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Passive Design for Indoor Thermal Environment in Building

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Abstract—*Thermal comfort-the state of mind, which expresses satisfaction with the thermal environment, is an important aspect of the building design process. This paper reviews the importance of passive techniques and research developments in indoor thermal comfort around the globe, and groups these developments around two main themes; thermal comfort in ancient residences of India and technical advances in thermal comfort in modern day construction. Finally the paper questions the policies in adopting the conventional technologies against appropriate technologies in minimizing the embodied energy as against the thermal comfort achieved.*

1. INTRODUCTION

Passive design in buildings responds to local climate and site conditions in order to maximize the comfort and health of inhabitants while minimizing energy use. Passive design strategies refer to any technique or design feature adopted to reduce or increase the indoor temperature of buildings without the need of power consumption. The key to passive design is to take best advantage of the local climate. Surrounding vegetation and water bodies also plays a very important role in passive technique to achieve thermal comfort. Various research works have also been carried out on cool roof techniques so as to reduce temperature in building interiors, which is very economical and efficient. Consequently, the aim of this study is to review current studies by various researchers to improve thermal performance of buildings interiors by adopting various design consideration, materials and passive techniques.

Human thermal comfort is defined as the conditions in which a person would prefer neither warmer nor cooler ambiances. According to British Standard BS EN ISO 7730, thermal comfort is defines as “the condition of mind which expresses satisfaction with the thermal environment”. Thermal comfort describes a person’s psychological state of mind and is usually referred to whether someone is feeling too hot or too cold. To achieve thermal comfort, the body must balance its heat gains and losses, while also responding to the prevailing environmental conditions namely temperature, humidity and ventilation. Thermal neutrality is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. The main factors that influence thermal comfort are those that determine heat gain and loss, namely air temperature, mean radiant temperature, air speed, relative humidity and materials used for construction. Under good thermal conditions, the human body can function at optimum levels, thus maintaining a good productivity. [2]

Thermal comfort needs may vary in different areas of the world based on the climate. India is a tropical country with composite climatic condition. The combination of high temperature and high relative humidity adversely affects the thermal comfort and indoor air quality. Special attention is hence needed to ensure thermal comfort within the buildings located in tropical climates.

Due to the severity of the prevailing conditions in tropical climates, comfort cannot be achieved by the functions of the body itself. Under such circumstances it is necessary to provide some assistance for cooling, either by adapting to natural, mechanical or hybrid means. Active cooling is a type of heat transfer that uses powered devices such as fans, air coolers or air-conditioners. Active systems work by using artificial energy to affect some kind of heat transfer, usually by conduction or convection. The term “passive” is used for an internationally established building standard with very low energy consumption [6]. Passive design has strong dependency on climate and areas. It is the most economical effective strategy for reducing energy consumption and maximizes thermal comfort inside the buildings. Applying passive cooling also improves indoor air quality, making the building more comfortable to live and work in. [1]

2. THE PRESENT PROBLEM

In the early 19th century and past, buildings were constructed keeping in mind the climate and the environment. The vernacular technologies like rammed earth, adobe, wattle and daub, cob walls (Fig. 1) used for masonry construction and thick roofs namely Jack arch roof, Madras terrace roof, Mud phuska roofs (Fig. 2) are exemplary examples which facilitated adequate passive thermal comfort strategies adopted in the tropical regions of India. Such buildings also featured larger number of small sized openings distributed throughout the building which helped in a better control of the ventilation within. The provision of fully paneled window and separate ventilators at higher levels can also be observed in such buildings.

With the increase in population and its concentration in urban and semi-urban areas, the pressure on land use pattern and maximizing the habitat has led to adopting multistoried buildings. With the advent of modern materials like cement, steel, reinforced concrete, polymer concrete, ferro-cement etc., trends in structural design of framed structures tend to minimize the ratio of carpet area to built-up area of the buildings. Structural designers are also inclined to taking up relatively modest reinforce concrete walls and roofs with thicknesses varying from 0.10m to 0.15m in place of 0.23 m thick brick masonry. Besides, the current practice by architects in employing fully glazed aluminum windows and deficiency of ventilators at higher levels for aesthetic reasons are some of the prevailing building technologies and techniques which differ from the past.

Use of such new trends in structural and functional components in buildings has decidedly disregarded the consideration of heat exchange in buildings. Applying large glazed areas on the external surfaces of the buildings in western countries which are exposed to colder seasons throughout the year helps in warming up its interiors and might be a relevant concept. However larger glazed areas for buildings in tropical climates like India would increase the greenhouse effects and increase the internal temperature in contrast to the basic outlook of maintaining heat loss from the buildings. The thinner walling elements additionally increase the heat gain process. Such deviations achieved through aesthetical requirements and fanciful patterns adversely affect the thermal comfort which forcefully need to be balanced by adopting active strategies like air conditioning. Moreover, unwanted thermal energy also accumulates in buildings and dwellings from a variety of sources, such as heat from interior appliances, equipment, and occupants. Undesirable thermal energy storage is a critical issue in the tropics where cement-based materials (concrete) are routinely used in the construction of buildings. Concrete and other cement-based material can absorb thermal energy for long periods of time especially when they are subjected to high ambient temperatures. Moreover, cement-based buildings retain thermal energy for periods of time exceeding the normal diurnal cycle and do not allow enough time to dissipate the absorbed thermal energy at night when backward radiation cooling is significant. As a result, mechanical air conditioning systems require considerable energy to maintain comfortable indoor conditions resulting in substantial energy costs.

In summary the vernacular materials and technologies of the past which were relevant to live in harmony with climate and environment are in conflict and contrasting to the new approaches. An efficient and inexpensive passive cooling system is needed which can be implemented readily using commercially available materials to help reduce energy consumption and cost. Passive techniques use free, renewable sources of energy to provide cooling, heating, ventilation needs for households which in turn will reduce the use of mechanical means. Attempts need to be done to practice all possible means of applying passive techniques before resorting to energy consuming mechanical systems.

Fig. 1: Traditional techniques for masonry construction using mud

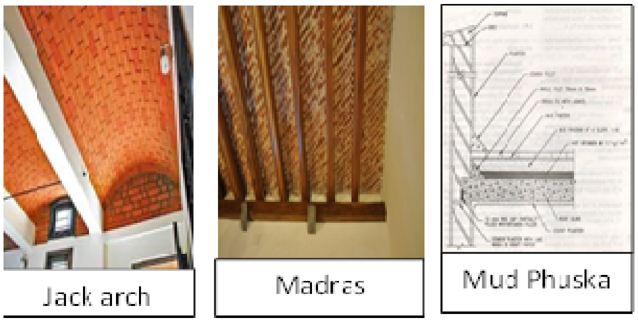

Fig. 2: Conventional Roofing Techniques

3. A REVIEW OF PREVIOUS WORK DONE

Efforts in the further sections have been made to collate the studies conducted in the past by various researchers in different parts of the world. Attempt has been made to compare the different research approaches under various titles as explained further.

Design Considerations

Nayak [4], has worked on design considerations and thermal performance of a hostel building using passive techniques for a composite climatic condition of Delhi, India. The place experiences three definite seasons: hot-dry early summer, warm-humid late summer (monsoon period) and cold-dry period in winter. Three different designs approaches were tried which included 1) Roof evaporative cooling system to provide comfort during summers, 2) Provision of south window with horizontal projection(for providing summer shade) to have direct heat gain for winter heating, 3)Effectiveness of ventilation achieved by providing a north window.

The ground floor of the building has been proposed to be partially underground. Partial sinking would allow greater use of the coolness of the earth in summer and reduce the wall areas exposed to insulation. The roof is also proposed to be three layered structure of brick, mudphuska and concrete of thickness 0.05 m, 0.10 m, 0.15 m respectively. It was observed that the demand of cooling during summer by using roof evaporative cooling and painting the roof white effected in reducing the indoor temperature by 6˚C. The direct solar gain through the southern window during the winter helped in maintaining an indoor temperature was 17˚C-18˚C in winter when the ambient temperature was 9˚C-10˚C. In order to ascertain the performance of the design, its thermal analysis using computer simulations was carried out and the performance was seen to be satisfactory. The analysis showed that the indoor temperatures were reduced to greater extent.

Raman et al.,[5] studied that passive solar heating is a well-established concept in cold climates, but passive systems which provide heating, cooling and ventilation depending on the season are less common. Large areas of Central and Northern India have a composite climate, which includes hot-dry, hot-humid and cold climatic conditions. This paper describes the development of a solar passive system, which can provide thermal comfort throughout the year in composite climates. In the first phase, first passive model comprising two sets of solar chimneys was developed and monitored for its performance for one complete year. A standard thermal network analysis was carried out to find out the thermal conditioning (heating/cooling) load of the building per unit volume for a design inside-outside temperature difference of 11°C for model 1 which worked out to be 2.904 W/m^3 K. In order to reduce this thermal conditioning load of the building, retrofitting measures were carried out on windows, door, roofs and walls.

The retrofitting measures were 1) windows were changed to double glazing panel with a curtain, 2) the door was insulated by adding a plywood sheet and a 25 mm thick thermocole sheet, 3) all the four walls were insulated from outside by providing a 25 mm thick thermocole sheet and a 25 mm air gap (the air gap was created by constructing a ferrocement cladding all around the walls), 4) similarly the roof was insulated from inside with thermocole and ply sheet was used to create air gap. Applying the analysis again the load of the modified structure was calculated to be 0.861 W/m^3 K. Performance of first passive model was satisfactory in winter it could maintain the indoor temperature at 19-20°C, which was considered as comfortable for Delhi's winter. The summer performance was not found satisfactory.

Based on the feedback and experience, an improved version, second model was developed. In second model both the trombe wall and sack cloth cooling concepts were incorporated, in order to make it more effective and also to give it a more compact and aesthetic appearance. The performance of the second passive model was much better than first model. The second passive model maintained the indoor temperature of about 28°C during summer and about 17°C in winter, which was considered as a very satisfactory performance for composite climate. The second passive model system consisting of a south wall collector, a roof duct wetted on the top side by an evaporative cooled surface, and insulated walls seems to have a good potential of achieving thermal comfort in composite climates experienced over larger part of India.

Building Material

Vaclav Koci et al., [6] carried out study on the architectural, constructional, and material solution of a brick-built passive family house with a computational analysis of the overall thermal performance. Software analysis was carried out. The first objective of the computer simulations was to find such a U value of external walls which would reduce the overall U value of the whole building. The obtained results show that the thickness of the thermal insulation layer can be reduced several times if hollow bricks with lightened brick body and sophisticated systems of internal cavities are used, instead of traditional bricks. In addition, it preserves some very important advantages characteristic for common brick structures, such as the fast water vapor transport through the wall, good thermal accumulation properties and fire resistance, or a low risk of biological degradation. Therefore, a hollow brick block can be considered a suitable construction material for the passive-house design. This solution is particularly suitable for the Central European countries where using ceramic brick, in general, in building structures is a well-established tradition; it was the most frequently used building material for many centuries.

Field Survey

Mishra and M. Ramgopal, [3] carried out a thermal comfort field survey inside a naturally ventilated laboratory in the tropical climatic region of India. The building chosen is used for courses in an undergraduate engineering curriculum. The study aimed at assessing how the occupants perceive their thermal environment in a school building while carrying out their normally scheduled tasks. A total of 121 acclimatized subjects were interviewed and 338 responses were collected during the months of spring semester. Survey results show a strong correlation between indoor comfort conditions and outdoor temperature. Occupants show adaptability across a comfort zone that is well beyond recommendations of rational models. Overall, 78% of the responses found their thermal environment to be acceptable. Based on indoor temperature observations, comfort temperatures were calculated for the subjects using Griffiths' method. The comfort temperature values are then related with prevailing mean outdoor air temperature to give an adaptive comfort equation. Predictions from the equation show satisfactory to good agreement with the predictions from similar equations in comfort standards.

Various Passive Approaches

Hanan M Telab [1], in her study postulated that passive design responds to local climate and site conditions in order to maximize the comfort and health of building users while minimizing energy use. The key to design a passive building is to take best advantage of the local climate. Passive cooling refers to any technique or design features adopted to reduce the temperature of buildings without the need for power consumption. Consequently, the aim of this study is to test the usefulness of applying selected passive cooling strategies to improve thermal performance and to reduce energy consumption of residential buildings in hot arid climate of Dubai, United Arab Emirates. One case building was selected and seven passive cooling strategies (shading devices, evaporative cooling, double glazing, indirect radiant cooling, natural ventilation, cool paints coating, green roofing) were applied. Energy simulation software – namely IES – was used to assess the performance of the building. Solar shading performance was also assessed using Sun Cast Analysis, as a part of the IES software. Energy reduction was achieved due to both, harnessing of natural ventilation and minimizing of the heat gain by applying good shading devices alongside the use of double glazing. It also showed that shading devices can block solar heat and could also provide lighting. Additionally, green roofing proved its potential by acting as effective roof insulation. The study revealed several significant findings including that the total annual energy consumption of a residential building in Dubai may be reduced up to 23.6% by adopting passive cooling strategies.

Roof Treatments

Yahyah Adil [9], conducted studies on roof pond cooling of buildings in Bagdad, Iraq having hot arid climates. The objective of his study was to cool the interiors with water from outside by using a roof pond. A building was used to test the effect of roof pond which was ventilated mechanically for summer cooling. Thermal measurements were taken for the room in normal conditions without pond and also with pond without any mechanical ventilation. The result showed a marked improvement in the interior temperature with a significant reduction during the peak time. Without a pool average interior temperatures were actually higher than ambient temperature. Adding a roof pond reduced the temperatures and also stabilized rises and fall in the interior temperatures.

Vanderley M. John [7], investigated the thermal performance of cool colored acrylic paints containing infrared reflective pigments in comparison to conventional colored acrylic paints of similar colors applied on sheets of corrugated fiber cement roofing in Brazil. Results demonstrated that the cool colored paint formulations produced significantly higher NIR Reflectance than conventional paints of similar colors, and that the surface temperatures were more than 10°C lower than those of conventional paints when exposed to radiation. The study shows that cool paints enhance thermal comfort inside buildings, which can reduce air conditioning costs.

Paulo Cesar Tabares-Velasco[8], conducted experiments on green roofs using vegetation as passive cooling technique. Experimental data collected in the “cool plate” apparatus show that evapotranspiration controlled the intensity of all other heat fluxes, depending on the plant and environmental conditions. Also, under the described laboratory conditions, the uninsulated green roof samples with plants showed an average heat flux reduction of 25% compared to samples without plants. This reduction was due to the plants providing extra shading, additional water storage and better water control mechanisms The results obtained were modest.

Their results showed that the outer and inner surface roof temperatures were reduced significantly. Several studies were conducted in roof pond cooling, passive cooling systems for cement-based roofs. Each study determined that passive cooling was the best method for lowering the roof temperature and inside air temperature.

4. CONCLUSIONS

Literature review shows that a lot of studies have been conducted on thermal comfort of existing buildings using passive cooling techniques. By implementing passive cooling techniques it is possible to achieve better thermal performance with low cost and maintenance.

Several factors have contributed to the existence of an inefficient building stuck in India, including a construction boom, lack of stringent green building practices and codes, artificially cheap prices of electricity compared to income and limited awareness with green building practices when compared to most of the advanced countries. So there is need to propose objectives such that the usefulness of applying various passive strategies is tested to improve thermal performance of buildings in India, which will also lead to reduction in energy consumption in residential building. Following are the suggested objectives-

- To study the indoor thermal performance of buildings having reinforced concrete roof subjected to
    i) temporary biomass cover (Coconut thatch) during summer
    ii) two coats of cool paint (acrylic based)
    iii) terrace vegetation
- To study the relative performance of different approaches to the passive cooling of roofs.
- To assess the thermal performance of building interiors by applying roof pond and terrace vegetation techniques.

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