Sustainable Habitat for Emerging Economies

Futoshi MIYAOKA
[Nihon University]

Khuplianlam TUNGNUNG
[Kobe Design University]

Yuichiro KODAMA
[Kobe Design University]

Arvind KRISHAN
[Principal, CASA]

ABSTRACT

Affordance of thermal comfort, as a key to sustainable habitats in emerging economies, entails a socio-economically responsible response to the imperatives of local climate, low-energy, and lifestyle changes. Since passive house thermal comfort depends on occupant’s lifestyle, low-energy architecture that integrates passive techniques and lifestyles becomes avant-garde. Thermal comfort is the absence of discomfort in the occupants’ mind because of the body’s interaction with environment parameters: temperature, humidity, and air speed, which are enhanced by ventilation. Since socio-cultural lifestyle changes due to globalization and developments resulted in new notions of comfort and adaptation to heat producing equipments, lifestyle is recognize as essential to low-energy paradigms during operations, and heat loss or gain through appropriate ventilations and storage of heat or cold in high thermal mass envelopes could be beneficial. The case study, Bidani Eco-house in Faridabad by Dr. Arvind Krishan is a haveli inspired plan form with appropriate open-spaces, orientation, or geometry, and envelope with low U-value local stones and glass facade, which are expected to reduce heating and cooling load if integrated with lifestyle. Research methods encompasses questionnaire with users, field survey, monitoring of hourly indoor temperature with data loggers, and a series of parametric simulations with Solar Designer ver. 6. The paper discusses passive techniques and lifestyles, through 1) indoor temperature fluctuation without air-conditioning to highlight the effects of ventilation modes, air change rates, and thermal mass on environmental comfort parameters, 2) comparative energy performance analysis of annual (2013) cooling, heating, and lighting load with GRIHA benchmark to validate the successful integration of lifestyle and passive design. The house low-energy EPI (Energy Performance Index) of 126MJ/m²/year shows that thermal comfort is affordable with relative low-energy in a rapidly changing cultural expectation of modern life.

INTRODUCTION AND BACKGROUND

This paper, essentially, reports "Sustainable Habitats for Emerging Economies" from the perspectives of "thermal comfort" afforded by the integration of passive design and lifestyle as a low-energy solution during operations. Thermal comfort, as a subjective response or state of mind, is primarily influence by the body’s heat exchange with the environment parameters: temperature, humidity, air speed (Olesen & Brager, 2004), and corresponds to a temperature range of 20-30°C DBT and 30-60% relative humidity in still air. (Govt. of India, Energy. n.d.). Personal parameters: clothing, activity, or metabolic rate s are not covered in this report. Economic developments and socio-cultural lifestyle changes due to globalization resulted in new notions of comfort and adaptation to heat producing equipments, high energy use, and subsequent lost of the native habitats milieu. So, lifestyle is recognize as essential to low-energy operations. In India, lighting and household appliances such as: refrigerators, air conditions, water heaters, and ceiling fans accounts for 10% of electricity consumption,

1. Enclosed courtyard in private mansions in India and Pakistan.
while housing and commercial sectors accounts for 29% of electricity consumption and rises at the rate of 8% annually. (Govt. of India Planning, 2011). In India, majority of the households are dependent on ceiling or table fans for cooling in summer, and air-conditioning use is relatively less. In view of the construction as the second largest economic activity (8%), and the projected urban population of about 600 million by 2030 (Govt. of India Planning, 2011), India's energy consumption during construction and operations is expected to increase, exponentially. This paper is limited to low-energy imperatives during operations, and doesn't cover full life cycle cost analysis for the construction period.

Traditional architecture manifests the local climate, lifestyle, and materials. Faridabad, located at coordinates: 28.9°N, 77°E; and 216m above mean sea level is in ‘composite climate’, with extreme climate swings: maximum DBT of 45°C for about 2 and half months, followed by hot-humid monsoon, and minimum DBT of 3°C for a shorter winter heating period. The region, besides some haveli typology housing, is largely characterised by dense settlements, and compact planning with narrow pedestrian access that serves as socio-spaces and extension of work spaces to the semi-public ground floors adjacent to the access routes. In the poorer sections of the city, houses are often constructed next to each other with little or no setbacks. Traditional homes, in the area, are introverted spaces with a courtyard open to perimeter rooms and sky, high thermal mass local stone walls of 400-500mm thick, roof with 50mm stone slabs supported by wooden beams, small size openings with Jaalis and Chajjas for privacy, airflow, and shade, as shown in Figure 1. (Archinomy, n.d.). Shops and bathroom serves as buffer, and terrace can be used for outdoor sleeping. With the first floor reserved for women folks, these traditional introverted houses have small openings on the exterior walls, but larger openings to the internal courtyard. Bidani Eco-house is located in a medium density Faridabad residential neighbourhood, mostly with 1 or 2 storey detached houses on a plot size of 1000m².

Motivation and Objectives

The past decades have witnessed unprecedented revolution of science and technology that brought great economic and socio-cultural benefits. However, it was also a nature-human dichotomy period, when vernacularism or passive design ideologies escaped our collective wisdom, subsequent adaptation to heat producing equipments, generic modernism, and destruction of the native habitats milieu. In an emerging society where majority of its population can't afford active heating and cooling systems, passive design techniques that envisaged reduction in artificial lighting, heating or cooling, and innovative use of locally sourced low embodied energy materials are key to low-energy paradigms. In Delhi's traditional architecture, mutually shading haveli heat sinks, high thermal mass local stone walls keep the inside cool due to time-lag in the day while its high emissivity allows rapid cooling of the surface at night. Within the framework of socio-cultural changes and new notions of lifestyle comforts, the paper aims to highlight Bidani Eco-house passive techniques, its integration with lifestyle, and subsequent low-energy paradigm when compared with GRIHA² energy performance benchmark.

HYPOTHESIS AND METHODOLOGY

Re-interpretation of traditional passive techniques and pragmatic response to the adverse or advantageous climatic parameters, such as: temperature, solar radiation, humidity, air speed, etc presents sustainable habitat solutions, in contemporary emerging economies. Its subsequent manifestation in architecture is primarily defined by the availability of resources on the one hand, and lifestyle-praxis on

3. Perforated stone or lattice screens in Indo-Islamic architecture.
4. Sun-shading device for roof or windows in India, and usually supported on large carved brackets.
the other. Unlike traditional compact plans, modern buildings produced much heat of their own and heat loss or gain through appropriate ventilations or air changes through open-spaces and storage of heat or cold in high thermal mass envelopes, through responsive lifestyles, could be beneficial. Through site observations and measurements with data loggers and a series of parametric simulations and analysis with Solar Designer ver. 6, the paper highlights 1) passive low-energy architecture techniques in the house, 2) effects of ventilation modes, air change rates, and thermal mass on thermal comfort parameters in various seasons, 3) energy performance analysis with GRIHA® and simulations. Data loggers was logged from 7th - 10th January, 2014, in the living room and bedroom, and simulations were performed for a whole year covering 3 representative days of each of the 12 months, and best ventilation modes and air change rates were highlighted, in a manner close to how the house is operated.

THE ARCHITECTURE

Passive strategies differs base on a place climatic parameters: temperature, radiation, humidity, air speed, etc and their re-interpretation on the site, plan form and geometry, and envelope limits or allows the structures heat gain or loss. Given the composite climatic pre-requisites, Bidani Eco-house attempts to account for varied complex low-energy imperatives: minimizing summer heat gain during hot-dry season, maximization of passive ventilation during the hot-humid periods, passive solar heating in winter, and visual comforts. While the plan form and geometry’s orientation aids or hinder solar radiation, the large volumetric composition of the living space with adjacent haveli¹ heat sink is expected to enhanced porosity, thereby, ventilation and air-changes while thermal mass walls and mud-phaska² roof attenuates heat gain in the day, it enhance heat loss at night, as shown in Figure 3 & 4. Additionally, mutual shading with haveli¹ voids and solid blocks or pergolas and trees, thermal buffer spaces, and evaporative cooling from water sprinkled on the front lawn are expected to reduce heat gain.

Table 1. Passive Design Techniques in Bidani Eco-house

<table>
<thead>
<tr>
<th>Area/ Location</th>
<th>Passive Techniques</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Grass lawns and perimeter trees</td>
<td>Evapotranspiration, bio-purifier</td>
</tr>
<tr>
<td>Plan form &amp; geometry</td>
<td>Re-interpreted haveli¹ typology with</td>
<td>Heat sink, minimize heat gain,</td>
</tr>
<tr>
<td></td>
<td>minimum east &amp; west exposure</td>
<td>visual comfort, privacy</td>
</tr>
<tr>
<td>Buffer</td>
<td>Toilets, stores, garage on S-west</td>
<td>Reduce heat gain</td>
</tr>
<tr>
<td>Courtyard</td>
<td>Pergolas and north-east location</td>
<td>Shade, heat sink</td>
</tr>
<tr>
<td>Roof</td>
<td>RCC with mud-phaska² and stones</td>
<td>Insulation, thermal mass</td>
</tr>
<tr>
<td>Ceiling</td>
<td>Concrete, white paint</td>
<td>Diffused light, visual comfort</td>
</tr>
<tr>
<td>Walls</td>
<td>Low U-value local stones and concrete</td>
<td>Thermal mass, low-energy</td>
</tr>
<tr>
<td>Fenestrations</td>
<td>Eaves/awnings, single glass, wire mesh</td>
<td>Natural ventilation &amp; safety</td>
</tr>
<tr>
<td>Floor</td>
<td>Stone with mortar on concrete</td>
<td>Ground contact, thermal mass</td>
</tr>
<tr>
<td>Verandah/ Porch</td>
<td>Deep eaves and pergolas</td>
<td>Shading</td>
</tr>
</tbody>
</table>

Site Landscape

The house creates its own landscape microclimate in responds to the adverse local composite climate and air pollution, within its inscribed territory. Bidani Eco-house with a built up area of 295 m² on a site area of 1000 m² has a width to depth ratio of 1:3, with the shorter side oriented towards the north and access road, which restricts design flexibility and limits generation of ideal plan form and geometry, or orientation. During the hot summer seasons, open lawns with >50% grass cover, and perimeter trees provides shade, acts as a bio-purifier to the hot-dusty air and cools the environment by evapotranspiration, and increase air speed due to narrow path of the hedges and open spaces, as shown in Figure 2. The site’s access road runs east west, and adjacent buildings and landscape trees provide shading from the harsh morning or afternoon sun from east and west.

Plan Form and Geometry

Buildings plan form’s compactness or openness, and thereby, porosity to its surrounding landscape or geometric composition with respect to solar geometry, and envelope thermal mass can aid or hinder heat gain or lost, while its orientation can be crucial to control solar radiation and stabilizing extreme temperature swings. Temperature swings in the house is expected to be stabilized by shaded Northeast.

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5. A type of waterproofing on roof terrace in India. It consist of a mortar bed of mud soil compacted by pressing with a weighty instrument, laid to slope and tiles are laid on top.
**Figure 2** (a) Plan form with spaces layout around N-east oriented *haveli*¹, and test rooms: 1. Atrium Living room, 2. Bedroom, and (b) High thermal mass walls with local stones, or concrete and greeneries.

*haveli*¹ heat sinks, high thermal mass local stones or concrete envelopes to the east and west, as shown in **Figure 2 & 3.** The *haveli*¹ heat sink opened towards northeast forms the central fulcrum, like traditional dwellings, with various spaces: bed rooms, dining room, large volumetric living space, etc around it, as shown in **Figure 2(a).** The oblique alignment of the plan form and geometry is expected to enhance passive cooling since only the narrowest elevations are exposed to the east-west low angle solar radiation while *mud-phaska*² roof allows the building to consistently minimize high altitude mid-day solar radiations, but allows indirect natural light for visual comforts, as shown in **Figure 3.** Pergolas, louvers, eaves, and awnings provides shades to openings. The large atrium living-room with low sills wraps around the shaded N-East *haveli*¹ heat sink, and the geometry of its ziggurat-like roof structure with glass and louvers on the vertical side allows for low altitude winter sun to penetrate while doubly functioning as summer time's hot air exhaust vent, as shown in **Figure 3.** These passive techniques, in combination with responsive lifestyle, such as: flexible cooling from various ventilation modes or air-changes as per seasonal conditions and evaporative cooling from vegetation are expected to maintain indoor "thermal comfort" in summer and winter, with low-energy.

**Figure 3** (a) Summer cooling with geometry & pergola shading and heat sink to *haveli*¹, and louvers, (b) Winter heating from south-east low altitude solar radiation.

**Building Envelope**

A building's envelope encompasses walls, floors, roof, windows, etc. The materials such as: high thermal mass local stones and concrete for the main envelope, beige granite stone floor (originally terrazzo), RCC slab roofing with *mud-phaska*², etc, are all locally available within reasonable distances, and thereby, low embodied energy, as shown in **Figure 4.** Local stonewalls with 1.5Wm⁻² low U value (Roaf, S, et al. 2001) and concrete provide thermal mass to attenuate diurnal thermal swings, and single glazed windows with safety grilles and awnings allows night ventilation in summer and southeast.
radiation ingress in winter. Buffer spaces, such as: toilets and stores, garage on the south-western perimeter, pergolas, eaves enhance thermal performance of the building by eliminating solar penetration to living spaces, and thereby, reducing cooling load in summer time, as shown in Figure 7(b).

SIMULATIONS AND ANALYSIS

In order to highlight the most representative way the house is used and the role of the building fabric, in various seasons of the year, a matrix combinations of ventilation modes, and air change rates were analyze through parametric simulations with Solar Designer ver. 6 (http://qcd.co.jp/). The outcomes are discussed in hourly indoor temperature fluctuation for various climate conditions of winter and summer, and monthly best for a whole year, as shown in Figure 5 & 6. Representative days of each month were selected based on the weather conditions: very sunny, cloudy, and sunny. These 3 days, after extensive parametric simulations, were found to be representative of the months' ambient temperature fluctuation pattern. The simulated atrium living room is 15m x 7m x 7m high to account for extra volumes of adjacent abutting smaller rooms, and openings of size 8mX5m on the S-East and 2mX2.4m on the N-east were incorporated, as shown in Figure 2 & 4. N-East and S-West walls are considered to be 30cm thermal mass local stones with low U-value of 1.5Wm⁻², and others are 23cm concrete with plaster and no extra heating affect was considered from adjacent rooms. The floor is in earth contact, and adequate insulation added for mud-phaska⁵ roofing along with 20cm RCC. Deep eaves, both vertical and horizontal are incorporated considering the geometry, as shown in Figure 3 & 4. As internal heat sources, a constant 418.68kJ/h for refrigerators, 1.8MJ/h for laundry 2 hours/day, and 1.67MJ/h for 2 family members and 2 domestic help were set everyday for 8 hrs. Windows have curtain insulations.

Extensive parametric simulations for various ventilation mode and air change rates for winter (January) and summer (May), on representative days, shows the best ventilation modes: night-ventilation
(30 ACH at night, 1 ACH in the day) in summer, and in winter air-tightness (1 ACH, both in the night and day), as shown in Figure 5. Next, monthly best ventilation modes and ACH for a year were selected and temperature fluctuation in the test room highlighted for each month, as shown in Figure 6. The maximum solar radiation on the South facade was about 2.657 MJ/m$^2$ in January and 1.2 MJ/m$^2$ in May, and the glass serves as the media for heat egress in summer and solar heat ingress in winter, as shown in Figure 3. The monthly average indoor temperatures are: January, 17.4°C; February, 19.2°C; March, 24°C; April, 24.24°C; May, 31.3°C; June, 31.3°C; July, 30.7°C; August, 30.4°C; September, 28.4°C; October, 26.22°C; November, 22.83°C; December, 19.06 °C, as shown in Figure 5 & 6. The maximum monthly temperatures for cooling period were: May, 36.86°C; June, 35.98°C; July, 35.04°C; August, 34.4°C; Sept, 31.6°C; October, 30.1°C, as shown in Figure 6. Based on this findings and the heating, cooling and lighting loads for the year 2013, we could surmise that attenuation of indoor temperatures swings in summer and lifestyle responsive to seasonal and daily temperature fluctuations have resulted in reduce energy consumption, as shown in Figure 7(b). Thermal performance of the atrium living room, "as-built orientation" and hypothetical "south orientation", was analyzed from the perspectives of energy performance, and, "as-built orientation" was about 4.9% more energy efficient under Flex Vent System, 18°C< AT <30°C, with 30ACH when AT (Ambient temperature) is 18-30°C, and 0.5ACH at other times for 8 hours occupancy per day. The envelope has sufficient number of operable doors and windows. Active cooling was required for parts of summer. However, night-ventilation allows the natural microclimate to prevail and the room air temperature dropped to almost the same level as the outdoor temperature, while closing the openings during the day allows the high thermal mass envelope to retain lower indoor temperature throughout the day in summer, and thereby energy savings. In hot-dry periods, evaporative cooling from water sprinkled grass lawns and ventilation airflow afforded by optimized open spaces and haveli$^1$ attenuate heat gain. In winter, daytime ventilation or 'air-tightness' and green house effect from south-east facade glass could afford an average indoor temperature of about 17.4°C and extra heating was required, as shown in Figure 5(a). Discomfort Index, DI=0.81Td+0.01H(0.99Td-14.3)+46.3, where Td=Indoor Temperature(ºC), H=Relative Humidity (%), developed by the American Weather Bureau (US) in 1957, was used to calculate DI after finding the absolute humidity in g/kg of dry air, and relative humidity(%) on psychrometric chart. One percent of the population feels unpleasant if discomfort index exceeds 75, and all will become uncomfortable if it exceeds 80. The house, as-built, is uncomfortable with Discomfort Index above 75% in May, and parts of summer months, as shown in Figure 5(b).

Figure 6  Simulated monthly best temperature (°C) fluctuation from January to December, in atrium living room (as-built), due to the effects of ventilation modes, air changes, shading, and thermal mass.
ENERGY PERFORMANCE ANALYSIS AND SITE MEASUREMENTS

The building envelopes high thermal mass helps in attenuating extreme temperature swings. But it also resulted in a stable low temperature, as shown in Figure 7(a). The atrium living-room recorded a low temperature of 15.5ºC average, with a high of 24.1ºC because of high thermal mass and painting of the top glass openings on south-east that blocks off solar radiation. The bedroom, on the other hand, has a comfortable indoor temperature of 19.2ºC average and a high of 24.1ºC since a heater was used and the bedroom had access to Southeast and Southwest solar radiation through glass windows and thermal mass walls retains heat, as shown in Figure 2(a). Through questionnaires, the authors ascertained thermal comfort, was afforded by Flex Vent system, where a conditioner was on when the temperatures are not within comfort zone, say 18-30ºC. At other times, operable openings are opened and plenty of ventilation and air changes were allowed. The DI, Discomfort Index for site measurement was below 75% in both cases, as shown in Figure 7(a).

The authors conducted site measurements on the 7th to 10th of January 2014, as shown in Figure 7(a). Bidani Eco-house is a residential building with a total built-up area of 295m², and a multi-generational residence. The grandparents live in the ground floor, approx. 195m², while the son and his wife, and grand children used to live in the upper floor, approx. 100m². The house occupancy is 24x7 for the grandparents, but the son and family do not continuously live in the house. Additionally, domestic helps encompassing a mother, father and 2 children also stays in the house sometimes. The possible sources of heat in the house are electronic equipments, such as: computers, TV, portable heat radiators, room electric heater, kitchen cooking stove, etc. The total heating, cooling, and lighting loads for 12 months, in 2013, was 37440MJ. According to GRIHA Version 3.0, “the annual energy consumption of energy systems in a residence (24x7 occupancy) should not exceed the benchmark limits of 360MJ/m²/year, as shown in Figure 7(b). Eco-house Bidani's Design EPI (energy performance index) of 126MJ/m²/year and 192MJ/m²/year for the total floor area and pro-rata occupied area respectively, as per occupancy validates the performance of passive design techniques, as well as the Bidani family's lifestyle responsiveness to passive ventilation cooling or passive solar heating, as shown in Figure 7(b).

Simulations were done to analyze energy performance index for Eco-house Bidani, if the house was fully occupied all year round, and total heating and cooling load was 63265MJ for 295m². So, the simulated energy performance index (EPI) for the whole building under Flex Vent System (18-30) was 214MJ/m²/year which is lower than GRIHA benchmark of 360MJ/m²/year, as shown in Figure 7(b). Energy performance for the house was calculated by applying the actual pro-rata area of 195m² (occupied area), to the current annual (2013) consumption of 37440MJ and the result 192MJ/m²/year. The actual EPI was lower than simulated heating and cooling load of 214MJ/m²/year, which further validates lifestyle responsiveness of the occupants.
CONCLUSIONS

In contrast to the conventional practices of closing doors and windows at night for security and to keep off unwanted bugs, appropriate ventilation modes or air changes through lifestyles responsive to diurnal and seasonal climate swings, resulted in a low-energy, efficient EPI (Energy performance index) of 126MJ/m²/year for total area. Bidani eco-house attenuated extreme climate swings of a composite climate through passive design techniques infused into the plan form, geometry, and orientation to minimize solar radiations in summer and enhance southeast winter sun or visual comfort. While local stones high thermal capacity afforded time lag, its high emissivity enhance heat loss at night. The historic usage of *haveli* or the high thermal mass of local stones, and evaporative cooling prevalent to Delhi’s vernacular architecture are effectively re-interpreted towards "comfort affordance" through passive cooling or heating in summer or winter. Though 100% thermal comfort is not possible through passive cooling or heating, it is possible to reduce peak energy load. The build form and envelopes contiguous relationship with climatic parameters: temperature, radiation, and airflow directly affect the internal heat gain or loss. As learning, this paper highlighted various passive cooling and heating afforded by re-interpretation of traditional passive design techniques and subsequent integration with lifestyle towards low-energy paradigms for emerging economies. In view of Delhi's extreme climate and conduction of ambient heat, good solar glass could further attenuate heat gain or loss. Furthermore, the paper validates the possibility of using an interactive design tool, Solar Designer and Energy bills or GRIHA² benchmark for energy performance as an effective method in assessing the design as well as lifestyle-praxis. To conclude, passive design techniques and responsive lifestyle praxis are both a necessity for low-energy sustainable habitats in emerging economies during operations.

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