Affordance of Thermal Comfort Through Passive Design: A Case Analysis on Effects of Ventilation, Shading, and Thermal Mass in Delhi

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ABSTRACT
As concomitants to developments and globalization, Indian modernism witnessed unprecedented socio-economic and lifestyle benefits on the one hand, and adaptation to high-energy habitats and lifestyle, and subsequent degradation of the native habitats milieu, on the other. Unlike compact traditional buildings or occupants' lifestyle, modern buildings and its inhabitannts generate much heat. House-2 in Delhi by Morphogenesis, conceptualized as a ‘porous’ object with adequate thermal mass, is a radical re-interpretation of haveli typology to optimum plan forms to account for modern lifestyles and environmental imperatives. Thermal comfort is affected by the body’s heat exchange with the climatic parameters, and engineering of conduction, convection, radiation of heat or cold through various effects of ventilation modes and air change rates, solar shading, and thermal mass envelopes are hypothesized to afford better indoor environmental conditions; and thereby thermal comfort with low-energy. Solar Designer Ver 6 and Ecotect (2011) were used for analysis and simulations of the following cases: 1). House 2, As-built and light thermal mass with no shading, 2) 3 prototype rooms to check ventilation effects on glazing area, thermal mass, and insulation. The results are shown in 1) hourly indoor temperature fluctuation without air-conditioning and Discomfort Index, 2) annual heating and cooling load in a year. The analysis shows that Flex Vent mode was more energy efficient than Normal conditions without ventilation. While thermal comfort was not fully afforded for during summer, passive design in House 2, as-built, perform better than light thermal mass, and hence improved energy efficiency. Hypothetical case analysis showed insulation was insulating in both summer and winter for the hypothesis cases.

INTRODUCTION
Affordance of thermal comfort mandates passive design techniques that account for low-energy imperatives during operations, such as: reduction in artificial lighting, heating or cooling, and innovative use of low embodied energy materials during construction. In India, housing and commercial sectors accounts for 29% of electricity consumption and rises at the rate of 8% annually. (Govt. of India Planning, 2011). The case study, House-2 in Delhi by Morphogenesis, was conceptualised as a platform to investigate two issues central to design today: the family as a social unit and the environment. The residence is a network of water bodies and re-interpreted L-shaped landscape. The forecourt landscape with grass, open spaces and retaining ‘heat’ or ‘cold’ with high thermal mass envelopes are expected to be conducive to thermal comfort.

RESEARCH METHOD
The last few decades of Indian modernism, as concomitants to socio-economic developments, imported technology and praxis without context increase energy demands and degraded the native habitats milieu. Given the complex multi-functional needs of modern buildings, pragmatic re-interpretation of traditional passive techniques into contemporary design as a response to the socio-economic and low-energy imperatives becomes utmost. In traditional architecture passive techniques, such as: haveli provides solar shading, grass lawns and water bodies provides evaporative cooling; high thermal mass walls and roofs attenuates diurnal heat gain, and its high emissivity allows rapid cooling at night; and Jaalis afforded privacy and airflow. (Ali, A. 2012). Historical references are: Taj Mahal, Red Fort's emperor’s throne divan-o-khas, Agrasen ki Baoli step-well in CP, Delhi. etc. This paper aims to highlight effects of ventilation modes and air change rates, solar shading, and thermal mass envelopes on environment parameters: temperature, solar radiation, airflow, and thereby thermal comfort.

RESEARCH METHODOLOGY
Thermal comfort, as a subjective response or state of mind, is primarily influenced by the body’s thermal exchange with the environment climate 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 (0.5-1.0 clo), activity, or metabolic rates (0.8-9.5 met) are considered to be suited to the season, and the occupants skin temperature and sweating rate as indicated in PO Fanger’s Comfort Analysis are not covered. Human body cools down in 3 processes: convection, radiation, and perspiration which are enhanced by ventilation (United States, DOE, Energy. 2001). This paper analyze thermal comfort from the perspectives of the environmental parameters due to the effects of ventilation modes and air change, shading, and thermal mass, through conduction, convection, and radiation of heat or cold. Compact traditional buildings or its occupants lifestyle produce little or no heat, where as modern buildings produced much heat of their own, and heat loss through appropriate open-spaces can be beneficial. (Kishan, A. 2001). Ventilation to favorable microclimate through open spaces and retaining ‘heat’ or ‘cold’ with high thermal mass envelopes are expected to be conducive to thermal comfort. Besides site survey in Dec, 2013, analysis and simulations were conducted with Solar Designer ver 6 and Ecotect (2011) on effects of ventilation modes, air change rates, shading, and envelopes thermal mass or glazing, and insulation for a year in House 2, as-built, light thermal mass, and 3 prototype rooms. The paper highlights simulation results in 1) hourly indoor temperature fluctuations and DI (discomfort index), 2) annual heating and cooling load in normal and flex vent systems.

THE ARCHITECTURE: PASSIVE DESIGN TECHNIQUES

1. Enclosed courtyard in private mansions in India and Pakistan.
2. Perforated stone or lattice screens in Indo-Islamic architecture.
3. Mughal emperor’s Hall of Private Audience with important guests to deal with important state affairs.
4. Step well to cope with seasonal fluctuations in water availability and evaporative cooling.

Figure 1 (a) Building plan form with re-interpreted haveli for heat sink, shade, and airflow; (b) Build envelope with wood and limestone cladding and landscape trees. Images: Courtesy of Morphogenesis (architects). A ‘place’ vernacular architecture and passive design techniques are the manifestation of the local climate, socio-praxis, function, resources and its re-interpretation is expected to afford relative thermal comfort with low-energy. Given the composite climate pre-requisites and complex programme functions, House-2, in response, was conceptualized as a porous object, through a network of water bodies and re-interpreted L-shaped haveli plan that serves as heat sink, shade, airflow or air changes, and envelope with high thermal mass and high emissivity, and visual comfort, as shown in Figure 1 & 2. Site Landscape
House 2’s site has a zoning constraint, width to depth ratio of about 1:3 with the shorter side oriented to north entry, and the need to provide for a built-up area of 1508m² on a limited site area of 1003m². Given the pre-conditions that inhibit generation of ideal plan form and geometry or surrounding dusty environment, the site was conceptualized to be a veritable oasis with its own microclimate afforded by radical re-interpretation of haveli2 landscape. The foreground landscape with grass, tropical plants serve as bio-purifiers and evaporative cooling, while terrace lap-pools and lotus pond afford evaporative cooling, and perimeter trees provides shading, as shown in Figure 1 & 2.

Building Plan Form and Geometry
The solar altitude and azimuth, determines the position of the sun. And House 2’s orientation, plan form and geometry with respect to sun, compactness or openness envelopes porosity and thermal mass are expected to favorably regulate convection,
radiation, and conduction of heat or cold. Given the composite climate extremities, House 2 has a solar glass facing the N-east haveli heat sink and lap-pool, operable for night ventilation and heat egress, while high thermal mass envelopes with wood and limestone cladding in the South and West controls heat ingress, as shown in Figure 1 & 2. These passive design techniques and perimeter trees minimize low altitude east and west solar radiations. Heat conduction is further attenuated with buffer stairs, services, and lap-pool, as shown in Figure 1 & 2. The barrel roof and walls high thermal capacity is expected to provide longer time lag, and high emissivity external surfaces are expected to enhance heat loss to sky at night. An outdoor terrace pool deck and haveli lawns, as shown in Figure 2, save energy by reducing indoor occupancy hours. The diurnal solar geometry’s shading pattern was analyzed with Ecotect (2011) for summer, on June 22nd from 8:00 a.m. to 18:00 p.m, as shown in Figure 3, winter, spring, and autumn solstices. The analysis shows that the plan form and geometry, landscaped trees, and projected eaves shaded the east glass surfaces adequately, except for a brief interval from 9:00 to 11:00 a.m, as shown in Figure 3.

RESULTS AND OUTCOME: COMPUTER SIMULATIONS ANALYSIS

Figure 9:00 a.m.

Figure 11:00 a.m.

Figure 13:00 p.m.

Figure 3  Shading analyses for House 2 with Ecotect (2011) on 22nd June with East facade mostly shaded through the day.

Figure 2 & 3

Thermal performance of the building was analyze using Solar Designer Ver. 6 (http://gcd.co.jp/). In Delhi, with high temperature swings, ventilation, and air changes allows the more comfortable part of the day's microclimate to prevail and be retained in the thermal mass, through night-ventilation in summer, and day-ventilation or air-tightness in winter. The simulated living-room atrium, in House 2 (as-built) is considered to be 17m x 12m x 7m high, with high thermal mass in the south and west, high performance glass in the north-east, and adequate insulation for the envelopes wood and limestone panels, as shown in Figure 1 & 2. Deep eaves, horizontal and vertical, are considered as per shading analysis, as shown in Figure 3. As internal heat sources, a constant 0.84MJ/h for refrigerator, 1.8MJ/h for laundry and dishwashers 6 hours/day, and 3.3 MJ/m²/day for hot water, a daily load of 3.6MJ/h. The maximum solar radiation on the east facade was about 2 MJ/m² in January and 2.7 MJ/m² in May, and the glass serves as the media for heat loss to the shaded northeast haveli as shown in Figure 2 & 3.

The monthly average indoor temperatures are: January, 18.11 ºC; February, 20.4°C; March, 25.26°C; April, 24.4°C; May, 31.4°C; June, 31.1°C; July, 31.3°C; August, 30.8°C; September, 28.7°C; October, 26.47°C; November, 23.97°C; December, 20.22°C, as shown in Figure 5 & 6. The maximum indoor temperatures for cooling seasons were: May, 37.1°C; June, 36.36°C; July, 35.9°C; August, 34.7°C; Sept, 31.8°C; October, 30.33°C. Thermal performance of House 2, “as-built” and “light thermal mass”, was analyzed from the perspectives of DI (discomfort index) and energy performance, and two extremities for January and May are highlighted. Discomfort Index, DI=0.81Td+0.01Hd(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. House 2, as-built, is much more stable and lower than hypothetical House 2 with light thermal mass though Discomfort Index was above 75% (uncomfortable) in May and parts of summer, as shown in Figure 6(b). Annual heating and cooling load for Normal vent without ventilations in House 2, as-built, was about 16% higher than Flex Vent system, 18ºC AT -30°C, with 30ACH when AT (Ambient temperature) is 18.30 ºC, and 0.5ACH at other times, as shown in Figure 7(a). In hypothetical “light thermal mass” envelopes: 115 thick brick walls with no claddings and single glazing on east facade, energy consumption in Normal case increase from Flex Vent system due to the effects of ventilation modes, air changes, shading, and thermal mass.

The simulated, monthly best, indoor temperature (ºC) fluctuation from January to December, in atrium living room (as-built), due to the effects of ventilation modes, air changes, shading, and thermal mass, is shown in Figure 5. In order to cover the extremities of Delhi’s cold, hot-dry and hot-humid composite climate, the maximum solar radiation on the east facade was about 2 MJ/m² in January and 2.7 MJ/m² in May, and the glass serves as the media for heat loss to the shaded northeast haveli as shown in Figure 2 & 3.
temperature swings reduces energy consumption, as shown in Figure 7(a). Further simulation and analysis was done for 3 prototype rooms: A, B, & C each measuring 7mx4m with 1mx2.50 door each, to check ventilation effects on glazing area, thermal mass, and insulation. Room-A has a 6mX3m glazing with a 2m eave on South, Room-B & C have small glazing 2mx0.5m. Only Room-C was insulated with 10cm thick glass wool. Room-C with night-vent (30ACH at night, 0.5ACH in day-time) in summer, and all-day close (0.5ACH, day and night) in winter performed best and holds potential for reducing heat and cooling load, as shown in Figure 7(b). Besides solar radiation and convection, conduction of ambient heat through glass or low thermal capacity walls resulted in high summer temperature in Room-A & B, despite providing adequate sunshades.

Energy Performance Analysis

Figure 6 (a) Thermal comfort parameters: temperature (°C), RH(%), Di in House 2 living-room, As-built, and Light thermal mass, in January. (b) Thermal comfort parameters in May for House 2 As-built and Light thermal mass envelopes.

Figure 7 (a) Simulated heating & cooling load in House 2, as-built and light thermal mass, for 9 hours occupancy/day. (b) Simulated effects of night-vent (30ACH) in summer. All-day close (0.5ACH) in winter for hypothetical cases: A, B, & C.

SITE MEASUREMENTS AND ANALYSIS

The field survey of House 2 was done in the atrium living room and south conference on 16-18th December 2013. The conference room, due to its south and west exposure, thermal mass, and small openings has >20°C, and stable >70% average humidity, living room has low <20°C, and less stable <70% average humidity, as shown in Figure 8. In both cases, the walls high thermal capacity attenuates indoor temperature rise, and peaks at 16:00 hours though the external temperature peaks at 12:00, and retained heat to maintain a comfortable indoor temperature, when the external temperatures ranges from 13-27°C.

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INFERENCES AND CONCLUSIONS

The paper, essentially, highlights passive techniques conducive to affordance of thermal comfort with low-energy, from the perspectives of environmental parameters: temperature, humidity, and air changes. Personal parameters: clothing, activity, or metabolic rates, or skin temperature and sweating rates are not discussed in this report. Passive features regulate climatic phenomena of convection, radiation, conduction of ‘heat’ or ‘cold’ through different ventilation modes, air-changes, shading, and envelope materials. In summer, from May to October, thermal comfort was not afforded for fully, without active cooling. However, simulation studies shows that passive strategies and responsive lifestyle could attenuate heat ingress or enhance heat egress through night ventilation in summer, while allowing warmer natural microclimate to prevail and be retain in thermal mass through day ventilation or air-tightness greenhouse effect in winter. While 100% “thermal comfort” may not be possible through passive cooling it is possible to reduce peak energy load, considerably. The high thermal mass walls, and evaporative cooling prevalent to Delhi’s vernacular architecture have been radically reinterpreted while retaining progress of architectural heritage. The envelopes thermal mass, and air-tightness resulted in better insulation, from the less favorable climatic conditions of ‘cold’ or ‘heat’ from outside during summer or retaining heat generated by interior equipments, greenhouses, etc. in winter. The building allows for regulation of solar radiation by shading, convection of ‘heat’ or ‘cold’ through optimized forms or operable openings with various ventilation modes and air-changes, and storage of the same with high thermal mass envelopes. While high thermal mass help in attenuating heat gain in summer, it could also result in low stable temperatures in winter. Hypothetical analysis shows insulation was effective in summer and winter. Last, but not the least, heat loss or heat gain through conduction from atmospheric heat in summer can further be regulated more efficiently by optimizing the glass and concrete ratio on the perimeter surfaces at appropriate locations towards affordance of a thermally comfortable milieu that remembers the past, embrace the present challenges, and envisaged the future.

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