) is 1.99 while DUHOI (Winter) is 1.32. This gives a clear picture that this building performs better in summers as compared to winter.
Advantages

DUHOI is a robust parameter which can be applied to any building in any climate and it has many advantages-

1. The need for a virtual base case has been eliminated. Weather of a place where building is situated acts as the reference and building is supposed to respond to weather only.
2. In this manner, any building situated anywhere in the world can be compared without making comparison of scale of building, typology and systems involved.

Application to Green Building Rating Schemes

Before DUHOI is included in rating schemes as a credit or a prerequisite, extensive base work needs to be carried out. For all climates of India and world, finest examples of passive designing (traditional and contemporary) can be picked up and DUHOI can be calculated for them. Based on this an acceptable range can be set for each climate and credits can be awarded. This would ensure that any building which is intended to be constructed as green building must have an architectural design which responds to climate of the place unlike current scenario. This way, newer green buildings based on DUHOI parameter will look local and respond appropriately to climate.

CONCLUSION

DUHOI is a robust and universal parameter which can be applied to green building rating systems. This would help in utilizing full potential of architects in making green buildings which would respond to climate as the first step towards building green. This move will have substantial effect in reducing energy consumption by buildings throughout the world.

GLOSSARY OF HINDI WORDS

Haveli – Traditional courtyard type residence  Baithak - Living room
Chaughara - Largest bedroom in the corner of house  Rasodha - Kitchen
Pauli - Transition space from outer court to inner court  Sal - Bedroom/ Room

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Towards new design tools for integrating environmental criteria in the design process of architectural and urban projects in developing countries

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ABSTRACT

Cities are complex systems rapidly evolving in a context of strong interweaving between problems and solutions especially in developing countries. The architectural design and the city management processes are renewed by the eruption of sustainable development. These processes are multi-scale: new geographical, temporal and political scales are emerging, calling for new tools for monitoring architectural and urban environmental changes, for implementing comprehensive plans, or for communicating between practitioners. Number of communities in developing countries has taken initiatives to develop tools based on sets of sustainability indicators. But are these tools really helpful during the architectural design or the urban management processes characterized by complexity, fuzzy or lacunar data, various time and space scales and multi-actors decisions? We will demonstrate in this paper, that these systems, aiming at “a posteriori” diagnosis, cannot be used directly during these fuzzy processes, especially during their early phases very critical with respect to solutions. By adjoining them multicriteria decision support techniques, they may become powerful tools for decision support. Architectural and urban designs may be evaluated using a set of weighted environmental criteria and methods to aggregate the various dimensions involved. Some Electre methods based on the comparison between pairs of solutions have been successfully used in that sense. A step further away may be performed from decision to evaluation support tools, by comparing ongoing urban designs against convolutions of systems of practitioners’ values. This “value focused” approach, combined with the Electre-Tri method has been successfully integrated for evaluating the performance of urban projects, according to their distance to various user-defined systems of values.

INTRODUCTION

The urban development is characterized by various changes and mutations. The environmental impacts of urban designs may be numerous, diverse and sometimes conflicting. The magnitude of the relationship between these different impacts shows potential dangers from decisions related to a family of impacts: solving a problem often creates another.

In this context, a large number of communities have taken initiatives to develop a new understanding of how urban systems work and how they interact with their environment. These tools are mostly based on sets of sustainability indicators (Mori 2012). They are supposed to help urban practitioners to design and to implement comprehensive plans (Alberti, 1996; Briassoulis, 2001; Brandon, 2005). At the same time, specific international programs have been created to develop and
harmonize urban indicators worldwide, such as UNCSD (Stiglitz, 2009), OECD (OECD, 2011), (UNU, 2012).

Simultaneously, the urban decision is renewed by the eruption of sustainable development, and virtually all communities share concerns for the state of their environment.

The architectural design and urban planning processes are critical to global sustainability, but there is no consensus on how to model this sustainability (Owens 1986; Newman and Kenworthy 1989; Adolphe 1995; Tanguay, 2010). During these processes, practitioners are looking for solutions based on “reasonable compromise” between non-homogenous constraints instead of collecting optimal but partial answers: a new culture of the consensus that aims at "un-optimizing" urban decisions.

A rising information level characterizes this process. In the early stages, the information available is low because it is impossible to apply straightly all the constraints: design is a wicked problem (Conklin, 2005). Indeed, the early design stages of these processes have a hegemonic weight related with fundamental architecture, urban and technical choices. At the beginning of the process, the importance of design choices is maximum; at the end, it is minimum. This context of problem solving has been baptized “the paradox of the architectural or urban design process” (Adolphe, 1995) - see figure1.

![Figure 1](image)

Figure 1 The paradox of architectural and urban design (Adolphe, 1995)

Therefore, the potential consequences of design support tools are highest in the early stages. They should rely on simplified but robust information on the design. The architectural design and urban planning processes are lacking for decision or evaluation support tools, especially during the critical configuration phases for the modeling process of cities. One of the main difficulties on building these tools rises with the simplification needed for modeling various urban elements and their relationships. In that sense, new research approaches have recently tried to fill this gap by improving validation on test cases, by integrating ranking between architectural variations in real practices (Adolphe, 1995; Fontenelle, 2012), or by a better integration of demand side management (Dubois, 2013). Therefore, it is necessary to develop assessment tools based on simplified models compatible with the level of information available during the various stages of the design process.

SYSTEMS OF INDICATORS FOR THE SUSTAINABLE DEVELOPMENT OF SETTLEMENTS

In this context, the most promising family of urban evaluation tools are based on systems of indicators able to integrate a wide variety of problems and the complexity of their interrelations in the space and the time (Adolphe, 2001; Josza, 2005; Adolphe, 2008; Adelle, 2009). The sets of urban indicators contribute to the building of systems in which development and environment are completely integrated. But currently these sets of indicators still remain very heterogeneous in terms of purposes as well as content.

But what is an indicator? Generally, indicators quantify information by aggregating different and multiple data. In short, “indicators simplify information that can help reveal complex phenomena”
(TERM, 2001). Compared to raw data used for example in the urban databases, single indicators are used to model the reality into decision support tools. These indicators would provide a representative picture of environmental conditions; being scientifically sound; being simple and easy to interpret; providing a basis for comparisons at various scales; integrating a target or threshold against which to compare environmental quality and performance (Alberti, 1999).

Therefore, how to build proper systems of indicators that exceed thematic, alphabetic, or just concatenated lists? How to interconnect indicators in systemic approaches characterized by strong interactions between subsystems?

Some characteristics of these systems are fundamental: 1) an indicator means nothing out of a system: there are strong links between indicators in a system; 2) a system means nothing elsewhere referring to fundamental issues. It is therefore necessary to build different systems for regulation compliance, decision support, simulation and evaluation; 3) a system means nothing without mixing physical, social, political scopes: each geographic scale or each actor may develop a specific system of indicators.

The first stage of building these tools is typically a structural stage. Some models have been developed to structure these systems: the PSR model "Pressure, State, Response" (RESPECT 2000) ; the DPSIR model : "Driving forces, Pressure, State, Impact, Response" (TERM, 2001); the DPSEER model : "Driving forces, Pressure, State, Exposure, Effect on Humans, Response" (Webster, 1996).

The second stage of constructing these indicators sets may rely on the aggregation of indicators into single index or composite indices. In the context of the sustainable development, one can say that this aggregation makes it possible: 1) simplifying, by reducing complexity, or simply reducing a great number of data into a smaller number of useful information for the evaluation; 2) quantifying, by modeling, simulating, and by building a comprehension of the phenomena and stakes; 3) communicating, by helping the decision makers to give their own opinion within the framework of a negotiation, an equitable exchange.

As a conclusion, the indicators are now popular and widely used in all organizations working on sustainable development. A consensus appears at least on the general characteristics of indicators. A good indicator needs to condense meaningful information into simplified, relevant, reliable, transparent, workable, synthetic, robust and correctly interpreted at the appropriate geographical scale. However, construction of current indicator systems suffers from serious methodological flaws.

The most important limitation of the current systems may be related to their construction method: these systems are based on a bottom-up approach, starting from the available data, without a global reflection about the goals to achieve. As a result, their gain to improve sustainability performance has been often limited (Alshuwaikhat, 2002; Seabroke, 2004).

The implementation of exhaustive top down approaches, starting from the fundamental concerns of the users of the system, to format and select the indicators could solve this problem. However, it should then iteratively combine with operational bottom-up approaches to reach a good compromise.
To answer to this combined approach, we have moved off from this classical exercise of indicators concatenation, and to propose real decision support tools of the sustainable evaluation for urban projects, within an innovating morphologic and structural framework. This framework is based on the implementation, of multicriteria aggregation techniques. These tools allow to compare "the non-comparable", while implementing non-commensurable criteria or criteria which can get into conflict.

The main methods of multicriteria aggregation are primarily interested in alternatives or actions (Roy, 1985). They aim at putting forward the one or the better decisions to be taken, in comparison with the preferences of the decision-maker. These decision support tools are based therefore on a relative assessment: projects are compared to other ones in terms of sustainability performances. Some approaches are based on ELECTRE type methods, for ELimination and ChoicE Corresponding To Reality (Roy, 1993), and pairwise comparisons made without trying to bring the various criteria on the same scale value. They are able to manipulate complex concepts such as indifference, preference or veto thresholds to cope real-life decision context (Rousval, 2005; Fontenelle, 2012).

The multicriteria evaluation contributes to an exhaustive and synthetic census of information, while clarifying the results produced by the collections of indicators specific to each family of themes. The multicriteria evaluation is composed thus of two essential and indistinguishable aspects: the structuring model of information on the one hand and, the relative weighting of these criteria on the other (Adolphe, 2006).

The methods of partial aggregation are different from global aggregation ones mainly due to the three following aspects:

1) Data: evaluations of the indicators must be clear, probabilistic or fuzzy.

2) Operators of aggregation: the comparison of the evaluations of the criteria for each action can be performed by simple or complex fuzzy function (probabilistic or fuzzy evaluations). The over-ranking relationship between actions is established when a majority of criteria is better for an action than its competitor. The relations of indifference and incomparableness are also defined. The whole preference relations correspond to the criterion of over-ranking which constitutes the value of homogenization. Each preference relation represents the direction and the intensity of the preference between two actions.

3) Systems of preference: the decision makers define the weighting coefficients for the families of sustainability criteria.

This approach has been successfully used to evaluate the urban sustainability performance of urban designs at the district scale, in the SAGACITE Project (Adolphe, 2002). This project addresses the environmental influence of urban morphology at the neighbourhood scale. This work puts into perspective, objective indicators built from in situ measurements and environmental modelling, and subjective indicators related the perception of the users. The project is based on the simultaneous consideration of three concurrent areas: building, vegetation and transport. This resulted in the production of a decision support tool based on a Geographic Information System (GIS). This computing platform permits monitoring of existing urban projects (an “environmental dashboard”), comparison (intra or inter-urban) between sites, and scenario for urban spaces, taking into account environmental issues.

But the main limitations of this family of decision support tool are linked to the fact that they are based on relative assessment linked to partial two by two evaluations of actions. For most of the architectural and urban projects, practitioner are more obviously looking forward to compare their project with generic goals linked for example to its sustainability: this represents the shift between decision and evaluation support tools.
FROM DECISION TO EVALUATION SUPPORT TOOLS

“The evaluation process aims at quantifying and/or qualifying a system, thanks to all necessary information for building criteria allowing to attain the objectives concerning this system and pertinent in the framework of a wider activity but previously identified”. Therefore the evaluation consists of “an assessment using criteria for achieving objectives or the degree of proximity of a project compared to a norm” (Abernot, 1996). Therefore, we distinguish the decision, for which we will compare several projects, based on a "relative" comparison (Roy, 1993) and the evaluation for which we will compare a project to goals or user’s value systems, based on “absolute” comparison (Keeney, 1996).

The main motivations of these value focused approach are: 1) building a system of values as a reference for the evaluation; 2) knowing the reference system to understand the result of the evaluation; 3) explaining the system of values to justify the result of the evaluation; 4) communicating the system of values to build a consensus; 5) encouraging debate around the result of an evaluation; 6) monitoring the evolutions of the reference system for understanding the evolution of the evaluation.

In a first stage, we give privilege to the top-down approach, by defining the decision-makers' preoccupations for structuring the system of indicators, and by using a formal reconstruction system for the indicators selection.

When the object represents a major issue for the decision-maker concerning his position, it is a final objective, as opposed to the objective as a mean, which does not represent an end by itself for the decision-maker, but a means to reach a final objective. A strategic objective is a final objective that has the characteristic to be invariant during the time. A final objective can be decomposed; a means objective can be linked to various other ones (Fig.3-4). It is therefore possible to construct a structure (or hierarchy) of objectives for each decision-maker. To build the most exhaustive possible body of objectives, it is necessary to interview people representing each user group (Fig.5).

This value focused approach offers numerous advantages. It allows an interdisciplinary approach where the definition and the ranking of objectives structure the construction of the indicators system. It allows balancing objectives by propagating the weight in the hierarchy. Non-experts may use it to question and to structure the problems. At last it is easily applicable to wider contexts, such as sustainable development. The interviews are conducted in two stages. The first stage aims to define a first body of objectives. One lets the interviewee speak while asking non-directive questions. Taking some notes allows, then, to do a first census of objectives that appears along the interviewee speech. The second stage aims to explore the objectives that emerged from the interviews in the first phase. Thus, one can relate a means objective to an end objective while asking the question "Why this objective?". From a final objective, one can construct his superior hierarchy (bottom-up). To explore in depth the tree of the final objectives (top-down), one may ask "why this objective is important?" or "which facets of this objective are important?" (see Figure 5).
The last but not least advantage of the value focused approach is "the union" of several hierarchies, into a generic structure, while using a specific algebra (Keeney, 1992). One can thus structure the design of the system of common indicators for a population of decision-makers (Figure 6).

At last, we take into account the preferences of the decision-makers while using a multicriteria support method, the Electre-tri method (Yu, 2003). By using this method, it is proposed an ordinal evaluation of each objective.

This approach has been successfully used to evaluate the performance of urban sustainability of urban projects, in the PIE Project and to evaluation of sustainability of urban districts in developing countries (Adolphe, 2006). The "PIE" project aims to establish the specifications of a tool for the assessment of the environmental status of a geographical area selected in relation to the pressures (air, noise, water and soil pollution, impacts on space, on landscape, on fauna and flora, waste) enforced by the transport system. This tool for urban decision makers is based on sets of indicators structured by type of pollution. It enables a multi sectorial diagnosis from an aggregation of some (or all) of these indicators. These sets of indicators are based on two concurrent approaches: a top-down "back casting" approach based on concerns or objectives of decision-makers, and a bottom-up approach which starts from the operational constraints of the system. This tool uses multicriteria decision techniques allowing aggregation of basic indicators in sectorial indicators, and the construction of an operational approach for aggregating preferences of users of the system. This tool allows comparing the environmental impacts of different transport modes, technologies and policies.

The interests of this approach as well are numerous: the possible use of thresholds to consider the inaccuracy/uncertainty, the adequacy with the sorting approach, the comparison of the alternatives to a stable reference, the modularity, and finally, the incomparableness and no-compensation. The disadvantages are a weak readability and the lack of transparency. Possible applications of this method are the creation of a “global sustainability indicator”, the support of activity-based “participative democracy” and the evaluation of “local and personalized follow-up”.

CONCLUSION

Our work proposes a methodological framework for the decision and evaluation support of sustainable architectural and urban projects. The opportunities to use decision and evaluation support tools in the design or in the management process of architectural or urban projects are numerous. By simplifying a vast amount of information into a simple form, they make it much easier to read and
understand complex reality and to help a new understanding of how urban systems work and how they interact with sustainable development at various scales (Alberti, 1999).

In a context where urban policymakers are, more than ever, challenged by the task of redirecting urban mutations into a more sustainable way, these new approaches are very challenging because they allow a good integration of the cultural or social dimensions of development. There is no point in building highly efficient cities, if they are not appropriate by their users, or if the spaces created do not meet their expectations or the representations of such places. “Sustainability, at the community level, is perceived as a holistic concept and not simply the sum of the environment, economy, society, and culture. The links among these components are established by the people and expressed in terms of people needs and aspirations” (Alberti, 1999).

We think that introducing these techniques into the design management process of architectural or urban projects brings new opportunities such as: 1) Avoiding to “bury” the practitioners in a proliferation of often conflicting and specialized information and constraints: help them keep up controlling the process that they are expected to master, so forth avoiding a divorce between design and production; 2) switching to a strategy of design “optimization” to a strategy of “reasonable compromise” between various constraints.

On the contrary, the limits and threads of these approaches are mostly linked to the context of sustainable urban development process itself. The decision is very complex and strongly context-related. Each new project is for example leading to a new set of indicators (Tanguay, 2010), and new user defines its own system of values (Kahn, 2006). These new tools are not designed for an automatic design but rather as a decision support in a specific governance context (Litman, 2011).

We have successfully integrated these various techniques to evaluate the performance of urban projects in developing countries in terms of sustainable development (Adolphe, 2006). The next step is to interbreed various themes simultaneously, such as building and transportation (Santos, 2013). Another development envisioned is to focus on the robustness of these systems, by testing the resilience of the threshold measurements. Even though this assessment presents difficult tasks, it is an unavoidable step in order to translate that new knowledge into effective policies.

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Eco building schools in remote places | Case study: Cunene, Angola

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ABSTRACT

The need for more environmentally responsible practices is unquestionable in the scientific community and the construction is responsible for a large part of energy consumption and consequently for the environmental degradation. It is the architecture’s duty to modify this panorama, intervening in a way that is conscious and alert, both environmentally and socially, following the development of societies and their emerging needs. This paper aims to develop an intervention strategy, in an underdeveloped region, more specifically, in Cunene in southern Angola, projecting a model of pilot schools, low cost and with low incorporated energy costs, duly adapted to the climate specificities. The Cunene is an Angolan region which obtained most of their livelihood over time with the livestock. However, like so many other places, it lacks of educational structures that enable its development and that provide higher levels of learning to the community. The project includes the use of local ecological materials such as earth and bamboo. Enabling people to participate in the entire construction process, by moving knowledge to enable the development of the local economy, particularly in the production of adobes. Therefore, the community and the man have an active key role throughout the project. The land is withdrawn from a nearby project site, by appeal to human labor instead of the machine. In the case of bamboo, it is anticipated planting a species that best suits the local climate and construction. The whole proposal is designed so as to respect the three basic pillars of sustainability: economy, environment and society. Allowing these locations to progressively develop and so that social justice can be found.

INTRODUCTION

The present case study is located in the Cunene region, in the southern border of Angola. This choice is directly related to the evident lack of educational infrastructures in the region, as well as the high number of children outside of the school system and with the conviction that it is fundamental to invest in education in order to develop populations that reside in remote locations. It is essential to the decrease of illiteracy among its people and vital to the local and regional development.

According to various studies, most of the poor population on earth lives in rural settings. In this sense, the education of the population becomes extremely important and the community must participate in this process, becoming the foundation of the local development, while promotion civic and educational developments.

GENERAL FRAMEWORK OF THE ANGOLAN TERRITORY

Angola is located on the west coast of Southern Africa, bordered by the Republic of Congo to the north, to the east by the Democratic Republic of Congo and Zambia and Namibia to the south, making a land border of 4690 km. To the west it is bordered by the Atlantic Ocean shipping line corresponding to 1650 km long. (1)

The Angolan territory corresponds to a total area of 1,246,700 km2, dividing them into 18 provinces, which in its turn are divided into 163 municipalities subdivided into communes.
The official language is Portuguese, spoken mainly in the cities. However, there is a panoply of other languages used by its inhabitants, being distributed by well-defined geographical areas. The better-known languages are Umbundo, Quimbundo and Quicongo.

According to the last census in Angola, which dates from 1992, it was estimated at 10.31 million inhabitants, mostly from rural areas - about 6.159 million inhabitants - which corresponds to 59.7% of the total population.

The oscillations of the population have always been a constant in Angola, especially during periods of civil war, that caused constant displacement of the population, migrating to cities or emigrating to neighbouring countries.

Currently there is a steady exodus of younger people from rural to urban areas, in search of better quality of life, particularly due to the growing job search. So it becomes even more evident the need for emergent interventions in remote areas, unprotected and devoid of infrastructure resources, as well as becoming increasingly depopulated. This migratory population exacerbates already serious problems of uncontrolled growth in the suburbs, where extreme poverty is evident, showing serious housing, health, employment and illiteracy issues.

Several studies show that the majority of the African population is young with low education levels, a result of various factors - including the Civil War action - as well as economic and social factors, on which the action of the state is not sufficient to meet the current needs.

The climate in Angola is divided, generally, into two seasons: wet and hot summer, corresponding to the months from October to April and winter (known as cacimbo), corresponding to the months of May to September, dry with lower temperatures.

The morphology of the Angolan territory develops about 60% in highlands, which naturally influences regional climates. Cumulatively, we can see the influence of the cold Benguela current and the coastal breezes. All these factors are responsible for small local variations in climate, although the average annual temperature is high throughout the country.

**Education in Angola**

Focusing this document in our area of research: primary schools in remote environments, more specifically in the Cunene region, we realize the organizational logic of education in Angola.

The Angolan education system is divided into three levels: primary, secondary and tertiary. However, in order to reduce the deep levels of illiteracy and lack of education of a large population, noted mainly in rural areas, the subsystem of adult education emerged.

According to Trade and News Magazine, "22% of Angolan children of school age are out of school in urban areas. In rural areas, the estimate is 44%. Failure at school measured by the sum of the rates of repetition and dropout is extremely high, reaching figures of around 50% for 1st and 2nd grades. 42% for 3rd level of Regular Education. Regarding the dropout rates, the statistics presented indicate that 12.5% of children drop out of school in urban areas and 25% in rural areas (...) " (3)

It is noteworthy that the few schools operating in remote areas, hold serious construction problems, not being provided with the basic conditions for an adequate level of education. Many of these classrooms are constructed using solutions of "wattle and daub", using only local materials easy to obtain. However, the lacks of constructive knowledge, either endogenous or technical, have limited the quality and number of suitable classrooms.

Serious socio-economic problems, seen in this country, such as extreme poverty and social inequality are due largely to an inadequate education system, the result of prolonged civil war, and also due to the lack of physical structures and educational resources that enable a way of integrating active citizens in local and regional growth.
The lack of adequate primary schools subsequently condemn the formative and educational capacity of its citizens and inherently stall the growth of the country.

In remote or rural settings, this reality accentuates migration to the big cities, forcing this population to survive in the suburbs, deprived of employment opportunities or minimum health conditions, whereas if provided with adequate training in their unique environments they could secure better livelihoods and resiliency within their communities, thus enabling local development of consistent and sustainable manner as an alternative to migration to cities.

IMPLANTATION OF THE PILOT PROJECT

The proposed project intends to develop as a model for regions with the same geomorphological, social and human characteristics, duly adapted to the constructive specificities of each place.

It is located in the Catholic Mission of Okaunatoni in Cunene, southern Angola. And due to its difficult access, where most of the roads that connect to the mission are made of sand and because it is situated about 30 kilometers from the nearest locality - Xangongo, the resources and labor become scarce and difficult to obtain; there is an absence of construction companies operating in the local, or the ones that eventually mobilize to these places present honorary fees incompatible with the most disadvantaged populations. These factors, in addition to those that will be mentioned later in this article, reinforce the need for a project made by people, using locally available materials and easy construction.

The considerations / limitations with the surroundings of the project, with local populations or climate conditions are some of the criteria to be taken into account in formal conceptualization of the design solution. We intend to develop a solution that is functional, educational and acts as an empowering tool for a constructive change paradigm based on locally available materials.

We intend to use locally extracted materials, with local labor, and give men and women leading roles throughout the construction process, contributing to a more active and participatory architecture. Therefore, the communities will be taught new valances that will enable them, in the future, be able to
build their own houses as well as doing its maintenance, without being limited to the will of the government, which little supports these more remote communities.

The architecture has a key role in developing a methodology grounded in research and construction methods validated laboratorially, which will optimize techniques and local resources to build sustainable buildings at a low cost, such as the present study. The construction of pilot schools, with subsequent measurement and validation will ensure access, quality and educational equity to local populations.

The architect gains a role on this project that becomes more than an agent of change, beyond the designer role, contributing to the socio-educational integration of people and hence the sustainability of the most remote locations.

The aim of this work was to define innovative principles and essentially structural design recommendations for building cost-effective pilot schools for the regions of sub-Saharan Africa, anchored in bioclimatic principles and constructive, economic and environmental sustainability, addressing the specific conditions of each target region.

Main Planing Principles | Case Study

In this proposal we develop a series of bioclimatic principles that claim, through a rational use of natural resources, to better integrate the school building on site as well as reduce the costs of future maintenance of the same, ensuring comfortable and properly balanced environments, adapting available to local and improving their technical reality resources, so enabling them to prolong the life of the buildings.

Immediately we will consider the actual shape of the building, including its design. The solar orientation, natural ventilation and the correct choice of materials are essential principles for an integrated and properly adapted architecture.

The program of the proposed building is relatively simple, consisting only of two blocks of classrooms and a separate block with their sanitary facilities and a covered outdoor living space. Trees are to be planted in the patio, so as to ensure greater shading of buildings and, on the other hand, to ensure a slight cooling of the temperature. The shape of it will also be a simple consequence of the program itself and the choice made on the construction of the building: local materials and local labor.

The buildings will be deployed on a slightly raised platform floor level, thus protecting them from the risk of flooding - very common in the region - and secondly, to avoid the excessive wear and degradation caused by the action of water on the foundations and walls of adobe. This way the foundation and plateau will be built, if possible using stone, and in its absence, using repellent mortar in order to consolidate and stabilize, if exceptional circumstances of flooding may occur.

![Organizational schemes of pilot school, Cunene, Angola.](image)
The walls in raw ground work as support to a structure of bamboo which will anchor the coverage of the building, coated by sheet metal. Adequate ventilation of the building will be ensured by gables, releasing the wall of the casing, thus contributing to the cooling of indoor spaces and to reduce moisture levels, asserting the air quality and comfort.

The school will be located under the guidance recommended in Figure 5. These studies as well as showing the solar path in Ondjiva, during different periods of the year, show us which is the optimized solar orientation for this region.

The special configuration responds to the better orientation of classrooms, oriented in east / west direction, with the biggest facades turning to north and south, getting the best sun protection as well as lighting. Similarly, the toilets are placed intentionally so that setting the assembly to solar radiation throughout the day and year, as it may function as a natural sterilizing action of such areas that require greater care and control of fungi. It was also ensured a covered patio to the east, as well as outdoor galleries to ensure sheltering from rain and solar radiation to users throughout the year.
As mentioned earlier, this study serves as a prototype intended to be "replicated" in other places, with human, social and economically similar characteristics. Most importantly, we must bear in mind that "new projects" have to meet with the real needs of populations and adapt to the context in which they are entered, including solar orientation, the wind regimen, the labor and locally available materials. Therefore, it will be enabling a better adaptation of the shape / design of the place where the constraints will be installed.

Applied Materials

The earth as a building material has been the subject of some reluctance in the target countries of study, as its use is associated with a stigma of poverty and insecurity that people want to avoid. However, it is essential to realize that this preconceived idea is anything but reasonable and realistic. Initiatives to improve these communities should meet their needs, and earth is a material that fully meets the needs of the community, with economic and environmental advantages and ease of application with hand-local labour benefiting from this.

It is a local, natural, recyclable, non-polluting and foremost reusable material. A building on earth can simply stop being and the material returns to its origin being returned to nature without intervention or expenditure of energy or human action, characterizing the earth as a material with a closed cycle. Although besides these qualities, many other criteria lead us to choose the land to the detriment of other materials.

In hot climates, such as Cunene, issues relating to thermal inertia of the materials are very relevant and should be taken into account when designing a school building. The earth has the ability to regulate and smooth the external temperature fluctuations, maintaining the coolest spaces in warmer periods and in turn, maintaining milder temperatures when the weather cools, particularly during the daytime and night time periods.

The soils in Cunene region are very sandy and as such they require a binder material that unifies the mixture and makes it cohesive, capable of being used for construction. Consequently the addition of other materials in order to correct this situation is required. It is expected to be mixed lime or cement, whichever is easier and convenient to purchase on site.

Despite the obvious durability that buildings have on earth, simply because there buildings constructed with use of this material continue to leave your testimony in our landscapes, studies have been shown that the addition of other stabilizing components prolong their good conservation and avoiding construction issues, their natural erosion, particularly that caused by water.

Figure 6  "Stretches of rammed earth walls exposed for 20 years to atmospheric agents: (a) wall, stabilized with 5% lime earth; (b) on the ground without wall stabilization (mixed soil); (c) Wall ashore without stabilization;” (5)
The study corresponding to Figure 6, aims to demonstrate that the addition of stabilizing elements, such as lime, protects the walls exposed to weathering, from the erosion that is naturally subject. Consequently the stabilizer prolongs the good condition of the building, providing more stiffness and durability.

Since the buildings on earth are already being disseminated in much of the territory and becoming a current practice in these environments, it is intended that the community re-acquires the right knowledge, and adjusts its implementation and that consequently there is a constructive improvement of these practices. It is not intended that these techniques are vernacular revival, but rather, to adapt to new realities to constructive development. For all that, and the current resistance observed in these locations due to the onshore construction, we propose the application of plasters in order to address the weaknesses of the material.

Traditionally, in Angola earth constructions are already built with thatched roofs, but this material presents some weaknesses at the expense of others, especially in their natural susceptibility to the possibilities of fires. Cumulatively, the use of the stem for several years, has led to its gradual disappearance, not being available in construction sites, implying major shifts to its acquisition. Still contributing to the cause of the abandonment of this material, the current population has new rhythms of life that does not allow them to do the right and necessary maintenance to keep the stem in good condition.

In contrast to stem use, we propose the use of sheet metal. This material allows for a lighter support structure, since the material itself has little weight. Its displacement and application is relatively simple and does not require maintenance during the lifetime of the building.

Even though it is not a local material and considered sustainable in origin nor incorporation associated with energy, it is affordable, durable, lightweight, flame retardant, low cost and easy to transport. The application of the coating material enables to lighten the supporting structure and by their individual dimensions of each sheet cut together, the weak points of rain and wind action.

To the support structure it will use the coverage at the expense of the bamboo wood, commonly used in the region. The bamboo has a relatively rapid growth compared to other materials, within 2-3 years it can be extracted from the site and is mature enough to be used in construction. We intend to proceed with the planting of a species in a nearby location that best suits the local weather conditions and has the height, diameter and thickness suitable to be used in the construction of the building.

Unlike wood, which requires a much longer process of growth and still requires the use of machinery to cut and modelling, thus incorporating more energy in its transformation and the consequent need for more expensive and complex equipment, bamboo uses are very simple, economical and without the need of power tools, verifying a minor impact on the environment.

After the extraction of the material - and this is in the place where it will be used - there is a mechanism of preservation, which in addition can prevent rapid degradation, since the material has little resistance to micro-organisms and insects, it will increase its durability. This process can be done in two ways: by chemical or non-chemical methods. In this proposal we will use a non-chemical process where the bamboo is stored in tanks of water and could thus decrease its starch content, which will consequently make the plant more resistant to biological organisms and increase its durability. This technique of leaching of bamboo is an ancient method and used for several years in different communities to protect the material from the draining action of organisms. However, its variation is directly dependent on the durability of the species concerned and it might turn this treatment insufficient and it is necessary to add a chemical components into the water so as to make tougher materials.

One of the objectives pursued, when the choice of materials is bamboo, is to introduce new materials, with easy extraction and handling, responsive to the needs of these communities. Since there is still a profound lack of knowledge about these techniques, the population tends to reject it, even if unconsciously, so you will need to "democratize" and promote its use throughout a process of adaptation to the material, instructing the local population so it will benefit from constructive greatness of it, as well as the possibility of its using in other capacities - not only construction, but also with applications in woodworking and carpentry, with the construction of furniture.
There are already some examples of buildings in remote means, which involve the use of bamboo to make the structure of your toppings. Among them, we highlight the Handmade School in Bangladesh by the architect Anna Herringer and the Habit Initiative Cabo Delgado in Mozambique, by the architect Roswig Ziegert. (figure 7)

Figure 7 Bamboo structure construction by the local population

CONCLUSION

Local interventions of apparently little scale have global repercussions. It is vital that we intervene locally so that the long term scenario is different, dignifying the most disadvantaged communities.

However it is essential that the scientific community realizes that behind the choice of certain materials are rooted local prejudices that must be understood and taken down or assimilated and managed for an innovative solution that can be attractive and harmless on local traditions. The blind imposition of new solutions seen as superior risks the non-assimilation and not being fully understood by the target population. All communities have their patterns and desires that must be respected and reconciled in the intervention. Concessions on certain points of intervention should be taken into consideration, as the scientific community should cooperate and not solely teach, share knowledge and not just impose.

Photographic examples of schools considered "bio" and "eco" in remote environments advertised as examples for the scientific community are constant in failure in their places of deployment, for they were not assimilated by the population, resulting in innocuous buildings without result in pilot examples for the region. Certain orthodox and rigid solutions without added local inputs resulted in unique and beautiful examples, but not replicated, either by training difficulties of the population, or simply by their lack of identification, assimilation and understanding of forms of use, habits and customs.

It is our understanding that a sustainable conceptual solution for the measurement and scientific validations should be downstream of understanding anthropological and socio-cultural assimilation, and incorporate local religious architecture in the draft. This should just be a reflection of local and scientific assignments and reconciliations.

Acting locally avoids successive massive displacement of populations to cities and consequently decreases the informal, illegal and uncontrolled development in the outskirts of cities. Remote, inhospitable and prone to decay stands can gain new lives with this kind of interventions, that are beyond architectural, becoming social and economic transformations.

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Session PD: Thermal comfort

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Trust - Knowledge Consortium of Gujarat
Integrating User Awareness and Behavior into Building and Product Design for India: Survey in Eight Giant Cities in India

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ABSTRACT: Is India on a sustainable road or not? Between April 2012 and January 2014 the authors have conducted a quantitative paper and online based user survey on energy awareness and attitudes in Mumbai, Bangalore, Chennai, Delhi, Pune, Hyderabad, Ahmedabad and Kolkata. The survey was part of the project “Climate Related Energy Efficient Design - Product Solution (CREED-PS)” first funded under the aegis of Germany India Year 2011-2012 “Germany and India: Infinite Opportunities” with a focus on “City Spaces” and then as part of the project “DWIH Excellence on Tour. 2013-2014.” More than 2000 visitors were interviewed during the events about their individual energy consumption, their knowledge of selected energy issues and energy efficient building design and their sustainability attitudes. The majority of the visitors are part of the academic middle class group in India’s Megacities, as a limited group of India’s society. One of the main results are that living in energy efficient residences is very important for most of the respondents, although two third don’t know exactly the energy consumption of their household. Yet, most of the respondents are willing to spend more money in energy efficient and energy saving building devices and household equipment. Summing up one can say that the interviewed middle class group (Shukla, 2005, Mawdsley, 2004) is on the sustainable road, although we have identified several inexplicable contradiction in knowledge and awareness as topics for further research work that are relevant for building and product design. This paper illustrates on the one hand the use of survey as part of an integrated design process and suggests on the other hand collaborative approaches to educating architecture and design students about sustainability in building and product design.

Keywords: India, Energy consumption, Energy saving, Energy efficient building design, Sustainability, Standards of housing

INTRODUCTION

Today India is an emerging country with a 1.3 billion population (MHA, 2011) and a rapidly growing economy. The census 2011 estimated 168 million households in rural areas and 79 million households in urban areas. Most of Indian families and individuals still live in traditional rural houses or in buildings that are older thirty years. Yet, the economic boom since 2001, a growing middle class in Indian cities and the migration of people from rural areas to urban areas has accelerated a tremendous construction and investment boom in rapid sprawling metropolitan areas. According to the report of Global construction perspective Ltd. (2011) between 2013 and 2020 India will become, behind China and US, the third biggest construction market in the world with an annual growth rate of 8 %. It is more than evident that India with its high demand of construction material and energy consumption moves straight to a critical resource shortage and carbon emission collapse, if the government and the society do not counteract with sustainable strategies and action plans for energy efficient building design and energy saving technologies. With about 39 % of the total national energy consumption the construction and building area is the major energy consumer (de la Rue du Can, 2009).
In many discussions with Indian architects, scientists, energy experts and organization, e.g. the Bureau of Energy Efficiency (BEE) and the India Green Building Council (IGBC), it was mentioned repeatedly that the awareness and knowledge of stakeholders, investors and users plays a central role in the change process to more sustainability.

In general only few studies and publications about the mindset of the Indians on energy concerns are available. Alam, Sathaye and Barnes (1998) reported in an older survey of household energy use in the city of Hyderabad. The survey revealed the fuel transition from biomass-based fuels to modern fossil fuels and electricity in cities. Reddy (2004) using the data from the National Sample Survey (1983-2000), analyzed the dynamics of energy end-use in household sector in India. The paper reported that large variations in energy use exist across different sections of households urban/rural, low/high income groups, etc.

In 2011 the Mercom Capital Group (2011) conducted a survey on renewable energy awareness in the area around the cities of Bangalore and Mysore in Karnataka State. The limited survey based on 101 respondents of the rural area, 204 respondents of residential and 204 of commercial/industry. Overall findings of the survey were that a “general lack of education and understanding about renewable energy, though the people surveyed were very enthusiastic about renewable energy concepts”. Only 39 % of the rural respondents have heard the term „renewable energy“ or „clean energy“, in difference to 61 % of the residential/commercial/ industry respondents. About 32 % of residential and commercial/industry respondents answered that they have installed solar water heater, 6 % have installed solar panels, 1 % used wind turbines, 2 % biomass and about 60 % had no application of renewable energy installed (Mercom Capital Group, 2011). Likewise interestingly is that 46 % of all respondents don’t plan to install any type of renewable energy in the near future and 62 % were not aware (rural 80 %) of any government subsidies for renewable energy.

In another national survey on “Climate change in the Indian mind“ by the Yale University, GlobeScan Incorporated, and C-Voter 4,031 Indian adults were interviewed, using a combined urban (75 %) and rural (25 %) sample. This “study was designed to investigate the current state of public climate change awareness, beliefs, attitudes, policy support, and behaviors, as well as public observations of changes in local weather and climate patterns and self-reported vulnerability to extreme weather events.“ (Leiserowitz, 2012). The key findings concerning climate and energy policies were: “41 % of respondents said the government of India should be doing more to address global warming; 54 % said that India should be making a large or moderate-scale effort to reduce global warming, even if it has large or moderate economic costs; 38 % said that India should reduce its own emissions of the gases that cause global warming immediately, without waiting for other countries; 70 % favored a national program to teach Indians about global warming; 67 % favored a national effort to help local communities build check dams to increase local water supplies; a majority of respondents favored a variety of policies to waste less fuel, water, and energy, even if this increased costs; 53 % said that protecting the environment is more important, even if it reduces economic growth, while 28 % said that economic growth is more important, even if it leads to environmental problems“ (Leiserowitz, 2012).

AIM AND OBJECTIVES AND HYPOTHESES

The survey aims to assess energy efficiency awareness of the users in India and potential for integrating the same in building and product design.

Overall objectives

The survey followed some overall objectives related to the described target group:

1. Identification of knowledge, attitudes, awareness and behavior on energy issues to develop new concepts for energy efficient buildings in India.
2. Identification of different climate-related and city-related life-styles, housing, and amenities demands.
3. Identification of awareness/needs/methods/approaches to improve the efficient building design for investors and the energy saving behavior of urban dwellers.
4. Involving businesses and corporate social responsibility for promotion of energy efficiency and sustainable consumption.
5. Identification of energy efficiency related topics for information and education programs.

Research hypothesis

The survey is based on the following hypothesis that should be proofed:
H1: Higher educated people of the new middle class in urban areas have a clearer awareness and higher needs on energy-efficient lifestyle than lower educated people.
H2: The higher the income of people the lower the awareness of energy issues.
H3: Females are better informed on energy saving and efficiency than males.
H4: Younger dwellers are better informed on energy saving and efficiency than older dwellers.
H5: People with high individual energy consumption are willing to spend more money for energy saving activities.
H6: A good residential place has a higher priority than the distance to the working place.

METHODOLOGY

The survey was conducted in Mumbai (April 2012), Bangalore (June 2012), Chennai (August 2012), Delhi (October 2012), Pune (January 2013), Hyderabad (April/May 2013), Ahmedabad (November 2013) and Kolkata (March 2014) during the events “Germany and India: Infinite Opportunities” and “DWIH Excellence on Tour. 2013-2014.” The majority of the visitors are part of the academic middle class group in India’s Megacities, as a limited group of India’s society. More than 2000 paper-based questionnaires (250 for each location) were disseminated and collected. All filled out paper-based questionnaires were captured automatically with a scanner. The statistical evaluation of the questionnaires was conducted separately for each city and altogether for all cities. In total more than 2000 visitors were interviewed.

The paper and online-based (CREED) questionnaire in English language was created with the web-based software (EvaSys) Altogether the questionnaire was divided in 6 sections: (1) personal details, (2) mobility, (3) environment, (4) aspects for choosing the apartment/house; (5) environmental aspects, (6) general aspects. Questions were created in different formats (scale, single- or multiple-choice, and open).

In all automatically generated pdf-reports with EvaSys the case numbers were indicated for each question. Single-choice-questions and multiple-choice-questions were generated as a bar graph. Scale questions were generated as a histogram with average values, median values, and standard deviation. Additional the scale questions were diagrammed as a profile graph. Open questions were automatically identified and copied in the report as a picture-file. In the online-version open questions were recorded directly. For further statistical analyses the raw data were converted to an SPSS-file. The analyses were done with the statistical package SPSS version 20. In order to find out pattern in the data with a very strong correlation (r-value) and a very high significance (p-value) we conducted cross tabulation of age, sex, income, and occupation for all variables (items) in the questionnaire.

SURVEY RESULTS

General and Personal Data of the Respondents

More than one third (38.8 %) of the respondents live in a typical middle-class household with 4 persons. Nearly half of all respondents (45.3 %) were aged between 20 and 29 years. Only a small number of respondents (6.3 resp. 3.3 %) were older than 50 years. The majority of the respondents (77.7 %) were males. 65.5 % of the sample has a bachelor or master degree. This high %age depicts a strong focus on respondents with an academic background. The monthly income of the respondents is likewise nearly equally distributed. Probably the income group below 20.000 Rs. (37.7 %) consists predominantly of
students, freelancer or housewives. 27.7 % belong to the lower middle class has a monthly household income between 20,000 and 40,000 Rs.. 34.6 % belong to the upper middle class has an income above 40,000 Rs. (Meyer and Birdall, 2011).

**Priorities of Housing Standards**

In the first part of the survey the respondents were asked about the most important factors for choosing a new residence as an indicator of life-style, social priorities and sustainability awareness. Fourteen (14) social related, building related, life-style related and energy related questions were provided. The highest priority to choose a residence was a high performance of the location (73 %) followed by security of the location (70 %).

Figure 1 depicts the confirmation resp. the importance of the fourteen (14) investigated factors on living standards in the eight included Indian cities. The respondents could answer between “very important” and “unimportant”.

Q: To choose a residential for me is very important ... (% of respondents)

![Figure 1](image)

**Figure 1** Overview of living standard priorities

72.5 % of respondents consider a high priority of the location (district/quarter/street) for the apartment or house. This criterion of living standard has been the highest value of confirmation with an average value of 1.4 and a median of 1.0 with a deviation of 0.8. Because, this criterion implies a lot of sub-criterions like social and ethnic structure, population density, security, infrastructure (water and electricity supply, sanitation, garbage collection etc.), shopping opportunities, access to public transport, proximity to schools and kindergarten, cultural amenities, medical care and hospitals etc. The lowest confirmation of living standards of the respondents has “vastu” and “feng shui” with 27.9 %. A nearly equal share of 31.4 % find that unimportant. The age group above 60 years gives more importance to “vastu” and “feng shui” compared to other age group under consideration. The income group of 20,000 – 40000 Rs. places higher importance to “vastu” and “feng shui” in comparison to lower and higher income groups.

Other factors like saving of natural resources, low carbon emission, low noise emission, distance to work etc. and further investigated factors lays close behind the two top priorities. Amount of energy consumption, interior climate, price of residence, distance to public transport, home size and layout are less important factors to the respondents.
Environmental Knowledge and Attitudes

In the second part of the survey the knowledge and attitudes on building and product design issues should be identified. Nine (9) questions of use of material and electrical home equipment were provided.

The following Figure 2 depicts the knowledge and attitudes of the respondents on the nine energy related fields. The respondents could answer between “very familiar with …” and “not familiar with …” (% of respondents).

![Figure 2 Overview of environmental knowledge and attitudes](image)

Legend: ES = Energy Saving; EC = Energy Consumption; PV = Photovoltaic’s

Figure 2 Overview of environmental knowledge and attitudes

71.1 % of respondents were very familiar with the fact that natural ventilation contributes to energy saving. A similar high confirmation of energy saving measure we have seen by the items of natural lighting (68 %), solar shading (63 %), and public transport (62 %). Saving energy by using local material (49 %) was not aware by nearly half of the respondents. Only 34.2 % of respondents were very familiar with the fact that buildings consume more than 40 % of all resources; 18.6 % were not familiar with this fact. 31.5 % of respondents were very familiar with the fact that buildings can produce more energy than they consume; 23 % were no familiar with this fact. As well only 32 % of the respondents knew that Zero Plus Energy Buildings could produce more energy as they consume. All in all these results shows a widely superficial knowledge of the respondents in the field of energy efficient building designs since the users are well aware of the basic energy saving measures like natural ventilation and lighting but they are not aware of the state of the art of energy savings strategies like zero or plus energy buildings.

General Attitudes of Housing

In the third part of the survey the general attitudes of housing related to building and product design was investigated. Fifteen (15) questions related to energy consumption attitudes were provided. The extreme poles of this question battery were on one hand side disturbance through pollution (73 % agree strongly) and on the other hand side importance of driving a car (only 30 % agree strongly).

Figure 3 depicts the general attitudes of housing in the fifteen items. The respondents could answer between “I agree strongly with” … and “I disagree strongly with …” (% of respondents) on Likert scale.
Figure 3 General attitudes of housing

The most important issue of the respondents is the air pollution. 73% of respondents assert that air pollution is a very disturbing issue for them; for 91% it is disturbing and very disturbing. The second important opinion focused on the extension of public transport (70% agree strongly). In the following ranked items we found in general a linear decline of agreements. Yet, concerning the consuming attitude of the respondents one can consider a significant difference between the age groups. In general the older the respondents the more they have the attitude to buy energy efficient building equipment or amenities. In general one can assess a trend the higher income the higher are the tendency to buy always energy efficient equipment.

Interestingly, the alternative question that in the long term perspective innovation in energy saving is more important than fighting against poverty was strongly agreed by 52.3% of the respondents. This phenomenon is probably strongly related with the particular structure, occupation, income, education, attitudes and behavior of the Indian middle-class. “It is by reckoning the most polymorphous middle class in the world.” (Beteille, 2001).

Concerning the knowledge about energy efficient buildings is was intended to measure the level and intensity of knowledge and information of energy efficient buildings. These values inform about the relevance of the topic for the respondents and for further information and promotion campaigns. 39% of respondents assert strongly that their knowledge about energy efficient buildings is good, 70.3% answer “I agree” resp. “I strongly agree”. Between the age groups one can consider a tendency of higher knowledge in the age group 20 to 29 years and in the age group above 60 years.

48% of respondents assert that they would spend more money for an energy efficient home, 79% agree and strongly agree. The age group of 50 to 59 years has higher percentage of people who agree strongly for energy efficient homes. The group with higher income > 40000 Rs. place higher importance to energy efficient homes.

A deeper look into the age groups shows, that the high confirmation of the group above 60 years is very conspicuous and the increase of confirmation in the younger groups. The highest rejection one can see interestingly in the group below 19 years. Concerning the income groups there are no significant
differences in confirmation or rejection. Merely in the income group 20,000 to 40,000 Rs, one can assess a higher value of rejection. Interestingly, in this question the “neither nor” group is especially wide. All in all one can suppose a difference between to own a car as a status symbol and to drive a car actively under the current traffic circumstances.

CONCLUSION

In this article a selection of assessments of attitudes and awareness of energy consumption is shown and discussed. The hypothesis H1, H2, H3, H4 cannot be confirmed. In most of the measurements all respondents with a tertiary education have a clear awareness and a high demand of energy-efficient lifestyles. Females and males as well as older and younger respondents show no differences in the level of information of energy saving and energy efficiency. H5 and H6 can be confirmed. Respondents with higher energy consumption and a higher income are willing to spend more money for energy saving activities and a good residential place has a higher priority than the distance to the working place, although for choosing a residential place the proximity to the workplace or the college is very important.

Between the eight investigated cities the survey found no significant differences in attitudes and awareness of the respondents. The quality of the location and the security of the location have the highest priority. Air pollution is one of the most important disturbing factors. We assess a clear attitude for an energy saving and energy efficient residential place. Most of the respondents vote for a strong extension of the public transport system.

This survey shows a picture of attitudes and awareness of a selected population segment with mainly tertiary education. Although this group is very important for the economic and social progress in India, more data and information of urban population with low income and low education, and from people from rural areas with lower income level is needed. With this data it would be possible to get a more holistic picture of attitude and awareness of energy saving and sustainability. For that purpose further research is needed, particularly for the transmission to a deeper eco-friendly education and knowledge-building and pro-environmental behavior (Vlek and Steg, 2007, Steg and Vlek, 2009, Geller 2002, Altomonte et. al., 2013). The usefulness of the value-belief-norm (VBN) theory for pro-environmental behavior analysis has been successful tested and disseminated in the psychological literature (Stern et. al., 1999).

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Perception of Indoor Temperature of Naturally Ventilated Classroom Environments during Warm Periods in a Tropical City

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ABSTRACT
According to the adaptive hypothesis, contextual factors and past thermal history modifies building occupants’ thermal expectations and preferences. This paper cites the findings of a research that was based on a field investigation, for a detailed understanding of perception of thermal environments, by students, inside typical classrooms of Dhaka, Bangladesh, during the pre-monsoon (hot-dry) and monsoon (warm-humid) seasons of a year. One hundred individual responses, by subjects in naturally ventilated classrooms, provided comprehensive data, through a standard questionnaire survey, which was then used for analysis of their responses and preferences, with respect to the measured indoor thermal environment. This research revealed that thermal adversities, encountered in summer, are quite well tolerated by the acclimatized and adapted students, of Dhaka city. The findings reconfirmed that sensation, comfort and preferences about air temperature, inside classrooms of this tropical country, are markedly different from set international standards. The ‘neutral’ temperature of the students was identified, which was found to be much higher than the international standard. Therefore, if thermal comfort standards are contextualized, for naturally ventilated classroom spaces in Bangladesh, it is likely to minimize the pressure on energy and allow for more sustainable architecture.

Keywords: Perception, Sensation, ‘Neutral’ temperature, Adaptation, Classroom environment

INTRODUCTION
Any comfortable environment is a holistic phenomenon, involving synergy of thermal comfort, indoor air quality, other environmental factors, such as, the type of building and its psychological relevance for the occupants (Croome, Gan, and Awbi, 1992). According to ASHRAE 55-2004, thermal comfort is a subjective response, and is defined as the state of mind that expresses satisfaction with existing environment (Brager and Richard, 1998), which is widely driven by perception and expectation of the occupants. Therefore, the same thermal environment may be perceived differently by different occupants, or different occupants may perceive the same thermal comfort sensation for different thermal environments (Brager & Richard, 2002), (Auliciems, 1981), (Rajasekar & Ramachandraiah, 2010). While the idea of a comfortable environment for all, would involve the consideration of individual preferences, there is a set of general conditions of air and radiant temperatures, airflow, humidity, etc, in which a
majority of the people would be at ease (Mallick, 1994). Thermal comfort is a key component for quality of indoor environments (Appah-Dankyi & Koranteng, 2012). Methods for defining a ‘comfort zone’ or ‘comfort range’ of acceptable temperatures are based on associating ideal conditions with a feeling of neutrality, or on conditions that are totally unnoticeable (Brager & Richard, 2002). ‘Thermal neutrality’ for a person, is the condition in which the subject would prefer neither warmer, nor cooler, surroundings (Fanger, 1972).

According to the adaptive hypothesis, contextual factors and past thermal history can modify building occupants’ thermal expectations and preferences (Brager & Richard, 1998, 2000 and 2001), while people with environmental control options, are more easily thermally satisfied, than when they perceive not to have control. Temperature and Humidity are two of the prime indicators of thermal comfort. International standards and related predictive models predict that subjects in cool climates, from where the standards have originated, feel much warmer than subjects in naturally ventilated buildings in warm climates (Tablada, Peña, & Troyer, 2005). Therefore, occupants in naturally ventilated buildings of tropical countries are tolerant of a significantly wider range of temperatures, explained by a combination of both behavioural adjustment and psychological adaptation (Brager & Richard, 1998). Such results can form the basis of indoor temperature standards, more elevated than standards set for cooler climates.

Institutional buildings mainly operate during the hottest part of the day, with young adult occupants. Research findings indicate that the thermal sensation of the younger subjects (age 22-25 year) is, in general, 0.5 scale units higher in comparison with their elderly counterparts (age 67-73 year) and that young adults prefer a lower temperature in comparison with elderly persons (Schellen, van Marken Lichtenbelt, Loomans, Toftum, & de Wit, 2010). Therefore, if the indoor environment is found comfortable for fit young adults in the summer season, then the rest of the older population will also find it to be comfortable. So, efforts should be made to predict the temperature, or combination of thermal comfort variables (air temperature, relative humidity and air velocity) which will be found comfortable in classroom environments of Bangladesh, in order to set contextual local standards.

![Figure 1](image)

Naturally ventilated classroom environments in Dhaka

The study of thermal comfort in classroom environment is very important because it directly affects students’ health and also energy consumption of the building (Markus & Morris, 1980). This paper cites a study of the classroom environment of undergraduate students in Dhaka, Bangladesh, aimed to investigate thermal sensation, acceptability and preference of indoor climatic conditions by students in naturally ventilated classroom environments, as shown in Figure 1, during the hottest period (April-July) of the year. During this study, five naturally ventilated classrooms were investigated on six separate occasions during the selected critical period (April-July), and the environmental data were recorded, along with responses, through questionnaires, of the subjects to these conditions. The responses were correlated with the corresponding recorded environmental data, to identify the acceptable air temperature range, along with the ‘neutral’ temperature.

Findings of such studies can lead to formation of local standards of thermal acceptability, which can result in reduction of building energy consumption.
RESEARCH METHODOLOGY

Field investigation in multiple-cases, with a structured questionnaire, and measurements of simultaneous environmental conditions, was adopted as a methodology, to produce primary data during this research.

A total of 100 subjects, in naturally ventilated classrooms, of five institutions, provided comprehensive data through a questionnaire survey, on six occasions during the survey period, for the analysis of indoor thermal condition and their preferences. Transverse surveys were conducted in April, May, June and July (2013) in Dhaka, located in a tropical climatic zone.

All the selected students, aged within 18-25 years, were engaged in sedentary work, and wore summer clothing (between 0.35-0.5 clo), while all the selected classrooms had similar options of adjustment to neutralize the physiological factors affecting their thermal condition. Students had similar types of social class, as they came through the same type of educational background and set up. Naturally ventilated institutions were selected with similar materials (brick and concrete) and classrooms having glass openings were selected to get similar type of micro environment of building design.

The micro-climatic parameters were measured simultaneously during questionnaire survey, in order to relate these to the thermal responses. A Digital Thermometer Hygrometer (Zeal PH1000) was used for measuring air temperature (indoor/outdoor temperature) at positions, as shown in Figure 2. The airflow, mainly generated by running ceiling fans, as is common in Dhaka, was found to be on average, 0.475 m/s.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Represents</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>indoor air temperature, relative humidity, air velocity (at 01m above floor level)</td>
</tr>
<tr>
<td>+ +</td>
<td>outdoor air temperature, relative humidity, air velocity (at 01m above ground level)</td>
</tr>
<tr>
<td>♂</td>
<td>ceiling fan</td>
</tr>
</tbody>
</table>

**Figure 2** Positions of taking measurements of environmental variables

**Table 1. Thermal sensation scale (ASHRAE Scale and modified used in this research)**

<table>
<thead>
<tr>
<th>thermal sensation</th>
<th>very cold</th>
<th>cool</th>
<th>slightly cool</th>
<th>neutral</th>
<th>slightly hot</th>
<th>hot</th>
<th>very hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHRAE SCALE</td>
<td>-3</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>+1</td>
<td>+2</td>
<td>+3</td>
</tr>
<tr>
<td>(Fanger’s Scale)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified ASHRAE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCALE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensation Scales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sensation Scales**

A modified version of ASHRAE Scale was used (ASHRAE, 2005), as shown in Table 1, for measuring thermal sensation, and answering the question: *How are you feeling (Thermal sensation)*
inside the classroom? This was because previous studies show that ‘cold’ discomfort is not an option in the warm seasons of Dhaka, and therefore, the options of ‘cool’ [-2] and ‘very cold’ [-3] were not mentioned in the questionnaire.

Comfort voting

The voting scale, as shown in Table 2, was used, to assess ‘comfort’, and answer the question: How does the classroom feel like to you (air temperature)?

Table 2. Comfort voting of air temperature, relative humidity and air velocity

<table>
<thead>
<tr>
<th>Comfort voting</th>
<th>uncomfortable</th>
<th>neutral</th>
<th>comfortable</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>+1</td>
<td>+2</td>
<td>+3</td>
</tr>
</tbody>
</table>

Preference Scales

To cross match comfort with preferences about air temperature, the ‘McIntyre preference scale’ was used (McIntyre, 1980), as shown in Table 3, answering the question: What change in the temperature do you want in the classroom?

Table 3. Preference Scale of air temperature used in this research

<table>
<thead>
<tr>
<th>Thermal preference</th>
<th>extreme cold</th>
<th>much cooler</th>
<th>slightly cooler</th>
<th>no change</th>
<th>slightly warmer</th>
<th>much warmer</th>
<th>extreme hot</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>-2</td>
<td>-1</td>
<td>0</td>
<td>+1</td>
<td>+2</td>
<td>+3</td>
<td></td>
</tr>
</tbody>
</table>

The subjects also voted on their assessment of the environmental acceptability on subjective scales, as shown in Table 4, by responding to the question: How do you rate the overall acceptability of the thermal environment at this moment?

Table 4. Subjective scales of ‘acceptability’ used in this thermal study

<table>
<thead>
<tr>
<th>Acceptability</th>
<th>not acceptable</th>
<th>acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>+1</td>
<td>+2</td>
<td>+3</td>
</tr>
</tbody>
</table>

ANALYSIS AND RESULT

A total of 600 responses (100 students for 6 times) were investigated during the survey period, of which 251 (42%) were male and 349 (58%) were female. The measured indoor environmental parameters during the study period (April to July, 2013) are shown in Table 5.

Table 5. Measured indoor environmental features of selected classrooms

<table>
<thead>
<tr>
<th>Measured indoor environmental features</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of Mean indoor AT (ºC)</td>
<td>27.95 - 32.6</td>
</tr>
<tr>
<td>Range of Mean indoor RH (%)</td>
<td>52.5 - 80</td>
</tr>
<tr>
<td>Range of Mean indoor AV (m/s)</td>
<td>0.05 - 0.9</td>
</tr>
</tbody>
</table>

Comparison of indoor and outdoor environmental conditions

The outdoor temperature, measured at one meter (01m) above the ground level outside selected classrooms, is compared with simultaneously measured indoor conditions, as shown in Figure 3, showing a strong correlation, increasing and decreasing in a similar pattern.
Regarding thermal acceptability, it was found that only about 43% of the responses (257 out of 600 respondents) ‘accepted’ their immediate classroom environments to be comfortable. But about 73% responses lie within inside the three central categories \( \text{vote} = -1, 0, +1 \) of the sensation scale, which imply acceptability (ASHRAE Standard 55, 2004), showing that though the respondents were not in absolute thermally acceptable conditions, the conditions were, nevertheless, close to acceptability. The mean value of thermal sensation vote (TSV) was found to be 1.003 which lies very close to the ‘slightly warm’ vote category \( \text{vote} = +1 \). But since the three central categories imply acceptability, it can be said that, in general, students are reasonably satisfied with the air temperature of their classroom.

**Comfort Votes on air temperature**

In order to cross check the responses of the thermal sensation scale, a question, *How does the classroom feel like to you (regarding air temperature)*, was included in the survey, about the comfort sensation regarding the temperature experienced in the class, which varied between 27.95-32.6 °C. For the response, a 3 point rating scale was used: Uncomfortable, Neutral and Comfortable. In this question regarding the indoor air temperature, 55% responded that their classroom condition is ‘uncomfortable’. This contradicts the voting mentioned previously where 73% found conditions acceptable (voting between the -1, 0, +1 range).
But voting against a question, *How does the classroom feel like to you (regarding air temperature)*, on a 7 point rating scale: uncomfortable degrees of -3, -2 and -1, neutral (0) and comfortable degrees of +1, +2 and +3, reveals that 71% responses were in the acceptable comfort conditions of air temperature, the students voting in between the -1, 0, +1 range, as shown in Figure 4.

Therefore, compared with the acceptable thermal sensation votes (73% between -1, 0, +1) and ‘comfort’ votes (71% within the acceptable -1, 0, +1 range), there is a close similarity between ‘thermal sensation’ and ‘thermal comfort’ due to air temperature, among these students. Moreover, on cross checking, it can be concluded that the students are aware of their environment, and that their responses to it are consistent.

**Correlation between thermal sensation votes and air temperature (Mean)**

The six hundred thermal sensation responses were plotted in a scatter plot diagram, against the simultaneously measured air temperatures, as shown in Figure 5.

The slope of this plot, generated through the computer software, reveals certain dependence between these two variables. The low $R^2$ value is considered indicative of the wide variability of the perception of thermal sensation vs. the actual air temperature, which is not uniform, particularly in naturally ventilated tropical spaces.

Figure 5  
Thermal sensation votes VS air temperature (Mean)

This figure shows that the higher the air temperature, the higher the thermal sensation vote (TSV). When the air temperature (Mean) is 29.9 °C, the TSV is ‘slightly cool’ [-1], and as the temperature rises up to 31.2 °C, the thermal sensation vote indicates the ‘very hot’ [+3] condition.
Through the graph, shown in Figure 6, it was possible to identify a ‘neutral’ air temperature which may be perceived as ‘neutral’ by the undergraduate students (age 18-25 years) of Dhaka, Bangladesh.

The temperature range between the two lines of ‘slightly hot’ [+1] and ‘slightly cool’ [-1], forms the acceptable temperature range, (ASHRAE Standard 55, 2004), i.e. 29.89 ºC to 30.54 ºC. The intersection of the TSV Vs the Mean air temperature slope with the ‘0’ TSV, has been identified as the ‘neutral’ temperature, i.e. 30.20 ºC, where the thermal sensation is ‘just right’. This figure is undoubtedly much higher than that acceptable according to published international standards.

Also the very narrow acceptability range of only 0.65 degC is surprising, where thermal studies in cooler climates have revealed acceptable ranges of ±2 degC (Fanger, 1972). The reason for this is probably the high level of the neutral temperature and the state of acclimatization for the tropical population in naturally ventilated buildings.

**RECOMMENDATIONS**

This research concludes that, thermal adversities encountered in summer are quite well tolerated by the acclimatized and adapted students of Dhaka city. It is essential to provide a comfortable and healthy indoor environment to its dwellers in various seasons to perform their works effectively (de Dear, Fountain, Popovic, Watkins, Brager, Arens, & Benton, 1993). The neutral temperature was established at a value of 30.20 ºC, which is much higher than international standards. The findings reconfirmed that sensation, comfort and preferences of this tropical country, along with the acceptable range of temperature, are markedly different from set international standards. Therefore, developing a more relevant and
contextual thermal comfort standard, for naturally ventilated spaces in Bangladesh, is an imperative, which will also accommodate different expectations, preferences and adaptation means.

Relevant thermal standards for indoor thermal conditions of Dhaka should be set on an urgent basis. As there is a very close relationship between internal temperature standards and energy usage, setting a higher acceptable temperature value will allow greater energy savings, thus allowing for a more sustainable energy balance in the country.

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The Authors acknowledge support of the Department of Architecture, Bangladesh University of Engineering and Technology (BUET), where the M.Arch Thesis course formed the impetus and inspiration of the research cited in this paper.

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Thermal Perception of Users of Different Age Groups in Urban Parks in Warm Weather Conditions

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ABSTRACT

Studies of thermal comfort in open spaces in various climatic and cultural contexts, seek to create design guidelines for attractive outdoor environments, which improve the quality of urban life. In general, these studies characterize microclimates and define the conditions for actual and/or calculated thermal comfort by predictive indexes in streets, squares and parks. In this context, this pilot study aimed to characterize the thermal perception of users and changes of the range of PET (Physiological Equivalent Temperature) for thermal neutrality according to the age of visitors to a park in the city of Bauru, State of Sao Paulo, Brazil. The study was conducted through microclimate monitoring and structured questionnaires to users in warm weather conditions. Results showed higher frequency of thermal sensation between comfortable and warm; a differential thermal preference according to the major microclimatic variations observed between morning and afternoon; little tolerance to the effect of direct solar radiation and minor differences of PET index between the age groups of children and teenagers and greater variations between these groups and adults/elderly.

INTRODUCTION

The open spaces have several ways of daily use in the city and, therefore, an important aesthetic and recreational function (Raja & Virk, 2001). Chen and Ng (2012) advocate that open spaces are key to more sustainable cities because they accommodate pedestrian traffic, the outdoor activities and contribute to the livability and urban vitality. Thus, they encourage more people to attend the open spaces in the cities benefitting their physical, environmental and socio economic dimensions.

The quest to create the most attractive open environments has contributed to the growth of research in open spaces, focused on different aspects, including thermal comfort. In this approach, the pioneering studies investigated the thermal environment, the human comfort parameters (Nikolopoulou, Baker & Steemers, 2001), the characteristics of space usage (Zacharias, Stathopoulos & Wu, 2001), the relationship between comfort psychological adaptation (Nikolopoulou & Steems, 2003), and thermal comfort and behavior patterns of users on streets, squares and parks (Thorsson, Lindqvist & Lindqvist, 2004).

These researches show the complexity of the evaluation of comfort in open spaces and proved that there is a close relationship between the thermal environment and the number and distribution of users, and also between the behavior of people in open spaces. These findings significantly influenced the

In general, these researches seek to analyze the thermal quality of open spaces, based on qualitative aspects (thermal perception of the users) and quantitatively with the use of different predictive indexes of comfort, such as the Physiological Equivalent Temperature - PET (Mayer & Höppe, 1987; Höppe, 1999), to define the limits of thermal comfort. The aim is to create design subsidies that favor the creation of pleasant microclimates for human society and, consequently, contribute to the increment the daily use by the population.

So it is important that architects and landscapers use tools that have been developed from research in the area, with the goal of designing open spaces with adequate comfort conditions. Considering especially the effects of expanding cities adversely affect the microclimates of these spaces, because of the significant heat islands effects (Lin et al. 2013).

In this context, this research shows results of a pilot study investigating microclimates and thermal perceptions of users of a park located in Bauru, midsize city of São Paulo State, Brazil. However, the difference here presented, in relation to other similar studies, is to attempt to identify possible variations of PET for thermal neutrality according to the different age groups of visitors.

MATERIALS AND METHODS

Characterization of the study area

The study area is the Municipal Zoo of Bauru (Lat. 22°18'54" S, Long. 49°03'39" W and average altitude of 530m), medium-sized city in the Midwest of São Paulo state, Brazil. According to Köppen climate classification, the local climate is Aw - tropical climate with summer marked by high temperatures and rainfalls and mild and dry winter. Figure 1 shows the thermal range of the city, from the analysis of historical data of air temperature over the period of ten years (2001-2010). The table also includes the minimum and maximum temperatures of two days of field survey in the months of October and November 2013.

![Figure 1](http://www.ipmet.unesp.br/)

The Zoo is an important recreational space for the city and region, comprising an area of 20 acres inserted into a region of cerrado vegetation of more than 200 acres (www.zoobauru.com.br). Its inner
space consists of totally unshaded areas of direct solar incidence, areas partially shaded by vegetation and areas shaded by built covers, as can be seen in Figure 2 respectively.

To analyze the thermal perception of the users, one of the areas of longest permanence time within the park, "the Food Court" (Figure 3) was chosen. This place is quite shaded by vegetation and is used for relaxation and meals by users who have family picnics or to school tours. The permanence time at the site varies from a few minutes to two or three hours.

**Figure 2**  Different areas of the Zoo: a) Area of felines (left) and circulation spaces, unshaded sites of direct solar incidence; b) Area of birds and local open spaces of permanence (center) partially shaded by adjacent vegetation; c) Area of primates, reptiles and penguins (right), areas shaded by built covers.

**Figure 3**  Partial internal map of Bauru Zoo, especially the Food Court, site of the data collection. Adapted from www.zoobauru.com.br.

**Microclimate Monitoring**

To monitor the microclimate in the food court, a mobile weather station was used with the following sensors: 1. Globe Temperature Sensor (Model 1: 0613 1712; manufacturer: Testo), built with official ping pong ball painted in gray-bourgeois (emissivity 0.9, solar reflectance 0.3); 2. Temperature and Humidity Data Logger (Model: Testo 175-H1); 3. Heated Sphere Omnidirectional Anemometer (Ø 3 mm, Model: 0635 1549; manufacturer: Testo); 4. Net radiometer (Kipp & Zonen manufacturer).

As this is a pilot study, with the aim to assess methodology for a larger project, the monitoring was carried out in just 2 days in warm weather conditions (October 26 and November 3, 2013), from 9 am until 4 pm, at intervals of 5 minutes. This Corresponds to 1 hour after the park opening team and one hour prior to its closing, During Which there is a greater number of people visiting the park.

**Structured questionnaires**

Structured questionnaires were applied to a sample of 115 users simultaneously to the monitoring
of the microclimate. The questionnaire (Figure 4) addressed a question about the Actual Sensation Vote (ASV) on a 7-point scale, and questions about thermal preference, feeling about the wind and relative humidity. Personal data of each user were also collected: age, gender, weight, height, clothing, activity developed.

In the questionnaires, users were divided into 3 age groups: children (under 12 years), teenagers (13-20 years) and adults/elderly (over 21 years). In this division, children had some difficulty in understanding the questions and required further explanation of each question so that they could give a response that reflected their real thermal perception.

This study was unable to establish an optimal sampling in view of the lack of quantitative survey of visitors by park management. Moreover, the greater permanence space analyzed is used only by part of the users and not all park visitors. Thus, the option was to interview the maximum number of people available, coming to a final number of 115 respondents.

![Figure 4](image)

**Figure 4** Part of the questionnaire applied.

**Thermal Comfort Index**

In-loco surveys were used as input data of RayMan software (Matzarakis, Rutz & Mayer, 2007), to calculate the index PET (Physiological Equivalent Temperature), developed by Höppe (2002). This index is widely used in Brazilian studies (Dacanal et al., 2010; Fontes et al., 2012; Labaki et al., 2012, among others), due to the representativeness of their results, and also the ease of use by RayMan software.

For the insertion of data in the software, it was necessary to calculate the mean radiant temperature with Software Comfort 2:02 (Ruas, 2002) and also the body surface of each user, using the formula of Dubois (http://www.sbn.org.br/equacoes/eq6.htm) for the conversion of metabolic rate in W/m2 for W. Thus, the PET index was determined for each user and the following analyzes were performed: 1. Distribution of the thermal sensation frequency (ASV) and the thermal preference of users (for all users and by age group); 2. Frequency of users’ thermal sensation in relation to ventilation and relative humidity; 3. Distribution of PET range for users in general and for different ages.

**RESULTS AND DISCUSSION**

During the fieldwork (October 26 and November 3, 2013), the data from the local weather station (IPMet) characterized the weather as hot and dry, with temperatures above the historical average for the months in question. In those days, the mornings were mild, with temperatures ranging from 23.8 °C to 24.9 °C at 9am in the early surveys, and reached 31.5 °C at 4pm, end of microclimate monitoring. The relative humidity reached the highest value of 73.7% and the lowest 40% in the afternoon.

The data collected in the Food Court showed more pleasant microclimates observed in the IPMet, due to the fact that it is a place partially shaded by vegetation. The difference in air temperature in these two sites got an average of 1.4°C and reached the highest value of 2.8°C at 10:15am of the second day.
Regarding the relative humidity data the values mean monitored in zoo were until 8.7% higher than values observed in IPMet.

Figure 5 shows the behavior of the temperature and relative air humidity over the two days of measurement at fixed measuring point in the park. The air temperature ranged from 22.6 to 31.9°C and relative air humidity from 41.9 to 75.2%. The graphs show the high temperatures and low humidity in the afternoon. These data contributed decisively to thermal perceptions in this period compared to those observed during the mornings.

![Graph showing temperature and relative humidity](image)

**Figure 5** Temperature and relative air humidity during the measurement days in Bauru.

Regarding the questionnaires, the profile of the respondents had similar numbers between the genders, with 52% male and 48% female. As to age, 39% were children under 12 years, 18% of young people under 20 years and 43% of adults and elderly, with almost all wearing light clothing in view of the high temperatures of the period. 70% of the respondents were from cities in the region or further afield and only 30% were local residents.

Users proved tolerant to high temperatures, since 87% of respondents stated to be feeling comfortable (thermal satisfaction), although the thermal sensation was "little warm" or "warm." This difference between satisfaction and thermal sensation is due mainly to the influence of psychological aspects, since that was a moment of leisure in an environment surrounded by greenery. However, users have shown little tolerant to solar incidence, avoiding some of the circulation spaces with great exposure of direct sunlight. There was a tendency for users to take shelter in places shaded by vegetation, such as the Food Court, and also in areas with built roofing, instinctively seeking milder microclimates.

During the afternoon, with increasing temperature around 32°C, many users felt uncomfortable, and indicated thermal sensation of "warm". Figure 6a shows the frequency of the Actual Sensation Vote (ASV) for the period, where it is possible to observe a significant number of people in a comfortable situation, but a greater number of people feeling uncomfortable by the heat (+1, +2 and +3).

Regarding thermal preference (Fig.6b), users preferred cooler temperatures (52.2%); the same temperatures (33.9%) or warmer (13.9%). There were differences in thermal preference in relation to time of day. In the morning the users preferred the same temperature or warmer. During the afternoon, the user preference was for lower temperatures.

As for the relative air humidity, 53% of users were satisfied, 31% considered dry and 19% wet. The analysis of the periods (morning and afternoon) shows that the perception of "dry" weather was concentrated during the afternoon (42-50%) and "wet" in the morning (50-75%). However, on this variable, users were satisfied throughout the day.

In relation to the wind, 57% of users said they felt satisfied with the condition of the moment and 43% thought there was little wind. The air velocity measured was low and varied from 0.2 to 2.4 m/s. This aspect can be attributed to roughness of the vegetation. This behavior was also found in research in the woods of the city Campinas-SP, Brazil, developed by Dacanal et al. (2010). The responses on this variable showed to be very subjective. There is no clear relationship between air velocity and thermal perception of the user.
Figure 6 Frequency of ASV and Frequency of Users’ Thermal Preference, respectively. 
ASV: scale: -3 = very cold, -2 = cold, -1 = little cold, = 0 indifferent, 1 = little warm, 2 = warm, 3 = very warm.

Figure 7 shows the ASV analyzed by age group (children, young people and adults/elderly). The total number of children interviewed was 45 and ASV this age group was distributed between "a little warm" (28.8%), "neither cold nor warm" (26.6%), "warm" (15.5%) "very warm" and 2.2% "a little cold." Among young people (21 respondents), the highlight was the "hot" ASV (42.9%) and "neither hot nor cold" (33.3%). The "a little warm" scale appears with values of 14.3% and "a little cold" with 9.5%. Among adults/elderly (49 respondents), the most prominent feeling is "hot", with 38.8%, followed by "neither cold nor hot" and "a little warm", both with 22.4%. The remaining reached 4%.

Figure 7  Comparison of actual thermal sensation ASV between age groups.

To define the range of comfort, the set of values of PET for each vote sensation was evaluated by means of statistical graphs Boxplot (Figure 8) which displays the PET data grouped according to the ASV, considering the total sample and the different range age (children, young people and adults/elderly). According to this graph, 50% of the central values for range of PET to the thermal neutrality were distributed between 23.5 to 29.1°C, with a median value of 25°C. This range shows values above the ones previously found by Fontes et. al (2012) for the city of Bauru (16-27 °C). However, the superposition with other intervals that indicate discomfort, either by heat or cold, makes it difficult to define precisely the limits of thermal comfort and thermal discomfort.

When analyzing the different age groups, the adults/elderly demonstrate greater tolerance to heat, with values of neutrality for PET between 25.1 to 30°C and a median value of 26.5°C. The values for the comfort range of other users are similar, i.e., they show values of PET from 23.2 to 26.5°C for children and from 22.1 to 26.7°C for young people and a median values of 24.3 and 24.1°C respectively.
The evaluation of the thermal environment of open spaces is important to create design guidelines that can help to improve the comfort and consequently the quality of life of users. In this study, developed in warm weather conditions, it was found that users of the park have little tolerance for direct solar incidence. Thus, for these weather conditions, future interventions should prioritize site shading, either through afforestation and/or built covers, not only in places of greater permanence, but also in the circulation spaces.

The assessment of the Actual Sensation Votes (ASV) pointed to a variation between the thermal sensations "neither cool nor warm", "little warm", "hot" and "very hot". Regarding thermal preference, most users preferred colder temperatures, specifically in the afternoon, when the air temperatures were very high (above 28 °C) and relative humidities were lower (around of 55%). The percentage of users who preferred the same local temperature was also significant.

In the microclimatic conditions evaluated, the range of thermal comfort found to PET index was 23.5 to 29.1 °C for the total sample. This range shows minimum and maximum limits above those previously found by Fontes et al. (2012) for the city of Bauru (16-27 °C). In both studies were there superposition that indicate ranges of comfort/discomfort, difficulty in proving the establishing clear limits of thermal comfort in open spaces, those already established in the literature. Regarding the analysis of the limits of thermal comfort by age groups, the differences between children and young people ranges were not significant (23.2-26.5 °C, 22.1-26.7 °C to children and young people respectively). However, the differences between those thermal comfort limits and of the adult/elderly group (25.1-30.0 °C) were higher. This result shows higher tolerant to heat for that age group.

For being a pilot study, the field survey carried out in just two days was sufficient to test the methodology for the larger project that aim analyse the user thermal comfort by age group. This research is unusual in surveys conducted in open spaces and can be used in architectural design in order

Figure 8 Range of PET related to ASV range of the users, and separated by age group: children, teens and adults/elderly. In the general graph, the percentage of respondents to ASV value to "Neither cool nor warm" is 26%.

CONCLUSION

The evaluation of the thermal environment of open spaces is important to create design guidelines that can help to improve the comfort and consequently the quality of life of users. In this study, developed in warm weather conditions, it was found that users of the park have little tolerance for direct solar incidence. Thus, for these weather conditions, future interventions should prioritize site shading, either through afforestation and/or built covers, not only in places of greater permanence, but also in the circulation spaces.

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For being a pilot study, the field survey carried out in just two days was sufficient to test the methodology for the larger project that aim analyse the user thermal comfort by age group. This research is unusual in surveys conducted in open spaces and can be used in architectural design in order
to prioritize the needs of the largest portion of users. Thus, in the case of Bauru Zoo, an environment comfortable for children’s recreation may prevail over the other, creating more pleasant spaces and encouraging the permanence of that public.

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Environmental sustainability in scholastic facilities: an integrated assessment of building and food

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ABSTRACT

A methodology for the integrated sustainability assessment of schools facilities is presented together with its application to a case study in Milan. The study uses quantitative indicators such as non-renewable primary energy to quantify the total amount of energy used by student related to building energy consumption for comfort conditions and to food embodied energy consumed in the school canteen (from agricultural production to the cooking stage). The result is a critical review of possible sustainability improvements of the school service. In particular heating and electricity uses and food consumption are shown in the form of non-renewable primary energy. The final part describes the main improving strategies and measures their effectiveness in terms of primary energy reduction, expressed in terms of MJ per student per year of non-renewable energy. The proposed strategies include improvement measures on building envelope and on diet changes towards low energy scenarios.

INTRODUCTION

The work presented in this paper is part of the “Bioregione” research, funded by Fondazione Cariplo (www.fondazionecariplo.it). It illustrates a summary of the current state of development of the methodology Elar (Ecodynamic Land Register) with data relating to the school service. Elar is a methodology to support energy and food integrated plans aided by application tools. The aim is to guide the suggestion of local self-sufficiency scenarios in an area defined as local (Clementi, 2008).

Thus, in accordance with the bioregional paradigm, this methodology should be used as a tool to assess the achievement of the self-sufficiency in local areas of different entity, from the municipal scale to larger areas.

The Bioregion research aims to propose different scenarios to bring together the local demand of catering and the supply potential of the region of Lombardy considering the public facilities sector.

As the school service is one of the main actors who express the collective demand for food in the regional area, Elar has been implemented in such a way as to allow the evaluation of the environmental impacts of the school service.

These activities allow the achievement of two main aims:

1. the development of different scenarios to bring together the local demand of catering and the supply potential of the region of Lombardy considering the school sector (the main aim of the Bioregion research);
2. the development of the database to support Elar, with useful data to integrate the school service in the development of integrated food and energy plans.

All the data collected in this phase of the investigation allow to compare the energy consumption of buildings (energy consumption for heating and electricity) with the energy consumption due to the food supply chains.

In this way it is possible to assess the whole school service and to evaluate its sustainability level. Using quantitative indicators (such as the primary energy amount) and an appropriate functional unit (such as the annual primary energy consumption per student) it is possible to verify the effectiveness of different improvement scenarios.

**METHODOLOGY**

The main stages of Elar are the evaluation of the local demand for energy and matter and the implementation of local self-sufficiency scenarios through the adoption of best practices (stored in a specific database). The first aim is to reduce the energy and matter demand in the school sector, the second one is to better understand how the energy and matter demand could be satisfied by the local and renewable supply.

The studies conducted in the school sector reported in this text are related to the first phase, and they aim at reducing the energy and matter levies.

The ways to reduce the consumption of energy and matter in the school sector are listed in a database that shows different studies and data taken from the literature about specific best practices potentially transferable to the case studies investigated.

The transferability of good practice are related to the awareness of similar conditions related to the case study under analysis.

Considering the energy consumption of school buildings, similarities must be verified by the following points:

1. Climatic conditions (the same/similar weather conditions)
2. Use condition (the same use of the building)
3. Technological features (similar thermo-physical properties of the envelope an systems features)
4. Geometric features (similar ratio between surface and volume and between transparent/opaque areas)

Considering food consumption, similarities must be verified by the following other points:

1. Climatic conditions (to associate information on best practices about food production in the local context)
2. The number of users
3. The type of users (age of groups, etc.)

The choice of several alternatives is entrusted to impact indicators such as the accounting for primary energy and equivalent productive land (basic condition for estimating the level of local self-sufficiency).

In this first phase, the primary energy amount is the impact indicator considered.

Up to date, the applications of Elar (Clementi, Scudo, 2013) have mainly been related to the residential sector and to the population food demand and mobility.

The research presented in this text deals with the evaluation of integrated services focusing on the school service.

Future insights will be related to other types of services, such as health services, sports and public administration in order to have a most comprehensive scenario of all the activities that have taken place in the area under analysis.

Following the general steps of Elar, the next part of the text is organized as below:

1. Information about the energy consumption of the school sector in Italy is presented;
2. The case study and its energy/matter demand during a year is shown (considering all its
3. Information on best practices for upgrading school buildings is shown, highlighting the possibility of reducing the energy consumption and the ability to use renewable energy (such information is stored in the Elar database of good practices).

4. Some of the possibilities to reduce the demand for energy and matter relating to the food supply system are suggested.

5. In the final part of the text, an integrated assessment of the effectiveness of the strategies is shown, identifying the relative weight of the different strategies on the total non-renewable primary energy consumed per student each year.

THE ENERGY CONSUMPTION OF SCHOOL BUILDINGS IN ITALY

The overall energy consumption of all the Italian public schools (representing approximately the 85% of the total energy consumption in the schools sector) and private schools, was estimated at 990,000 Tep/year, of which 762,000 of fuel for heating and 228,000 of electricity.

Italian schools consist of 62,217 buildings and they comprise up to 8,845,213 students.

In the Italian case, considering that a Tep is equal to 11,630 kWh, the fuel consumption would amount to 886,060 MWh and the primary energy consumption for electricity would be equal to 2.65164 million of MWh.

The contribution per student in Italy would amount to 1,002 kWh/student = 3,606 MJ/student and electricity consumption is equal to 299 kWh/student/year = 1,079 MJ.

Dividing this last value by the efficiency of the national electricity system (45.9%), it appears that the annual electricity consumption per student amounts to 137 kWh/year. The total energy consumption for the school service in Italy amounts to 4,685 MJ/student.

THE CASE STUDY: A SCHOOL BUILDING IN MILAN

The case study is a primary school building in a district in the east side of Milan. It houses 300 students and it is occupied in the morning and in the afternoon from Monday to Friday (from 8am to 5pm).

Figure 1, 2. Aerial view of the school in Milan taken as case study (source: Google Maps) and view of the south façade.

Climatic factors

Degree days 2,404 (comfort temperature: 20°C)
Annual solar radiation incident on a horizontal surface: 1,450 kWh/ m²

Geometrical features

Floors above ground: 3
Eaves height: 15 m
Net area: 4,362 m² (the total area amounts to 14.6 square meters per student)
Value of S/V of the building: 0.38
Technology features

The opaque vertical envelope is composed of two types of both full plastered brick, the first one covers 4,290 m², the thickness is 17 cm, the thermal transmittance is 1.34 W/m²K; the second one constitutes the masonry spandrel and it covers 520 square meters, the thickness is 43 cm, the thermal transmittance is 2.46 W/m²K.

The vertical windows are composed of wooden frame with single glazing and they cover 1,341 m², the thermal transmittance is 5.7 W/m²K.

The total vertical surface amounts to 6,151 m², so the transparent surface occupies the 22% of the total vertical surface. The part of the opaque envelope with higher value of transmittance amounts to 8, 5%. The thermal transmittance of the covering amounts to 1 W/m²K, of the ground slab 0.7 W/m²K.

Energy Consumption for heating in winter

The building annually consumes 146 kWh/m² of natural gas. Since the square meters per student amount to 14.6 m², the per capita consumption of non-renewable primary energy is 2,132 kWh/student, equal to 7,673 MJ/student.

Electrical consumption

Breaking down the energy consumption of the building the following items emerge:
- power consumption of the heating plant: 12,500 kWh (29%)
- personal computer: 7,500 kWh/year (18%)
- Copiers: 1,000 kWh/year (2%)
- washing machine: 400 kWh/year (1%)
- Lighting system: 21,000 kWh (50%) ..

Adding together all the components, the total energy consumption for the building is equal to 42,400 kWh of electricity, equal to an amount of non-renewable primary energy of 1,107 MJ per student.

ENERGY UPGRADE STRATEGIES ON THE BUILDING

The assumptions relating to the possible ameliorative actions to reduce energy consumption of the building were chosen among similar cases in the database of Elar. The Pirandello primary school in Moncalieri (province of Turin) was adopted as case study, cause of similar climatic conditions and similare geometrical and technological features.

Climatic factors

Degree days 2,553 (comfort temperature 20°).
Annual solar radiation incident on a horizontal surface 1,470 kWh/m²

Geometric factors

Floors above ground: 3
Gross surface area of 5,049 m²
Value of S/V of the building: 0.35
Vertical dispersant surface 3,363 m², % of total glazed area of the vertical surface 30%.

Technological factors

Opaque vertical envelope transmittance of walls 1.45 W/m²K, transparent surfaces 6.1 W/m²K, covering 0.31 W/m²K, ground slab 1.44 W/m²K.

Energy consumption before the intervention

The real energy consumption for heating in the case of Pirandello school is 759,069 kWh, the gross volume amounts to 19,441 cubic meters, so the real consumption per cubic meter would be 39 kWh,
similar to the value of the school of Milan. In this latter case the actual consumption amounts to 146kWh/m² considering the net height of each floor of 4 m, the consumption for each cubic meter would amount to 36.5kWh/m³.

**Energy upgrading strategies on the building**

The actions proposed in the case of Pirandello school in Moncalieri, are extracted from the data published by Silvia Tedesco (Tedesco, 2010) and consist solely of measures to improve the performance of the building envelope. They provide insulation of the ground floor, the insulation of opaque vertical external envelop, roof insulation and replace the transparent parts with double-glazed windows with low-emittance layer, thermal transmittance 2W/m²K.

In the case of the vertical opaque the upgrading intervention was hypothesized to isolate the masonry from the inside with polystyrene pre-coupled panels and plasterboard, not to lose the aesthetic connotation given by the presence of the elements in the facade. The implementation of this intervention guarantees a reduction of the heat dispersions for transmission greater than 60%. The thickness of the insulation measures 5 cm and 1 cm plasterboard.

The estimated reduction in primary energy consumption result of the proposed actions would amount to 65% of total consumption, going from 53.52 kWh/m³/year to 18.61 kWh/m³/year (theoretical continuous operation).

In the case in Milan adopting the same types of intervention consumption for heating could be reduced by the same percentage, then passing from 146 kWh/m² to 51kWh/m², the contribution per student would therefore decrease from the current 7,673MJ/year to 2,686MJ/year.

**STRATEGIES TO REDUCE ELECTRICITY CONSUMPTION**

An additional intervention to reduce energy consumption could be provided replacing the lighting systems with LED lamps instead of fluorescent lamps. By adopting this solution, the actual consumption of 21,000 kWh would be reduced to 16,800. Such a calculation was performed by estimating an efficiency of 85 lumens/watt, compared to 65 lumens/watt related to fluorescent lamps. The reduction in consumption would amount to 20%, it would affect 10% of total electricity consumption (electricity s1 in Figure 4).

Considering the orientation of the building the installation of a photovoltaic system on the roof can be an effective solution. The system could perform energy exchange with the local power grid. One square meter of PV system tilted at 15 ° and facing south, allows the production of about 150 kWh of electricity (solar values extracted from the “pvgis” solar atlas with a safety margin of 5%, www.re.jrc.ec.europa.eu/pvgis/), the production of 141 kWh of electrical energy per student would require the installation of 0, 94 square meters per student of PV polycristalline collectors with the same orientation and tilt. 282 square meters of photovoltaic panels are therefore needed on the roof. The surface of the roof slopes facing south is sufficient to accommodate such an amount of solar panels, consequently, the balance between the consumption and the production of electricity in a year will be equal to 0 (electricity s2 in Figure 3).

**ENERGY FOR FOOD SUPPLY AND CONSUMPTION**

After noting that the number of students in the school is 300, estimation of food demand relative to meals eaten at school was carried out as follows:

The type of food in terms of the proportion of each type compared to the total mass was derived by taking the same proportions determined from the total food purchased in the urban area of Milan by the public school canteens (Spigarolo, 2014). The main foods between those consumed each year were taken into account, particularly those whose weight consumed per year per student exceed 1 kg (Table 1).
Table 1. Amount of food consumed annually by each student in the school canteen (only quantities exceeding a kg were considered) and primary energy.

Data sources related to the primary energy content associated to each food are reported in the references in the following order (a: Mila I Canals et al., 2008; b: Assomela, 2012; c: www.lcafood.dk; d: De Cecco, 2010; e: Karakaya, 2011; f: Gonzales et al, 2011)

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<td>Potatoes</td>
<td>10.16</td>
<td>9.85</td>
<td>55.87</td>
<td>c</td>
</tr>
<tr>
<td>Yogurt</td>
<td>4.13</td>
<td>15.52</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Oranges</td>
<td>2.62</td>
<td>8.77</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Carrots</td>
<td>6.54</td>
<td>11.05</td>
<td>35.95</td>
<td>c</td>
</tr>
<tr>
<td>Pears</td>
<td>3.06</td>
<td>10.25</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Lettuce</td>
<td>1.96</td>
<td>3.32</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Lettuce out of season</td>
<td>1.96</td>
<td>98.21</td>
<td>0.00</td>
<td>f</td>
</tr>
<tr>
<td>Pasta</td>
<td>8.13</td>
<td>127.65</td>
<td>44.72</td>
<td>d</td>
</tr>
<tr>
<td>Zucchini</td>
<td>3.88</td>
<td>6.55</td>
<td>21.32</td>
<td>c</td>
</tr>
<tr>
<td>Eggs</td>
<td>2.06</td>
<td>18.88</td>
<td>11.33</td>
<td>c</td>
</tr>
<tr>
<td>Rice</td>
<td>3.24</td>
<td>22.03</td>
<td>17.82</td>
<td>c</td>
</tr>
<tr>
<td>Tangerines</td>
<td>2.82</td>
<td>9.44</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Poultry meat</td>
<td>5.20</td>
<td>91.53</td>
<td>28.60</td>
<td>c</td>
</tr>
<tr>
<td>Tomato sauce</td>
<td>1.86</td>
<td>18.91</td>
<td>10.20</td>
<td>e</td>
</tr>
<tr>
<td>Beef</td>
<td>2.45</td>
<td>191.31</td>
<td>13.50</td>
<td>c</td>
</tr>
<tr>
<td>Olive oil</td>
<td>2.57</td>
<td>61.59</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Fresh cheese</td>
<td>3.51</td>
<td>155.63</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Tomato</td>
<td>1.22</td>
<td>3.66</td>
<td>0.00</td>
<td>f</td>
</tr>
<tr>
<td>Tomato out of season</td>
<td>1.22</td>
<td>61.07</td>
<td>0.00</td>
<td>f</td>
</tr>
<tr>
<td>Milk</td>
<td>3.40</td>
<td>12.78</td>
<td>0.00</td>
<td>c</td>
</tr>
<tr>
<td>Fennel</td>
<td>2.66</td>
<td>4.50</td>
<td>14.63</td>
<td>c</td>
</tr>
</tbody>
</table>

The estimate concerning the non-renewable primary energy demand for food has been carried out using data from the scientific literature covering the main part of the food chain from production in the field up to the cooking. The stage of waste management are excluded from the counting. The table in figure 3 relates the annual food consumption to the amount of non-renewable primary energy used for the food production and cooking. To estimate the contribution of energy for cooking, the same value for all food cooked was adopted (equal to 5.5 MJ / kg), as an average value between the available data on cooking of vegetables, pasta, rice and meat (Carlsson Kanyama et al, 2001).

The total non-renewable primary energy consumed annually by each student for food consumption amounts to 2,127 MJ/year.

SCENARIOS TO REDUCE THE ENERGY CONSUMPTION IN FOOD DEMAND

The diet proposed to reduce energy consumption related to food demand consists of the following strategies:
1. Replacement of frozen vegetables with seasonal vegetables.
2. Replacement of vegetables produced in greenhouses with seasonal vegetables.
3. Replacing beef with chicken meat.
4. 50% reduction in protein intake from animal foods and replace them with foods of vegetal origin characterized by the same amount of protein.

To assess the relative weight of each action on the total, various scenarios are formulated. They allow to verify the contribution of different strategies to weigh the relative reduction compared to the total.

The first concerns the elimination of frozen vegetables, replaced with seasonal vegetables. The percentage reduction compared to the total primary energy used for feeding amounts to 7.3%.

The second adds to the strategies of the previous scenario the elimination of the vegetables grown in greenhouse, replacing them with seasonal vegetables. The percentage reduction compared to the total primary energy used for feeding increases to 17.4%.

The third suggests to replace beef with chicken meat: the percentage reduction compared to the total primary energy used for feeding increases to 26.9%.

The fourth is a further improving effect of the scenario 3 and foresees the replacement of 50% of the proteins derived from animals, (poultry meat and dairy products) with proteins of vegetal origin (in this exemplary case legumes). The percentage reduction compared to the total primary energy used for feeding increases to 30.6%.

**CONCLUSIONS**

Performing an assessment of the aggregate possible strategies, it appears that the use of non-renewable primary energy per student may be reduced by a percentage equal to 63.7%.

In summary, it is the result of a 65% reduction in fuel consumption for heating due to energy efficient refurbishment of the building, a neutral electricity budget achieved through the installation of a photovoltaic system on the roof, and a reduction of the energy used to produce the foodstuffs consumed in the school canteen at 30.6%.

As mentioned in the introduction, the experimental approach adopted in this study is aimed at the creation of tools to support the achievement of self-sufficiency at the local scale, through the development of integrated food and energy plans.

The spread and development of this approach are closely related to the intention by public institutions and local communities to build more resilient regional systems, based on the use of locally available resources and less dependent on fossil fuels.

The calculation of non-renewable primary energy applied to all consumption categories that characterize the service provided is therefore a first essential step in this direction. The next step has not been treated in this text and has been presented in other publications (Scudo et al., 2013), it concerns the attachment to the primary energy accounting of the extension of local land needed to produce the food and renewable energy sources, intended as potential energy supply.

**ACKNOWLEDGEMENTS**

We wish to thank Professor Maria Fianchini for providing data concerning the characteristics and actual consumption of the school building under analysis (Ferrazza, Galimberti, Tondini, 2007), and Roberto Spigarolo for providing data on food consumption of the scholastic sector in the urban area of Milan (Spigarolo, 2014).
Figure 3. Comparison among items that constitute the total non-renewable primary energy per student per year. Items followed by the letter "s" refer to the improved solutions proposed in the scenarios presented in the text.

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Milà i Canals, L., Muñoz, I., Hospido, A., Plassmann, K., McLaren, S. 2008. Life cycle assessment (LCA) of domestic vs. imported vegetables. Case studies on broccoli, salad crops and green beans. Published by:Centre for Environmental Strategy, University of Surrey, Guildford (Surrey) GU2 7XH, United Kingdom.


Towards Sustainable Modular Housing: A Case Study of Thermal Performance Optimisation for Australia

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ABSTRACT

The need for affordable housing is a growing issue requiring sincere and urgent attention globally. With increasing focus on climate change and other environmental issues our housing must be environmentally sustainable too. We also need housing in remote areas where conventional construction is both cost and resource inefficient. Prefabrication offers great opportunities for both sustainability and affordability and hence is emerging as an attractive alternative to conventional on-site construction.

In this context, the CRC for Low Carbon Living in Australia has been engaged to develop designs for sustainable and affordable modular homes. The early optimisation was undertaken using AccuRate Sustainability – Australia’s national benchmark software tool for rating the thermal performance of residential designs. An iterative process was employed where the rating software was used as a design and analytical tool to generate optimised designs for various orientations and climate zones throughout Australia. This paper explores the process of improving the performance of an existing design and developing a thermally optimised new design, and presents some of the early results of this optimisation.

The results show significant improvements in the thermal performance when compared to the existing design, but more importantly, the combined engineering and design research efforts developed general design principles that seemed to work well for most of the climates and orientations studied. This research contributes to the debate on integrative design process and its significance for sustainable built environment in general; it also ascertains the path forward for a more comprehensive approach to net zero energy and self-reliant modular housing – the eventual aim of the project.

INTRODUCTION

The need for adequate affordable housing is now considered a major issue in both industrialised and emerging countries (St Andrews Centre for Housing Research et al., 2014). With increasing focus on climate change mitigation and adaptation along with other environmental concerns these housing solutions need to be environmentally sustainable too. Both in Australia and overseas prefabricated housing solutions have been identified and are being proposed as an important path that can deliver both sustainable and affordable housing (Quale, 2012; The Greens, 2013). There is also a significant need for
adequate solutions for remote area housing (regional communities, mining towns, emergency shelters, etc.) where conventional on-site construction is both costly and resource inefficient. Off-site construction or prefabrication in such situations becomes an especially attractive alternative.

In this context a multidisciplinary research team at the Cooperative Research Centre for Low Carbon Living (CRCLCL) has been engaged by Nova Deko, a modular housing manufacturer, to develop design solutions for ‘Sustainable and Affordable Living through Modular, Net Zero Energy, Transportable, and Self-Reliant Homes and Communities’(Low Carbon Living CRC, 2014). The project is currently in its second year and this paper explores the recently completed first stage of this project – improving the operational performance of an existing design – and discusses the process of developing a thermally optimised new design for sustainable modular housing as per Nova Deko’s requirements.

This paper presents the findings from the early thermal performance optimization process – a combined engineering and architectural design research effort – that started with the original design called ‘Samara Pod’ and finished with the creation and optimization of the final improved design called ‘conceptPod’. An important part of this process was the well-designed integration of various services including domestic hot water, photovoltaic (PV) system, electrical services, equipment, white goods, and rainwater harvesting. The reason for this was twofold. First, to achieve a standardised and integrated product, so the installation of the complete Pod is easier, quicker, and therefore more cost effective. Second, to apply whole systems thinking during thermal performance optimization so the final design was efficient not only operationally but also throughout its lifecycle. In order to maintain the focus on the subject matter and in response to the space limitations here, however, the research on PV and other services integration is considered out of scope for this paper. The research presented here is a work in progress and achieving a net zero energy or self-reliant status, the eventual aim of the project, will be subject to further optimisation and renewable energy, water and waste system integration.

METHODOLOGY

The research for the project began with a study of literature on theory and practice of prefabrication and then employed an ongoing collaborative and integrative design process. The optimisation was performed as an iterative process using AccuRate Sustainability, a Nationwide House Energy Rating Scheme (NatHERS) accredited software, which measures thermal performance based energy efficiency of residential designs in Australia (CSIRO, 2014). The software, from here on referred to simply as AccuRate, was tested and validated using the Internation Energy Agency BESTEST protocol and was found to be very satisfactory (Delsante, 2005). During simulation AccuRate automatically switches between mechanical air conditioning and natural ventilation modes to maintain indoor thermal comfort within parameters specified by regulatory requirements. In doing so it calculates heating and cooling demands to maintain comfort conditions over a whole year. The total annual energy load (MJ/m2) expresses the overall thermal performance in a star rating for the specified climate zone. The rating ranges between 0 and 10 stars where a 0-star indicates the building envelop practically having no effect in reducing thermal discomfort while at 10-star performance the occupants are likely to need little or no mechanical cooling or heating to maintain comfort (Ren et al., 2013).

The National Construction Code’s Building Code of Australia (BCA), in the absence of any specific state level regulations, requires all new houses to meet the minimum thermal performance of 6-stars for their regulatory approvals. Considering that the subject design will anyway need to be rated for regulatory compliance and that AccuRate has robust modeling capabilities to use it as a design decision making tool the research team decided that AccuRate was a very suitable tool for this particular research. The objective was to achieve as high a start rating as possible thereby minimising the size of a PV system to offset the remaining energy requirement.

The scope for this study included five key climate zones from Australia and eight orientations for each zone. The iterative process was designed so that the pod design and its thermal performance was improved to a satisfactory level for one climate and then that optimized design was used as the base model for improvement in the following climate, and so on. The idea behind this was to test if the “good
design principles” applied in one climate could serve as a good starting point for a similar climate. To apply this approach the researchers used the following climate sequence: Brisbane, Sydney, Melbourne, and Hobart, i.e., from North to South, or warm to colder climates. Finally, the climate of Darwin, which is located further north, was also tested taking Brisbane results as the base model.

The process was essentially a parametric study where three key strategies – shading, insulation and glazing – were tested and parameters, such as type, position and amount of glazing, shading and insulation, were changed individually in order to reach local and global optima. Although this required several iterations, due to space limitations only the first and the last simulation results are presented here. Three main types of shading devices tested were fixed horizontal, fixed vertical (wing walls), and “operable shading” such as operable louvers or sails. The performance of several types of glazing options were analysed mainly based on their U-value (W/m²K) and solar heat gain coefficient (SHGC) value. Different types and levels of insulation based on their R-values (m²K/W) were also tested for each location. As a general principle, the level of insulation was maximized and glazing was reduced, while trying to maintain good cross ventilation and connection with the outdoors. The optimization was finalised when no further meaningful improvements in the thermal performance (measured by star rating from the AccuRate simulation) could be achieved by modifying Shading, Glazing, and Insulation.

Changes in other parameters of the design were scheduled for the next stages of the project and hence were considered external to the scope for this particular exercise. Nevertheless, design quality and aesthetics of the interior spaces and the exterior, services and technology integration, weight of the completed Pod, and non-thermal environmental concerns were always part of the consideration even if they are not elaborated on in this paper due to space limitations. In every climate the simulation was started with the orientation of the front façade with bi-fold doors at the North before testing other orientations. The exposure was kept Suburban and ground reflectance as 0.2 in all AccuRate simulations.

EXISTING DESIGN AND ITS PERFORMANCE

The study started by taking the existing design of Samara Pod as the base model for Brisbane. The house with a simple rectangular floor plan (Figure 1) is manufactured with lightweight steel framing in a wide 40 foot shipping container size. The design has been developed so that a nearly complete house would be shipped to any site. With minimum onsite assembly requirements, except when other external features such as outdoor deck and additional shading were required, the house would be ready to occupy in a matter of days after arriving on site (Figure 2). The first AccuRate simulation was based on material specifications listed in Table 1 and produced a rating of 5.1 stars with detailed results tabled in Table 2.
Table 1. Specification of Samara Pod Base Model

<table>
<thead>
<tr>
<th>Element</th>
<th>Construction</th>
<th>R value (Up/Dn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall</td>
<td>FC board/Reflective Barrier/Insulation/Plaster Board</td>
<td>3.38 / 3.38</td>
</tr>
<tr>
<td>Internal Wall</td>
<td>Plaster Board/Air Gap/Plaster Board or FC board</td>
<td>0.44 / 0.44</td>
</tr>
<tr>
<td>Roof/ceiling</td>
<td>Steel/Ref. Barrier/Insulation/Plasterboard</td>
<td>4.12 / 4.35</td>
</tr>
<tr>
<td>Floor</td>
<td>Timber/FC board/Insulation</td>
<td>3.05 / 3.05</td>
</tr>
<tr>
<td>Windows</td>
<td>Glass/Air Gap/Glass; SHGC = 0.48; U = 3.92</td>
<td>0.25</td>
</tr>
<tr>
<td>Shading</td>
<td>As per Samara Pod (900mm North, 320mm rest)</td>
<td>NA</td>
</tr>
<tr>
<td>Underfloor</td>
<td>Enclosed 500mm height subfloor</td>
<td>NA</td>
</tr>
</tbody>
</table>

PERFORMANCE OPTIMISATION ACROSS DIFFERENT CLIMATES

Brisbane is located in a subtropical (no dry season) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). The performance of the base model in Brisbane indicated disproportionate energy use in cooling. To address this issue main priority was given to reducing the amount and altering the type of glazing to reduce heat-gain. Through intense integrative design exercises a series of changes were identified and simulated. This included minor modifications to the internal layout mainly to redesign the bathroom and laundry to achieve better integration of various services. Key changes were in the building envelope for strategic placement of a mix of different types of high performance glazing (U=1.5 and SHGC=0.5 or less) especially on the East and West, and various types of shading devices especially on the North. With the help of these changes the optimised design – the conceptPod – was finally able to achieve 7.6 stars with total energy demand reduced to about 55% of the Base Model when the glazing area to floor area ratio was reduced to about 52% from the original 64%.

Table 2. Thermal Performance Improvement of conceptPod Base Model in Brisbane

<table>
<thead>
<tr>
<th>Description</th>
<th>Heating (MJ/m²)</th>
<th>Total Cooling (MJ/m²)</th>
<th>Total Energy (MJ/m²)</th>
<th>Rating (Stars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model conceptPod</td>
<td>12.3</td>
<td>41.0</td>
<td>53.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Optimised conceptPod</td>
<td>10.3</td>
<td>19.2</td>
<td>29.5</td>
<td>7.6</td>
</tr>
</tbody>
</table>

As discussed earlier the conceptPod for Brisbane was taken as the Base Model for Sydney, which is located in a temperate (no dry season – warm summer) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). The simulation for Sydney rated the design at 7.0 stars. Several modifications were made to the design, mainly shading and wing walls size and positions, but the best results were obtained with operable shading to the North allowing winter sun in the living areas and the bedroom, and deep shading in the form of a carport to the East. This gave a rating of 7.9 stars (Table 3).

Table 3. Thermal Performance Improvement of conceptPod Base Model in Sydney

<table>
<thead>
<tr>
<th>Description</th>
<th>Heating (MJ/m²)</th>
<th>Total Cooling (MJ/m²)</th>
<th>Total Energy (MJ/m²)</th>
<th>Rating (Stars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model conceptPod</td>
<td>12.7</td>
<td>17.1</td>
<td>29.9</td>
<td>7.0</td>
</tr>
<tr>
<td>Optimised conceptPod</td>
<td>7.8</td>
<td>15.2</td>
<td>23.0</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Melbourne has a temperate (no dry season – warm summer) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). When the optimized design for Sydney was tested for Melbourne, it rated at 6.9 stars, a decrease of 1 star compared with Sydney. A large number of changes in shading, glazing size and insulation were made without any significant improvement to the overall performance. It was only after converting most of the glazing into high performance glazing equivalent to top of the range double glazed windows that the rating of the Pod increased to 7.7 stars (Table 4).

Table 4. Thermal Performance Improvement of conceptPod Base Model in Melbourne

<table>
<thead>
<tr>
<th>Description</th>
<th>Heating (MJ/m²)</th>
<th>Total Cooling (MJ/m²)</th>
<th>Total Energy (MJ/m²)</th>
<th>Rating (Stars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model conceptPod</td>
<td>59.0</td>
<td>27.3</td>
<td>86.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Optimised conceptPod</td>
<td>36.6</td>
<td>27.0</td>
<td>63.6</td>
<td>7.7</td>
</tr>
</tbody>
</table>
Hobart has a temperate (no dry season – mild summer) climate as per a modified Koppen classification (Bureau of Meteorology, 2012) and has a large proportion of energy use in heating spaces. Surprisingly, when the Melbourne design was simulated in the Hobart climate the obtained rating was, already higher than Melbourne, at 8.1 stars. A similar result was obtained with the base Samara Pod, which achieved a 6.0 star rating, highest so far of all tested climates. Because the obtained rating with the conceptPod was already above 8 stars, the optimization for this climate was based on obtaining the best rating possible while limiting the standard double glazing in the main windows for the living area and the bedrooms. Finally, with strategically placed high performance glazing and carefully sized and positioned operable horizontal and vertical shades the final design resulted in a rating of 7.6 stars.

<table>
<thead>
<tr>
<th>Description</th>
<th>Heating (MJ/m²)</th>
<th>Total Cooling (MJ/m²)</th>
<th>Total Energy (MJ/m²)</th>
<th>Rating (Stars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model conceptPod</td>
<td>64.0</td>
<td>4.6</td>
<td>68.6</td>
<td>8.1</td>
</tr>
<tr>
<td>Optimised conceptPod</td>
<td>82.1</td>
<td>7.1</td>
<td>89.3</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Darwin is on the other end of the climate spectrum when compared to Hobart. It is located in the tropical (Savana) climate as per a modified Koppen classification (Bureau of Meteorology, 2012). Because of its proximity with the equator, the sun here can be in the South (summer) as well as in the North (winter). This meant that shading on both of these façades had to be considered very carefully. For this climate the optimized Brisbane Pod was taken as the based model. The first simulation showed a rating of 5.9 stars, the lowest rating obtained so far for any first iteration. After several changes, without much improvement, the highest rating of 7.2 stars was obtained when all Northern windows were made high performance glazing equivalent to triple glazing, insulation was maximized everywhere and 450mm fixed horizontal shading, similar to an eave, was added to all facades. However, the aesthetics of this solution remained unresolved with an intention to revisit the design and thermal performance improvement strategies employed in this climate. The maximum rating of 7.2 stars is the lowest achieved for all climates after the optimization and may be indicative of the limits of the current Pod design, its size or the small number of improvement strategies tested so far.

<table>
<thead>
<tr>
<th>Description</th>
<th>Heating (MJ/m²)</th>
<th>Total Cooling (MJ/m²)</th>
<th>Total Energy (MJ/m²)</th>
<th>Rating (Stars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Model conceptPod</td>
<td>0.0</td>
<td>356.8</td>
<td>356.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Optimised conceptPod</td>
<td>0.0</td>
<td>275.3</td>
<td>275.3</td>
<td>7.2</td>
</tr>
</tbody>
</table>

**ORIENTATION SENSITIVITY ANALYSIS**

The designs of Samara Pod and climate optimised conceptPods when simulated for all five climate zones across eight orientations they produced results as illustrated in Figure 3. The Brisbane results show that the conceptPod performs relatively well (above or close to 6 stars) for five of the eight orientations, mainly between North and East. The performance decreased markedly when the Pod was oriented to the South and West, with the West having the lowest thermal rating (4.7 stars) due, not surprisingly, to the increase in required cooling. The overall performance of the conceptPod showed improvements between 1.5 to 3.0 stars when compared to the Samara Pod. It is important to notice that the conceptPod design not only achieves a better rating, but is also more resilient to orientation changes.

Similar to Brisbane, in Sydney the conceptPod performs consistently 2 to 3 stars better than the base Samara Pod. In this case however, the performance penalty in the west and south orientation are less pronounced, with a minimum rating of 5.8 stars when facing west. This is an encouraging result as it shows a greater flexibility and resilience of the design to orientation changes. The conceptPod achieves near or above 6 stars rating across all orientations.

The results of the simulations show that orientation has lesser effect in Melbourne than in Sydney or Brisbane. This supports the hypothesis that in Melbourne the thermal performance is dominated by the R value of the envelope and quality of windows, instead of the solar gain. The Pod performs very
well in all the orientations, with a minimum rating of 7.0 stars for the West orientation. This is also true for the base Samara design which obtains a more consistent performance for all orientations. The conceptPod performs consistently around 2.5 stars better than the base Samara Pod.

**Figure 3**  Orientation sensitivity analysis of Samara Pod and conceptPod

As evident in Figure-3 both the Samara Pod and the conceptPod perform very well in Hobart, although the conceptPod obtains minimum 1.5 stars more than Samara Pod across all orientations. It is worthwhile to note that, similar to Melbourne, the orientation of the Pods has less effect on the thermal performance, with only 0.8 stars and 0.7 stars of difference between the minimum and maximum rating for the Samara Pod and the conceptPod respectively. This may be due to the lesser effect of solar gain, optimised adaptive shading and highly insulated building fabric minimizing heat-loss from the Pods.

In Darwin the conceptPod performed reasonably well with performance varying between 6.6 stars as minimum on East and 7.2 stars as maximum on North (a difference of 0.6 stars). On the other hand, the base Samara Pod performed poorly, with a maximum rating of 3.6 stars when facing South, and a
minimum rating of 2.1 stars for East and West orientations. This is a strong result showing the resilience and adaptability of the conceptPod design.

**IMPROVED DESIGN AND ITS PERFORMANCE**

All the lessons learnt from the optimization in each climate were applied to create a final design. The objective was to create a conceptPod that would work as best as possible in each climate. Even if the performance in some locations might be less than optimized, it could still have a good performance. This approach of standardisation, although counterintuitive and contrary to the notion of mass-customisation, was found to offer good manufacturing efficiencies for this particular manufacturer as it would require minimal changes in the Pod depending on the final location of the installation. In order to achieve this, further reviews of the effects of insulation levels and glazing types were carried out. It was found that two main insulation configuration (external wall/roof/floor) could be used in the Pod design depending on the location, for example, \( R = 4/4/2 \) for warm/hot climate such as Brisbane and Darwin, and \( R = 6/6/2 \) for mixed/colder climate such as Melbourne. Similar testing of glazing alternatives found that it was more effective to upgrade the main windows from double to triple glazing than to improve the insulation in the walls and roof from R4 to R6. It was also encouraging to find that the combination of triple glazing and insulation of \( R=6/6/2 \), resulted in ratings above 8 stars for Brisbane and Melbourne.

![Figure 4](image.png)  
**Figure 4** New integrated design of the conceptPod viewed from the North

The final conceptPod included carefully sized and located fenestrations with a mix of different types of high performance glazing. In combination with a mix of fixed and operable horizontal and vertical shading devices they simultaneously satisfied critical requirements of a good design – views, connection with the landscape, sense of spaciousness, privacy, aesthetics, and so on – and the essential aspects of a high thermal performance building – precise solar protection, passive solar heating, effective crossflow ventilation, and so on – to result in a truly integrated design.

A final set of simulations was carried out in order to assess the performance of the final conceptPod having insulation levels of \( R=4/4/2 \) and triple glazing in the main window as it was considered best option for balance between performance and cost. The simulations results are shown in Table-7. The only change in the Pod design between each location was the SHGC value of the glazing. The operable shades were designed to be easily adaptable to each climate without changing the overall design. The final results showed consistency with the earlier optimization exercise. The final conceptPod design performed well above regulatory requirements in all climates and achieved star rating up to 8.6 stars.

![Table 7](image.png)

<table>
<thead>
<tr>
<th>Location</th>
<th>North (Stars)</th>
<th>East (Stars)</th>
<th>South (Stars)</th>
<th>West (Stars)</th>
<th>Comments</th>
</tr>
</thead>
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<td>Brisbane</td>
<td>8.6</td>
<td>7.8</td>
<td>6.9</td>
<td>6.3</td>
<td>Glazing with SHGC = 0.3</td>
</tr>
<tr>
<td>Sydney</td>
<td>8.3</td>
<td>8.2</td>
<td>7.4</td>
<td>7.3</td>
<td>Glazing with SHGC = 0.3</td>
</tr>
<tr>
<td>Melbourne</td>
<td>7.7</td>
<td>7.5</td>
<td>7.4</td>
<td>7.1</td>
<td>Glazing with SHGC = 0.5</td>
</tr>
<tr>
<td>Hobart</td>
<td>8.2</td>
<td>8.1</td>
<td>7.7</td>
<td>7.9</td>
<td>Glazing with SHGC = 0.5</td>
</tr>
<tr>
<td>Darwin</td>
<td>6.7</td>
<td>6.2</td>
<td>6.7</td>
<td>6.3</td>
<td>Glazing with SHGC = 0.3</td>
</tr>
</tbody>
</table>
CONCLUSION

This study was designed to test several ideas and principles regarding the performance of the current Pod design and the limits of various strategies. The results of the final outcome show significant improvement in the thermal performance when compared to the existing design. More importantly, the combined engineering and architectural design research efforts produced an overall design that is easily adaptable for most of the climates and orientations studied. It is well-established that an optimized design for an individual climate and orientation would provide better result than a single “one size fits all” design. However, this particular optimisation process revealed that integrated design approach, with strategically embedded flexibility and economically rationalized redundancy in the type, amount and location of shading, glazing, and insulation, could result in a robust overall design outcome. This outcome – the conceptPod – showed remarkable resilience, for which the performance penalty from different locations and orientations was minimized significantly.

This research contributes to the debate on integrative design process and its significance for sustainable built environment in general; it also ascertains the path forward for a more comprehensive approach to net zero energy and self-reliant modular housing. The next phase of this research focuses on further integration of services and low carbon technologies to achieve this outcome. The lessons learned so far are being used to develop a next generation of ‘greenPod’, a prototype of which will be tested for a year to measure its actual performance and to compare with its predicted performance.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Cooperative Research Centre for Low Carbon Living (CRCLCL) for its support to the research project and for the PhD scholarship to the corresponding author that has contributed to this research. Acknowledgement is also due to Nova Deko for its funding support to the CRCLCL and for facilitating this research.

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Sustainable Habitat for Developing Societies: Learning from European Experiences

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ABSTRACT

The aim of sustainable development is a big challenge in the building sector. On one hand new technologies and materials are available, on the other hand life cycle assessment, including the energy performance and indoor air quality should be in line with green building standards. In many cases key players do not share common objectives for the project, may not understand how their work affects others.

Integrated design is thinking about how the parts fit together. But no matter what the scope of the project, structural design, heating, ventilation, air conditioning, lighting and wiring, and other key parts of the project are viewed as interrelated parts of the whole project. “Nearly Zero Energy Building” will be the standard for new buildings in Europe from beginning of 2020, due to the European Building Directive. Austria was one of the forerunners in eco building in the last twenty years. The measures and the experience how eco building, low energy and passive house standard disseminated in Austria are well documented and available.

The toolbox for integrated design contains experience with the most relevant elements: Starting with the establishment of clear project goals and quality management and ending with final inspection protocols, user information and maintenance. Certification systems for buildings aim to make sustainability transparent and provide a means of comparison. The paper proposes a similar concept for India, making the most of European experiences in building process and energy demand optimization and taking into consideration existing subsidies by the Government of India and evaluation procedures within the Green Buildings Rating System India.

Even though the climate is different, principles and products are basically same all over the world. After the discussion useful elements of the toolbox can be adapted to promote sustainable engineering and buildings.
INTRODUCTION

Many of today’s global problems arise from the availability and use of natural resources, caused by growing population and changes in lifestyle. The Ministry of New and Renewable Energy of India (Energy Access, 2012) states that India has the world’s 5th largest generation capacity and it is the 6th largest energy consumer accounting for 3.4% of global energy consumption.

In Europe the construction sector is in a change process, especially concerning the energy aspects. Buildings effect 40 % of total EU energy consumption and generate 36 % of greenhouse gases. To decarbonize the European economy reducing CO₂ emissions by at least 80 % and energy consumption by as much as 50 % by 2050 is necessary.

According to the EU Building Directive, European Parliament (2010), all member states have to ensure that by December 2020 all new buildings will be “Nearly Zero Energy Buildings”. The various green successful schemes and initiatives undertaken by Austria will be discussed and understood. Austria is also a forerunner in eco building and passive houses.

INTENT AND OBJECTIVES

Need for sustainable habitats

Today, India is the second fastest growing economy in the world. In India, construction is the second largest economic activity after agriculture.

National Resources Defence Council and the Administrative Staff College of India have proposed a report on Strengthening the Indian Real Estate Market Through Codes and Incentives (2014) which clearly states: If all the states across India adopted the Energy Conservation Building Code (ECBC) and developers participated in strong programs for rating commercial buildings, an estimated 3,453 TWh of cumulative electricity could be saved by 2030, the equivalent of powering as many as 358 million Indian homes annually between 2014 and 2030 based on the current annual consumption level for electrified households. Additionally, 1,184 million tons of CO₂ emissions could be avoided by 2030. This underlines the need for sustainable habitats in India by creating a mass awareness and implementing stricter building standards.

Need for new policies and measures

According to IEA statistics report (2011), the electricity consumption in India has nearly doubled from 407.48 TWh in 2000 to 835.40 TWh in 2011 and the CO₂ emissions have risen drastically from 972.13 Mt of CO₂ to 1745.06 Mt of CO₂. From these figures we can infer the higher are the electricity consumption, higher is the CO₂ emissions. Though India has a number of policy initiatives to mainstream energy efficiency and green buildings as control and regulatory instruments, including appliance standards, mandatory labelling and certification, energy efficiency obligations, and utility DSM (Demand Side Management) programs; economic and market-based instruments; fiscal instruments and incentives; support, information and voluntary action, there is definitely a strong need for better solutions to create a wider impact to achieve low carbon economy in the coming years.

Integrated Design

Integrated Design is advisable in managing the complex issues arising from planning buildings with high environmental and social ambitions. Key issues are collaboration in multi-disciplinary teams,
discussion and evaluation of multiple design concepts as well as clear goal setting and systematic monitoring. In the early design phases, the opportunities to positively influence building performance are great, while cost and disruptions associated with design changes are comparatively small.

The Integrated Design Approach will result in better energy performance, reduced environmental problems, optimized indoor climate, lower running costs, reduction of risks and construction defects, user acceptance and higher process quality concerning timelines, construction cost, quality of work delivered.

EXISTING POLICIES AND MEASURES IN EUROPE

Case study Austria

Austria is a European country with a comparable high share of Nearly Zero Energy Buildings and was one of the forerunners in eco building in the last twenty years. This development was enabled by a sample of instruments:

Building Codes: The building codes are adapted step by step towards the “Nearly Zero Energy Standard” to implement the European Building Directive on national level. The National Plan OIB, (2011) specifies the limits for heat energy demand, primary energy and CO$_2$ for new buildings and also in case of renovation.

Subsidies: In Austria subsidies for building or renovation are available if specified building standards e.g. heat energy demand, are documented in the obligatory energy passport. In general the energy performance must be better than the building code requirement. The City of Vienna evaluates social housing building projects by an interdisciplinary jury and launches competitions for sustainable building. The subsidy for a solar thermal plant with a solar fraction of the heating energy demand (for heating and hot water) of at least 30 percent is 25 percent of the eligible investment costs.

Government initiative for public buildings: For public buildings, the governments of the provinces take the responsibility as a trend-setter in green public procurement; specific criteria were developed by consultants in tight cooperation with the administration. The Planners Guideline Planungsleitfaden Vorarlberg (Fechner, Haas, 2010) is a crucial tool for the implementation to be practiced.

National Programs: Programs are the third pillar beside the legal and economic instruments for climate policy. The Austrian Program on Technologies for Sustainable Development “Building of Tomorrow” initiated innovation in sustainable buildings like Passive House demonstration projects, development of building concepts and components, social studies. The Program "Factory of Tomorrow" addresses the trade and industry as well as service enterprises to focus on zero-waste and zero-emission technologies and methods of production, increased use of renewable raw materials for materials and products, development of new partnerships and co-operations as well as in-house models for further training and participation of employees in order to achieve these objectives.

Klimaaktiv is embedded in the Austrian federal climate strategy, consisting of a bundle of measures of regulation, taxes, and subsidies. Klimaaktiv has gathered all voluntary and supportive measures under one umbrella in the four thematic clusters construction, energy efficiency, mobility and renewable energy. The climate protection program goes into partnerships to realize climate friendly building.

The core objectives of klimaaktiv are:

1. Training for professionals: the European BUILD UP Skills initiative launched national stakeholder platforms to develop roadmaps for vocational training concepts in the construction sector. By this the needed skills to realize the Building Directive shall be built up. klimaaktiv supports and provides qualification and coordinates training and vocational education in various fields.

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2. Setting standards and safeguarding quality by introducing quality standards for products and services and by establishing quality management systems, e.g. for biomass district heating systems or for buildings. This is important, because young and booming markets often cannot provide sufficient quality.

3. Providing information and advice, raising awareness; klimaaktiv mainly focuses on offering consulting to companies interested in making their production processes energy efficient, or renovating their facilities, or introducing mobility management, or changing over to energy efficient appliances and IT systems. klimaaktiv provides support for consultants by equipping them with new tools, by benchmarking energy efficiency and by offering further training on specific issues.

4. Activating and networking partners; successful climate protection depends on the commitment of existing initiatives and networks as well as on that of the business and the public sector. klimaaktiv aims at bringing these players together and at creating a powerful network for climate protection.

Figure 1: This Logo is used by partners of the initiative to express the engagement in climate protection

Building standards: In Austria several certification schemes are in use to label buildings:

* **EU Green Building:** compared to other systems this standard is not covering many aspects of sustainable building

* **klimaaktiv building standards:** for new and renovated buildings, free available on www.klimaaktiv.at, with reference to passive house standards

* **OGNB,** Austrian Sustainable Building Council (including klimaaktiv criteria)

* **BREEAM,** Building Research Establishment Environmental Assessment Methodology

* **ÖGNI,** Austrian Association for Sustainable Real Estate Management (ÖGNI), Germany’s DGNB.

The use of building standards is required for public buildings or for funding occasionally

Consultancy: Energy advising is very common in Austria to raise the awareness and to help to make best use of subsidies. Consultants are organized in networks by the provinces. The service is offered free or to a low price, sometimes it is part of the subsidy.

Tools for planners: Sustainable Buildings require new competences in management of integrated planning processes. Starting with the establishment of clear project goals and quality management and ending with final inspection protocols, user information and maintenance. As an example, the series “Quality line” for the optimized integration of solar heat, heat pumps, HVAC, is provided by the klimaaktiv initiative, (Fechner, J., 2012) Qualitätslinien Haustechnik.

<table>
<thead>
<tr>
<th>Table 1. Quality Line in the Construction Process</th>
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<tbody>
<tr>
<td>Step</td>
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<tr>
<td>1. Basic Decisions</td>
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<td>2. Call for Tender/Cost Estimate</td>
</tr>
<tr>
<td>3. Selection of Tender, Contract</td>
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<tr>
<td>4. Quality control</td>
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</tbody>
</table>
For the selection of energy efficient electric appliances a consumer friendly database is run by klimaaktiv, presented on www.topprodukte.at. Professionals find here the most efficient pumps, boilers and many other components, end-user are most interested in energy demand, investment and running costs of household appliances.

WHICH OF THE PRESENTED STRATEGIES AND MEASURES CAN BE REGARDED AS USEFUL FOR SUSTAINABLE BUILDINGS?

• Sustainable building must be defined in the context of the country, its climate, culture and society. Sustainable concepts have to unite ecological, social and economic requirement, they are always the result of discussion, valuation and negotiation. Exchange of experience and learning from each other is urgent to solve problems on global level.
• Certification schemes provide information and criteria for sustainable buildings. Depending on the origin of the scheme the criteria are based on the understanding of the creator and his system.
• A Sustainable Building Strategy is the basis for a coordinated and effective development of the building sector. The EU Building Directive is an efficient policy strategy, but it covers only the use of energy. Other aspects of sustainability need to be met.
• National programs for sustainable buildings are triggering innovation and good practice support the market transformation. As soon as sustainable solutions are available, legal and economic measures (e.g. subsidy schemes) are necessary to implement such a strategy. Quality management is crucial, it is the responsibility of the investor and user to define sustainable quality and proof, as the legal requirements and the administration only regulate some aspects.
• National initiatives like klimaaktiv are bundling measures to reach grassroots level. If the government introduces such a scheme, it is available nationwide for free.

Seven steps can be identified as core elements referring to existing practice in Europe and India, the authors propose to implement and coordinate these measures within a national initiative:

1. Analysis of building practice incl. energy performance, poor quality and damages (first part of SWOT analysis). In cooperation with Universities such research can be a field of learning and many researchers can be involved.
2. An innovation program for sustainable building produces the options for the future, involving Universities and the building industry.
3. Building standards for all relevant kind of buildings incl. domestic buildings (e.g. klimaaktiv building standards in Austria or in Switzerland MINERGIE)
4. Analysis of stakeholders and actors (to learn about their need for capacity building) and definition of learning targets.
5. Development of a vocational training scheme for sustainable building incl. certification (e.g. ISO 17024). Trainings can be offered by educational institutions, based on contracts.
6. Networking and partnership. Persons who absolved special trainings are invited to join the network of sustainable building professionals
7. Evaluation of trainings, refining trainings.

An evaluation of Austrian tools towards adaptation to India could be made; Energy Consulting for investors and for users could be mentioned; universities could engage in a targeted exchange of academic staff and students to learn from each other.
OUTCOMES: RECOMMENDATIONS FOR SUSTAINABLE HABITATS IN INDIA

A program “Sustainable Building for India”, implementing the discussed strategies and measures can make sustainable habitats a greater success in India.

- Awareness raising should start with presentation of good practice, e.g. an award for sustainable buildings (http://www.klimaaktiv.at/bauensanieren/staatspreis.html or http://iet.jrc.ec.europa.eu/energyefficiency/greenbuilding).

- Besides (more or less expensive) certification schemes additional incentives should be developed. The above mentioned strategies and measures can be used but must be adapted, as India has different climatic conditions; the architecture of the building varies from region to region.

- The Government of India can encourage industries; especially SME’s to come up with new green materials at affordable cost so that the end user can implement the green idea into reality.

- In India, Excise Duty is imposed on every product that is manufactured in factories. The Government should intervene by reducing the service tax and other taxes imposed on products manufactured by Certified Green Factories to encourage green practices.

- The Government of India can introduce subsidy schemes either nationwide or state wide for green building practices to encourage active participation by the public.

- To encourage Sustainable Building and also to increase the share of renewable energy, an increase of the budgetary allocation by the Government of India is necessary.

- The Government of India can enforce a strict regulation all over the country to increase the share of renewables from the existing 1% to 10% like the EU Building Directive.

- Construction workers should be trained to understand the various green building practices throughout the construction period. Before the Project work has begun, the contract should have a mandatory agreement that trainings in green building practices have to be undertaken by supervisors, clients at different stages of the project to understand the purpose.

- When constructing a new building, license from EIA has to be obtained. Renewable practices must be stressed and included in the license procedure.

- When the customer approaches bank for loans for green residential or commercial projects usually environmental approvals are requested for the financial closure but no such requirements regarding energy approvals.

TOOLBOX FOR INTEGRATED DESIGN FROM AUSTRIAN INITIATIVE ‘KLIMAAKTIV’

Klimaaktiv provides tools for effective Integrated Design for Sustainable Buildings in Austria. These tools are available for free and have great potential to be used as powerful tools for Indian habitats. Guidelines for optimized integration of photovoltaic, solar heat, HVAC and electric appliances, air quality are given. Klimaaktiv would also help in the transfer of knowledge for India to make integrated design reachable to all. The various Tools are listed below.

1. Photovoltaic calculator is an efficient tool (xls tool) for the rapid assessment of efficiency of photovoltaic systems for new construction and renovation buildings. It is available in the web link (http://www.klimaaktiv.at/tools/erneuerbare/pv_rechner.html)
2. Solar heat: Guidelines for counselling, call for tender, acceptance protocol are given for systems for residential buildings for heating water, with or without integration in the heating system.
(http://www.klimaaktiv.at/publikationen/bauen-sanieren/qualitaetslinien/solarwaerme.html)

3. HVAC:
Guideline for counselling, call for tender, acceptance protocol
(http://www.klimaaktiv.at/publikationen/bauen-sanieren/qualitaetslinien/komfortlueftung.html)

4. Heat Pumps:
Guidelines for counselling, call for tender, acceptance protocol buildings for compact devices
(http://www.klimaaktiv.at/publikationen/bauensanieren/qualitaetslinien/komfortlueftung.html)
and to find the right heat pump heating, JAZcalc derives the seasonal performance factor under standard conditions for a quality geothermal community
(http://www.klimaaktiv.at/tools/erneuerbare/JAZcalc.html)

5. Indoor Air Quality: criteria in klimaaktiv
- HVAC
(http://www.baubook.at/kahkp/?URL_R=http%3A%2F%2Fwww.baubook.at%2Fm%2FPHP%2FKat.php%3FSKK%3D1761.13213.13214.13255.13257.13243%26SW%3D8%26ST%3D12&SW=8)
- Selection of building products (low emission) (www.baubook.at)
- Qualitycontrol(http://www.baubook.at/m/PHP/Kat.php?SKK=1761.13213.13214.13255.13257.13245&SW=8&ST=12)

6. Environment data: baubook.at also provides data for Global Warming Potential, Acidification Potential and Primary Energy (grey energy)
(http://www.baubook.at/m/PHP/Baum2.php?ST=44&SW=8&auto_right_frame=y)

7. In order to make the quality of a building measurable and comparable, the climate-active building standard was developed.
(http://www.klimaaktiv.at/bauen-sanieren/gebauedeklaration.html) and in English (http://www.klimaaktiv.at/english/buildings/Buildings.html)

8. There are various Labels: e.g. solar key mark for solar thermal
(http://www.estif.org/solarkeymarknew/) or EHPA for heat pumps (http://www.ehpa.org/). It is easy to handle quality labelled products.

CONCLUSION

Even though the climate is different in Austria and India, many principles and in the meantime also many products are basically the same all over the world. Useful elements of the presented toolbox can be adapted to promote sustainable engineering and building.

The leading engineering schools can initiate innovation for sustainable building, facilitating hands-on “real life” education and continuous exchange with industry on new technologies, materials and process design. Such an educational model focusses on the student’s role as active “innovation broker” between his employing company and the teaching and research staff at the university. Austria can contribute and bring in examples for innovative and successful didactic and organizational elements and their actual benefit for regional enterprises.
ACKNOWLEDGMENTS

I would like to express my very great appreciation to Mr Johannes Haas and Mr Johannes Fechner who agreed to be co-authors for this paper and assisted me with quality information about Austria and also I am thankful to Mr Sivagnanaselvam Chinnayan for giving a good insight into the Building system in India. I am particularly grateful for the assistance given by klimaaktiv in Austria for the collection of data. I also specially wish to acknowledge Mr Michael Bobik, my department Head at FH Joanneum for supporting my participation in PLEA 2014.

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[All websites accessed: 17th October 2014]
“LEED-Oriented” Projects in Mainland China and the Indication to Sustainable Practice in Developing Countries

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ABSTRACT
As one of the largest developing countries in the world, China is undergoing a period of massive construction. Meanwhile, the urgent energy intensity reduction agenda requires energy efficient and environmental friendly design to be implemented nation-wide. Specific guidelines and green building assessment system have been established in mainland China. This study will review two LEED awarded projects in southern and northern China, to reveal how the “LEED-oriented” practice came to success through decision-making, design strategies and specific system integration. The design team adopted new mindset and methods in their practice and benefited the projects: 1. Pre-project decision-making; 2. Performance-based design; 3. Integrated system approach. Energy efficient systems and green design features introduced great customer experience with low energy cost. The paper offers technical project details. Quantitative data from post-occupancy survey are provided to investigate the actual performance of the operating systems and explore the possible issues; occupant satisfaction is also being studied. Through case projects, it was showed that leading edge green building assessment systems help to identify the general structure for environmental issues and increase public awareness in developing countries. Certain limitations of existing practice are discussed, and suggestions on enhancing green building design practice in developing countries are summarized.

INTRODUCTION
China is one of the biggest developing countries in the world and facing the challenging energy and environmental issues. Estimated by the World Bank, half of the world’s new construction will take place in China up to 2015. With such rapid developing speed, the released International Energy Outlook (U.S.EIA, 2011) predicted that about 50% of energy consumption grow will be come from China and India in the next 2 decades. At the same time, national and local environmental problems have manifested along with the resources shortage. Eight of Chinese large cities have been rated as the top-ten air pollution cities in the world; nearly 2/3 cities in China facing water shortage and in particularly severe areas water resource per capita only reaches 4% of the world’s average. With all the above and similar developing issues and problems being brought to the surface, the Chinese government has announced an aggressive energy intensity reduction agenda which has set the carbon emission reduction target to be 40%-45% up to 2020, comparing to the 2005 standard. In China, about 25% of electronic use goes to building consumption including lighting, cooling, heating and cooling. The energy reduction target sent a strong signal to the industry to speed up the “green building evolution”. The rising attention
and the government’s support have driven the environmental practice in China and as well as the
development and implementation of building code and green building evaluation systems.

Local green building evaluation systems have been established in China. The Green Building
Evaluation Standard (GBES) was created in 2006, and in 2003 the Building Assessment System of 2008
Green Olympics was developed to offer guidance on green practice in stadiums and supporting facility
construction for the 2008 Beijing Olympics event. At the same time, several comprehensive foreign
evaluation systems have entered China; the most well-known “Leadership in Energy and Environmental
Design” (LEED) system has rapidly dominates the market of green building certification in the recent
years. Based on the most updated data posted by USGBC, for the top ten countries with offshore LEED
projects, China is at the third place; there are 1156 registered and certified projects in mainland China
with the total building area being 66.5 million gross square meters. In the certified projects, nearly 70%
were awarded LEED Gold or LEED Platinum. Professionals in the industry also endorse the system, the
number of LEED GA and LEED AP reached 1,092 (1% in the world) in mainland China, ranking at the
third place. 30% of these registered LEED professionals are architects; the rest are consultants, planners,
ingeniers, and interial designers. It can be seen from these data that LEED system has leading the field
of green building evaluation in mainland China.

With LEED and its method been introduced to offshore areas, questions have been arise on how
does the system address the “acclimatized” issues in developing countries, especially some Asian
regions with distinct cultural context. More research attention should be placed on strategies of refining
the green building evaluation systems to better serve the industry and promote the green development in
these developing countries.

![Figure 1](image)

**Figure 1** left: Vanke Center (Shenzhen) was certified LEED Platinum award; right: Linked Hybrid
(Beijing) was certified LEED ND award

**OBJECTIVE AND METHODOLOGY**

Through two "LEED-oriented" projects in mainland China as case study, this paper would first
demonstrate how pre-project target setting and performance-based integrated design let to LEED-awards
and occupant satisfaction. Secondly, base on post-occupancy survey, actual energy performance of the
LEED-certified buildings will be investigated. Project information including technical details, energy
data, operation cost, and occupant feedback will be revealed in the paper. Successful target-oriented
working mindset of these cases will be summarized and how far would the LEED system guides the
projects to the energy-efficient outcome and some possible limitation will be discussed. Suggestions on
refining the green building assessment systems in developing countries will be offered at the end of the
paper.

**CASE STUDY: LEED-ORIENTED PROJECTS**

The two LEED-awarded projects selected for case study are the Linked Hybrid, Beijing and the
Vanke Center, Shenzhen (fig. 1). Steven Holl Architects designed both projects with consistent design
mindset. These two projects locate in different climate zones and facing varying environmental issues;
yet pre-project target setting and performance-based integrated design successfully let the projects to
LEED awards. The Vanke Center, Shenzhen and Linked Hybrid, Beijing are rewarded LEED Platinum
and LEED ND respectively.
1. Pre-Project Decision Making

In both of the projects, client and the design team had set their goal on LEED award at the pre-project stage and the green design strategies were worked out based on the environmental structure in LEED. Showing in Table 1 is the crosscheck shortlist of the rating environmental aspects in LEED and the green design strategies in Vanke Center.

<table>
<thead>
<tr>
<th>Required Aspects in LEED</th>
<th>Design aspects</th>
<th>Systems and strategies applied</th>
</tr>
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<tbody>
<tr>
<td>Sustainable Sites</td>
<td>Sustainable site selection</td>
<td>traffic, climate, and views</td>
</tr>
<tr>
<td>Water Efficiency</td>
<td>Water saving</td>
<td>rainwater collection and grey water system</td>
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<td>Energy and Atmosphere</td>
<td>Building forms</td>
<td>floating structure for ventilation,</td>
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<td></td>
<td>Envelop design</td>
<td>Adjustable shading system</td>
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<td>Energy systems</td>
<td>thermal energy storage technique</td>
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<td>CO2 monitoring system under floor air distribution system</td>
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<td>solar water heaters and PV panels</td>
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<td>ground level greening and slope green roof</td>
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<td></td>
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<td>efficient lighting design</td>
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<td>Materials and Resources</td>
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<td>recycled and reused products</td>
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<td></td>
<td></td>
<td>Adjustable ventilation system</td>
</tr>
</tbody>
</table>

The expectation on the “green performance” of the project had been well defined at the pre-design stage. With the clear target, the green design of the project was improved and the efficiency of design-construction process was increased.

Despite the significance to the industry, green practice is at the starting stage in many developing countries. From the Vanke Center case, it can be seen that LEED offers comprehensive direction and clear environmental structure for green practice in developing countries, and greatly speed up the local green development.

2. Performance-Based Design and System Integration

The second case is Linked Hybrid, Beijing, which was awarded LEED ND in 2011. The selling point for the apartments in Linked Hybrid was the ‘constant temperature and humidity’ living environment: comfort and relatively constant thermal environment would be provided in the apartment with the temperature ranging at 20-26°C and humidity within 30-70%; acoustic control at 35-45db level. This performance was achieved by the system-integrated design. One set of geothermal power system, ceiling radiation, and the fresh air supply system offer comfort indoor experience and outstanding energy performance in Linked Hybrid.

- **Geothermal Power**

In Linked Hybrid, a large geothermal heat pumps system has been installed to achieve high energy efficiency. Geothermal system is known as the most advanced energy utilization plan; it takes advantage of the temperature consistency and heat storage of the earth. The system CUP can be as high as 5-7; while air-conditioning usually has CUP of 2.5-3.
A typical geothermal heat pump system includes 3 parts: the ground heat exchanger, the heat pump unit, the delivery system. In Linked Hybrid, the ground exchanger is formed by 632 water pipes. The system buried right under the garage floor and reached 100m deep. The geothermal system uses the PE “DN32 double-U” pipes to run the water, which are lying every 5m in grid array, between the anti-floatation piles. This is a closed-circuit loop, and materials with large heat conductivity is used to fill up the gaps surrounded the heat exchange pipes. Every loop is formed by 6-8 water pipes, and 5-6 loops are ended in one water supply and return header. PE pipe with an expected 50-year life circle were employed to minimize the maintenance; and during construction the pipes had gone through multiple pressure tests. If leakage happens during operation process, the particular loop in problem can be shut down in the inspection camber. By placing the system right under the building’s foundation (See fig.2), Linked Hybrid project started the practice of installing geothermal heat pump in core urban areas.

With its delivery system, the geothermal power offers constant indoor comfort for apartments in Linked Hybrid. There are 8 heat pump units in the system, 4 units are used to heat up/cool down the fresh air ventilates; while the other 4 units of 1200kw are used for the ceiling radiation system. In most of the year, the system works alone to supply cooling and heating to the 220,000m$^2$ in the neighborhood. Only in the coldest or hottest months, extra power supply from boiler and cooling tower would be needed. Water was circulated in the pipe array inside the ceiling structure and heat radiation from the ceiling would regulate the temperature in the apartment. In summer, 30 °C warm water is cooled down to 25°C by heat exchange with ground and further cooled to 18°C by the heat pump unit to circulate in the ceiling radiation system inside each apartment. In winter the original water temperature was 3°C and would be heated up to 8°C by the ground heat and goes up to 31°C by the heat pump unit. To deal with the peak period, 2 refrigerators of 2000kw would be added to assist the geothermal heat pumps and cool the water to 7~12°C in mid-summer. For the coldest months, 4 boilers of 1400kw would be provide extra power support; and 45~50°C water will be running in the loop system to offer radiation heating in the apartments.

The structure for the ceiling radiation system was formed by 2mm thick PB plastic pipes with the outside diameter being 20mm; all these piles were installed as a layer of the ceiling slab (see fig. 2 and fig. 3). The water circulated inside the loop is around 18~21°C for refrigerating in summer and up to 28~31°C for heating in winter. Inside the ceiling slab, the water pipes are lying more densely at the north side than the south to offset the difference caused by orientation; and a more uniform thermal environment will be created in the apartments. The year-round indoor temperature is between 20 to 26°C in the apartment. At the same time, the ceiling is insulated from other parts of the envelopes, such as the partitions and external walls to avoid heat loss.
In terms of indoor thermal regulation, the ceiling radiation is more energy-efficient compared to the traditional air-conditioning system, as water has a larger heat capacity and is better medium of energy than air. To maximum the performance and energy efficiency, the thermal regulation system was separated from fresh air supply in the project. A “low turbulence, low mixing, low cooling” fresh air supply system was installed in the apartment. In each hour, 300m$^3$ volume of fresh air is sent to the apartment, which is much higher than the current national standard of fresh air supply (30m$^3$/person.hour). The system allows non-mixing heat exchange between the used and fresh air; 60% heat from the used air can be reclaimed by the system to pre-heat/pre-cool the fresh air before it enters the apartments. The geothermal system supports the heat reclaim set in the building. In summer, the fresh air is cooled to be 2°C lower than the indoor temperature and has been humidified. The section of the air shaft would become narrower every 3-4 floors to avoid air pressure decreasing and stabilize the wind speed (fig. 3). The design has saved both material and power on air pumping.

The system-integrated design has also been applied in the Vanke Center Shenzhen. In the project, an ice-storage system was employed to support the air-conditioning in summer months. The system uses electricity to make ice and store energy during night-time hours, and this energy will be released and provide cooling during daytime hours. The system has two advantages. First the system operates at night and avoids the load peak of the city power network. Second the system would have higher CUP comparing to air-conditioning cooling, as it uses water as heat medium instead of air. Under floor air duct network was installed to deliver the cool air to different components of the building. Cool air comes out at ground level and fills up the space up to about 2 meter height; such design increase the efficiency of the system as the cooling energy was distributed within the domain of occupant activity (fig. 4). A CO2 monitor is connected to the system and the airflow at the fresh air inlet would be adjusted based on the indoor air quality. Heat recover set was installed to collect waste heat from used air for fresh air pre-cooling.

Figure 4 The air outlets in the lobby and offices in Vanke Center

Vanke Center takes full advantage of solar energy. Solar water heaters and PV panels were
installed on the large green roof (fig. 5). The solar water heaters supply hot water to the swimming pool and bathrooms. The large amount of PV panels is expected to provide up to 15 percent of the total energy need of the building and estimated annual output is 280,000 kilowatt-hours. The power generated by PV panel will support the dehumidification and refrigeration systems in the building.

**Figure 5** Solar water heater and PV panels on the roof

Great amount of energy consumes on lighting in the office building (Irish Energy Centre, 1995). An efficient lighting design in offices can save energy remarkably. The project combines daylighting and high efficient luminaries and induced lamps in the lighting design. The building has large double-glazing facade to allow sufficient daylight to enter the offices. A set of perforated louvers is set up to provide certain level of shading to the facades, and its angle can be automatically adjusted according to the solar attitude or manually operate by occupants based on the need (fig. 6). Meanwhile, daylight has been integrated in the system where the requirement on stable lighting is less strict, such as underground parking; or in some places the daylighting is combined with the artificial light as a delicate supplement (fig. 6). Some of the open space was well designed so the source of nature lighting will not be blocked.

**Figure 6** Left: the application of daylight in the lobby and underground space. Right: The external shading device and adjustable perforated louvers

### 3. Post-occupancy survey and occupant satisfaction

Rare data on post-occupancy building performance and operation cost was reported for LEED awarded buildings. Post-occupancy survey is essential for green design enhancement and reveals whether the systems and green design feature could function properly. Satisfaction of occupants and their behavior pattern in the buildings offers valuable reference for architects and benefits green practice.

The energy system in Linked Hybrid combines the geothermal power with boiler and cooling tower. The EMO manager of Linked Hybrid stated that in most of the year, the geothermal system could fully cover the neighborhood’s demand in cooling and heating. In the coldest and hottest months, extra support is applied. This system cost 50% more than a standard energy system, but running in low operation cost with outstanding energy performance. Table 2 shows the initial investment and operation cost of different energy systems in mainland China. A survey was conducted when the integrated system in Linked Hybrid had been running for 12 months to supply heating and cooling for total 220,000m2 areas. According to the Estates Management Office, the electricity peak occurred in January and February, during these winter months the operation cost of the system was 700,000RMB/month. A close number has been recorded in June and July. This number has already included the energy used for boiler and cooling tower, namely, it is the total cost for heating and cooling in winter and summer. May and October had the lowest consumption according to the records. The electric bill for these two months is...
about 350,000RMB/month. The annual operation cost on cooling and heating for this neighborhood was approximately 6,000,000RMB.

<table>
<thead>
<tr>
<th>Initial Investment</th>
<th>Operation Cost</th>
</tr>
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<tbody>
<tr>
<td>Gas turbine</td>
<td>Gas</td>
</tr>
<tr>
<td>Chiller/Heat pump</td>
<td>Electricity</td>
</tr>
<tr>
<td>Compression chiller</td>
<td>Water cooling towers</td>
</tr>
<tr>
<td>DE-Absorption chiller</td>
<td>CO₂-emission</td>
</tr>
<tr>
<td>Cooling towers</td>
<td>Gas</td>
</tr>
<tr>
<td>Boiler</td>
<td>Gas</td>
</tr>
<tr>
<td>Energy piles</td>
<td>Electricity</td>
</tr>
<tr>
<td>Ground water wells</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Comparison on initial investment of different energy systems

When the building was put into operation, the Vanke people were happy to see that the thermal storage system, the under floor air distribution system brought thermal comfort to the building and had a better energy performance with lot money saved on electric bills. The solar PV panels offer 15% of the power for the building and reduce the CO₂ emission. Water saving strategy saves 30% of the total consumption. The innovation of the construction of the project saved 80,000,000 CNY budget.

To allow the user to be in control of comfort and operating the system is essential for saving energy and operation cost, and more importantly, to achieve occupant satisfaction. People can stand some degree of discomfort when they are in control of the conditions in their workplace (Cohen et al., 1999). Yet to what extend should the occupants be granted the control worth discussion. When user involvement is not appropriately designed, it can also result in wrong operation of the building and wasting energy. Leaman's study (1999) revealed that user reaction and response could be reckless sometimes, such as over-compensating for relatively minor annoyances, not choosing the most proper system to operate but instead the ones that are convenient to hand, and lacking responsiveness in adjusting the systems with the change of the environment.

In the Linked Hybrid case, occupants can regulate the temperature and fresh air supply by a controller inside the apartment, which has a limit though, considering the comfort range and energy consumption of the ceiling radiation system. The integrated system set the temperature range to be 21-22 °C for winter and 24-26 °C for summer, occupants can adjust the indoor temperature within 2 degree. When the apartment is unoccupied for couple days, the system can be switched off while small amount of fresh air will enter and circulate the space due to the pressure in the duct. So the apartment is still ventilated without extra energy consumption, and there won't be unpleasant smell when occupants come back days after.

The energy system of Vanke Center showed a slightly different picture. Data from EMO recorded the total energy output of the PV panels was 1358,460KWh since the building was put into operation, and the annual output of the system was 272000 kWh, reached about 97% of the expected value. According to a recent interview, the EMO stated that after 5 years’ operation, the PV panel system has been malfunctioned and under repair. On the other hand, test result from 2013 revealed that the ice store air conditioning system had a low efficiency in ice making (less than 50%). The data above demonstrates the performance of the energy systems in Vanke Center are not functioning as designed.

Nevertheless, the design of Vanke Center values the comfort and satisfaction of the occupants. Great efforts were made on different aspects to meet the comfort range, including temperature, humidity, lighting and views. Occupants can flexibly control the working environment according to their personal needs. In the working space separated lighting switch and a control panel for air conditioning are provided to each staff. “People working together in a big office usually have different needs for air-conditioning. a centralized cooling system hard to satisfy everyone and sometimes makes people sick. Now this is no more a problem to us.” A staff claimed in the interview. Furthermore, everyone working
DISCUSSION ON GREEN PRACTICE AND EVALUATION SYSTEM ESTABLISHMENT

These two case studies demonstrated that LEED and LEED-initial practice benefits the green building development in mainland China, and the positive effects can be summed up as below:

1. The LEED system offers clear environmental structure for green practice and in developing countries;
2. Training process and technical support introduce knowledge input and increase the amount of local professionals;
3. Large and demonstration projects can promote international cooperation and communication between different expertise.

However, the high cost and large investment of these LEED-oriented projects make it difficult to widely adopt this mode in developing countries. Energy performance of some of the LEED projects are relied on high-tech systems, and these projects to some extend, neglect the passive design and environmental planning methodology. This, as revealed in the case study, has its shortcoming. Based on the above, suggestions on enhancing green practice in developing countries are summarized:

- climate-based passive design
  A great portion of developing countries and regions locate in severe and harse climate zones. To identify the climatic issues and formula strategies of climatic design with passive approach is vital in these regions. It is regional-applicable and much less cost-demanded; and a larger cost-and-return ratio can be obtained from climate-based practice in these regions than it was in the moderate climate zones.

- energy efficiency of heating and cooling systems
  As Chmutina (2010) has pointed out, improve the cooling and heating system can save up to 70% of energy in China; energy efficient heating and cooling system is essential for the green development in China. Since air carries relatively less energy per unit volume, it is not recommended as energy medium. Furthermore, the heating and cooling system should be separated from fresh air supply.

- standard setting and occupant behavior study
  User involvement is essential for both energy saving and occupant satisfaction. The “comfort” standard should be set as an acceptable range instead of a neutral condition; at the same time allow the occupants to adjust the systems within this boundary. It can firstly let the user have the control, and secondly avoid energy waste caused by overreaction of the users. At the same time, branching and operation systems are preferred to centralized control.

REFERENCES

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Session PE : Materials

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Faith - Knowledge Consortium of Gujarat
Survey on electrical energy use in Asia office facility and economic analysis through the application of Battery Energy Storage system (BESS)

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Topics: Control Techniques for Energy Management, Building Reuse and Refurbishment
Keywords BESS, Building energy, Peak Shaving, Electric energy, Energy pattern

ABSTRACT

The battery energy storage system (BESS ENERGY STORAGE SYSTEM) is afford storing electric energy of the light load zone release time of the maximum load that may be referred to enable the device. Technical problems in the past due to cost and practical application of the burden to have had a lot of trouble. Due to recent advances in electric vehicles and energy storage devices, the weight of the product density, and product price declines to bring such products to use the matching conditions favorable due to recent social product is applied in many areas and the study who being accelerated. The installation of the battery energy storage products is the maximum energy load of the building users and the required time for the charges to enable the effective use of energy in the building to ease the economic burden of the users have had the energy to give energy providers the burden on the facility expansion this can be a benefit by reducing each other can be described as a method. In fact, the electrical energy storage facilities near field can be said more, but the actual large office building in the applying existing facilities and use of electrical energy for the estimation of the amount provided by the Institute of Energy Research, public buildings energy relative coefficient is used to obtain and afford the actual usage pattern by comparing the work proceeds. Electric energy savings and light load hours of the base rate and the maximum load of the electric peak shaving time by looking at how much it costs to save energy costs and payback period of the initial investment products see if how much can be said for the research.

1. INTRODUCTION

Recent forms of distributed renewable energy power supply is enabled to store electrical energy in an energy storage device (ESS, Energy Storage System) is increasing the interest. The advent of high-density high-efficiency conventional rechargeable batteries store electricity in many areas, it is impossible to escape from what used to be trying to promote. The use of the electric energy storage technology, especially since the maximum power demand on the energy to move the load to a light load zone that enables the necessary electric power demand of the facility for enabling efficient operation. In terms of the power demand of the energy provider by enabling the administration of the generator and the environmental problems caused by expansion of the transmission and distribution equipment, such as to reduce the investment cost can induce a strategic electricity supply. Construction of the electrical energy storage system in order to examine the storage medium should be on the preceding study, regeneration of energy storage in order to find the most suitable medium and utilizing the analysis of the characteristics of each medium should be applied.
2. METHODS

In this paper, the basic structure of the ESS and the ESS for different kinds of features introduced and examined with respect to domestic and international market trends. In addition, ongoing trends related to domestic and international standardization want to analyze the characteristics of the system. These previous studies of one of the devices after the ESS technology applied to the BESS system by looking office building heating and cooling energy peak load management can respond effectively to make sure that after viewing the parties to this paper.

Due to changes in electricity tariffs rising cost of energy use in buildings

Analysis of the building’s energy use patterns destination

After application of the ESS destination building operational analysis

The resulting value of destination property derived

3. COST OF ELECTRICITY

If the time zone differential of seasonal fare and each season depending on the hourly cost of the power supply to charge a differential fee system can be said. In other words, in the case of the summer season, winter, spring, fall is divided into 24 time zones, separated by time sensitive afford each season, and the differential rates will apply. Korea Electric Power to supply the exclusive sales structure. Therefore, consumers can choose power bill narrow. Korea Electric Power provides electricity to the unit price, and the average fee structure by use of the following can be classified as shown in the table.

<table>
<thead>
<tr>
<th>Energy price</th>
<th>~2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Season</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

30th INTERNATIONAL PLEA CONFERENCE
16-18 December 2014, CEPT University, Ahmedabad
4. ANALYSIS OF THE BUILDING'S ENERGY USE PATTERNS DESTINATION

4.1 Analysis

Location: Daejeon, 139 West seonsaro   Completion date: 12/10/1997

<table>
<thead>
<tr>
<th>&lt; Land area &gt;</th>
<th>(Unit: ㎡)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Construction area</td>
</tr>
<tr>
<td>518,338</td>
<td>28,703</td>
</tr>
</tbody>
</table>

Building Structure: Steel Reinforced Concrete

Building Size: 2 underground floors / ground 20 floors

Maximum height: 91.9m,   Above is: 36.22N,   The floor and: Typical floor 4.2m, up to 5.4m (ground floor)
4.2 Data

Monthly amount of electrical energy in 2009
(Unit: kWh)

Monthly amount of electrical energy price in 2009
(Unit: Dollars)
4.3 Solving the building energy use pattern

According to the data extraction KEPCO contract type sales database of customers to find out the average hourly power consumption can be seen. In order to calculate the predicted values relative load factor is the monthly Energy Management Corporation load pattern of educational holiday season working load pattern is used.

\[
\text{Load forecasting} = \text{peak demand} \times \text{relative factor}
\]

24 hours relative load factor set to 1000, the average of each time slot representing a load index. How to calculate the relative coefficients are as follows. Classification by type of weekday working and living in the form of electricity usage behavior will be classified by considering the impact. National Day of the week from Tuesday to Friday, the day of the week, not working day-to-day work was set takes place. Working day by working day by day to show a different behavior on Sunday, Saturday and Monday were classified. Closed on Sunday conducted the day of the week as a whole , and performed according to the five-day workweek on Saturday and the other working day and appear in the form of the load is carried entirely closed on Sundays and also the load of the different forms of the need for analysis elsewhere there. 24 hours, the average load factor relative to the respective time slot 1000 is set to represent the low and high load index. Therefore, there is no unit . In order to forecast electricity usage statistics based on the classification of the contract type classification, hierarchical classification, one type-specific sorting, classification and utilization peaks were classified by type of case working days ( not include holidays from Tuesday to Friday) Sunday, Saturday, Monday, and was used. If the seasonal peaks by use of classification was based on the peak day occurred. 75,684 of these data, the industry has been created on the basis of the distribution of the Classifieds.
4.4 Adapting BESS

ESS installed capacity of 90% compared to the average operating efficiency is assumed to keep the amount of planning time and was discharged afford.

※ 8:00 a.m. to 7:00 p.m. discharge time Average price: 1256.5kW

※ (load values-day average value -1256.5) of the load values: 1736.4 kW

<table>
<thead>
<tr>
<th>Time</th>
<th>Load values</th>
<th>(Load values-Daily average values)</th>
<th>(Load values-Daily average values-1256.5kw)</th>
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<tbody>
<tr>
<td>0~1</td>
<td>3593.1</td>
<td>-1329.8</td>
<td></td>
</tr>
<tr>
<td>1~2</td>
<td>3519.2</td>
<td>-1403.6</td>
<td></td>
</tr>
<tr>
<td>2~3</td>
<td>3455.2</td>
<td>-1467.6</td>
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</tr>
<tr>
<td>3~4</td>
<td>3406</td>
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</tr>
<tr>
<td>4~5</td>
<td>3420.8</td>
<td>-1502</td>
<td></td>
</tr>
<tr>
<td>5~6</td>
<td>3612.8</td>
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<td></td>
</tr>
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<td>6~7</td>
<td>4050.8</td>
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<td>1288.7</td>
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<td>4036</td>
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<td>22~23</td>
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<td>23~24</td>
<td>3706.3</td>
<td>-1216.6</td>
<td></td>
</tr>
</tbody>
</table>

CASE .1
Proper capacity planning: 1MW (taking into account the 90% efficiency usage is described 900kW)

CASE. 2
Proper capacity planning: 2MW (taking into account the 90% efficiency usage is described 1800kW)

CASE. 3
Proper capacity planning: 3MW (taking into account the 90% efficiency usage is described 2700kW)
4.4 PROFITABILITY ANALYSIS

DOE’s Sandia National Laboratories in the U.S. and launched in December 2012 ES-Select program, which was used as a database for information on battery storage system is as follows: Looking at the graph data 1kWh report if the price of $ 600 provided by the DOE, which shows the price of lithium ion in the price of industrial facilities and container type is determined by the middle of $ 400 was calculated assuming that the payback period. $ 400 per 1kw converted to the current exchange rate at the price of 440,000 won per 1kW to 2MW estimate of 880 million won in the case of the configuration was assumed to be costly.

<table>
<thead>
<tr>
<th>CASE 1</th>
<th>Original A</th>
<th>ALT B</th>
<th>A - B</th>
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<tbody>
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<td>657,047</td>
<td>630,290</td>
<td>26,757</td>
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<tr>
<td>Using amount</td>
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<td>2,496,469</td>
<td>105,970</td>
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<td>Reduce amount</td>
<td>14,152 dollars/ year</td>
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<table>
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<td>Using amount</td>
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<td>20,783 dollars/ year</td>
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<thead>
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<th>CASE 3</th>
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<td>Using amount</td>
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<td>Reduce amount</td>
<td>26,972 dollars/ year</td>
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</table>
CONCLUSION

Proceed in this study, the largest electric energy for the purpose of attention is focused on the investigation at this time and through the analysis of BESS actually have any effect on the building knowing about view. In fact, using the coefficient of relative configuration to look at energy usage and the actual usage is quite similar to the value estimate was confirmed. This allows the using of the monthly amount of electric energy consumption and in the process configuration. 3-4 hours in the case of ESS equipment to maximize the efficiency of the product can have an office building, the M-shaped energy load because it has a tendency of electric discharge by a particular time in a simple way, that there is a limit and then derives an analysis was. In the case of ESS equipment prices are falling faster in the state, but I think at this point, when the basis of a longer period of time had recovered. Future due to the rising cost of energy is electric charge realized the work is ongoing at the time BESS electricity rates will be rise building is an important element to be operated is obvious. In fact, users using BESS is to reduce the total amount of electrical energy, but not at the national level and a personal level to adjust the amount of load that can be used to reduce rates because they can serve as positive role in society generally we look forward to.

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Performance of Phase Change Materials for Cooling of Buildings in Mild Climates

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ABSTRACT

The effect of phase change material (PCM) integration in buildings is investigated in mild climates for the entirety of the hot season. The incorporation of PCMs in building materials is particularly interesting because it allows for the thermal storage to become a part of the building structure while being completely passive. Simulations in a typical single-family home are carried out, and the effect of incorporating PCMs in different building components is analyzed. Results show an important reduction in cooling energy.

1- INTRODUCTION

World electricity consumption is expected to double by 2025, increasing at a significant rate of 3.5 % per year. Furthermore, the demand for thermal comfort in both domestic and commercial buildings is currently rising. The additional energy demand significantly contributes to the increasing consumption with a peak demand in mild and hot climates. However, any action must start by reducing the level of energy consumption or at least delaying the peak demand.

To shift the peak energy demand (ideally few hours), the thermal mass of buildings can be used to store energy and lessen indoor temperature fluctuations. Nevertheless, the requirements of a thermally massive building often conflict with cost or aesthetics that require buildings to be increasingly lightweight. Incorporating phase change materials (PCMs) into buildings is a way to artificially increase the thermal mass of lightweight structures (Zhang et al, 2007). Heat storage can either take sensible or latent forms. Sensible storage is accomplished by increasing the temperature of the material, whereas latent heat storage is accomplished by changing the physical state of the material. To store the same quantity of energy, a smaller amount of material is required for latent storage. For example, a common building material, such as concrete can store about 1 kJ/kg when subject to a temperature increase of 1°C, whereas a PCM, such as calcium chloride hexahydrate can store/release up to 193 kJ/kg on complete phase transition (Kenneth and Gates, 2000). This huge increase of thermal storage capacity for PCMs and their almost isothermal discharge could be used to stabilize ambient temperatures inside buildings.
Currently, the available commercial micro-encapsulated PCMs are made with paraffin waxes embedded within small polymer spheres of about 10-20 µm in diameter. When in powder form, PCMs can be mixed directly into the building material or internal wallboard without risking leakage. The additional latent heat capacity for the distributed PCM increases the overall effective heat capacity when compared with sensible storage alone (Khudhair and Farid, 2004). The main advantage of setting a PCM in wallboards and incorporating it into the internal side of the external envelope of a building is to have a large surface in contact with the indoor air.

Recently, incorporating phase change materials (PCMs) in building materials to reduce the cooling needs has been investigated in many studies. An extensive literature review on micro encapsulated PCMs and the application in buildings can be found in (Osterman et al, 2012) or (Zhao and Zhang, 2011). However, these studies mainly address lightweight or reduced scale constructions (laboratory scale testing, (Tardieu et al, 2011). Therefore, the obtained results cannot be generalized and are inconclusive regarding the benefits in real buildings and climates. Indeed, the experience conditions for the reduced scale generally lead to a large day/night temperature variation, which allows the PCMs to swing widely around the melting temperature. In this case, charge and discharge cycles are fully accomplished, and in turn, PCMs are in their optimum working mode. However, when simulating a long period (all the hot season for example), it is the average values that must be considered. A PCM can perform badly on a particular day, but might still perform well on average for the whole season.

With this work, our aim is to see how PCMs can reduce thermal loads in real buildings and how they can decrease fluctuation of indoor temperature to improve summer thermal comfort. Additionally, we will try to see if a unique optimum switch temperature exists and what parameters influence this temperature.

2-MATHEMATICAL MODEL

For the mathematical modeling, a nodal method was used. With nodal methods, a system is decomposed into isothermal (but not necessarily elementary) volumes. Each volume Vi is represented by a node with calorific capacity $C_i=\rho_iC_p_iV_i$. The heat exchange of a node with its neighbors is represented by thermal conductances (opposite to thermal resistances) characterizing different modes of heat transfer (conductive, convective, radiative and “fluid”). The energy conservation equation at node i connected to its neighboring nodes j and with a heat source $Q_i(t)$ is as follows:

$$C_i\frac{dT_i}{dt} = C_i \frac{dT_i}{dt} = \sum_j G_{ij}^c(T_j - T_i) + \sum_k G_{ik}^r(T_k - T_i) + Q_i(t)$$

(1)

$G_{ij}^c$ and $G_{ik}^r$ are conductive (or convective) coupling conductance and radiative conductance, respectively. When applied to all nodes, the energy conservation equation leads to a set of nonlinear, yet ordinary algebraic-differential equations. A dynamic solver is then used for the transient resolution. This type of method provides a very powerful tool for modeling complex systems with heterogeneous interactions, such as a building, and the precision is within the limit of validity of the isothermal assumption of the chosen nodes. In our case, the main advantage of those methods is the ability to consider the wallboard as an isothermal single node and then not necessarily solve the melting front position. The modeling of latent heat change use only its effective capacity $C_{ef}$, which is temperature dependant. It is treated as non-linear, such as others temperature dependant physical properties or conductances (natural convection or radiation for example). The actual solvers are robust and can deal with the very sharp evolution of $C_{ef}$. 
The encapsulated PCMs are particularly candidates for this type of modeling because they are randomly mixed with gypsum to form a homogeneous material. The heat capacity is the sum of the capacities of the constituents (sensible and latent) as shown by (Shukla et al, 2012) and the density is the weighted average of densities.

3- PCM CHARACTERIZATION

Among key parameters for PCM simulation, thermal properties such as switch temperature and the enthalpy variation with temperature of are of primary importance. From the enthalpy variation \( h = f(T) \), which can be determined by several methods, such as Differential Scanning Calorimetry (DSC) or T-history, the effective capacity, \( C_{ef} = f(T) \) is as follows:

\[
C_{ef} = \frac{\partial h(T)}{\partial T}
\]  

(2)

Because the model takes into account the phase change by the variation of the heat capacity during the phase transition, it is necessary to know its explicit variation versus temperature. There are several representations for this variation of \( C_{ef} \). (Feustel, 1995) gave a simplified representation with an exponential symmetrical shape:

\[
C_{ef} = C_{sl} + \frac{\Delta H}{2} \left[ \frac{2\beta / \tau}{\cosh^2 \left( \frac{2\beta}{\tau} (T - T_m) \right)} \right]
\]

(3)

Where \( C_{sl} \) is the liquid phase heat capacity; \( \Delta H \) the fusion latent enthalpy and \( T_m \) is the melting temperature (or switch temperature), \( \beta \) is a shape parameter and \( 2\tau \) is a range where 99% of the phase change occurs (melting or freezing). The solid-solid peak transition is neglected because the temperature is not relevant for the wall’s operating temperature. The representation is also using equal capacity values for liquid and solid phases. No hysteresis was also assumed between melting and freezing, which is generally the case with organic PCMs. In fact, in our calculations, a slight hysteresis (a shift of approximately 1°C) had practically no effect on long-term simulation if the switch temperatures are close to the optimum values.

Different values for the conductivity of gypsum with PCMs are found in the literature ranging from 0.15 W/mK to 0.6 W/mK mainly because different conductivities of the gypsum matrix are reported. A conductivity of 0.3 W/mK is considered for this work and the change of phase of the PCM do not have a substantial influence on thermal conductivity of the wallboard (Jaworski and Abeid, 2011).

4- THE CASE STUDY MODEL

Among numerous factors that influence energy consumption and performance of buildings with PCM integration, the following main parameters are identified:

- Local construction systems (envelope and windows).
- Local climate: solar irradiation and ambient outdoor temperature.
- Internal loads: the personal occupancy and electrical appliances (lights, TV, computers, etc.).

The case study involves a typical residential single-family house with an area of approximately 104 m² area, two bedrooms, one living room, one kitchen, one bathroom and one storage room.
Two windows (simple glass $U=4.4\ \text{W/m}^2\text{K}$) are located in the north and south walls and the window-wall ratio (WWR) is approximately 12% (see figure 1 for the sketch). The constructive system is typical of the Mediterranean countries with a relatively heavy envelope (solid concrete end-terrace roof and measonery brick walls). Windows are shaded is by roof eaves and shutters (shading factor $f_s=0.5$) in the summertime and the solar absorptivity is assumed 0.5 for the roof and the walls.

![Fig 1. Sketch of the building model.](image)

Exterior walls are traditional double brick walls with a 5 cm air gap (see table 1 for thermal characteristics of building components). The levels of insulation seem to be lower compared to those in continental climates, but they are sufficient for the Mediterranean region. PCM (when being present) of varied switch temperature between 24°C and 32°C is embedded in the wallboard of gypsum plaster of 15 mm nominal thickness. They contain between 0% (no PCM) and 30% mass fraction of encapsulated paraffin and are set into the internal face of the walls or the ceiling.

<table>
<thead>
<tr>
<th></th>
<th>Roof</th>
<th>Ext. Wall</th>
<th>Floor</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U-value [W/m²K]</strong></td>
<td>1.26</td>
<td>1.23</td>
<td>2.41</td>
<td>4.40</td>
</tr>
</tbody>
</table>

The study is carried out for the city of Djelfa, Algeria a typical Mediterranean city with a sub-continental climate: a mild-warm climate and relatively hot and dry summer. When the indoor temperature exceeds 26°C, cooling is activated and split system room air conditioners with 100 W/m² power are used. Thermal loads for occupancy and appliances are omitted to obtain a non perturbed comparison for PCM efficiency. For the same reason, only the absolute indoor temperature (and not operative or adaptive temperatures) is considered. The internal convection coefficient is difficult to determine because deviations of more than 100% can be found in the literature (David et al 2011). In this study, $h=8.3\ \text{W/m}^2\text{K}$ is used for vertical walls (according to ASHRAE recommendations, Diaconu and Cruceru, 2010) and $h=3\ \text{W/m}^2\text{K}$ for ceilings (stratified hot air on top) as average values for combined transfer coefficients (convective and radiative).
5- RESULTS AND DISCUSSION

The year round cooling performances of a PCM are evaluated. However, only the summer period is considered, i.e., June, July, August and September (the period from June 1st to September 30 is also generally the period where the differentiated electricity price for on peak and off-peak period exist in many countries). Two very simple indicators are used.

The first indicator is for a passive house (free cooling without air conditioning) with a “discomfort index” $I_{\text{sum}}$ (Zhang et al 2007, modified by scaling it for the considered period):

$$I_{\text{sum}} = \int_{\text{season}} (T_{\text{in}} - T_{\text{set}}) \, dt$$

when $T_{\text{in}} > T_{\text{set}}$  

(4)

This indicator shows how long (and how much higher) the indoor temperature is above the comfort temperature, which is assumed to be 26°C (overheating). The second indicator is for an air-conditioned house and shows the primary energy demand $Q_c$, or the quantity of primary energy that needs to be removed from the indoor building by an active cooling system to confine the indoor air temperature to a maximum of $T_{\text{set}}=26°C$.

$$Q_c = \int_{\text{season}} q_c \, dt$$

(5)

Figure 2a shows the indoor temperature with a 30% PCM fraction weight and $T_m=25°C$ and figure 2b shows $T_m=27°C$ ($\Delta H=160 \text{ kJ/kg}$). From those figures, we can see that for $T_m=25°C$, the PCM performs well early in the hot season in June and in late September, but less so in the middle of the hot season (the hottest days). With $T_m=27°C$, the PCM seems to work mainly in the middle of the hot season (July and August). The adjustment of the switch temperature permits to control of which days of the hot season are concerned by PCM action.

![Fig 2a. Evolution of the indoor temperature without and with PCM, $T_m=25°C$.](image)
Table 2 shows the discomfort index $I_{sum}$ and the cooling load $Q_c$ for a PCM set on the internal face of walls and the ceiling for different switch temperatures and for a PCM fraction weight of 30% and with $T_{set}=26^\circ C$. It is clear with those two indicators that the optimum switch temperature is between 26 and 27°C. However, a switch temperature close to this range would provide slightly different results. The maximum reduction on cold demand with the incorporation of PCMs is about 20% which is in the average of results found by the others studies.

Table 3 shows the two indicators with PCM only set on the walls and Table 4 shows those with PCM only set on the ceiling (internal face). The results show that the optimum switch temperature is approximately 26°C for the walls and approximately 31°C for the ceiling. This is because the walls and the roof do not receive the same amount of solar irradiation and consequently, do not operate at the same temperature.
Note that even if the areas (and then the PCM quantities used) for the ceiling and the walls are equivalent (102 m² and 113 m², respectively) and the received irradiation is different, the PCM perform in the same way (16.5% and 18.5% in reduction of the cooling demand, respectively). In fact, the ceiling receives more solar irradiation than external walls but has in revenge a weak convection heat transfer coefficient compared to the walls.

6- CONCLUSION

The incorporation of encapsulated PCMs in building materials such as gypsum wallboards was investigated for the entirety of the hot season to reduce cooling energy or enhance thermal comfort. The PCMs are found to perform well a reduction of approximately 20% for cooling energy. This PCMs performance is realized even in mild climates characterized by low day/night temperature swings, which make night time ventilation less efficient for discharging the PCM. Anyway, the reduction of the cooling energy is obtained with relative large quantity of PCM. A local economic efficiency analysis must confirm the process profitability.

The PCMs have better performance on surfaces that undergo the widest temperature variation. Incorporating PCMs on the ceiling give the best compromise gain/cost and is relatively easy to realize even in existing houses. This shows their potential use for refurbishment of actual buildings which is the weak point of all energy conservation policies.

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Proposal of a Methodology for the Architectural Design of Timber Houses

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ABSTRACT

This paper presents the principles of a method for the architectural design of timber houses based on the experience gained by timber companies. This proposal has as its major goal the challenging of the scenario of countries like Portugal where a shift in the design and construction methods integrating wood as a material could result in a much more sustainable habitat. A set of interviews was carried out with Portuguese companies in the sector of timber houses. They were questioned about their customers, design methods, the architect’s role and the choice of structural systems. Based on the interviews it was possible to characterize the market and identify the main procedures about design. The most relevant ones were the importance of the architectural type definition, the support of a catalog, the relationship between formal and structural types and the architect’s lack of knowledge about timber. The collected information pointed to an architectural design method to be used by Portuguese architects who, until now have often played a secondary role when a timber house was designed partly because the timber companies dominate the whole process. Some of these companies offer catalogues of design solutions that support customer’s choices. The architects generally reject this type of method because of its supposed uncreative and impersonal results. The method here presented through some basic principles aims at collecting some positive lessons from the catalogue method, defining a process based on the recognition of Formal types and Construction types. This is the framework of a tool intended to help the Portuguese architects to deal with the range of the options available (solutions, companies, structural systems) and a support to help in deciding which construction system to choose.

INTRODUCTION

The adoption by architects of an architectural design method based on the information provided by the experience of timber house companies could lead to an increase in the use of timber houses. The replacement of Portuguese current concrete houses would originate several environmental benefits. The sustainable use of wood in single-family houses has been the subject of studies which conclude that there are advantages in its use over conventional solutions such as reinforced concrete (Monahan & Powell, 2011; Monteiro & Freire, 2012) and even over competing systems, such as light steel framing (Bolin & Smith, 2011; Rabbit, White, & Gervais, 2012). It is argued that the replacement of wood construction materials could result in a reduction of carbon emissions (Sathre & O’Connor, 2010). Even recognizing that there is no consensus on the results of such studies (Coelho, 2012; Gervasio, 2013) there are other arguments to consider when dealing with timber construction: the construction time and the prefabrication level. The average construction time for the current single-family houses in 2012 was 25 months (INE, 2013) while the construction time for wooden houses in Portugal is less than 6 months (Morgado & Pedro, 2011).
Although Portugal has a forest richness that could, with a growth in domestic demand, provide some of the raw material for construction (Marques Morgado, 2012; Machado, 2004), the old tradition of building some house elements such as roofs, floors and some walls with wood was lost. But in the final of the 20th century the scenario began to change with the appearance of pioneer timber house construction companies. Usually the whole design process was managed by these companies almost without the advice of architects. Besides, until recently structural wood was not considered by Portuguese architects as a solution. Today their growing interest by timber houses can be observed through three situations: 1) the presence of timber construction companies that integrate architects or are managed by them; 2) the emergence of a small number of architects who become specialized in timber construction; and 3) the proliferation of commercial or academic proposals for modular house designs in timber, with high impact on the architectural community, but with reduced reception from the real housing market. Moreover, the single-family house is one of the most important works of Portuguese architects (Domp, 2014). This way the architects, required by law to design a house (Law n. ° 31/2009), are very well positioned to inform their clients about the possibility of building with wood. Additionally, houses in Portugal are one of the most significant types of the building housing stock: 13,500 houses were built in 2012 against 1,212 apartment buildings (INE, 2013). However the architects’ current design method may not be appropriate to timber house design. So this work does not focus on specific house solutions to reduce energy or to improve carbon sequestration. Instead of this it proposes a general method to allow architects to put into practice a more sustainable type of construction using wood, replacing the common practice of choosing by default concrete and brick.

Objectives and methodology

The objectives of this article are:
  1) To provide a summary of the results of 15 interviews with Portuguese timber house companies;
  2) To propose the principles of a design method based on some aspects of companies’ experience;
  3) To identify the relevant typological principles connected with timber construction in Portugal;
  4) To identify the main issues to integrate in design procedures;
  5) To identify the relevant criteria for choosing a timber structure from the set of various solutions.

The current work involved:
  1) The review of related literature and continuity with the research already carried out by the authors (Morgado, Guedes, Ferreira, Cruz, 2013; Morgado, Guedes, Ferreira, Cruz, 2012);
  2) Interviews with managers, technicians or sales technicians;
  3) Analysis of the interviews;
  4) The proposal of a method to support architectural design through its basic principles.

Initially 25 companies were pre-selected and contacted, because they were among better well-known companies in the Portuguese market or represented the diversity of the national reality. Because of this, companies that do not refer the product “House” in their advertisements, or those whose structure seemed to be very fragile or only with a very short period of activity have not been considered. From the group of selected companies, 15 were interviewed with predefined questions and 10 showed no availability to answer. The interviews took place between April 10 and May 8, 2014, having been made in most cases in the headquarters of each company. Only in one case the interview was conducted using a form filled online.

The interviewed persons were: ten managers, two design technicians and three sales technicians. The headquarters of these companies are located in a vast territory extending 380 kilometres of the Portuguese coastline (up to about 60 km east inland) from Vila Nova de Cerveira (north) to Setubal (south). Timber houses account for over 80% of the workload of seven of the interviewed companies, while in the other eight there is a variation between 5% and 55% of their area of activity.

The interviews were supported by a questionnaire with eight main groups of questions: 1) Companies information; 2) Clients; 3) Construction Process; 4) Conception and design; 5) Role of the architect; 6) Choice of structural systems; 7) Structural systems’ features; 8) Design method. The interview will be analysed as a whole in another publication, so only the relevant questions for the goals of this paper will be considered.
THE INTERVIEWS

In the context of design methodology, national companies were classified based on the following criteria: the level of integration of the architect’s activity, the number of building systems offered and the main companies’ activity. Thus seven companies regularly work with architects, four occasionally work with them and the other four cover a market in which the activity of the architect is residual. Regarding the number of structural systems available for clients to choose from, seven companies offer three or more systems, four companies have only two systems and the other four companies emerge with just one structural system. All companies include design and construction activities (inside the company or with external partners) and five of them do not manufacture their products, as they are just partners of foreign factories.

Construction systems

The dominant building systems are light timber-frame panels and post-and-beam, offered by eight companies and also the log construction present in six companies. With only three answers each system, appear cross laminated timber (CLT), light timber frame, plank and columns, three-dimensional modules and heavy mixed systems are present in three companies. Four companies offer heavy mixed systems (post-and-beam with light timber frame, planks or logs). The preferred system of most companies is the light timber-frame panels with four choices, followed by post-and-beam with three choices and cross laminated timber, light timber frame and heavy mixed systems with two choices.

Clients

From the point of view of the interviewed companies, the arguments that lead a customer to choose a timber house are the Comfort (ten answers "very important" and four "important"), followed by the special architectural Aesthetics associated with wood (seven "very important" and six "important") and the Speed of construction process (five “very important” and ten "important"). The Environmental factors (three "very important" and five "important") and economics (three "very important" four "important") are less consensual. Regarding the type of agents who contact those companies, the final consumers are the most frequent, followed by architects. Most companies say that customers who approach them had already decided to build in wood. However the contacts are usually made in order to get a quote to compare with quotes those clients already have from other companies.

Construction process

The most common construction process consists in the prefabrication of components regarding the specific settings of each project (twelve answers "often" and one "occasionally") and it is also common to use prefabricated market standard elements (five answers “often” and nine “occasionally”). However, the onsite manufacture with reduced prefabrication is still considered cost-effective by some companies (four answers "often" and three "occasionally"). Some companies work with complete modules (three answers "often" and three "occasionally") or partial modules. All companies considered that distance is not a limiting factor of the project’s viability, although it may increase the final work cost. The final prices quoted by companies for a wooden house ranges from about € 500/m2 up to € 1000/m2. The average price indicated by the 15 companies is about € 800/m2.

Method and design conception

Most companies (with one exception) consider, among other possibilities, the timber house design as a completely custom solution. All companies include a showcase of solutions available for client consultation, functioning in some cases as "catalogues of solutions" or books of patterns. This is a common device in the companies activity, whether based on pre-defined solutions (eleven responses), or based on a customisable modular system (six responses). The companies with a larger production of houses tend to offer a detailed catalogue presenting different types of solutions grouped in families of “styles” and structural types. Only two companies declared not to provide such a device, coinciding with situations where timber houses are a secondary activity. Among companies using the catalogue of solutions, only two considered it to be "less important", with the others considering that it is "very important" (five responses) or "important" (six responses).
The purpose of the "catalogue of solutions" is for most companies (seven responses) a reference to support customer choices, with only two companies considering that the catalogue offer products that customers actually accept and buy without any changes. Four companies considered that catalogues work more as a marketing medium. It was noticeable that several companies use their already built houses or their exhibition prototypes as models that act also as a "catalogue". When addressing the companies, most customers already have a pre-set idea of the functional type of house they want to build (twelve responses), but are often less informed about the symbolic type (language, proportions, details, finishes) and it is frequent that they are not enough aware about structural type definitions. Although with less answers, the client without predefined ideas also consults the companies for the support of the design services from early stages (two answers "often", nine "occasionally"). Architects, as expected, consult those companies with more defined ideas about functional and symbolic solutions, although not often with pre-defined ideas of the structural types. Companies use the pre-defined customer ideas as a starting point, although some minor adjustments (fourteen responses) are always required. When customers do not have pre-set ideas the most widely used process is the customization of solutions based on the catalogue (eight responses) and the definition of completely customized solutions process.

The architect’s role

All companies offer architectural design, structural engineering and the other engineering services. However seven of them hire external architecture services and other seven hire external structural engineering services. The intervention of architects, in addition to the design development phase for authorities' approval, is generally lower in the phase of construction documents and in the coordination tasks. It should be noted that normally, in cases where the architectural services are hired by the client, the company prepares a set of documents to be reviewed by the architect responsible for the design approval. Regarding the knowledge of timber construction specificities, the architect is seen by companies as a professional who demonstrates "many difficulties" (seven responses) or "some difficulties" (seven responses). The most highlighted aspects were the difficulties about durability constraints (eight responses "many difficulties" and five "some difficulties"). The structural and hygrometric behaviour of wood and the construction details were also highlighted, although not with so much importance. It may be added that one of the interviewees considered that cases where the architect’s solutions fail are explained by the importing of architectural models from central and northern Europe, whose performance in the national climate (thermal and humidity conditions), turn out to be deficient. The architect is nevertheless considered an important partner, as expected, for the completion of approval designs, the implementation of the program and the definition of formal solutions. Questioned about whether the intervention of the architect leads to more complex, more expensive, or later problems, most companies found that that it does not affect the normality of the work, although some companies indicated negative responses and no company indicated that the architect’s intervention has a positive effect on these parameters. Five companies answered that architects are responsible for more complex processes, four mentioned higher costs and three mentioned later problems. Most companies defend that the structural engineering must be integrated in the company (eight responses), opposite to a minority (four responses) that consider that it should be integrated into the project team or that should be hired by the company (two answers). Some companies noted that when the structural designs are undertaken by external offices, the structural components tend to be the oversized.

Choosing the structural systems

During the initial project definition, clients do not usually think about structural systems. Half the companies responded that it is rarely mentioned, while three considered that this aspect is never mentioned. The choice of structural types occurs frequently (seven responses) and occasionally (eight responses) simultaneously to the choice of the formal type. It is also frequent (nine responses) and occasional (three responses) that the choice is made after the formal type definition. Only in three cases was the choice of structural type done beforehand (frequently and occasionally). The simultaneous choice of structural and formal types occurs mainly in cases in which companies have an organized catalogue of solutions associating a structural type to each formal type. Some interviewees mentioned that when clients choose as a reference the catalogue solution, they already know which structural system will fit better.
The choice of the structural type which is usually held in the early stages of the project is done by considering the adequacy to the architectural solution as the most important criterion (nine responses "very important" and three "important"). The remaining criteria are less important, but economy is still the second most mentioned criterion, being considered as "very important" (four responses) or "important" (three). The other mentioned criteria are the construction schedule, the quality of the construction process and finally, the environment is considered a "less important" criterion (ten responses) or "not important" (four responses). Regarding codes and standards, the majority of responses devaluates its impact on the choice of the structural system, with most companies responding that their influence is less important or unimportant. However, the thermal requirements are those to which companies assign more importance over the other ones (structure, aesthetics, specific timber standards), with one "very important" response and four "important" responses. For the characteristics of the built envelope, seven companies said that different climatic zones have influence in their settings while eight said exactly the opposite. These latter companies said that the offered solutions always include the definitions to face in the most unfavourable situation.

The influence of structural types on the settings of formal types was considered mainly as "less important" (nine responses) or "unimportant" (two answers). The comparative analysis of structural systems is undertaken "often" or "occasionally" by seven companies, and “rarely" or "never" by the remaining eight. When questions were asked about the adequacy of structural systems to specific architectural characteristics, the responses were predictable, associating the post-and-beam to wide structural spans and larger windows, interior open spaces, stylistic flexibility, contemporary and “structural truth” character. The light timber frame panels were associated to stylistic flexibility, contemporary character and with minimized loads on the foundations. The log construction and the column-and-planks were associated to the “structural truth” character and the traditional character (though one company does believe that the contemporary character is also possible). The cross laminated timber panels are also mentioned, but less often (because only three companies work with them), associated to large spans, protruding volumes, stylistic flexibility and contemporary character.

**Design process**

Most companies (fourteen responses) can easily provide a construction cost estimate with a sketch drawing (1/200 scale), implying the existence of reference prices per square meter, although there are additional factors to consider such as the level of quality of finishes and the scale factor, reducing the price by square meter as the amount of work increases. With a design development project (1/100 scale), all companies already provide a final budget. Companies are flexible about the time the contract administration should take place, most of them (nine responses) considering that this step must only occur after the municipal approval is obtained. Throughout the interviews development, it was noted that the issue of construction documents (construction drawings) phase executed by the architect only occurs in some cases, as a large part of the details and specifications are made by the company. The detail drawings of architecture tend to be complementary (when they do exist) to manufacture and assembly drawings of the structure, envelope and interior partitioning. Seven companies think that the construction drawings must be coordinated by the company, while four answered that it should be a simultaneous process.

![Figure 1](image)

Some interview results based on 15 answers: (a) Arguments to choose a timber house (b) Presentation of design services (c) Criteria to choose a structural system (d) Architects difficulties.
ARCHITECTURAL DESIGN METHOD

An overview of the design process adopted by companies of timber houses and architects in Portugal can be described through the following three reference models (A, B, C):

A - Developed by the timber house sector companies. With solutions built from tested designs or catalogues or still modular systems (although contemplating customization). The companies have a preferred range of structural systems to offer. The architectural services in each project can be minimized due to the accumulated experience and the repetition of solutions. The advantages of this process are construction quality and process efficiency. Architecture in this case is understood as a product. The client chooses the product, but he must adapt himself to the company's standards and offer.

B - Developed by architects according to the model propagated by architecture schools in Portugal. With solutions based on the specific nature of each commission and ruled by conceptual principles or inspiring models of contemporary architecture, with the aim of obtaining unique and innovative features, with a large investment in aesthetics, more than durability. The architect integrates the well-known construction system with reinforced concrete. The architectural services are carried out with great endeavour in construction drawings. The advantages of this process are its formal quality and uniqueness. The resulting architecture is seen as an artistic product. The client chooses the architect, but he should adapt himself to the architect’s choices.

C - Developed by architects who provide services adapted to the reality of the average client of the single family houses in Portugal, with the aim of their satisfaction. With solutions based on preferred customer models and with reduced conceptual and aesthetic thought. The building system makes use of the current reinforced concrete. The architectural services are performed with reduced effort in construction drawings, using known details. The advantages of this process are the smaller costs of the design services, and the improved customer satisfaction, but the resulting architecture is often a rather banal product. The customer chooses the architect and this one must then satisfy his particular requirements.

We want to propose now an alternative system: D - To be developed by architects under a collaborative process with wooden houses sector companies. With solutions developed from a knowledge base made by a "catalogue" of architectural types which provides information on achievable solutions with timber structures, recognizing customer preferences but expanding the range of available solutions and the suitability to each scenario, with great emphasis in construction drawings, in durability concerns. The advantages of this method, compared to the process A, are the greater range of customer choices and the independent support that is provided. Regarding process B, communication and customer satisfaction are improved by a choice supported by a typological catalogue, seeking to obtain durable solutions. Finally, in relation to procedure C, there is the advantage of offering a personalized service with greater effort in architectural thought and greater conceptual attention to context and a more sustainable solution in wood.

Typological systematization

The typological systematization of the timber houses universe will be part of the information that allows us to acquire knowledge of market possibilities and that enable the communication between architect and client. The set of possible types results from the subdivision of architectural types into subtype systems. Thus, each architectural type includes a formal type and a construction type. The first is defined by features of architectural design, while the second is defined mainly by engineering features. The architectural type can in turn be subdivided into functional, spatial and symbolic types (Figure 3). The construction type can be subdivided into structural, envelope and partition types. Although the “types” can be described by rules, thus being different from "models" (or concrete solutions), it is useful to build a "catalogue" with models which represent the main types, because it will improve the communication between the client and the architect, avoiding misunderstandings. Dialogue can be established enabling the client to make choices from the various possibilities. On the other hand, architects can advise the client about the most adequate type of solutions without missing possibilities. The symbolic type is particularly important in the context of architectural types. It is defined in terms of characteristics, such as the roof shape, the degree of openness and the kind of finishing. The structural type (Morgado, Guedes, Ferreira, & Cruz, 2012) is of great importance in the context of building types, defined according to the characteristics of its vertical elements.
Proposed design method

After the collection of data gathered from the context (codes, standards and customer requirements which include the functional requests, values and preferences, cost limits, time limits and environmental sensibility) the program is defined by the architect. The program will be based on the definition of successive types: functional type, spatial type and symbolic type which together define the formal type. After that the construction type will be defined: structural type, envelope type and partition type, but at any time the decisions can be questioned, thus implying a comeback to any previous stage. In the sketch design phase, solutions are developed and evaluated based on the selection criteria and respective weights defined in the previous phase. The structural solution (or structural solutions, in case there exist alternatives) will be evaluated based on the suitability to the architectural solution, the economy (including the costs provided by companies), the process (including deadlines and assessment of companies) and possibly on environmental impacts of the solution and also other criteria defined for each case. After the solution and the construction company have been chosen, the activity of the architect, besides the integration of all engineering services, will be focused on the architectural features that can ensure the durability of the building through the general settings and particular details.

Figure 3  Example of a typological catalogue made by symbolic types and structural types

Following this proposal it is required that the architect welcomes a set of new practices and new skills: 1) It is required a knowledge of the cultural aspects of wood architecture to support the choice of formal types; 2) It is required a knowledge of structural systems and the understanding of its relation with architectural forms; 3) It is required an awareness of the criteria for selecting the structural types; 4) This calls for a better understanding of the specificities of wood and the constraints of durability. Architectural firms interested in building wooden houses could also define their own catalogues, following the suggestion of Colin Davies (Davies, 2005): "Pattern books could be used to promote the sale of certain commercial products, but more importantly, they could also be used to promote good architecture and sound, sustainable building practices (…) It seems completely feasible for architects to adopt, or readopt, the pattern book principle. It may even be an essential precondition for the achievement of that century old ambition to bring architecture to the masses".
CONCLUSION AND DEVELOPMENT

Based on interviews conducted with the timber houses design, manufacture and construction companies, it was possible to recognize some important aspects of the national market and of the design process. Based on the information collected, the framework for a proposed method targeting the optimization of timber house design in Portugal was outlined. The information that had greatest impact on the proposal were: the existence and the importance of a typological catalogue, the relevant criteria for the choice of structural type (suitability for the architectural solution, cost limits and time limits), and the difficulties evidenced by architects in relation to wood construction. This last situation requires some actions to improve the knowledge about wood considering the solutions’ durability. The details of this proposal are in development within a Doctoral Thesis, with several Portuguese companies supporting case studies aimed at testing the characteristics and constraints of each construction system.

ACKNOWLEDGMENTS

This paper was only possible due to the friendly collaboration of the following Portuguese enterprises: Casema, Carmo, Colicapela, Fuldex, Ideaewood, Jular, Lacecale, Logdomus, Loghomes, Novo Habitat, Pinho Casa, Portilame, Rusticasa, Tosca and Tisen. We particularly want to thank the persons (managers, technicians and commercial technicians) from each company, who dedicated part of their time to participate in the interviews: Nuno Rebocho, Susana Valente, Tiago Antunes, Carlos Silva, Amilcar Rodrigues, Helder Santos, João Carmo Simões, Sérgio Barbosa, Pedro Teles, Elisabete Ferreira, Veascelav, Luís Rocha, Berta Villas, Pedro Pinhão and Luís Jorge. We also wish to thank the FCT - Fundação para a Ciência e Tecnologia do Ministério da Ciência, Tecnologia, e Ensino Superior.

REFERENCES


Window Components’ Heat Control versus Orientation under the Extreme Hot Climate of the UAE

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ABSTRACT
The United Arab Emirates (UAE) has one of the world’s largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy, used primarily for cooling due to its extreme hot climate. Recently, the government launched several housing programs intended to meet the need of future Emirati beneficiaries, of which the Emirati Family Housing Program aims at providing 13,000 detached residential units by 2017. Orientation of typical housing design is solely governed by urban planning layout. More critically, windows did not show any adapted heat control treatment in relation to orientation, despite the windows significant impact on heat gains under the local extreme hot climate. This study aims at optimizing the thermal performance of the window’s components in relation to orientation in a typical house. The impact of orientation in the existing design indicated a 10% higher energy consumption for the west-oriented units compared to the east ones. Thereafter, the impact of window’s components including glass (double reflective glass, double tinted Low-E and double squared Low-E), frame (vinyl) and a shading device (automated slatted blinds) were tested. The best performing components were then combined into two scenarios: the first one included a vinyl frame and double tinted squared Low-E glass and the second had Low-E glass, vinyl frame and automated slatted blinds. The results indicated a reduction of the total annual energy consumption ranging between around 6% when facing east and 13% when facing west. More importantly, the optimal window components highlighted similar performance independently from orientation.

INTRODUCTION
The reduction of buildings’ environmental impacts is an internationally agreed agenda. A number of studies have established that urbanization is one of the main drivers behind environmental impacts including global warming, depletion of natural resources and air pollution (Smith, 2005, Seto et al, 2011). The building sector in the United Arab Emirates (UAE) has experienced a tremendous expansion in the last forty years due to population growth and economic development. Presently, the UAE has one of the world’s largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy. The residential sector in the UAE accounts for about 65% of newly constructed buildings according to the National Statistics Center (Statistics Center, 2013) and is responsible for 39% of the consumed energy, used mainly for cooling purposes (Saifur, 2012; RSB, 2013) (Figure 1). Amidst the overall country’s growth, the residential sector developed in the form of extensive housing programs provided by the government to its citizens. The majority of these housing programs are in the form of detached houses, the most demanding type of houses in terms of cooling, especially under the local extreme hot climate (St Clair, 2009). A survey of housing typology in a representative community highlighted typical housing design where the units’ orientation is solely governed by urban planning layout (Abuimara, 2013). More critically, windows did not show any adapted heat control treatment in
relation to orientation, despite the windows significant impact on heat gains under the extreme hot climate. This paper presents the result of an experimental investigation that explored the potential contribution of advanced window’s components to optimize the thermal performance independently from the impact of orientation while maintaining the architectural design unity.

Figure 1: Energy Consumption by sector in the UAE (Source: Saifur, 2012)

HOUSING DESIGN, ENERG Y EFFICIENCY AND CLIMATIC CHALLENGE IN THE UAE

The UAE’s desert climate, characterized by extremely high summer temperatures, imposes serious challenges to both designers and owners alike. Despite the extreme hot climate, controlled building thermal regulations were not introduced until 2003 in Dubai, addressing envelope insulation and glazing requirements in an attempt to curb the increasing energy issue in the building sector. These prescriptive insulation guidelines were then incorporated since 2011 in the Green Building Regulations (DEWA, 2014). More recently, the Urban Planning Council (UPC) in Abu Dhabi has established Estidama, the local green building rating system. This, aims at achieving sustainability and energy conservation in buildings through the provision of guidelines for newly constructed buildings. However, these guidelines are not fully implemented as they are still in the process of integration to the local building code (AlNaqbi et al, 2012).

Since the discovery of oil in the sixties, the UAE government amplified its intervention in the housing sector, acting as the main housing provider for its citizens at both federal and local levels. Governmental housing has evolved over time and comes currently in the form of communities that comprise a large number of detached houses (Abuimara, 2013). The Emirati Housing Program is the most recent program launched by Abu Dhabi Urban Planning Council (UPC), aiming to provide 13,000 detached houses until 2017 in the form of communities and neighborhoods in cities of the Abu Dhabi Emirate (UPC, 2011). These communities aim at the accommodation of social and cultural values along environmental adaptation through the design and construction of modern, high quality, sustainable units meeting Estidama requirements (Estidama, 2014). Al Falah Community; the research case study, located near the city of Abu Dhabi is part of the Emirati Housing Program and includes a substantially completed number of detached houses (ALDAR, 2009).

THE CASE STUDY; AL FALAH COMMUNITY IN ABU DHABI

Al Falah master planned community, part of Abu Dhabi 2030, has been designed to provide community facilities along with alternative social housing options for Emirati citizens. It consists of five residential villages with a total of 4,857 detached villas including a range of community amenities (Figure 2). Houses at Al Falah come in nine different designs varying in terms of size and architectural style. Villas come in three, four and five bedrooms typology ranging respectively from 300m$^2$, to 350 and slightly over 400m$^2$. All houses are located in large plots of over 1000 m$^2$ (30m x 35m), and
surrounded by 2.5m high boundary walls (ALDAR, 2009). The villas were designed in 2008, prior to the development of Estidama; the local green rating system. They include some general sustainability measures including external wall and roof insulation, efficient water fixtures and high performing ventilation and air conditioning units (G.M.H. 2009).

The three different architectural styles, labelled Andalusian, Heritage and Modern as illustrated in Figure 3, share otherwise the same layout (ALDAR, 2009). The master plan layout governs houses orientation with no indication of any window treatment adaptation per orientation.

EXPERIMENTAL INVESTIGATION

First, the dominant type of houses was identified through a typological classification survey of all houses. The five-bedroom villa emerged as the dominant type accounting for 50% of the total number of houses in Al Falah community, while 20% were 3 bedroom houses and the remaining 30% were four-bedroom houses (Abuimara, 2013). Next, a comparative evaluation of the Window to Wall Ratio (WWR) in all living spaces was reviewed and compared among the three architectural styles. Ranges of WWR of 24% to 30% and 50% to 60% were identified respectively for bedrooms and the living room indicating potential for window design optimization (Abuimara, 2013). The modern style house exhibited an overall slightly higher WWR than the other styles and was selected as the case study (Figure 4). Table 1 summarizes the characteristics of the base case including location and the building construction characteristics.
Figure 4: The dominant house type in Al Falah community; the five bedroom modern style house ground floor plan and main façade perspective

<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Location</td>
<td>Abu Dhabi 24.42°N, 54.65°E</td>
</tr>
<tr>
<td>Area</td>
<td>Total Area (GF+FF)</td>
<td>402.36 m²</td>
</tr>
<tr>
<td></td>
<td>Footprint</td>
<td>212.56 m²</td>
</tr>
<tr>
<td>Building Envelope Materials</td>
<td>Windows</td>
<td>Tinted double pane glass with air gap in aluminum frame (U-value= 0.81, SHGC = 0.45 and Tvis = 0.57)</td>
</tr>
<tr>
<td></td>
<td>Walls</td>
<td>Insulated concrete panels. (20cm thick concrete panel with 6cm polystyrene insulation) R=11; Calculated using Opaque (Version 2) software based on the existing construction details</td>
</tr>
<tr>
<td></td>
<td>Roof</td>
<td>Hollow core concrete slab with water proofing and heat insulation layers R=18; Calculated using Opaque (Version 2) software based on the existing construction detail.</td>
</tr>
<tr>
<td></td>
<td>Wall / Ceiling reflectance = 70%</td>
<td>Colors range between white and cream (construction documents: ALDAR,2009)</td>
</tr>
<tr>
<td>Ratio of Glazing per Façade</td>
<td>Front Façade</td>
<td>26.55%</td>
</tr>
<tr>
<td></td>
<td>Right Side Façade</td>
<td>13.4%</td>
</tr>
<tr>
<td></td>
<td>Left Side Façade</td>
<td>9.03%</td>
</tr>
<tr>
<td></td>
<td>Rear Façade</td>
<td>16.2%</td>
</tr>
<tr>
<td>Air Conditioning System</td>
<td>Package Unit</td>
<td>Seasonal Energy Efficiency Rate (SEER)=13</td>
</tr>
<tr>
<td>Indoor Temperature</td>
<td>Lowest indoor comfort degree = 21.1 C (70F)</td>
<td>According to California Residential Code</td>
</tr>
<tr>
<td></td>
<td>Highest indoor comfort degree = 23.88C (75F)</td>
<td></td>
</tr>
</tbody>
</table>

The impact of orientation on the thermal performance of the existing house design (base case) was first tested using the Home Energy Efficient Design software (HEED 4.0 build 34); software developed by the University of California Los Angeles (UCLA). HEED is a dedicated energy evaluation tool for the thermal performance of houses and its outputs include among other data the annual electrical energy consumption, cooling loads and lighting loads.
The next step, in line with the original objective of this research explored thermally improved window components that do not impact the building architectural style. A reduction of window-to-wall ratio as well as addition of external shading devices as needed per each orientation were not considered. Hence, optimized glass alternatives and window frames were first individually assessed for each orientation in order to identify the contribution potential of single items. The glass and frames selection was based on their improved thermal properties and their availability in the market and included the tinted double pane Low-E glass, the tinted double pane Low-E squared glass and the tinted double pane reflective glass while the frame was limited to vinyl frame (Cardomy & Haglund, 2012). In terms of window shading, external operable slatted blinds were selected for implementation on all windows. These automated slatted blinds are light colored venetian blinds that close if the sun is on the window and interior temperature is above the set comfort level. The blinds are either fully open or fully closed. The selection of this type of automated blinds meets two requirements. First, they can be adjusted to suit all orientation in residential neighborhoods similar to the one under study, with thousands of houses allocated in different orientations that otherwise would have required specific shading designs for each orientation. Second, it maintains a distinctive uniformity as a specific orientation based design would have conflicted with the research objectives that aim at maintaining the architectural appearance of houses. Finally, a combination of optimum window components was carried out.

RESULTS AND DISCUSSION

Orientation Impact; Base Case

The impact of orientation on the annual thermal performance and the derived energy consumption was assessed. The annual electrical energy consumption, cooling loads and lighting loads for each cardinal orientation of the existing design are presented in Table 2.

Table 2. Base Case Annual Energy Consumption, Cooling and Lighting Load per Orientation

<table>
<thead>
<tr>
<th>Power Usage (Kwh)</th>
<th>Orientation</th>
<th>North</th>
<th>South</th>
<th>East</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Electrical Energy</td>
<td>46,087</td>
<td>46,048</td>
<td>43,200</td>
<td>47,393</td>
<td></td>
</tr>
<tr>
<td>Cooling Load</td>
<td>29,455</td>
<td>29,434</td>
<td>27,163</td>
<td>30,400</td>
<td></td>
</tr>
<tr>
<td>Lighting Load</td>
<td>1,677</td>
<td>1,671</td>
<td>1,868</td>
<td>1,714</td>
<td></td>
</tr>
</tbody>
</table>

The first observation highlights a variable load for each orientation, emphasizing the impact of window design on the total energy used (Figure 5). The change of orientation with the main façade’s higher ratio of glazing affected variably the annual energy consumption. The highest annual energy consumption rate was for the west orientation, while the east orientation displayed the least.

Figure 5: The Base Case Annual Energy Consumption per Orientation
The North and South orientation shared similar energy consumption rates. The recorded difference between the highest and the lowest annual energy consumption rates was 8.85%. This reduction in annual electrical energy consumption is linked to the reduction in cooling loads as it was reduced by 10.65% when the orientation changed from west to face east. This reduction can be explained as the east facing facade receives the least amount of solar radiation in the morning while the temperature is still low while the west facing receives the afternoon and evening direct solar radiation along with transmitted heat at day heat peak times. Finally, despite the use of window system with tinted double pane glass in the original design, the impact of orientation heat gains as verified remains, justifying the need to explore further the optimum potential of window components’ heat control.

**Thermal Performance Optimization**

A vinyl frame with thermal break and three alternate types of glass were considered as indicated along their characteristics in Table 3. The impact of these single component changes on the annual energy consumption per orientation is presented in Table 4 and Figure 6 for the glass alternatives contribution.

<table>
<thead>
<tr>
<th>Table 3: Thermally Improved Glass Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Tinted double pane glass, Aluminium frame with no thermal break (Existing Design) – Base Case</td>
</tr>
<tr>
<td>Tinted double pane glass, Vinyl frame (thermal break)</td>
</tr>
<tr>
<td>Tinted double pane Low-E glass, Aluminium frame</td>
</tr>
<tr>
<td>Tinted double pane Low-E squared glass, Aluminium frame</td>
</tr>
<tr>
<td>Tinted double pane reflective glass, Aluminium frame</td>
</tr>
</tbody>
</table>

**Table 4. Total Annual Energy Consumption for Optimized Glass**

<table>
<thead>
<tr>
<th>Variable</th>
<th>North</th>
<th>Total Kwh</th>
<th>East</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>46,087</td>
<td>46,048</td>
<td>43,200</td>
<td>47,393</td>
</tr>
<tr>
<td>Tinted double pane glass, Vinyl frame</td>
<td>43,624</td>
<td>43,571</td>
<td>41,464</td>
<td>44,664</td>
</tr>
<tr>
<td>Reduction</td>
<td>5.35%</td>
<td>5.38%</td>
<td>4%</td>
<td>5.76%</td>
</tr>
<tr>
<td>Tinted, double, Low E-Glass</td>
<td>44,626</td>
<td>44,580</td>
<td>42,225</td>
<td>45,709</td>
</tr>
<tr>
<td>Reduction</td>
<td>3.17%</td>
<td>3.19%</td>
<td>2.26%</td>
<td>3.55%</td>
</tr>
<tr>
<td>Tinted, double, Squared Low E-Glass</td>
<td>43,072</td>
<td>43,045</td>
<td>41,846</td>
<td>43,663</td>
</tr>
<tr>
<td>Reduction</td>
<td>6.54%</td>
<td>6.52%</td>
<td>3.13%</td>
<td>7.87%</td>
</tr>
<tr>
<td>Tinted, double, Reflective Glass</td>
<td>44,665</td>
<td>44,616</td>
<td>43,573</td>
<td>44,869</td>
</tr>
<tr>
<td>Reduction</td>
<td>3.10%</td>
<td>3.11%</td>
<td>-0.86%</td>
<td>5.33%</td>
</tr>
</tbody>
</table>

The results indicate that the highest savings in total annual energy consumption were obtained for all orientations with the double tinted squared Low E glass. The savings were from almost 8% in the case of west-facing house, 6.5% for the north and South and 3% in the case of east-facing one. The vinyl frame outperformed the aluminum one and contributed with a 4% reduction for the east façade and slightly about 5% for all the other orientations.

It should be noted that the total annual electrical consumption does not highlight the differential impact of each type of glass on lighting and cooling loads. On these grounds, the tinted doubled Low E glass generated 6% to 10% savings in cooling loads in comparison to the base case, indicating better heat control. The double reflective glass on the other hand, produced fewer saving because of the excessive lighting loads which ranged between 110% and 130%, due to the low visible transmittance of the reflective glass which led to an increased dependency on artificial lighting. In summary, if the double reflective glass indicates a better heat control, this is countered by its low light admission that will adversely affect lighting load, leaving a negative annual energy usage balance.
Window Systems Thermal Performance Optimization

The next step consisted of optimised combinations of glass, frame and one type of shading devices. Two scenarios were considered; the first thermally optimized window system consisted of a vinyl frame with the double squared low-E glass and the second scenario had a vinyl frame, double low-E glass and shading in the form of light colored automated slatted blinds. The results indicate savings from 6% to almost 12% for the first scenario (Table 5 and Figure 7). Of more relevance, it should be stressed that the four orientations yielded similar annual energy consumption with marginal variation (1 to 3%) compared to the base case.

### Table 5. Total Annual Energy Consumption for Optimized Window Systems (Scenarios 1&2)

<table>
<thead>
<tr>
<th></th>
<th>North</th>
<th>Total Kwh</th>
<th>East</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Case</strong></td>
<td>46,087</td>
<td>46,048</td>
<td>43,200</td>
<td>47,393</td>
</tr>
<tr>
<td><strong>Scenario 1: Tinted, Double, Squared, Low E+ Vinyl Frame</strong></td>
<td>41,407</td>
<td>41,429</td>
<td>40,551</td>
<td>41,839</td>
</tr>
<tr>
<td><strong>Reduction</strong></td>
<td>10.15%</td>
<td>10.03%</td>
<td>6.13%</td>
<td>11.72%</td>
</tr>
<tr>
<td><strong>Scenario 2: Vinyl Frame +Low E Glass+ Slatted Blinds</strong></td>
<td>41,136</td>
<td>41,046</td>
<td>40,439</td>
<td>41,107</td>
</tr>
<tr>
<td><strong>Reduction</strong></td>
<td>10.74%</td>
<td>10.86%</td>
<td>6.40%</td>
<td>13.26%</td>
</tr>
</tbody>
</table>

The second scenario with vinyl frame, Low E-Glass and automated slatted blinds carried a potential annual energy savings from 6.5% for the east and up to 12.7% for the critical west orientation (Table 5 and Figure 7).
These savings are due to the reduction of direct solar gain which is being blocked by the automated shading device and the reduced transmitted heat the usage of low E glass. The variation of the thermal performance between orientations ranged from 1 to 3% compared to 8.85% between east-facing and west-facing house in the base case.

CONCLUSION

This research has investigated the thermal optimization of windows components in relation to orientation in a representative governmental housing project in the UAE. The thermal performance of the dominant house type was first tested in relation to the cardinal orientation. The west facing house carried almost 9% more annual energy consumption than the east orientation. Then, single window components were tested for the energy savings potential. A vinyl frame with thermal break and three efficient glass alternatives were identified, and tested including: double reflective glass, double Low-E glass and double squared Low-E. The latter provided optimum performance with savings ranging from 3% to 8% of the total annual energy consumption, respectively for the east and west orientations while the vinyl frame with the original glass type yielded between 4% and 5% energy savings. Subsequently, the most efficient components were combined and tested. The double squared Low-E tinted glass and vinyl frame yielded savings ranging from 6% to 11.7% respectively for the east and west orientation. More importantly, the optimal window components highlighted similar performance independently from orientation, thus enabling flexibility in housing planning projects with increased thermal efficiency and energy savings.

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Investigation of thermal resistance and bridging in examples of contemporary and vernacular solid wall architecture

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ABSTRACT

Contemporary architecture has tended to increase envelope insulation levels in an unceasing effort to reduce U-values. Traditional masonry architecture in contrast was devoid of insulation, except for the inherent insulative nature of vernacular materials. Also the consistency of the outer membrane of the building skin diminished any impact due to bridging. In contemporary highly insulated walls bridges are numerous due to the necessity to bind inner and outer structural skins through insulation layers. This paper examines thermal bridging in an example of contemporary façade design and compares it with an example of traditional vernacular architecture currently being researched which is characterized by a lack of bridging elements. Focus is given to heavy weight materials of high thermal mass, which appropriately for passive architecture help moderate fluctuations in internal temperature. In an extensive experimental study samples of highly insulated precast concrete sandwich panels and lime rendered masonry walls are tested in a guarded hot-box. The building construction methods are compared for static and dynamic thermal transmittance, via heat flux and surface temperature differential measurements. Focus is given to the differential heat loss due to the thermal bridging in the sandwich panels and its associated impact on overall heat loss relative to traditional masonry construction.

INTRODUCTION

Building envelopes are becoming increasingly capable at retaining heat. European and national regulations are emphasizing ever-lower U-values, increasing pressure on building designers to augment the insulation content of walls so as to meet these targets.

Standard domestic construction is generally either of solid masonry wall, timber or steel frame construction. Focusing on solid wall construction, Stazi et al. (Stazi, Vegliò, Di Perna, & Munafò, 2013) define the 3 different wall construction categories common to temperate climates as (i) capacity, (ii) stratification and (iii) resistance. In Western Europe since mid 1900s cavity wall (stratification) construction has prevailed (Hens, Janssens, Depraetere, Carmeliet, & Lecompte, 2007). Prior to the postwar emphasis on cavity wall stratified construction, solid or capacity walls were common. Monolithic or rubble stone walls were common in vernacular construction, and still constitute the envelope of many farmhouse and cottage architecture in the European and Irish context. Today many of
this building stock is in need of thermal upgrade. Contemporary insulation materials trap moisture and prevent these traditional structures from ‘breathing’. Novel alternatives based on natural, sustainable materials are required.

Today cavity walls are often in the 3rd category described by Stazi, *resistance*, given that many have been either retrofit with pumped interstitial insulation or augmented with a layer of internal or external insulation. Another type of *resistance* wall is the precast wall, or sandwich panel type. This construction type, which is becoming increasingly popular in Europe and is already well established in the tilt up construction market of the US, is endowed with the benefits of prefabrication which ensure time, cost and quality efficiencies of factory floor construction. In multi-story construction precast sandwich panels (PCSP) must be designed to ensure composite action between the interior and exterior concrete wythes. Lower U-values imply thicker insulation layer, which in turn implies larger tie elements, often metallic and hence highly conductive of heat. So even though specified U-values might be achievable using high levels of insulation, the thermal bridging impact of the ties becomes relatively more significant as the insulation gets thicker, a phenomenon now well established (Mao, 1997).

There are a number of reasons why PCSPs are specified (robust nature, finished surface etc.) but primary amongst these is their superior thermal mass properties over lightweight construction alternatives. They might be viewed as closer in thermal mass terms to traditional solid wall structures than to contemporary frame structures. They have a *capacity* likely to impact on the internal thermal environment however, the heat transmission to the outside is minimized due to the interstitial insulation layer. However, thermal bridges are numerous in PCSPs (Lee & Pessiki, 2006). Thermal bridging in contemporary facades has long been recognized as a significant failing in the *resistance* model of façade design with some authors claiming up to 30% of building heating requirements are given to façade thermal bridges (Theodosiou & Papadopoulos, 2008).

This paper investigates *R* and *U*-values in two wall construction methods. The construction types are disparate but enable exploration of the impact of thermal resistance and bridging in contemporary (insulation heavy) solid wall construction in contrast to a sustainable, vernacular-appropriate, alternative (with inherent insulation properties). These are compared and contrasted with past research in the literature that documents thermal bridging in other common construction methods, including frame construction. The theoretical *U*-values are compared with the real *U*-value calculated experimentally via hot-box testing procedure. The traditional envelope consists of an insulating lime-hemp render applied to the external of a solid brick masonry wall. Lime-hemp is under general research investigation by these researchers as an appropriate ‘breathable’ insulation method for historic building renovation. An example contemporary envelope is investigated via PCSP samples. These sandwich panels include significant insulation layers. Although the U-value when analysed both with and without the impact of thermal bridging is relatively low the relative impact of thermal bridging is significant and needs to be accounted for.

**METHODOLOGY**

Experimental and simulation studies were undertaken. The experimental program was based on five wall samples; (i) a solid clay-brick masonry wall bound with hemp-lime mortar, (ii) a lime-hemp (2:1 by mass ratio) render applied to (i), (iii) a lime-hemp (1:1.25 by mass ratio) render applied to (i), (iv) PCSP with 240mm insulation and 240mm deep, 3mm thick bridging plate, (v) PCSP with 160mm insulation and 80mm deep, 2mm thick bridging plate. The impact of the bridging plate was then investigated using a simplified Finite Element Model (FEM) that was developed.

**Experimentation**

A one-sided hot box is used to measure the total amount of heat transferred from one side of the specimen to the other for a given temperature difference, irrespective of the individual modes of heat
The internal environment is tightly controlled (at 35°C) however the external environment vary with ambient indoor conditions. EN ISO 8990 and ASTM C1363-05 specify similar hot-box testing procedures and methods of heat exchange calculation. Neither consider the sample configuration but instead calculate the total heat transfer that passes through the sample under test based on recorded heat flux and temperature values (Asdrubali & Baldinelli, 2011). According to BS ISO 9869-1 data is taken for a minimum of 3 days for each heat flux recording and care is taken to choose days of minimal temperature variation. Samples taken every 10 minutes are averaged according to the average method described by equation (1).

\[ R_t = \frac{\sum_{i=1}^{n} (T_{Si} - T_{So})}{\sum_{i=1}^{n} (q_i)} = \frac{T_{Si} - T_{So}}{\phi/A} = \frac{\partial T}{\partial T} \ (m^2 K/W) \]  

(1)

where, \( T_{si} \) and \( T_{so} \) are inside and outside surface temperatures, \( \phi \) is the heat flux over area \( A \).

The whole building heat loss might then be characterized (CIBSE Guide A, 2006) using the equation,

\[ H_t = \sum A U + \sum L \Psi \]  

(3)

where, \( H_t \) is the whole building heat loss, \( A \) is the area of all surfaces, \( \Psi \) is the thermal bridge and \( L \) is its length of thermal bridges.

A number of methods of calculating thermal bridging in PCSPs with varying levels of accuracy have been proposed in the literature, as previously reviewed (O’Hegarty & Kinnane, 2012). For a 2D analysis Griffith et al (Griffith, Finlayson, Yazdanian, & Arasteh, 1997) present a THERM based parallel path method of U-value approximation that is adopted here. Given their depth to thickness ratio the bridging plates in this study might be approximated to propagate heat in the 2D plane. The parallel path U-value (\( U_p \)) is given by,

\[ U_p = F_B U_B + F_N U_N \]  

(4)

where \( F_B \) is the fraction of bridged section and \( F_N \) is the fraction of non-bridged section.

To further evaluate the effect of thermal bridging in the precast panels in this study a FEM was developed. The model was a simplified representation including concrete, insulation and plate geometry and properties, but without reinforcement detail.

**Masonry Walls.** Figure 1 shows the 1m x 1m brick masonry wall (Figure 1 a)) and lime-hemp render subsequently applied to one half of the wall (Figure 1 b)). A second and different mix is applied to the other half of the wall and both are monitored for heat loss (Figure 1 c)). No thermal bridging is evident in the 1m² section of masonry wall, and the lime-hemp render is homogenous over the complete surface of the wall. Two lime-hemp renders were investigated with different proportions. Mix 1 was based on the standard mix commonly used in industry – proportions 2:1, lime:hemp. Mix 2 reduced the
lime content and increased the hemp content with the aim of achieving greater thermal insulation – proportions 1:1.25, lime:hemp. The brick is a filled-clay, machine-pressed brick, presoaked and bound with a Natural Hydraulic Lime 3.5 mortar. Approximate density and thermal conductivities are 1200 kg/m$^3$ and 0.36 W/mK respectively (CIBSE Guide A, 2006).

![Image](image1.png)

Figure 1 a) Masonry brick wall, b) one half of wall rendered with lime-hemp render, c) heat flux probes and surface temperature sensors installed for hot-box testing, and d) infra-red image during testing.

**Precast walls.** Two precast concrete sandwich panels (1m x 1m) were tested in the guarded hot-box. An example panel configuration is shown in Figure 2. The exact plate and panel configuration is given in Table 2. The plates that are responsible for ensure composite action are also shown in Figure 2. These are threaded with reinforcement bar prior to casting. The exterior wythe of both panels is 100mm, the internal wythe which is structurally salient is 120mm. The wythe of insulation layer varies from 240mm in panel 1 to 160mm in panel 2. The insulation is Expanded Polystyrene (EPS) with thermal conductivity of 0.035 W/mK. Approximate density and thermal conductivity for concrete are 2200 kg/m$^3$ and 1.7 W/mK respectively (CIBSE Guide A, 2006).

![Image](image2.png)

Figure 2 a) precast sandwich panel configuration, and b) example of plate tie used and method of attachment to rebar prior to casting of concrete.

**RESULTS**
Key results for the hot-box analysis of the brick masonry and PCSPs are documented in subsequent tables.

**Masonry walls.** The results of the hot-box and thermal resistance tests are presented in Table 1. The thermal benefit of adding the lime-hemp insulative render to different wall types is evident. The thermal resistance increases by approximately 50% with the addition of 21mm lime-hemp render layer.

### Table 1. Experimental heat flux, R and U-values of the brick masonry with lime-hemp render

<table>
<thead>
<tr>
<th>Wall construction</th>
<th>Heat Flux W/m²</th>
<th>R-value m²K/W</th>
<th>U-value W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick and lime mortar</td>
<td>48.35</td>
<td>0.175</td>
<td>2.89</td>
</tr>
<tr>
<td>Brick and lime mortar with lime-hemp render (Mix 1)</td>
<td>36.5</td>
<td>0.259</td>
<td>2.33</td>
</tr>
<tr>
<td>Brick and lime mortar with hemp lime render (Mix 2)</td>
<td>37.74</td>
<td>0.274</td>
<td>2.25</td>
</tr>
</tbody>
</table>

The lime-hemp render can be seen to add an additional 0.084 m²K/W and 0.1 m²K/W to the bare brick masonry wall R-value.

**Precast walls.** Precast concrete sandwich panels were investigated for overall thermal resistance and for the effect of bridging. Aggregated results of hot-box tests for the two panels are described in Table 1.

### Table 2. Key dimensional parameters and experimentally calculated heat flux, R and U-values of the precast concrete sandwich panels

<table>
<thead>
<tr>
<th>Panel and Plate dimensions</th>
<th>Heat Flux W/m²</th>
<th>R-value m²K/W</th>
<th>U-value W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel 1.</strong> Insulation width - 240mm Plate width - 350mm</td>
<td>Plate thickness - 3mm Plate depth - 240mm</td>
<td>4.24</td>
<td>4.54</td>
</tr>
<tr>
<td><strong>Panel 2.</strong> Insulation width - 160mm Plate width - 260mm</td>
<td>Plate thickness - 2mm Plate depth - 80mm</td>
<td>4.69</td>
<td>3.13</td>
</tr>
</tbody>
</table>

Heat flux values are low in both PCSPs as might be expected given the considerable quantity of insulation within the panels. Panel 1 with 240mm insulation has a 45% greater thermal resistance than Panel 2 with 80mm extra insulation.

### Table 3. Experimental evidence of thermal bridging due to plate connectors in precast sandwich panels

<table>
<thead>
<tr>
<th>Panel and Plate bridge dimensions</th>
<th>U non-bridged location</th>
<th>U bridged location</th>
<th>U % locational difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel 1.</strong></td>
<td>0.22</td>
<td>0.45</td>
<td>104%</td>
</tr>
<tr>
<td></td>
<td>0.33</td>
<td>0.49</td>
<td>48%</td>
</tr>
</tbody>
</table>
The heat loss through the concrete surface is considerably greater at the location of the plates than over the centre. The plates are 55mm below the surface yet the heat flux increases from 4.24 to 10.46 W/m² in Panel 1 and 4.69 to 9.9 in Panel 2. The effect of bridging is relatively considerably more evident in Panel 1 than in Panel 2. This is due to the greater depth (240mm vs 80mm) and thickness (3mm vs 2mm) parameters of the plate.

A 240mm deep plate is 24% of the cross section of the panel, and an 80mm plate, 8%. Using the parallel method equation (4) the U-value for Panel 1 and Panel 2 can be corrected to 0.277 W/m²K and 0.34 W/m²K respectively, to account for the thermal bridging along the line of the panel.

**Finite Element Model.** Results of the FEM model of the precast concrete sandwich panel are shown in Figure 3. The steady state heat profile is shown in Figure 3(a) when the interior wythe of concrete is heated in a hot-box to 35°C. The temperature at the internal face of the exterior wythe, on the other side of the insulation later, of the precast sandwich panel is as low as 23.7°C. The model shows minimal temperature impact of thermal bridging on the panel with the outer face of the exterior wythe only fractionally higher (0.3°C) than standard room temperature 22°C.

![Figure 3](image)

**CONCLUSIONS**

This paper presents an experimental study of two solid walls, an example sustainable vernacular construction and an alternative highly insulated contemporary, solid wall constructions. Both constructions have their individual strengths. In the vernacular construction, sustainable materials with less well recognized insulative ability are investigated. Brick and stone solid walls are characterized by low U-values, however introduction of the lime-hemp render layer enhances the thermal resistance of solid architecture construction by up to 16% in some cases, and 50% on the single leaf brick wall. Even with the addition of the lime-hemp render the thick vernacular masonry walls listed in Error! Reference source not found. retain high U-values. However, given their lack of spot bridging, thermal capacity capability and recognized benefitial impact on the internal environmental conditions in appropriate
climates (Martín, Mazarrón, & Cañas, 2010), traditional solid solid wall constructions retain advantages over contemporary façade systems. These walls are generally also devoid of thermal bridging.

In the example of solid but panelised contemporary wall construction, although the U-value of the wall is low due to a significant insulation layer, thermal bridging exists and effects the overall thermal performance. However, given the relatively small area over which it acts its impact is not seen as a considerable deficiency. Next stages in this research study involve analysis of the thermal mass effects of both wall types. The walls will behave differently in dynamic environments. The position of the insulation layer within the build up of the contemporary wall reduces the fluctuations in temperature that the sandwich panel wall will experience relative to a solid alternative.

The study is not without its limitations, and these are subsequently outlined. The hot-box used is somewhat more primitive than that used in past studies – given that its made of four walls created by layering insulation panels - however it can offer approximate thermal resistance values. A limitation of the study is the impact of dynamic environmental conditions on the ambient air on the cold side of the hot-box. Although the surface temperatures vary in a very narrow range (~2-3°) relative to the ambient air temperature fluctuations (~5-6°). Another matter that should be noted is that the steady state modeling study returns lower heat flux values, of up to 33%, than the experimental study. The model does not capture the reinforcement bar and hence the conductive route of bars to plate is not modeled. The bars lie perpendicular to the plates, but contact them at a number of locations.

Further research aims to develop accurate models of thermal bridge in solid wall construction and to investigate alternative sustainable insulation materials. The transient effects of thermal bridging and its impact on thermal storage and diffusivity will be investigated through experimental and numerical simulation. This paper outlines some of the basis for this research by investigating examples of traditional, capacity, wall types, and contemporary, resistance wall types through an experimental steady state evaluation.

ACKNOWLEDGMENTS

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NOMENCLATURE

\[ R_t = \text{thermal resistance} \]
\[ R_{si}, R_{so} = \text{thermal resistance of inside surface and outside surface} \]
\[ U = \text{thermal transmittance} \]
\[ \Psi = \text{thermal bridging} \]

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Session PF: Vernacular architecture

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Progress - Knowledge Consortium of Gujarat
Diurnal Radiative Cooling of Spaces in Mediterranean Climate

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ABSTRACT

The absence of solar radiation at night gives good opportunities for passive cooling of buildings in hot climates with frequently clear sky. However the possibility of also taking advantage of a clear sky cooling potential during the day is seldom considered.

Thermal radiation to sky can be used to cool. A body surface emits thermal radiation (far IR) and if direct solar radiation (visible and near IR) and thermal radiation coming from other surfaces do not reach it, there would be a net heat flux out.

A previous prototype was done with a simple element. That experiment confirmed that was possible to reduce around two degrees the interior temperature of the test unit exposed to sun light in July.

In this work a new design based on the first one is developed to adapt it to architectonical needs in order to reduce interior spaces temperature in hot climates.

The aim of this design is focused to so an architectonical adaptation is needed. Modular and replicable units could be a solution that permits to fulfill large flat surfaces as roofs or other architectonic elements. In this occasion, measurements were taken from a modular model with a geometrical design that avoided de direct solar incidence. These measurements were taken by a pyrgeometer during two weeks of August and results were similar to the previous experiment.

INTRODUCTION

A body surface emits thermal radiation (far InfraRed, IR), and if it can be made that direct solar radiation (visible and near IR), and thermal radiation from other bodies (far IR) do not reach the body surface, there would be a net heat flux out of the body, cooling it (Head 1962). The cooling can be obtained by selective surfaces, that reflect visible and near infrared solar radiation (near IR), avoiding direct solar gains, while they are emitters for far infrared radiation, if they are appropriately exposed, and allowing radiation going to sky. Cooling can also be achieved with the help of reflective surfaces and geometry (Trombe 1967 and Hull 1986). A polished surface with high reflectance to infrared radiation is able to reflect the image of the sky and maintain the radiation characteristics (Granqvist 1982). An emitting surface “seeing” the reflected image of sky, will loss energy to the reflected part of cold sky (Craig et al. 2008).

The previous prototype tested in Barcelone was done with a single element (Serra et al. 2010). In that occasion, the analysis let us know that it is possible to reduce the inside temperature of a chamber, in about two degrees, during the sunny hours if an emitting surface can see nothing but the cold sky zone and its emitted radiation is thrown far away without reflection that take it back. That prototype checked
the effect with a single element covering the entire top side of the box. The vertical development was very high and this difficulties the practical applications in architecture.

In this work we consider the possibilities of irradiative cooling in Mediterranean climate for cooling interior spaces of buildings. We want to test a variant of the first model that incorporates the principle refrigerator to a replicable element that fill a flat roof being easy to construct and modular. The second main goal is about the system should use cheap, easily available materials in the existing industry such us aluminum foil and cardboard.

To face this challenge we have deepened the geometric study of the protection element of the emitting sheet, so that the surface occupied by the protection system was reasonable and the effective emitting area was the largest as possible. Geometry must help us to make that the emitting surface only would see the cold zone of the sky even by reflection.

The emitting surfaces were white painted metal sheet as in the first model. In order to reduce thermal exchange with exterior air (Johnson 1975, and Golaka et al. 2007), we installed a thin 50 µm transparent polyethylene film 3 mm before the emitting surface. In this way the polyethylene film does not receive direct solar radiation and its life is expected to be longer because no significant UltraViolet (UV) radiation reaches the film. The test model was made with common materials and located in a village near the Mediterranean coast, and measurements were taken, by a pyrgeometer, during two weeks of August.

**GEOMETRICAL APPROACH**

Those two features, an easy construction and avoid IR radiation, can be both obtained if a suitable geometry for a lateral screen system is designed. We did a very detailed study of the geometry of the unit module. Such geometry should comply with the protection requirements of solar incidence both direct and reflected. The geometric study started from the solar path during the worst day -summer solstice- on a stereografic diagram, to narrow the sky zone without the sun passing throw, see Figure 1. Zones 1 and 2 on the diagram represent the coolest zone of celest voult, away both from the sun path and from the horizon, to avoid radiation emitted from extern objects that could reduce the net heat flux out from our emitting surface.

![Figure 1](image.jpg)

**Figure 1** A stereographic diagram for Barcelona, near 41º north latitude. Zones 1 and 2 are preferred for thermal radiation exchanged. Zone 1 has lower equivalent radiant temperatures.

The vertex of a 134º opening cone, looking to the correct direction to the north for this latitude about 41º north, will never see the sun it sees the cold sky zone (see figure 2). We must place the emitting surface behind the initial vertex to obtain a large enough area for the irradiative surface,
although this brings up a narrower conical element. So we extended the generatrices of the cone beyond the vertex looking for an orthogonal angle with the opposite sheed to avoid reflected rays coming back. Then we transformed the cone to a pyramidal piece because planar forms are more useful to replicate and add elements. This choice should provide an eligible prototype for construction useful to add units in order to fulfill a roof.

![Diagram of a conical unit element]

**Figure 2** The diagram shows the overture of the first conical unit element with an overture of 134º toward the cold zone of the sky, and the geometrical definition of the replicable pyramidal unit.

Finally the side flaps were extended to protect the interior of possible radiation reflected in them and even folds were we calculated graphically the correct angle to improve the efficiency of the global suitable surface. Lateral slopes in contact to the emitting surface respond to the pyramid design explained above, bottom slope was further worked in order to maximize the efficiency. Its tilt was modified in the far part because the high of incident solar rays in that point was minor and if we fold it back we can reduce the occupied roof area by each basal unit (see figure 3).

![Diagram of a pyramidal unit]

**Figure 3** Shows the two sections of the basal unit and the reflected sun rays of sun on the side screens. Folding the northern screen reduces the ratio between emitting surface and global roof surface.

Different units can be easily aggregated. Some faces are extended in order to cover the horizontal roof with high performance. Lateral extreme screens are also extended to avoid sunlight entering during the first and last hours of the summer days. As a result of this process, we obtain a geometric model with an effective surface area of 1/6 of total roof area.

**PROTOTYPE AND MEASUREMENTS**

The roof model was installed on a 50cmx50cmx30cm box, with 7 cm of expanded polystyrene thermal insulation, see figure 4.
The emitting surfaces were white painted metal sheet. In order to reduce thermal exchange with exterior air (Tazawa 1996, and Tazawa 1997), we installed a thin 50 µm transparent polyethylene film 3 mm before the emitting surface. In this way the polyethylene film does not receive direct solar radiation and its life is expected to be longer because no significant UV radiation reaches the film.

The model has been checked during a period of sunny days of August, in a roof of a house in Sant Llorenç del Penedés (near Barcelona).

Measures of thermal emission have been done with a Pyrgeometer 1239 from Hukseflux thermal sensors with a Cambell Scientific datalogger 21538, and compared with solar radiation from a Pyranometer at the automatic meteorological station (XEMA 2013) placed in El Vendrell (5 km from the scale model). Both devices measure total (direct and diffused) radiation in different wavelengths.

The obtained results for the modular case show that during some sunlight hours the interior temperature is higher than exterior temperature.

The figure 5 shows the measured solar radiation and the thermal radiation emitted to the sky. The average of received solar radiation is higher than emitted thermal radiation. The emitted is relatively low due to the Mediterranean Sea influence, because of meteorological reasons (dominant South component winds from the sea, in summer, and large evaporation of water). Relatively high humidity (near 67% with mean temperature near 26°C) lowers the cooling radiation effect, because the opacity of water vapors to IR radiation. However, according to the measurements from the Pyrgeometer, it should be pointed out that even in this case, it is possible to emit near 100 W/m² to the sky.

With the above data and the exterior temperature we computed a thermal balance equation for the interior of the model. We take into account the exterior air temperature, the thickness of the thermal
insulation, the thermal radiation from the emitting surfaces, a heat transfer from the sun exposed sides of the model (surface temperature measured with a 66 IR Thermometer from FLUKE) and an approach to the diffuse radiation on the roof.

![Graph showing exterior and interior temperatures over time]

**Figure 5** Dotted line shows the exterior temperature and continuous line the interior one.

The measured interior temperatures at 14h are no more than 0.3°C different from those calculated by this approach. An excessive entrance of heat due to direct solar radiation incidence on the model area increases exterior surface temperatures. A high value of diffuse radiation conditions of Mediterranean summer sky also contributes to reduce the efficiency of this prototype as cooling device.

If solar protection had been applied to the lateral walls of the modular system, as it was done in the first model, the computation result would be 1.3 °C lower. In this case, the interior temperature would be lower than external temperature during almost all day. Further on, an increase of roof thermal insulation in the parts which receive direct sunlight could have improved the results.

**CONCLUSION**

We consider two prototypes of radiative cooling roof. First one is a simple unit where the whole roof acts as IR emitting surface and lateral protections to direct sunlight are added. Second one is a modular design where the emitting surface is 1/6 of the roof area because of the integrated sunlight protections.

In both cases the space to be cooled was near 40x40x30 cm and was thermally insulated with at least 5 cm of expanded polystyrene except for the emitting surfaces.

First prototype was tested in Barcelona and the measured interior temperature was near 2°C lower than exterior. This result is in agreement with a basic calculation taking into account heat transfer through the walls and thermal emission from the roof. Exterior surfaces of the model were at exterior air temperature because they were protected from direct solar radiation.

In the second case the interior temperature was 2.5°C lower than exterior only during night hours, while it was near 2.5°C higher than temperature during some sunlight hours. This result can be understood because of solar gains through the sunlit walls and indirect solar radiation gains through the roof. The measured interior temperatures at 14h are no more than 0.3°C different from those calculated by the thermal balance equation. If solar protection had been applied to the lateral walls of the modular system, as it was done in the first model, the result would have been better.
Summarizing, the possibilities of diurnal radiative cooling during summer in Mediterranean climate are mainly bounded by three factors. First of them is the relatively high humidity and low transparency of atmosphere to IR radiation. However, according to the measurements from the Pyrgeometer, it should be pointed out that it is possible to emit near 100 W/m² to the sky in our summer climate. Second one is the need to restrict, with an appropriate geometry, the aperture of the radiating system to the cold zone of the sky vault. And third factor is the absolute need to reduce the entrance of direct or diffuse solar radiation. Even with these bounds, we show that it is possible to obtain diurnal radiative cooling in sunny places by appropriate selection of geometry and easy to obtain materials.

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Measurement of Thermal Radiation Properties of Large Heating Equipment Using Infrared Thermography

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ABSTRACT
Most modern houses no longer use traditional heating systems (e.g., the fireplace, stove, the pechka, the ondol, and the kotatsu) and instead rely on mechanical heaters, as the latter have greater functionality and more features. However, as the traditional systems use wood, a natural energy resource, they are more suitable for reducing the consumption of fossil fuels. Further, they provide a unique sensation of warmth as they dissipate heat through thermal radiation.

In this study, in order to reevaluate the heating characteristics of traditional heating systems that use wood, we devised a new method for measuring their thermal radiation properties. On the basis of the concept of the luminous intensity distribution, we defined the "thermal radiant intensity distribution," which is calculated by integrating the luminance of thermal radiation in each direction. A thermal image is constructed by assembling pixels representing the surface temperatures determined from a parallel projection of the heating equipment. Hence, the luminance of thermal radiation could be found for all the directions from the pixels to the observer.

We employed the proposed method to investigate a large firewood stove in operation in the winter, and determined its thermal radiant intensity, which was found to be 47–121 W/sr; this value is much greater than that of an electric heater (an 800 W electric heater has a thermal radiant intensity of 15 W/sr). It was assumed that, as traditional heating systems do not include a fan, larger systems are installed within the building structure and warm not only the air with the rooms but also the room surfaces, such as the walls, floors, and ceilings.

INTRODUCTION
In most modern houses, traditional heating equipment (e.g., the fireplace and stove in European countries, the pechka in Russia, the ondol in Korea, and the kotatsu in Japan) has been replaced by mechanical appliances such as air conditioners and fan heaters because of their better functionality and useful features. However, as traditional equipment use wood-based biomass, including firewood and wood charcoal, which are natural energy resources, they hold more potential in the near future from the view point of reducing fossil fuel use. Further, they also provide a unique sensation of warmth, owing to thermal radiation. For example, just after the Great East Japan Earthquake in 2011, firewood stoves were in high demand, especially in the arenas where the refugees lived for a few months in the winter season.
The reason for this was not that the supply of other fuels was limited but rather that the heating capability of the stoves was better. It is for this reason that we have chosen to investigate the thermal radiation properties of traditional heating equipment.

Figure 1 Firewood piled up under the eave of a traditional Japanese house.

1. EXOTHERMIC CHARACTERISTICS OF TRADITIONAL HEATING EQUIPMENT

Takamiya et al. have classified the heating equipment installed in vernacular architecture in Eurasia into Types #1 to #12 on the basis of their design characteristics, including factors such as whether the hearth is enclosed, where the exothermic part (i.e., the area, device, or unit from which the heat emitted) is located, whether it has a chimney, and what is its relation to the building. Developing this idea a little further, we have added the method of heat transfer to the classification system and reordered the types, deleting Types #6 and #7, as shown in Table 1.

With respect to the heating capability, Types #2 and #3 produce lower amounts of heat because these equipment pieces are "movable" and can be located in different places in the house, depending on the conditions. The "unified" types are graded from Type #1 to Type #12, that is, from "open" to "closed" on the enclosure of the hearth and "just around the hearth" to "dedicated part (in the next room)" on the exothermic part; these heaters are greater in size and have higher efficiencies. All the types except for Type #10 either do not have chimney or have an indoor one. Further, for all equipment types, heat transfer occurs through "radiation" or "conduction." Modern mechanical heaters, which are small and high-powered in comparison, distribute heat by blowing warm air in the room. As traditional heating systems do not include a fan, larger pieces of equipment are usually installed within the building structure to warm not only the air in the rooms but also the room surfaces, such as the walls, floors, and ceilings.

Table 1. Types and Characteristics of Heating Equipment

<table>
<thead>
<tr>
<th>Type</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#8</th>
<th>#9</th>
<th>#11</th>
<th>#10</th>
<th>#12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater</td>
<td>Open hearth</td>
<td>Brazier</td>
<td>Kotatsu</td>
<td>Stove</td>
<td>Fireplace</td>
<td>Pechka</td>
<td>Kang</td>
<td>Kachel-</td>
<td>Ondol</td>
<td>Kang</td>
</tr>
<tr>
<td>Enclosure of the hearth</td>
<td>Open</td>
<td>Closed</td>
<td>Semi-Closed</td>
<td>Closed</td>
<td>Closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part of the exothermic</td>
<td>Just around the hearth</td>
<td>chimney</td>
<td>Dedicated part</td>
<td>Dedicated part in the next room</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chimney</td>
<td>Without chimney</td>
<td>Indoors</td>
<td>Outdoors</td>
<td>Indoors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relation to building</td>
<td>Unified</td>
<td>Movable</td>
<td>Fixed</td>
<td>Unified</td>
<td>Unified</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method of heat transfer</td>
<td>Radiation</td>
<td>Convection and Radiation</td>
<td>Convection and Radiation</td>
<td>Convection, Radiation, and Conduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. METHOD FOR EVALUATING THERMAL RADIATION PROPERTIES USING INFRARED THERMOGRAPHY

2.1 Thermal imaging

To determine the warmth-producing abilities of traditional pieces of heating equipment that make use of radiation and conduction rather than convection for heat transfer, as mentioned in Chapter 1, where the concept of luminous intensity (cd(= lm/sr)) distribution was described, we calculated their "thermal radiant intensity (W/sr) distributions." The thermal radiant intensity distribution of a heating system is a thermal radiation property and is obtained by integrating the luminance of thermal radiation (W/(sr m²)) in every direction. The thermal radiant intensity for a specific direction is measured as follows:

1. Obtain thermal images using an infrared thermography system (i.e., a thermocamera) from a position at a specific distance from the center of the target heater. The nearer one is to the heater, the more detailed is the image obtained. However, if one is too near, the image will be distorted, in contrast to the image obtained from a parallel projection, because of the wide visual angle. However, it is difficult to keep the object distance large when photographing in the up/down directions. To ensure that the entire target heater was in the eyeshot of the thermocamera (horizontally 21.7° × vertically 16.4°) and to maintain the object distance at a reasonable value, we set it to 1.5 m.

2. Photograph the front side and in all the directions of the horizontal/vertical sides in steps of 22.5°. That is to say, photograph in 16 directions for each aspect, for a total of 41 directions (= (16 × 3) – 6 – 1), while excluding the 6 duplicated intersections and the upward view from below. If the shape of the heater is symmetric, it is enough to photograph 28 directions (= 41 – 1 – (3 × 4)).

3. Project the image of the concentric circles and radial lines on a wall of the room in which the photographs are being taken. Set the thermocamera at the intersection of these lines to pinpoint the object distance and the photography direction. We projected only one-fourth of the concentric circles (see Figure 2). Changing the top/bottom and the right/left directions allowed us to take photographs in limited space.

![Figure 2](image)

Figure 2  Procedure for obtaining the thermal image: the thermocamera is located at an object distance of 1.5 m; this can be confirmed from the shadow on the wall.

2.2 Calculating the thermal radiant intensity

If one considers a thermal image as a set of the surface temperature data that is the parallel projection of a heater, the thermal radiant intensity (W/sr) can be obtained by summing the luminance of the thermal radiation (W/(sr m²)) from each pixel of the thermal image of the entire target heater to the observer, that is, in the direction normal to the thermal image (see Equation (1)). The denominator "2π" in Equation (1) represents the whole solid angle (sr) of the thermally imaged surface.
3. MEASUREMENT OF THERMAL RADIATION PROPERTIES OF A LARGE FIREWOOD STOVE

3.1 Background for proposing a novel measurement method

The method described in Chapter 2 for measuring the thermal radiation properties has the following limitations:

1. It requires that the heater to be imaged be placed at a certain distance so that the entire heater fits in the eyeshot of the thermocamera.
2. The directions for which we can measure the thermal radiation properties using thermocamera are limited.

However, most traditional heating systems are large. Therefore, using this method, it is not possible to evaluate the thermal radiation properties in smaller houses as well as one can in the case of large houses.

3.2 From thermal imaging to thermal solid figures

Using the photogrammetry software "SurveyFromPhoto," it is possible to construct thermal solid figures from thermal images. We constructed thermal figures using bitmapped images with a 256-value palette. A heater and its thermal solid figure are shown in Figures 3 and 4, respectively. When constructing the thermal figures, the following four steps have to be followed, as per the specifications of SurveyFromPhoto. It should be noted that a thermal image has fewer pixels and colors than does an optical image. That is to say, it does not seem to have a third dimension.

1. The target can be photographed at any distance and from any direction and position. However, SurveyFromPhoto requires that each image has more than ten identity points. Further, among these, more than four of the identity points should be enclosed in several different images.
2. Before photographing the heater, place a piece of aluminum on any sharp edge or protrusion on the body of the heater so that its shape is visible and the identity points can be set with precision. Then, photograph the heater against a background of a different temperature.
3. Take photographs from each direction in front of the aluminum piece so that the identity points are distributed stereoscopically, as this will allow a precise solid figure to be constructed.
4. Take photographs from each direction in front of the major plane so that distortion-free images can be obtained to form the polygons that are used to construct the solid figure.

Figures 3 and 4  Photograph of the investigated electric heater (power of 800W) and its thermal solid figure.
3.3 Calculating the thermal radiant intensity

To calculate the thermal radiant intensity, Equation (1) can be used, provided the area of the pixels is determined as follows:

1. Push the PrtScn key on the keyboard when a thermal solid figure is displayed in the direction in which the thermal radiant intensity is to calculated, and open a copy of the image in the GNU Image Manipulation Program (GIMP).
2. Count the number of the pixels corresponding to the length of the reference line indicated in the image, and calculate the area of a single pixel (m²) using Equation (2).
3. Erase all the pixels from the image, except those representing the target heater, either using the "fuzzy select" function of GIMP or manually (i.e., erase the pixels one by one), if necessary.
4. Save the image, which is now of only the target heater, in the BMP format and convert it to the CSV format using the software BMP2CSV, which allows one to change data formats.
5. Open the CSV file in Excel. The temperatures corresponding to the individual pixels can be found from the values in the spreadsheet and the color scale of the thermal image.

\[ S = \frac{L^2}{N^2} \]  

(2)

3.4 Characteristics of the measurement method

When using the measurement method described in Chapter 2, the amount of thermal radiation emanating from the heating equipment is measured directly. Therefore, we can determine the actual values. On the other hand, in the case of the method described above, a thermal solid figure constructed using a software program is used as a virtual heater and is used for the measurements. Therefore, one can call the former method a direct one and the latter an indirect one.

The differences between the direct and indirect methods are listed in Table 2. The advantages of the indirect method are that the object distance and direction can be changed freely when taking the photographs. This makes it possible to photograph heaters in small rooms quickly. There are also a few disadvantages in that a number of different software programs are needed for the calculations. It should be noted that the distance for calculating the thermal radiant intensity, which is correlated to area of the pixels, is finite in the direct method, in which it is considered the object distance. On the other hand, it is infinite in the indirect method because the image constructed using SurveyFromPhoto is based on orthogonal projections. There is also a difference in the metric used to determine the size of the heating equipment. The solid angle (sr) is used in the direct method, while the projection area (m²) is employed in the indirect method. Hence, it may be said that the two methods are quite different.

<table>
<thead>
<tr>
<th>Method</th>
<th>Direct</th>
<th>Indirect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target for measuring thermal radiant intensity</td>
<td>Heating equipment</td>
<td>Thermal solid figure built using a software program and used as a virtual heater</td>
</tr>
<tr>
<td>Object distance</td>
<td>Distance at which the entire target heater fits in the eyeshot of the thermocamera</td>
<td>Actual distance, which depends on the space available in the room</td>
</tr>
<tr>
<td>Direction of photography</td>
<td>Direction of measurement</td>
<td>Actual direction for constructing the thermal solid figure</td>
</tr>
<tr>
<td>Software</td>
<td>NS9200 (NEC) Excel (Microsoft)</td>
<td>NS9200 (NEC) Excel (Microsoft) SurveyFromPhoto (Freeware) GIMP (Freeware) BMP2CSV (Freeware)</td>
</tr>
</tbody>
</table>
### 3.5 Comparison of the results obtained using the direct and indirect methods

Figure 5 shows the thermal radiant intensities of the heater shown in Figure 3 as measured using the direct and indirect methods. The solid angle and thermal radiant intensity/solid angle ratio determined using the direct method, as well as the projection area and luminance of thermal radiation are also shown in the figure.

On comparing the thermal radiant intensity distributions obtained using the two methods, it was found that the distributions had similar shapes (oval) on the elevation side. However, the directions of the peaks on the sectional and horizontal sides were different. The maximum intensity was noticed in front of the heater, that is, at #13 in Figure 5, when using the direct method, while a gap of 22.5° or 45° existed when using the indirect method. This is because the grille and fire back do not affect the results obtained using the indirect method. That is to say, an exact heating element was not built in the virtual thermal solid figure but was represented by a thermal image plane instead. The difference in the thermal radiant intensities obtained using the two methods was less than 1.5 W/sr (i.e., 17%).

Further, on comparing the parallel values, that is, the thermal radiant intensity/solid angle ratio obtained using the direct method and the luminance of thermal radiation determined using the indirect method, the directions of the maximum/minimum values were similar. Thus, it can be surmised that the indirect method is suitable one.

#### Table 3.5

<table>
<thead>
<tr>
<th>Distance for calculating the thermal radiant intensity</th>
<th>Finite</th>
<th>Infinite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric used to describe the size of the heating equipment</td>
<td>Solid angle</td>
<td>Projection area</td>
</tr>
</tbody>
</table>

#### Figure 5

Comparison of the results obtained using the direct method (left) and the indirect method (right).

### 3.6 Thermal radiation properties of a large firewood stove

#### 3.6.1 Measurement procedure.

We employed the indirect method to measure the thermal radiation properties of a large firewood stove used routinely in the house. The target stove had a well-
designed but complicated shape, as shown in Figure 6. The measurement was performed under the conditions listed in Table 3. Several kinds of air-dried firewood, such as Japanese cedar, cherry, sawtooth oak, and zelkova, to name a few, but not pine, were burned as per usual use. As can be seen from the thermal image in Figure 7, the surface temperature of almost the entire stove exceeded the upper limit of the range of the thermo camera (120 °C). Even though the stove was installed in a large room of a detached Japanese house, it was in a corner surrounded by houseplants and pieces of furniture. Therefore, the area that could be photographed was restricted.

3.6.2 Measurement results. The thermal radiant intensity, projection area, and luminance of thermal radiation of the large firewood stove are shown in Figure 8. The most important point to note is that the thermal radiant intensity was determined to be 47–121 W/sr, which is much greater than that of an electric heater (an 800 W electric heater exhibits a thermal radiant intensity of 15 W/sr). The main reason for this is that the entire surface of a stove is an exothermic area, and a large stove has a large area. Because the upper limit of the temperature range of the thermocamera was 120 °C, the thermal image obtained could not have indicated higher temperatures. However, if one assumes that the internal temperature of the stove was 200 °C, the thermal radiant intensity would be more than 2.1 times higher, as per Equation (1).

Figures 6 and 7 Photograph of the investigated large firewood stove (made of cast metal; width = 742 mm, thickness = 607 mm, and height = 797 mm; maximum power = 14.0 kW, as listed in the catalog) and one of its thermal images.

Figure 8 Thermal radiation characteristics of the large firewood stove.

<table>
<thead>
<tr>
<th>Table 3. Measurement conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date and time</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Jan 26, 2011 10:30 AM to 12:00 PM</td>
</tr>
</tbody>
</table>
CONCLUSION

In this study, we proposed direct and indirect methods for measuring the thermal radiation properties of traditional heating equipment. Using the indirect method, we measured the thermal radiant intensity distribution of a large firewood stove and found that it radiated a large amount of thermal radiation. Shukuya has noted that using radiant warm exergy for heating purposes is more effective than using convective warm exergy as the former results in both greater thermal comfort and a low human-body exergy consumption rate. It is likely that the exergy consumption rate is a function of the quality of the warmth. The high thermal radiant intensity of the stove allowed it to not only warm the air in the room but also the room surfaces, such as the walls, floors, and ceilings. This probably accounts for the uniqueness of the warmth generated by traditional heating equipment. An exploration of type of walls and ceiling finishes should lead to a better understanding on how living spaces are heated through heat reflection/convection. We intend to pursue these goals in a future study.

ACKNOWLEDGEMENTS

We wish to express our gratitude to Ms. Hitomi Oba, Ms. Maki Ooka, and Ms. Rieko Matsumoto for their assistance and helpful suggestions. We also thank Mr. Hara for providing us with an improved version of SurveyFromPhoto, and Ms. Midori Hayasaka and Mr. Ko Kamata for offering a place to measure. This work was supported by a Grant-in-Aid for Scientific Research (KAKENHI) (No. 26560031) from the Japan Society for the Promotion of Science (JSPS).

NOMENCLATURE

\[ E = \text{thermal radiant intensity (W/sr)} \]
\[ L = \text{length of reference line (m)} \]
\[ N = \text{number of pixels corresponding to the length of reference line} \]
\[ S = \text{area of a pixel (m}^2\text{)} \]
\[ T = \text{temperature of a pixel (K)} \]
\[ \sigma = \text{Stefan-Boltzmann constant (}=5.67 \times 10^{-8}\text{)} (\text{W/(m}^2\text{K}^4)) \]

Subscripts

\[ i = \text{pixel index number} \]

REFERENCES

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Phantom Loads in Residential Projects in Medellín, Colombia

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ABSTRACT

Energy efficiency’s specialized bibliographic sources define phantom loads as a dispensable electric energy inversion that some appliances make on secondary functions, such as light’s pilots, remote control receptors and digital clocks. This investigation was developed in the “Laboratorio de Estudios y Experimentación Técnica en Arquitectura”, LEET (Technical Experiments, of the Universidad Pontificia Bolivariana Architecture School, FAD-UPB). It proposes the verification, analysis and quantification of the phantom loads in residential buildings located on Medellín, Colombia, emphasizing on its origins based on the kind of appliances, its technologic validity and the use factor. The applied methodology on this investigation was based on energy consumption measurements during the stand-by mode of all the appliances of eleven similar socioeconomic condition residential buildings. A wattmeter was used as the main measurement tool. The results of this investigation revealed on quantitative data the impact of phantom loads over the total electric energy consumption bill of the analyzed buildings. Results also allowed classification of phantom loads according to how much the energy leak is, and its use. Consolidated data of this investigation prove that phantom loads are 3.73% of the total electric consumption. This represents an opportunity of finding alternatives for an efficient management model of the cities electric consumption. This paper’s conclusions are the first approach to the energy leaking problem in the national context.

Keywords: phantom loads, energy conservation, electricity, sustainable house.

INTRODUCTION

Invention of the incandescent lamp in the year 1860 by English chemist Joseph Swan (National Museum of American History), defined the beginning of a process of colonization of households by technology that favored, during the following years, the invention of several electrical appliances, such as the telephone, the radio, the television set and the oven, among many others. During the decade of 1970, advances were carried out in the field of electronics: the personal computer was invented, as well as video games, cell phones and Internet. For all human needs that arose, a non-manual device was created to solve it, and that automatization process of daily household life known as automation, foresaw times of a high demand for electric energy.

Simultaneously to technological advancement in the twentieth century, there emerged under the general ignorance, a phenomenon related to the electric energy consumption: “phantom loads” or “ghost loads”. Since the invention of the remote control in 1903, some household electronic devices used it as the main command, which adaptation to radios and television sets required a new operational mode to...
use household devices, known as “stand-by” mode, by which the device has a percentage of electric energy to keep a receptor functioning, and allows it to be turned on at the order of the control.

The characteristics of households and the contemporary way of life, highly depending on electronic household devices, consolidated the set of phantom loads associated to each of the electric devices as a not negligible element on the monthly energetic budget. It is stated, according to studies carried out in the year 2000 in the main Australian cities (Energy Efficient Strategies, 2006), that the monthly average consumption by concept of phantom loads in Australian households was 86.8Wh per person, a figure that grew over a period of five years, reaching 10.7% of the monthly energetic consumption, that is to say, 92.2Wh per person, of a monthly average household total consumption of 265kWh.

The Colombian context, and specifically regarding the city of Medellin, Antioquia, still has no record of studies or measurements carried out with the goal of quantifying phantom loads and the calculations for its incidence within the monthly total electricity consumption in residential buildings, for which this investigation applied to a specific context is considered pertinent.

THEORETICAL FRAMEWORK

The term “vampire Load” refers to the existing similitude between the fangs of the mythical character and the two common terminals in an outlet. There is no clarity as to whom and when this concept was first used to define power loss in household appliances during “stand-by” mode; however, it is attributed to swiss engineer Sandberg, E. (1993) the first use of the term “Leaking Electricity”, during the conference “Electronic home equipment – Leaking electricity”, in Rungstedlund, Denmark, according to which an electricity leak is defined as: “Energy demand of television sets, CD players and other electronic devises during inactive mode”, making this a first approach to the concept of phantom load.

Nowadays, definition of the phantom load concept is directly related with modes in the use of electrical household appliances: off, in passive waiting mode, active waiting mode, and programmed start. Power consumption is not considered phantom load during active mode: “standby consumption (or phantom) is the one generated while the household appliance is not performing its primary function”. (Energy Efficient Strategies, 2006)

METHODOLOGY

For the investigation purposes, eleven study cases were done in residential buildings in the city of Medellin, with area, typology, and population number variations, considering only the socio-economic levels 4, 5 and 6. The decision to collect this information in high economic levels is based on the presumption that the amount of household electronic appliances is greater per capita, thus increasing the possibilities of phantom load loss. Next there is a general description of study cases:
Table 1. General Information of each Study Case

<table>
<thead>
<tr>
<th>Study cases general information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case No.</strong></td>
</tr>
<tr>
<td>SC01</td>
</tr>
<tr>
<td>SC02</td>
</tr>
<tr>
<td>SC03</td>
</tr>
<tr>
<td>SC04</td>
</tr>
<tr>
<td>SC05</td>
</tr>
<tr>
<td>SC06</td>
</tr>
<tr>
<td>SC07</td>
</tr>
<tr>
<td>SC08</td>
</tr>
<tr>
<td>SC09</td>
</tr>
<tr>
<td>SC10</td>
</tr>
<tr>
<td>SC11</td>
</tr>
</tbody>
</table>

Each study case consists of the measurement of electricity consumption of all electronic devices that remain connected to an energy source, during time intervals of: 0, 5, 10 and 20 minutes, which allows to obtain a weighted average consumption, and decrease this way the possibility of calculating irregular and/or atypical power consumption levels. The result of this operation expressed in Wh, is then multiplied by the number of **daily hours of dispensability** of the household appliance; that is to say, how many hours in a day such appliance could remain disconnected without affecting the lifestyle of the inhabitants, and that for practical issues was defined as 7, which represents daylight or night hours destined to sleeping, obtaining this way data for “Phantom/Day consumption (Wh)”. Finally, column “Phantom/month consumption (Wh)” is shown, which is equivalent to multiplying the latter column by 30, the number of average days in a month.

In a simultaneous way to the application of measurements, other data was collected through observation and surveys, related to the characterization of each electric household device, an a greater understanding population habits, as well as the effective state of electrical devices. Additional data collected: **a)** category of use; that is to say, what is the purpose of the household device: computing, refrigeration and/or heating, entertainment, cooking, accessories or laundry; **b)** **brand** of the appliance, **c)** a brief description in case it is relevant, and finally, **d)** approximate age in years according to categories: 0 – 5 years old, 5 – 10 years old, 10 – 15 years old, and older than 15.

Table 2. Information Collection Table

<table>
<thead>
<tr>
<th>Room</th>
<th>Household appliance</th>
<th>Category</th>
<th>Approximate Age</th>
<th>Min 00</th>
<th>Stand-by mode consumption (%)</th>
<th>Average</th>
<th>Dispensability Hours / Day</th>
<th>Phantom used / Day (%)</th>
<th>Phantom used / Month (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store</td>
<td>Telephone</td>
<td>Accessorio</td>
<td>1 – 5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>6.00</td>
<td>0.00</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Common fridge</td>
<td>Casone</td>
<td>1 – 5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>6.00</td>
<td>0.00</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Pelatoni S.A.Fridge</td>
<td>Casone</td>
<td>10 – 15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>6.00</td>
<td>0.00</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Ultrocel i larm</td>
<td>Accessorio</td>
<td>10 – 15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>6.00</td>
<td>0.00</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Hood</td>
<td>Casone</td>
<td>10 – 15</td>
<td>130.00</td>
<td>130.00</td>
<td>130.00</td>
<td>134.00</td>
<td>172.250</td>
<td>7</td>
</tr>
<tr>
<td>Garage</td>
<td>Coffee maker</td>
<td>Casone</td>
<td>5 – 10</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>6.00</td>
<td>0.00</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>TV</td>
<td>Entertainment</td>
<td>10 – 15</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>6.30</td>
<td>0.300</td>
<td>7</td>
</tr>
</tbody>
</table>
For every residential complex, a survey was performed regarding people’s habits, concerning topics related to electric savings that represent a percentage of incidence in the total phantom loads, such as finding out if people disconnect or not cell phones and personal computers when these devices are totally charged, and their willingness or not to modify their conduct once informed with respect to this issue.

All measurements were done on a 20 minute time span for each device, through the use of a wattmeter called *Kill a Watt* with a precision range of 0.2%. Neither temperature nor humidity variations were considered at the moment of measurements, neither possible electrical fluctuations derived from the hour at which the electrical consumption was registered.

**RESULTS ANALYSIS**

- For the eleven study cases, energy waste levels by way of phantom loads are equivalent to 3.73% of the total of monthly electric consumption for every household, which allows us to corroborate the existence of phantom loads in the urban residential sector in the city of Medellin. Next, the calculation of percentage representativeness of phantom loads in the monthly electric consumption, organized by study case and expressed in percentage:

  **Table 3. Calculation of Percentage Representativeness of Phantom Loads in the Total Monthly Electricity Consumption**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Phantom load (%)</th>
<th>Phantom loads average consumption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC01</td>
<td>6.96%</td>
<td></td>
</tr>
<tr>
<td>SC02</td>
<td>3.70%</td>
<td></td>
</tr>
<tr>
<td>SC03</td>
<td>3.92%</td>
<td></td>
</tr>
<tr>
<td>SC04</td>
<td>5.66%</td>
<td></td>
</tr>
<tr>
<td>SC05</td>
<td>4.02%</td>
<td></td>
</tr>
<tr>
<td>SC06</td>
<td>5.63%</td>
<td></td>
</tr>
<tr>
<td>SC07</td>
<td>1.08%</td>
<td></td>
</tr>
<tr>
<td>SC08</td>
<td>0.77%</td>
<td></td>
</tr>
<tr>
<td>SC09</td>
<td>0.95%</td>
<td></td>
</tr>
<tr>
<td>SC10</td>
<td>1.35%</td>
<td></td>
</tr>
<tr>
<td>SC11</td>
<td>7.04%</td>
<td></td>
</tr>
</tbody>
</table>

Of all the study cases, SC08 showed the least percentage of incidences due to phantom loads, with a 0.77%, and the SC11 the greatest, with a 7.04%. The aforementioned are distant data from the average, because the majority of cases can be placed between 3 and 6%.

- The analysis of power consumption according to activity shows that the greatest energy deviation is found in household appliances destined to Entertainment, with a 40.89% of the total of electricity consumption by way of phantom loads, far from the second place taken by appliances related to Computation, with a 23.59%. The activity that represented the least power expenditure due to phantom loads was Refrigeration/heating, with 0.43%, due mainly to conditions of humidity and temperature in Medellin being close to thermal comfort range, reason for which these household electronic appliances are not commonly found for residential use.
Table 4. Calculation of Phantom Consumption According to Activity Type Related to Household Appliance

<table>
<thead>
<tr>
<th>Usage categories</th>
<th>SC01</th>
<th>SC02</th>
<th>SC03</th>
<th>SC04</th>
<th>SC05</th>
<th>SC06</th>
<th>SC07</th>
<th>SC08</th>
<th>SC09</th>
<th>SC10</th>
<th>SC11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessory</td>
<td>0.04%</td>
<td>0.13%</td>
<td>27.70%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>17.17%</td>
<td>9.00%</td>
<td>27.23%</td>
<td>60.32%</td>
<td>32.00%</td>
<td>6.50%</td>
</tr>
<tr>
<td>Refrigeration/heating</td>
<td>0.89%</td>
<td>0.90%</td>
<td>0.80%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>3.86%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Conservation</td>
<td>7.70%</td>
<td>4.74%</td>
<td>24.57%</td>
<td>21.50%</td>
<td>19.06%</td>
<td>6.44%</td>
<td>0.00%</td>
<td>27.23%</td>
<td>20.71%</td>
<td>58.75%</td>
<td>78.81%</td>
</tr>
<tr>
<td>Entertainment</td>
<td>4.82%</td>
<td>86.34%</td>
<td>41.82%</td>
<td>60.81%</td>
<td>85.07%</td>
<td>72.51%</td>
<td>12.22%</td>
<td>45.53%</td>
<td>14.89%</td>
<td>9.16%</td>
<td>18.64%</td>
</tr>
<tr>
<td>Laundry</td>
<td>0.00%</td>
<td>0.00%</td>
<td>2.45%</td>
<td>8.54%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>9.66%</td>
<td>22.82%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Kitchen</td>
<td>79.95%</td>
<td>2.79%</td>
<td>3.43%</td>
<td>10.81%</td>
<td>4.24%</td>
<td>3.87%</td>
<td>65.16%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

- Analysis of electricity consumption according to age of household appliances allowed investigating about the relevance of the “technological life” variable; in other words, incidence of age and the degree of technological update on energetic waste loads. Next, a graph that relates age to phantom consumption of household appliances:

Table 5. Age of household appliances and average consumption according to age

<table>
<thead>
<tr>
<th>Appliances age and average consumption according to age</th>
<th>Average electricity consumption (Wh)</th>
<th>Weighted average (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of appliance (in years)</td>
<td>SC01</td>
<td>SC02</td>
</tr>
<tr>
<td>1 - 5</td>
<td>1.26</td>
<td>3.45</td>
</tr>
<tr>
<td>5 - 10</td>
<td>0.79</td>
<td>0.72</td>
</tr>
<tr>
<td>16 - 15</td>
<td>25.04</td>
<td>0.00</td>
</tr>
<tr>
<td>&gt;15</td>
<td>1.50</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The average consumption in Wh of household appliances according to approximate age indicates that those that are between 10-15 years old have an average phantom consumption equivalent to 3.36Wh, the highest among analyzed appliances; however, consumption of those that are over 15 years old is only 0.46Wh; that is to say that, according to general performance, it is possible to state that there is no direct relationship between age and phantom load consumption, which allows to say that technological update of household appliances does not necessarily imply a decrease in phantom loads.

- Another analysis item in this investigation seeks to establish what percentage of household appliances have electricity leakage in their secondary functioning modes, and simultaneously establish levels according to leak energy quantity. Established ranges for this analysis were: equal to 0Wh, less than 1Wh, between 1-5Wh, and more than 5Wh.

Table 6. Classification of Phantom Loads According Electrical Consumption

<table>
<thead>
<tr>
<th>Classification of Phantom Loads according to electricity consumption</th>
<th>SC01</th>
<th>SC02</th>
<th>SC03</th>
<th>SC04</th>
<th>SC05</th>
<th>SC06</th>
<th>SC07</th>
<th>SC08</th>
<th>SC09</th>
<th>SC10</th>
<th>SC11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal to 0</td>
<td>45.71%</td>
<td>25.57%</td>
<td>17.36%</td>
<td>12.50%</td>
<td>15.15%</td>
<td>42.42%</td>
<td>70.90%</td>
<td>30.40%</td>
<td>41.15%</td>
<td>33.33%</td>
<td>25.00%</td>
</tr>
<tr>
<td>Less than 1W</td>
<td>22.86%</td>
<td>23.81%</td>
<td>21.76%</td>
<td>9.00%</td>
<td>9.08%</td>
<td>12.12%</td>
<td>10.90%</td>
<td>46.15%</td>
<td>41.15%</td>
<td>33.33%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Between 1 - 5W</td>
<td>22.64%</td>
<td>28.57%</td>
<td>43.48%</td>
<td>62.50%</td>
<td>45.49%</td>
<td>32.90%</td>
<td>20.00%</td>
<td>15.38%</td>
<td>17.65%</td>
<td>22.22%</td>
<td>25.00%</td>
</tr>
<tr>
<td>More than 5W</td>
<td>5.17%</td>
<td>19.05%</td>
<td>17.36%</td>
<td>25.90%</td>
<td>27.27%</td>
<td>15.15%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>11.11%</td>
<td>56.00%</td>
</tr>
</tbody>
</table>

Results according to the eleven study cases indicate that 33.89% of diagnosed household appliances did not have phantom loads, namely, electric consumption during secondary use mode is equal to 0Wh. Next, the graph summarizing classification previously mentioned:
According to statistics of the Mayor’s Office of Medellín, in 2010 there were a total of 641,780 residential units in the city of Medellín. Extrapolating results from this investigation from the phantom loads data per household unit equivalent to 8.16kWh, means affirming that for the city’s total households, the monthly electricity leakage is equivalent to **$5,236,924.8kWh**.

Table 7. Number of households per Socio-Economic Stratum and Commune

<table>
<thead>
<tr>
<th>No.</th>
<th>Commune</th>
<th>Number of households per socio-economic stratum and commune</th>
<th>Total commune</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>Popular</td>
<td>13,100</td>
<td>13,410</td>
</tr>
<tr>
<td>2</td>
<td>Santa Cruz</td>
<td>4,022</td>
<td>4,321</td>
</tr>
<tr>
<td>3</td>
<td>Manrique</td>
<td>11,196</td>
<td>11,896</td>
</tr>
<tr>
<td>4</td>
<td>Antioquia</td>
<td>4,643</td>
<td>4,943</td>
</tr>
<tr>
<td>5</td>
<td>Candelaria</td>
<td>364</td>
<td>394</td>
</tr>
<tr>
<td>6</td>
<td>Aclon de Oeste</td>
<td>7,042</td>
<td>7,642</td>
</tr>
<tr>
<td>7</td>
<td>Robledo</td>
<td>5,010</td>
<td>5,510</td>
</tr>
<tr>
<td>8</td>
<td>Villa Hermosa</td>
<td>14,009</td>
<td>14,709</td>
</tr>
<tr>
<td>9</td>
<td>Bogota</td>
<td>1,474</td>
<td>1,574</td>
</tr>
<tr>
<td>10</td>
<td>La Capellanía</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>La Candelaria</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>La América</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>13</td>
<td>San Javier</td>
<td>17,010</td>
<td>18,410</td>
</tr>
<tr>
<td>14</td>
<td>El Polo</td>
<td>17</td>
<td>34</td>
</tr>
<tr>
<td>15</td>
<td>Guayabal</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>16</td>
<td>El Pilar</td>
<td>1,210</td>
<td>1,210</td>
</tr>
<tr>
<td>Total</td>
<td>79,583</td>
<td>211,273</td>
<td>188,032</td>
</tr>
</tbody>
</table>

The cost of that wasted energy is COP $ 2,038,858,872 million pesos monthly, according to the cost of 1 kWh as of January 2014. Data, discriminated by stratum, is shown next:
Table 8. Cost of Wasted Energy due to Phantom Loads According to Stratum

<table>
<thead>
<tr>
<th>Socio-economic stratum</th>
<th>Number of households</th>
<th>Monthly phantom consumption (kWh)</th>
<th>Cost kWh</th>
<th>Cost phantom loads consumption COP $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratum 1</td>
<td>79.563</td>
<td>8.16</td>
<td>379.07</td>
<td>$246.105.163</td>
</tr>
<tr>
<td>Stratum 2</td>
<td>211.273</td>
<td>8.16</td>
<td>379.07</td>
<td>$653.512.010</td>
</tr>
<tr>
<td>Stratum 3</td>
<td>188.032</td>
<td>8.16</td>
<td>379.07</td>
<td>$581.622.688</td>
</tr>
<tr>
<td>Stratum 4</td>
<td>76.108</td>
<td>8.16</td>
<td>379.07</td>
<td>$235.418.118</td>
</tr>
<tr>
<td>Stratum 5</td>
<td>56.455</td>
<td>8.16</td>
<td>454.88</td>
<td>$209.550.843</td>
</tr>
<tr>
<td>Stratum 6</td>
<td>30.349</td>
<td>8.16</td>
<td>454.88</td>
<td>$112.650.049</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$2,038,858.872</strong></td>
</tr>
</tbody>
</table>

- Based on results of the survey made to one person per household about some habits and their influence on phantom loads, results indicate that 63% of those interviewed decide not to disconnect their laptops from electricity once they are completely charged, and 90% decide not to disconnect their desktops when they finish using them. However, the survey indicates that 55% of those interviewed in fact disconnect their household electrical appliances at night, or during their absence during the day.

Table 9. Results survey made to a resident per residential unit

<table>
<thead>
<tr>
<th>Questions</th>
<th>Cases do estudio</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you disconnect your laptop charger once the device has been fully charged?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>36.30%</td>
<td>63.64%</td>
<td></td>
</tr>
<tr>
<td>Do you disconnect your desktop once you’re done using it?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>9.09%</td>
<td>90.91%</td>
<td></td>
</tr>
<tr>
<td>Do you disconnect your household appliances during the night or when you are absent during the day?</td>
<td>Sí</td>
<td>Sí</td>
<td>Sí</td>
</tr>
<tr>
<td></td>
<td>45.45%</td>
<td>54.55%</td>
<td></td>
</tr>
<tr>
<td>Assuming that important household appliances such as the fridge, surveillance and security systems, and at least one telephone were to remain turned on and functioning, would you be willing to disconnect all your household appliances if there was an automatic mechanism that did it for you?</td>
<td>Sí</td>
<td>Sí</td>
<td>Sí</td>
</tr>
<tr>
<td></td>
<td>100.00%</td>
<td>0.00%</td>
<td></td>
</tr>
</tbody>
</table>

The results of the survey show that, even though there is a degree of ignorance about the levels of electrical consumption during secondary functioning modes in some devices, and that the majority of the people do not disconnect electrical devices when done using them due to laziness or lack of knowledge, there is a high degree of acceptance to the proposal of solution alternatives that take care of disconnecting electronic appliances automatically, as is proposed in the last question of the survey, to which 100% of those surveyed answered in an affirmative way.

CONCLUSIONS

According to set objectives for the development of this investigation, this has been achieved:

- Demonstrating the existence of phantom loads in the urban residential sector of the city of Medellin, Colombia, according to analysis of electricity consumption made in eleven residential units with stratum 4, 5 and 6.
- Quantifying percentage incidence of phantom loads consumption over the total electricity...
consumption of diagnosed households, equivalent to 3.73% of the monthly electricity consumption; that is to say, an average of 8.16kWh per house.

- Establishing independence between phantom loads and technological update expressed in age and technological updating of appliances, through quantitative demonstration that there is no relationship between both variables.

- Quantifying economic and energy investment at a city level (Medellín) that represents loss of electricity by way of phantom loads in residential units, equivalent to 5,236,924.8kWh and COP 2,038,858,872 million pesos.

ACKNOWLEDGMENTS

The development of this investigation was possible thanks to the participation of Architecture students of Universidad Pontificia Bolivariana, Juan Camilo Paniagua, Mateo Alzate, Juan Camilo Fernández and Valerie López, who were active members in collecting information of every study case. Also thanks to the people who allowed student access to all rooms in their households with the goal of making all pertinent measurements.

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Renewable Energy Application in Floating Architecture

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ABSTRACT

Climate change like global warming brings sea and river level rise. Usable land in urban area becomes less and the price of real estate increases due to continuous development. Reclamation method for land supply has been regarded as environmentally negative. And people want to enjoy the life on water rather than on land or mountain according the improved income level. Therefore floating architecture on water has been emerging as a creative and alternative to the building on the land of waterside region. The aim of this study is to investigate the status of renewable energy applications in sample floating architectures and to suggest some reference ideas for new building projects around the waterside. Most popular renewable energy sources for the floating architecture are solar heat energy, solar photovoltaic energy and hydrothermal energy. Especially hydrothermal use of the water underneath the floating building may have a huge advantage in tropical region and cold region because there is a great temperature difference between the water and the outdoor air in extreme climate regions. Therefore hydrothermal energy can be used for air-conditioning in tropical region and heating in the cold region. Wind energy also can enhance the possibility of self-supporting floating architecture if building integrated small wind turbine with little noise is developed. Hybrid system of solar photovoltaic energy with wind power will be highly popular when the design of the hybrid system is integrated with that of floating architecture. Of course, detailed disadvantages of floating architectures should be investigated and countermeasures to overcome are to be suggested for further study.

INTRODUCTION

Climate change like global warming atmosphere brings a rise in sea and river level. Usable land in urban area will be less and the price of real estate is going to rise due to continuous expanding development. Reclamation method for new land supply is regarded as environmentally negative and very difficult to proceed without the public consensus. People like to live and enjoy leisure activities near or on water according to the improved income level. New floating buildings such as house, restaurant, school, exhibition and meeting, yacht club house, hotel, ferry terminal, prison, and café are being built around the world. Therefore floating architecture on water has been emerging as a feasible and strong alternative.

Floating building is easy to get various renewable energy sources because there are not so many physical obstacles in the sea or river. More solar and wind energies can be obtained on the water than on the urban land. Especially hydrothermal use of sea or river water beneath the floating building might be a great advantage because the temperature of water is usually lower than that of outdoor air in summer and the reverse in winter. Therefore hydrothermal energy can be used as cooling in tropical region and heating in the cold region.
Floating Building can be generally regarded as positive in ecosystem because the building has a closed premises services system, sometimes stimulates diversity in water milieus and provides a protected habitats for small fish and other aquatic animals. The underside of floating building foundation can even be rough to encourage the attachment and growth of water plants, algae and shellfish. The water plants have a purifying effect on the water (Koen Olthuis & David Keuning, 2010). A large-scale floating architecture or a number of floating buildings can be criticised as throwing a shadow to the bottom of the water, so some countermeasure for the passage to give the sunlight to the bottom of the water should be considered.

The aim of this study is to review the concept of floating architecture and renewable energy in architecture, to investigate the renewable energy applications in planned and realized floating architectures, and to suggest some reference ideas for new building projects around waterside. Research method includes the navigation of related websites, site-visits, and the review of reference documents and literatures. Sample floating architectures with strong points of renewable energy applications are chosen to analyze.

FLOATING ARCHITECTURE

As the advantageous points of floating homes have been known to public, the new residents with interesting have rebuilt the new and luxurious floating homes replacing the old and poor ones in San Francisco and Seattle, USA. In Portland, USA, a large number of modern and large loating homes have been built on the Willamette River and near net zero energy floating home with solar PV system, solar water heating, hydronic heating, rainwater collection and reuse, and reclaimed and certified wood has been built in the North Portland’s Tomahawk Island Floating Home Community. In Steigereliland IJburg, Amsterdam, Netherlands, there are 75 floating homes consisting of detached and row houses. So floating architecture becomes popular and familiar with the ordinary person.

Figure 1 Floating Homes in Seattle, USA(left) and Portland, USA(right)  
(Source: photos by the author, 2012)

Floating architecture can be defined as a building for living or working space that floats on the water with floatation system, is moored in a permanent location, does not include a water craft designed or intended for navigation, and has a premises services (electricity, water/sewage, gas) system served through connection by permanant supply/return system between floating building and a service station on land, or has self-supporting service facilities for itself.

RENEWABLE ENERGY IN ARCHITECTURE

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water or space heating, motor fuels, and rural (off-grid) energy services (Renewable energy, Wikipedia, 2014).

In architecture, wind power, solar energy and geothermal energy in renewable technologies are
generally being applied in the design and practice. Especially various applications of solar energy through solar heat panel and solar photovoltaic (PV) cells, and hydrothermal energy like geothermal energy are usually introduced in floating architectures on water.

Wind power, tidal power and wave power can be considerable if there is proper system to be integrated with floating architecture and to be harmonized with the natural environment. Wind power is highly expected to be used in floating architecture because wind power resource is abundant on water space and small wind power turbine for the building is under development.

Hybrid system of solar energy with wind power will be useful and complementary because the sun usually shines when there is no wind in day time and the wind usually rises when there is no sun. So solar-wind hybrid renewable energy system will be popular when the design of the hybrid system can be integrated with that of floating architecture.

PLANNED FLOATING ARCHITECTURE

Floating Mosque, Dubai (2007)

The floating mosque has modern and traditional Islamic designs. The interior is characterized by giant funnel-shaped transparent columns that do not only support the roof, but also allow filtered light to illuminate the inner space (Waterstudio, 2014). The building has 1 storey superstructure and the large pontoon made of concrete and styro-foam, and basically connects the water supply/return lines from the station of inland. But the building is designed self-supporting as possible in terms of energy.

![Model of Floating Mosque (left) and Water Cooling System (right)](Source: http://www.waterstudio.nl/projects/30, 2014)

The flat-roofed floating mosque is environmentally friendly by using the hydrothermal temperature, pumping sea water from the Arabian Gulf through a vein-like system of wall and floor cools the building structure down by 15 degree Celsius(from 45 degree to 30 degree), reducing the cost of cooling by around 40 percentage. Air conditioning by the electricity from solar photovoltaic cells brings the temperature down even further to 21 degree Celsius. Electricity from solar energy is also required for the pumping machine (James Reiln, 2007).

The roof and walls absorb little heat because of porous external cladding, consisting of a sponge-like ceramic material with extremely low density. The thick external walls have a high accumulative capacity due to their high density and large size (Koen Olthuis & David Keuning, 2010). Therefore, water cooling system can be more effective than any other measure.

The Ark (2010)

A massive dome-shaped building concept with living space of around 14,000 square meters, the Ark, is proposed to get maintenance of security and precaution against extreme environmental conditions and climate change together with protection of natural environment from human activities. The arch-shaped building has a structure that enables it to float safely and stay autonomously on the surface of the
water. The Ark was also designed to be a bioclimatic building with independent life-supporting systems, including elements ensuring a closed-functioning cycle (Alison Furuto, 2011).

The Ark concept, designed with the UIArchitects Work Program “Architecture for Disaster Relief,” could be realized in various climates and especially in seismically dangerous regions because its basement is a shell structure without any ledges or angles. A load-bearing system of arches and cables allows weight redistribution along the entire corpus in case of an earthquake. And also its prefabricated frame can allow for fast construction (Anastasia Vdovenko, 2014).

Figure 3  
Perspective (left) and Section Diagram (right) of The Ark  

The building has an optimal relationship between its volume and its outer surface, significantly saving materials and providing energy efficiency. Its shape is convenient for installing solar photovoltaic cells at an optimal angle toward the sun and wind turbine on the roof.

The cupola, in the upper part, collects warm air which is gathered in seasonal heat accumulator to provide an uninterrupted energy supply for the whole building complex independently from outer climate conditions in winter. The heat energy from the surrounding environment - the outer air, water or ground - is also used.

The structural solidity is provided by compression of timber arches and tension of steel cables. The framework is covered by a special foil made of EthylTetraFluoRoEthylene(ETFE). It is a strong, highly transparent foil that is self-cleaning, recyclable, and more durable, cost-efficient and lighter than glass. The foil itself is affixed to the framework by special metal profiles, which serve as solar energy collectors for heating water and as gutters for collecting rainwater from the roof (ARK, 2014).

REALIZED FLOATING ARCHITECTURE

IBA Dock, Germany (2009)

In 2010, the international building exhibition IBA had a slogan “City in a Climate Change” with a goal of a CO₂-neutral city development. The IBA Dock as the information and event center of Hamburg is constructed upon a floating pontoon. The building is now being used for Urban and Architecture information center in Hamburg and also the 2013 Hamburg International Gardening Exhibition. The IBA Dock not only houses the exhibition IBA, but is also itself an exhibition of innovative building and integrates numerous renewable energy technologies (IBA DOCK, 2014).

The IBA Dock has 3 storeys and 1,640 square meters floor area. The building is situated on an approximately 43m long and 26m wide concrete substructure pontoon and the superstructures of building are made of steel in prefabricated modular construction (IBA Dock/Architech, 2012). The building is setting new standards in the area of climate protection. In addition to 25cm thick insulated outer walls, the IBA Dock uses the sun and water of the Elbe for generating energy.

The building is based on “zero balance concept”, which focuses on solar energy management and systems that provide buildings with sustainable heat and cooling all year round. 16 rooftop solar heat
panels with a total surface area of about 34 square meters are positioned facing south at the relatively steep angle of 50 degrees to maximize the heating of water in the colder months.

Solar energy captured from these collectors feeds into an electric heat pump that draws its environmental heat from water taken directly from the Elbe using a heat exchanger built into the base of the concrete pontoon. This provides both the heating and cooling requirements for the water and air conditioning of the building, with excess energy able to be temporarily saved for later use. The building features heating and cooling ceilings that either heat the rooms in colder months or cool the room in warmer months.

Figure 4      Exterior (left) and Interior (right) of IBA Dock

The 44 kW heat pumps, along with a ventilating machine that provides air exchange for the entire building, are powered by 103 square meters of south-facing solar photovoltaic cells located on the roof terrace and angled at 30 degrees that deliver 14.8 kWp (kilowatt peak). The electricity needed by the heat pump is covered by the photovoltaic device on the IBA Dock. No further cooling or heating energy is needed (Darren Quick, 2012).

Floating hotel "Salt & Sill", Sweden (2008)

The first floating hotel in Sweden opened alongside the famous seafood restaurant “Salt & Sill”. The location is small but peaceful island and very limited space was available around the restaurant. Therefore a floating hotel was the only way to realize the owners’ dream to offer a complete service with food, drink, conference and accommodation at the same time (SALT & SILL, 2014). The hotel is very popular even though it is located in rural and coastal area in Sweden. So there are many visitors with different purposes all the year over.

Figure 5      Exterior (left) and Roof (right) of Floating Hotel "Salt & Sill"
(Source: photos by the author, 2011)
The floating hotel has 2 storeys and 23 rooms with 46 beds. All the rooms have their own entrance and access to an outdoor seating area. The building is mainly made of wood on concrete pontoon. Premises services (electricity, water supply and sewage) are served through connection lines between the floating hotel and the service station of near land.

During the construction of the building, protection of environment has been the most important agenda. A positive impact on outdoor life, little or no effect on the island environment, no noise and pollution of air should be kept. The building used local raw materials such as the pine wood from Swedish forests, and only environmentally friendly paint. They have even used the left over quarrying stone to build a new lobster reef under the concrete pontoon for the consideration of environment. In the hotel, heating energy is actually generated from the warm sea water underneath the floating building in winter (Costas Voyatzis, 2008).

**Autark Home, Netherlands (2012)**

Autark Home is a self-sufficient and passive floating home with European passive house certificate. A prototype of Autark Home is currently anchored in the river Maas, Maastricht, Netherlands and draws a huge number of eco-conscious visitors due to its unconventional construction design.

The floating home has 2 storeys and 109.4 square meters floor area, outer wall with 55cm thick massive EPS, isolated windows and doors, triple glass and no cold bridges. In terms of energy, there is an isolated water tank with capacity of 4,000 liters and 6 solar heat panels on the roof to keep the water at a temperature of 70 to 80 degree Celsius for 4 to 5 days (Autark Home, 2014).

![Figure 6](http://www.autarkhome.de/, 2014)

River water is converted to gray water and high-quality drinking water through a filter. And drinking water is made again by purification system through reverse osmosis in combination with the sand and UV filter. Gray water can be used as flushing & washing water and for the floor heating & cooling. Before the waste water returns to the river, the water is cleaned for 90% by a built-in filtration system. Like other passive houses, each room has its own ventilation. The incoming fresh air is heated or cooled by outgoing exhausted air through a heat recovery ventilation system.

The electricity is supplied by 24 solar photovoltaic cells with a total output of 6,360 Wp(watt peak). The electrical energy is stored in 24 batteries, each with a capacity of 1000 Ah, supplying enough electricity for 4 days for a normal family. The system can deliver 5300 kWh a year. On the display of the monitoring system in the living room, solar production can be viewed. In adverse weather conditions, a bio-diesel generator supplies the home with additional power (REM, 2012).

Even though there are no service utilities to be connected around the floating building, this kind of floating building with self-sufficient system can be built and operated without any problem. So floating architecture with self-sufficient system such as water treatment and electricity power system can be built freely any distance away from the quayside.
RENEWABLE ENERGY APPLICATIONS IN SAMPLE FLOATING ARCHITECTURES

Renewable energy applications in sample floating architectures are as follows (see Table 1);

<table>
<thead>
<tr>
<th>Name of building</th>
<th>Renewable energy source</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating Mosque</td>
<td>hydrothermal energy, solar PV cell</td>
<td>structure cooling system by water</td>
</tr>
<tr>
<td>The Ark</td>
<td>solar PV cell, solar heat panel, wind power</td>
<td>bioclimatic building, ETFE</td>
</tr>
<tr>
<td>IBA Dock</td>
<td>hydrothermal energy, solar heat panel, solar PV cell</td>
<td>prefabricated modular construction, heat exchanger</td>
</tr>
<tr>
<td>Floating hotel &quot;Salt &amp; Sill&quot;</td>
<td>hydrothermal energy</td>
<td>environment protection</td>
</tr>
<tr>
<td>Autark Home</td>
<td>solar heat panel, solar PV cell</td>
<td>self-sufficient &amp; passive system, bio-diesel generator, heat recovery ventilation system</td>
</tr>
</tbody>
</table>

Most popular renewable energy sources for the floating architectures are use of solar energy (heat panel and PV cell) and hydrothermal energy. Especially use of hydrothermal energy may have a huge advantage in tropical region and polar region because there is a great temperature difference in the water and the outdoor air of the extreme climate regions.

Use of hydrothermal energy in renewable energy is applied to the projects such as Floating Mosque, IBA Dock, and floating hotel “Salt & Sill”. And solar PV cells are mostly used in the projects like Floating Mosque, The Ark, IBA Dock, and Autark Home. Solar heat panels are used for The Ark, IBA Dock and Autark Home.

Until now, it is very hard to find out wind power application in floating architecture. Usually there is more wind resource on water space of sea or river than on urban land because there is daily land and sea breeze circulation and no windbreak on water. If small wind turbine with little noise is developed, it will be applied more often for the floating architecture on water than for the building on urban land.

Usually hybrid system of solar energy with wind power will be useful and complementary because the sun shines when there is no wind in day time and the wind usually rises when there is no sun. So solar - wind hybrid renewable energy system will be more popular when the design of the hybrid system is intergrated and harmonized with that of floating architecture.

CONCLUSION

Due to the climate change, people’s preference to live and enjoy activities on water, and frequent natural disasters like flooding & earthquake, floating architecture can be a strong and attractive alternative to the existing building on land. This paper aimed to investigate the renewable energy applications in floating architecture and to suggest some reference ideas for new building projects around waterside. Sample floating architectures with strong points of renewable energy application are chosen to analyze.

Comparing with the usual buildings on land, floating buildings on water have great advantages in terms of using renewable energy. Possibilities of solar energy and wind power are much higher in floating architecture because there are no obstacles around water space. And hydrothermal use of the water beneath the floating architecture is easier and more economic than geothermal use in the building on land.

Most popular renewable energy sources for the floating architecture are use of solar energy and hydrothermal energy. Especially use of hydrothermal energy may have a huge advantage in tropical region and polar region because there is a great temperature difference in the water and the outdoor air of the extreme climate regions.

It is very hard to find out the wind power applications in realized floating architectures until nowadays. Usually there is more wind resources on water than on urban land because there is no
windbreak on water space. And also there is daily land and sea breeze circulation around watersides. If small wind turbine with little noise is developed and integrated with the floating building design, wind power can have the priority to be applied due to product efficiency.

Hybrid renewable energy system of solar energy with wind power will be more popular when the design of the hybrid system is intergrated and harmonized with that of floating architecture. And also tidal power and wave power can be considerable to apply if proper system for the floating building is developed.

By the way, disadvantages of floating architectures such as shadows to the bottom, water pollution from concrete pontoon, and other negative effects to the ecosystem should be investigated in detail and countermeasures to overcome are to be suggested for further study.

ACKNOWLEDGMENTS

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ANALYSIS OF DAYLIGHT PERFORMANCE IN CLASSROOMS IN HUMID AND HOT CLIMATE

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ABSTRACT

This paper assesses the classrooms daylighting performance in hot and humid climate, by means of simulation in DAYSIM, considering the use of shadowed windows. The intention is to identify classrooms configurations that are still able to provide enough daylighting during the day. The study is orientated to the city of Natal, Northeast of Brazil, 5º S, on the coastal area, whose principles of passive building design emphasize daylighting and shading. An ambient with unshaded windows will be exposed to the excess of glare and thermal gains, inducing the occupants to close the curtains and turn the artificial lights on. Shading the window, it will be necessary to increase the window size to increase the diffuse light. Fortunately, these recommendations converge to create more opened architectural spaces, increasing the relation between inside and outside. However, the daylighting levels for different room depths depend on the combination of opening size and performance of the external shading. A classroom was modeled, simulated and analyzed, considering the combinations of three size openings (20%, 40% and 60% of window-to-wall ratio), four main façade orientations (North, South, East and West), and seven types of shading (horizontal overhang, drop edge overhang, 5º sloped overhang, horizontal overhang with side protection, horizontal overhang with three louvers, double horizontal overhang, double horizontal overhang with three louvers). Analyzes based on the useful daylight illuminance (UDI) showed limitations due to the occurrence of glare, caused by diffuse daylight next to the window. Detailed simulations confirmed a high level of influence of the combination of sky visible fraction and openings in the daylight performance.

Keywords: Daylighting, window-to-wall ratio, shading device.

INTRODUCTION

Despite the daylight availability in Brazilian cities, there are no recommendations for classrooms. This paper aims to discuss the daylight potentials in Natal. Natal, Northeast of Brazil, 5º of latitude, has great availability of diffuse light, but, according to the climate file, there is a lot of annual and daily variability in the daylight distribution. The diffuse light also causes glare, so it is important to design a shading device that also protects from this type of solar radiation. The hour of glare incidence depends on the orientation façade. The north and south façade receives solar radiation during almost the entire day, while the east façade has a better daylight distribution during the morning, and the west during the afternoon. This daily variation influences directly in the choice of the shading device. Façade orientations with fewer fluctuations can have a satisfactory daylight distribution with static shading devices, but façade orientations with more oscillations must have a dynamic shading device with manual or automatic control of the blinds and even of the lighting if it’s necessary the integration between daylighting and electric light.

Mardaljevic and Nabil introduced (REINHART, MARDALJEVIC et al., 2006, p.16) a dynamic daylight performance based on workplane illuminances, which determines when the daylight levels are ‘useful’ “for the occupant, that is neither too dark (100lux) nor too bright (2000lux). The upper threshold...
is meant to detect times when an oversupply of daylight might lead to visual and/thermal discomfort.”

Mardaljevic (MARDALJEVIC, et al., 2011, p.5) on his study for daylight metrics in residential buildings suggests that “the occurrences of illuminances greater than 3,000lux (i.e UDI-e) should not, by design, be eliminated altogether, and that moderate occurrence may in fact be beneficial. What exactly the “optimum” levels of exposure might be is not yet known.

METHODOLOGY

The research method consists in a daylighting impact quantification of architectonical characteristics. The method consists of two approaches into two groups. There are variations in relation to the window-to-wall ratio (WWR), façade orientation and shading devices. From the behavior of the results of the first phase it was decided to make a refinement of the shading device geometry and the façade orientation. The procedures comprise the determination of hypothetical and representative models with different configurations, simulated in Daysim software (REINHART, 2010), which results are processed in spreadsheets developed specifically to complement the available metrics in Daysim, as shown in Figure 1.

Figure 1 Research method steps.

The modelling concerns the input parameters of Daysim simulation software and presents the phases, procedures and sources detailed. The Daysim software was chosen due to the dynamic simulation, high processing speed, acceptable operationalization, outputs compatible for daylighting metrics processing and assessment.

Modelling

In the absence of a council law or guide for educational building, the model’s characteristics were obtained from the “Fundescola” legislation (FUNDESCOLA, 2002), which prescribes recommendations for schools projects. The cases analyzed are based on a common case, from which variations are created. The common features of all models are a classroom with dimensions of 7.20 m x 7.20 m. The simulations were realized with the empty room, without the distribution of the desks. The specularity properties used in this research were previously determined in the folder “Daysim for Sketch Up”, in the Daysim software.

1. Walls: 88% of reflectivity.
2. Ceiling: 88% of reflectivity.
3. Floor: 88% of reflectivity.
4. Openings: single pane glass with a visible transmittance of 90%.

The base case variations concern size of openings, façade orientation and shading devices, modelled in Sketch Up and exported to Daysim. There are three sizes of openings, characterized by Window-to-wall ration (WWR) of 20%, 40% and 60%.

Simulation

The Daysim simulation process consists of the input data, the simulation and the output data. The input data concerns climate file, modelling, sensor file, Daysim material database. The output data concerns daylight autonomy output file, daylight coefficient file, daylight factor output file, glare profile, annual illuminance profile, internal gains file for coupling with thermal simulations, and useful daylight illuminance. The annual illuminance file data was converted in percentages of useful daylight illuminance between 300-2000lux. The simulation process consisted of two phases:

1. Phase 1: classroom (7.20 m x 7.20 m), with window-to-wall-ratio (WWR) of 20 % and 40 % and shading devices, such as horizontal overhang, sloped overhang, horizontal overhang with side view protection, horizontal overhang with a drop edge, and light shelves in half or the models with WWR 40%, as shown in figures
2. Phase 2: classroom (7.20 m x 7.20 m), with window-to-wall-ratio (WWR) of 40 % and 60 % and shading devices, such as double horizontal overhang, double horizontal overhang with three horizontal louvers, horizontal overhang with three horizontal louvers, besides the use of light shelves in half of the models;

The calculation of the sensor file is based on the standard NBR 15215-4 (ABNT, 2005, p. 6 e 7), which determines the number of the sensors through an equation that relates the width, depth, and height between the work plane and the topo of the window. The sensor file for WWR 20% had 36 sensor points and for WWR 40% and 60% had 16 sensor points.
**Data processing**

The data processing generated the following products: illuminance curves, useful daylight illuminance 300-2000lux (UDI 300-2000lux), isolux curves, hourly useful daylight illuminance 300-2000lux (UDI 300-2000lux) and occurrences indications with Useful Daylight Illuminance 300-3000lux (UDI 300-3000lux). The summer and winter solstices illuminance curves contribute to assess the daylighting distribution and the glare intensity, for each line of sensors, for each hour determined in the occupancy profile. The lower threshold of the Useful Daylight Illuminance was calculated according to the minimum illuminance level for classrooms prescribed in the Brazilian electric light regulation (ABNT, 2013, p.20), and the upper threshold was calculated for 2000lux according to Mardaljevic and Nabil (2005, apud REINHART, MARDALJEVIC et al., 2006, p.16). The occurrences indication was calculated for a Useful Daylight Illuminance between 300-3000lux, according to the indication of Mardaljevic (2011, p.5). This last interval was calculated to test the improvement of daylight performance with the modification of the upper threshold.

The useful daylight illuminance was generated from the annual illuminance profile output, with illuminance data for each sensor points and each 1/12 per hour. The UDI 300-2000 lux spreadsheet was converted in isolux curves, as shown in Figure 3, generated in Surfer software by the Krigging method. LANDIM, MONTEIRO et al (2002, P.5) present a table summarizing the main interpolation methods. According to the authors, each method presents advantages and disadvantages, according to four categories: fidelity to the original data, smoothness of curves, computing speed, overall accuracy, as shown in Table 3. The Krigging method had the best accuracy and fidelity. The graphic represents the daylight distribution, easily understandable, as shows in Table 2.

![Isolux curves from east orientation, 40% WWR, horizontal overhang, with light shelf](image)

### Table 2  Interpolation methods  
(LANDIM, MONTEIRO et al., 2002, p.4)

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Fidelity to the original data</th>
<th>Smoothness of curves</th>
<th>Computing speed</th>
<th>Overall accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangulation</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Inverse distance</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Surface Trend</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Minimum curvature</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Krigging</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

The hourly useful daylight illuminance 300-2000lux (UDI 300-2000lux), as shown in Table 3 and Figure 4, is an hourly occurrence for each day, based on the occupancy profile, from 08:00h to 16:00h. The occurrences indications with useful daylight illuminance between 300 and 3000lux, as shown in Table 4, indicates the percentage of glare, comfort and low illuminance for each zone. MARDALJEVIC et al. (2011, p.5) suggest that illuminances above 3000 lux should not be discarded, because the optimal daylight exposure level is still unknown, and the thermal gains can be mitigated by the use of air-conditioner system.
RESULTS AND DISCUSSION

Based on the illuminance curves, the light shelves perform better as internal shading. The light shelves didn’t increase the daylight zone, or contribute to uniform the illuminance curve, but the glare incidence in the first row of sensors was reduced, in general, as shown in Figure 5 and 6, in the first graphic the highest illuminance curve was next to 3500lux, in the second case the highest illuminance level was 5000lux. The light shelf use reduces the glare incidence at the first row of sensors for almost a half.

In general all of the 20% WWR models have an accentuated daylight curve close to the opening, and no glare occurrence, Figure 6, the daylight zone depth was smaller than the half of the room. The sloped overhang model had the best daylight distribution for east orientation, with 20% WWR. Other orientations produced UDI between 80% and 64% in the first row of sensors. The daylight zone depth was 1.95m, for a 90% UDI, for east orientation. The 40% WWR models simulated at the first phase have daylight zone depth equals de room depth, however with glare occurrence at the first row of sensors causes an UDI lower than 75%, as shown in Figure 7.
The first phase simulations demonstrate glare incidence in the first row of sensors, mainly for the 40% WWR (11h illuminance curve: highest illuminance value = 2000 lux, lowest illuminance value = 750 lux), and high illuminance gradient for 20% WWR (11h illuminance curve: highest illuminance value = 1200, lowest illuminance value = 450 lux), as shown in Figures 8 and 9, the daylight distribution varies during the day.

The UDI table shows the values of UDI for the different sensors, according to the sensors map. It was detected a 90% UDI only for the period between 9:00h and 14:00h for east orientation model, as shown in Table 5 and Figure 10.

The second simulation phase was realized with 12 different models, only for the north orientation, with two openings size (the 40% and 60% WWR), three different shading devices (horizontal overhang with three louvers, double horizontal overhang, double horizontal overhang with three louvers) and with or without light shelves.

The double horizontal overhang had a similar effect to light shelf, reducing the glare incidence in the first row of sensors. The models’ daylight distribution with no light shelves performed better with 40% WWR; the 60% WWR had a reduction of a glare incidence in first row of sensors. To decrease this incidence and improve the daylight distribution, it was inserted internal shading device in the light
shelves. The 40% WWR model accentuated the illuminance gradient, reducing the daylight zone depth, as shown in Figure 11 and 12. The 60% WWR model resulted in a better daylight distribution and low glare occurrence, as shown in Figure 13 and 14.

The occurrence indication detects the glare occurrences in a UDI between 300-3000lux for each daylight zone. The daylight zone distribution was done according to the sensor map, which has some variations according to the façade orientation. Each table bar refers to one daylight zone at the sensor map, according to the figures 15, 16, and 17. The change of the UDI upper threshold to 3000lux had increased the occupants’ comfort level frequency, mainly in 40% WWR models. The 20% WWR model with the best performance was the horizontal overhang with the best comfort indication in the daylight zone six (67%), comparing to the other models that had lowest indications (sloped overhang - 61%, horizontal overhang with side protection – 59%, horizontal overhang with drop edge – 49%), as shown in Table 6. The 40% WWR opening with the best daylight distribution was the double horizontal overhang with three louvers with light shelf had a first row of sensors with a glare indication of 0%, as shown in Table 7. The 60% WWR opening with the best daylight distribution was the double horizontal overhang with three louvers and light shelf had the first row of sensors with glare indication of 1%, as shown in Table 8. In the second phase models the glare occurrence was reduced or eliminated in both size of openings (40% and 60% WWR), but for the 40% WWR there was a bigger reduction in the daylight zone six than in the 60% WWR (81% - in the first, 87% in the second).

Table 6 Horizontal overhang, WWR 20%, north, without shelf

Table 7 Horizontal overhang with three louvers, WWR 60%, north, without shelf

Table 8 Horizontal overhang with three louvers and light shelf, WWR 60%, north, without light shelf

Figure 15  Daylight zones for the WWR of 20% fort the North façade
Table 7  Double horizontal overhang with three louvers with light shelf 40% WWR

![Image](image1.png)

Figure 16  Daylight zones for the WWR of 40% fort the North façade

Table 8  Double horizontal overhang with three louvers and with light shelf 60% WWR

![Image](image2.png)

Figure 17  Daylight zones for the WWR of 60% fort the North façade

CONCLUSION

The analysis method demonstrated that a single criterion is not enough, leading to combine other resources, such as illuminance curves for each time of the day, for each month of the year of the climate file, calculation of UDI between 300 and 2000lux to obtain a flexible and suitable interval, visible sky factor quantification for each opening and shading system, introduction of occurrences indications with UDI between 300 and 3000lux.

The performance comparison among different fenestration systems and orientations indicates few differences, with UDI varying between 90% to 100 %, while the annual and daily daylight variability are very significant. The shelves were used as an internal shading system, avoiding the glare in the first row of sensors, and reducing the daylight zone. This system was suitable to 60%WWR and the glare eliminated at the first row of sensors while 40% WWR has reduced 50% of the daylight zone.

Each WWR had different daylight performances: In the phase 1 the 20% WWR didn’t have glare occurrences, but the daylight curve had a high declination after the daylight zone of 3,50m. In the phase 1 the 40% WWR had glare occurrences in the first row of sensors, which was reduced with the use of louvers. In the phase 2 the 40% and the 60% WWR had the glare occurrences reduced or eliminated in the first row of sensors. The daylight zone of 40% WWR had a variation between 3,54m and 4,75m and the daylight zone of 60% WWR had achieved a daylight zone of 7,20m.

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Session PG : Passive Design

PLEA2014: Day 3, Thursday, December 18
9:25 - 10:10, Contentment - Knowledge Consortium of Gujarat
Energy codes for Mediterranean Climates: comparing the energy efficiency of High and Low Mass residential buildings in California and Cyprus.

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ABSTRACT

Population growth, city sprawls, increase of households and overuse of resources, affect the environment and impact greatly the energy use. About 40% of the energy demand in US and Europe goes to the buildings, with residential exceeding the commercial. Building codes and energy standards aim to reduce the consumption by setting minimum standards. “Architecture 2030” and “Europe 2020” target a higher reduction. Energy simulations are the first step towards the goals. Energy code compliance software evaluate energy and environmental performance of a building by approving or rejecting it according to the estimated outcome. Variations of materials, building strategies and systems affect the energy use and consequently its efficiency. How do two different compliance code software programs, evaluate a same building performance in a Mediterranean climate? For this study, a comparative analysis using two code compliance software: Energy Pro and iSBEM-CY has been conducted. A two story simple family detached house was selected with two construction design options: (a) high thermal mass and (b) low thermal mass in the sub-tropical Mediterranean climate. For this selected climate condition, Los Angeles in California and, and Larnaca in Cyprus were chosen in the study. Through this comparison the variations have been examined whether they meet both codes and ultimately the most energy efficient design option for each region has been identified. Differences in the inputs, outputs and parameters between the two software programs which are estimated to have impacted the results have been identified and described.

INTRODUCTION

Building energy usage accounts for 40% of the total energy consumption in the U.S. (DOE, 2008). Architecture 2030 and Europe 2020 target the reduction of the building energy sector by 50% to 100% (i.e., net zero energy). Federal and State energy codes and requirements become more stringent to meet the energy reduction target. Although the number of households increased in the U.S. from 1980-2009, the average household energy consumption actually decreased (RECS, 2013). In contrast, household energy consumption in the EU-27 increased by 7.5% (EEA, 2012) between 1990 and 2009.

Energy consumption in buildings has a major impact not only on the environment but also on building occupants’ environmental comfort. Since 90% of the modern people spend their time indoors (EPA, Report to Congress on indoor air quality: Volume 2. EPA/400/1-89/001C, 1989), thermal comfort and indoor environmental quality have a great impact on people’s health and productivity. Therefore, the
design of a building should consider the climate conditions. The Mediterranean climate in both cities studied, Los Angeles as shown in Figure 1 and Larnaca as shown in Figure 2, is sub-tropical, with the warm to hot summer and mild winter. Both climates are semi-arid.

Climate change, urban sprawl, and heat island effect have increased building energy demands. Depending on the heating and cooling seasons, temperature swings between indoor and outdoor environment vary. More specifically, and from a climatic perspective, the parameters that affect this fluctuation are humidity, solar radiation, outdoor temperature, etc. For indoor conditions, the number of occupants, their activities, lighting, and equipment all contribute to the energy consumption. High peak loads, especially during the summer, can result in the use of bigger mechanical systems. Consequently, the amount of energy use increases and operating costs follow accordingly. A major building component which affects buildings energy usage and its efficiency is its envelope. Therefore it is necessary to study the climate conditions of every site location and to identify the most appropriate design strategies for it.

The annual average and monthly temperature ranges of the two locations are shown in Figures 1 and Figure 2. Mean temperatures in Los Angeles (Figure 2), located in California climate zone 8 are within the comfort zone in July, August, and September. The rest are below the comfort zone and heating is required. The average annual ΔT in Los Angeles is 21°F (6.1 C°) with the highest recorded temperature at 98°F (36.6 C°) and the lowest at 34°F (1.1C°). In Cyprus, only May and October provide mean temperatures within the comfort zone. From June to September there is a need for cooling. The rest of the months show a heating demand. The average annual ΔT in Larnaca is 7°F (13.8 C°) with the highest recorded temperature at 98°F (36.6 C°) and the lowest at 34°F (1.1 C°).

HIGH & LOW MASS BUILDING PERFORMANCE IN MEDITERRANEAN CLIMATES

Historically, buildings in Mediterranean climates were constructed with high mass materials. Specifically in Cyprus, for the vernacular architecture, stone and adobe blocks were mainly used in the structure. Nowadays, the majority of the residential buildings are constructed with concrete and brick. Controversially, in California's dwelling history, buildings tended to be of lightweight construction, primarily wood. Until today, the tradition of lightweight buildings is still the common practice for residences. Materials with high thermal capacity absorb solar radiation during the day and release it during the night. This property of the materials has been used in architecture as a passive strategy to achieve desired indoor temperature levels and comfort. By contrast, materials with low thermal capacity have a limitation in storing heat. As a result, this thermal phenomenon can cause the shift of peak temperatures between indoors and outdoors very quickly, i.e. thermal lag is reduced. This study examined the properties and performance of the typical high and low mass envelopes in a residential building for the Mediterranean climate of Los Angeles and Larnaca. Thermal mass is classified into (a) exterior thermal mass- defined as the mass of the elements which are exposed to the exterior environment, and (b) interior thermal mass- defined as the mass of the elements inside the envelope such
as interior walls, floors, chimneys, ceilings, etc. (Chi-wai, 2003). In this study, thermal mass refers to the constructed building elements, both interior and exterior, excluding any movable objects such as furniture.

Figure 3  Internal temperature profiles of high and low levels of thermal mass.

High Mass - Cyprus

Residential buildings in Cyprus are primarily constructed out of high mass materials. The building structure is made out of reinforced concrete and the non-bearing walls with brick. There are two main variations for the wall assemblies in the iSBEM-CY code compliance software:

1. Double brick wall 1'(30cm) thickness with 2"(5cm) air gap in the middle, U-value 0.198Btu/ft²°F (SI: 1.29W/m²K).
2. Double brick wall 1'(30cm) thickness with 1"(2.5cm) air gap and 1"(2.5cm) extruded polystyrene U-value 0.107Btu/ft²°F (SI: 0.608 W/m²K).

According to the Cypriot building code only the second material assembly (b), complies with the energy rating standards. A wall with higher U-value than 0.149 Btu/ft²°F, even if it has such a relatively low insulation-performance, is allowed when the thermal mass is adopted as a passive strategy for heating and cooling. These wall assemblies are both provided in the Cypriot code compliance software.

Low Mass – California

For a California residential building, the wall assembly was preselected from HEED, Scheme 1: the auto generated code compliance energy model was adopted:

1. Stucco or Face brick on 2x4 Wood studs at 16" with Plaster board interior with the U-value 0.09 Btu/ft²°F (SI: 0.511 W/m²K).

METHODS & APPROACH

For this study, a single family detached house of 1,600 sq.ft. (148.64m²) was initially designed in HEED (Home Energy Efficient Design). HEED is an energy design tool primarily used for low rise residential buildings. For the performance comparisons, two building energy models were used in each location, Los Angeles and Larnaca: high and low mass. During the study it was observed that in HEED the Larnaca climate was translated into California climate zone 8. The energy performance of the high mass simulation showed an annual average EUI of 28.07 kbtu/sf/y (88.55 Kwh/m²), and an EUI of 34.81 kbtu/sf/y (109.81 Kwh/m²) was estimated for the low mass. From this comparison the first drawn conclusion is that the high mass buildings are more efficient overall throughout the year than the low mass for the Mediterranean climate. The next step was to use EnergyPro to identify whether the models comply with the California energy code, Title 24. Similarly, the models were designed to the corresponding Cypriot code compliance software iSBEM-CY. The generated outcomes from the two code compliance software were compared. Software similarities and differences were found and
described.

EnergyPro

EnergyPro is one of the California code compliance (Title 24) energy analysis program and one of its potential is the energy verification for low-rise residential buildings and whether they comply with the energy code. For the purpose of issuing a certificate based on the code, the software is originally designed only for California climates, and the software adopts DOE-2 for a simulation engine. The Larnaca climate files were not able to be used per the software notification: Larnaca does not have a valid California Climate Zone for the California Title 24 calculations. In order to run the models the Los Angeles weather file Climate 8 was used. All the building elements were checked and verified in the software. The models were designed as single zone for more accurate calculations of the thermal mass impact to their energy use intensity.

High and Low mass building in EnergyPro. EnergyPro assumes certain thermal mass characteristics for the calculations. All residential buildings are considered to contain a pre-set amount of “light” thermal mass. Heavy thermal mass is modeled based on the conditioned area of slab floor as 20% exposed 80% of it as rug-covered slab and 5% of the non-slab area as exposed 2 inch thick concrete (EnergySoft, 2011). Concrete floors that are covered by carpet are not considered exposed thermal mass.

For the calculations of the high mass building loads, all the required values were taken from the Cypriot code and converted to IP units. The material properties selected in this study are listed in Tables 1 and 2. Walls, roof and floor had to be customized in order to generate the same U-values. The U-values were managed to be adjusted 95%. One of the of the software’s limitation is that customizing high mass components for Heat Capacity (HC) is not possible. A default HC condition of the selected wall type was adopted in this study, while some of the other elements were changed to “0” as shown in Table 2.

Performance of the thermal mass in EnergyPro. Using Energy Pro, an experiment was made before the residential building was modeled. The scope was to identify whether the software encountered the thermal mass impact to the energy use intensity by changing the settings of the thermal mass for roof, walls and floor. In the software two available options exist regarding the thermal mass and how it affects the energy calculations, these are: None or Mass Type. Under Mass type these variations are available: Adobe, Concrete heavyweight, Concrete lightweight, Masonry partial grout, Masonry solid grout, Wood solid logs and Wood cavity wall. After selecting the Mass type the option of having it exposed (as pre-mentioned above) or not is available. Furthermore, the thickness of the mass can be imputed.

For the testing, a Masonry partial grout wall was used, and the heavyweight concrete mass was selected for the roof and floor. Two variations were made. Figure 4 shows the performance of the same envelope “with non exposed mass” and “with exposed mass”. The form of the line demonstrates the effect of the thermal mass to the envelope’s efficiency. The smooth curve illustrates this transition and decrease of the EUI as expected. During the experiment, none of the other settings in the model were changed. The total ΔEUI between the 6” (0.15m) non-exposed to 30” (0.76m) thickness exposed is about 6kBTU/sq.ft./y (18.92 Kwh/m²).

The next step was to examine the effect of the thermal mass to the overall building’s performance. In this case all the building systems were used as per the code requirements. The efficiency of the systems is listed in Table 1. Similarly, two runs were made, with the mass non-exposed and exposed. As shown in Figure 5, it is clear that the exposed thermal mass contributes to the reduction of the energy loads and can be calculated in EnergyPro.
For Cyprus, the corresponding code compliance software is iSBEM, which stands for interface of Simplified Building Energy Model. The program is based to the British SBEM software and BRE rating system. Since the law of certifying buildings’ performance launched in 2010, the iSBEM-CY is new and consequently has some limitations. The rating system of certifying buildings has a range from A to F. A building will be certified only if meets at least the “B” rating score of EUI: “A” < 15.99 kBtu/ ft², “B” from 16 kBtu/ft² to 31.99 kBtu/ ft², “C” from 32 kBtu/ ft² to 46.99 kBtu/ ft², “D” from 47 kBtu/ ft² to 63.69 kBtu/ ft², “E” from 63.7 kBtu/ ft² to 94.99 kBtu/ ft² and “F” > 95 kBtu/ ft².

High mass building in iSBEM-CY. For the design of the model that meets the code, the building elements with the highest U-values were used. This was made for two reasons:

1. To test if the model will get a certification.
2. To compare its energy use intensity with the model in EnergyPro.

In iSBEM-CY as mentioned at 2.1 High mass – Cyprus, only two available wall assemblies exist: the one with higher U-value than the code requirement and one that meets the requirements. In the user’s manual there was no reference for the one that does not apply. The assumption for the first type is that it’s being used for existing buildings. If none of the above choices is desired, alternatively someone can input its own U-Value. Similarly, the “Cm” setting, which is the Heat Capacity of the element, can be modified. There is no option for changing the thickness as in EnergyPro. In the same way all the envelope elements such as roof, floors, doors and windows, can be adjusted. Regarding the effect of thermal mass in the iSBEM-CY, it is not clear yet. More details are given at 3.3 Comparison of performance and 3.4 Comparison of software.

Low mass building in iSBEM-CY. For the design of the low mass code compliance building from California, all the values and units were converted from IP to SI. The U-values and heat transfer coefficient were inputted. Therefore, walls, roofs, floors, doors, were only assigned by these properties while glazing had additionally the Tvis (L-solar) and SHGC (T-solar). Table 2 shows all the values and units required for the high and low mass code compliance residential buildings of Los Angeles and Larnaca.

COMPARISON OF PERFORMANCE

Overall four runs were made in the two software, EnergyPro and iSBEM-CY: In EnergyPro: High mass that meets the Cypriot code and, Low mass Title 24 code compliance. In iSBEM-CY: High mass that meets the Cypriot code and Low mass Title 24 code compliance. For the highest possible accurate results the same HVAC and domestic hot water (DHW) systems were used as shown in Table 1.
Table 1. Building Systems and Efficiency

<table>
<thead>
<tr>
<th>System</th>
<th>Type</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHW</td>
<td>Gas Boiler</td>
<td>59% Energy Factor</td>
</tr>
<tr>
<td>Heating</td>
<td>Gas Furnace/Boiler</td>
<td>78% AFUE</td>
</tr>
<tr>
<td>Cooling</td>
<td>Split System</td>
<td>SEER 13, EER 13</td>
</tr>
</tbody>
</table>

In EnergyPro, model (2) was the low mass Title 24 code compliance. The goal was to see if a residential house which complies as “B” performance to the Cypriot code would comply to Title 24. Indeed, the runs showed that the model did meet the California code requirements. Similarly, model (4) was designed in iSBEM-CY, with the standards of the California code. In this case, the model met the requirements of the Cypriot code and was classified as “B” in its performance. Table 2 shows the inputs used in the two software and the modifications that were made in order to abridge the models between their values as much as possible. In the Building components “h/m” stands for the property of the high mass energy model, and “l/m” for low mass.

Table 2. Building Component Properties

<table>
<thead>
<tr>
<th>Building Component</th>
<th>EnergyPro U-value</th>
<th>EnergyPro HC</th>
<th>iSBEM-CY U-value</th>
<th>iSBEM-CY HC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Btu/h ft²°F</td>
<td>Btu/ ft²°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall (h/m)</td>
<td>0.148</td>
<td>16.3</td>
<td>0.149</td>
<td>5.145</td>
</tr>
<tr>
<td>Wall (l/m)</td>
<td>0.095</td>
<td>0</td>
<td>0.095</td>
<td>0.10</td>
</tr>
<tr>
<td>Roof (h/m)</td>
<td>0.131</td>
<td>0</td>
<td>0.132</td>
<td>11.025</td>
</tr>
<tr>
<td>Roof (l/m)</td>
<td>0.028</td>
<td>0</td>
<td>0.028</td>
<td>0.10</td>
</tr>
<tr>
<td>Floor (h/m)</td>
<td>0.36</td>
<td>0</td>
<td>0.35</td>
<td>11.368</td>
</tr>
<tr>
<td>Floor (l/m)</td>
<td>0.034</td>
<td>0</td>
<td>0.034</td>
<td>0.1</td>
</tr>
<tr>
<td>Door (h/m)</td>
<td>0.60</td>
<td>0</td>
<td>0.669</td>
<td>0.49</td>
</tr>
<tr>
<td>Door (l/m)</td>
<td>0.50</td>
<td>0</td>
<td>0.50</td>
<td>0.10</td>
</tr>
<tr>
<td>Glass (h/m)</td>
<td>0.67</td>
<td>Tsolar=SHGC=0.76</td>
<td>0.669</td>
<td>Tsolar=SHGC=0.76</td>
</tr>
<tr>
<td>Glass (l/m)</td>
<td>0.669</td>
<td>Tsolar=SHGC=0.76</td>
<td>0.40</td>
<td>Lsolar=Tvis=0.49</td>
</tr>
</tbody>
</table>

The energy use intensity of the models in the two software programs is shown in Figure 6. As illustrated, the high mass residential building in EnergyPro is more efficient than the low mass. In contrast, in the iSBEM-CY the low mass is shown to be more energy saving. The assumption for this difference lies in two possible reasons:

1. The iSBEM-CY does not calculate in the same way thermal mass as the EnergyPro High mass that meets the Cypriot code.
2. The lack of the elements thickness customization when changing the U-value and heat capacity of the assembly might not reflect the performance respectively.

The difference between the two software results in performance is beyond 100% in EUI as shown in Figure 6. The outcomes were expected vary but the disparity had not been anticipated to be so high. The results were estimated to differ due to the factors shown in Table 3. The software engines for the performance calculations differ. EnergyPlus has a higher resolution of inputs than iSBEM-CY, which is a simplified building energy modeling tool taking many parameters as defaults. Therefore the algorithms for heat transfer or the calculation of infiltration, radiation and conduction etc. are different; but they have not been examined for the research. The weather files used in the software differ and their values impact the performance calculations. Geometry in this study was the same. Finally the compatibility of the file format for comparison would provide more answers but iSBEM-CY does not use or generate .gbXML files or similar; and consequently more detailed comparison between the files could not be implemented.
A comparison among the two code compliance software has been performed. Similarities, differences and their limitations have been identified:

**Similarities**

Both EnergyPro and iSBEM-CY were used for code compliance verification of residential and non-residential buildings. None of them showed a graphical representation of the building. None of the software is a design tool.

**Differences**

The iSBEM-CY software does not use .xml files for the model design but .nct. As a result, it was not possible to import and use the same project files between the software. Instead they had to be designed separately in the iSBEM-CY. It generates though .xml files for the official submission to the Register. The iSBEM-CY requires a SHW (Solar Hot Water) system since it is required by law. In EnergyPro the SHW is optional. For the purpose of this study, SHW was used in both cases. In EnergyPro it is not required to add an HVAC for cooling or heating. A fact which can give a better understanding of effect the buildings elements have to its performance. The two software use different units: EnergyPro uses the imperial system (IP) and the iSBEM-CY the metric system (SI). Regarding the result outputs, EnergyPro according to the EUI shows % of savings compared to the Title 24. iSBEM-CY generates the EUI and categorizes the building between the A to F range, where A the most efficient. EnergyPro and iSBEM-CY do not have the same options of adjusting the elements and building systems.

**Limitations**

For the iSBEM-CY, there are several settings which need to be adjusted in the Control Panel before running the program: for example, changing the “Regional and Language Settings” to United Kingdom, and changing the “User account settings” to “Never Notify”. If these settings are not changed, the software will not run properly, and will fail to make the calculations and generate the reports. iSBEM-CY has a limited library of building elements and systems compared to EnergyPro. It is not currently
possible to input the envelope’s thickness manually. Therefore, it was not possible in the iSBEM-CY to evaluate how it calculates the effect of the thermal mass on the building’s performance.

CONCLUSIONS

One of the most important findings in this study is that high mass buildings are more energy efficient in Los Angeles and in Cyprus the low mass. Taking into consideration the graphs as shown in Figure 1 and Figure 2, we could identify that more months are heating dominant than cooling in both locations. According to Climate Consultant, HEED and EnergyPro High mass residential buildings are more efficient than the low mass buildings in this climate. The EnergyPro and HEED results confirmed it. The Cypriot vernacular architecture and current construction materials applied also reinforce the use of high mass materials as more efficient. Therefore, building materials with high thermal mass are suggested as a passive strategy for enhancing the building performance in this climate. The iSBEM-CY results contradicted these conclusions and consequently further studies should be carried in regards to iSBEM-CY to evaluate its outputs.

Furthermore, both the High and Low mass models passed the EnergyPro with 24% energy savings compared to Title24. Similarly, both the High and Low mass models passed the iSBEM-CY and were rated as “B” in their performance. EnergyPro counts thermal mass into its calculations. In contrast for iSBEM is not clear at what percentage its being calculated since the high mass had greater energy consumption compared to the other software. The attempt to simulate the models without an HVAC was possible in EnergyPro. iSBEM-CY cannot proceed to the calculations without an HVAC system. The assumption is that the developers of the software did not want to allow certification without an HVAC since the climate it Cyprus makes a mechanical system mandatory. Finally, Title 24 is more stringent than the Cypriot Energy code.

For Future works, a more extensive research with the iSBEM-CY software in order to obtain a clearer understanding of how the thermal mass is being perceived and calculated. Finally a comparison of the high and low mass models in other software could be used for validation of the results.

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Architectural Design: form follows sustainability?

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ABSTRACT
This paper describes different technological and architectural designs developed as the 2013 fall term project for the studio “Architectural Design VII” in partial fulfillment of the Architecture and Urbanism undergraduate programme belonging to the Federal University of Rio Grande do Sul, Brazil. The pedagogical aim of this project was to stimulate students to achieve high-level technological results along with expressive architectural solutions. The chosen case study was a residential unit ranging from 60sqm to 70sqm, able to house a married couple. The design brief was similar to the one adopted by the competition Solar Decathlon, held in the USA, Europe and China. The Studio methodology consisted of three steps: shape concept, performance evaluation and technological and architectural refinement. The shape concept is an exercise addressed to support the emergence of creative shapes with the contingent risk of getting unpredictable technological results; the following step consisted of the proof-of-concept of the house’s energy autonomy, whereby the students were asked to demonstrate the project’s electrical energy consumption and its capacity to autonomously supply at least the equivalent amount of energy. The performance tests involved evaluations related to natural lighting and thermal balance, daily and annual energy balance and reciprocally, the contribution of renewable energy and input sources such as photovoltaic cells and rainwater collection. In its final stage, the term project featured the refinement of the conceptual architectural design focusing on the integrated design of three building systems (structural, construction and installations). As a result of the term, it was observed that the adopted methodology produced reliable results for the pedagogical purpose in the fourteen projects presented, however the final stage may require more temporal importance in the schedule of the discipline.

1. INTRODUCTION
This work aims at describing the architectural design process using different technological and architectural designs developed during the 9th semester of the five year undergraduate program in Architecture and Urbanism at the Federal University of Rio Grande do Sul, Brazil. The main pedagogical aim of this term project is to encourage students to achieve high-level technological results along with expressive architectural solutions (Corrêa & Cruz, 2012). The chosen case study was a residential unit, 70 sqm, home for a married couple, and with a design brief similar to the one adopted by the Solar Decathlon (U. S. Department of Energy (1), 2014), held in the USA, Europe and China.

A previous evaluation of certain architectural solutions form the Solar Decathlon had raised the question about the limitation of sustainable homes regarding their form. Therefore, the term’s challenge was to answer the question as to whether it would be possible to design an expressive architectural shape

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while maintaining a consistent relation between form and environmental performance, specifically the balance between energy consumption and production. This assessment is based on the assumption that sustainability issues naturally cause considerable modifications in the architectural language of the designed houses. The need to use photovoltaic and solar panels, new building materials as well as assembly and disassembly techniques and last but not least, the need to optimize the architectural form in order to maximize the reception of solar radiation destined to create major implication in the final designs. It was observed that a significant number of projects featured very conventional house designs concealing the visual impact of the technical elements responsible for the environmental performance of the house. From the students’ points of view, various Solar Decathlon solutions – although featuring high scores according to the competition standards - did not introduce any particular contribution regarding their respective architectural form. All this reasoning has led to the question of how to achieve a good and optimized architectural design standard along with an optimized energy performance. Consequently, the problem of how to evaluate the students’ designs, when considering the consistency between sustainability issues and architectural form, arised. In order to accomplish this goal a pedagogical strategy has been set whereby a) the students were asked to start from an architectural vocabulary inspired by sustainability issues such as natural forms used for solar radiation capture, b) the students were submitted to an evaluation system which provides them with a permanent assessment during their design process in relation to the studio’s theme, i.e. the consistency between sustainability and architectural form, among others. The 9th semester studio methodology consisted of three sequential steps or exercises: i) the development of the shape concept, ii) a proof-of-concept including computational performance evaluations of the proposed architectural shapes and iii) final technological adjustment.

The remaining paper is divided into four parts: In the first part, the three stages are described. The second part presents the evaluation system and its results are analysed. In the fourth and last part, some conclusions are drawn in order to clarify the limitations and point out perspectives of the adopted methodology.

2. THE THREE STAGES METHODOLOGY

2.1 Development of the Shape Concept

The shape concept exercise was intended to support the emergence of expressive shapes with the contingent risk of provoking unpredictable structural solutions and energy performance results. Other issues, such as gray water collection and treatment, energy consumption and building materials, were considered peripherally as indicated by the structured list of requirements establishing the main design goals to be developed at certain points of time during the term.

This first phase was subdivided into two exercises: in the first one, the students analysed one entry to the Solar Decathlon competition and, in the second exercise, the students developed their own shape concepts. The analysis of the competition’s house was divided into four topics.

Varios aspects have been highlighted during the teaching, the first among those was the architectural language and to what extent it expressed the materials, technologies, equipments and strategies for the production and conservation of energy as well as the achievement of environmental comfort. The question is: Are the “green” characteristics visible or not? These features may exist but they might not be visible or distinctive.

The second topic was about building technology and implies prospecting two factors: on the one hand the description of basic structural characteristics of the building, on the other hand the identification of novel components not found in conventional constructions. Building technology also involves materials, which are used for structure, waterproofing, foundations, thermal insulation, internal and external coating. The student should describe aspects of employed technological innovation in materials by linking these factors to corresponding goals, such as energy conservation, thermal comfort, cooling, among others.
The third issue involved the analysis of passive strategies and materials proposed for thermal insulation on horizontal and vertical planes. The shape, size, position and orientation of the openings and sealing elements also should be presented and the students were supposed to verify the way each element contributes to the thermal and visual comfort of the analysed project.

The fourth focus, denominated Ergonomics, was related to the technological innovations articulated throughout the arrangement of spaces and the flexibility offered by furniture components. This variable was intended to assess different levels of ease of use during the operation of spaces such as kitchen, bathroom, living room and bedroom by the end-user.

The second exercise was referred to as “conceptual shape”, which would be used by the students during the term’s subsequential time. Its purpose was to encourage the students to research more creative concepts, in a process which may require taking a step backward to achieve the principles of sustainability. The use of materials, technologies, devices and strategies intended to produce and maintain energy, as well as achieving a suitable level of environmental comfort may generate a relative tension between the architecture of the building and the need to achieve one or more specific performances. The authors sustain the hypothesis that the process of challenging freedom of expression on the one hand and a technological and environmental performance on the other will intrinsically produce a pedagogical gain.

The shape concept exercise took about two weeks, and the students were asked to respond to the four major areas already established in the previous exercise: the architectural language, the structural system and materials, sustainability and ergonomics. This strategy was useful to inform the role of these different aspects visually and allowed greater control, increasing the likelihood of design success during these first steps of the form finding process (Turkienicz & Westphal, 2012). Using a storyboard strategy, the students described the main design ideas by means of images and text, which reflect the origins of the formal concept (Aroztegui, 2013). The resulting storyboard - describing the relation of chosen objects to the basic ideas of sustainability, such as mainly energy production or conservation - has led to the student’s preliminary design (Fig. 1, all future figures refer to the project from the same authors). In sequence, the students proposed transforming specific geometric concepts of the generating object, suffering mutations and evolutions in such a manner that it finally incorporates aspects of form as well as structure, but also left a appropriate degree of uncertainty in order to accept future peculiarities regarding the envelope, materials and ergonomics (Fig. 2).

Figure 1 Student work “Solar House”: (a) concept based on the Eno Rubik magic cube; (b) and (c) rotations of the slices providing different positions for better insolation; (d) summer insolation; (e) the final form (students: Fernando Netoux, Rodrigo Lima).

Figure 2 Generative strategy: (a) the insertion of an inner tube inspired by the Airbus’s structure; (b) external shape: the seventeen square structures are rotated 10º in relation to the adjacent ones, the exterior components work as an external envelope.
2.2 Proof of Concept

The second stage consisted of the proof of concept regarding the house’s performance whereby the students were asked to demonstrate required inputs, outputs and other specific performance values. Throughout the presentation of the project’s energy, thermal comfort, and natural lighting performance, it was required to demonstrate the consistency between form and environmental performance, at a point when the preliminary study had been concluded. The results were obtained by means of computational simulations and aided stipulations of contributions of the photovoltaic panels and rain water collection. The proposed building assessment creates a quick preview of the concepts, such as electrical energy consumption, thermal comfort and natural lighting, based on assumed simplifications or annual, monthly, daily, and hourly data derived from a global database of weather information. By using these results the students may improve their designs (Bergman, 2012). The stipulation and simulation of environmental variables required a theoretical base on specific technologies, which - in the beginning of the term – were disseminated during a series of lectures on Structural Building Systems, Photovoltaics, Passive Houses, Efficient Lighting, Environmental Comfort and Waste Water Treatment.

In more detail, the results were achieved using dynamic spreadsheets and the computation tool Autodesk Ecotect Analysis (Autodesk Inc., 2014), importing the model either from Google/Trimble SketchUp or from CAD. This tool was chosen due to its free access and ease of use, also guaranteeing quick results due to short processing times. Another alternative would be EnergyPlus (U. S. Department of Energy (2), 2014), but it use was discarded because time constraints are making it impossible to guarantee the student’s necessary theoretical and practical capacitation.

The students were able to determine whether the model was receiving suitable natural lighting levels using the Daylight Factor analysis (Fig.3a). In other words, a model with satisfying results is very likely to achieve savings of artificial lighting during daytime hours. Furthermore, the analysis of the Incident Solar Radiation contributed to the evaluation of the project’s potential to produce and store solar energy consequently resulting in the capacity to heat the interior space during winter and attending the need for shade in the summer month (Fig. 3b, 3c, 3d). The thermal comfort analysis uses discomfort expressed as Degree Hours in order to evaluate and compare the projects’ performance (Fig. 4).

![Figure 3](image-url)

**Figure 3** Solar Analysis: (a) daylight analysis shows daylight factors between 2 and 10% in the interior zone, (b) solar radiation analysis for 21/JAN, (c) solar radiation analysis for 21/MAR, (d) solar radiation analysis for 21/JUL.
The energy balance evaluation should consider the entire amount of electricity consumed by appliances such as electric lighting, refrigerator, dishwasher, washing machine, and microwave oven as well as the energy produced by renewable sources such as photovoltaic panels (Fig. 5). The performance tests also involved the water balance created by the comparison between the points of consumption such as showers, washbasin, toilets, kitchen sink, dishwasher, washing machine and the water generated by the process composed of rainwater as well as gray water collection and respective treatments. In more detail, the autonomy from external fresh water sources is in most cases addressed by using stored and treated gray water for irrigation, cleaning and toilets. Indeed, the harvested and treated rainwater is reused for drinking and washing purposes.

2.3 Final Technological Adjustment

In its third stage, the term project featured the refinement of the architectural design through the integration of aspects related to structure, construction and installations. This step emphasized the
importance of correlating the architectural language with the technological demands. In other words, the students were encouraged to propose architectural solutions, which absorbed the technological demand (Fig 6). This phase enabled formal refinement, since at this point the student had the quantitative data needed to improve or change the qualitative aspects of his/her design. Energy consumption tables with negative results meant that energy demands had to be reduced or, alternatively, production had to be increased. As the production of energy is basically the result of the performance of the photovoltaic panels, it may be necessary to increase the efficiency of the product, optimizing the position related to the solar incidence or implementing a larger area of panels. In this final stage, the term project featured the refinement of the conceptual architectural design, which can enhance the conceptual form, but needs to additionally consider the building as it is conceived as a whole system, where the structure integrates the installations and the constructive system solves every different type of joint and/or interface between all components. For example, the structural systems as well as the sealing components may be designed as part of the solutions for HVAC, electricity and hydraulics systems (Fig. 7).

![Figure 6](image)

**Figure 6** Sections: (a) hot water tank supplied by the solar thermal collectors integrated into the eternal envelope’s structure; (b) technical equipment such as drinking-water tank, gray water tank, non drinking-water treated water tank, gray water treatment tank, black water tank, hot water tank, water pump, and solar inverters are placed under the house’s flooring.

![Figure 7](image)

**Figure 7** Technological adjustments: (a) the tube section forms the structural system of the house; (b) the final design.

### 3. THE EVALUATION SYSTEM AND RESULTS

The evaluation results showed that, during the first steps of the form finding process, the students obtaining above average scores for the conceptual integration of elements responsible for the environmental control presented the best solutions for the architectural and technical realization of the building envelope as well. The detailed resolution of the architectonical elements, such as photovoltaic panels, solar thermal collectors, solar protection and/or insolation, has been handled best by students who had managed to integrate these concepts into the overall idea at the beginning of the course. The same group of students would be expected to achieve the best performances. However this is not confirmed by the results at hand. Throughout the performance analysis of these student’s designs, the results have no obvious correlation with either the successful integration of the concepts into the idea or their detailed solution in the architectural elaboration of the project. A typical example is the balance...
between solar gains for daylighting on the one hand and heat accumulation caused by the same source of energy. These aspects involve a combination of profound studies of theory and practical experience, which students typically do not present at this given academic level.

When analysing the results by standard deviation for the categories related to the architectural elaboration of the building envelope as well as the resulting performance, two main observations can be made. Firstly, the lowest deviations are found in the categories regarding the photovoltaic panels and the energy balance, respectively; these categories also present the highest average scores. Secondly, by far the greatest deviation among the categories for the building envelope was found regarding warm-water production, while for the performances most differentiated scores have been obtained for thermal comfort, which consistently presented the lowest average scores. The first fact can be explained by prior education and the project’s focus in this specific criterium. An enquiry, although performed during a later semester, shows that students consider solar energy as the topic on which they have the most complete knowledge base compared to other technologies like thermal power generation or waste water re-utilization. Starting the semester with the analysis of case studies from the Solar Decathlon has predictively led to concepts and consequently technical solutions that are fit for this type of technology and have resulted in well elaborated energy generation mainly based on it. The second co-relation shows that the students either did not have sufficient prior knowledge of certain other technologies, such as warm water generation, or were not able to acquire such knowledge either from the theoretical lessons, from examples such as the analysed case studies or on their own during project development. Especially in the case of the thermal comfort the deviation must be explained by the low scores some groups obtained with wrongly executed simulations or erroneous representation and misinterpretation of the results they obtained with Autodesk Ecotect.

4. FINAL CONSIDERATIONS

In general, it may be affirmed that throughout the 14 projects turned in at the end of the term, the proposed methodology has ensured a relative homogeneity of results with respect to the pedagogical objectives outlined at the beginning of the semester. The evaluation of pedagogical procedures indicated the importance of emphasizing a constructive awareness even in the initial stages of the design process. Although the designs developed in 2013/2 reached high levels of formal exploitation (Fig. 9), the projects show a difficulty in reconciling this exploitation, especially with the constructive systems employed.

In more detail, the initial phase of the course, dedicated to the student’s analysis of one project from the Solar Decathlon competition, functioned as an introduction to the methodology developed for the course. Nevertheless, the authors noted that the students did not assimilate sufficient knowledge during this stage in order to incorporate innovative solutions from the analysed projects into their own. As improvement, the authors will try to implement the use of physical models of the analysed projects in future semesters to improve the three-dimensional understanding of the implemented solutions and consequently raise the level of detailed understanding of the system as a whole. Another desired enhancement would be additional time for the refinement of the project based on the performance results obtained. Two weeks dedicated to this revisitation of the proper project would not only sharpen the understanding of the results itself, but also strengthen the understanding of the intertwined processes of sustainability, architectural form, and employed materials.

Finally, the integration of the architectural language, the building energy consumption and other described sustainability issues, involving building systems and requirements, have both process-related and aesthetic aspects. The concern with the process of all parts of the design emphasizes that sustainability is at the core of the design process together with other design parameters such as function, structure, construction and installations. The teaching strategies used is leading the authors to develop a methodological path to design, evaluate, demonstrate and qualify the object at all design stages, from conception to installation. The exploration of architectural language during the conceptual phase and preliminary studies of the house gave the students an opportunity to bind architectural forms to the goals of environmental performance. The three-step methodology has helped students to expand their
awareness of the risks of designing without attention to environmental aspects. At the same time, the manipulation of performance models throughout computational tools allowed the students to feel confident in their environmentally tested designs.

![Images of building designs](Figure 9) Results: (a) Shadow House; (b) Cube House; (c) Gigogne House; (d) Fold House; (e) Cell House; (f) Origami House; (g) Tree House; (h) Energy House; (i) Allegro House; (j) House T; (k) Vitori House.

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Technical and Culturally Sensitive Solutions to Foster Sustainable Housing in Southern Angola

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ABSTRACT

Studying housing solutions demands a multidisciplinary concern in order to come up with comprehensive answers able to account for physical, social and cultural needs. It is, therefore, fundamental to bring up those needs into the housing creation process.

In the City of Ondjiva, in Southern Angola, as throughout the world we can observe a lack of habitability in its slum areas, associated to the existing economic conditions. In most cases the settlement isn’t provided with basic infrastructures, does not respond adequately to the climatic demands, which leads to the development of unhealthy environments. Additionally, the house in the city follows European or contemporaneous models which don’t produce culturally oriented answers for the local inhabitants. As a result, the poorest housing areas are characterized by two major inadequacies: constructive and cultural.

This proposal intends to bring into the discussion the need for architectural solutions that are culturally sensitive (user-oriented), as solely technical solution appears to be detrimental to the diversity of ways of life characteristic of contemporary cities. Furthermore, it intends to alert to the need of exploring new technologies in order to turn the expertise accessible to the housing construction current actors, in a context of great poverty.

The goal of this proposal is to create an innovative IT tool, an Expert System which will integrate both results from environmental-behavior studies of a specific cultural group, and sustainable design solutions. It will be produced as a tool to help in the design of individual housing profiles and consist on the construction of a System of Relations between three pre-established group of settings, cultural, everyday life activities and architectural, in order to find a multidisciplinary response for the problematic of housing inadequacy and lack of constructive, comfortable and hygienic conditions.

INTRODUCTION

This paper is based on a research done under the PhD program in Architecture at EPFL and IST, focused on the search for alternative solutions to foster sustainable housing development in Southern Angola. The main goal of this research is to improve housing design and construction processes in slum areas, where self-building prevails; it explores the use of new technologies in order to make expertise accessible to the housing construction current actors, in a context of great poverty. The research is addressed to the case study of self-built housing in the City of Ondjiva in Southern Angola, giving special attention to the cultural aspects of the Kwanyama People (local majority group) and to the region’s climatic conditions.
It stands on the following premises: The poorest housing areas in the City of Ondjiva are characterized by two major inadequacies: cultural and constructive. It is therefore, urgent to find adequate cultural and technical solutions to foster sustainable housing construction.

Ondjiva, as a City, was implemented in 1915 by the Portuguese military forces and it was designed and developed according to European models as well as the housing models within the City. After almost one century it can be observed that the urban areas have developed in complexity and dimension. Levels of acculturation have also increased, but despite this process of change since 1915, the existence and search for traditional housing models persisted; strong traditional traces are still present all over the city, particularly in the poorest housing areas where traditional values prevail, reflected in daily practices and in the living space. Simultaneously the housing construction in the City poorest areas lacks of sufficient habitability conditions due to the lack of construction knowhow and due to the economical conditions in which the majority of the population arrives at Ondjiva, not allowing them to hire a constructor or to have access to better construction materials.

Cultural inadequacies

There is a great body of literature on Ondjiva and the Kwanyama region which brings to the attention, among cultural, socio-economic and migration issues, facts about the construction of vernacular housing, to be considered in this work (Estermann 1961, Monteiro 1994). There is however no information on the issue of slums in the City of Ondjiva, besides the government urban plans and reports which present a general overview on the main construction and architectural characteristics in the City (Government of the Province of Cunene 2005).

In the City of Ondjiva, self-built houses correspond most of the time to two main aspects: an urgent need for shelter (built according to the scarce economic resources) and to the perception that each one has about what should be a “better house”. Usually a better house corresponds to the houses of the wealthier people, houses constructed with more durable materials and following standard typologies (European models are the most followed). As a result, a self-built house in the poorest areas is generally a parallelepiped simply subdivided in the possible number of divisions (the most common are 2 or 3 divisions as shown in Figure 1).

Figure 1 Examples of housing construction in the poorest housing areas of Ondjiva

Nevertheless, if not in terms of house form, we find a lot traditional traits within the City, especially in the exterior arrangements and in the way people inhabit both the interior and exterior spaces. For example, the internal layout of the house consists mostly on bedrooms, which for the most traditional people, are only used to sleep at night; during the day, the interior of the house is rarely used. Instead, there are other structures that are constructed in the exterior of the house to be used during the day, which replicates the traditional habits of a vernacular housing: covered structures which serve as living rooms, named Okatala (even if sometimes there is an internal one,) or external kitchens, also with special specificities, named Epata. Therefore, where the main house building (generally a family house is constituted by more than one building) tends to follow the city social patterns, annex structures are the ones often built for specific traditional proposes or activities. As such, the main building assumes a “false centrality”, a symbolic and representative centrality, while the annex structures embrace the real family needs, tasks and everyday life practices, full of traditional and cultural significance. This conflict of social aspirations and customs (on one side the desire for wealthier houses, according to the
contemporary society patterns and on the other side the persistence of traditional values and practices) leads to great incoherence in the self-built housing structures and spaces.

Constructive inadequacies

Along the general lack of infrastructures related to the economic conditions, most of the buildings do not respond adequately to the climatic rigorous demands, offering unhealthy environments.

The climate of the Kunene province, where the City of Ondjiva is located, is essentially of the semi-arid type, with the rainy season coinciding with the summer months (when the average temperatures are higher). The average temperatures in the region are close to the ASHRAE Comfort Standards (ASHRAE, 2005), having an annual average temperature of around 23°C. However, in terms of maximum daytime temperatures, these are often outside conventional comfort boundaries, as well as the large temperature variations between night and day, reaching amplitudes greater than 15°C. The absolute minimum value recorded for Ondjiva is -2.3°C in June 1944 and the maximum values of 40.5°C and to 39.9°C were achieved in November 1941 and September 1964, respectively (Govern of the Kunene Province, 2005). Daytime temperatures around 30°C or more are frequent, with a drop to 10°C during the night, meaning that extreme conditions are verified, which can potentially lead to (excessive) energy consumption through the use of HVAC - unless oriented bioclimatic design strategies are applied.

In a study made under the Sure Africa project's investigation (http://www.sure-africa.org) the conventional comfort zones of ASHRAE were overlapped with the zones of influence of the various passive techniques based on research conducted by Givoni (1969). The results showed that according to its climatic characteristics, Ondjiva is under the influence of four passive cooling techniques such as day and night ventilation, thermal inertia, evaporative cooling and humidification. There is a period where heating is needed, which can be obtained in a passive way by taking advantage of solar energy, for example by orientating the building according to the sun projection or by a correct sizing of the glazed surfaces (Correia Guedes and Aleixo, 2011).

The current self-built buildings in the City usually do not present any of these characteristics. On the contrary, they commonly have no enough natural ventilation, no sufficient inertia, adequate shading or a correct solar orientation. The solar orientation is random except when it is related with traditional aspects, placing the main entrance at East. Figure 2 show the thermal and humidity performance of 3 different housing buildings within the city, for the period of one day; the respective buildings, among 17, were monitored with data loggers, measuring the interior and exterior temperatures and humidity values in intervals of 30 minutes, between June and July of 2013.

Figure 2  Temperature and Humidity monitoring of three buildings in the City of Ondjiva
These buildings represent the worst, medium and the best types of self-building construction in the City in terms of thermal comfort. The first one, at left in Figure 2, corresponds to an urgent need for shelter and it is composed of one room only, built with zinc boards, fibber cement boards and wood or pick to stick structures. The second one, in the middle, corresponds to a medium solution, built with handmade cement bricks and uninsulated zinc boards for the roof. The third one, at right, corresponds to an improved and phased construction, which started in 2000, with the construction of two single rooms; in 2001 a small interior kitchen and w.c. were added and in 2005 the living room and one sleeping room were built. The building materials differentiate from ruins remains (stone, bricks, etc) in 2000, handmade adobe bricks in 2001 and cement bricks in 2005, and the roof is made of simple zinc boards with no insulation. The exposed measurements correspond to the part constructed in 2005.

As shown in Figure 2 the 3 buildings have a weak thermal performance. Work made on building performances analyses for the City of Ondjiva (Correia Guedes, Aleixo and Pereira, 2011) show that some of the best practices for construction are:

1. Building optimum orientation: E-W axis orientation;
2. Minimum glazing distribution to East and West facades, 15% to 30% maximum of glazing areas in South and North facades, horizontal and vertical shading devices on East and West facades and horizontal ones on South and North facades are passive strategies which improve the building behaviour;
3. Rammed earth walls on existent buildings have better performance than the usually used concrete block without insulation;

In summary, the house construction in the city doesn’t present oriented answers for either cultural (social, community and everyday activities aspects) or the buildings’ comfort needs. The buildings where the largest part of the population lives in Ondjiva, particularly in suburban areas, are still very poor, with low levels of habitability; most of the times, they are buildings that respond to an urgent need for shelter, not being constructed to last and which lack of almost all the support basic infrastructures. This brings us to the next point: “what is needed?”

THE NEED FOR WHOLE AND MULTIDISCIPLINARY ANSWERS

Solely technical solutions can be detrimental to the diversity of ways of life characteristic of contemporary cities; interior comfortable spaces will not be enough if they won’t allow the continuity of cultural specificities. For example, the houses built recently in the City by the Government for the community do not offer proper external shaded spaces for group reunions, exterior kitchens, separated dining spaces, separated husband/wife sleeping rooms neither respond to the strong hierarchies within the family. These are specificities of traditional cultural patterns that when neglected may have serious results (Rapoport, 1969). Indeed, it is in the outside space that the most traditional activities take place and annex structures are often built by the inhabitants to meet the specificities cited above.

There is an urgent need to bring whole and multidisciplinary answers to the housing processes in the city of Ondjiva, in particular to the self-building one, instead of trying to stop those processes or change their current actors. Only by reaching the individual actors is it possible to find a global answer for the improvement of the living conditions. As we suggest, it is fundamental to relate culture to the built environment on the search for culturally oriented housing solutions; but the central problem resides on how is that relation established and in the variables that are applied in the relation process: How to define the settings that make up culture? How to understand the world views and values standing behind what is called culture? How to understand which values should or not prevail in the future housing design? And finally, how to relate culture with technology?

Culturally Sensitive Approaches and Technological Answers

Culture has been one of the main concerns in the study of housing since the 1960’s when several authors began looking to the built environment as a result of many culture influences. Assessing culture is particulary relevant when trying to analyse and evaluate its impact, in this case, on housing.
The Environmental-Behavioural Studies (EBS) model from Amos Rapoport represents an important tool in analysing which factors influence the house form, allowing to evaluate those factors and to measure them in order to understand how the build environment (housing) responds to their inhabitant’s specific needs. The EBS model from Rapoport breaks down the influence of culture, on one hand as a group of social variables that can be measured within a System of Relations, and on other hand as an expression of lifestyle and values which leads to the activities happening in a specific space. For the author, the design of one space where a certain activity will take place corresponds to the specific arrangements which need to be done for the activity to happen, paying attention at the same time at how the activity is done, the meaning of that activity for the culture and its social or ritual significance (its latent aspects) (Rapoport 1988). The goal of Rapoport’s EBS model is to provide a framework for the understanding and study of the group of settings which compose the Built environment, and for the establishment of a system of relations between those settings and the latent aspects of activities, leading finally to the “housing profile” (final result).

Existing works on culturally oriented housing studies are not yet completely applied to housing design. Indeed, the existing research is more focused on housing evaluation rather than new housing conception processes (see Khattab 1993 and Sungur & Cagdas 2003). On the other hand, there are multidisciplinary approaches on housing development, but almost all of them stand in one-to-one participatory relations between the architect and the future inhabitants (UNHabitat, Diébédo Kéré). That is perhaps the most correct and productive approach but it is difficult to implement in a context of massive self-building production, at least without changing its current actors. Designing for each individual is a difficult, if not impossible, task to achieve and it is impossible to think that it would be economically viable. Therefore there is an urgent need to think on alternative solutions to improve the existing poor housing conditions in the poorest housing regions in the World; not only multidisciplinary solutions but accessible solutions and of easy application in the context of self-building housing in slums. How, then, to come up with a multidisciplinary solution easily accessible to the self-builders in a context of poverty and architects absence? How to share the knowledge?

HOW TO MAKE THE KNOWLEDGE ACCESSIBLE TO THE SELF-BUILDERS IN A CONTEXT OF POVERTY AND ARCHITECT’S ABSENCE?

First, in order to develop integrative and oriented design, it is fundamental to understand which procedures are more appropriate to share specific information, and how to make this information comprehensive and fully applicable (Friedman 2003; Akrich 1987). As Yona Friedman suggests, other languages than sole formal one of architecture must be found, which must be simple (understandable and easy to use), significant (direct, clarifying which consequences are implied in one decision made according to the plan described through that language) and interpersonal (discard form expressions that can have different meanings to different persons) (Friedman 2003).

This proposal intends to build up a similar System of Relations to the one proposed by Amos Rapoport, which will relate three pre-established group of settings, cultural, everyday life activities and architectural, in order to be able to give specific answers to the housing construction. Plus, it intends to bring the System of Relations to the future inhabitant and the future inhabitant to the System of Relations, turning it user interactive, which is possible by the creation of an Expert System, an IT tool that will embed and support the System of Relations. It is important to remember that we are working in a context of architect’s absence and where the house planning procedures do not include a prevailing housing design. Therefore the search for alternative solutions is based on the following postulate: if we can’t have experts orienting everyone’s house construction, we can at least try to make the expertise accessible to everyone. It is in this sense that the Expert System is created; it shall be able to replace the expert and transmit the knowledge to its users, in a simple, significant and interpersonal way. The Expert System will allow simulating specific housing profiles – at the same time bio-climatically optimal and culturally sensitive – as a way to combine the advantages of a face to face participatory process and an improved building procedure.
The development of an Expert System

“An Expert System is one in which human Expert knowledge about a specific domain is encoded in an algorithm or computer system” (Luger 2004); “the core of an Expert System is the knowledge-base, a database in which the main domain-related intelligence is encoded. Such a database is typically populated using the knowledge of one or more human Experts (…) In addition to being an informative stand-alone resource, the knowledge-base is a critical component in the Expert System” (Lee and Andersen 2009). The knowledge base will be constructed according to the available data resources, that is either heuristics either experimental, either qualitative either quantitative. It will also be based in optimization methods or algorithms for building design decisions, as the genetic algorithm (GA) (Goldberg 1989). In the proposed Expert System the user will be guided through a step-by-step process in which programmatic and constructive directives definitions are gradually decided towards the user’s goals while respecting the pre-established System of Relations between cultural, activity systems and architectural variables. As stated, this system is meant to be user-interactive, flexible, and oriented to the specific case of Kwanjama People building their houses in the City.

The concept behind the System of Relations is the systematization of the architectural thinking process when conceiving a house for a particular user. It is fundamental to fully understand the cultural and personal context in which the user lives to better understand the needs and wills towards his future housing; this is, to be able to define the group of settings (aspects) which compose the built environment and therefore the architectural form.

The System of Relations – one of the most fundamental research question at stake - will be reflected in a decision “tree” that after inserted in the Expert System and according to the user’s input, will lead to the final Housing Profile (group of culturally, architectural and personal oriented directives for the housing conception). It constitutes the Expert System’s knowledge base and it is built on the principle that every aspect/variable, within the climatic and constructive, cultural and activity system’s contexts, has an architectural implication. The set relations are translated into a decision tree, which is constructed by accomplishing the following steps, as shown in Figure 3:

**Step 1** – Defining the **aspects/variables** within the Kwanjama culture; aspects of the people living in self-built houses in the City and their everyday life practises, of the construction procedures, climate and local environment (social, economic and urban);

**Step 2** – Understanding which **architectural implication** can each aspect/variable have;

**Step 3** – Defining the **group of aspects/variables** within each architectural implication (as the group of settings that compose the architectural form);

**Step 4** - Defining which **relations** within each group of aspects will influence the architectural form;

**Step 5** – Defining the **procedures** that will allow, ultimately, establishing the System of Relations.

![Figure 3 Proposed steps to create the System of Relations](image-url)
These steps allow constructing the System of Relations, which takes the path of a decision tree, as shown in Figure 4 (a); in the decision tree the departure point is the step 3 (the step 1 and 2 allow achieving to this point) in the sense that the departure point is an architectural implication (house form, division, partition, roof, material, glazing, shading, etc); to arrive to the concrete parameters of that architectural implication or form, all the aspects/variables influencing the architectural form will be inserted in the tree. According to the user’s opinion the aspects/variables within the decision tree will be accepted or refused, and only the validated ones will be related in order to establish the final directives for the construction.

Figure 4 Part of the Decision Tree (Olupale: traditional living room) and (b) example of the Expert System layout (Onü: traditional main entrance; Oshinhanga: traditional living room for children)

The Expert System final layout will take the form of a query, as shown in Figure 4 (b), in which the user can be an active participant in the decision of his own oriented housing profile. In order to facilitate the understanding of what is being asked in the Expert System and to help the user decide, almost all the aspects or implied decisions will be illustrated through schematas as shown in Figure 4 (b). The expected Expert System’s output will be a group of directives for the oriented housing design. Its’ expected result does not intend to reach the final design of the house and it does not intend to contribute with possible housing models because those models could later be at risk of being applied as standard models and spread without respecting the ideal of housing that responds to particular activities or particular latent aspects of those activities. It is intended, though, to help people choose among a vast group of possibilities, based on rigorous studies, and to orient them in a more sustainable construction of their house. It is made for a context of architect’s absence and where the house planning procedures do not include a prevailing housing design. If one of this Expert System’s outputs would be floor layouts or
other technical drawings, these wouldn’t, most probably, be used by the common inhabitant (he wouldn’t know how). Plus, one fact supporting the feasibility of this proposal is the one of the existence of a close collaboration between the administrative housing office and the local population; almost every one desiring to build a house, goes first to the local administration to ask for a land plot. Unfortunately this relation stops here, most of the time, and the inhabitant builds the house without regard to any constructive or architectural rules. Nonetheless, the existing dialog suggests that a computer tool to be used by the poorest housing area’s residents wanting to build a house would be of easy implementation at the local administrative habitat’s office (since the majority of the concerning population do not have access to a personal computer).

CONCLUSION

More than a tool, the Expert System is expected to constitute a method which allows translating the environment behavioural studies concept from Amos Rapoport into direct applicable solutions for a culturally oriented housing design combining it furthermore with bioclimatic considerations. It intends therefore to constitute an alternative in the development of better living conditions in contexts of poor housing conditions, such as the ones of Ondjiva, through the application of a multidisciplinary approach. The Expert System will allow a more culturally and bioclimatic oriented self-construction and will bring new possibilities for the housing policy development, either among government institutions, NGO’s or inhabitants. Therefore, the meaning of this research is in its contribution with solutions that may deliver in the future, better or more appropriate housing in slum contexts, where the self build houses lacks mainly of an oriented guiding and supervision.

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Sustainability and the Urban Planning Context: Housing Development in Algeria

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ABSTRACT

This paper describes research into the development of housing in Algeria. It focuses on the history of traditional dwellings and the importance of outdoor space located inside the building - typically in the form of a courtyard. Courtyard dwellings in the city of Constantine are examined in some detail. The rapid urbanisation process taking place in Algeria in recent years together with difficulties in the planning system since colonial times has caused difficulties in responding to housing needs. The concentration of the population in smaller areas of cities has led to the need for more compact yet comfortable dwellings. The paper describes how the situation might be dealt with in the township of Jijel. A number of stakeholders are being consulted and the key results of in-depth interviews with architects are reported. The findings from the review of the existing housing areas and survey are then interpreted to make suggestions for development in the future.

Keywords: housing, urban, courtyards, design, Algeria

1. INTRODUCTION

Algeria has experienced a number of invasions and colonisations through history and this has brought new peoples and new cultures to the area with consequently new commercial and demographic inputs. These have combined with the already rich variation created by climatic regions and traditional cultures to produce a wide variety of traditional dwelling form.

In modern interpretations of architectural history, traditional architecture is often considered to be an expression of sustainability as previous generations were forced by circumstance, to build in harmony with nature and climate. Further the products were matched to cultural and social values in a much more linked way than generally occurs in the present day (Makani and Talebi, 2011). As a result traditional settlements are often considered a source of sustainable design principles because they were built using locally available materials, and with respect to thermal comfort and cultural needs of the local community (Bouchair and Dupagne, 2003).

An interesting facet of many traditional housing designs was the attempt to have some kind of outdoor space indoors; the most successful exemplar of which is the courtyard house. Courtyard houses can have many beneficial attributes – in cultural terms and also in providing the means to reduce discomfort associated with climate.

In modern dwellings there is often an attempt to bring together elements of tradition together with modern needs and also to match to the needs or urbanisation. In rapid urbanisation it is frequently the need to produce smaller and more densely packed accommodation and in such circumstances the ability to create any kind of courtyard environment is severely limited. One way of creating some kind of
outdoor-indoor space is through the provision of individual balconies. Balconies can be left open or can be enclosed.

This paper consists of three main components: firstly examples of traditionally designed dwellings which have been researched are described and evaluated; secondly particular examples of the courtyard house are examined in more detail; and thirdly, the attitudes of architects to sustainability and the ability of current urban and housing design policies to meet needs is reported following interviews.

2. TRADITIONAL DWELLING TYPES

Examples of older style traditional houses in Algeria according to Benmatti (1982) can often be divided into three categories: courtyard houses in the towns of north of the country which can be seen in the medina of Constantine for example; housing to be found in the rural and semi-urban areas of the North (this form of housing is less homogeneous than the first category and includes the example of Kabylia); and a third category associated with housing settlements in the South; examples being M’zab, Souf and Hoggar.

It is interesting to note in the following descriptions how the old styles of dwelling accommodated social and cultural needs whilst also dealing with the excesses of the climate. Some dwellings had only private interior space; some had both private and more public interior space; and in some cases the means of achieving all requirements was the use of a courtyard.

2.1 The Kabylia House

The Kabylia Berber villages are situated in the summit, slopes of mountains or in high plateaus where a dense population live from land exploitation. Topography and climate are the factors that determine spatial structure of the village, streets and alleys which follow the geographic configuration of the site. The urban fabric is often constrained by a circular road around the summits of hills, and the houses or ‘Axxam’ are organised along radiants or alleys that are perpendicular to the circular road. The dwellings are often grouped and link to each other to form a larger family house.

The family house shelters the whole extended family, with the overall dwelling extended by the construction of new houses sometimes in the courtyards of the parent’s house. In these traditional forms where space is not limited in the same way as in modern development, two or three generations may live together and form a sub-quarter (Toubal and Dahli, 2009).

In such rudimentary houses the family, its animals, its furniture, artifacts, equipment and products all come together (Maunier, 1926). Humans and animals are juxtaposed with minimal vertical or horizontal separation. The dwelling typically had three different spaces: a high living room for people with a fireplace, a low stable area for animals and water storage, and a shed for faring equipment and crops. The rooms are used by both male and female as the men typically spend the whole day outside working on the land and only come to the house to eat and sleep. The relationship between public and private space is not well determined in the plan as the house is effectively considered as a private place.

In Kabylia houses, high humidities can be found in spaces and activities related to water such as the kitchen and bathrooms. The Brasier or ‘Kanun’ occupied the driest places (Loeckx, 1998). The courtyard in the kabylia house is located exterior to the house where traditional summer activities such as pottery making are performed.

The house has a rectangular form and the dimensions are typically: exterior 7 to 7.5m length and approximately 5m wide with wall-height of about 3.5m walls. The dimension can vary depending on the needs of families and the wealth or otherwise of the household. The external walls of dwellings are thick and are normally constructed without windows and thus permit protection of the interior house from cold in winter and heat in summer; the only opening is the door. The walls are constructed from local stone and the roofs have two slopes and generally use roman tiles or clay. The structural frame is based on wooden Ash beams and olive branches, and is supported by its low side walls (Maunier, 1926).

2.2 Soufi House

The traditional houses of Oued Souf are known as Soufi Houses. The Soufis or the inhabitants of Oued Souf were originally from Yemen; looking for water and better climatic living conditions, they crossed Egypt and Tunisia to settle in Oued Souf a city in the Algerian Sahara which borders Tunisia and Libya. The city is 620 km southeast of the capital Algiers. The city is located within the Oriental Grand
Erg (Great East Sand Sea).

Oued Souf is known as the ‘city of a thousand and one domes’ for its particular architecture characterised by the uniformity of styles using cupolas, domes and vaults. The old city is situated in the city centre and surrounded by three main roads, which separate the traditional urban fabric from the new town. The old city also exhibits a traditional architecture showing a compact urban structure which is characterised by a dense network of narrow twisting alleys, different in width and direction providing shaded movement between neighbourhoods (Bourbia and Awbi, 2004).

The houses are arranged around a central courtyard covered by palms branches. They are constructed by using locally available materials particularly the desert rose, stones and plaster. The original traditional dwelling of Oued Souf is called Haouch and designated to house extended families. The house is surrounded by its external thick windowless walls and attached to three other houses in order to provide a minimum exposure to solar radiation. The walls are constructed making use of local materials such as ‘gypse’ which helps to ameliorate thermal discomfort in summer by absorbing the heat during the day and releasing it at night. Also, as sand does not store much heat due to the air between its particles. It cools down quickly after sunset and may even generate morning fog in desert conditions.

The thermal performance of ‘isothermal’ flat roofs can be improved by adding thick layers of earth. In the case when the roof is a dome (the area of a half sphere is three times that of a flat terrace), it will receive relatively much less solar radiation. Therefore, it warms more slowly than a flat terrace (Fezzai et al, 2012).

The traditional house of Oued Souf comprises a semi-public transitional space ‘skiffa’ which provides privacy for the courtyard from external strangers. The skiffa is often endowed by ‘khamsa’: a traditional way to protect the house from bad-eyes of other people. The doorstep/doorway signifies the separation between the indoors and outdoors. Also, the house includes a kitchen, a cellar or ‘khabia’ and a number of rooms ‘ghorfa’ or ‘damsa’; if the ceiling has a form of a vault, the rooms will gradually grouped together in order to satisfy the increased needs of the households.

In the North and South parts of the house, two covered spaces called ‘sabat’ open onto the courtyard. The North Sabat permits a maximum exposition to solar radiations in winter while the South Sabat and an excavated underground area provide the protection from heat in hot seasons (Nabila, 2007).

2.3 Hoggar Dwelling

The Touareg are the people who live in Hoggar; their origin is a mixture of Sudanese, Berber and Arabic. The Touareg are a group of tribes who live in the high mountains of Hoggar in the extreme south of the Algerian Sahara (Benmatti, 1982). The region of Hoggar is the highest land region in the Sahara where many summits exceed 2500m. Despite the southerly location, the region is relatively favoured in terms of climate, and in comparison to other parts of the desert it is less hot and experiences higher rainfall.

The Touareg live in tents or in small buildings called ‘zeriba’. The tents are relatively primitive and consist of a wide leather velum envelope formed by assembling tanned goat or sheep skins painted in red and sewn together. This roof is supported by a tall wooden column in the centre and generally three other columns shorter than the first: one in the middle of the open side of the tent, the two others in the two extremities from that point. Despite its primitive form, the tent can be closed at night almost completely which can protect the inhabitants from the cold nights of winter. One half of the tent is reserved for male use (storage of clothes, saddle and weapons); the other part is occupied by the woman (clothes, personal items, and kitchenware); however the two parts of the tent are not separated by any physical barrier (Demoulin, 1928).

The Zeriba is a small hut representing an intermediate stage between the nomad’s tent and more modern forms of house. It is made of stones and covered by palm leaves. The zeriba has generally a cubic form approximately 2.5 m square in plan but sometimes with a conical roof (Pandolfi, 1994).

2.4 Traditional Courtyard Houses

Courtyard housing is a universal type of habitat and it is not unique to the Arab world or to Algeria. It is widespread in diverse regions in different geographical locations, climates, societies and cultures: several civilisations have used it as the main design component of housing such as the Assyrians, Persians, Greeks, Romans, Byzantines and more recently found in Islamic architecture. However,
although courtyard housing was a key feature of traditional design in many parts of the world, there are significant differences of function and importance relating to the function of the interior courtyard in the Islamic region.

The importance of courtyards has increased under the influence of the Islamic religion and subsequently Arabic architecture took this to form a specific room/space characteristic in plan, in form and in decoration. In this, the courtyard became one of the main architectural features of Arabic houses and gave opportunity to develop a variety of associated features: loggias, galleries, high level openings, oriel and elaborate sun-shade ornamentation (Edwards et al, 2004).

The study will focus on the medina of Constantine as one of the oldest medinas in Algeria and in which fine examples of traditional forms of Courtyard Houses are to be found.

3. THE MEDINA OF CONSTANTINE

Constantine is one of the oldest cities of Algeria which dates from 3000 BC. It is situated in the centre of the North East of the country. The city was a base of the Phoenicians, Romans, Vandals, Arabs, Ottomans and finally the French. The medina of Constantine is classified as of national heritage significance. The urban fabric of the medina is extremely dense and the network of streets and routes in the medina follows directly the morphology of the site. Unlike the streets and boulevards of occidental countries, the layout of roads has an organic plan and has no regular geometric form.

An analysis of the plan of the medina shows that the urban fabric has two different urban forms: a central area of souks (markets) which is exclusively related to commerce and culture; and a private residential area. The division of these areas is explained by the principle of separation between public (commercial) and private (residential) zones.

The traditional quarter of Souika is situated in the South East of the Medina. It still retains the major part of its original urban structure. The plan of Souika is composed of a homogenous irregular urban fabric. The residential clusters form small neighbourhood units within which basic neighbourhood facilities were provided such as a bakery, public baths, mosque and a school. The clusters are formed by a maze of roads with a spatial hierarchy from winding alleyways ending by cul-de-sac which maintain the public/private relationship and separation.

Streets in residential areas are either partially covered by cantilevered volumes sabat or totally by additional living spaces. Overall the hierarchy of streets is as follows:

1. A commercial axis as a public street.
2. Secondary roads as semi-public streets.
3. Alleyways and small streets/cul-de-sacs as private roads.

The difference between the main commercial axis and the private cul-de-sacs is one of the important characteristics of the residential urban fabric of the Arab-Islamic medina. This variation allows the separation between the private domain of housing and the public areas in order to provide privacy of houses on the urban scale. See figure 1 for an image of a typical house in Constantine.

Figure 1  Traditional house in the City of Constantine, Algeria
4. SPATIAL ORGANISATION OF THE COURTYARD HOUSE

Traditional houses in the medina of Constantine have a simple irregular geometric form consisting of two or three-storey structures surrounded by external windowless walls and organised around the courtyard. The houses are in most cases provided with pitched roofs inclined to the patio/courtyard area. The plans of the houses are generally similar in their basic characteristics but may vary in detail, and spatial organisation and the hierarchy of spaces in the houses are very similar.

Courtyard houses of Constantine are generally found in three forms:

- Houses with columns and arches which indicate occupancy by more affluent families.
- House with large pillars, columns and lintels, which represent the more generally found dwellings occupied by intermediate households.
- The third form is similar to the second but is differentiated by the elevation of its patio from the floor to allow the use of the ground floor as a store area. This type of house is generally located in more commercial street areas.

Generally however there is no social or spatial segregation between poor and rich families and both live side by side with each other, the only signs of difference being the height of the house and the decoration of the external doors. In all cases the courtyard receives and distributes sunlight and fresh air to the other parts of the house.

The courtyard also serves as the focus for the preparation of food, and as a laundry, children’s play and outdoor living space. It also acts as a circulation space surrounded by alleyways and arched galleries which are designed to avoid any direct visual intrusion (from the semi public spaces into the private central space of the house). Further it provides a covered transitional space between the rooms and the open part of the court.

The courtyards of vernacular dwellings in Constantine have a regular form: square or rectangular. Their length is varies between 8-10m, whilst their depth is between 2-3m, possibly because of the limit of available cross-beam length.

![Typical layout of a courtyard house in the City of Constantine, Algeria (ground floor left, first floor right) Key: 1 = Public (Bit, skiffa); 2 = Semi public (Services); 3 = Private (Female and family living, or bedroom; 4 = Open space (Courtyard); 5 = Transitional spaces (Riwak).](image)

![Typical layout of a courtyard house in the City of Constantine, Algeria (ground floor left, first floor right) Key: 1 = Public (Bit, skiffa); 2 = Semi public (Services); 3 = Private (Female and family living, or bedroom; 4 = Open space (Courtyard); 5 = Transitional spaces (Riwak).](image)

The rooms generally located at its two extremities are elevated doukana (storage places). The central area of the room (Kbu) is opposite to the door and is balanced by two lateral sitting bay areas. The house is accessed through the skiffa, a small angled space which connects the public (exterior), semi-public and private spaces of the house (Barkat, 2006). The skiffa is also the reception area for visitors, particularly men who are not allowed to enter into the house. This place is connected directly to a reception room which is the most decorated room in the house and designated to receive male guests. Figure 2 shows the generalised form of the courtyard house set on two storeys.

5. THE PROVINCE AND CITY OF JIJEL

The Province of Jijel is located in the north east of Algeria and until 1974 it was a sub-prefecture of
the Province of Constantine. It is bordered by the Mediterranean Sea to the North with a coastline of 120 kilometres, and the Provinces of Skikda in the East, Bejaia in the West, and of Setif and Mila in the South. It is divided into 28 communes and 18 sub-prefectures (Dairas) and has a total area of approximately 2400 km$^2$ of which 82% is mountains; it has an estimated population of 650,000, most of whom live in the North part of the Province. The actual City of Jijel has an estimated population of 134,000 inhabitants and occupies just 62 km$^2$ (2.6%) of the land area of the province, and this results on a high density of population of 2,140/km$^2$ (when the average density is just 264 persons/km$^2$ (Wilaya de Jijel, 2013).

Due to its strategic location, Jijel has been an attractive destination for colonists since the pre-Roman times. The city was prosperous in Phoenician, Carthaginian, Roman, Byzantine, and Arabic times. Following a large earthquake in 1856, the reconstruction of the city took place under the French occupation resulting in a new city designed by Scheslat in 1861. The city was built in an orthogonal plan focused around the military garrison ‘the citadel’. The plan was similar to European cities with a triangular form constrained by the terrain form and also by the layout of ramparts, the rules of fortification, and the location of the gates into the city. According to the principles of Haussmann’s urbanism, this plan included the key elements of urban fabric: the regularity of pathways, the alignment of the road structure, and the important role of public areas and squares.

The distribution of the population of showed a concentration of colonists in the North part of the triangle, close to the citadel, the Sea and around the already existing facilities. The native population was grouped in the South West part of the city and occupied a very dense area with very tight access from narrow streets. In 1885, the port was rebuilt and later the Eastern area became an expansion area for the colonists who built housing developments with beautiful villas facing the beach. On the local Arab side, informal settlements spread parallel and outside the triangle and created two new quarters: la Pepeniere and the Faubourg (Safrai, 2008).

After Algerian independence, Jijel witnessed an increase in population arising from a rural exodus towards the city. However, no spatial expansion was planned and little organized construction took place. This resulted in the densification of indigenous quarters and the appearance of other new spontaneous quarters: village Mustapha, la Crete, etc.

From 1974, with the nomination of Jijel to the status of provincial town and the implementation of a special development programme, there has been a considerable rise of population (the population has multiplied by 3 times in a period of 20 years, from between 1977 and 1998.

6. HOUSING POLICY AND HOUSING DEVELOPMENT IN JIJEL

Since the 1970s there has been a very sharp increase in demand for housing, particularly social housing. In this period the city initially grew haphazardly by juxtaposition of urban entities in particular informal housing. The urbanisation of the city occurred rapidly and without much detailed forward thinking on urban development in both medium and longer terms. This has impacted on the fragile balance between the urban system inherited from the colonial period and created morphological and functional failures that make urban management rather complex (Safrai, 2008).

From 1985, the increasing housing crisis and the emergence of informal settlements lead to the launch of a major public housing program and the creation of three new zones of urban habitat ‘Zone d’Habitat Urbaine Nouvelle’, each of which have been designed to accommodate 50,000 inhabitants (Hallal, 2007). These Zones were well intentioned; however their implementation has been less satisfactory because of the emergence of informal settlements. This situation was aggravated particularly in the period between 1990-2000 due to the civil war, the resulting insecurity, and the degradation of living conditions in rural villages and mountains. Urban and architectural decisions in Algeria and particularly in Jijel have sometimes been made according to political and personal evaluations which are sometimes more powerful than urban planning instruments, and this can have significant adverse impacts.

One of the key design features which is seen in the high density development to meet urgent social needs in Jijel has been the lack of development with regard to traditional design. This has led to multi-storey apartment blocks which have forms of outdoor-indoor spaces – balconies etc, but without the attributes understood and liked by the indigenous population, see for example Figure 3.
7. SURVEY OF BUILDING PROFESSIONALS

The research project, of which this paper reports a part, is involved in integrating the views of stakeholders into the design and construction process in a much more influential way. However in order to do this, existing knowledge and attitudes must be known. A number of detailed interviews have been carried out with stakeholders, and the results of the first phase of these, with an influential group of architects and other professionals is reported here.

The study was carried out with twenty-one architects and engineers working in either private bureau or public administrations. The aim of this questionnaire was to assess the knowledge of architects in Algeria in terms of sustainability which can affect the quality of design and the sustainability of the built environment. It also sought views and understanding on differences between traditional and modern design of dwellings.

- On the question concerning sustainable development objectives: 16 professionals answered that they have an idea of the objectives and on what makes a building sustainable; however, only 3 out of 21 gave a suitably detailed definition and the others just related the subject to energy consumption. In addition, 17 out of 21 think that the Algerian Government is not making sufficient effort to raise awareness amongst public and professionals on the topic of sustainabili

- In relation to comparisons between modern apartments and traditional courtyard houses in terms of sustainability, 14 respondents out of 21 preferred the traditional house and they argued that the traditional design respected the lifestyle of local inhabitants. Also, they stated that the courtyard provides more natural light and better ventilation to the dwelling.

- A majority of interviewees (14 out of 21) also agreed that traditional architecture satisfied the needs of the local population in terms of space, while only 7 out of 21 thought that modern design and construction met the needs of the inhabitants. 13 out of 21 interviewees claimed that traditional design met the needs of local population in terms of comfort. However, only 4 out 21 agreed that traditional design respected urban level regulations in Algeria. Some of the interviewees think that is because the regulations were only devised some time after traditional design had evolved.

- All the interviewees agreed that it was important to consider the opinion of future inhabitants in the design of new houses.

- It was clear that the majority of professionals do not have sufficient understanding of the subject of sustainable development which affects the quality of the built environment.

- The vast majority (20 out of 21) of the architects interviewed thought that the quality and impact of urbanism and the built environment in Algeria is poor and lacks respect of regulations.
Some of the interviewees suggested that the design of future housing projects should fulfill the ‘real needs’ of households. They also believed that future design should consider the climatic and environmental factors of the region. Moreover, they thought that the Algerian government should improve the quality of construction in terms of space, comfort and aesthetics.

8. CONCLUSIONS

Vernacular houses in Algeria have varied according to different climatic and geographical regions. Houses design, the use of local building materials and construction system were adopted for each region separately in order to cope with different environmental factors and resource availability. Thus each type fulfilled social needs and society values and traditions in different ways.

However, it is not possible simply to use the systems and practices from previous generations but there is need to study and learn from their experiences and the sustainable systems they introduced (Eiraji and Nambar, 2011) but also to adapt. Human behaviour and culture should also be considered in modern housing design (Vaziritabar, 1990) and future cities should be created by learning from historic and traditional cities: conserving cultural heritage and promoting sustainable development in order to suit contemporary needs.

Urban policies which lead to new housing development need to take into account the older traditional forms but in new ways such as to introduce new forms that can replace the older courtyard form seen so successfully used in Constantine. New housing must also be sustainable and therefore new policies and actions must be informed by current stakeholder views but also seek to address and modify those stakeholders’ opinions. The results of the interviews indicate areas which require attention and can be developed for more sophisticated analysis. This research ultimately aims to combine sustainability potential in traditional architecture with modern technologies and occupant needs to create new sustainable cities that suit present and future needs of the inhabitants.

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Expographic Lighting in Reused buildings, a Preliminary Assessment of Three Museums in Algiers

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ABSTRACT

The city of Algiers comprises eight museums, more than half of them are reused buildings. In this paper, we are interested in the museographic lighting requirements in reused buildings that haven’t been initially designed for expographic purpose. The conversion of buildings into museums may have some constraints. Natural light is an important constraint whose modeling depends on formal, structural and spatial characteristics of the building. And supplying with artificial lighting depends largely on it, thereby having direct repercussions on energy consumption. Conversion of historic buildings, in itself exhibition subjects, can also reduce adaptive space possibilities to museographic lighting requirements. This paper is the synthesis of a master preliminary study where we attempt to assess the exhibition’s lighting quality in three reused buildings, based on blueprints (metric supports), the author’s observation and photographic supports. This preliminary assessment is aimed to evaluate the case studies through literature recommendations of “accent” and “ambient” lightings in exhibition spaces. Despite the constraints related to the conversion of a building into a museum and the importance of lighting design in expographic quality, it may be possible to ensure a lighting quality by adapting the collection types to the space opportunities especially related to natural light. The heavy architectural structures present more constraints than light architectural structures, limiting exposition to permanent collections, especially 3D artworks with consequent dimensions that are the best recommended with natural lateral lighting. Oppositely, the light architectural structures induce flexible and big spaces that seem to be the best adapted to temporary collections especially when offering natural zenithal lighting for “ambient” requirements.

INTRODUCTION

Exhibitions, representing places of themes, interaction, communication and entertainment, are available in a wide range of types, varying according to the theme, content, temporality, scenography and the space housing the exhibition. Museums, being the warehouse of our tangible cultural heritage, represent the largest exhibition venues [1]. Museum culture in Algiers tends to be developed through various activities that take place in the institutions of the capital, and whose number is increasing. This has in part led to the conversion of a number of buildings into museums to host this kind of cultural events. The quality of a museum exhibition is conditioned by a number of requirements related to visitors comfort, artworks conservation, and to the exhibition space itself. It is through these requirements that “lighting” is raised as a predominant factor [2]. In this work, the interest is focused on expographic lighting, especially on two of its components, which are “ambient” and "accent" lighting. The third being the “orientation” lighting that has a very little influence on modeling space and appearance of the exhibited artworks. The expographic lighting is provided by the combination of natural and artificial lighting that depends on some parameters: temporality (with exhibits that may be permanent or temporary), the type of collections on display (2D or 3D objects), and the space housing the exhibition. If the natural lighting is yet a challenge that has to be met in the first phases of the design...
process, because its management and modeling depend entirely on the formal, structural and spatial characteristics of the building, that influence the distribution of illuminance, luminance ratios, and the perception of light, what to say about the building converted to host a museal exhibition, that involves considerable constraints, inducing an important supply of artificial lighting with considerable energy consumption [3, 4]. In this paper, we attempt to raise the qualitative aspect of museum lighting through some recommendations issued from a preliminary assessment of three case studies. These recommendations could help the architect to integrate lighting feature in upstream of his reflection in the design of a museum or conversion of a building into a museum.

**MUSEOGRAPHIC LIGHTING REQUIREMENTS**

**Combined lighting**

The perception of the exhibition, the visitor intuitive orientation and quality of environments are a central concern in a museum space. A suitable level of lighting must meet the requirements of the conservation works and facilitate the adaptation of visitors to the area, while distinguishing each space from another, etc [5]. The museum lighting is defined as an underlying factor in exhibition quality, and is declined in different types, but the focus in this paper is on its role of expression element through expographic lighting, as “ambient”, and “accent” lighting. “Accent” lighting helps to highlight the exhibits and the architecture, and to emphasize their various components and characteristics. This induces the creation of a hierarchy in perception, depending where attention must be captured [6, 7]. “Accent” lighting is designed for numerous purposes such as differentiating objects or artwork through various levels of illumination, or more precisely to model sculptures, etc [7, 8]. While “Ambient” lighting is generally a diffused lighting designed primarily to show the proportions in a space and the limits of a room. It provides the space a general brightness that facilitates the observation of displayed artworks, as well as showcasing the space itself [2]. So, we can admit that museum lighting is a secondary language, meeting the criteria of a semiotic system as its other elements, resulting in the interaction between space, object and visitor [9]. With all these considerations, the expographic lighting depends largely on the exhibition theme and the expected impression and emotion to provoke. Concerning the conversion of a “historic” building into a museum, the expography has to embrace the space, avoiding any additional structure that might affect the building itself as an authentic “heritage”. Its design is related to the exhibition temporality, the exhibits type (2D or 3D) and the existing natural lighting devices.

**Natural lighting**

Advances in artificial lighting tend to reduce the importance of natural lighting in architecture, and so in the exhibition spaces. But improving the architectural experience, ensuring greater satisfaction through the artwork appreciation, connecting the visitor with the outside, ensuring a positive psychological impact, and reducing the energy consumption; are all reasons that encourage the integration of natural light in exhibition spaces [3, 10, 11, 12, 13]. Natural light is assured by different device typologies—with various characteristics and effects, such as lateral lighting device, zenithal lighting device and polar oriented skylight [8]. Concerning the “ambient” expographic light, configuration and characteristics of the space play an important role, because the space’s height and surface, the proportions of openings, and so on, determine its ambience. Soft diffused light is generally considered as a leading “ambient” lighting element. For the “accent” lighting, zenithal and polar oriented devices are the most recommended for lighting two-dimensional subjects (2D) and present the best compromise for daylighting a flexible space hosting temporary exhibitions, preventing direct sunlight from penetration and overcoming the reflection that causes glares. While the lateral lighting device is the most constraining for 2D artworks and particularly for temporary exhibitions, it is better suited to permanent exhibitions composed of 3D objects due to the shading patterns generated by the luminous flux.
In the following table are summarized the literature recommendations about expographic natural lighting devices that we classified into four ascendant degrees of quality: “less recommended”, “just recommended”, “well recommended” and “highly recommended”. [Tab.1]

<table>
<thead>
<tr>
<th>Natural lighting</th>
<th>Ambient</th>
<th>Accent</th>
<th>2D</th>
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<tbody>
<tr>
<td></td>
<td>Lateral</td>
<td>Zenithal (skylight/overhead)</td>
<td>Polar Oriented skylight</td>
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<tr>
<td></td>
<td>Just Recommended</td>
<td>Highly Recommended</td>
<td>Well Recommended</td>
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<td></td>
<td>Highly Rec.</td>
<td>Well Rec.</td>
<td>Well Rec.</td>
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Rec. = Recommended

The openings type plays an important role in the exploitation of exhibition space; so it is recommended to optimize the exhibition surface by minimizing the openings surface. A well-designed natural lighting strategy could direct visual accent to the display without glare surface at modest levels of lighting. In this context, the electrical lighting loads can be reduced and compensated by the natural light, instead of an increase in competition with excess of clarity [8]. The objectives of natural lighting exploitation in the exhibition spaces consists in maximizing the light source by using its features and eliminating its defects and drawbacks. This is done by considering parameters and requirements related to the space, the exhibits sensitivity, as well as the visitors’ comfort [9, 11]. And so, natural lighting should be considered before each exhibition program for both conservation and exhibition requirements. Its expertise generally supported by detailed graphics on devices and openings, should be perfected by an experimental computer modeling showing the lighting comportment [2, 11].

**Artificial lighting**

Unlike natural lighting, the peculiarities of artificial lighting are precision in controlling the direction and amount of light used, as well as the constancy (regularity) [8]. The exhibition spaces are therefore not subject to seasonal or diurnal variations, contrary to natural light, but characterized by stability and adapted control, more suitable to the standards of artworks conservation. For the temporary exhibitions characterized by a short time visit in a museum, the flexible lighting is the most recommended, which only the artificial lighting could offer, through focused rail systems, rotary and swivel spots, etc. [4]. Artificial source typologies are classified according to their distribution of light, and there are three main types. Firstly, the “direct light” which can be diffused, focused or framed. The “direct diffused light” gives the background a significant importance by uniting it to the exhibit, while a “direct focused lighting” narrows it. “The direct framed lighting” decontextualizes subjects through the contrast it creates, and therefore allows the reduction of the illumination. Secondly, the “Indirect lighting” and finally the “direct/indirect lighting”. [4]. [Tab. 2]

<table>
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<tr>
<th>Artificial lighting</th>
<th>Ambient</th>
<th>Accent</th>
<th>2D</th>
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<tbody>
<tr>
<td></td>
<td>Diffused</td>
<td>Focused</td>
<td>Framed</td>
<td>Indirect</td>
</tr>
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Rec. = Recommended / ¹ For dramatic ambiances / ² For soft ambiances

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One of the main concerns of artificial lighting is energy consumption. Each project must have accurate energy balance and where possible, a comparison with the previous installation. In addition to this assessment, it is recommended to use low-consumption lamps, such as LED or compact fluorescent lamps [14]. The use of motion sensor or timer which could improve the conditions of artworks conservation is also recommended for energy economy [14]. In theoretical view, natural light should be considered as the main source of expographic lighting and artificial lighting should be considered as a complement, to bear deficits or to meet the conditions of conservation works. Even if all the criteria cited above, are difficult to combine in a museum, they must be carefully stated and considered for best expographic lighting quality [2].

METHODOLOGY

Case studies

The Museum of Modern Art of Algiers

The museum of modern and contemporary art in Algiers, called MAMA (Musée d’Art Moderne d’Alger), was inaugurated in 2008. It is the first major commercial structure devoted to the cultural sector and the first conversion operation of an old colonial monument of such importance (Fig. 1a). The museum is currently entirely devoted to temporary exhibitions and hosts 2D and 3D artworks. The building is constructed on five floors, including a basement arranged as a Central Exhibition space (atrium) and the exhibition galleries are arranged around the atrium on the different floors (Fig. 1b,c). With a natural light structure, it has three glassed domes, surrounded by small skylights, shaped like stars (Fig. 1c). A staircase initially centered in the atrium has been removed during the building conversion to offer the museum more flexibility in terms of planning.

![Figure 1:](a) Elevation    (b) Section    (c) 1st floor plan.

The national Museum of Folk Arts and Traditions

The historic Palace where are kept the ethnographic collections of the Museum of Arts and Popular Traditions was built in 1570 by the Ottomans. Located in the old city, it became a museum of popular arts and traditions in 1961 after the acquisition of a permanent collection that includes around two-thousand objects related to crafts and other popular arts, which are predominantly three-dimensional. The museum itself is an exhibit, regarding the importance of its history and architecture. The exhibition entity consists of four levels with floors built around a patio and equipped with lateral openings (Fig. 2 a, b, c). The whole building occupies an area of 595 sqm, and has been constructed by a rigid structure with masonry walls. The museum hosts its permanent exhibition, as well as temporary or itinerary ones.

![Figure 2:](a) 2nd floor plan    (b) Section    (c) Elevation.

30th INTERNATIONAL PLEA CONFERENCE
16-18 December 2014, CEPT University, Ahmedabad
The National Museum of Antiquities

The National Museum of Antiquities is the oldest museum in Algeria and Africa, inaugurated in 1896. After several displacements of the collections, the conversion of the first normal school of teachers into a museum permitted to fix these collections. The museum currently hosts historical and archeological pieces reflecting the history of Algeria and the Maghreb for two thousand years, with a collection of sculptures, ceramics, lamps, Roman pottery… which are mostly three-dimensional objects, through permanent and temporary exhibitions. The building, with a rigid structure of masonry walls, has several spaces distributed in the ground floor and arranged around a courtyard (Fig.3 a, b). It has side openings with a skylight in the dome (temporary exhibitions space) (fig.3 c).

![Figure 3: (a) Ground floor (b) Elevation (c) Temporary exhibitions space.](image)

Method

This study was conducted in two major phases: the first based on a literature review of exhibition types, requirements and conditions of expographic lighting quality. Through this literature review, we tried to synthesize the recommendations of the expographic lighting, combining natural and artificial lighting, in terms of “ambient” and “accent” lighting (for 2D and 3D objects). These recommendations have been formulated as a reference tool used in the following phase. The second phase concerned the assessment of expographic lighting quality in three reused museums with the recommendations’ filter. This assessment is essentially based on observation, graphic and photographic supports collected by the author.

RESULTS

The following table summarizes, from literature review, the recommendations related to the choice of lighting type, whether natural or artificial, depending on expographic requirements for “ambient” and “accent” lighting.

<table>
<thead>
<tr>
<th>Natural</th>
<th>Artificial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral</td>
<td>Zenithal</td>
</tr>
<tr>
<td>Ambient</td>
<td></td>
</tr>
</tbody>
</table>

Rec. = Recommended / ¹ For dramatic ambiences / ² For soft ambiences

Museum of Modern art

Museum of Antiquities

Museum of arts and Traditions

30th INTERNATIONAL PLEA CONFERENCE
16-18 December 2014, CEPT University, Ahmedabad
Case 1: The Museum Of Modern Art of Algiers

The “Museum of Modern Art” hosting temporary exhibitions has a number of advantages in term of “expographic” lighting such as overhead natural lighting devices, which theoretically represent the best source recommended for temporary exhibitions. But the devices composed of three large domes and little skylights do not ensure a sufficient “ambient” lighting because of the important height of the atriums, composed of 4 floors (fig.4a). To resort to this weakness, a supplied indirect artificial lighting has been installed with fluorescent projectors oriented to the ceiling (55W/4000K/ IRC>90), direct projectors oriented to the floor (fig.4b) and indirect lighting embedded in the ceiling (indirect diffuse-batten fluorescent luminair- 54W/4000K/ IRC>90) (fig.4d). The central atrium space is then provided with a soft light uniformly distributed. Without the “accent” lighting, the paintings form a single unit with their background. Artificial light plays its substitution but also its widening work role, and meets the needs of “accent” lighting, highlighting the exhibits and offers opportunities necessary for the flexibility of a space welcoming temporary exhibitions. Through rotating spotlights on rails, that ensure the emphasis of artwork with a direct focused or framed lighting (halogen lamps 50W-3200K-IRC100) (fig.4e), it highlights the artworks that stand out from their background, to guide the look toward the artwork, an effect exacerbated by a lower “ambient” illumination (fig.4c). These devices generate a combined lighting predominantly artificial for the temporary exhibitions.

Figure 4: Interior photographs of the museum (atrium and the gallery at the 1st floor).

According to the synthesis table (tab.3), the MAMA museum should meet the "Highly recommended" device for natural lighting, but in reality, with the narrow and deep spatial form of the atrium the natural light is insufficient for “ambient” requirements and completely absent for “accent” expographic requirements. So, deficient natural lighting has been supplied by focused artificial lighting, highly recommended for 2D and 3D objects, adapted to temporary exhibitions that the museum welcomes. Although the artificial lighting ensures adequate expographic lighting, its dominance induces important consequences on the energy consumption.

Case 2: The Museum of Popular Arts and Traditions

The “ambient” lighting is provided by a diffused natural light penetrating through the entrance and windows (fig.5). The lack of artificial lighting here may be a problem when the illumination drops. The “accent” lighting here is provided by adjustable halogen spotlights (20W-3000K-IRC>90), with direct light focused but illuminating a small area of the space and the exhibits in the showcase (fig.5). The exhibits are mostly three-dimensional and lack “accent” lighting, knowing that the diffuse daylight in this space offers little modeling, especially when the sky is cloudy.
The specificity of this museum lies in the fact that it is a "heritage", with heavy loadbearing walls of historical nature. In this case, the lighting of the building and its architecture is as important as objects that are exhibited. The exhibition spaces here are too small for the collections that are hosted and do not allow the visitor to move back and appreciate the exhibition. According to the table 3, the museum should meet the "highly recommended" devices for artificial lighting, but in reality, the presence of this light does not meet the quality requirements, given the number and orientation of lighting devices, that do not fit the needs in terms of expographic lighting. As for the natural lighting, the only existing device is side lighting, which does not necessarily ensure the level of illumination needed for the exhibition, which would have been suitable for permanent 3D collections of small or average size only. The adaptation of the exhibition to the space should be taken into account by the designers, through the ability of the building to accommodate (structure, accessibility, strength of the frame, etc) with a light that targets the architecture of the building, as well as the exhibits.

Case 3: The National Museum of antiquities

Natural diffused light entering through the windows positioned at an important height (gaining exhibition surface) and featuring a diffusing glazing, helps illuminate the space and the objects that are on display (fig.6a). This natural source is supplied by a direct artificial light, with fluorescent tubes (58W-5250 lm-IRC>80) (fig.6b, c), which remains insufficient in case of illumination drop, given the number of devices and surface space. In this museum, the emphasis of the collection is ensured by natural lateral light which in case of high levels; significant shading patterns are generated on sculptures. In the table 3, lateral natural lighting is highly recommend, but in this case study the high proportions of the sculptures, compared to the space measurements and the windows’ disposal, led to the need of artificial light supply for “accent” requirements. This supply should enhance the exhibition quality of the artworks, but artificial “accent” lighting is only present in the showcase (direct diffused lighting).

According to the synthesis table 3, the Museum meets the "highly recommended" devices for artificial lighting, but in reality this light does not answer all the quality requirements, in terms of number and type. With the lateral natural lighting, the spaces are only side-lit, which is certainly favorable for some sculptures, but in excess for high sculptures and insufficient for accentuation of small 3D objects and 2D objects. All the “accent” expographic lighting defaults should be corrected by supplying the space with artificial lighting adapted to each space and to each type of objects. In this museum, two main problems arise: the first is the abundance and numerous varieties of museal objects.
face to the rigidity of the spaces (fig. 6a, c) and the second is the same combined lighting devices existing in all exhibition spaces despite the big variety of the collections. For these permanent collections, improving the combined lighting according to every collection requirements will considerably enhance the expographic quality; but in our opinion, if the museum was adapted to the first collections in 1896, today this important cultural heritage deserves to be hosted in a new building museum with more flexibility and more adapted expographic lighting, specially designed for these collections.

CONCLUSION

Some converted museums offer better expographic lighting than others. Through this preliminary study, it seems clear that the conversion of a building into a museum requires an assiduous appraisal to evaluate the opportunities that the building offers. Strengths and weaknesses should be studied in accordance to numerous factors among which are the exhibition type (permanent or temporal), the collections requirements (2D, 3D, proportions), the conservation requirements and the energy consumption. From the case studies assessment, we retain that more the converted building offer flexible spaces, more it can fit the expographic lighting requirements but with heavy consequence on energy consumption when the natural lighting is insufficient. The Museum of Modern Art of Algiers seems to fit the expographic lighting requirements for temporary collections with the flexible spaces it offers, particularly the central atrium capturing the zenithal natural ambient lighting, even if insufficient. In its category as a museum of temporary exhibition, it seems to be a good example needing extensive study of its artificial lighting in order to reduce the energy consumption. In its category as a museum of permanent exhibition, the museum of Popular Arts and Traditions seems also to be a good example of collections adaptation to the space. The natural lighting is insufficient and the supplying artificial lighting should enhance both the expographic and the historical character of the building. The third museum seems to be the worst example, where spaces don’t fit either objects proportions or lighting requirements. The main recommendations we retain from this preliminary study is that in a reused building, the “natural lighting” should be the first considered and foremost factor to chose appropriate collections and to supply with adapted artificial lighting with energy consumption care.

REFERENCES

Deconstruction + Reuse = NØ Waste

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ABSTRACT

How much does it cost to rehabilitate and extend, with optimal conditions of habitability, a non-used building versus starting a new one from scratch?

One of the main challenges we are facing nowadays in order to fight against climate change is the efficient use of resources in all areas of society. From the scopes of architecture and building sciences, the efficiency in the management of resources will be key for improving our capacity of adaptation towards the requirements of sustainable development and climate change. This issue is directly linked to the topic of rehabilitation versus building from scratch (starting with a new floor plan).

The research developed for the thesis "Life cycles of materials. Building from scratch versus rehabilitation and extension of the traditional dwelling from Extremadura" presents values that go far beyond the estimations made for the initial hypothesis; the impacts on the quality of the natural environment of a renewed-extended existing dwelling is 63,42% lower than the impacts generated by building a new one. Specifically in economical terms, the costs of a renewal/extension of an existing dwelling are 36,90% lower than the costs of a new building.

Having these data values, a quite important question is still in the air: Which will be the steps required to be able to acknowledge society about this issue?

We have completed an empirical demonstration in the case study of the dwelling in C/ Colón 36, in Castuera (Spain), where we present the process to obtain satisfactory results using the following methodology:

DECONSTRUCTION + REUSE = NOWASTE

INTRODUCTION

Nowadays, the habitation requirements for dwellings leave out any possibility of renewing traditional housing. Everyone wants to live in a new house, and never think about renewing an old dwelling using popular architectural technics. Although this type of dwelling was already designed with integrated passive architecture, their owners are just either waiting for its collapse or to be demolished in order to build new ones.

Throughout history, in different regions of the world, many cultures have reutilized materials from other constructions to build new dwellings, great buildings, monuments... But after the industrial revolution it is only considered to build using new materials.

We believe it's time to change this paradigm. Some architects have thought of this idea, as we have now the technology for analyzing materials and creating virtual designs before building. That way we are able to calculate if it's feasible or not, and how these materials can be reutilized in order to obtain more efficient buildings. I've been working and researching on processes of reutilization and on this type of architecture since 2004. We have worked with passive design, materials reuse, simulation software, Life Cycle Analysis, situated technology and local knowledge, obtaining the best design answers for the needs of its inhabitants. These technics are: DECONSTRUCTION + REUSE = NO WASTE.

INTENT AND OBJECTIVES OF APPLIED RESEARCH

Our intention is to answer the following question: ¿How much does it costs to renew and extend, in optimal conditions of habitation, a non used building versus a new construction? When we ask "How
much does it costs" it refers to economical value but also to environmental impact.  

GENERAL OBJETIVE: To determine, through comparison, how much it costs to rehabilitate and to extend, in ideal conditions of habitability, a building in disuse versus a new building: environment impact and economic value.  

SPECIFIC OBJETIVE, working on interventions with real projects:  
1. Acquiring knowledge about construction system in dwellings from Extremadura (Spain).  
2. Acquiring knowledge about construction systems in new dwellings.  
3. Assess the materials and construction systems to be efficiently reutilized in dwellings renewal.  

METHODOLOGY AND TOOLS  
The methodology is based on the following processes: search of bibliography, search of data bases (demography, climate, materials, construction details and local technology), analyzing traditional construction systems in Extremadura and in projects of new dwellings built from scratch.  
The tools used for obtaining these results are:  
1. SIMAPRO (ECO-INDICATOR 99); valuation of damages in several areas of impacts:  
   2. Ecosystem Quality: (m2·yr·PDF) square meters of surface of vegetal mass that will endanger some species that may potentially disappear  
   3. Resources: Megajoules needed to obtain low quality minerals and fossil fuels in the future.  
2. ARCHISUN: acquiring and comparing values of energetic consumption in dwellings after built.  
3. Price basis of Extremadura: overview for comparing the costs in € between the following case:  
   1. Unused dwellings after renewal and extension.  
   2. New dwellings built from scratch.  

OUTCOMES AND COMPARATIVE  
In this research, we have compared two cases to be able to know the impact and economical cost in each construction unit, but also the energetic costs after finishing the construction process. The analyzed buildings had similar dimensions, but for a better comprehension and comparison, in the impact analysis we have work with built square meters. This way we managed to work with exactly the same measurement on each construction unit, as normally each material is measured in different units (concrete: m3; steel: Kg; brickwork: m2; etc... ).  
First, we have evaluated the damages created in the quality of the natural ecosystem. Each building has similar installations (bathroom, kitchen, living room, sleeping rooms, etc... ), therefore, we are analyzing only six construction units (soil movement, foundations, structure, brickworks, finishes and roofing), because these units have the largest differences when analyzing the impact. More information can be found in "Ciclo de Vida Material. Construcción de nueva planta versus rehabilitación y ampliación en la Vivienda Popular Extremeña". This work has been developed in "La Serena", which is a region in the south east of Extremadura (Spain). We show the general comparison of these two types of constructions. On a second phase, we have analyzed the energetic expenses after the construction process was finished, this way we can value how efficient is each type when they’ll be used. The data is showed per year, in a 50-year life cycle. Finally, we present one of the most important issues for our society, the economical value, answering the main question for this research.  

Comparative of Ecosystem Quality impact  
The comparative analysis of the case studies (new dwelling versus renewal-extension of a dwelling) is presented by categories and areas. With the obtained results, we can understand that renewing and extending a dwelling has less impact than building from scratch. A first graph shows the impact in several areas (human health, quality of the natural ecosystem and resources).
In all areas, the damage by square meter in renewed and extended dwelling will be 60% lower than in a new construction. In terms of quality of the natural ecosystem, it's 2.7 times lower than in the worst case scenario. For human health is 3.45 times lower, and for resources it's 3.13 times lower than what is produced by square meter compared to a new dwelling built from scratch.

![Figure 1: Impact comparison by areas between new dwelling and renewed-extended dwelling](image1)

![Figure 2: Impact comparison by categories between new dwelling and renewed-extended dwelling](image2)

This research has the exact value for each construction unit, for more information please consult on the book. Now, for a better comprehension, we show the uncertainty graph of Monte Carlo. This way we will know which are the originating causes for the emission of kg.eq.CO2 on each category for new dwelling or for a renewed-extended dwelling. In the analysis, the values from the renewed-extended dwelling (green) are subtracted to the values of the new dwelling (red).
In the comparison, there are construction units with a proportional relationship lower than 9.35 times. It's the case of brickwork and roofing. The reason for this is that in these units, most of the materials are reused from other constructions or from the renewed dwelling itself (bricks, roof tiles, sand, clay, wood or sticks). In the case of the external finished, the relation is 2-3 times, because even if we reutilize sand and clay we need lime to make the mortar (in some cases, we will need cement and steel too). Lime has a lower impact, but this material (and it happens the same with cement) requires transformation process to be able to use it for construction. Finally, our goal for this research study in the comparison between new versus renewed-extended and this last aspect (extension) is the reason why there is a bigger impact in this unit, as shown in Table 1.

The average value of the total comparison shows that each square meter of newly built surface has a level of emissions of 2.73 times versus surface of a renewed-extended dwelling. Also, with an approximate calculation, we can obtain a comparative value of new versus renewed; if the dwelling is not extended, we need don't need to make new foundations. In this case, the square meter of renewed dwelling has 4.79Kg.eq.CO2 less of emissions. If we subtract in the structure of the building a part of the concrete, steels and pre-fabricated elements, the renewed dwelling will have an impact 75% lower. This way, the emissions of Kg.eq.CO2 generated by the structure would be 1.82. In other construction units we should also subtract some elements, but these data values are enough to demonstrate how much lower the impact would be. Still, discounting these values, renewing a dwelling would generate 6.08Kg.eq.CO2 versus 45.26Kg.eq.CO2/m2 of the new construction. Therefore, we can see how the impact of the renewal would be much lower; precisely 7.24 times lower.

Table 1: Uncertainty comparative newly built dwelling and a renewed-extended dwelling (Kg.eq.CO2)

<table>
<thead>
<tr>
<th></th>
<th>New house</th>
<th>Renewed-extended dwelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>7,060</td>
<td>4,790</td>
</tr>
<tr>
<td>Structure</td>
<td>14,640</td>
<td>7,060</td>
</tr>
<tr>
<td>Masonry</td>
<td>9,650</td>
<td>0,770</td>
</tr>
<tr>
<td>Roof</td>
<td>6,480</td>
<td>0,700</td>
</tr>
<tr>
<td>Cladding-finishes</td>
<td>7,430</td>
<td>2,790</td>
</tr>
<tr>
<td>TOTAL SUM</td>
<td>45,260</td>
<td>16,110</td>
</tr>
<tr>
<td>All built work package</td>
<td>45,58</td>
<td>16,67</td>
</tr>
</tbody>
</table>

Figure 3: Uncertainty analysis. Impact on the quality of the natural ecosystem for each m² built of new dwelling versus m² of renewed-extended dwelling.

The average value of the total comparison shows that each square meter of newly built surface has a level of emissions of 2.73 times versus surface of a renewed-extended dwelling. Also, with an approximate calculation, we can obtain a comparative value of new versus renewed; if the dwelling is not extended, we need don't need to make new foundations. In this case, the square meter of renewed dwelling has 4.79Kg.eq.CO2 less of emissions. If we subtract in the structure of the building a part of the concrete, steels and pre-fabricated elements, the renewed dwelling will have an impact 75% lower. This way, the emissions of Kg.eq.CO2 generated by the structure would be 1.82. In other construction units we should also subtract some elements, but these data values are enough to demonstrate how much lower the impact would be. Still, discounting these values, renewing a dwelling would generate 6.08Kg.eq.CO2 versus 45.26Kg.eq.CO2/m2 of the new construction. Therefore, we can see how the impact of the renewal would be much lower; precisely 7.24 times lower.
Comparative energy consumption after construction.

The ARCHISUN analysis will give us the energetic expense for each construction, and it shows that the renewed-extended dwelling has a better behaviour. Normally, people think that an architecture renewal performs worse than a new dwelling, but as we see in the following table, it can be seen how this popular concept is wrong, it all depends on a good design before constructing or renewing. Considering that both projects were thought of as efficient designs, we can observe more favorable values when we renovate re-using local materials versus building with conventional materials (concrete from a factory, steel from who knows where, wood form another continent, etc...).

**Table 2: Comparison of energetic consumption once the construction works are finished**

<table>
<thead>
<tr>
<th>GENERAL DATA</th>
<th>NEW HOUSE</th>
<th>RENEWED-EXTENDED DWELLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume:</td>
<td>893.00 m³</td>
<td>840.96 m³</td>
</tr>
<tr>
<td>Peoples:</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Building use::</td>
<td>permanent housing</td>
<td>permanent housing</td>
</tr>
<tr>
<td>Median temperature sensation winter:</td>
<td>10.89 ºC</td>
<td>11.63 ºC</td>
</tr>
<tr>
<td>Median temperature sensation spring:</td>
<td>22.41 ºC</td>
<td>22.93 ºC</td>
</tr>
<tr>
<td>Median temperature sensation summer:</td>
<td>31.10 ºC</td>
<td>31.58 ºC</td>
</tr>
<tr>
<td>Median temperature sensation autumn:</td>
<td>24.14 ºC</td>
<td>24.44 ºC</td>
</tr>
<tr>
<td>Natural light</td>
<td>7.55 lux</td>
<td>9.87 lux</td>
</tr>
<tr>
<td>Acoustic insulation</td>
<td>26.31 dBA</td>
<td>25.61 dBa</td>
</tr>
<tr>
<td>Heating:</td>
<td>10.61 kWh/m³ year</td>
<td>4.98 kWh/m³ year</td>
</tr>
<tr>
<td>Refrigeration:</td>
<td>4.50 kWh/m³ year</td>
<td>3.60 kWh/m³ year</td>
</tr>
<tr>
<td>Lighting:</td>
<td>4.13 kWh/m³ year</td>
<td>4.12 kWh/m³ year</td>
</tr>
<tr>
<td>Hot water:</td>
<td>2.28 kWh/m³ year</td>
<td>2.36 kWh/m³ year</td>
</tr>
<tr>
<td>Kitchen:</td>
<td>2.01 kWh/m³ year</td>
<td>2.14 kWh/m³ year</td>
</tr>
<tr>
<td>Others:</td>
<td>1.29 kWh/m³ year</td>
<td>1.30 kWh/m³ year</td>
</tr>
</tbody>
</table>

Comparative economic cost.

In the current society, this is perhaps the most important comparison for the citizens. We are talking about money, most of the time or maybe always, it's the only issue apparently. Again, as in the previous cases, the table shows that the dwelling built from scratch is more expensive than the renewed dwelling. Therefore, the good values are not only related to the impact in the quality of the natural ecosystem or the energetic expense after the construction process, it also happens in economical terms.

**Table 3: Costs comparison between each type of construction. These prices include the costs of labour, materials and required machinery for each construction unit. [http://basepreciosconstruccion.gobex.es/](http://basepreciosconstruccion.gobex.es/)**

<table>
<thead>
<tr>
<th>SUMMARY CONSTRUCTION UNITS</th>
<th>NEW HOUSE</th>
<th>RENEWED-EXTENDED DWELLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>P001- Deconstruction and previous work</td>
<td>- €</td>
<td>5,988.59 €</td>
</tr>
<tr>
<td>P002- Earth movement</td>
<td>979,03 €</td>
<td>5,864.77 €</td>
</tr>
<tr>
<td>P003- Foundation</td>
<td>8,330.88 €</td>
<td>23,646.07 €</td>
</tr>
<tr>
<td>P004- Sanitation installation</td>
<td>2,166.87 €</td>
<td>2,215.43 €</td>
</tr>
<tr>
<td>P005- Structure</td>
<td>28,486.30 €</td>
<td>5,460.42 €</td>
</tr>
<tr>
<td>P006- Masonry</td>
<td>17,487.20 €</td>
<td>7,793.80 €</td>
</tr>
<tr>
<td>P007- Cladding-finishes</td>
<td>22,374.43 €</td>
<td>2,244.72 €</td>
</tr>
<tr>
<td>P008- Roof</td>
<td>21,884.84 €</td>
<td>2,623.68 €</td>
</tr>
<tr>
<td>P009- Paint</td>
<td>4,670.55 €</td>
<td>2,298.96 €</td>
</tr>
<tr>
<td>P010- Electricity installation</td>
<td>5,042.32 €</td>
<td>6,679.42 €</td>
</tr>
<tr>
<td>P011- Plumbing installation</td>
<td>7,095.49 €</td>
<td>8,392.19 €</td>
</tr>
<tr>
<td>P012- Doors and Windows</td>
<td>20,436.12 €</td>
<td>11,269.85 €</td>
</tr>
<tr>
<td>P013- Locksmith installation</td>
<td>224.75 €</td>
<td>2,773.86 €</td>
</tr>
<tr>
<td>P014- Security and health</td>
<td>1,256.52 €</td>
<td>1,238.76 €</td>
</tr>
<tr>
<td>BUDGET EXECUTION MATERIAL</td>
<td>140,435.30 €</td>
<td>88,490.52 €</td>
</tr>
</tbody>
</table>

The most important differences are in the three first units (de-construction and previous works, soild movements and foundations). This happens because in the renewed-extended dwelling included a new basement, therefore these construction units are more expensive. In the rest of cases, reusing
materials is cheaper and the most important issue to obtain reduced prices is in the construction. These budget estimations do not include yet the costs of quality control and taxes (proportional for both cases).

INFERENCES AND CONCLUSION

With all the data obtained we can see that the renewed-extended dwelling is cheaper than the newly build dwelling. It is important to understand that we need a well designed process of de-construction and re-utilization of materials to be able to obtain these good results. In a renewal process we first need to know if the existing building is in a ruin condition; this will be a main requirement for the proposal. A building will be considered to be in a ruinous condition when it presents large structural damages or when in needs a partial reconstruction of over 50% of the building. If the existing building is in a ruinous condition, it will be better to completely de-construct it and to re-use the obtained materials in a new construction, either on the same location or in other location, but not too far, in order to reduce the impact in the quality of the natural ecosystem.

The values previously shown give us the knowledge to be able to answer our questions regarding impact on the quality of the ecosystem and the economical costs of building a new dwelling or renewing-extending an existing dwelling:

1. Impact in the quality of the natural ecosystem in a new dwelling is 2,73 times larger than in a renewed-extended dwelling. It is important not to forget that, if we just renew, the impact of a new house will be 7,26 times bigger for each square meter built. The Kg.eq.CO2 emissions are proportional; each square meter of new dwelling will have 45,58 versus 16,67 in a renewed-extended dwelling. This means the Ecosystem Quality impact is 63,42% less.

2. The economic cost of a new house (140.435,30€) versus a renewed-extended dwelling (88.490,52€) is 36.9% cheaper. Any person would want to renew a dwelling if they knew that the costs are lower than purchasing a new house.

EMPIRICAL DEMOSTRATION, APPLIED RESEARCH, PRACTICE WORK.

We decided to work at the neighbourhood called "El Cerrillo" (Castuera, Spain). It's the oldest and most traditional area of this village. We investigated private and public spaces, types of dwellings, age,
materials and the most important of all, the quality and the potential of each dwelling. We found 407 dwellings, 222 with permanent use, 112 non-used and 73 dwelling in rental regime or temporal use.

Many dwellings are in good conditions and a renewal process would be feasible. That is why, in the following step, we went to dwelling built upon traditional and popular technics from Extremadura, where we can work and obtain empirical results about DECONSTRUCTION + REUSE = NO WASTE.

We worked at the dwelling located at C/Colón 36 (Castuera, Spain). The goal is to un-build the roof (tiles, soil, sticks, wood desks, nails and wooden beams) and adobe walls; as shown in next figure.

Figure 5: Deconstruction process.  www.architectureindevelopment.org/project.php?id=354

Figure 6: Reutilization processes.  www.architectureindevelopment.org/project.php?id=354

Before deciding for the reutilization, we test the materials (strength and durability). We will be able to reutilize 65% of the roof tiles for the same function, and the rest for different functions than the original one (filling up walls, or noise isolation in the fundations). The adobe can be used to increase the walls in the perimeter. Soil as a fill up material in walls, to join the adobe with the facade mortar. The sticks were used as formwork, creating the dome to improve the weight distribution in the structural part of the 2nd floor and carry the loads to the walls of the first floor.
Wood beams to make windows and door lintels and support wood pieces as shown the Figure 6. The clapboard and nails were used to build alveolar slab wood, where we use new wood boards (OSB) and glulam wood beams. The insulation is solved with natural sheep wool, using local materials.

Thus, we obtained our goal, this is one of the many works that we have done, after research “Ciclo de Vida Material”, we have done in Proyecto áSILO; with the hope that these results can be useful in other parts of the world.

Figure 7: left photo: inside the dwelling. Right photo: main facade; Colón 36, Castuera (Spain)

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In the translation: Shylar Abshire and Jéssica Alcántara River, Manuel Torres Rodríguez

NOMENCLATURE

\[ \begin{align*}
    kg &= \text{kilogram} \\
    eq &= \text{equivalent} \\
    CO2 &= \text{carbon dioxide} \\
    \text{m}^2 &= \text{square meter} \\
    \text{m}^3 &= \text{cubic meter} \\
    \% &= \text{percentage} \\
    ^\circ C &= \text{Celsius degree} \\
    kWh &= \text{kilo Watts hour}
\end{align*} \]

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Building a Generic Methodological Framework for a Sustainability Tool Tailored for Architect-Designers

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ABSTRACT

Success in sustainable building depends on a number of factors. Within the competency of project participants, it is crucial that architect-designers have the knowledge and ability to adopt the issues of sustainable building into their designs. An approach on the way towards sustainable architectural designs is to apply methods and tools. These tools aim to act as a bridge, an interface between scientific proven knowledge and the daily practice of architect-designers. Although the use of sustainability tools by design teams is increasing, the present state of contemporary designs regarding the full scope of sustainability indicates a gap, an inadequacy of existing tools.

The target of this research is to build a generic methodological framework for a sustainability tool specifically tailored for architect-designers. First, a literature study identifies specificities of determining factors, resulting in supposed criteria for aimed tool. Second, a review on existing kinds of sustainability tools is carried out. Synthesized issues are pointed out and the assumed inadequacy is verified. Third, an outlook is proposed. Based on identified criteria and issues, a presumed promising concept for aimed tool is delimited and a set of starting points for the further development are selected. Finally, a proposition for the generic methodological framework is formulated.

The result of this exploratory study is a confirmation of the hypothesis that prevailing up front kinds of sustainability tools are inadequate for architect-designers. Suggested generic methodological framework is seen as a possibility for the development of an operational sustainability tool specifically tailored for architect-designers.

INTRODUCTION

The demand and urge for sustainable development has been increasing the last decades. Due to the multi-dimensional complexity of the concept of sustainable development in combination with the complexity of the building sector, the gradation of multidisciplinarity and the size of project teams are expanded. In response, the need for well-understood planning and design processes of sustainable built environments has also been increased (Abdalla et al., 2011).

On the top of critical success factors for delivering a sustainable project is the competency of project participants (Bakar et al.). Whatever the ‘project delivery system’ is, it is seen that the architect-designer fulfills a central role in the project team (Molenaar et al., 2009). As a consequence and by extension, it can be stated that the architect-designer plays a crucial role in delivering sustainable built environments.

A generic and ever expanding approach on the way towards sustainable building is to apply methods and tools. These enable the planning team to identify the effects and interactive relationships of
social, economic and ecological dimensions, and deal with these in the planning and/or construction process. (Hegger et al., 2008, p.191). Despite the huge range of tools on the market, the awareness of their existence and the increasing implementation by project teams, the built environment still indicates a gap regarding sustainability. This gives rise to the presumption of an inadequacy of existing methods and tools for sustainability. Given the earlier stated central role of the architect-designer, this inadequacy could be related to incompatibilities, and/or contradictions between the user and the method / tool.

Given a transition towards a sustainable built environment is necessary and architect-designers display a wavering approach, a specific tailored tool for architects is desirable, advisable, and could be successful. The primary objective of this paper is the development of a generic methodological framework for a sustainability tool specifically tailored for architect-designers.

In order to develop a tailored tool, the aimed user has to be known, identified and recognized. First, a literature study identifies specificities of determining factors, resulting in supposed criteria for aimed tool. Second, a review on existing kinds of sustainability tools is carried out. Synthesized issues which the aimed tool should address are outlined. Third, an outlook is proposed. Based on identified criteria and issues, a presumed promising concept for aimed tool is delimitated and a set of starting points for the further development are selected. Finally, a proposition for the generic methodological framework is formulated.

This paper adds to the knowledge of sustainability tools. By explicitly taking into account and focusing specific features of the architect-designer and the process of designing, it stresses the need for a new approach for, and development/ discussion of tools within the field of architectural designing.

This paper is derived from the first part of an ongoing doctorate dissertation on sustainable group housing projects (Janssens, ongoing). This specific research is an explorative attempt for the building of aimed generic methodological framework rather than a research with strict conclusions. The outcome is tentative and preliminary and needs further discussion and verification, both in the fields of academics and practitioners. Outcomes highly depend on conducted literature study of selected corpus of sources, and are not supposed to be salutary or the only possible ones.

DEVELOPMENT OF SUPPOSED CRITERIA FOR AIMED TOOL

Identification of influencing factors

Following aspects are believed to affect the composition of criteria: ‘the architect-designer’ as the actor, ‘designing’ as the activity, ‘the built environment’ as the object and finally the aim of ‘a sustainable development’.

The object: the built environment. The built environment relates people to spaces through built forms. It ranges in scale from interiors, buildings, neighbourhoods to districts and cities, including their supporting infrastructure. It refers to a broad-ranging interdisciplinary field that addresses design, construction, management and use. The built environment could be defined as the human-made space or surroundings that provide the setting for human activity, live – work – recreate, on a day-to-day basis. It comprises an infinite variety of functions to meet the endless range of human interests and proclivities. In another sense, the built/constructed environment involves some of the most elaborate forms of artifice—varieties of materials, complex engineering, infrastructures of technical interconnection and relationships to nature. The built environment refers to a practice-oriented discipline, in which the end product is a material, spatial and cultural product of human thinking and labor, taking into account interactions among the constructed, social and natural environments.

The aim: sustainable development. The essence of sustainable development is to provide for the fundamental needs of humankind in an equitable way without doing violence to the natural systems of life on earth (Kemp & Martens, 2007). Following Our Common Future (WCED, 1987), numerous efforts were made to operationalize the concept. The most common is the triangular representation with three pillars ‘environment’, ‘society’ and ‘economy’. In some contexts these pillars come to be referred to as ‘Planet, People, Profit’ (Elkington, 1997).

Concerns for the relationship of humans to environment, natural and built, increasingly deploy the rubric of sustainable development, making it one of the fundamental concerns of contemporary times. The definition of Our Common Future has been interpreted in many ways, caused by the fact that the
vision and the description are linked to many different aspects. Some interpretations give the notion that sustainable development is a specific field or discipline, other emphasizes the dynamics emerging from different imperatives. Either way, the vision concerns complex, multi-disciplinary problems that have to be handled from both holistic and analytical approaches.

The activity: designing. Despite real differences between the end products created by designers in various domains, design can be seen as a generic activity: ‘Many forms of design then, deal with both precise and vague ideas, call for systematic and chaotic thinking, need both imaginative thought and mechanical calculation’ (Lawson, 2005, p.4). Nevertheless considerable revisions about design theory, several authors claim that our current understanding of design is still incomplete. This does not imply that designing is mysterious and obscure, but that it is complex (Lawson, 2005). Tjallingii (Tjallingii, 1996) states that designing is the creation of promising combinations and opportunities regarding the physical context, the use and management.

The actor: the architect-designer. The working field of the architect-designer is the built and yet to build environment, ranging in different scales and specialties. Literature is vague and apparently no one feels able to offer a succinct description that they are confident would be widely agreed upon and yet fully describe the work of all architects. Lawson (Lawson, 2004, p.1) states: ‘It is quit impossible to find two people who call themselves architect and yet hardly share any of their daily tasks’. Following Lawson (2005, p. 4), the working field of the architect-designer lies near the middle of the spectrum of design activity. Design in the built environment requires both technical knowledge and expertise, as well as visual imagination.

### Pinning down synthesized features of actor and activity factors

Factors of the actor (the architect-designer), and the activity (designing) are complex and heavily loaded. A commonly accepted defined framework is inexistent. However, for the purpose of this research, a self-compiled set of widely subscribed features was made, backed by selected corpus of relevant sources. Synthesized features are provided in table 1. Within the scope of this paper, providing referencing notes on displayed features is not possible. Therefore only general references are given: Cross, 2006; Lawson, 1980; Lawson, 2004; Lawson 2005; Rehal, 2002; Van Dorst, 2005. Classified features may not be seen as strict, as there is a strong overlap in, and interdependence of, characteristics of the ‘architect-designer’ and ‘designing’.

#### Table 1. Synthesized features of actor and activity.

<table>
<thead>
<tr>
<th>The actor: ‘the architect-designer’</th>
<th>The activity: ‘designing’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicit &amp; implicit knowledge</td>
<td>Exploratory &amp; satisficing</td>
</tr>
<tr>
<td>Different levels of expertise &amp; experience</td>
<td>Responsive &amp; integrative</td>
</tr>
<tr>
<td>Complexity management</td>
<td>Convergent &amp; divergent</td>
</tr>
<tr>
<td>Solution focused</td>
<td>Resultant, emergent &amp; abductive</td>
</tr>
<tr>
<td>Metaphoric appreciation</td>
<td>Reflective (simulating) &amp; ambiguous</td>
</tr>
<tr>
<td></td>
<td>Iterative, personal &amp; unique</td>
</tr>
<tr>
<td></td>
<td>Narrative &amp; imagery</td>
</tr>
</tbody>
</table>

### Cross-factor reflections

Sustainable building is a combination of disciplines, a necessary package deal to prevent us from trade off effects. This complexity describes the problems of sustainable development and at the same time shows the daily practice of an urban designer or planner. The practice of finding ‘promising combinations’ (Tjallingii, 1996) is the common ground for sustainable transition and design. In a designerly way of thinking one combines possible solutions from disciplines which are by nature different (Van Bakel, 1995) (Cross, 2006).

In both aspects, built environment and sustainable development, there are no right or wrong answers. Actions must be decided in process of negotiation and dialogue, and the long-term perspective is central within the quest. Lundeqvist (1995) and Edén (2002) conclude that features of sustainability resemble, in general, any traditional design problem. Because the similarities between features of the
built environment and sustainability, and the architect-designers ability of dealing with complexity and multi-disciplinarity makes him suitable to deal with the sustainability quest. Despite sustainability is often dealt by, or pushed off to, a wide range of project partners, the architect-designer can and should take up the mandate in view of sustainable successes in a designerly way. Both aspects, sustainability and the built environment, are so complex that chances for success largely depend on the knowledge, a deep understanding and experience of the architect-designer. It is important that this knowledge and experience building is supported, made possible and not prevented or penalized.

Supposed criteria a tool should comply

This final subsection provides an overview of criteria which a sustainability tool for architect-designers is supposed to comply with.

Table 2. Supposed criteria for aimed tool.

<table>
<thead>
<tr>
<th>Supposed criteria</th>
<th>Description</th>
</tr>
</thead>
</table>
| Random usability               | • No mandatory, design activity structuring successive process: free timing of startup, enter and use, free consultable, allowing an iterative, cyclical or linear process.  
                                   • Allowing using different design approaches.  
                                   • Serving an incremental and radical optimization of (yet to be) designed / built environments.  
                                   • Meeting architect-designers' diversity: suitability to preferences and difference in levels of expertise. |
| Apprehensible communication     | • Ensuring a transfer of knowledge and insights to the architect-designer (primary user of tool).  
                                   • Ability to act as a discussion platform for project actors.  
                                   • Providing an attractive/suitable display and representation of the content (photo, sketch, ...). |
| Problem framing                | • Providing background information: identification, structuring and limiting of the problem.  
                                   • Setting boundaries for the design problem (and solution): support the development of the brief.  
                                   • Connecting partial problems, mutually and with the design process. |
| Solution focused moving         | • Displaying principles, measures, concepts, combinability’s.  
                                   • Providing non- and contextualized exemplary solutions: single, multiple and/or integral oriented. |
| Source of knowledge and insights| • Inclusion of scientifically and practically proven knowledge.  
                                   • Linking theoretical knowledge with practical relevance. |
| Enabling innovation             | • Indicating the need and importance of verifying displayed facts and building episodic knowledge/insights  
                                   • Stimulating knowledge building by designing.  
                                   • Incorporation of incentives for own research. |
| Non-limiting                    | • Safeguarding creativity and unicity of design/project.  
                                   • Space for interpretation, implicit knowledge/experience.  
                                   • Balancing between prescription and freedom/voluntariness: open-ended / non-committal.  
                                   • Indicating the non-restrictiveness of displayed substantive body of knowledge. |

DETERMINATION OF ISSUES OUT OF EXISTING KINDS OF SUSTAINABILITY TOOLS

Identification and description of existing kinds of tools

As there is no strict classification of tools, for the purpose of this section, we suggest a threefold classification. Knowledge based or qualitative tools involve instruments providing guiding principles (e.g. ‘Trias-model’) on the one hand and guidelines (e.g. ‘Practical Recommendations for Sustainable Construction’ of the EU) on the other hand. Both kinds are based on proven knowledge and experiences.
Guiding principles offer a simple structure which has to lead to sustainable successes. They formulate generic recommendations, strategies, etc. Guidelines link sustainability in a direct way to decisions, but without offering a structure for the design process. Checklists, catalogues and directives often include targets, criteria and/or measures which can be considered or must be implemented to match set requirements. Performance based or quantitative tools include life-cycle impact assessment, outdoor and indoor social and environmental quality. Quantitative tools can focus on single or a limited amount of sustainability criteria or on multiple criteria. Single or limited sustainability oriented tools (e.g. EcoQuantum) are often developed for scientific research. Aspects of sustainability are clearly defined and demarcated (e.g. energy, material). Multi criteria tools (e.g. BREEAM) are focused on the use by practicing actors in the building sector, aiming to be implemented in practical real-life applications like buildings and neighbourhoods. A matrix assists designers in identifying design criteria, document proposed design performance and calculate the number of achieved credits, leading to an overall rating. Performance based tools, more in specific market oriented tools, can also include a rating system, often supplemented with a certification system and labelling. These labels are used in view of market positioning, recognition, publicity and entitling/obtaining funds, fiscal benefits, subsidies, grants etc. Ad hoc tools are project specific developed tools. They can be qualitative or quantitative, or a combination of both. Usually these tools are initiated on the occasion of a large scale project like urban regeneration programs, and new neighbourhoods/districts (e.g. PIMWAG-system ECO-VIIKKI, Helsinki, Finland).

Analysis on prevailing strengths/weaknesses and synthesized issues

An exhaustive analysis with regard to displayed classification of existing kinds of tools is not a goal in itself. A quick suitability scan in a general perspective leading to strengths and weaknesses enables uncovering issues. Table 3 provides an overview. Consulted authors are: Abdalla et al. (2011), Gowri (2005), Janssens (2013).

<table>
<thead>
<tr>
<th>Kind of tool</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge based tools (qualitative)</td>
<td>• Informative</td>
<td>• No / limited and inadequate insights in mutual relations in and between theoretical and practical aspects</td>
</tr>
<tr>
<td></td>
<td>• Assistance in decision making</td>
<td>• Vague descriptions</td>
</tr>
<tr>
<td></td>
<td>• Preserve freedom and creativity</td>
<td>• Comprehensive elaborations</td>
</tr>
<tr>
<td></td>
<td>• Mapping sustainability aspects on to components, indicators, measures, etc.</td>
<td></td>
</tr>
<tr>
<td>Performance based tools (quantitative): Multi criteria</td>
<td>• Presumed integrality</td>
<td>• Limited sustainability scope</td>
</tr>
<tr>
<td></td>
<td>• Presumed accessibility</td>
<td>• Degree of expertise required</td>
</tr>
<tr>
<td></td>
<td>• Indicator for quality’s</td>
<td>• No guarantee for successes</td>
</tr>
<tr>
<td></td>
<td>• Measuring is knowing</td>
<td>• Dubious quantifiability of criteria / scoring / weighing</td>
</tr>
<tr>
<td>Ad hoc tools</td>
<td>• Project specific tailored</td>
<td>• Focus on criteria / indicators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Often misused as checklist</td>
</tr>
<tr>
<td>Overall</td>
<td>• Identification and definition of sustainability, enabling communication and negotiation</td>
<td>• Dubious effectiveness, efficiency, complexity reduction, up-to-dateness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Susceptible to subjectivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Extensiveness</td>
</tr>
</tbody>
</table>

Synthesized issues
Preserving objectivity - Providing insights - Attention for manageability – Actual Integrality - Being inspirational
OUTLOOK FOR A SUSTAINABILITY TOOL FOR ARCHITECT-DESIGNERS

Suitability review and delimitation of a presumed promising concept

This subsection verifies the suitability of two mainstream kinds of tools using two short quotes from literature.

‘The so-called educational tools, including guidelines, rules-of-thumb and best practices seems to be more coherent with the architectural practice, in which the construction of knowledge and decision making is strongly based on referential procedures.’ (Albuquerque, 2007)

‘However, the methods of science are perhaps surprisingly unhelpful to the designer. Modern building science techniques have generally only provided methods of predicting how well a design solution will work. They are simply tools of evaluation and give no help at all with synthesis. Daylight protractors, heat loss or solar gain calculations do not tell the architect how to design the window but simply how to assess the performance of an already designed window.’ (Lawson, 2005)

Design tools are a somewhat controversial subject for architect-designers. Many architects dislike talking about their work process in terms of methods or tools, because it suggests a repetitiveness that is contradictory to creativity. It must be obvious that the specificity of architects, their design methodology and the complexity of designing is so individual that it is impossible to discover an existing or develop a tailored ‘tool’ which satisfies all. ‘Designing is far too complex a phenomenon to be describable by a simple diagram.’ … ‘The word “design” is applied to an extraordinarily wide range of activity include at one extreme something that could also be called “engineering” and at another something that could also be called “art”.’ … ‘Design is a highly personal and multi-dimensional process.’ (Lawson, 2004)

Delimitation of a presumed promising concept

Weaknesses of existing kinds of tools, synthesized issues and previous suitability review gives rise to the development of an innovative concept for aim framework.

• Focus on pre-design and early design considerations and later design inspiration
• Physical – spatial approach instead of a constructive technical approach
• Knowledge based instead of performance based
• Design supporting instead of design process structuring
• Solution focused instead of problem focused
• Knowledge building instead of full exhaustive and limitative display

Selection of a set of starting points for the further development

A description of the complete set of starting points is not possible within the limited length of the paper. As these starting points represents the basis of the further development of presumed promising concept, they will be discussed and documented in depth during the oral presentation. By way of illustration, two important starting points are outlined in this sub section.

General model of high level creative strategies in design. Three key aspects appear to be common in the creative strategies exercised by designers (Cross, 2006). First, taking a broad ‘system approach’ to the problem. Rather than accepting narrow problem criteria, often set by the client or e.g. regulations, aiming for high-level problem goals. Second, ‘framing’ the problem in a distinctive and sometimes rather personal way, stimulating and pre-structuring the emergence of design concepts. Third, designing from ‘first principles’. Designers either explicitly or implicitly rely upon ‘first principles’ in both the origination of their concepts and in the detailed development of those concepts.

The phenomenology of concepts. Ramirez (2000) finds it appropriate to operate with three kinds of concepts: ideological, diffuse and compact concepts. The ideological concept hides and idealizes preferred ideas, notions and situations which are desired and may be realistic. Typical political rhetoric is very often dominated by ideological concepts, such as freedom, sustainability, quality, equality and so forth. Diffuse concepts are somewhat ambiguous and often need to be connected to a particular context, situation or experience to be understood. Diffuse concepts refer to phenomena that really exist but are
difficult to precisely describe through definitions. Compact concepts are used in science where the studied object is the concrete material world and where unambiguous, well-defined definitions and context independence are the central characteristics. While the built environment is interdisciplinary, all three kinds of concepts are necessary in the design process, whereas a specific order is relevant. Rehal (2002) states: ‘In the earlier stages of the process, it is mostly diffuse and ideological concepts that are in focus. When the artefact begins to take shape, the thought process transgresses from diffuse concepts to more compact ones.’ This way, concepts are used appropriate to the design stage. Complexity and subjective matters (such as aesthetics, culture, artefacts) which ought to be negotiated during the design process, are kept open as long as possible. The further compact concepts are used or developed, the more the design is ready.

**Preliminary proposition for aimed tool**

Taking into account the outcomes of explorative study, a process of reasoning, synthesizing and a continued evaluative leap (trial & error) to supposed criteria, results in a preliminary proposition. A knowledge structure is believed to be suitable for aimed generic methodological framework. This design supporting structure can be implemented in a cyclical or linear process of design, for random referencing, backgrounding, inspiration, ideation, and/or for selecting final solutions in whole or in part. The actual deployment of the structure depends on the preferences and level of expertise of the user.

A full description of the proposed knowledge structure is not possible within the limited length of this paper. A detailed and illustrated discussion will be the focus of the oral presentation.

The general outline of the framework approaches a gradation from theory to practice, and from problem to solution. The framework consists of implicit and explicit elements, preceded by a backgrounding and followed by a synthesizing part. Implicit elements are incorporated in the structure and content, while explicit elements are recognizable and distinctive parts as such. Implicit elements are: best real-life practice backed, cross structure referencing, suitable representation techniques, database of knowledge, building of episodic knowledge, transcending the specific, no value judgement, non-exhaustive display, combinability’s, satisfying and optimizing. Explicit elements are given in figure 1.

![Figure 1: Explicit elements of preliminary proposed generic methodological framework.](image)

**FINALIZING REMARKS**

Developing a tool, within the sustainability quest for the built environment specifically tailored for architect-designers, is an innovative but complex task. Tentative building and display of proposed framework in this paper must be seen as an incentive for discussion and further research. Experts in this field and related aspects are well placed for verification, adjusting and a further development.

The perspectives at short term are twofold. First, this research will be supplemented with a verification. Preliminary outcomes are to be presented to a selection of practicing architect-designers after which they will be asked to provide feedback. Second, in order to test the feasibility of aimed
content of the tool, a specific substantive body of knowledge will be investigated and integrated in the framework. Both perspectives enable an evaluative loop of verification and adjustments, leading to improvements. During this process it is important to constantly safeguard developed and adjusted criteria, and to prevent relapsing in issues of current sustainability tools.

The preliminary result of this exploratory study is a confirmation of the hypothesis that prevailing up front kinds of sustainability tools are inadequate for architect-designers. Suggested generic methodological framework is seen as a possibility for the development of an operational sustainability tool specifically tailored for architect-designers.

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Ventilation Cooling Effects of the Rammed Earth Wall Built in the Hotel Guest Room

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ABSTRACT

In Nov. 2013, a hotel was completed beside the Biwa-lake in Moriyama city, Shiga Prefecture, Japan. This is a three storeyed building with 14 guest rooms. The main structure is reinforced concrete but the rammed earth walls were built as the partitions between guest rooms. The rammed earth, which was made from local and natural soil, was expected to work as a thermal mass for passive cooling in the summer time. Each hotel guest rooms faces to the west and has a good view of the lake. In this area, the prevailing wind in the summer time was west-east, and the ventilation cooling, utilizing this wind was planned. The design of this building was studied based on the results of simulation studies and it was expected to reduce 75% of cooling load. This paper discussed: 1) the design process of this building, 2) the results of simulation studies, 3) the performance of the ventilation cooling effects.

1. INTRODUCTION AND BACKGROUND

Building low environmental impact architecture, throughout the life cycle, is a form of construction required for the coming years. When you build a building, making buildings that used local natural resources of the land, as much as possible, is the new imperative. Production of soil wall is known for its lesser environmental load or energy consumption than reinforced concrete. Rammed-earth, which is made by pressing soil inside frames, has a beautiful layered texture and humidity conditioning, and large thermal capacity. Then, we can use this wall, indoors, as a thermal mass to reduce heating and cooling load. In the former investigation we made experimental building with rammed earth in Kobe, then simulated and measured the thermal performance of the building. We presented how to use the rammed earth as thermal mass in the area.

In Nov. 2013, a hotel was completed beside the Biwa-lake in Moriyama city, Shiga Prefecture, Japan by Architects Ryuichi Ashizawa Architect & Associates, and Soil-wall consultants, Kumiko Hatanaka design office, as shown in Figure 1(a). This hotel has 3 rammed earth partition walls, as shown in Figure 1(b). The authors investigated with the former method how many cooling load this rammed earth reduced. Furthermore, for more effectiveness, the effect of passive cooling by outside air intake was subjected to ventilation simulation in order to determine the opening position.
2. DESCRIPTION OF THE ARCHITECTURE

The hotel has three stories with fourteen guest rooms, one restaurant and one banquet room. The hotel has a wide view to the lake in the west. The Music hall that is used mainly for wedding ceremony is on the north to the hotel. The walls of the guest rooms are built with reinforced concrete except one. The floors are made by raised wood. Rammed earth walls are used as partition for rooms. The room has a rammed earth wall in the north or south. The windows are designed to ventilate from the west, the lakeside to the east, as shown in Figure 2(a) & 2(b).

Figure 2  a) Music hall and 3rd floor plan and target room 4 for simulation, and b) Part plan of hotel room, Room 4
3. SIMULATION FOR THERMAL PERFORMANCE IN SUMMER (GUEST ROOM)

3-1. Simulation Model and Method

Although the forms of 14 guest rooms are varied, we computed the cooling load of “Room 4”, as shown in Figure 2(b), in the summer as a typical room. The room is twenty two square meters wide. The plan and elevation is distorted. The room is four metre wide on the west side. Although there is a bathroom and a closet in the east, for the simulation we assumed it simple form regardless of the parts. Figure 3(a) & 3(b) shows common details of the shape and specifications of room to simulate. We show the result of simulation on next page. On these information shown below, we varied materials of thermal mass.

The room was considered to be 4m wide, 4m deep, and 2.5m high. The opening of terrace side is made with double glazing in wooden frame. The wall thickness of guest room is 250mm, so we simulated considering that there are no heating affect by the next room which shares the wall as well as upper or lower rooms. Therefore, other than the west face, a glass wool of 500 mm thick on the outside of the Thermal mass was considered. We set 2.3m depth eave which is positioned over the terrace and 1.8m length on the sidewall of the terrace. As internal heat, we set 210J/h from refrigerator constantly, and 882J/h from two hotel guests who stay between 17p.m. and 8a.m. in the guestroom. We assumed that during the night time, between 18p.m. and 7a.m. a curtain would be closed as a night insulated door and when the outdoor temperature is between 18- 26 ºC, the outdoor air inlet would be open. In this case, simulation model is Room 4, which is call “Real model”. There is a rammed earth wall at north side wall. The floor was covered with a wooden floorboard. The west side have big window. The walls of guest rooms are built with reinforced concrete except one, as shown in Figure 3(a) & 3(b). The thermal mass material is changed, and what kind of cooling load, was calculated according to the flow diagram, as shown in Figure 4(a). Material constituting the respective models, are as shown in Figure 4(b). Material properties are, as shown in Figure 4(c). We simulated the thermal performance with the design tool “Solar Designer ver.6” developed by the authors.

<table>
<thead>
<tr>
<th>form</th>
<th>width: 5 × depth: 7 × height: 3.8(m) raised floor</th>
</tr>
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<tbody>
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<td>eaves</td>
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<tr>
<td>wing wall south side</td>
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<td>east window position</td>
<td>from floor: 0.8 (m)</td>
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<tr>
<td>east window position</td>
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<td>west window size</td>
<td>width: 4.7 × height: 3.05 (m)</td>
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<tr>
<td>west window position</td>
<td>from floor: 0.8 (m)</td>
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<td>west window position</td>
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<tr>
<td>insulation thickness ceiling</td>
<td>0.5 (m)</td>
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<td>insulation volumetric specific heat</td>
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<tr>
<td>outdoor solar absorptance floor, wall, ceiling</td>
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Figure 3 a) Specifications of simulation model of “Real Model”, b) Data used for simulation
a) Simulation flow

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<th>Model name</th>
<th>sub name</th>
<th>South wall</th>
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<th>Floor</th>
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<tbody>
<tr>
<td>A</td>
<td>Wooden</td>
<td>W</td>
<td>W</td>
<td>G</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>B-1</td>
<td>1 rammed earth</td>
<td>W</td>
<td>W</td>
<td>RE</td>
<td>G</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>B-2-1</td>
<td>3 rammed earth/dense</td>
<td>RE</td>
<td>RE</td>
<td>RE</td>
<td>G</td>
<td>W</td>
<td>W</td>
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<tr>
<td>B-2-2</td>
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<td>RE</td>
<td>RE</td>
<td>RE</td>
<td>G</td>
<td>W</td>
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</tr>
<tr>
<td>B-2-3</td>
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<td>RE</td>
<td>RE</td>
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<td>RE</td>
</tr>
<tr>
<td>B-3</td>
<td>5 rammed earth</td>
<td>RE</td>
<td>RE</td>
<td>RE</td>
<td>G</td>
<td>RE</td>
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<td>RC</td>
<td>W</td>
</tr>
<tr>
<td>C-3</td>
<td>5RC</td>
<td>RC</td>
<td>RC</td>
<td>RC</td>
<td>G</td>
<td>RC</td>
<td>RC</td>
</tr>
</tbody>
</table>

W: Wooden, RE: Rammed earth, RC: Reinforced concrete

b) Materials of each models, c) Thermal mass material properties

Figure 4  a) Simulation flow, b) Materials of each models, c) Thermal mass material properties

3-2. Thermal performance in summer

Figure 5  a) Annual cooling load for A & Real model, and b) Annual cooling load for A & B types

Figure 5(a) shows the comparison of the cooling load for “model A”, made in wood (plywood), as shown in Figure 4(a), 4(b), 4(c), with the “Real model”, as shown in Figure 2(b). Rammed earth thermal mass walls are expected to work well for the cooling load. B-1 has a rammed earth wall in the
north side, and the rest of the walls of the guest room is built with wood, as shown in Figure 4(a), 4(b) & 4(c). B-2 has 3 rammed earth walls. B-3 has 5 rammed earthwalls, as shown in Figure 4(a), 4(b) & 4(c). The analysis shows that the cooling load decreases with increase in rammed earth walls, as shown in Figure 5(b). Figure 6(a) shows thermal mass works well for the cooling load. C-1 has one reinforced concrete wall in north side and the other walls are built with wood, C-2 has 3 RC walls, C-3 has 5 RC walls, as shown in Figure 4(a), 4(b) & 4(c). In this case also, the cooling load decreases as the amount of RC walls increase, as shown in Figure 6(a). Figure 6(a) shows comparison of cooling load for “Real model”, which has wooden floor and one rammed earth wall. So, it has less thermal mass and a little bigger cooling load than C-3. But “Real Model” has less cooling load than C-2.

![Cooling Load Comparison](image1)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W/mK)</th>
<th>Specific heat capacity (kJ/m3K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-2-1 Dense rammed earth</td>
<td>0.70</td>
<td>1381</td>
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<tr>
<td>(B-2)B-2-2 Middle dense Rammed earth</td>
<td>0.58</td>
<td>1130</td>
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<tr>
<td>B-2-3 Rough rammed earth</td>
<td>0.47</td>
<td>837</td>
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</table>

a) Model C-types & Real model b) Model B-types comparison and material properties

Figure 6  a) Annual cooling load for C types & Real model, b) Annual cooling load for B types and Thermal conductivity and specific heat capacity of rammed earth with various density.

![Cooling Load Comparison](image2)

![Cooling Load Comparison](image3)

Figure 7  Annual cooling load / Ventilation mode and no ventilation mode
Rammed earth has various conditions determined by what the type of soil used, and how hard the earth was rammed. So, we considered three different thermal conductivity and volumetric specific heat of rammed earth: Rammed earth 1 is high density; Rammed earth 2 is mid density; Rammed earth 3 is rough, low density. Figure 6(b) shows that as the density of the rammed earth increases, the cooling load is lower. The cooling load comparison of the cases shows that in the dense version built, the cooling load is reduced. In case of the “Real model” the cooling load decrease, if we compare to C-1 & C-2 modes. When only active cooling is used windows are closed and air change rate of 0.5 times per hour is considered, and when the outdoor temperature range is 18–26ºC, 15 ACH, natural ventilation is used. The simulation results of 3 ways using ventilation mode and non-ventilation mode, and cooling load is reduced by 75% in ventilation mode, as shown in Figure 7.

3-3. Conclusion

This examination shows ventilation is effective to be used in the guest room to reduce the cooling load. And Rammed earth is an effective material to reduce cooling load and embodied energy. Then, rammed earth is the next generation’s material. And, the simulation is an effective tool for verification of the same.

4. DESIGN OF THE WINDOW (GUEST ROOM)

4-1 Simulation Model and Method

The thermal environment simulation, showed cooling load reduction and the ventilation cooling effects obtained by taking advantage of the heat storage of the rammed-earth wall. Night ventilation takes in the cold air of the night, and stores it until the next day. For this purpose, it is necessary to ventilate an appropriate amount while considering appropriate security and privacy. In this section, we describe the design of the opening to ensure a desired flow distribution and airflow, and introduce the simulation results of the flow.

Western windward side is a picture window to capture the views of Lake Biwa. In order to retain the view, a window for ventilation was provided for at the position of the feet. The louver door installed at the east entrance leeward location was designed to allow wind flow, and through the common corridor, as shown in Figure 8(a) & 8(b). Under these conditions, we investigated the air volume flow and felt the wind present at the guest locations. We simulated the wind flow with “STREAM”.

4-2 Study of the wind flow

Study of the relative positions of the inlet and the outlet are, as shown in Figure 8(a) & 8(b). In Model 1, a window is arranged at a position frontally facing the entrance, and in Model 2, the window is arranged in a position diagonal to the entrance, as shown in Figure 8(a) & 8(b). In view of the locations of residents and placement of furniture, we decided to model-1 wind flow in a region where there is a bench in front of the bed, as shown in Figure 8(a) & 8(b).
4-3 Study of the amount of air

In order to easily adjust the air flow, the position and size of the opening of the common corridor was changed, as shown in Figure 9. Model 3, as shown in Figure 9, is a view after the change. Originally, a window was placed near the ceiling of the front of the entrance door that had been placed randomly, and took larger opening area. As a result of the reconfigured scheme, the wind went from the foot opening, and goes out of the high window, and air volume is increased than Model 1.

4-4 Conclusion

In order to enable the guest to adjust and incorporate their own style, the authors consider how to open the window and placement of the opening, and were able to ensure proper ventilation and air-flow path.
5. CONCLUSION

The building design, based on the above studies, was completed and is currently in operation. The authors consider making comparison between the actual measured value and actual simulations, responsive user praxis of opening the window to introduce outside air, and the feel and experience of hotel guests through questionnaire, and the mechanisms of outside air intake. Furthermore, our objective is to advise the hotel management on the low energy practices.

6. REFERENCES

SOLAR DESIGNER. http://qcq.co.jp/
CFD tool STREAM. http://www.cradle-cfd.com
Posters in absentia

PLEA2014
Impact of Vegetation in Urban Open Spaces in Dhaka City; In Terms of Air Temperature

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ABSTRACT

Dhaka is a highly vibrant megacity with almost 15 million populations (World Bank, 2013). Due to high density in an undisciplined urban setup, the city is in real scarcity of open and green spaces for her large number of dwellers. The rapid growing population in conjunction with very immediate developing urbanization has led to unplanned and uncontrolled expansion of Dhaka which is resulted in the gradual loss of open and green spaces in the city. In the quest of meeting the great demand of urbanization, the city has hardly saved some of her natural spaces. Unfortunately these very few existing open spaces are not even well preserved with natural greeneries or vegetation; as a result this lack of green and plantation severely affects the microclimate of those spaces. Whereas the use of vegetation and plantation as an element of urban landscape, has always great environmental benefits and opportunities both in the scale of micro and global climate; like temperature control, solar radiation control, wind control, reduction of air pollution by absorption the pollutant and noise reduction etc. Urban vegetation minimizes direct solar radiation of the surface, optimizes wind velocity and its form and configuration influence temperature, air humidity and wind pattern of an urban setting. Vegetation create green barrier as visual boundary, natural screen and space buffer as a major element of landscape design.

The objective of this paper is to discuss the impact of vegetation in urban air temperature and explore the possibility of vegetation configuration to maximize the cooling effect in urban open space in Dhaka city. For researching these issues, a short field survey has done in two significant urban squares to find out the answer of the proposed research query. An evidence based microclimatic simulation software ENVI-met is also used to compare the outcome data of the field survey.

INTRODUCTION

Preface

The rapid growing population in conjunction with very immediate developing urbanization has led to unplanned and uncontrolled expansion of Dhaka which is resulted in the gradual loss of open and green spaces in the city. In the quest of meeting the great demand of urbanization, the city has been developing her infrastructure as well as built environment by continuous ignorance of nature which has hardly saved some of her natural spaces. Comparing with rural surroundings, this built environment of Dhaka city is mostly uncomfortable to her dwellers’ experience. Expansion of unplanned urbanization and built structure results cutting a large number of trees and converts the green areas in concrete surfaces. A minimum 25% of forest cover is suggested for a healthy living (Mowla, 1984) where at present in old Dhaka (old part of the city) only 5% and new Dhaka (new part of the city) 12% of land is
green and open (Mowla, 2011). Green spaces with vegetation have great environmental benefits and opportunities. Vegetation has potential to reduce environmental temperature. Its form and configuration influence solar radiation, temperature, air humidity and wind flow of an urban setting. This paper states the impact of vegetation in urban air temperature and explores the possibility of vegetation configuration to maximize the cooling effect in urban open space in Dhaka city.

**Statement of Problem**

Use of excessive exposed hard surfaces like brick and concrete pavements and plaza, pitched road, buildings, air-conditioning system etc are responsible for raising urban air temperature. The urban spaces of a city are considered more vibrant when it can allow more people for outdoor activities. So it is important to create attractive and welcoming open spaces for the public, where outdoor comfort can be an important criterion. Again, air temperature is a vital aspect for this outdoor comfort. It is found that when meteorological data of average air temperature for Dhaka is 28 C (23 Feb, 2012) then the average air temperature of the paved area of Shahid Minar is 32 C (Field Study). Vegetation is an important element of nature. Being an organic element, vegetation has some impact on local microclimate as well as global climate. That is why this study is focused on the impact of vegetation in urban open spaces in Dhaka, in terms of air temperature.

**Objective**

The objective of this study is:
- To determine the impact of vegetation in open spaces in Dhaka city in terms of Air temperature.
- To find out the possibility of vegetation configuration to maximize the cooling effect in urban open space in Dhaka city.

**Methodology**

The methodology of this study can be described in three steps and these are:

**Step 1:** Literature Review and Theoretical Basis: Study the relationship between vegetation and basic four environmental components and the impact of vegetation on the open spaces from different paper, journal, books, articles etc.

**Step 2:** Field Study: A short field survey (in two urban open spaces) has been done in the current situation of Dhaka. This part is very important for this research because this research is based on field study and the output provides the current microclimatic data of the study area. Two urban spaces of similar context are taken for this study. The “Shahid Minar Chatatar” (approximate area 120000 sft), located in the Dhaka University area and the “Pantha Kunja” square (approximate area 260000 sft), located beside the city commercial zone, Karwan Bazar node, Dhaka. Both spaces are laid in north-south direction and consist of both paved and green area. This step will find out the answer of the query, whether is there any variation of air temperature happened for presence of green vegetation and urban pave?

For data collection, 6 Points (spot) have been taken (in almost equal distance) on an imaginary line along the centre (north-south direction) for the both cases for measure the air Temperature, Humidity and Air Velocity. Here for Shahid Minar Chatatar, lump sum 500 ft distance has being taken, where after every 100 ft one data point has located in the case study 1 (**Figure 6a**) and for Pantha Kunja, lump sum 1000 ft distance is being taken, where after every 200 ft in park area and every 100 ft in paved area, one data point has located in the case study 2 (**Figure 7a**). All data (18 set) have been taken on that imaginary line above 1m ground level with the Kestrel 3000 Pocket Weather Meter. The data was being taken on February, 2012 on morning 10.00 am, noon 1.00 pm and evening 4.00 pm.

**Step 3:** Simulation: Microclimatic simulation has been done by ENVI-met software to compare with the survey results. The full areas (draw in **Figure 6a & 7a**) of the two urban spaces are considered for ENVI-met modeling. Input data are found from field survey and weather data of Dhaka.
Limitations

A number of limitations have observed in this study, like time, resource and some practical problems. The survey for this study is held in the month of February where June to September are the hottest (considering highest temperature database) months for Bangladesh. During the survey it was very difficult to locate accurate point for measurement. Sometimes it was difficult for the users and different activities on the spots.

LITERATURE REVIEW

For this paper, urban space means that the space which is designed or created and used for different public activities in Dhaka and vegetation means the plants of an area or a region. Vegetations can be classified in different categories. In broader classification: Herb, Shrub and Tree. Herbs are seed-bearing plant whose aerial parts do not persist above ground at the end of the growing season whereas Shrub is a woody perennial plant, smaller than a tree. Trees are any large woody perennial plant with a distinct trunk giving rise to branches or leaves at some distance from the ground. Again In terms of density, according to John P. Caouette and Eugene J. DeGayner, there are two types, Low (SDI < 280) and High (SDI > 280) (Caouette and DeGayner, 2008). Stand density index (also known as Reineke's Stand Density Index after its founder) is a measure of the stocking of a stand of trees based on the number of trees per unit area and diameter at breast height of the tree of average basal area.

Now the relationship of vegetation and four major components of the climatic features of environment, Solar Radiation, Air Temperature, Humidity and Air Flow discusses below.

There is close relationship between vegetation and solar radiation. According to Wardoyo (2011), individual leaves of the vegetation allow, some radiation to be transmitted through them (20%), absorb some radiation (55%), and reflect some radiation (25%). The leaf absorbs the solar radiation and re-transmitted it by evapotranspiration which increases relative humidity and reduces air temperature (Wardoyo, 2011). Large trees with spreading canopy can also provide shade and protect surface from direct radiation. Bueno-Bartholomei and Labaki found that, the structure of the crown, dimension, shape and colour of vegetation leaves influence reduction level of solar radiation (Bueno-Bartholomei and Labaki, 2005).

Vegetation in open space has low reflectance value that helps to reduce the air temperature in an urban surrounding. Vegetation does not radiate the long wave radiation which helps to maintain lower air temperature. Evapotranspiration reduces air temperature and increases relative humidity (Wardoyo, 2011). Tree shade also helps to reduce the air temperature. Zahoor (1997) in Pakistan found that vegetation has significant influenced to local temperature and effective in reducing air temperature about 6 – 7 °C.

Again, according to Wardoyo (2011), vegetations also influenced the pattern of air movement through guidance, filtration, obstruction and deflection. Air movement sometimes depends on vegetation characteristic and configuration. Scudo (2002) establish that geometry, height, permeability and crown of the vegetation are the structural vegetal characteristic that influenced the controlling air movement.

Evapotranspiration reduces air temperature that increases relative humidity. It is found that relative humidity is always higher in the green areas.

Again the environmental criteria in Dhaka City are also important for this study. Bangladesh is in Warm Humid Tropics. Generally she has six seasons according to natural, cultural and social activities. But climatically, the climate of Bangladesh can be divided into four seasons. According to Hossain and Nooruddin meteorologically the climate of Bangladesh is categorized into four distinct seasons Winter (cool dry), Pre-Monsoon (hot dry), Monsoon (hot and wet), Post-Monsoon (hot and wet), where Winter months (December to February) temperature 21-26 C, Pre-Monsoon (March to May) temperature max 34 C, Monsoon (June to September) avg. 31 C, Post-Monsoon (October to November) temperature bellow 30 C (Ahmed, 1996). Average Relative Humidity is 60-80%. Radiation on a horizontal surface 5.00 kWh/ m2 and Air Flow 4.1 m/s (Ahmed, 1996).
The simulation tool, ENVI-met is a three dimensional microclimate model designed to simulate the surface, plant, air interactions in urban environment with a typical resolution of 0.5 to 10 m in space and 10 sec in time. Typical areas of application are Urban Climatology, Architecture, Building Design or Environmental Planning, just to name a few. ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. (ENVI-met web)

**TYPES OF VEGETATION AND CLIMATE COMPONENTS**

Table 1. Impact of Vegetation and Climate Components

<table>
<thead>
<tr>
<th>Classify plants</th>
<th>Solar Radiation, Air Temperature, Air Flow and Relative Humidity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrub</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (SDI &lt; 280)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High (SDI &gt; 280)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**In General**

**Herb**

- Direct solar radiation and Air temperature is higher than other cases in open spaces.
- Uninterrupted wind flow.
- Relative humidity depends on density of green.
- Reduces dust and no visual barrier.

**Figure 1: Impact of Herbs**

**Shrub**

- Sometimes small shaded area or sometimes direct solar radiation in open spaces.
- Shrubs hinder the natural wind flow in human level, but a large or smaller shrub allows air flow in human level.
- Relative humidity is high in human level.
- Sometimes filters air and create barrier.
- Flowering shrubs are good in terms of aesthetics.

**Figure 2: Impact of Shrubs**

**Tree**

- Create shaded spaces.
- Allows gentle wind movements in human level, and filters or guiding the movements in.
- Sometimes ground cover do not grow in the soil because of large shading tree and lack of solar radiation.
- Air temperature is less in the shading area.
- Relative humidity is high under the tree.

**Figure 3: Impact of Trees**

**Low (SDI < 280)**

- Allows direct solar radiation.
- Allows gentle wind flow.
- Air temperature is less than a paved area.
- Relative humidity is moderate.
- Allows ground cover in the soil.

**Figure 4: Impact of Low Density Green**

**High (SDI > 280)**

- Do not allow direct solar radiation.
- Hinder wind velocity sometimes allows tunnel effect.
- Air temperature is less than other situation.
- Relative humidity is high.
- Sometimes do not allow good grass on ground and Create dark shade.

**Figure 5: Impact of High Density Green**
FIELD STUDY

Case Study 1: Shahid Minar Chattar

“Shahid Minar Chattar” is a historically and culturally significant place for Dhaka city. This monument carries the memories of our language movements on 1952. This public space is a large hard paved area with small green and large trees. Green area is surrounded the main monument area. A number of paved stairs leading to the upper platform of the monument is an important public plaza for socio-cultural activities. There is no large structure along the monument. This area is completely exposed to the sun. 6 points are being taken for data collection, which are as follows. (Figure 6)

Point 01: Located in a Green space (soil) with tree shade behind the main monument.
Point 02: Located in Red Brick pave with no shade and no green. Higher than ground level.
Point 03: Located in Large Red Brick pave with no shade and no green.
Point 04: Located in a Green space (soil) with tree shade. There is pave around this area.
Point 05: Located in a Green space (soil) with tree shade. But beside the road pave.
Point 06: Located in the road pave.

Case Study 2: Pantha Kunja Square

Panthan Kunja is the only open space cum green space in Karwan Bazar area, one of the important commercial hubs of Dhaka city. It has two parts: one is Green Park with large trees and limited pave area and another consists of large pave with small green area (herbs and shrubs). This area is also completely exposed to the sun. 6 points are being taken for data collection, which are as follows. (Figure 7)

Point 01: Located in a Green space (grass) with tree shade with little pave.
Point 02: Located in a Green space (grass).
Point 03: Located in a Green space (grass) with tree shade.
Point 04: Located in Large Yellow and Red Brick pave with no shade.
Point 05: Located in Large Yellow and Red Brick pave with no shade beside small green.
Point 06: Located in the footpath pave beside the road.

Figure 6 (a) Top view and section of Shahid Minar (b) Point 01 (c) Point 02 (d) Point 03 (e) Point 04 (f) Point 05 (g) Point 06

Figure 7 (a) Top view and section of Pantha Kunja (b) Point 01 (c) Point 02 (d) Point 03 (e) Point 04 (f) Point 05 (g) Point 06
Results and Findings from Field Survey and Software Simulation

Figure 7  (a) Top view and section of Pantha Kunja Square (b) Point 01 (c) Point 02 (d) Point 03 (e) Point 04 (f) Point 05 (g) Point 06

ENVI-met Simulation

Figure 8  (a) Average Air Temperature Diagram (b) Average Relative Humidity Diagram
Here are the charts of average value of Air Temperature and Relative Humidity which are being found from field data (Figure 8). For ensuring human comfort in any urban context, relative humidity is equivalently relevant and important with temperature. That is why, in field survey, Relative humidity has always taken in consideration for analytical observation.

**VEGETATION AND OPEN SPACE CONFIGURATION**

It is found from Case study 01 and Case study 02 that air temperature in a green space is remarkably less than a paved or built space in Dhaka city. In Case Study 01, Average Air Temperature in green area varies from 30.5 C to 31.8 C where in paved area varies from 32.1 C to 33.1 C. In Case Study 02, Average Air Temperature in green area varies from 30.9 C to 31.3 C where in paved area varies from 31.5 C to 32.4 C. Here some other issues can be considered as follows.

**Orientation:** An imaginary line is taken through Case Study 01 considering north south direction. In our country, the wind flows from south east direction in summer. So point 01 is 30.1 C which is less than point 04 and point 05 (31.8 C and 31.9 C) for the wind flow through the plaza area from south. Again an imaginary line is taken through Case Study 02 in same north south direction. In this case, the large green is in the south part of the square which create cool environment in pave area on north.

**Shade:** The shaded area of green space is much cooler than the exposed area. Shade can provide by large trees or other minimal built objects. In Shahid Minar point 01 is always shaded by large dense trees. So the air temperature in point 01 is always cooler than other green spaces. In Pantha Kunja point 02 is exposed to the sun. As a result, air temperature in point 02 is higher than point 01 and 03.

**Types of vegetation:** It is also an important issue. In Shahid Minar, there are small numbers of trees founded in selected green area. There are a few grasses found during this survey. There is no herb, shrubs and trees in the paved area. In Pantha Kunja, there are herbs, shrubs and trees founded in the park area with grasses on ground which helps to reduce the air temperature as per survey data. In the pave area there is also small green area founded with herbs which might helps to reduce the air temperature.

**Vegetation Density:** Vegetation density also effects the cooling. More dense vegetations increase Evapotranspiration, which reduces the air temperature. Pantha Kunja green area is denser than the Shahid Minar green area and it is also a cause of less average temperature in Pantha Kunja.

**Area of the Vegetation:** In Shahid Minar almost 80,000 sq ft green area and 40,000 sq ft in pave area where as in Pantha Kunja 240,000 sq ft green area and 20,000 sq ft pave area. Average temperature in Pantha Kunja is less than the Shahid Minar area (survey). Larger area of vegetation contributes in better cooling effect.

**Surrounding Vegetation and Presence of Built Objects:** Surrounding area has also an impact in the air temperature. Here surrounding area is not considered enough. For Shahid Minar, if a 500 ft diameter circle is considered, more green area with few built area are found which has a cooling impact on local air temperature. In Pantha Kunja, if a 1000 ft diameter circle is considered, more exposed pave and glaze area with more built structure are found.

**Vegetation and Relative Humidity:** Relative Humidity is much related component to air temperature. As per graph (Figure 8(a) & 8(b)) air temperature and humidity varies in vice versa. Temperature rise is responsible for reducing the relative humidity. In this study the relative humidity data has also taken for observation.
OBSERVATION

Vegetation has tremendous impact on local microclimate. From the observation of this study some points can be illustrated as follows:

- Presence of vegetation minimizes direct solar radiation and reduces microclimatic air temperature (3C - 4C) in an urban space.
- As wind flows from south east in Bangladesh (generally), vegetation locating in south can help to reduce the air temperature on the pave locating in the north.
- Large and dense trees create shade. Air temperature is less in the shaded space than an exposed area (1C – 2C). Even air temperature in the shaded pave is less than the pave exposed to the sun.
- Air temperature also depends on types of vegetation used in a space. Types and configuration of herbs, shrubs and trees are important for local air temperature.
- Density (trees) is also an important component for reducing air temperature. Dense vegetation helps to reduce air temperature by screening solar radiation.
- Area of vegetation affects the local air temperature. Large area of vegetation can keep lower the air temperature where as presence of hard exposed material or structure in the green area is responsible for increasing the air temperature.

CONCLUSION

The urban open spaces are very vital part of a city and considered more successful when these spaces can allow more people for different outdoor activities. So it is always very essential to design comfortable urban spaces for city dwellers. Dhaka is a city of hot and humid climate with high average temperature. Direct solar radiation and scorching heat of sun not allow city people to have maximum use of city open spaces specially in day time. Vegetation has great potential to reduce this air temperature (3C - 4C) of urban microclimate and ensure sustainable breathing space. Again vegetation creates shaded cool area with lower air temperature for the users. Designing an urban space with large area of vegetation on south side may create comfortable environment. Vegetation configuration can be one of major determining factors to get benefit of urban open spaces in Dhaka city with the best utilization of it, in her every aspect of urban landscape design.

ACKNOWLEDGEMENT

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Caouette J. P. and DeGayner E. J. (2008), Broad-Scale Classification and Mapping of Tree,Size and Density Attributes in Productive,Old-Growth Forests in Southeast Alaska's Tongass National Forest, Society of American Foresters
Exploring the Current Practices of Post Consumer PET Bottles and the Innovative Applications as a Sustainable Building Material – A Way Ahead

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ABSTRACT

PET stands for polyethylene terephthalate and PET bottles are occupying an indispensable position in common man’s life. Food processing industries across the world are using PET bottles as effective containers for storing juice, beer, carbonated and non carbonated drinks. The different parameters which determine the form of PET bottles during designing, manufacturing and production phases are cost per unit, need, volume, color, intrinsic velocity, size, shape etc. Irrespective of a wide range of applications, initiatives in recycling post consumer PET is sporadic. The disposal of PET bottles in the environment, significantly contributes to ecological imbalance. Interpreting the negative impacts and adopting the principles of Reuse B and C by Romans, pioneers are searching for rational and technical solutions to check this issue. In construction industry, hybrid actors are using PET bottles as moulds for developing alternative blocks. Technocrats are recycling PET products physically into fibers, pellets and flakes for partial replacement of fine and coarse aggregates in conventional building materials. This paper intends to consolidate such initiatives addressing building systems, materials and artifacts. It discusses an overview of such applications and other intuitive trends which are emerging in Indian context.

INTRODUCTION

The technology of storing liquid products for transportation, distribution and use is defined as packaging. Our ancestors used baskets and storage units made of natural fibers and indigenous materials like stone, earth etc. Use of paper and metal plated containers for such applications dates back to the 10th century (Packing, 2012). Glass bottles, plastic containers and polyethylene are used predominantly in today’s context. Polyethylene terephthalate, a versatile material is playing a primary role in packaging industry in today’s context, simultaneously increasing the production process. The drawbacks during the disposal phase is raising a question, whether the invention is a boon or a bane, revolving around the societal benefits (Andrady & Neal, 2009) and the negative impacts in the environment (Webb, Arnott, Crawford, and Ivanova, 2012).

HISTORY

According to the archaeologists, a novel concept, “Post consumer packing material as a resource, specifically in construction”, is traced from the Hellenistic age. Interpreting the problems posed by disposal of „amphorae“, Romans came up with an innovative idea to reuse them in architecture (Will,
1977). While doing so, the pointed base pots were either modified or unmodified. Romans classified reuse as A, B and C (Pena, 2007). When the amphorae were used as a storing unit, it was reuse A. Reuse B and C, denoting the applications in other fields without modification and with modification respectively. The beginning of 19th century witnessed similar application of glass and PET bottles in construction.

AN INSIGHT TO PET

Plastic is a commonly preferred packing material for various goods in today’s fast moving contemporary world. They are classified in to seven categories based on recyclability (Society of plastics, 2013) and polyethylene terephthalate denoted as PET, PETE or PETP ranking number one. The credit of inventing PET goes to chemists Whitefield and Dickson, the employees of Calico Printer’s Association in 1941 and was patented only in 1973 by Wyeth. Semi crystalline thermoplastic polyester, durable, low gas permeability, chemically and thermally stable, easily processed and handled, transparent, wear and tear resistant and non biodegradable are the general characteristics of PET. Based on its versatility, it is primarily used in textiles, films, utility ware, sportswear etc. Food processing industries prefer PET as it is hygienic, strong, lightweight (Petresin, 2013) and devoid of phthalates, dioxins, bisphenol A, cadmium, lead and other endocrine disruptors (NAPCOR, 2013). As PET is used predominantly in the form of bottles for storing carbonated and non carbonated drinks, this paper addresses to reuse the PET bottles in construction industry.

PET BOTTLE

Cap, neck, shoulder, body, hip and feet are the basic parts of a PET bottle (bottle biology, 2013). Containers for storing carbonated and non carbonated drinks have different intrinsic velocity, wall thickness, color and level of copolymer. With respect to the physical form, PET bottles used for storing carbonated drinks are designed with an additional twist in the neck, thicker wall, higher intrinsic value, lower copolymer level and a petaloid base (Bristogianni, 2012).

POST CONSUMER PET – REUSING VS RECYCLING

According to the Environmental Protection Agency, recycling, incineration and landfill are the general ways of disposing plastics are disposed in today’s context. Each method has its own disadvantages and drawbacks (Webb et.al, 2013). Its disposal is disturbing the ecological balance, directly or indirectly affecting the health of all living creatures (Rustagi, Pradhan & Singh, 2011).

![Figure 1: Reusing and recycling of PET at a macro level](image)

Recycling is classified as primary – re extrusion of pre consumer scrap; secondary or physical or mechanical treatment; tertiary or chemical treatment where the chemical structure is altered and quaternary treatment, focusing on energy recovery. Reusing is the most preferred option as the consumption of energy and resources are always less (Al-Salem & Baeyens, 2009) as in Figure 1.
Reusing PET bottles for packing continuously is not preferable; however the idea of reusing them in a different field requires innovation. PET bottle bricks as an alternative building material, a less energy intensified process, is successful in construction process. A rational and a pragmatic perception is the requirement in today’s context to address multifaceted issues simultaneously.

POST CONSUMER PET AND THE AVANT-GARDE PERCEPTIONS

Innovators and researchers are adopting different strategies to reuse and recycle PET bottles. Up cycling and down cycling are the processes involved in the manufacturing of new products with the treated PET bottles. While applying such concepts, the consumption of energy and the negative impacts generated during the production phase need to be kept to the minimum. Investigations on effective reusing or recycling of such used bottles in the construction sector, marks the beginning of the next industrial revolution. A holistic, pragmatic approach rich in aesthetic values (Pramar, 1973), as the focal point, the vision of the architects and environmentalists, technocrats, product designers and artists are interpreted in Table 1.

<table>
<thead>
<tr>
<th>Post consumer PET bottles</th>
<th>Hybrid actors - Holistic</th>
<th>Technocrats-Rational approach</th>
<th>Product designers-Innovations</th>
<th>Artists-Aesthetic expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmodified / Reuse B</td>
<td>Partly objective, and subjective, Aesthetic values</td>
<td>Objective, Economical, Utilitarian</td>
<td>Subjective, Partly functional and Emotional</td>
<td>Subjective, Aesthetic, Emotional</td>
</tr>
<tr>
<td>Modified / Reuse C</td>
<td>Ecocentric</td>
<td>Problem solving</td>
<td>Transforming the overlooked</td>
<td>Promoting Awareness</td>
</tr>
<tr>
<td>(secondary and tertiary)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Unique perceptions**

Examples

- Bottle bricks with different fillers, PET bottle as a filler
- Partial replacement in building materials
- Screens, lamp shades, planter boxes, chandeliers, furniture etc
- Murals, sculpture

EXPLORING THE ‘ECOCENTRIC’ APPROACH

„Ecocentric“ approach is one among the six competing logics of sustainable architectural practices - built forms are parasitic in nature and revolve around the post consumer waste (Guy & Farmer, 2001). With self sufficiency and incorporating the principles of a living organism, Reynolds designed „earthships” in 1970s. With his attitude towards post consumer waste as a resource, he developed building systems by using tires, glass bottles and aluminium cans. Creating the base for a man made floating island (Mader, 2011) with PET bottles is an exceptional eco centric idea.

Interpreting the role of PET bottles and ‘Reuse B’

Following Reynolds’ strategies, Froese initiated to construct small structures with PET bottles firmly held in position with nylon ropes in 2001 (Pachecho, 2013). PET bottle buildings are bio climatic, cost effective, non brittle, easy maintenance, resistant to abrupt shock loads; strong, durable, versatile, easy handling and reusable are the characteristics of such built structures (eco tec, 2002). Habitable spaces, activity centers, learning centers and latrines are constructed using PET bottle bricks at Honduras, Nigeria, Central America, Philippines and India. Architects and technocrats are searching for a variety of solutions to reuse post consumer PET bottles in building envelopes for permanently built forms, temporary structures and interiors as in Figure 2.

With a holistic approach, PET bottle bricks are being made with a variety of filling materials such as adobe or sand (eco tec, 2002, May 4), liquefied adobe, inorganic waste (Saraswat, 2013), sand and cork (Shoubi et al, 2013). PET bottles are stacked one on top of the other to build green houses (Alvarado,
When adobe is used as a filling material in PET bottles, it should be tightly compacted with a stick as well as a compressor and then tightly closed (Can steel, 2014).

A unique brick with PET bottle itself as filler (Mehta and Ellis, 2007) is developed by Lima. Bottles are effectively used to replace the concrete in roofs and investigations on the monolithic casting of such discarded transparent containers is in the progress (Radu & Christiana, 2011) and as fillers in slabs (Pandya, 2012) as shown in Figure 2.

Figure 2: Post consumer PET bottles – Ecocentric approach

They are used as sandwich panels in the constructing emergency shelters (Bristogianni, 2012), as partitions with and without visual continuity and also as fillers in concrete roofs and space frames changing the perception of ‘post consumer packaging waste. PET bottle partitions, designed in Danone office and in Morimoto restaurant, is a value addition initiative. In Morimoto restaurant, experiencing the two storied partition integrated with LED lights is a unique idea, bewildering the visitors to think about the workmanship and material (webecoist, 2011).

PET bottles and ‘Reuse B’ in Indian context

In a country like India the development is uncontrolled, unorganized, use of virgin construction materials increasing day by day increasing the proportion of the shelterless. Architects and others are adopting the ideals of ecocentric practices, zoning on the experimentation (Chan,2007) with post consumer waste. According to Antonoides (1992), materials are the flesh, bones and skin of the built forms and are categorized based on their influence on the structure and function. Initiators like Yatin Pandya, Prashant Lingam and Patrick San Francesco are the eye openers to experiment with post consumer PET bottles in constructing small scale buildings like activity centers, learning and habitable spaces for social causes in different Indian contexts.

Figure 3: (a) Front elevation (b) Rear elevation (c) PET bottles as fillers in roofs

A multi activity center at Ahmedabad by Yatin Pandya, Principal architect, Footprints EARTH, firmly believing in recycling waste as environmental, economic and architectural imperative as one of the sustainable principles, is playing a vital role in building the centre with waste materials. PET bottle bricks filled with fly ash are one of the materials for the envelope. A technique of using PET bottles as fillers in flat roofs and as bricks in walls integrated with aesthetic values as in Figure 3.

Hyderabad based entrepreneurs Prashant Lingam and Aruna, designed a prototype shelter using bamboo and PET bottle bricks covering an area 225 square feet. Bamboo is used as structural members and nearly four thousand PET bottles with earth is used in the construction. A typical bonding with bottle bricks is shown in Figure 4. They are aspiring to promote this as a model house under Indira Awas Yojana, a scheme initiated by the Government of India for housing.
In Delhi, a learning centre as shown in Figure 5 was constructed by a non-government organization, „Samarpan Foundation” founded by Mr. Partick San Francesco using six thousand PET bottles with a prefabricated roof. A typical bonding is developed using one liter bottles for walls as well as flooring. The designed space roofed with simplified steel trusses and prefabricated sheets.

A model house of area 250 square feet is constructed using PET bottle bricks in Chennai. Figure 6 shows the unique bond developed by the Foundation, replacing steel reinforcement with 3cm X 3 cm Nylon 6, to improve the tensile strength. Techniques for constructing a vault and flat slab using PET bottles are developed. For the construction of one cubic feet volume of load bearing wall we require sixteen half liter bottles and nine one liter bottles.

In our University Campus, we in collaboration with Samarpan developed a typical bond for the construction of a compound wall as shown in Figure 7. Further, PET bottle columns, where three half liter bottles and one liter bottles are stacked vertically in a typical course with nylon 6 as the reinforcement, runs around the column in clockwise and anticlockwise direction as shown is casted at the Council of Scientific and Industrial Research, Chennai for structural and seismic investigation.

ROLE OF PET IN ‚REUSE C‘ FOR DEVELOPING ALTERNATIVE BUILDING MATERIALS

Innovative applications of physically recycled post consumer PET
The secondary recycling is classified as physical reprocessing, melting and reforming. Investigations on mechanical, thermal, electrical, light weight properties of such materials with physically modified PET granules, pellets, fibers as partial replacement for fine or coarse aggregates are progressing. Such developed materials and composites are effectively used in pavement and roads. With respect to melting and reforming or reengineering, PET bottles with inherent interlocking property are designed and developed by Miniwiz with properties like translucent, insulating, light, strong and mechanically recyclable material. It is created in order to tackle three environmental problems – waste accumulation, resource scarcity, greenhouse gas emissions simultaneously (Hegenwald, Ackermann, Neugebaue, Finkbeiner, 2013). Reusability, recyclability, non toxicity, low volatile compounds, on site production, scratch resistant, easy maintenance, simple installation and affordability are the distinctive features of this building material (Miniwiz, 2011).

**Figure 8: Post consumer PET and „Reuse C“**

**Innovative applications of chemically recycled PET**

Investigations on polymer concrete (Tawfik & Eskander, 2006), polymer mortar (Reis et al, 2011) or polyester composite tiles (Icduygu et al, 2013) are emerging, where the chemical composition of the PET is modified through chemical treatment as in figure 8. Applications in the construction of habitable spaces need to be addressed and impacts created during the treatment and production phase is to be investigated.

**CONCLUSION**

The initial perception on the use of PET bottles in construction is changing day by day. A paradigm which emerged as PET bottle bricks in the construction of load bearing walls with steel trusses and prefabricated metal sheet is at present witnessing flat roofs with nylon 6 replacing steel reinforcement and intuitive vault construction. Apart from this ingenious bonds and columns using PET bottles gives a new direction to think about beams, foundation and simple trusses. With a holistic approach, designing phase of PET bottles with interlocking property is innovative. Even though research on the effective use PET in developing new material as an option, solutions exploring the application of PET bottles as structural members, foundation, retaining walls and secondary elements like street furniture, kerbs, road dividers, pavements and other landscape elements is to be looked in to. Strategies, approaches and practices integrating the relationship incorporating a total rethinking on junk as a resourceful building material integrating waste need to be nurtured and shall be enhanced. The Governing bodies shall
formulate policies to propagate this eco centric approach via appropriate practices, research investigations on the properties of the materials and construction techniques.

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Study on Passive Energy Efficient Retrofit of Existing Buildings in Humid Tropical Area: Summery and Extension based on Research in Lingnan Area of China

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ABSTRACT

The paper describes the climate, the thermal comfort and the key points to strengthen the buildings’ climatic adaptability in Lingnan area of China, which is a part of the geographical distribution of the world’s hot and humid area. Based on this, it makes a summery and extension of some general possibilities for passive energy efficient retrofit of existing buildings in humid tropical area.

At present there are around 50 billion Sqm existing buildings in China. Most of these have some problems such as high energy consumption, conflict between function and space, and improvement demands for environmental condition. It is practically significant to discuss the energy efficient retrofit under reasonable cost control.

There are passive technology and active technology in energy efficient retrofit. Passive technology means certain architectural methods that make the buildings stronger in regulation and adaptation to the climate. It is low-skilled, less in investment, easy to manage, as well as universal and durable, therefore suitable for low-cost promotion in large number.

The Lingnan Humid Tropical Area has similar climatic characteristics, such as hot summer and warm winter, humid climate and abundant rainfall. One significant is that the high temperature and the humid weather come up almost over the same period. The buildings have similar features in passive design for climatization, therefore there are certain rules to follow.

The paper introduces a case of energy efficient retrofit in this area, and sum up several passive technologies used in the case, and evaluates how it affects on economic and environmental benefits.

Finally, based on this, the paper makes a summery and extension by listing several strategies for existing buildings passive energy efficient retrofit in humid tropical area, and generalizing several passive energy saving possibilities on four different level: environment, space organization, material and structure, use and management of the buildings.

KEYWORD
Humid Tropical Area, Existing Buildings, Passive Technology, Energy Efficient Retrofit, Lingnan
PRESENT SITUATION OF EXISTING BUILDINGS AND THE NECESSITY TO RETROFIT

According to a statistical data from the “Existing Buildings Retrofit Evaluation Criteria” preparation group of China Academy of Building Research in June 2013, there are around 50 billions square meters of existing buildings in China. Most of these have some problems such as high energy consumption, conflict between function and space, and improvement demands for environmental condition. Strategies need to be taken to ameliorate the situation immediately.

Buildings in developed countries have got long service life and always been reused well. In America, buildings have an average service life of about 80 years. Over 70% of the construction works are related to old buildings reuse. However, the number in China is shorter than 30 years. Annually, demolition of old buildings equal to almost 40% of the new construction area. There is 0.8t carbon being released when 1 m² new area is constructed. As a result of the rapid urban development and updates, recurrent demolish and construction of building industry, It has been a vicious cycle of resources waste and environmental pollution. Appropriate retrofit of existing buildings can bring lots of positive results, such as less investment, shorter construction period, cost saving, environmental improvement, construction waste reducing and the low-carbon business.

BRIEF INTRODUCTION FOR PASSIVE TECHNOLOGY

Generally, there are passive and active technologies in energy efficient retrofit. Passive technology means architectural methods that make buildings stronger in adaptation to climate. It relays on natural energy such as sun radiation, to satisfy normal operation and improve the indoor comfort. It requires organize the building elements such as function and form synthetically. These measures are closely related to the site environmental and climatic conditions, so manifest in various forms in different area.

It is low-skilled, less in investment, and easy to manage, as well as universal and durable, therefore suitable for low-cost promotion in large number. However sometimes we need additional active technology to make up for its deficiency to regulate. Energy efficient retrofit of existing buildings should mainly rely on passive technology and supplementary on active technology. In long-term practice, Lingnan traditional villages have accumulated lots of experience, which inspire us today, “cold lane” e.g. It is a narrow alley between two rows of folk houses in Lingnan traditional villages. Together with those patios and courtyards system in the houses, it plays an important role for sunshading and ventilation.

CLIMATIC CHARACTERISTICS IN LINGNAN HUMID TROPICAL AREA

Lingnan Area is a place in South China which is next to the equatorial. It contains Guangdong and Hainan Province, southern Fujian and eastern Guangxi Province, which is across the mid subtropical, south subtropical and tropical areas. (Figure 1)

This area has a long and hot summer but short and warm winter. The annual sunshine hour is around 1800h to 2100h, which ranges from 40% to 50% in full year. The sunshine period is not long but both direct radiant and scattering are intense. The annual noon minimum incidence angle is about 41°. The average air temperature is 21°C to 24°C in full year, 28°C to 29°C in the hottest month, and 14°C to 17°C in coldest month. Extreme maximum temperature can reach 38~42°C. There is abundant rainfall, around 1700mm annually. The monthly air relative humidity is 65% to 85%. The hot and humid weather come up almost over the same period, from April to October.

Figure 1 Location of Lingnan area in geographical distribution of the world's hot and humid area.
KEY POINTS FOR BUILDING ENERGY SAVING IN LINGNAN HUMID TROPICAL AREA

Lingnan area is close to the equatorial, so the solar radiation is intense. Therefore sunshading is needed to prevent the buildings from being heated directly. The summer is humid as well as hot, so that all outward interfaces are heated strongly by scattering. Therefore it is necessary to improve the thermal performance of the building envelope. Ventilation can help to bring away the heat as well as prevent moisture indoor. Furthermore, cooling down the building and its circumstance is good for improving the thermal environment of activities space. Sunshading, insulation, ventilation, cooling are the key points to improve the thermal environment. Other measures such as daylighting also help to save energy.

CASE STUDY: ENERGY EFFICIENT RETROFIT OF THE HEADQUARTERS OF CHINA MERCHANTS PROPERTY DEVELOPMENT CO.LTD

Case Overview

The project is located in Shenzhen. Originally it is a factory of RC frame structures, built in 1980, with 4 floors and a total construction area of 16200 Sqm. It used to be a factory of SANYO for producing electronic products, until the company moved out in early 21th century. Later the empty building was acquired by the China Merchants Property Development co.ltd and transformed into an office building for 500 employees. The retrofit design carried out from 2006 to 2007 before the project was completed in June, 2008. After the project, the building has 5 floors and a total construction area of 24260 Sqm, including 4600 Sqm area of parking garage. (Figure 2)

Design Strategy

The design strategies used in this project include both passive and active technologies. The former can be summed up on four levels. (Figure 3, 4)

1. Environmental level. Strategies include: increase the green, set up artificial wetlands and a landscape pool, use water-seepage ground material, create a three-dimensional green area on the retracted roofs in north side. These methods bring about a cool protective layer that can reduce thermal radiation to indoor.

2. Space organization level. By removing part of the original floor, the building obtains high space on outer layer, which will not affect the indirect lighting for inner rooms. The atrium in the middle helps to improve ventilation and lighting.

3. Material and structure level. The building uses fixed level sunshading panels made of silver-white metal in south facade, inner roller shutter windows in east facade, boston ivy with steel mesh as eco-shading in west facade. Hollow Low-e glass is used for the glass curtain wall. Those reserved original 240mm clay walls are added with aerated concrete block inside and coated with light-colored exterior paint. Solar panels are arranged on roof, which make use of solar and act as roof-sunshading simultaneously.

4. Use and management level. Those rooms that are less frequently used, such as multifunctional hall, are arranged on the upper layer, as a thermal insulation layer. The same principle is used in the meeting and reading rooms in south side. A high exhibition hall is added to the north, which contributes to promoting ventilation. The parking garage in basement makes good use of the spaces of poor lighting and ventilation. The office is disposed inner, surrounding the atrium.
The retrofit also uses several active technologies, such as air-conditioning fresh air system, high-efficient lighting, energy-saving elevator, etc. These methods also make great effects.

**Energy Saving Effect**

Considering the building energy consumption characteristics of this region, the air conditioning energy consumption is selected as building energy evaluation index. This building contains 16259 Sqm air-conditioning area. It’s equipped with 1 High temperature chillers, 9 liquid desiccant dehumidification new air units, 1000 Sqm cold radiation capillary, and 2800 Sqm VRV multi-unit air conditioner. According to the building energy consumption monitoring data provided by the China Merchants Property in 2011, the Total annual energy consumption of unit construction area is 66.7 kwh/Sqm·y, while the number of the other Grade A office buildings in Shenzhen is around 140-200kwh/㎡·y. It means that the total building energy-saving rate has reached 52.4%-66.7%. According to an energy simulation calculation by DEST and DOE2, about 27.3% of the energy-saving rate is obtained through passive methods. Using passive way in this retrofit project contributes to saving around 326,000-592,000 kwh of electricity annually. (Table 1, 2, the air-conditioning area is calculated as 16259 Sqm)

**Table 1. Building Energy Monitoring of the Headquarters of China Merchants Property Development co.ltd ( in 2011, Data reorganized from the China Merchants Property)**

<table>
<thead>
<tr>
<th>Project</th>
<th>Use area of all types of air-conditioning equipment (Sqm)</th>
<th>Unit A</th>
<th>Unit B</th>
<th>Unit C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit A Unit B Unit C</td>
<td>13180</td>
<td>2800</td>
<td>279</td>
</tr>
<tr>
<td>Total annual energy consumption of air conditioning (kwh)</td>
<td>790000</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sub annual energy consumption of air conditioning (kwh)</td>
<td>620000</td>
<td>100000</td>
<td>70000</td>
<td></td>
</tr>
<tr>
<td>Sub annual unit energy consumption (kwh/ Sqm • y)</td>
<td>47.4</td>
<td>35.7</td>
<td>259.0</td>
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<tr>
<td>Annual unit energy consumption of air conditioning (kwh/ Sqm • y)</td>
<td>31.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total annual energy consumption of the building(kwh)</td>
<td>1650000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual energy consumption of unit construction area(kwh/ Sqm • y)</td>
<td>66.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Annotation: Unit A=Temperature and humidity independent unit
Unit B=VRV air conditioner
Unit C=Constant temperature and humidity unit

**Table 2. Proportion of Passive Technology Contributed to Energy Saving (Data reorganized from the energy simulation calculation through DEST and DOE2, Lin Wusheng)**

<table>
<thead>
<tr>
<th>Project</th>
<th>Energy saving contribution rate (%)</th>
<th>Sub Projects’ saving rate relative to the proportion of the Total energy saving rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope structure</td>
<td>12</td>
<td>18.2</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>30</td>
<td>45.5</td>
</tr>
<tr>
<td>Natural ventilation</td>
<td>6</td>
<td>9.1</td>
</tr>
<tr>
<td>Electric lighting</td>
<td>16</td>
<td>24.2</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>2</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>100</td>
</tr>
</tbody>
</table>

Annotation: rate (Passive methods) = rate (Envelope structure) + rate (Natural ventilation)
SUMMERY AND EXTENSION: PASSIVE TECHNOLOGY FOR ENERGY EFFICIENT RETROFIT OF EXISTING BUILDINGS IN HUMID TROPICAL AREA

Lingnan area has climatic characteristics similar to other hot and humid area. So the strategies can be applicable generally. Based on the study above, we make a summery and extension for passive technologies for energy efficient retrofit of existing buildings in humid tropical area on four levels:

1. Environmental level. Many elements of environment can be improved, such as the plants, water, ground pavement, etc. Adding or adjusting plants can help to wind-guide and sunshade. Grass brick, absorbent brick or planting ground, instead of concrete have better evaporation permeability, which contributes to regulating thermal comfort. Overheading the bottom of the surrounding buildings is effective to improve the environment ventilation. (Table 3)

2. Space organization level. Potentials for energy saving on this level can be excavated by space addition, subtraction and reorganization. Atrium and courtyard inserted into the existing space can improve ventilation and daylighting. Air-pulling shaft set up with existing staircase in high-rise buildings help to form the Venturi effect. Increasing of gray space like outdoor gallery and balconies is beneficial for ventilation and sunshading. Body ways such as over-handing, make conditions for self-shading. Size variation of the interior space can adjust indoor air pressure for air floating. Unnecessary partition walls that block wind flow should be taken away. (Table 4)

3. Material and structure level. Energy saving on this level mainly target on the building envelope. Various forms of sunshading can improve the comprehensive shading coefficient. Mossoon window is favourable for humid tropical area because of its excellent function for ventilation. Using energy saving glass for windows can improve insulation. Affixing ceramic tiles, coating with light-colored paint, adding green to the outer surface, or double skin wall can help to improve the heat transfer coefficient. Wind-guide wall added on outward can guide wind into the building. Adjusting the vents on outward interface help to make optimum ventilation and a homogeneous wind field. Water-storing roof, planting roof or shading on rooftop can reduce heat transfer. Skylight improves daylighting and ventilation both. Adding eco-epidermal to an existing building can strengthen its climate adaptability. (Table 5)

4. Use and management level. Space we use is not absolutely static. It can be adjusted to be better climate-adaptive. For instance, site the main space in the upwind sides, so to make good use of the windward, while the auxiliary space in the west as insulation layer. Open or close the atrium according to season to form chimney effect in summer and insulation effect in winter. Activity venue should be adjusted according to the comfort change of indoor and outdoor. (Table 6)

Table 3. Summarized Passive Retrofit Technologies on Environmental level.

<table>
<thead>
<tr>
<th>Object</th>
<th>Instance</th>
<th>Schematic diagram</th>
<th>Major effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>Adding plants along the north side can help guide wind into the building</td>
<td><img src="before-after.png" alt="Schematic Diagram" /></td>
<td>Ventilation</td>
</tr>
<tr>
<td></td>
<td>Adjusting combination of the trees and shrubs can change the air path and guide wing into the building</td>
<td><img src="before-after.png" alt="Schematic Diagram" /></td>
<td>Ventilation</td>
</tr>
<tr>
<td></td>
<td>Planting deciduous trees in the direction of sunlight, would help shade solar radiation in summer but allow sunshine in winter</td>
<td><img src="before-after.png" alt="Schematic Diagram" /></td>
<td>Sunshading</td>
</tr>
</tbody>
</table>

Before vs. After
Refer to Table 3 (continued)

<table>
<thead>
<tr>
<th>Object</th>
<th>Instance</th>
<th>Schematic diagram</th>
<th>Major effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Water arranged help to improve microclimate through evaporative cooling. Temperature difference that caused also benefits ventilation</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Ground material</td>
<td>Grass brick, absorbent brick or planting ground have good evaporation cooling permeability, which help to regulate thermal comfort</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Surrounding buildings</td>
<td>Increase overhead rate of the buildings' bottom is effective to improve environment ventilation</td>
<td>Before</td>
<td>After</td>
</tr>
</tbody>
</table>

Table 4. Summarized Passive Retrofit Technologies on Space organization level.

<table>
<thead>
<tr>
<th>Object</th>
<th>Instance</th>
<th>Schematic diagram</th>
<th>Major effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrium, Courtyard</td>
<td>Atrium and courtyard can be inserted into the existing space to improve ventilation and daylighting</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Air-pulling shaft</td>
<td>In high-rise buildings, air-pulling shaft can be set up together with the existing staircases, so as to form the Venturi effect</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Gallery, Balcony</td>
<td>Increase of gray space such as outside gallery and balcony can form air pressure difference, that benefit ventilation and sunshading</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Body</td>
<td>Use body ways such as overhanging to create condition for shape-shading and guide wind into the building</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Transition space</td>
<td>Create size variations of the interior space that form indoor air pressure difference, which help to form wind fields for better air floating</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Partition wall</td>
<td>Unnecessary partition walls should be take away so as to make room for air flow</td>
<td>Before</td>
<td>After</td>
</tr>
</tbody>
</table>
Table 5. Summarized Passive Retrofit Technologies on Material and structure level.

<table>
<thead>
<tr>
<th>Object</th>
<th>Instance</th>
<th>Schematic diagram</th>
<th>Major effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doors, Windows</td>
<td>Horizontal, vertical, comprehensive, baffle-style or shutter, etc. can be used to improve the comprehensive shading coefficient</td>
<td><img src="image1" alt="Schematic diagram" /></td>
<td>Sunshading</td>
</tr>
<tr>
<td></td>
<td>Mossoon window is favourable for humid tropical area because its excellent function for ventilation</td>
<td><img src="image2" alt="Schematic diagram" /></td>
<td>Ventilation</td>
</tr>
<tr>
<td></td>
<td>Use energy saving material for windows, such as coated, filmed, hollow, vacuum, heat-absorbing, painted, and photocromic grass, etc</td>
<td><img src="image3" alt="Schematic diagram" /></td>
<td>Insulation</td>
</tr>
<tr>
<td>Walls</td>
<td>Affixing ceramic tiles, coating with light-colored paint, green-wall, or double skin wall can improve the heat transfer coefficient</td>
<td><img src="image4" alt="Schematic diagram" /></td>
<td>Insulation</td>
</tr>
<tr>
<td></td>
<td>Adding wind-guide wall besides the vents can be helpful to guide wind into the building</td>
<td><img src="image5" alt="Schematic diagram" /></td>
<td>Ventilation</td>
</tr>
<tr>
<td></td>
<td>Vents layout on diagonal can make optimum ventilation and a homogeneous wind field indoor</td>
<td><img src="image6" alt="Schematic diagram" /></td>
<td>Ventilation</td>
</tr>
<tr>
<td>Roof</td>
<td>Planting roof, water-storing roof, shading framework on rooftop, etc. can reduce heat transfer greatly</td>
<td><img src="image7" alt="Schematic diagram" /></td>
<td>Insulation</td>
</tr>
<tr>
<td></td>
<td>Oblique skylight, high-side window, roof skylight, etc. are useful for daylighting and ventilation</td>
<td><img src="image8" alt="Schematic diagram" /></td>
<td>Daylighting</td>
</tr>
<tr>
<td></td>
<td>Adding eco-epidermal to an existing building can strong its climate adaptability</td>
<td><img src="image9" alt="Schematic diagram" /></td>
<td>Insulation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>reserved elements</th>
<th>retrofit elements</th>
<th>water</th>
<th>wind</th>
<th>sunlight</th>
<th>heat</th>
</tr>
</thead>
</table>

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Annotation: all the technologies showed on the tables 3-6 above just provide possibilities but not fixed pattern. We can make appropriate choices from the tables, according to the actual situation, such as the cost, feasibility or historic preservation, etc.

CONCLUSION

1. The paper summarizes the key points as sunshading, insulation, ventilation, cooling and daylighting to strengthen the buildings’ climatic adaptability according to the climate and the thermal comfort in Lingnan area of China.

2. For the purpose of an understandable and practical design reference, the paper classifies the passive technologies for energy efficient retrofit of existing buildings in humid tropical area on four levels: environment, space organization, material and structure, use and management of the buildings.

3. Through a case study of energy efficient retrofit of the Headquarters of China Merchants Property Development co.ltd. The paper discusses the energy savings and economic benefits of energy efficient retrofit of existing buildings.

4. Further study may target on more specific methods for passive energy efficient retrofit of existing buildings and detail how they work, and how all the technologies react to the changing conditions of climate, social economic and the continues rapid advances in active technologies.

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Feng Lindong, 2008. Study on appropriate building shading technology in hot summer and warm winter zone. Degree thesis of Xi’an University of Architecture and Technology.


Table 6. Summarized Passive Retrofit Technologies on Use and management level.

<table>
<thead>
<tr>
<th>Object</th>
<th>Instance</th>
<th>Schematic diagram</th>
<th>Major effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function planning</td>
<td>Site the main space in the upwind sides to make full use of the windward, while the auxiliary space in west, as an insulation layer</td>
<td><img src="image" alt="Schematic diagram" /></td>
<td>Ventilation Insulation</td>
</tr>
<tr>
<td>Manually adjust</td>
<td>Open or close the atrium according to the season change, so as to form chimney effect in summer and insulation effect in winter</td>
<td><img src="image" alt="Schematic diagram" /></td>
<td>Ventilation Daylighting</td>
</tr>
<tr>
<td>Venue selection</td>
<td>Select activity venue according to comfort changes, e.g. arrange daytime activity indoor, while enjoy the breeze outdoor in the evening</td>
<td><img src="image" alt="Schematic diagram" /></td>
<td>Ventilation Cooling</td>
</tr>
</tbody>
</table>

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16-18 December 2014, CEPT University, Ahmedabad
Preliminary Study on Natural Ventilation for Hospital Building in Hot and Humid Regions

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ABSTRACT

This essay proposes the necessity of natural ventilation of the hospital buildings in the hot and humid regions from the perspective of energy saving. It integrates the existing natural ventilation technologies from traditional houses and other types of buildings in such area to further investigate the natural ventilation design methods for the purposes of energy saving and requirements satisfaction, thus to provide useful data for the engineering design in the future.

KEY WORDS
Hot and Humid Regions, Hospital, Natural Ventilation, Passive Design

1. INTRODUCTION

In today’s world, the energy issues which are drawn more attentions worldwide are generally recognized as one of the four survival prerequisites we are facing. It is estimated that the population will come to 10 billions by the end of this century, resulting in more severe conditions of energy consumption.

The energy consumption of buildings has been taking a significant proportion in energy consumption of human life. According to the experiences from industrial developed countries, the building energy consumption took a ratio of 35% in total energy consumption. In China, the building energy consumption holds 1/3 of total energy consumption and is still increasing.

Being different from normal civil buildings, the hospital building is a fairly complicated form in public architectural design field involving a lot of specialties, as there are too many types of energy required for hospital operation. Based on relevant data, the hospital energy consumption is 1.6-2 times than normal public buildings. Nowadays, the hospital buildings in China in fact have faced with tremendous energy consumption pressure which drives us to focus on energy-saving researches. The energy-saving hospital is not only for reducing the operation cost of hospital, but also to lighten the burden of maintenance cost for medical services.

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2. NATURAL VENTILATION DESIGN FOR BUILDINGS IN HOT AND HUMID REGIONS

2.1. Climate features

The climate in the hot and humid regions features as high rainfall amount, high humidity and temperature, strong sunlight, and violent lightening. The humidity and temperature are stable all the year. The year-around temperature is about 27°C with large amount of rainfall, while the humidity is 80%-90%, therefore, such regions are under hot and humid conditions all the year.

Such climate condition, existing in widely areas of China, is a combination of high temperature and high humidity. The energy consumption of the buildings under this kind of climate condition inevitably become a major issue to be solved if we aim to achieve absolute conformity and modernity of architecture.

2.2. Basic design principles of the buildings in hot and humid regions

Following factors must be taken into account for the buildings in hot and humid regions: heat protection, moisture proof and good ventilation in summer; but cold proof and heat preservation in winter are not necessary. Open design is preferred in overall planning, individual design and structure processing, making good use of natural wind; the building shall avoid a western exposure with sunshade; storm rain, flood, moisture and lightening proofs shall be seriously considered.

2.2.1. Heat protection

In hot and humid regions, the temperature in summer is very high and lasts so long that heat protection is the priority task for the buildings in this area. Amongst building shading is the most effective way to isolate the heat. Many shading methods are adopted for the hot and humid regions, from large cantilevered roof used in traditional houses, "Special shading method invented by Professor Xia Shichang" that is commonly used in Guangdong and Guangxi, to modern building shade. All are designed to reduce direct radiation from the sun onto the building, while using shading structure to improve ventilation performance for heat dissipation.

2.2.2. Moisture proof

Most hot and humid regions laid along the ocean or are located where rivers and lakes are spread over, so the relative humidity in such areas are greater than that in inlands. As a result, the adjustment of humidity in the building should be considered in addition to heat protection and temperature cooling. In particular at the end of spring and the beginning of summer, necessary measures shall be taken for moisture and mould proof of the building envelope, while reducing the effects of high temperature and humidity on human body and improving indoor comfort.

2.2.3. Ventilation

The climate characteristics of high temperature and high humidity in such area determine that the enclosing structure is not good enough to prevent solar radiation from into the room for the traditional buildings, ventilation shall be used for heat dissipation. Ventilation substantially is the flow of air, which is produced by pressure difference of air. The people living here learned a lot of experiences from their construction practices, so as to resist to those climate characteristics of high temperature, long duration, strong solar radiation and greater humidity.

3. NECESSITY OF VENTILATION FOR HOSPITAL BUILDING

Hospital building is high-energy consuming building and energy is used mainly for air condition and illumination. As a case study in Guangdong, electricity consumption of air condition is obviously seasonal, identical to the monthly electricity consumption of the hospital and the average temperature of Guangdong area. Its peak is from May to September, which is the hottest period, accounting for 50% of the total monthly electricity consumption. (Fig.1-3) In addition, the electricity consumption of air condition has a close relationship with the number of month using it. Hospitals with good natural ventilation can reduce or even cancel the use of air condition in transition season so that their annual electricity consumptions are lower, while hospitals with bad natural ventilation have to use air condition all year long which leads to a higher annual electricity consumption. (Fig.4) Electricity consumption of
illumination remains the same without seasonal difference. Its difference is caused by the hospital size and the area using natural lighting only.

In summary, speaking of energy-saving of the hospital building, the energy consumption by air conditioner is the very first thing we need to discuss. If we adopt natural ventilation to reduce the burden of air conditioners, the operation costs of the hospital may be reduced as well as of the medical and health services, moreover, it provides high quality indoor air that is comfortable for the patients.

Figure 1  Monthly average temperature of Guangdong area from 1981 to 2010(Source: GangDong Weather Bureau)

Figure 2  Monthly electricity consumption of 10 hospitals in Guangdong area in 2011(Source: Drawn according questionnaire by Zhang Chunyang and Peng Dejian)

Figure 3  Monthly electricity consumption of a hospital in Guangdong area (according to purpose) in 2011(Source: Drawn according questionnaire by Zhang Chunyang and Peng Dejian)

Figure 4  Number of month using air condition of hospital in Guangdong area in 2011(Source: Drawn according questionnaire by Zhang Chunyang and Peng Dejian)

4. STUDY ON NATURAL VENTILATION DESIGN FOR HOSPITAL BUILDINGS IN HOT AND HUMID REGIONS

4.1. Natural ventilation by wind pressure

The wind pressure may be used as the main measure for implementation of natural ventilation in good wind environment. This kind of wind for ventilation by wind pressure is “Through Flow”. According to the wind tunnel test: when the wind flows to the building, the positive pressure only will be generated on windward side of the building by blockage of the building. And, the negative pressure will be generated on appropriate places when the flow bypasses each side and the back of the building. The ventilation by wind pressure refers to such ventilation implemented by the pressure difference between the windward side and the leeward side of the building. The value of pressure difference is related to the form of building, the included angle of the building and the wind, and the ambient environment. When the wind flows to the front elevation in vertical way, the positive pressure at the center of windward side reaches to the maximum value, and the maximum negative pressure appears at the corner and ridge. (Fig. 5)
Another effect caused by wind pressure is the Venturi Effect. When the air flows, the flow rate will be accelerated because of shrinkage of space, thus the shrink section forms a negative pressure zone.

The layout suitable for such climate conditions in this area is that all rooms will be directly ventilated with good sunlight and the balconies or veranda shall be provided around the building. However, such space design is difficult for most of functional spaces in the hospital building. Therefore, all rooms in different position at each floor shall have ventilated air, and the through flow is required for plane design.

According to authors’ experiences, there are two common strategies for hospital building design: 1. The air inlet of each functional area, as reasonable as possible, shall be placed in the dominant wind direction in summer time, without wind-shield wall, and the air outlet is placed on the other side. The inlet and outlet shall be aligned or displaced, so as to guide the air to flow into and circulate in the open plane from one side of the building. 2. Consecutive consulting rooms or wards in rows block the flowing air and shades the corridor space, therefore, the consulting room and ward shall not be arranged consecutively along the side of the building. It is recommended that some rest rooms or waiting rooms are designed in the middle of the corridor to leave the ventilation opening, so as to form through flow by wind pressure, thus to improve the ventilation performance of consulting room, ward and waiting space. (Fig. 6)

The waiting space and consulting room may be designed with courtyard concept, so that the wind can be flown into the room from the windows or holes on the building. When the courtyard window opens, the air may flow into the building for ventilation. (Fig. 7)

Secondly, take an example of bottom overhead method, which has seen more often in traditional building. The hospital building is designed to elevate the ground floor so as to improve slow flow on the ground floor and generate faster free-air speed in where is helpful for directing air flow. In addition, the air into the first floor will be in the building shadow by such overhead design, thus to reduce the air temperature and improve indoor thermal comfort. Except for some public rooms and necessary inspection rooms, the overhead design shall be available to the ground floor of hospital building as practicable as possible so that the internal building will have a better natural ventilation effect in the summer time and transitional seasons as well as a smoother process of thermal pressure ventilation. (Fig. 8)

Furthermore, the two ends of medical spaces shall not be closed, such as clinic and medical technology section, and open design is developed to generate positive and negative pressure difference at the opening of two ends of the building. Such opening is connected to the corridor, resulting in gathering and guidance of the outside air flow because of continuity of corridor, thus to improve indoor ventilation effect. The veranda assists wind guidance, also creates a comfortable zone with cool air due to shading effect, to some extent that the indoor comfort level will be increased.
From figure 9 to 12 are measuring analysis of ENT secondary waiting area of Panyu Central Hospital without air-conditioning, outdoor maximum temperature is 35°C and minimum temperature is 27°C in that day. It can be known from the data in figure, in waiting area there almost has lasting natural winds, whose speed is in the range of 0.1-1.0m/s. Since the outdoor temperature is too high, the eratura and humidity in waiting area are not effectively reduced too much. Moreover, as the activities of patients, the humidity in middle of waiting area is higher than the other two test points. However, according to the interview, patients in waiting area do not feel uncomfortable when they are in high temperature and humidity; on the contrary, the indoor environment with lasting natural winds make them feel more comfortable.
Lastly, the ventilation by wind pressure also can be achieved by design of detail structures, in order to optimize the air quality in the room and improve thermal comfort degree.

**Leading wind by sunvisor:**

The sunvisor is widely used in the hot and humid regions. The building sunvisor is not only able to effectively resist solar radiation, but also to change the indoor ventilation performance by adjusting the form of sunvisor and the position in the enclosing structure to improve the indoor comfort, taking the position of wind entering into the room and airflow pattern into account. For example, the louvers may change the air flow upwards or downwards when the wind enters into the room; the horizontal sunvisor on the window may direct the air flow upwards; the gap between the horizontal sunvisor and the wall may direct the air flow downwards; when the louvers are fully opened, the wind in wider area may be flown into the room. (Fig. 13)

![Figure 13](source: Allan Konya, Design primer for hot climates)

**Options for window opening:**

Normally, these windows with greater opening and ventilation areas are selected for the hospital building. Opening out by casement window is commonly adopted because of good ventilation and greater opening areas. In case of a higher numbers of opening windows and narrow average width of opening window, the vertical hung window can be fully opened and reaches the maximum ventilation rate with air leading effect, so it is recommend as well. The doctor offices, as auxiliary function of the hospital, are always located in west-east direction, the louver (i.e. vertical hung window) is preferred to meet the requirement of wider ventilation area and direct air flow in the summer time and transitional seasons for the purposes of sun-shading and air leading effect.

In order to improve indoor ventilation performance, it is suggested that the upper ventilation window shall be set up on the partition in the corridor and ventilation louver is provided on the doorstop to reduce hot air circulation.

**4.2. Natural ventilation by thermal pressure**

Another principle for natural ventilation is the thermal pressure difference generated by the air inside the building, which is so called “Chimney Effect”. The thermal pressure difference in the building, namely, “Chimney Effect”, can be used to achieve natural ventilation for the buildings which are affected by the layout of surrounding buildings and tall plants. According to the principle of rise of hot air, the dirty hot air is vented out from the upper air outlet, and the outside fresh cold air is sucked from the building bottom, in order to implement natural ventilation. In building design, the vertical chambers, like stair well and atrium shall be designed to meet the elevation difference of air inlet and outlet. The higher the temperature difference of inside and outside temperatures and elevation difference of air inlet and outlet, the more obvious the thermal pressure effect. Being different from natural ventilation by wind pressure, the ventilation by thermal pressure is more suitable to the ever-changing and adversely outside wind environment.

The courtyard may be designed for the hospital building in the hot and humid regions. The courtyard is one of well-known characteristics for Chinese residence. In the hot and humid regions, the traditional residences use such structure to create a good indoor ventilation condition. The courtyard design for the hospital building reflects the thermal pressure effect used by these residences in the hot and humid regions, so as to improve the natural ventilation performance.
1. Light roof prolongs from the surface and open a window on the side of prolonged section as the air outlet, utilize and heat the accumulated air. Under heat pressure drive, the airflow is inhaled from the windows at each floor and then vent out after rise, thus to strengthen the chimney effect of the courtyard, and use the thermal pressure to provide side ventilation for the courtyard. (Fig. 14)

2. Set up exhaust chimney and increase height of air outlet, add the elevation difference of air inlet and outlet and the thermal difference of the air in the courtyard, and improve the natural ventilation by thermal pressure.

3. Combine the courtyard design to set up an integrated ventilation channel, use the courtyard space as the ecological exchange space, conduct overall design on building structure layer and courtyard space, and create an integrated ventilation channel to facilitate the natural ventilation of hospital building.

4. Set up pitched skylight to catch the wind on the windward side, and bring the outside natural wind into the courtyard to form natural ventilation; utilize the wind pressure difference of front and back of the pitched skylight on the leeside to draft the indoor air for coordination of courtyard ventilation.

4.3. Combination of wind pressure and thermal pressure for natural ventilation

Due to the building is subject to the weather conditions, geographic location, ambient environment and building layout, the natural ventilation design is normally combined by wind pressure and thermal pressure in practical application. The wind pressure and thermal pressure play different roles. In the less deep sections, the wind pressure is prevail for ventilation, while in the deeper sections, the ventilation by thermal pressure is adopted. (Fig. 15)

Taking the Shenzhen Binhai Hospital as an example. There are air vents provided at the front and back of the hospital street so that wind pressure ventilation will be achieved. In addition, the top of hospital street has an elevated roof to provide a good lighting condition without direct radiation from the sunlight. Therefore, the whole elevated roof forms the ventilation by thermal pressure and eliminates the hot air on the top as well. As mentioned above, the Shenzhen Binhai Hospital is able to implement the ideal natural ventilation by combining the wind pressure and thermal pressure, thus to significantly reduce the energy consumption. (Fig. 16)
4.4. Assisted mechanical ventilation

In some large-scale buildings, due to longer ventilation path and greater flow resistance, the natural ventilation hardly can be achieved only by wind pressure and thermal pressure. For those cities with serious air pollution and noise pollution, the direct natural ventilation will be harmful for human health when it brings the awful air and noise into the house. In this case, the assisted mechanical ventilation system is usually adopted. This system has a full set of air circulation channels, supplementing by some air treatment methods satisfying the ecological concepts (for example, soil pre-cool, pre-heat, heat exchange of deep well water, and it facilitates indoor ventilation by certain mechanical means. Comparing with fully natural ventilation, the mechanical plant with auxiliary power may consume a certain volume of energy, but this system is able to re-organize the air flow to achieve a better performance of natural ventilation.

The roof of hospital street of Guangdong Panyu Central Hospital is designed to a ventilated roof. The assisting mechanical ventilation plants, water curtains, are provided at the two sides of the roof, in order to reduce the temperature of hospital street and purify the air quality for natural ventilation. (Fig. 17)

5. CONCLUSION

The air conditioners used for hospital building in the hot and humid regions have enormous energy consumption. This essay discusses about the design strategies of hospital building in the hot and humid regions from the perspective of energy saving, and makes a contribution for constructing a energy-saving and adequate hospital building.

Figure 17  Roof view and water curtains in Guangdong Panyu Central Hospital (source: photographed by the author)

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Design Optimization of Glazing Façade by Using the GPSPSOCCHJ Algorithm

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ABSTRACT

Engineering design is a process to find the best solution to satisfy various design criteria. This work aims to optimize the glazing façade performance and the window size by minimizing the heating, cooling and electric lighting demand of office buildings. Accordingly, this paper presents a comprehensive analysis in order to study the balance between daylighting benefits and energy requirements in perimeter office spaces taking into account glazing properties control with window size, orientation and climatic conditions. The glazing area and thermophysical properties of the window were taken as the main variables. The optimization was carried out by using a combination of Energyplus 7.0.0 and GenOpt softwares. The energy consumption can significantly change affected by geometric parameters, materials properties and types of window glass, orientation and climatic conditions. Optimum range of each parameter was calculated in order to minimize annual energy consumption with a hybrid multidimensional optimization algorithm: GPSPSOCCHJ algorithm. Furthermore, since the annual energy consumption effectively depends on the type of air conditioning system, the optimization process was carried out individually with both evaporative cooling system and compression cooling system. The results indicated that using the evaporative cooling system compared is more appropriate and economical in comparison with the compression cooling system. Also, investigations indicated that reflective double glass and low-e double glazed with argon layer glass is appropriate for Tehran office building and can respectively allocate the maximum level of window area and the minimum of energy consumption.

Keywords: Glazing façade, Optimization, GPSPSOCCHJ optimization algorithm, Energy consumption

INTRODUCTION

Window is considered as one of the most important components influencing the thermal performance of buildings. Their shape, size, optical and thermal properties, orientation and shading/daylighting attachments determine the interior daylighting conditions as well as the visual and thermal comfort for the occupants. The balance between daylight provision and reduction in energy consumption or demand through appropriate control of solar has been investigated in a few studies by several researchers (Lee et al., 1995; Citherlet et al., 2001; Franzetti et al., 2004; Hvid et al., 2008; Tzempelikos et al., 2010). Coupling between daylighting and thermal simulation is necessary for a comprehensive analysis. In 1998, Clarke et al. compared the annual energy consumption of three different types of glazing system using ESP-r and found reductions of about 4.5%, 10.9% and 6% in maximum heating capacity, maximum cooling capacity and total energy consumption respectively.
Optimized glass facade design may improve exploitation of daylight and result in significant savings in electricity consumption for lighting. Reinhart (2002) calculated the daylight availability for several Canadian locations considering the effects of climate, external shading, facade orientation, glazing type and occupancy schedules. The study showed that location, orientation and blind slat angle all have a significant impact on daylight autonomy while external objects and glazing type were less important. Optimized glass facade design may improve exploitation of daylight and result in significant savings in electricity consumption for lighting. Reinhart (2002) calculated the daylight availability for several Canadian locations considering the effects of climate, external shading, facade orientation, glazing type and occupancy schedules. The study showed that location, orientation and blind slat angle all have a significant impact on daylight autonomy while external objects and glazing type were less important.

The sophisticated characterizations of window and shading systems sparked a large amount of studies on this topic (Reinhart and Walkenhorst, 2001; Walkenhorst et al., 2002; Robinson and Stone, 2006; Loutzenhiser et al., 2007), and various calculation models that predict illuminance on the interior surfaces of a building as well as on the work plane level are available (Mardaljevic, 2001; Fakra et al., 2011). The different models have some limitations; for example, some models use constant glass transmittance, some others use limited evaluation metrics such as daylight factors (Ghisi and Tinker, 2005); and some have limitations in sky luminance inputs. Moreover, it is complicated to modify existing software codes to adapt specific necessities or to present results using different measures. As to the latter, advanced daylighting metrics may be properly used in daylight performance evaluation (Nabil and Mardaljevic, 2006; Reinhart et al., 2006). Finally, the significant computational time, the complex calculation procedure and the inability to interpret simulation results are all factors preventing the design community from picking up the advanced design analysis schemes with very few exceptions (Reinhart and Wienold, 2011).

This study has been tried to optimize the window size and glass type with the objective of minimization of annual energy consumption function. In such a way, while reducing energy consumption, occupants’ thermal comfort and the brightness level of each space remain in the acceptable range. For this purpose the modeling of thermal and visual performance of building’s transparent façade is performed by EnergyPlus software and the results are optimized by GenOpt software and GPSP SOCCHJ algorithm and the effect of all parameters among solar heat gain coefficient (SHGC), thermal transmittance of window ($U_{value}$), and visual transmittance is considered. Finally, calculations and evaluations will lead to provide window design recommendations due to climate.

**METHODS**

In this paper, as shown in [Figure 1](#), a case room is considered in accordance with the case No. 600 in ASHRAE 140 standard. Accordingly, this sample space is an office with the dimensions $6 \times 8 \times 2.7$ m$^3$ in the middle of a tall building which only a wall with 8m width and 2.7m height is in contact with outdoor climatic conditions of Tehran. According to [Table 1](#), the wall adjacent to the outdoor is specified by common materials for office buildings that respectively from in to out includes veneer plaster, insulation, concrete block, stucco and stone.

<table>
<thead>
<tr>
<th>Field</th>
<th>Units</th>
<th>obj1</th>
<th>obj2</th>
<th>obj3</th>
<th>obj4</th>
<th>obj5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
<td>stone</td>
<td>stucco</td>
<td>concrete</td>
<td>insulation</td>
<td>plaster(light)</td>
</tr>
<tr>
<td>Roughness</td>
<td></td>
<td>medium</td>
<td>Smooth</td>
<td>medium</td>
<td>medium</td>
<td>medium smooth</td>
</tr>
<tr>
<td>Thickness</td>
<td>m</td>
<td>0.03</td>
<td>0.0254</td>
<td>0.2</td>
<td>0.0508</td>
<td>0.01</td>
</tr>
<tr>
<td>Conductivity</td>
<td>W/m.K</td>
<td>3.17</td>
<td>0.72</td>
<td>0.33</td>
<td>0.03</td>
<td>0.16</td>
</tr>
<tr>
<td>Density</td>
<td>kg/m$^3$</td>
<td>2560</td>
<td>1856</td>
<td>1380</td>
<td>43</td>
<td>600</td>
</tr>
<tr>
<td>Specific heat</td>
<td>J/kg.K</td>
<td>790</td>
<td>840</td>
<td>880</td>
<td>1210</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Table 1. The wall adjacent to the outdoor construction**
As shown in Table 2, eight types of window glass have been considered: 6mm clear single glazed, clear double glazed with argon layer, clear double glazed with air layer, low-e clear single glazed, reflective clear single glazed, low-e clear double glazed with argon layer, low-e clear double glazed with air layer, reflective clear double glazed with air layer. Dimming of overhead electric lighting is determined from interior daylight illuminance calculated at one or two reference points. Two reference points in coordinates $3 \times 1.6 \times 1$ m$^3$ and $3 \times 6.4 \times 1$ m$^3$ toward the wall adjacent to the outdoor are considered as lighting evaluation criterion. Also, in order to simulate the thermal and lighting energy demands, the EnergyPlus software is used.

**Table 2. Types of window glazing construction**

<table>
<thead>
<tr>
<th>Field</th>
<th>Obj1</th>
<th>Obj2</th>
<th>Obj3</th>
<th>Obj4</th>
<th>Obj5</th>
<th>Obj6</th>
<th>Obj7</th>
<th>Obj8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name</strong></td>
<td>6mm clear single glazed</td>
<td>clear double glazed with argon layer</td>
<td>clear double glazed with air layer</td>
<td>low-e clear single glazed</td>
<td>reflective clear single glazed</td>
<td>low-e clear double glazed with argon layer</td>
<td>low-e clear double glazed with air layer</td>
<td>reflective clear double glazed with air layer</td>
</tr>
<tr>
<td><strong>Outside layer</strong></td>
<td>Clear 6mm</td>
<td>Clear 3mm</td>
<td>PYR B clear 6mm</td>
<td>REF a clear 6mm</td>
<td>PYR B clear 6mm</td>
<td>PYR B clear 6mm</td>
<td>REF a clear 6mm</td>
<td></td>
</tr>
<tr>
<td><strong>Layer2</strong></td>
<td>Argon 13mm</td>
<td>Air 13mm</td>
<td>Argon 13mm</td>
<td>Air 13mm</td>
<td>Argon 13mm</td>
<td>Air 13mm</td>
<td>Argon 13mm</td>
<td></td>
</tr>
<tr>
<td><strong>Layer3</strong></td>
<td>Clear 6mm</td>
<td>Clear 6mm</td>
<td>Clear 6mm</td>
<td>Clear 6mm</td>
<td>Clear 6mm</td>
<td>Clear 6mm</td>
<td>Clear 6mm</td>
<td></td>
</tr>
</tbody>
</table>

EnergyPlus is one of the most comprehensive whole-building energy simulation tools that are capable of modeling several features including solar irradiance and illuminance under different sky conditions, advanced fenestration systems, blind controls, indoor illuminance maps, lamp controls, and heating/cooling energy impact associated with daylighting controls (Seo et al., 2011). Building model, location and Climatic conditions design in Softwared environment. EnergyPlus weatherdata file is used for energy performance calculations and indoor climate analysis. Hourly based outdoor climate data (dry-bulb air temperature, relative humidity, wind speed, direct solar radiation and diffuse radiation on horizontal surfaces for 8784 hours) was used to create the model for calculation. Comparability of current study results for other climatic areas can be done through monthly and yearly average parameters which are indicated in Table 3 (Hanni.al et al., 2012).

**Table 3. Reference year parameters**

<table>
<thead>
<tr>
<th>Month</th>
<th>Air temperature {\degree}C</th>
<th>Relative humidity %</th>
<th>Wind speed m/s</th>
<th>Direct solar radiation Wh/m2</th>
<th>Diffuse radiation Wh/m2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>2.4</td>
<td>63</td>
<td>1.7</td>
<td>3014</td>
<td>1176</td>
</tr>
<tr>
<td>Feb</td>
<td>4.8</td>
<td>55</td>
<td>2.5</td>
<td>3506</td>
<td>1604</td>
</tr>
<tr>
<td>Mar</td>
<td>10.2</td>
<td>44</td>
<td>2.9</td>
<td>3820</td>
<td>1923</td>
</tr>
<tr>
<td>Apr</td>
<td>16.2</td>
<td>36</td>
<td>3.3</td>
<td>4735</td>
<td>2343</td>
</tr>
<tr>
<td>May</td>
<td>22.3</td>
<td>30</td>
<td>3.3</td>
<td>5859</td>
<td>2396</td>
</tr>
<tr>
<td>Jun</td>
<td>27.5</td>
<td>24</td>
<td>3.1</td>
<td>7640</td>
<td>2319</td>
</tr>
<tr>
<td>Jul</td>
<td>30.9</td>
<td>24</td>
<td>2.8</td>
<td>7632</td>
<td>2032</td>
</tr>
<tr>
<td>Aug</td>
<td>29.5</td>
<td>24</td>
<td>2.2</td>
<td>7234</td>
<td>2049</td>
</tr>
<tr>
<td>Sep</td>
<td>25</td>
<td>25</td>
<td>2.3</td>
<td>6687</td>
<td>1642</td>
</tr>
<tr>
<td>Oct</td>
<td>18.2</td>
<td>33</td>
<td>2.1</td>
<td>5238</td>
<td>1488</td>
</tr>
<tr>
<td>Nov</td>
<td>11</td>
<td>45</td>
<td>1.8</td>
<td>3959</td>
<td>1169</td>
</tr>
<tr>
<td>Dec</td>
<td>5</td>
<td>59</td>
<td>1.5</td>
<td>2992</td>
<td>1085</td>
</tr>
<tr>
<td>Avg</td>
<td>16.9</td>
<td>38.5</td>
<td>2.5</td>
<td>5193.0</td>
<td>1768.8</td>
</tr>
</tbody>
</table>
By considering constraints that describe below, the building annual energy consumption with a focus on providing residents thermal comfort is calculated by EnergyPlus.

1. $-0.5 \leq \text{PMV} \leq 0.5$
2. The minimum illuminance required by international standards on the desk: 500 Lux
3. Heat generated within the space caused by a computer, printer, and other accessories available: 800 W
4. Number of people: 4
5. Hours due to the discontinuous use: 7:00 to 16:00
6. People with the metabolic rate of 100 W while seated
7. People clothing thermal resistance, 0.6, 0.5, 0.7, 0.9 clo respectively for spring, summer, autumn and winter conditions.
8. Constant heating set point: 23.5°C
9. Constant cooling set point: 26°C
10. Internal gains for lights: Lighting level calculation method is used to create the maximum amount of lights to this set of attribute choices: 400 W

![Figure 1 Office space in the initial position study](image)

A key part of using optimization tools with artificial intelligence-based algorithms for optimal design is defining an appropriate objective function and constraints. In the issue examined in this article, inside light level, inside temperature, sunshade dimensions, wall thermal resistance, energy consumption in order to provide lighting, heating and cooling. All are measurable quantities that can be offered based on the objective function and constraints. On the other hand, the purpose of this study was the amount of illumininance inside the building and its thermal behavior which is obtained by minimizing the building's annual energy consumption influenced by the optimal size of the window and its different types. For daylighting control types available in EnergyPlus, optimization algorithms must support discrete (on-off or 2 or 3 steps controls) and continuous (dimming control) variables. In addition, the selected algorithm should support intrinsic approximation problems. Detailed buildings energy simulation tools such as EnergyPlus, TRNSYS, and DOE-2 involve solving a series of systems of partial and ordinary differential equations that are coupled to algebraic equations. Therefore, an optimal solution for a continuous cost function may be difficult to obtain without using a heuristic approach (Wetter et al., 2003). Wetter (2008) recommends hybrid algorithms using the General Pattern Search (GPS) method coupled with the Hooke-Jeeves algorithm with multiple starting points or the Particle Swarm Optimization (PSO) algorithm. Using this algorithm in GenOpt, with EnergyPlus output as input of the optimization problem, can be found to answer the issue.

As previously noted, the objective function of this issue is the total annual energy consumption which is minimized by determining the coefficients for the efficiency and production cost of the energy. The above issue is optimized and analyzed for two efficiency, compression cooling system and evaporative cooling system in Tehran climate.
RESULTS

Order to determine and Analyzed the optimum dimensions of the window at the four main directions, for 8 types of glass studied by using either compression or evaporative cooling system, after performing optimization for 64-state results were as follows. Figures 2, 3, 4 and 5 show the optimal window area respectively for the North, South, East and West orientations, for evaporative cooling system in comparison with compression cooling system. As can be seen, the use of evaporative cooling system in the same condition the optimum window size will be larger in all four directions. According to Figure 2, in the north, reflective double glass in both cases is an option and its size in evaporative cooling system is $4.5 \times 2.25 \text{ m}^2$ (47% of surface) and in compression cooling system is $4 \times 2 \text{ m}^2$ (37% of surface). As shown in Figure 3 in the south, reflective double glass is the best and its optimum size in evaporative cooling system is $5 \times 2.5 \text{ m}^2$ (58% of surface) and in compression cooling system is $4.31 \times 2.15 \text{ m}^2$ (43% of surface).

**Figure 2** Comparison of optimal window sizes for eight types in North, for systems, evaporative cooling and compression cooling

**Figure 3** Comparison of optimal window sizes for eight types in South, for systems, evaporative cooling and compression cooling
Figure 4 Comparison of optimal window sizes for eight types in East, for systems, evaporative cooling and compression cooling.

Figure 5 Comparison of optimal window sizes for eight types in West, for systems, evaporative cooling and compression cooling.

Data in Figure 4 indicate that East is a good choice for reflective double glass and the dimensions of evaporative cooling system is $2.23 \times 4.46 \text{ m}^2$ (46% surface) and of compression cooling system is $4 \times 2 \text{ m}^2$ (37% of surface). As well as shown in Figure 5 in west direction, if using compression cooling system reflective double glass, and if using evaporative cooling system Low-emissivity double glass with argon layer and reflective double
glass are better choice and Their dimensions are respectively $1.98 \times 3.96 \text{ m}^2$ (36% surface) in compression cooling system and $2.23 \times 4.46 \text{ m}^2$ (46% surface) for both glasses in evaporative cooling system.

The Figure 6 shows that the optimum surface area for eight types of glass windows in the four cardinal directions, by using Evaporative cooling system instead of compression cooling system, increases in various glasses from 13 to 300 percent. As seen in Figure 6, using an evaporative cooling system the window size can be significantly increased with the objective to minimize the energy consumption. Among this low-emissivity double glass with argon layer with more than 300% increase in the south had the highest and reflective double glass with air layer with up to 34%, had the lowest increase. This difference is due to the Low-emissivity double glass is greater than reflective double glass amount of solar energy.

Also, Figures 7 and 8 show the window optimum area for eight types of glasses in four different directions with each of the desired cooling system. It is observed that with evaporative cooling system, the optimum amount of window area in the south is higher than the other main directions and the area of reflective Double glazed window in both systems is higher than the other window.

Figure 6 Percent increase in the optimal value of the window area for eight types in four directions, for use of the evaporative cooling system for comparing compression cooling system

Figure 7 The optimal value of the window for the evaporative cooling system efficiency
DISCUSSION AND CONCLUSION

In this study, the effects of location, material and size of the windows were investigated in order to minimize the annual energy consumption of administrative units with emphasis on the effect of fenestration surface. The results indicate that using the evaporative cooling system compared to compression cooling system is more appropriate and more economical in Tehran climate and if office window has been placed in the optimum orientation, glass area can allocate up to 50% of façade surface. Also, reflective double glass and low-e double glazed with argon layer glass are appropriate for Tehran office building units and can respectively allocate the maximum level of window area and the minimum of energy consumption. Moreover, in the same conditions, using the evaporative cooling system, window optimum size in the four main directions can be varied from 19% for single-glazed window to 58% for reflective double-glazed window in the South direction.

REFERENCES


Reversible constructive system for environmentally sensitive and energy efficient schools in different climate conditions

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ABSTRACT

This research aims to develop a dry assembly, easy to build, flexible and reversible constructive system for the building of energy efficient (temporary) schools located in different climate conditions.

With the intent to build schools characterized by good spatial and technological quality, high level of indoor comfort and low energy consumption it was necessary to develop an extremely simple (but at the same time extremely versatile) constructive system, able to easily adapt to different design, environmental and energy strategies. The developed system uses cross laminated timber and other natural materials and consists of small and light modular elements that can be quickly assembled according to different configurations.

Spatial-functional, technological-constructive and energy-environmental performance of the developed system have been evaluated, tested and optimized in an intense “try and test” phase in different climate zones: cold (Helsinki, Finland), temperate (Rome, Italy) and hot (Nairobi, Kenya).

In particular, the spatial-functional quality was evaluated by the application of the system in several different design configurations of kindergartens optimized with respect to following parameters: type of teaching activity, age and needs of users, spaces functionality and flexibility, paths and relationships between different (indoor and outdoor) spaces and multifunctionality of the common areas.

In relation to technological-constructive performance particular emphasis has been given to: rapidity and simplicity of assembly of building elements, expandability and modifiability of the building in response to the changing needs, cost and simplicity of maintenance over time and use of natural and low environmental impact materials.

To reduce the annual energy consumption (for heating, cooling and lighting) different active and passive environmental strategies and devices have been developed for the three different chosen climatic zones. The level of hydrothermal, acoustic and visual indoor comfort has been evaluated and quantified with the support of thermodynamic simulations and the annual energy demand was also calculated and optimized trough appropriate software.

In conclusion, tests (design application and simulations) conducted in this research have shown that the developed reversible constructive system (applicable in temporary schools) combines good spatial-functional and technological-constructive qualities with a high level of indoor comfort and a low energy consumption. Moreover, the system resulted extremely efficient also in very different climatic conditions, thanks to its easy adaptability to different configurations and strategies.
INTRODUCTION

Building - high quality and low energy consumption - schools (particularly kindergartens) are a priority of the many governments in the world. In Italy, e.g., more than 50% of school buildings do not correspond to current spatial, functional, energy and seismic standards and urgently need to be renovated, expanded or replaced. In some regions of Germany it is an urgent need to build many kindergartens to ensure every child a place to spend the day while its parents work. Even in most developing countries (Africa and Southeast Asia) the humanitarian interventions are focusing their field of action on the creation of schools: e.g. Zambia needs immediately 10,000 classrooms. Moreover, in many countries, there is also the need to provide temporary school buildings (quickly realizable and totally removable) to be used after natural disasters or during the redevelopment of existing schools.

Furthermore, an investigation carried out a few years ago by the U.S. Green Building Council (USGBC) has estimated that in the U.S. “more than 55 million students spend hours every day in buildings with poor ventilation, inadequate lighting, inferior acoustics and antiquated heating systems” (www.usgbc.org). Because of this, USGBC started a study called “Greening America’s Schools - Costs and benefits” which concluded that “Greening school design provides an extraordinary cost-effective way to enhance student learning, reduce health and operational costs and, ultimately, increase school quality and competitiveness” (Kat, 2006). Based on these research results and with the aim of promoting the development of energy-efficient schools, 2006, USGBC launched LEED for schools. These new suite of rating systems recognizes the unique nature and educational aspects of the design and construction of schools. Also the U.S. Department of Energy has promoted a program called “EnergySmart Schools” that shares “best practice and technologies for achieving significant savings in both new construction and school renovation”. This program also provides tools and training for school planning, financing, operation & maintenance, and energy education. Moreover, the ASHRAE has just published an “Advanced Energy Design Guide for K-12 School Buildings”.

OBJECTIVES AND METHODOLOGY

On the basis of the above considerations this research aims to develop an easy to build, flexible and reversible constructive system for the building of high spatial-functional quality, good technological-constructive standard and excellent energy efficient school buildings located in different climates. The idea of designing buildings in different climatic conditions was born from a faculty exchange between UNICAM, Italy and Cal Poly, USA in which 2nd year architecture students have been involved in the design of energy-efficient school buildings located in different climatic zones in Italy and in USA (Rossi, 2012). Based on this very positive didactic experience it was decided to accept “the challenge” of designing in different climatic conditions also for this research, particularly for the design of a very versatile constructive system.

To achieve this goal, the research has been organized into the following phases:

1) Detailed analysis of: A) spatial, functional, energy and seismic standards for school buildings in different countries, B) types of learning and teaching and their impact on the design of the spaces, C) materials and constructive systems with lower environmental impact and suitable for use in reversible processes, D) Climatic conditions and indoor comfort standards in three cities chosen as case studies, E) passive and active energy strategies and devices efficient in different climate.

2) Development of a constructive system in cross laminated timber.

3) “Try and test” of the spatial-functional, technological-constructive and energy-environmental performance of the developed constructive system in different climate through appropriate tools.

4) Optimization of the constructive system on the basis of the results of the “try and test” phase and development of the final system.

5) Application of the system in 3 case studies: Helsinki-Finland, Rome-Italy and Nairobi-Kenya.

6) Evaluation of results of applications.

DEVELOPMENT OF A CONSTRUCTIVE SYSTEM FOR SCHOOL BUILDINGS

With the intent to develop a constructive system for the building of energy efficient (temporary) schools located in different climatic conditions, particular importance has been given to achieving a high level in three categories of performance: spatial-functional, technological-constructive and energy-environmental. In this paper, for reasons of space and in relation to the topics of the conference, more emphasis is given to the last one.
Spatial-functional performance

In school buildings the type of teaching and the specific needs strongly influence the spatial-functional aspects (Dudek, 2007). At the same time the architecture (as consequence of the spatial-functional choices) plays an extremely important role: it houses not only the spaces in which it is possible to perform a certain function but, if well and smartly designed, it is able to improve the way and the efficiency in performing this function. The Dutch architect Herman Hertzberger, who has more than 50 years experience in design and construction of all kinds of school buildings, believes that in school buildings “architects should [...] create spatial conditions that will benefit learning in general sense. The building should provide a general framework for education and learning, while being flexible enough to respond to changing demands [...]. Schools are where you can withdraw and adopt a position with respect to others, where you learn to assume a place in society”.

Because of this, kindergartens designed in this research aim to be designed “as a city” and at the same time “as a home” (Hertzberger, 2009). “As a city”: with public and private spaces, “squares” to meet other students, enough playgrounds, visual links and a “streets” system. “As a home”: where children don’t feel lost and have a sense of security. Between the many possible spatial-functional configurations, three (based on different teaching concepts and adequate to the different climatic conditions typical for the specific case study) are chosen: 1) compact: with a big indoor collective space as middle point and short connection ways between the different rooms, suitable for an “open concept” of kindergarten, where kids of different ages are free to move between the various spaces - recommended for cold climate; 2) linear: with a bigger distance between the different rooms and more open to the outdoor space, suitable for a “classical concept” of kindergarten, where kids of different ages play in different rooms - recommended for temperate climate; 3) courtyard: with a big covered outdoor collective space as middle point, suitable for a “outdoor concept” of kindergarten, where kids spend a lot of time a day outdoor - recommended for hot climate (see fig. 1).

All configurations include some standard spaces (see caption of fig. 1) characterized by a careful study of surface color - which can be aggregated in different ways, based on different teaching concepts or climate conditions.

**Figure 1** Three possible spaces configurations for the three studied sample schools. Legend: 1 (internal or external) collective space, 2 classrooms also containing bathrooms for children, 3 solar greenhouses that can be also used as porches, 4 bathrooms for faculty and staff, 5 big multifunctional space (canteen / collective play room), 6 technical room, 7 offices.

Technological-constructive performance

Requirements that have greatly influenced the development of the constructive system are:

a) Reversibility of the system for the use in temporary buildings: dry-assembly technology.

b) Application of the same modular and versatile easy-to-build elements in different configurations.

c) Use of low environmental impact components: natural and recyclable materials.

With regard to this last requirement, it is not possible to identify materials or construction systems that have a low environmental impact in so many different climatic zones (culture and economies). In order to preserve the original idea of the research to "design in different climatic zones with the same constructive system", but inevitably at the expense of low environmental impact in some climates, it was decided to use natural materials such as wood. This material has a good relationship between cost and environmental impact in cold climates (e.g. in Finland wood is a traditional building material) and in
temperate climates (e.g. in Italy the government is trying to promote the use of wood from environmentally sustainable plantations as building material), while it is less eco-friendly in hot areas such as in Africa. Here the developed constructive system could be realized with local wood or other local natural materials. Being the building single-storey, materials with particularly high structural features are not required. Based on the above considerations, it was decided to use beams and pillars of laminated wood (Gutdeutsch, 1996) for the big collective space (not provided in the African application) and cross laminated timber wall- and ceiling-panels (Lehmann, 2012) for the rest of the building (e.g. classrooms, bathrooms and offices, which are designed as prefabricated boxes). The outside wall covering is made of painted wooden slats, while the thermal insulation is in wood wool or pressed cellulose. Structural elements are identical in the different possible design configurations, while the layers of the building envelope (in particular thickness and materials of thermal insulation) change in the different climatic zones in order to improve the energy-environmental performance. Sizing of modular elements (easy movable by one to three not specialized people), construction details and assembly systems (see fig. 2) have been developed in close cooperation with Italian manufacturers of wood components. This collaboration has allowed evaluating feasibility and costs.

Figure 2  Project proposal for Rome: exploded isometric and detail section of a classroom.

Energy-environmental performance

The achievement of high energy-environmental performance has been the main objective in the development of the construction system and in the design of its possible applications in kindergartens located in different climatic conditions. The most difficult challenge has been to design one constructive system and many design solutions able to meet requirements sometimes contradictory to each other: 1) design a very flexible system: elements should be as "neutral" as possible, in order to work well in any design configuration, 2) application of the constructive system in low energy consumption and high comfort buildings: design and technological solutions should be "specific" and calibrated on the basis of
different local climate (Ford, 2007) and users needs. The search for balance between "neutral elements" and "specific design solutions" has led to a long “try and test” phase finalized to reach an energy balance optimization understood as result of double simultaneous adaptations: the one dedicated to energy needs based on climate condition and the one dedicated to the environmental comfort for users. So building elements, in particular facades, have been conceived as three layered element: an external cladding, a middle “control” layer (dedicate to modulate thermal and moisture fluxes through the whole building surface) and an inner structure (a mechanically more rigid part of the wall). This design methodology is inspired from the research “The Perfect Wall” carried out by Joseph W. Lstiburek (Lstiburek, 2008).

With the intent to achieve high energy-environmental performance, this research aims to develop not only the elements composing the constructive system, but also the "assembly method" and the relations of these elements. This "assembly method" involves the use of (active and passive) strategies and devices for the improvement of the environmental control. As strategies it means e.g. building orientation towards cardinal points and prevailing winds, surface-to-volume ratio and windows orientation. The devices are e.g. solar screens, high performance building envelopes (e.g. characterized by high thermal transmittance or high thermal inertia), ventilation chimneys, Trombe walls, solar greenhouses, photovoltaic etc.

APPLICATION IN THREE CASE STUDIES AND ENERGY EFFICIENCY VERIFICATION

With the intent to verify the spatial-functional, technological-constructive and energy-environmental performance of the developed constructive system, it has been applied in three case studies located in Helsinki Finland, Rome Italy and Nairobi Kenya.

With regard to the environmental-energy performance, accurate analyses of the local climatic conditions (temperature, rel. humidity, wind speed, direct and diffuse solar radiation etc.) were conducted with the support of the software Meteonorm (fig. 3).

Figure 3     Example of climate data analyses: solar charts and monthly temperatures.

The climate data were the basis for the elaboration of psychometric charts (fig. 4), in which different design strategies and devices (thermal mass, passive solar heating, natural ventilation etc.) are verified in relation to the maximization of “users comfort zone”.

On the basis of this results, in each of the three chosen cities, appropriate strategies and devices have been developed and applied in a design project (fig. 5) that are shortly presented in the following paragraphs.
**Helsinki** (Cold climate: winter strategies and devices)

*Orientation of the building:* main axis direction east-west, $S/V = 0.56$ (compact form, low thermal dispersion), *U-value* Nord façade: 0.19 W/m²K (passive building) *Insulation material:* wood wool, *Window to wall ratio* Nord façade: 20% , *Window to wall ratio* South façade: 85%, *Other devices:* maximizing day lighting through windows in the roof and in the south side, efficient solar greenhouses, heating system (see figure 5).

**Rome** (Temperate climate: winter and summer strategies and devices)

*Orientation of the building:* main axis direction east-west, $S/V = 0.63$ (articulated form, medium thermal dispersion), *U-value* Nord façade: 0.35 W/m²K (compatible with the Italian regulation) *Insulation material:* wood wool and pressed cellulose, *Window to wall ratio* Nord façade: 30%, *Window to wall ratio* South façade: 50% in winter and 35% in summer, *Other devices:* building envelope characterized by a high thermal mass $M_s = 230$Kg, high thermal inertia $Y_{ie} = 0.10$ W/m²K , windows and solar screens suited to maximize day lighting and solar gains in winter and to minimize them in the summer, solar greenhouses in winter / porches in summer, passive cooling through stack and cross ventilation optimized for the specific climatic conditions, evaporative cooling, heating and cooling system (see figure 5) (Beckera et al., 2007; Filippin et al, 2007).
Nairobi (Hot climate: summer strategies and devices)

Orientation of the building: square plan around a outdoor covered collective space, $S/V = 1.12$ (permeable form), U-value façades: no thermal insulation, only acoustic insulation exclusively for classrooms (pressed cellulose or local materials), Window to wall ratio: ca. 35%, different for different orientation. Other devices: building raised above the ground separated volumes and raised roofs to maximize natural cross and stack ventilation, high heat loss common areas outside under a large cover that shields even the buildings below, no heating and cooling system (see figure 5).

The energy efficiency of these design choices has been quantified through a set of affordable design tools like: thermo K8 (a common practice used software for the analysis of thermal performance of multi-layered single constructive elements), Heat (to proof thermal bridges) and Autodesk Ecotect (a dynamic simulation model managing each thermal zone in an inter-zonal calculation process to evaluate the comfort level and to calculate the energy demand during the time). The energy performance is quantified under static and dynamic conditions and is verified (if possible) in relation to the regulation of the three different chosen countries (particularly Finland and Italy).

The analyzed parameters are:
- For the single constructive elements (particularly façades): U-value, superficial mass, thermal lag , decrement factor, periodical thermal transmittance, vapor diffusion resistance and air permeance (based on recursive-steady state calculation Glaser method).
- For the single rooms. Classrooms: thermal hydrometrical comfort - PMV, acoustic comfort, day lighting and lighting comfort on the floor and on the work level. Greenhouses: annual passive solar gain.
- For the whole building: annual energy demand for heating, cooling and lighting, annual passive solar gain in cold climate and in temperate climate in winter (see figure 6).

![Figure 6](image_url)

Annual passive solar gain - case study Helsinki.

From an energy simulation point of view the results consider thermal comfort range of 5°C temperature swing an 10% relative air humidity as a driver for air-mass-envelope exchange of sensible and latent heat according the idea of minimize, or exclude the role of HVAC facilities during three seasonal condition (spring autumn and winter). Even if the results of building simulations can be simplified it takes in account a sensible reduction in monthly degree day for heating and cooling according the energy saving methods in the three climate conditions. This acts as a whole building design considering alternative design solutions in a didactic perspective for students as a possible experimental platform to better improving cost, comfort and energy efficiency standards.

Simulations were not carried out after the project end but as very important part of a optimization recursive design process. Indeed, this “open-solution model generator” approach typical for the used software (in particular Ecotect) is a simple design methodology for the designer (e.g. architects) to control the different results and influences of a particular design solution (e.g. building shape or...
assembly method), air change rate, occupation, internal loads etc. to internal comfort level, energy demand and energy balance of the entire building. With the intent to minimize the use of active systems, passive solar analyses (fig. 6) are one of the most interesting intermediate results of this research for the appropriate use of devices like greenhouses, evaporative cooling etc.

All the simulations carried out in the three case studies have shown a high level of environmental comfort and an extremely small internal energy demand for heating, cooling and lighting in relation to the climatic zone. Kindergartens designed in Helsinki and Rome achieve the standard “near to zero energy building” (with the use of passive devices and active systems like photovoltaic and solar collectors). Moreover, in all three buildings PMV has values between -1 and +1 even in periods with extreme climatic conditions (Helsinki in winter or Nairobi in summer).

CONCLUSION

In conclusion, tests (design application, static and dynamic simulation) conducted in this research have shown that the developed reversible constructive system (applicable in temporary schools) combines good spatial-functional and technological-constructive qualities with a high level of indoor comfort and a low energy consumption for heating, cooling and lighting. Moreover, the system resulted extremely efficient also in very different climatic conditions, thanks to its easy adaptability to different configurations and strategies.

This work was born in a school of architecture as a graduate thesis presenting an environmental research scenario for locations with peculiar climate and performance needs based on the final better judgment from the design team. From an educational operative perspective the work of comparison between different performance responses is an open-mind attitude to stimulate the research in sustainable construction methods.

The architectures' primary role is guaranteed as the method gets a lot of dedicated input information to lead in the design phase. Each information can have a particular importance in processing the ideas from a sketch or from a detailed commission request, (for example from a local government program).

The collaborative role of building physics became not abstract or simply theory, but is addressed to be an useful cooperation design technique.

REFERENCES