Bioclimatic architecture as an opportunity for developing countries

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ABSTRACT

The proper adjustment of the architecture to the climate is one of the basic characteristics of vernacular building. Nowadays this area received an important support through the application of cutting-edge technology. Still, despite the clearly visible change of attitudes towards nature, more detailed analysis often lead to the conclusion that the arising buildings are very rarely based on extensive studies of local bioclimatic conditions. The purpose of this paper is to discuss how the traditional ways of adapting dwellings to the climate are combined with advanced technology and applied in contemporary bioclimatic buildings. Three important case studies are briefly presented in order to demonstrate that the relevant distinguishing feature of bioclimatic architecture is to go beyond the scheme of low-energy buildings, constructed from renewable materials and meeting the conditions of sustainable development certification systems. It is much more vital for the true green design to implement the structures in the ecosystem in such a way that they become an integral part of it. Thus understood bioclimatic architecture is logical, well adapted to the climate and therefore also economical. It creates great opportunities and should be perceived as the solution for the developing countries (as well as for the whole world).

INTRODUCTION

The idea of bioclimatic architecture is closely related to the proper adjustment of the dwelling to the climate. That is also one of the characteristics of vernacular building, based on the traditional ways of adapting architecture to the specific climatic conditions. Vernacular architecture is directly linked to the available resources that influence building techniques (Balbo, 2013, p.37). Furthermore, it is customized to the functional needs and cultural background of the inhabitants. The main difference between vernacular and bioclimatic building lies in the ability to select the technological solution most appropriate to the climate. In traditional architecture that kind of knowledge has been naturally transferred from one generation to another. In bioclimatic building the concept of architecture optimally adapted to the local conditions received an important support through the application of advanced technologies. Due to the combination of traditional climatic solutions and cutting-edge technology, bioclimatic dwelling is well suited to the needs of the contemporary user. The other difference involves proper understanding of complexity and sensitiveness of the natural environment. Bioclimatic architecture is based on holistic approach, including in-depth environmental analysis. Ultimately, the bioclimatic building should become an integral part of the ecosystem and ensure the symbiosis between the cultural and natural processes. However, despite clearly visible change of attitudes towards nature, the alarming datum is that more detailed analysis of projects often lead to the conclusion that although the idea of so-called sustainable design is manifested all over the world, in fact, the arising edifices are
rarely based on extensive studies of bioclimatic conditions as the wider aspect of the problem is sometimes simplified (or even ignored) within the design process oriented towards the energy certification achievement (e.g. Telles, 2012).

Analysis of the various solutions, used in similar climatic conditions, combined with the application of contemporary knowledge allows to develop and to implement technologies that will help to customize the newly erected buildings to the requirements of the modern user. Two biggest challenges in this area are connected with the indoor climate and lighting (McIntyre, 1980; Mahdavi, 1996). Adequate lighting of the interiors with the use of daylight not only positively affects the user comfort, but also has a significant impact on reducing electricity consumption. Although this aspect is considered by the designers more often than the natural cooling, the proper use of daylighting should be further promoted.

The necessary factors of the comfortable indoor microclimate are: thermal comfort, proper air humidity, adequate air exchange rate, the correct oxygen content (this parameter can be improved for example by the introduction of green plants inside the building) etc. In most of developing countries the challenges of thermal comfort derive from the necessity of cooling the indoor air. Despite many criticism, the plant air conditioning systems are so widespread that they are most frequently applied in purpose to provide low temperature and low humidity in the buildings (Mahdavi, 1996). That kind of cooling is commonly used, especially in the offices, retail spaces or public buildings, regardless the high costs, electricity consumption, environmental impact and without considering the application of natural systems, based on local bioclimatic conditions. In many cases the only difference between conventional and so-called sustainable building is limited to the fact a part of electric energy for air conditioning systems comes from photovoltaic panels or other renewable sources.

**NATURAL VENTILATION SYSTEMS IN HOT CLIMATE**

Cooling systems in vernacular architecture in hot climate zones are based on natural ventilation. Among various schedules observed in traditional dwellings there are three basic models distinguished by Sørensen, that may be applied in contemporary bioclimatic architecture (Sørensen, 2008). These are:

1. Cross ventilation based on the pressure difference across the building shown in Figure 1a.
2. Chimney ventilation based on the stack effect i.e. underpressure caused by the rising hot air shown in Figure 1b.
3. The wind catchers and wind towers based on overpressure and underpressure presented in Figure 1c.

![Figure 1](image)

**Figure 1** Basic models of natural ventilation. Based on Sørensen (Sørensen, 2008).

In many regions some modifications improve these basic systems. In hot and humid regions, e.g. in Thailand, many traditional houses are openwork and built on high stilts, so that the cross ventilation is combined with the elevated floor as described by Tantasavasdi and presented in Figure 2 (Tantasavasdi et al., 2001; Tantasavasdi et al., 2007). In Japan, where the temperatures are lower, the floor is slightly raised above the ground. In both cases the air flows under the building to cool it in summer and – in case of the Japanese house – to separate it from the ground in winter. Also in both dwelling types the roof drainage systems (made of natural materials) allow for collecting rainwater.

Different solutions may be observed in hot and dry climatic conditions of Arab countries where the wind towers and wind catchers are quite common. They may be additionally combined with simple but
effective evaporative cooling systems described by Hassan Fathy (Fathy 1986) as shown in Figure 3. On the basis of these solutions some holistic concepts for bioclimatic architecture were created. The leading architectural workshops in this area are Mario Cucinella Architects (MCA) and TR Hamzah & Yeang.

![Figure 2 Natural cooling in Thailand. Based on Tantasavasdi (Tantasavasdi 2001).](image)

![Figure 3 Evaporative air cooling system in Egypt. Based on Fathy (Fathy 1986).](image)

ENVIRONMENTAL STRATEGIES IN THE CENTRE FOR SUSTAINABLE ENERGY TECHNOLOGIES (CSET) DESIGNED BY MCA

Centre for Sustainable Energy Technologies (2006-2008, Ningbo, China) was designed by Mario Cucinella Architects in cooperation with School of the Built Environment, University of Nottingham. The edifice is located in the Nottingham University new campus in Ningbo and it is dedicated to “(...) the diffusion of sustainable technology including solar power, photovoltaic energy, wind power and so forth” (Giorgi, 2006, p.90). The building itself represents advanced environmental strategies developed in direct relation to the local context. A very interesting hybrid system was applied in the project. It is based on the knowledge gleaned from vernacular architecture of hot climate areas (both dry and humid) and successfully combined with high-tech, environmentally safe technology. The non-conventional air-conditioning systems are supported with the cutting-edge technologies for the exploitation of renewable energy sources. The project was created with an intention to take the maximum advantage of the local bioclimatic conditions and to minimize the environmental impact of the building. Following the results of the local climate analysis, the designers developed the structure that allows to reduce the energy demand for heating in winter and cooling in summer. During the intermediate seasons (spring and autumn) the natural ventilation, triggered by a series of automated openings, provides comfortable temperatures and humidity, so there is no need to use plant air conditioning systems. Regarding the climatic conditions it was essential to establish the proper thermal insulation and create massive structures with high thermal capacity. The crucial part of the heating and cooling concept was the carefully controlled air movement within the building.

In hot and humid summer the passive cooling strategies are applied. Thereby the usage of plant systems is significantly diminished and limited only to the hottest days. During the warm part of the year the layer of the ground, located below the land surface, is colder then air. The incoming air is pre-cooled naturally when passing through the earth-to-air heat exchanger constructed in the form of a series of pipes buried in the ground as shown in Figure 4. Subsequently the air is further cooled and dehumidified by the air handling unit (AHU). Similarly the ventilation air coming through the air inlet in the tower is cooled and dehumidified by the AHU placed in a coverage. A solar chiller that pre-cools the external air for the tower ventilation is powered by hot water from solar tubes. Thus prepared air is distributed throughout the building. The chimney effect fastens the air exchange and the warm air is removed through the windows placed in the double skin south façade.

High thermal inertia of the green roof in the lower part of the building prevents overheating while thermal mass of the concrete surfaces supports the coolness distribution. The geothermal heat pump
produces cold water for cooling the concrete floors. The radiant cooling from the ceilings is effective and healthy so that the mechanical cooling is required exclusively for pre-cooling the incoming ventilation air. In such a way the correct passive cooling design of the building and the high inertia of its concrete structure provide optimal indoor microclimate during summer.

The angles and materials of the southern part of the building were designed to pre-heat ventilation air in winter. The external air inlets are located on the ground level, at the bottom of the double skin façade so that during sunny days the air is naturally heated by the passive solar gains. After reaching the appropriate temperature the air is distributed in the edifice. Other air inlets are situated in the ground, outside the building. The incoming air is pre-heated by the earth-to-air heat exchanger. Further heating is provided by the geothermal heat pump, which is powered by energy from the photovoltaic panels. The air heating system is integrated with the radiant air-conditioning ceiling. The radiating coils embedded in the floors are activated when it is necessary to heat ventilation air. The heat is stored by the concrete ceiling slabs and released gradually to provide proper thermal comfort during the day. The northern façade is well insulated to avoid heat loss during the cold season of the year. The heat transfer coefficient of the opaque walls is 0,25 W/m²K and of transparent parts 1,2 W/m²K.

![Diagram of building heating and cooling systems](image)

**Figure 3** Centre for Sustainable Energy Technologies (CSET, 2006-2008, Ningbo, China) by MCA, environmental strategies – summer. Drawing © MCA.

The whole building envelope was designed in favor to provide maximum usage of natural light as it was possible without glare and overheating during summer. Such solution reduces the use of artificial lighting and thus also the electric energy consumption. All the necessary artificial lighting systems are characterized by high luminous efficiency and low power consumption. Electricity, required to power that lighting as well as the office equipment, comes from especially redesigned photovoltaic system. The energy surplus produced during maximum solar radiation periods can be stored in batteries or sold to the nearby sports center. The BEMS (Building Energy Management System) controls the building operation and manages active and passive systems to optimize comfort level, while reducing energy consumption.
All the environmental strategies were chosen in purpose to create contemporary bioclimatic building that provides proper balance between local climate factors (sun angle, air and earth temperature in different seasons, wind, humidity), ecosystem (plants and species of the area), technology (including renewable energy sources) and the occupant needs (indoor comfort, reference to Chinese culture). The educational value of the project is connected with promotion of the concept of bioclimatic architecture that derives from the environmental studies and therefore is very well adapted to the natural and cultural context.

**BIOCLIMATIC ARCHITECTURE AND ECOSYSTEMS**

It should be noted that while sustainable development program in architecture strongly accentuates local aspects, under the label of sustainable architecture there is often an attempt to create a global golden rule of architecture. The evaluation methods are inherently characterized by some averaging, but the creation of the built environment truly adapted to the bioclimatic conditions requires an individual approach. Conducting environmental analysis is necessary each time for the specific location. Moreover, due to dynamic nature of ecosystems, analyses should be repeated and changes monitored (Yeang, 1996). Increased attention is given to the relationship between the architecture and the ecosystem (Hart, 2011). Ken Yeang, one of the most important creators and promoters of bioclimatic architecture, notes the necessity of integration of the following Eco Infrastructures:

1. Green - connected with natural habitats and the environmental biodiversity.
2. Gray - related to engineering that include sustainable energy and technologies oriented towards low environmental impact as well as zero CO$_2$ emissions.
3. Blue - concerning water management, rainwater harvesting and gray water recycling.
4. Red - referring to human culture i.e. law regulations, social norms and habits, user comfort, standard expectancy, materials as well as the human impact on the environment.

Each part of infrastructures described above is analyzed and developed in close relation to the existing ecosystem, with the intention to restore, preserve and enrich its equilibrium and biodiversity. Proper implementation of that strategy into the bioclimatic design leads to the authentic adaptation of architecture to the local context. Thus created holistic approach is an important distinguishing feature of bioclimatic architecture.

**RELATION TO THE ECOSYSTEM ON THE EXAMPLE OF SOLARIS BUILDING DESIGNED BY TR HAMZAH & YEANG**

Holistic and consequent approach to bioclimatic architecture can be observed in Solaris (2011, Singapore,) designed by TR Hamzah & Yeang. This 79-meters high structure is situated in Fusionopolis, in the area of the former military base which now became a fast developing business and research area of Singapore. Since the existing ecosystem was seriously damaged, one of the main goals of the architects was to restore and enrich its biodiversity in purpose to create equilibrium of the natural and built environment. Therefore the continuous perimeter ramp, with a length of 1500 meters, was designed to introduce maximum amount of green area into the building. The landscaped ramp established the link between One-north Park that reaches directly the building façade and Solaris towers. The higher tower has 15 and the lower 9 floors. Both of them house research facilities and offices. All the areas of the building are connected to the spiral ramp and passively ventilated atrium. The service path that goes through the ramp provides direct access for plants maintenance and is used as the linear park that leads up to the roof gardens on the top of each tower. This continuous landscaped spiral with a minimum width of 3 meters was designed for the benefit of the environment, as it enables fluid movement of small organisms between green areas of the edifice and thus contributes to biodiversity and health of the ecosystem. At the building corners the ramp expands to the terraces. As a consequence total landscaped area of the project covers 8,363 m$^2$, with the site area 7,734 m$^2$. That results with 108% ratio of landscape to site area and 95% of the landscaped area located above the ground level.
Bioclimatic concept combines traditional solutions developed for hot and humid climate zones with the most contemporary technology and knowledge. The climate-responsive façade design is based on studies of local climatic conditions, including the sun-path analysis. The specific building location at the equator and the east-west sun-path affected specific requirements of the façade shading. The first element of this strategy is the ramp with deep overhangs and the abundance of shade plants. The second solution in favor of the ambient cooling are the sunshade louvers with shape and depth determined directly by the solar-path analysis. The louvers and the green ramp created a pleasant buffer space which significantly reduced solar gains and glares. Consequently the heat transfer through the low-e double-glazed façades was also considerably decreased. The external thermal transfer value (ETTV) of the whole system is 39 W/m².

Figure 4  Solaris (2011, Singapore), by TR Hamzah & Yeang, bioclimatic section. © TR Hamzah & Yeang.

An atrium situated between the two towers is fully passively cooled and supports natural ventilation and daylight distribution within the internal areas of the building. An operable glass-louvered skylight system was installed on the roof over the atrium to enable stack effect cooling. Computational Fluid Dynamics (CFD) simulations were carried out to provide optimal thermal comfort with the controlled air flow in the atrium. Simultaneously, the active energy use was diminished. Both the louvers and the rainscreen walls are controlled by climate-responsive sensors to ensure protection against the precipitation and to allow natural ventilation during the rain. The atrium is directly connected to the landscaped area on the ground floor, linked to One-north Park which allows for cross ventilation. In order to provide optimal daylight penetration within the building's interior, the diagonal solar shaft was designed. It crosses the structure from the top of the higher tower down to the street level. The solar shaft gained more attractiveness with the landscaped terraces situated inside. Additional daylight is received from the façade shading louvers that create also double light-shelves and redirect the light into the building. To optimize the system performance a series of sensors measure the illumination level. When the sensors register a sufficient amount of daylight, the artificial lighting is automatically switched off. Thereby the energy consumption is reduced. As pointed out by Council on Tall Buildings and Urban Habitat (CTBUH), the reduction in overall energy consumption in Solaris building reached 36% compared to relevant precedents (CTBUH, 2012).

Due to the large amounts of vegetation located within the building, it was necessary to solve the
The problem of irrigation in an efficient and environmentally safe way. Based on the concept of bioclimatic design the attention was focused on the high average of rainfall in the area. Consequently a large-scale rainwater recycling system was proposed. Rainwater is harvested on the roof via symphonic drainage and on the perimeter ramp with the drainage downpipes. It is then stored in rooftop tanks and at the lowest basement level, beneath the place called Eco-cell. Eco-cell is located on the ground level at the building’s north-east corner, at the beginning of the ramp. It allows for penetration of natural light and ventilation air as well as for the plants extension into the car-park area below. A total storage capacity of Solaris rainwater tanks is over 700 m$^3$, which almost entirely covers the demand for watering plants. An integrated fertigation system provides plants with essential organic nutrients.

The project of Solaris building is adapted to local context on many levels. Similarly to CSET the design concept is based on analysis of the environmental factors, such as sun-path, sun angle, temperature and humidity. Moreover, the project’s bioclimatic strategy seriously takes into account the individual character of the ecosystem, including the need to restore and enrich its biodiversity. Consequently, the idea of bioclimatic architecture is created in equilibrium with the natural environment.

Two edifices described above: CSET and Solaris, are pioneering on a global scale. Promotion of such an approach is extremely important, as it helps to establish a model for developing countries. However, it is worth to notice that on a local scale it is possible to create bioclimatic architecture also with much lower budget. Solutions based on contemporary knowledge and technology, well inscribed into the local conditions and determinants, can be implemented at minimal cost. An impressive example was set by MCA who designed the school in Khan Younis, in the Gaza Strip.

![Diagram](image.png)

Figure 5  Kuwait School in Khan Younis (Gaza Strip, from 2014) by MCA. © MCA.

**KUWAIT SCHOOL IN KHAN YOUNIS, GAZA STRIP, BY MCA.**

The project of Kuwait School in Khan Younis (Gaza Strip, from 2014) was developed by MCA in partnership with UNRWA (The United Nations Relief and Work for Palestine Refugees in the Near East), with the financial support of the Kuwait Fund for Arab Economic Development. The aim of the concept was to create a green school that will provide high user comfort for 1500 children and will be totally safe for the natural environment. As the project is dedicated to the challenged area of Gaza Strip, where an access to most of resources is very limited, all the materials have to be affordable and locally sourced. The lack of fresh water is a very serious problem in Gaza Strip. Electricity is produced from
generators that cause environmental pollution. To deal with this facts Cucinella proposed the pilot project to promote green approach, which may be “part of the solution to the demographic boom in Gaza where people are struggling to build homes and schools with the resources they have” (Aburawa, 2012). Therefore an off-grid building, possible to build only with locally available and renewable resources was designed. All the construction systems are as simple as possible, avoiding excessive use of advanced and expensive technologies. The only exception concerns the implementation of photovoltaic cells, solar panels and thermal technologies that improve the quality of life without harming the environment.

The Kuwait School was designed as bioclimatic building, well adapted to the local climate and environment, with an intention to enhance the biodiversity of the ecosystem. The whole construction was created in such a way that its elements support bioclimatic strategies. The concrete foundation slab provides thermal mass. Low-cost pillars designed to increase inertia, are made of concrete-earth blocks pre-casted on site, with a diameter of 2.2 m and the inner cavity filled with ground from the excavation. Vaulted slabs are made of compressed earth block. Thus formed flat arches represent traditional and very simple building technique which does not require any formwork. Overhanging roof is made of inexpensive steel beams and reflective corrugated metal sheets. The overhang allows for natural ventilation and shades the earth-brick walls. Thermal control in the building is achieved with the earthen walls and floors providing thermal mass and protecting the interiors against direct solar gain during hot days as well as against cold winds. Further elements that prevent overheating are the façade shading panels and the overhanging roof. Air pipes, located beneath the foundation slabs, cool the ventilation air in summer and heat it in winter. 18 solar chimneys fasten the exhaust air extraction from the building. Finally, the inner courtyard was designed to create pleasant green area, support natural ventilation and reduce heat island effect.

Electricity, necessary to power electrical devices, will be provided by 1272 m$^2$ of amorphous photovoltaic cells located on the roof. Hot water for the heating coil will be delivered from 100 m$^2$ of the vacuum solar heaters. The classrooms will be naturally illuminated with daylight. Such designed building will have zero CO$_2$ emissions, will use zero oil and its heating demands will be 7 kWht/m$^2$ per year with 0 kWht/m$^2$ per year for cooling purposes.

The rainwater harvested from the roof will be used for the hygienic purposes. It will be stored in an underground tank. The recycled waste water will be used for flushing toilets (grey water) and for the plant irrigation (black water). This strategy will result in reducing water demand by 60 %. Each year water savings will bring 4600 m$^3$/y from waste water and 486 m$^3$/y from rain water.

In the project there are numerous references to the local tradition that makes it more accessible to residents and allows to express respect for their cultural heritage.

CONCLUSION

In the three case studies presented above traditional solutions developed in vernacular architecture were used as the inceptive idea as well as the source of inspiration for contemporary bioclimatic buildings. Basic methods of passive cooling and natural ventilation, commonly used in hot climate areas, were hybridized to achieve the optimal performance. In purpose to obtain the high level of indoor microclimate comfort, corresponding to modern user expectancies, advanced technology was applied. In first two edifices their budget allowed for some exemplary technological solutions, especially regarding climate responsive façade design as well as air preparation and distribution throughout the building. In CSET the non-conventional air-conditioning systems were supported with cutting-edge technologies for the exploitation of renewable energy sources. In Solaris the issue of restored, enriched biodiversity and the equilibrium of natural and built environment was of the utmost importance. The project of Kuwait School proved that the contemporary knowledge and technology, well inscribed into the local conditions and determinants, can be implemented at minimal cost. While photovoltaic cells, solar panels and thermal technologies were used to improve the quality of life, the whole architectural conception is based on passive strategies, simple construction methods and locally available, renewable resources.

The study presents the concept of bioclimatic architecture through the proper balance between
traditional ideas and modern technologies. This notion allows for practical and creative usage of contemporary knowledge transfer. Nowadays original methods, dedicated to various climatic determinants, developed and verified in different parts of the world, can be supported and improved by the application of cutting-edge technologies. Although in-depth analysis of local biological and climatic conditions should always be a starting point, the worldwide information exchange can result in entirely new hybrid systems designed for the specific location needs. It is worth to note that such an approach may be used also in the areas where the lack of indigenous examples hinders the selection of the most appropriate bioclimatic solution solely on the basis of vernacular buildings studies. Therefore the contemporary bioclimatic architecture can be defined as one that combines traditional knowledge about ways of adapting dwellings to the climate with advanced research, design and technological methods in purpose to create the built environment maximally integrated with the natural environment and especially with the ecosystem in which it is placed.

It should be emphasized that buildings that are well adapted to bioclimatic conditions do not exceed the budget for comparable facilities while their environmental impact is minimal. Growing respect for ecosystems results with architectural projects that enhance biodiversity for the benefit of natural and cultural environment. Thus understood bioclimatic architecture creates great opportunities and should be perceived as the solution for developing countries (as well as for the whole world).

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