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Thermal comfort in traditional buildings composed of local and modern construction materials

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Abstract

In recent years, there is a renewed interest towards the passive cooling features of ancient building architectures, which are cost effective, eco-friendly and best suited for the local climate. On the other hand, the modern construction materials, such as cement and steel, are highly durable. Thermal comfort of eight vernacular buildings that use modern construction materials to improve the structural durability was monitored in July 2014. The buildings are located in Hyderabad, India. They have many passive cooling features that include air cavities in the structures to reduce heat transfer, high thermal mass to reduce temperature fluctuation and induced ventilation to remove heat from the indoor. All the passive cooling features investigated were found to have an appreciable influence on the thermal comfort of the indoor space. The ventilated air gaps in the roof reduced the average temperature of the roof interior surface by 1.2 °C. The diurnal temperature fluctuation of the indoor air reduced by 0.9 °C in a building with a higher thermal mass compared to a building with thin walls and roof. All the eight buildings were found to be comfortable most of the time with a slight discomfort during late night and morning hours. The maximum CO_2 recorded was 550 ppm. This indicates that the buildings were adequately ventilated.

Keywords: Thermal comfort; Traditional building; Passive cooling; Modern construction materials; Building architecture; Energy conservation

1. Introduction

1.1. Need for a blend between local and modern construction materials

Construction techniques have evolved continuously from cave dwellings to modern high-rise buildings. Traditionally, buildings are constructed with locally available materials like stone, wood, mud and lime. In recent years, modern construction materials such as cement and steel have replaced most of the local materials, due to the high durability, low maintenance, low likelihood of corrosion and decay, and ease of construction of the former. However, modern construction materials are energy intensive and eco-destructive. The cement industry accounts for 2% of the global energy consumption and 5% of the global anthropogenic CO_2 emission (Worrell, 2014). The embodied energy in the modern buildings is 10–20% of its lifetime energy consumption (Deepak et al., 2014). In addition, the higher cost of the modern construction materials increases

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Nomenclature

t_n	neutral temperature, °C
t_{rm}	exponentially weighted running mean of outdoor temperature, °C
t_{od}^{-1}	diurnal mean outdoor temperature of the previous day, °C
t_{od}^{-2}	diurnal mean outdoor temperature of the day before and so on, °C
x	constant for response speed (varies from 0 to 1, recommended value 0.8)

the capital cost of the buildings. Therefore, buildings constructed with a predominant use of the local materials and a judicious use of the modern construction materials would be not only cheap but also durable.

1.2. Thermal comfort in vernacular architecture

Another important factor to consider during the construction of a building is the thermal comfort of the indoor space. However, in the past few decades, the thermal performance of the building is not considered during the design and construction phase. This results in buildings with a poor thermal performance. After the building is constructed, the indoor thermal comfort is achieved using mechanical air-conditioning systems that are not only energy intensive but also eco-destructive. This was not the case before the advent of the modern air-conditioning systems. Thermal comfort was achieved by designing the building to suit the local climatic conditions. For example, in hot regions, buildings were constructed with low ventilation to prevent discomfort from the infiltration of the hot outdoor air. In dry regions, the temperature fluctuation of the outdoor air is high. Hence, the buildings were constructed with a high thermal mass to reduce the temperature fluctuation of the indoor space. In warm and humid tropical regions, the ventilation in the indoor space was maintained high with wide building openings (windows and doors) facing the predominant wind direction, whereas the thermal mass of the building was low to avoid evening discomfort from the stored heat. In solar-intensive regions, the dome structured roofs were used to reduce the solar heat gain, as they provide self-shading and reduce the surface area to volume ratio.

1.3. Local Need for cheap, comfortable and durable dwelling

Rapid urbanization in India has increased the housing need in cities. In urban locations, the government provides housing to the poor, particularly during relocation of slums, to facilitate infrastructure development. It is estimated that the Indian government has constructed a staggering 13,000,000 houses in rural and urban locations and still 15,000,000 are estimated to be homeless (Reddi and Joglekar, 2005). In general, the houses provided by the government are not only small due to the high cost of the modern construction materials but also thermally uncomfortable due to the undesirable thermal characteristics of the construction material. Hence, a switch to the traditional architecture styles that have passive cooling features (Hatamipour and Abedi, 2008) and are cost-effective is considered. The traditional architecture would also improve local employment, as it is labour intensive. This would provide employment to the migrant workforce. In addition, the use of locally available materials would strengthen the local economy and results in a milder impact on the environment. However, vernacular architecture with pure local construction materials is less durable. Hence, new architecture with a blend of vernacular architecture (for passive cooling), local materials (for cost reduction and local employment) and modern materials (for structural strength) is developed.

1.4. Literature review

Passive cooling features of vernacular architecture have been extensively researched in recent years. Passive cooling can be broadly classified into heat prevention, heat modulation and heat dissipation.

Shading, thermal insulation, building orientation and glazing are a few heat prevention/reduction strategies. Zaki et al. (2012) simulated a conventional terraced house and found that the house would require mechanical air-conditioning for 24 h on a hot summer day. However, incorporating passive architecture like insulating roof and walls, adding shading devices to windows and orienting the building and windows in the best direction would reduce the mechanical air-conditioning requirement to 8.5 h. The potential of shading devices to reduce cooling demand is reported to vary from 10% to 50% (Prieto et al., 2017). In general, lower savings are reported for the buildings with a lower window–wall ratio. Use of louvers in a fully glazed building in Santiago, Chile, reduced the cooling demand by 54% (Pino et al., 2012). A 30% reduction in the primary energy demand (cooling and lighting load) was achieved by optimizing the design of shading device using a genetic algorithm (Manzan, 2014). In a tropical climate, solar heat gain through the roof was reduced by 63% using hollow clay tiles with a provision for ambient air to flow through it (Vijaykumar et al., 2007). Use of light colour paints (Suehrcke et al., 2008) and deciduous creeper

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