Comparing the thermal performance of ancient buildings and modern-style housing constructed from local and modern construction materials**

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The envelope of a building not only provides protection from the outside environment but also provides the thermal comfort required for its residents. Currently, interest is shifting towards the utilization of the passive cooling features of ancient buildings. Now, buildings are designed with a mindset of maximum use of solar and other renewable sources so as to reduce energy consumption and dependency on mechanical systems. Renewable energy utilization makes the building cost-effectively sustainable and almost by definition well suited to local climate. It is observed that the natural cooling arrangements provided in ancient buildings have considerable influence on interior thermal comfort. Such arrangements are often not considered when designing new structures. Hence, energy consumption in a modern structure is often greater for the same thermal comfort. Inside, humidity and room temperature, mean surface temperatures, air variation ratio and lighting are some factors affecting thermal comfort. The materials (such as cement and steel) used in modern construction are highly durable but not energy-efficient. A balance between energy efficiency and durability of modern buildings should be sought. This paper reviews the cooling arrangements in ancient buildings and compares thermal comfort inside them and modern structures.

Keywords: air temperature, air velocity, thermal comfort, thermal simulation, DBT = Dry Bulb Temperature, WBT = Wet Bulb Temperature

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1. Introduction

Nowadays the role of architects and engineers is increasing in the construction sector. When planning a building, along with its design, various factors need to be considered like its cost, environmental impact, aesthetic look etc. Building involves various steps from its preliminary designs to final construction. The various building systems put some restrictions on each other—they are interrelated. Each system has various subsystems; e.g., designing the building from an environmental point of view includes consideration of thermal, audio and video subsystems. This paper is about the thermal considerations when designing a building from the environmental point of view.

Sustainability must include consideration of the environmental, economic and social requirements all together when designing a building. All these aspects were indeed considered in ancient buildings but nowadays for modern structures building regulations mostly focus on environmental impacts, especially reducing the use of fossil fuel. Efforts are made to reduce CO_2 generation from construction of the building to its daily use. Ancient structures were already—indeed necessarily—sustainable with net zero energy consumption. As for the transportation of ancient building material, mostly men or animals were used, emitting little carbon. Even for lighting, interior heating and cooking, biomass was typically used, which is in itself a sustainable source of energy. Wind (aeolian) and water (hydro) energy were also used where available, either for transportation purposes or for aiding construction.

The paper compares thermal comfort in modern and heritage building (the tomb of Mohammad Ghaus) in Gwalior, India and the techniques that can be adopted from ancient buildings for creating better thermal comfort in modern buildings with less energy consumption. The temperature and humidity inside the heritage building was compared with the internal temperature and humidity of a modern-style buildings. The differences between the two are visualized by graphs.

2. Literature review

2.1. Research into traditional buildings

Some previous studies of traditional buildings in various parts of the world having different climatic conditions are summarized in Table 1.

2.2. Research on modern buildings

Some previous studies of modern buildings in various parts of the world having different climatic conditions are summarized in Table 2.

2.3. Comparison of traditional and modern buildings

A comparison of modern and traditional architecture in the north of Celebes by Sangkertadi et al. (2008) [13] evaluated ten modern and ten traditional buildings with 60 residents as the sample. The residents felt comfortable at temperatures up to 29 °C and relative humidity up to 60% with air flowing slowly.

Table 1. Observations on various traditional buildings.

№	Author(s), country & ref.	Buildings/ Structures	Building features and results	Climate
1.	Hatamipour & Abedi (2008), Iran [1]	Bushehr architecture	Properly insulated walls and roofs, light-coloured surfaces reduces heat gain through walls. Overhung shading, wooden sunshades and using trees for shading of buildings. High-roofed buildings with sufficient windows.	Hot and humid
2.	Dauda (2016), Ghana [2]	Jamestown lighthouse	The thatched roof, having pores, provides proper ventilation and allows hot air to escape through it.	Tropical
3.	Bodach et al. (2014), Nepal [3]	Vernacular houses	Courtyards and semishaded open spaces like verandas and balconies provide a cool environment in summer.	Subtropical
4.	Jain and Singh (2013), Bhopal, India [4]	Gohar Mahal	Includes landscaping, water bodies, orientation, site features, open spaces and envelope design.	Subtropical
5.	Manoj Kumar Singh et al. (2014), north-east India [5]	Vernacular buildings	Design was optimized TRNSYS 17 simulations. Windows and ventilators with large openings promote cross ventilation. Double-glazed windows and proper shading elements improve indoor thermal conditions.	Warm and humid climate
6.	Usha Bajpai and Sachin Gupta (2015), Lucknow, India [6]	Avadh architectural buildings	Due to its great thickness, the U-value of the wall was low. Usage of water and landscaping created a microclimate inside and around the building.	Warm and humid climate
7.	Mynani (2013), Tamilnadu, India [7]	Athangudi village buildings	Courtyard provides a cool inside environment during daytime.	Agricultural zone
8.	Praseeda et al. (2014), Bangalore [8]	Sugganahalli Building	Passive arrangements consume less operational energy under conditions of extreme climatic change. Embodied energy increases due to change in material. ASHRAE comfort standards and TSI model were used.	Tropical savanna climate
9.	Manoj Kumar Singh et al. (2010), north-east India [9]	Vernacular buildings	Carried out thermal performance evaluation of vernacular buildings. 50 vernacular houses with 100 residents were studied. Interior temperature swing did not exceed 10 °C. Interior day lighting was found to be insufficient.	Warm and humid climate

Table 2. Observations on various modern buildings.

№	Author(s), country & ref.	Buildings/ Structures	Building features and results	Climate
1.	Foudazi & Rithaa (2013), Western Cape, South Africa [10]	Residential buildings	Self-shaded courts, high ceilings, wall and roof with high thermal mass. East–west orientation with northern light roof, elongated north and south fronts for receiving daylight and natural ventilation.	Subtropical
2.	Sayed et al. (2013), Egypt [11]	"New Assist Housing"	Interior conditions were within acceptable bounds for natural ventilation and evaporative cooling taking bioclimatic conditions for the summer season into account.	Tropical
3.	Jayaseelan & Ganapathy (2007), Kanyakumari, Thirunelveli and Madurai districts [12]	Modern low-cost housing units	Houses at these three locations were thermally uncomfortable. Various solar passive arrangements were recommended to increase thermal comfort.	Tropical

Thermal performance of modern and traditional architecture in Thailand has been compared by Paruj Antarikananda et al. (2006) [14] using the ECOTECT simulation model. The modern structure consisted of brick walls, concrete floors and roof, plasterboard ceiling and tiles over the roof, while traditional buildings in Thailand have a high roof, adequate walls and windows and a central terrace. It was noted that the traditional structures, which use passive cooling techniques, are more responsive to extreme climatic conditions.

Modern low-income housing at Sarawak was found thermally uncomfortable as reported by Tinker et al. (2004) [15]. Traditional Malayan houses are well adapted to the prevailing climatic conditions and provide better thermal comfort inside. The comfort level has been investigated using computational fluid dynamics (CFD) and the corrected effective temperature index method. The authors observed that traditional structures are more comfortable than modern ones.

In Kerala, a questionnaire-based survey by Dilli et al. (2010 & 2011) of people living in traditional and modern buildings showed that 70% of people feel comfortable in traditional buildings in all climatic conditions while only 20% feel comfortable in modern buildings in the summer season [16, 17].

Subramanian et al. (2017) observed that the natural cooling arrangement in ancient buildings provides more thermal comfort than in modern buildings in all seasons [18]. They suggested employing the passive techniques of ancient structures in modern-style buildings.

Priya Shanthi et al. (2012) concluded that ancient buildings are more thermally comfortable than modern-style buildings in a similar environment [19]. The evaporative cooling phenomenon is the main cause for significant temperature variation between the inside and outside of ancient buildings.

3. Description of a selected heritage building (the tomb of Mohammad Ghaus)

A case study was conducted with the tomb of the prince-turned-sufi Mohammad Ghaus, situated in what is now the town of Hazira, Madhya Pradesh (Fig. 1).[1] It is around 500 years old—it was constructed on a rectangular plot facing east during the reign of the Mughal

[1] Latitude is 78.1774527° N and longitude is 26.2317800° E.

emperor Akbar in the 16th century and is a true example of Mughal architecture; the structure holds great importance in the history of the country. The beautiful tombstone itself and the stunning architecture of the mausoleum give the place a sense of serenity and peace, enhanced by being set in a lovely garden adjoining a cemetery for the saint's devotees.[2]

Figure 1. Heritage building (the tomb of Mohammad Ghaus) selected for the case study.

The mausoleum is built in the form of a square with hexagonal towers at its corners, each surmounted by a chhatri. More chhatris in blue tiles cover the tomb. The body of the building is enclosed on all sides by carved (using a pierced stone technique) stone lattices of elaborate and dedicated design, the whole being crowned by a large dome, which was once inlaid with blue glazed tiles.

4. Description of a selected modern-style building

The selected modern-style building is approximately 10 years old and just 150 m distant from the heritage building, and therefore has the same external climate. The building has two storeys (ground and first floor). It has three bedrooms along with other activity spaces such as veranda, study and kitchen (Fig. 2), with a maximum room height of 3.5 m. The brick walls are 10 inches thick and covered with cement mortar outside and with plaster on the inside. The concrete roof slab reinforced with iron rods provides no insulation. Single glazed windows are provided.

Figure 2. Modern-style building selected for the case study.

[2] The tomb is also the site of the annual Tansen Music Festival.

5. Methodology

The research objective is to compare the thermal comfort in a modern and heritage building in Gwalior (a subtropical region) and thereby discover techniques that can be adopted from ancient buildings for creating better thermal comfort in modern buildings with less energy consumption. For the case study, the building was selected from a range of naturally cooled heritage edifices considering various factors such as shape, size, design plan, types of ventilation and the physical attributes of the building such as construction type and material properties. Parameters characteristic of the internal and external climate, viz. temperature and relative humidity, were determined from wet bulb and dry bulb thermometers complemented by thermocouples and hygrometers in one heritage building and one modern-style building from morning (8:00 am) to evening (5:00 pm) for an interval of two days in the month of April[3] (i.e., during the hot summer season).

6. Results and discussion

Results are shown in Fig. 3. The ambient (external) temperature had a temperature swing of 17.3 °C (i.e., from 24.0 to 41.3 °C), while inside the ancient ("heritage") building the swing was only 5.8 °C (i.e., from 23.2 to 29.0 °C). During the night the internal temperature was maintained at around 23.2 °C while outside it was around 25.8 °C. The relative humidity inside fluctuated from 56% to 100%. Compared with ASHRAE[4] standards, the inside temperature fell in the thermal comfort zone. This favourable condition can be ascribed to the ancient building's thick wall, large veranda, curved terracotta roof tiles, yards, and wind catchers above the yards promoting natural ventilation and, hence, cooling. On the other hand the room temperature inside the modern-style building did not fall in the comfort zone of the ASHRAE standards. The reasons can be found in the concrete roofs reinforced with iron rods, small sunshades, thin walls, and minimal ventilation for cooling. Hence, occupants of such buildings sometimes resort to the use of electrically powered air cooling and conditioning machines, which consume energy.[5]

It should be noted that the minimum temperature in the ancient building was 22.5 °C, but 28.0 °C in the modern-style building. Similarly the maximum temperature in the modern-style building was 5.5 °C higher than in the traditional building.

Fig. 4 shows the temperature swings: while the external (ambient) temperature swung from from 26.9 to 42.0 °C, a range of 15.1 °C (Fig. 3), inside the modern-style building the swing was from 29 to 38 °C, a diurnal variation of 9 °C.

[3] 16 and 17 April 2018.
[4] American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[5] In principle these machines could be powered by photovoltaic solar cells on the roof of the building, which would also provide thermal insulation.

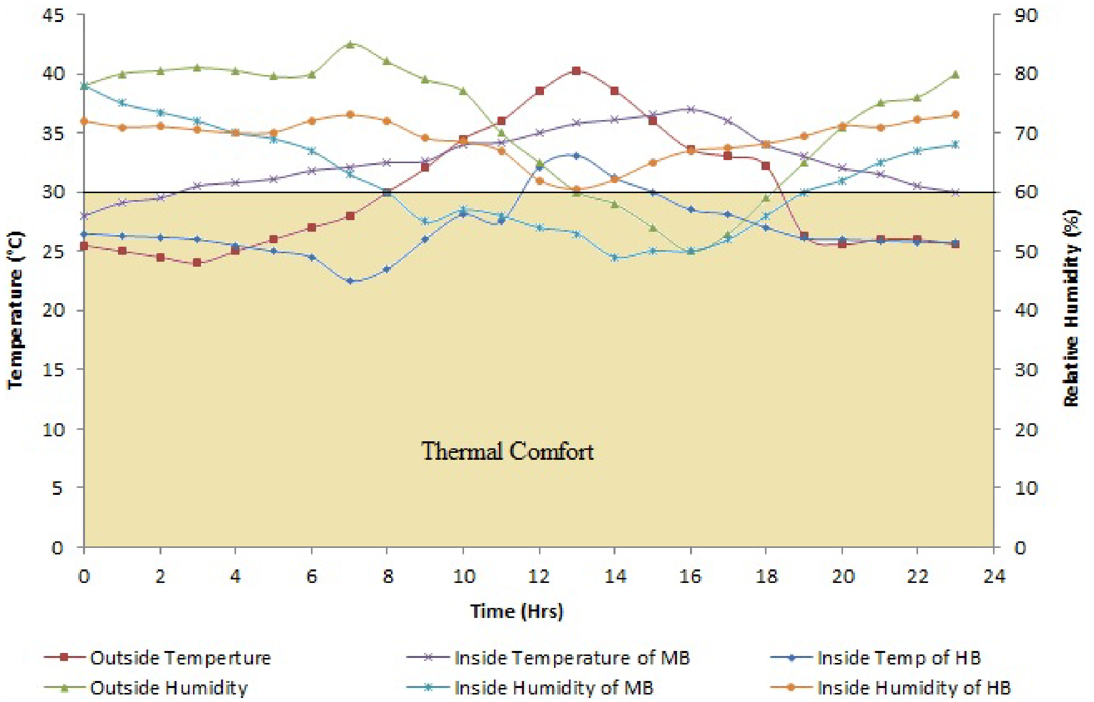

Figure 3. Comparison of internal temperature and relative humidity with ambient (external) temperature and relative humidity for the heritage (HB) and modern building (MB) (colour online). The ASHRAE thermal comfort zone is indicated.

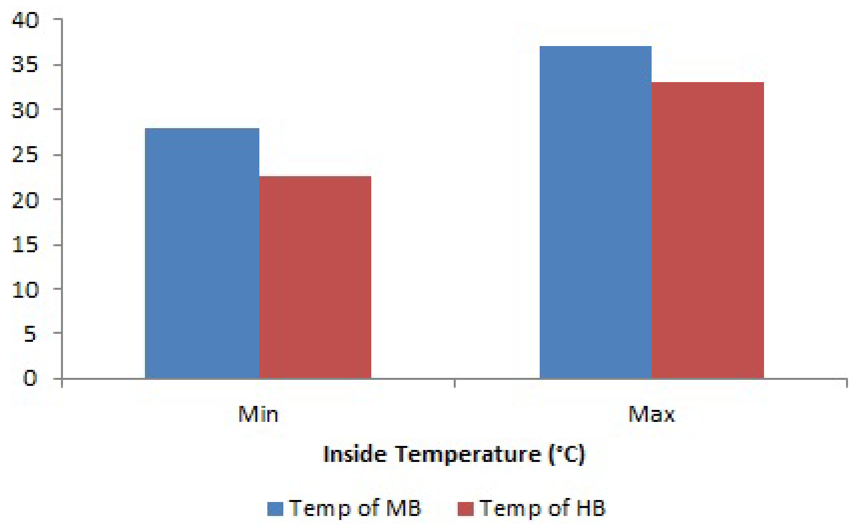

Figure 4. Internal temperature/°C variation in heritage (HB) and modern-style (MB) buildings.

7. Conclusions

The ancient building is indisputably more thermally comfortable than the modern-style building for the same external environment. The inside ambient temperature is much greater in the modern-style building than in the ancient building for the same outside temperature. The causes of the significant temperature difference between the inside and outside temperatures of ancient buildings in summer is because of the evaporative cooling phenomenon occurring in mud mortar-based traditional houses. The low thermal conductivity and thinner roof and walls of concrete-based modern-style buildings results in lower temperature differences when compared with traditional buildings. Hence, the features of traditional buildings should be used in modern construction.[6]

It is hoped that this research will not only increase energy savings but also help to promote socio-cultural advantages for the inhabitants of the built environment.

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[6] Costs of construction and maintenance are not considered in this study. Traditional buildings typically use locally sourced materials, whereas the cement and iron used in modern-style buildings are manufactured in large centralized factories. These modern materials have high embodied carbon, which is further increased by the need to transport them long distances to the building site. It should not be overlooked that the very large cement and iron industries constitute a strong vested interest that tends to oppose reversion to traditional building methods.

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