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Passive Cooling and Vernacularism in Mughal Buildings in North India: A Source of Inspiration for Sustainable Development

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ABSTRACT

In the present time, scrupulous use of energy is a challenge for the world population. The natural resources of energy are depleting day by day and the present resources seem inadequate to fulfill the need of human beings in future. Global warming and depletion of fossil fuels pose the dual crisis for sustainability. The building sector, being a major consumer of energy necessitates a critical scrutiny on this aspect. The techniques used for cooling, heating and ventilation of the buildings in the past were more harmonious with the nature. Use of locally available resources for design of historical buildings was energy efficient. The passive cooling in historical buildings provides a source of inspiration for sustainable development in contemporary world. In this paper, the author has examined various passive cooling techniques and locally available resources used in Mughal buildings in North India. The design elements of these buildings have evaluated on the basis of their suitability to the climate. The findings of this study suggest further research to explore guidelines for designing energy efficient buildings for sustainable development in the present era and future world.

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1. Introduction

With the arrival of Muslims in India, from twelfth century AD onwards, the merger of local and immigrated architectural techniques resulted into an astounding style. In the same way, their passive cooling techniques in buildings were merged together to provide new ways to cope with the extremes of the climate. The process of emergence of newer methods was continued for the next seven centuries leading to the development of several meaningful passive cooling techniques in buildings. Later, the industrial revolution influenced the globe and a population explosion in urban areas took place. These two factors promoted the use of non-renewable materials and high energy consumption in the building industry. In the absence of mechanical equipments, our ancestors designed and developed comfortable places with a little expenditure on energy. Unlike modern approach of making building's internal environment cool or warm, the intention was to give thermal comfort to the people with or without the building. In comparison to the historical buildings, our present day buildings are consuming more energy and resulting less comfortable habitation (Sundarraja *et al.,* 2009). Most of the modern building materials consume a considerable amount of energy even at the time of their manufacture itself. Modern architects are merely thinking about lowering down the temperature of internal spaces while historical buildings were designed by keeping in mind the comfort ability of the users.

Different building technologies reflect the amount of energy consumed during construction and their use. Artificial control of environment in buildings leads to the requirement of substantial amount of energy. The buildings consume natural energy in three ways (Gupta, 1988).

i) Maintaining the internal environment of spaces to make them comfortable.

ii) Controlling the microclimate.

iii) Procuring and manufacturing of materials for construction.

The above mentioned areas of energy requirements should be handled carefully to maintain sustainability. The response to these issues up to a certain extent can be observed in Mughal buildings. With the examples of few major projects of Mughal period in North India, this study deals with the exploration of principles evolved in Mughal buildings to make the building naturally cool which may inspire architects and planners to develop sustainable cities in the future.

2. Climatic characteristics

Before discussing the tools of passive cooling techniques used by Mughals, it would be pertinent to have some idea of the climate prevailing in North India. Composite climate occurs in most of the areas ruled by Mughals in North India which is characterized by dominated hot and dry conditions two third of the year and, a somewhat cold and a warm humid season occur in the remaining one third of the year. Being sufficiently far from the equator, this region experiences clear seasonal changes in solar radiations and wind directions. The remarkable mean diurnal changes may be observed from 11-12° C in hot dry and cool dry seasons while this range narrows up to 3-6° C in warm humid season. Relative humidity reaches up to 95% during the wet period. There is little or no rain during dry season. Hot and dusty winds blow during dry season. However monsoon winds are strong and steady (Koenisberger, 2001). Dominated hot and dry season remained a problematic situation in this region throughout the centuries. Even Babur, the first Mughal ruler in India complained about the dusty winds and climate of the region in his memoir '*Tuzik-i-Babri'* (Grover, 2002).

3. Microclimate Control

The gardens of paradise mentioned in the Holy Quran have been the source of inspiration throughout the Islamic world (Kausar, 2005). Mughals also used this tool not only as a symbol but to improve the quality of the immediate surrounding environment of their buildings. The environment outside the building is important to control the inside temperature of the building. The external air is treated by improving microclimate of the region which consequently enhances the quality of air inside the building. Vegetation was added to improve the quality of outer spaces and to enhance cooling by evapo-transpiration. The process of evapo-transpiration adds water vapors to the air and brings down the air temperature. The water bodies (still and moving) were added to the palaces to improve the humidity in hot and dry regions (Figures 1 and 2). Fountains are the better way to improve the quality of air as it sprinkles the water drops into the air and make the process of evaporation faster. Mughals also used fountain in their buildings. These water channels and fountains are found frequently inside the buildings. *Nahar-i-Bahisht* (canal of paradise) is an example of water channel which passes through internal spaces of the building to modify internal environment. Most of the Mughal buildings are surrounded by a landscaped area to modify the microclimate of the region. For example, in Red Fort, Delhi the entire building is surrounded by garden.

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Figure 1: A water body at Fatehpur Sikri.

Figure 2: Fountains improve the air quality in a hot dry climate.

4. Integrated Indoor-Outdoor Living

The relationship between human activities and nature was strong in the past. With the passage of time, this harmony was weakened resulting in buildings designed without context. Not all the spaces in Mughal buildings were maintained naturally comfortable at all times. With minor inconvenience, the users were suggested to shift from less comfortable spaces to more comfortable spaces depending upon the seasonal changes. Whenever it was uncomfortable inside the buildings, the people were suggested to use the outside spaces. For

example, the verandah acted as buffer for inner spaces to protect people from prickly heat while functioned as a place for organizing their daily activities during rainy season (Figure 3). The hierarchical positions of courtyard, verandah and inner spaces in Mughal buildings provide an organization of activities from one place to the other in relation to climate. For example, the Panchmahal at Fatehpur Sikri was built for Akbar's wives to enjoy their summer evenings (Ashar, 2003). But this structure seems inadequate to be used unless curtains or screens are put on the openings for further improvement of the internal environment and thus grass mats with sprinkled water were used to cover the openings in order to cool down the hot breezes (Figure 10). In Red Fort Delhi, the emperor's throne at the centre of *Diwan-e-Khas* is surrounded by two sets of openings four meters apart from each other (Figure 4). These openings were covered with grass mats with sprinkled water during summers and heavy quilts were suspended during winters. Another element to cover the openings was the roll up bamboo screens which could be easily adjusted to control the sun's penetration in the buildings in different seasons and to protect the easterly and westerly low inclination sun. The step wells were source of water on one hand while these were a shelter for extreme summer noon on the other (Gupta, 1984). Even today, people in villages spend their daytime on lower floors while they spend their nights on the terraces. The roof tops become the centre of activities on sunny days in winters. The purpose of natural cooling in historical building was to provide thermal comfort instead of lowering down the temperature of internal spaces by natural means.

Figure 3: Verandah worked as a buffer between indoor and outdoor spaces while it was a centre of activities during rainy season.

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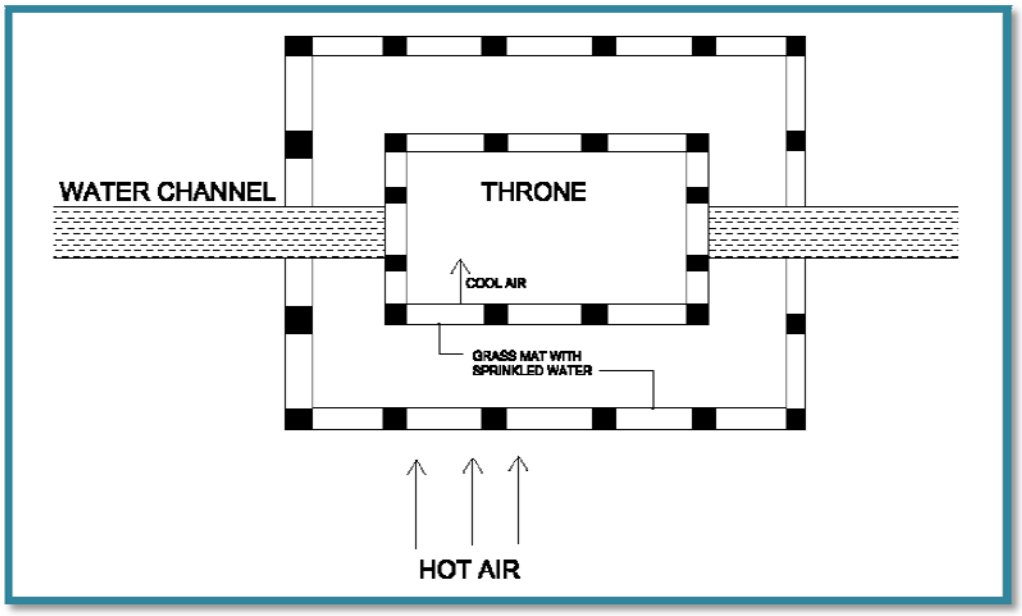

Figure 4: Emperor's throne at Red Fort Delhi.

5. Thermal Mass

Historical buildings have thick walls which seem mostly due to spanning and structural limitations of the materials but these walls are designed to provide a thermal insulation also. Thick walls of low thermal conductivity materials have low transmittance value of heat and larger time lag. The rate of heat flow within a wall depends upon the temperature difference between the outer and inner surfaces. Large thermal capacity structure absorbs most of the heat during the day and internal surfaces remain cool. To reduce the transmission of heat in Mughal structures, the temperature of outer surfaces was further controlled by shading the walls. When the outer temperature is lowered at night, the high emissive property of the walls allows cooling down the wall surfaces rapidly. Flat roofs get more radiations while vaulted and domed roofs prevent the absorption of heat of the summer's vertical sun. Arched ceilings have more space above the inhabitants for warm air to accumulate and finally it transmits the heat to the cool internal surfaces of the roof. Vaulted and domical roofs due to its larger surface area transmit the heat slowly to the interior spaces. Part of the domical roofs is always shaded from the sun and it reradiates the heat outside on the same time due to temperature differences.

6. Courtyard

Another feature of comfort adopted by the Mughals is the courtyard or *sahan*. In hot dry

and hot humid climates, courtyard is the centre of the building socially and environmentally. Courtyard provides a comfortable place for living. The courtyard makes a plan internally oriented and prevents the internal spaces from solar radiations and hot-and-dusty winds. It always shaded throughout the day even if the building is oriented to any direction. In the evening, air temperature falls considerably due to re-radiation to the night sky. The heated floor of the courtyard and the wall surfaces of the buildings raises the temperature of the air present in the courtyard which rises up due to its light weight and finally a fresh and cool air replaces the space evacuated by the hot air (Sharma *et al.,* 2003). In Mughal buildings, the courtyards are added with vegetation and water bodies most of the time which enhance the humidity, cool the air by evaporation, keep dust down and provide shade for comfortable living in hot dry seasons (Figure 5).

Figure 5: Courtyard at Jahangiri Mahal, Agra.

7. Shading Devices

The natural cooling may be achieved by cutting off the sun's radiations, reducing the absorption and slowing down the transmission of heat. The sunshades not only protect from sun's radiations through the windows but walls too. Buildings of the Mughal period have deep and inclined sun shades which are more effective as they cover the more surface area

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(Figure 6). Deep carving on building exteriors causes mutual shading in the day and in the evening and the extended surface area increases convective heat transfer to the air. Part of the domical roof is always shaded from the sun which re-radiates the heat outside.

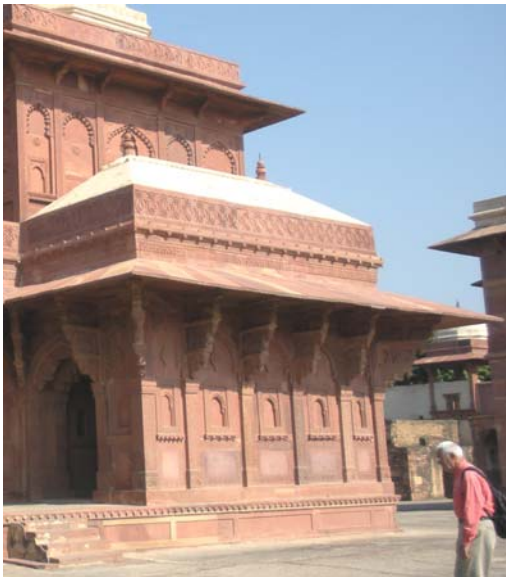

Figure 6: Deep inclined sunshades protect more area of walls and openings from the sun's radiations.

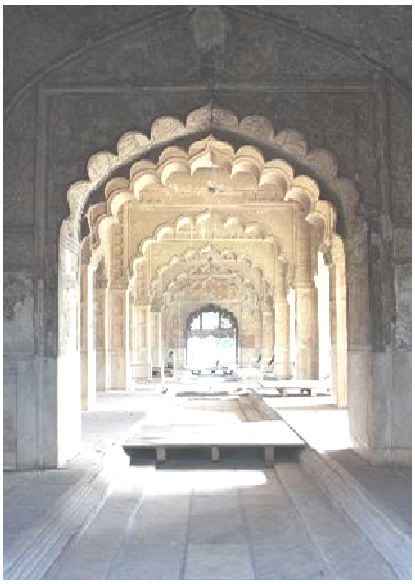

Figure 7: Water channel inside the building at Red Fort, Delhi.

8. Evaporative Cooling

Evaporative cooling had not only been the element of external spaces in Mughal buildings but the water channels and fountains were also part of the internal spaces, for example in Red Fort Delhi and Agra (Figures 7 and 8). To enhance the process of

evaporation, fountains were used which mixed the moisture to the air and increased the humidity. At times, *salsabil* was used to maintain the water pressure to force the water to come out of the fountain head (Figure 2). It consisted of inclined stone slab with wavy patterns which further increase the humidity in the air.

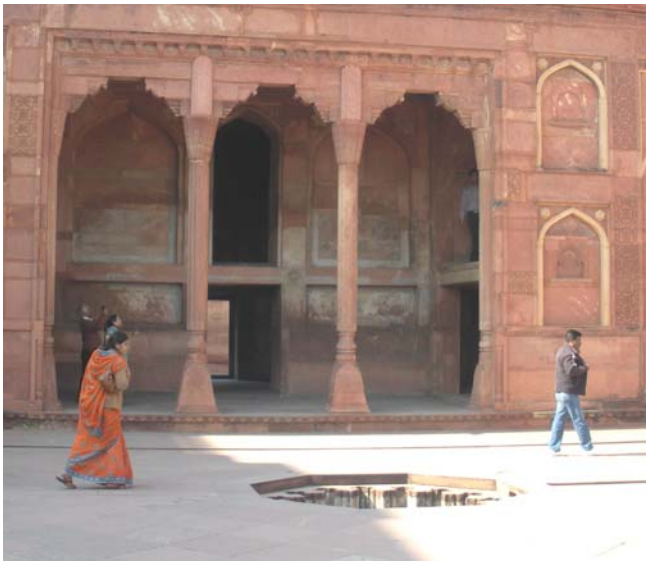

Figure 8: Water channel outside the building at Jahangiri Mahal at Agra.

9. Natural Ventilation

Natural ventilation is the result of differential wind forces on various building surfaces and temperature difference between outside and inside air. There are several factors which affects the air flow within the buildings such as microclimate, size and proportion of windows, orientation with respect to wind direction etc. A small window on a huge wall, as we see in most of the Mughal buildings allows the wind to move inside the building with a greater force. Tapered windows with smaller section inside also increase the velocity of entering air. When the air with a greater velocity enters into a wider space, sudden expansion results in lowering down of the temperature of inside spaces of the buildings. The hot air rises up in a domed space and the vents near the ceiling (Figure 9) allow hot air to escape (Soflaee & Shokouhian, 2005). One of the unique examples of natural ventilation in Mughal buildings is *Panchmahal* at Fatehpur Sikri. The five storey pavilion is an asymmetrical building diminishing from bottom to top and covered with a domed canopy. The building was designed for wives of Akbar to enjoy their evenings during summer (Figure10). Many compared it mistakenly with the windcather/tower or *badgir*, a common feature of Persian architecture (Alfieri, 2000).

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Figure 9: Vent near dome allows hot air to escape.

Figure 10: *Panchmahal* at Fatehpur Sikri.

10. Lattice Screen (Jaali)

Another strong feature of Mughal architecture which makes the internal spaces cool is lattice screen or *jaali*. *Jaali* is used frequently in Mughal architecture and is a prominent element. On one hand, it provides privacy and it controls the airflow and lower down the temperature of internal spaces on the other. When there is sunshine outside in the day, the internal spaces are not clearly visible from outside however, the diffused light is spread throughout the interiors. To get a clear outside view, a cutout is provided at eye level for the viewer sitting on the floor (Figure 11). *Jaali* in Mughal buildings mostly have a low sill or sometimes without sill so that the air could move near the floor.

Figure 11: *Jaali* ensures privacy and provides diffused light and view.

Figure 12: Indigenous trabeated system at Fatehpur Sikri.

11. Vernacularism

Muslims adopted the technology and architectural style of the region wherever they reached. However, they applied the intelligent assimilation of their imported technologies too. It makes a common vocabulary of style and technology throughout the Islamic world. In

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India, this assimilation may be observed in its architectural style and also at the level of socio-cultural elements. The architectural elements with their social and environmental significance like verandah and courtyard were incorporated by Mughals in their palaces. This attempt of Mughals made their buildings more harmonious with the nature. The technology for construction of buildings like the use of local materials with the help of local artisans made their buildings energy efficient as well. The style and technology developed by Muslims and especially by Mughals in India had indigenous characteristics of the region with a fragrance of foreign elements wisely induced. For example, the buildings at Fatehpur Sikri (Figure 12) were constructed in red sand stone which was procured from quarries near the site only and buildings were erected by indigenous trabeated technology with the help of local artisans (Lowry, 1985).

12. Conclusion

This work has examined various passive cooling techniques and locally available resources used in Mughal buildings in North India. The design elements of these buildings have evaluated on the basis of their suitability to the climate.

The environmental innovations in Mughal buildings may be used for the concepts or guidelines by the architects and planner for the design of buildings. These principles may be developed and clubbed with advanced technology to promote harmony between man and nature. As Fathy said, "*The principles that produced the traditional solutions must be respected. This is the only way modern architecture can surpass, in human and ecological quality, the achievement of vernacular architecture in the hot arid regions of the world*" (Fathy, 1986).

The findings from this study suggest further research to explore guidelines for designing energy efficient buildings for sustainable development in the present era and future world.

13. References

Alfieri, B. M. (2000). *Islamic Architecture of the Inian Subcontinent.* Laurence King Publishing.

Ashar, c. B. (2003). *Architecture of Mughal India.* Cambridge University Press.

Fathy, H. (1986). *Natural Energy and Vernacular Architecture: Principles and examples with reference to Hot Arid Climate.* Chicago: The University of Chicago Press.

Grover, S. (2002). *Islamic Architecture in India.* New Delhi:CBS Publication.

Gupta, V. (1988). Energy, environment and buildings. *Architecture+Design* , 83-91.

Gupta, V. (1984). Indigenous Architecture and Natural Cooling. *Energy and Habitat* , 41-48.

Kausar, S. (2005). Meaning of Mughal Landscape. *10th International Seminar "Cultural Landscapes in the 21st Century"*, (pp. 1-7). Newcastle-upon-Tyne.

Koenisberger, T. G. (2001). *Manual of Tropical Housing and Building.* Chennai: Orient Longman Ltd.

Lowry, M. B. (1985). *Fatehpur Sikri-Aresource book.* Bombay: Marg Publications.

Sharma, D. A., Dhote, K. K., & Tiwari, R. (2003). Climate Responsive Energy Efficient Passive Techniques in Buildings. *IE(I)Journal-AR* , 17-26.

Soflaee, F., & Shokouhian, M. (2005). Natural Cooling Systems in sustainable traditional architecture of Iran. *International Conference "Passive and Low Energy Cooling for the Built Environment"*, (pp. 715-719). Santorini.

Sundarraja, D. M., Radhakrishnan, S., & Shanthi Priya, R. (2009). Understanding vernacular architecture as a tool for sustainable development. *10th National Conference on Technological Trends(NCTT09)* (pp. 249-255). Trivandrum: College of Engineering Trivandrum.

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