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Passive cooling Techniques in Ancient Indian Buildings-A study

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ABSTRACT

The long-established historic architecture is known for providing cool indoor climatic conditions to its occupants using passive and natural cooling methods. It is therefore becoming very important to recognize the passive cooling Technique used in these ancient architectures. This paper thus tries to study some examples of Ancient Mughal architecture. Their building elements as a part of the important passive cooling methods. It has been found that natural ventilation and daylight should be the prime element in these designs, in order to attain effective passive cooling. Various passive cooling concepts, their application in the buildings and their respective impact have been studied. Shading, water features, courtyard planning with landscaping, Evaporative cooling and natural cooling are the most common elements found in support of passive cooling systems in the Indian Ancient architecture of Mughal era.

Keywords: Ancient Architecture, Day Light, Openings, Passive Cooling, shading, Evaporative cooling, Natural cooling, court yard

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INTRODUCTION

Mughal Architecture was a fully developed in style and a perfect influence as none was prior to it, in India prior to Mughals. It had a time-span of 132 years; practically from 1526 to 1658 this era is popularly called "MUGHAL ERA' although all the Mughal rulers including Aurangzeb took vast interest in architecture. The period of Shah Jahan (1627-1658) witnessed an excellent occurrence of activity in the growth of architecture. At the same time, it must also be accepted that a period of 102 years (1556-1658) covered by the reign of Akbar, Jahangir and Shah Jahan has a special significance for the encouragement of architecture.There is no hesitation in saying that architecture reached the height of its glory during the period of Shah Jahan. Mughal architectureis the unique Indo-Islamic amalgamated architectural stylethat developed in northern and central India under the support of Mughalemperors from the 16th to the 18th century. It is a remarkably symmetrical and decorative combination of Persian, Turkish, and Indianarchitecture. The buildings consume natural energy in three ways (Gupta, 1988) [1]

- Internal atmosphere of spaces to make them comfortable for occupants.
- Controlling the microclimate.
- Procuring and arranging of materials for construction

Main features of Mughal Architecture:

1. Range of buildings:

The Mughal rulers built outstanding gates (Darwaja), forts, mausoleums, mosques, palaces, and tombs etc.

2. Combination of Persian and Indian style:

The specimens of architecture constructed under the Mughals have become the

common heritage of both the Hindus and the Muslims. It is a happy unites of Hindu and Muslim architecture.

3. Specific characteristic:

A common feature of the Mughal buildings is the prominent domes, the slight turrets at the corners, the palace halls supported on pillars and the gateways.

4. Costly decorations:

The Mughal emperors in general but Shah Jahan ornamented his buildings with costly articles. One of the important unique features of the Mughal buildings is their ornamentation as compared with the simple buildings of the previous Muslim rulers of India.

5. Building material:

Traditional buildings are time tested and well known for consuming less or no energy through passive cooling systems. It therefore becomes essential to understand the passive cooling technologies used in Ancient Mughal architecture. It is necessary to extend and maintain the building the whole time its life which is dependent on selection of site, orientation of building, building material, shading devices, openings, windows, space utilization and courtyard planning, etc. Ancient structure term refers to the construction done by the local people using traditional methods, using locally available material in harmony with the environmental consciousness. In that architectural structure starting from the initial stage of construction to its occupancy introducing these methods with passive cooling techniques will help in reducing lifetime energy requirement of a building to a large extent. Most of the buildings were constructed in red sand stone leaving Taj Mahal and few buildings. The arrangement of various passive heating and cooling techniques in order to understand comfortable thermal temperature conditions has always been apparent in Ancient architecture.

CLIMATIC CHARACTERISTICS

India possesses a large multiplicity of climates ranging from extremely hot desert regions to high altitude locations with rigorously cold conditions like northern Europe. In India it is likely to define six distinct climatic regions. The six climates are normally nominated as hot and Dry, Warm and Humid, Moderate, Cold and Sunny, Cold and Cloudy and Composite.

Composite climate occurs in most of the areas in North India which is characterized by hot and dry conditions eight months of the year and, a somewhat cold and a warm humid season occur in the remaining four months of the year.

The maximum daytime temperature in summers is in the range of 32 – 43º C, and night time values are from 27 to 32^0 C. In winter, the values are between 10 to 25^0 C during the day and 4 to 10^0 C at night and relative humidity is about 20 – 25 % in dry periods and 55 – 95 % in monsoon periods. 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) [2] peculiarly hot and dry season remained a not easy situation in this Region (Delhi, Agra, Fatehpur –Sikri, Rajasthan) throughout the centuries. Mughal Emperor Babur, explained about the dusty winds and climate of the Indian region in his book '*Tuzik-i-Babri'* (Grover, 2002) [3].

PASSIVE COOLING

It covers all-natural processes and techniques of heat dissipation and modulation without the use of energy. Passive cooling Techniques can be grouped into three categories:

Solar and heat protection techniques (Reduce heat gains)

Microclimate

Climate is the average of the atmospheric conditions over a entire time over a large region. Small-scale patterns of climate, major from the influence of topography, soil structure, ground is known as microclimates. The most important

parameters related to climate are air temperature, humidity, moisture present in the air and wind. The microclimate of an area can be custom-made by suitable landscaping techniques, with the use of plants and water surfaces, Limor Shashua-Bar et al. [4] studied the climatic analysis of landscape planning for outdoor cooling in a hot-arid region, bearing in mind the efficiency of water use. Total Six landscape strategies were studied, using dissimilar combinations of trees, lawn etc.

Vegetation (Gardens, Lawns & Trees)

The gardens of heaven mentioned in the Holy Quran have been the source of motivation throughout the Islamic world (Kausar, 2005) [5].The gardens have been used as a mechanism not only as a symbol of luxury, but to improve the quality of the direct neighboring environment of the buildings The environment outside the building is important to control the inside temperature of the building. The outdoor air is treated by improving microclimate of the area which as a result enhances the quality of indoor air in the building. Vegetation was supplementary to improve the quality of outer places and to boost cooling by evapo-transpiration. The process of evapo-transpiration adds water vapors to the air which brings down the air temperature subsequently. Most of the old buildings are enclosed by a landscaped area to modify the microclimate of the area for example, in Red Fort, Delhi the entire building is surrounded by garden.

The Mughals gave a new representation of the landscape to areas in use by them. Gardens were built within towns, in outer edge, and along Buildings (Mubin, Gilani & Hasan, 2013) [6] Mughal garden is generally in a square or rectangular shape with rows of trees and flowerbeds, centrally positioned canals, waterfalls and running fountains (Mughal, 2011) [7] The three types ofgardenarranged by the Mughal Emperors were: s (Moynihan, 1980) [8]

Tombgardens; Humayun's tomb at Delhi [Fig-2], Akbar's tomb at Sikandara (Agra), Itmad-ad Daula's tomb at Agra and finally Taj Mahal (Agra)[Fig-1] exhibit the best and wonderful specimens of grand and noble's tomb gardens. Tomb gardens were a different variety with a much more defined role: to represent the gardens of heaven within which the deceased would find themselves in the afterlife.

Palacegardens; These gardens were extremely pleasant places to stay during the hot weather especially for the Begums who being not allowed to go into public places used to entertain themselves in the isolated portions where they feel like 'paradise'. In Rajasthan, these types of gardens were known as haveli gardens. Palaces are completely ornamented by Gardens to give good meaningful shapes (e.g. at Delhi and Agra) [Fig-3 &Fig-4]

Fig. 1: *Mughal Garden at Taj Mahal (Agra)*

Fig. 2: *Humayun Tomb (Delhi).*

Fig. 3: *Diwane khas (Red fort Delhi)*

Fig. 4: *Place Garden (Red fort Agra)*

Encampment gardens; Mughal encampment gardens were formed on Timurid lines. The court needed the security of an army when travelling from place to place and it was lovely to have good camp sites on the route, gardens serving this purpose well. The spectator area was a place for the emperor to sleep. Mughal emperors have planted beautiful gardens at their free time places where they were enjoying for rest and relaxation, along with their army. (e.g. the Shalimar Baghgardensat Srinagar [Fig-5 &Fig-6], Lahore and Delhi)

Fig. 5: *Shalimar bag Srinagar.*

Fig. 6: *Nishat bag Srinagar.*

The principal source of water to the Mughal gardens were: (i) lakes or tanks (ii) wells or step-wells (iii) canals, harnessed from the rivers, and (iv) natural springs. According to (Sumra, 2012) [9] the system for elevating water is an amplification of the Persian rehant system, sometimes called the Persian wheel[Fig-7]. Chambers within the baolis (step well) and water raising houses contained wheels with shafts driven either by humans or cattle. These wheels, in turn, rotate shafts that drive a belt of clay pots water-filled pots, up to the next stage of the water works.

Fig. 7*: Persian wheel for water lifting*

The Mughals developed hydraulic system by using Persian wheel to lift the water and obtained enough pressure necessary for gardens. The main reason behind the location of gardens on the bank of river

was that water was raised to the level of the enclosure wall by Persian Wheel.

Water surfaces

The water bodies (still and moving)[Fig-9 & Fig-8,10 and 11] were added to the ancient buildings, palaces to get better humidity in hot and dry regions Fountains are the superior way to improve the quality of air as it sprinkles the fine water droplets into the air thus makes the process of evaporation faster Fountains (Water surface moving).

Fig. 8: *Khas Mahal Agra Fort.*

Fig. 9: *A water body at Fatehpur Sikri*

Fig. 10: *Humayun Tomb (Delhi).*

Fig. 11: *Shalimar garden.*

Solar Control (Reduction of Heat gain)

Shading Devices

Shading means that partial or complete obstruction of the sunbeam directed toward a surface by an overriding object or surface. The reduction of heat absorption may be achieved by cutting off the sun's radiations falling directly on the surface [Fig-12]. This reduces the absorption and slowing down the conduction of heat to the structure. The sunshades not only protect from sun's radiations through the windows but walls also. Buildings of the Mughal era have deep and inclined shading which are more useful as they cover more surface area Deep carving on building exteriors results shared shading in the day and in the evening [Fig-13]. The widespread surface area increases convective heat transfer to the air. Few examples of shading are illustrated here.

Fig. 12: *Shading at fatehpur sikri.*

Fig. 13: *Deep shading*

Thermal Mass (Modify heat gain)

The building materials used in the construction ofmost of the buildings in Mughal erawas principally red sandstone[Fig-14], which is found in large quantity in Agra district and neighboring areas including Rajasthan also. Since it was a local material, and was easily available, it was an intelligent effort on the part of emperors to use it in construction of the Agra Fort, Delhi fort and Fatehpur-Sikri etc. This sandstone is very quick to respond towards a diversity of finishing like rubbed, honed, polished or sandblasted, with hand cut or sawn edges.The color of this sandstone ranges from light to dark red. According to Sarkar [10], Jahangir's period was known as a intermediary period in the decoration of buildings as red sandstone was replaced by white marble; during Jahangir's period a technique of interlocking of precious cut stones of different textures was introduced to create patterns.It was only after the later part of the Mughal dynasty (Shahjaha) that use of white marble was made in the buildings. Mughal architecture reached to the peak degree of excellence under Shah Jahan reign.

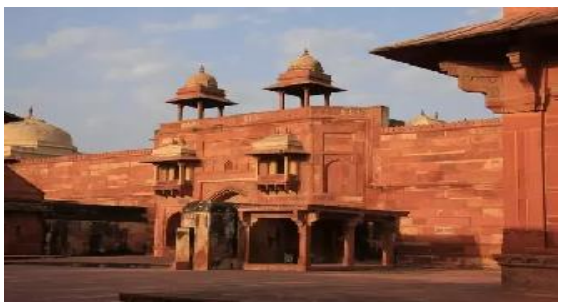

Fig. 14: *Fatehpur –Sikri (Red Sand Stone)*

Historical buildings have thick walls these walls are designed to provide a thermal insulation also. Thick walls of low thermal conductivity materials have low transmittance value of heat and with larger time lag. Large thermal capacity construction absorbs most of the heat during the day and internal surfaces remain cool. The temperature of outer wall 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 quickly. Flat roofs get more radiations while vaulted and domed roofs stop the absorption of heat of the summers straight down sun. Arched ceilings have more space above the residents for warm air to mount up 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.

Fig. 15: *Flat roof.*

Fig. 16: *Arch ceiling*

Courtyard

Another feature of comfort adopted by the Mughal emperors is the courtyard or *Dalan*. Courtyard is the centre portion of the building. In hot dry and hot humid climates, Courtyard provides a comfortable place for living. The courtyard plans 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 evidently due to re-radiation to the night sky. In buildings of Mughal era, the courtyards were added with vegetation and water bodies most of the time which improve the humidity, cool the air by evaporation, keep dust down and provide shade for comfortable living in hot dry seasons.

Fig. 17: *Jodha Bai Palace Courtyard.*

Heat dissipation Technique (Removal of internal heat)

Natural Ventilation (wind driven Ventilation)

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. Natural ventilation is the result of differential wind pressure on various building surfaces and temperature difference between outside and inside air. A small window on a huge wall, as we see in most of the buildings constructed by Mughal, allows the wind to move inside the building with a greater force.

Tapered windows with smaller section inside also amplify the velocity of entering air. When the air with a larger velocity enters a wider space, sudden expansion results in lowering down of the temperature of inside spaces of the buildings. The hot air rises in an arched space and the vents near the ceiling allow hot air to escape (Soflaee & Shokouhian, 2005). [11]

Fig. 15: *Panchmahal Fatehpur Sikri.*

Fig. 16: *Hawa Mahal Jaipur*

One of the unique examples of natural ventilation in Mughal buildings is The five storey pavilion is an asymmetrical building diminishing from bottom to top and covered with a domed top The building was designed for wives of Akbar to enjoy their evenings during summer. But it is not the wind catcher/tower or *badgir*, a common feature of Persian architecture (Alfieri, 2000) [12] wind towers (wind catcher) in hot and dry climates, where dusty winds make it not viable.

Air vents

Air movement is the most important element of passive cooling, it gives

comfort to people. It also cools buildings by carrying out heat of the building as warmed air and replacing it with cooler external air This requires well-designed openings (windows, doors and vents) and unrestricted air current paths.

Curved roofs [Fig-17] and air vents are used in combination for passive cooling of air in hot and dry climates, where dusty winds make wind towers not viable. A hole in the apex of the domed or cylindrical roof with the protecting cap over the vent directs the wind across it. The opening at the top provides ventilation and thus a escape path for hot air collected at top. Arrangements may be made to draw air from the coolest section of the structure as alternate to set up an nonstop circulation and cool the living spaces. this system is working due to pressure difference created by movement of hot and cool air having different air densities.

Fig. 17*: Curved roof.*

Lattice Screen (Jaali)

Another strong feature of Mughal architecture was designed to deal with the natural conditions and provide indoor thermal comfort without depending on other systems using energy. Such a passive method is the Jaali. Which makes the internal places cool is net screen or Jaali. Jaali is used recurrently in Mughal architecture and is an outstanding element. The Mughals Architectures jails used have mostly in geometrical, both with straight and curved lines. On one hand, it provides privacy and on the other, it controls the airflow and drop down the temperature of internal spaces. When there is sunshine outside in the day, the inner spaces are not clearly visible from outside however, the diffused light is extended throughout the Inner space. To get a clear outside view, a cutout is provided at eye level for the observer sitting on the floor. *Jaali* in Mughal buildings mostly have at different levels it may be at low ridge or sometimes without ridge so that the air could move near the floor. (Figure18 a&b).

Two laws of physics turnjaliinto air-conditioners:

1. 1 Venturi ‘s principal states that air is compressed and increases its speed when passed through a funnel causing a breeze.
2. Bounoulis law states that when air is compressed and released it becomes cool. Pandya 2011) [13] In desert areas, the mesh like structure sort out the dust associated with strong winds in the region. (Gandhi 2014) [14] Together these attributes of the Jaali make the building to breathe. Jaali ensures privacy and provides diffused light and view.

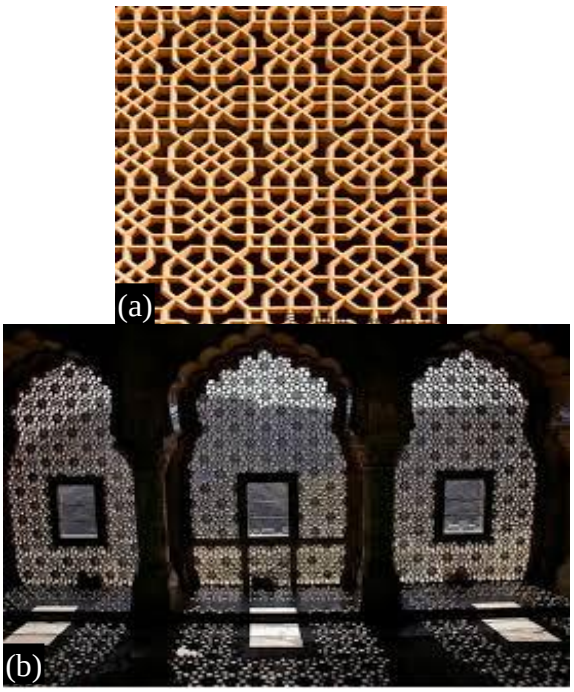

Fig. 18: *(a) Jali in Mughal buildings. (b) Jali in Mughal buildings*

Natural cooling (Evaporative Cooling)
Evaporative cooling is a very old process, having its origin some thousand years ago, in ancient Egypt and Persia. Evaporative cooling had not only been the element of exterior spaces in Mughal buildings, but the water channels and fountains were also part of the internal spaces., there are two types of evaporative cooling systems. Evaporative cooling can be direct or indirect.

Indirect evaporative system (Step well)
A traditional way of cooling in India was the Step well [Fig-19] a pond dug into the ground or surrounded by walls above ground so that the air is cooled by evaporating water. It acts as heat sink.

Fig. 19: *step well.*

Step wells can be rectangular, circular, or even L-shaped; they can be built from masonry, rubble, or brick; and they can have as many as four separate entrances.

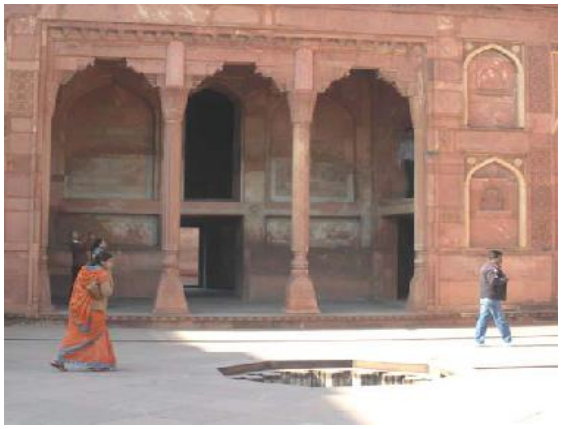

Fig. 20: *Water channel at Jahangiri Mahal at Agra*

Direct evaporative system (Fountains, sprinkles etc)
For example, in Red Fort Delhi and Agra to improve the process of evaporation, fountains [Fig-21] were used which mixed the water droplets to the air and increased the humidity. At times, tanks were used to maintain the water pressure to force the water to come out of the fountain head. Water has been used in the form of fountains and cascades to improve the thermal comfort of buildings. Evaporation of water helps to passively cool buildings, reducing the energy needed for air conditioning. When combined with other passive design techniques, adequate thermal comfort might be achieved.

Fig. 21: *Fountain in Delhi*

CONCLUSION

This paper has examined various passive cooling techniques and locally available resources used in an ancient building constructed mainly by Mughal in North India, Rajasthan and Agra. The design elements of these buildings have studied based on their suitability to the climate. The environmental improvement concepts in Mughal buildings may be used for the guidelines for the architects and planner for the design of buildings in present circumstances. Evaporative cooling can reduce indoor temperature up to 9.6 °C. Solar shading techniques alone can provide a fall of 6 °C in the room temperature. These principles may be further developed and clubbed with refined technology to encourage harmonization between man and nature. The findings

from this study suggest further research to investigate course of action for designing energy efficient buildings for sustainable development in the present era and future world.

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