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Analysis of Indian Traditional Buildings using Passive Cooling through Natural Ventilation Techniques

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Abstract: There is a rapid increase in the use of active cooling strategies for ventilation and air circulation in the recent scenario, and hence an urge of climate-responsive buildings is a need of today. Taking the advantage of local climate and designing buildings that decrease energy use can be achieved by implementing passive cooling strategies in a building. The present study focuses on how various solar passive techniques have helped in designing climate-responsive structures in the past and how its implementation can enhance the structure in modern construction techniques. By analysing structures from the past and studying the science behind them, the passive cooling effect and its development in design implementation can be examined. The paper concludes by having incited on how solar passive strategies can help to create a flexible building, responding to climatic effects and its evolution over a period of time.

Keywords: Climate responsive, Hot-dry climate, passive cooling, Traditional buildings

I. INTRODUCTION

Traditional buildings in India have proven to be strong, durable, and climate-responsive over a long period. These buildings have been proven to provide a comfortable environment inside the building even in extreme climatic conditions via natural and passive cooling techniques. Today architecture is isolated from the outer world and mechanical systems are used to create comfortable interiors deciding thermal comfort for people. As a result, understanding passive techniques and applying them in modern construction techniques is a need of today. Taking inspiration from the past a better understanding of climate-responsive structure can be achieved. Courtyard planning, lattice screens, cooling tower, jharokha, evaporative cooling, and landscaping with water bodies are a few techniques and elements which were used for passive cooling in traditional buildings.

These traditional structures are a very good example of vernacular architecture. The use of locally available materials offers a good solution to climatic constraints and by incorporating passive design 1-5 percent of energy can be saved (Gupta N, 2017). Passive cooling can be a solution to many design constraints which are now an issue to climate-responsive structures. It's important to understand that how in past passive cooling has helped in achieving a comfortable condition, even in extreme climates and how in today's context its application is possible in contemporary structures. The basic understanding of the passive cooling technique can be understood by using examples of traditional buildings such as Hawa Mahal, Chand Baori, and forts of the Mughal period. It is also possible to comprehend the use of passive techniques and their evolution over time.

II. PASSIVE COOLING TECHNIQUE AND IT'S IMPLEMENTATION

With an approach of creating places that can act as an energy source, the stress on the mechanical cooling systems can be decreased. Passive cooling can be achieved in a lot of ways and different strategies are used for providing comfort in different climatic zones. Passive cooling and natural ventilation systems help to establish a connection between the residents and the surrounding through the building, allowing them to connect with the outside environment. If passive systems are installed in existing buildings as a way for the population to improve their quality of life, energy consumption will increase very little while thermal comfort will improve significantly. If passive cooling systems are well integrated and widely accepted, it will be a significant step towards creating a more sustainable architecture globally. Many factors are taken into consideration while designing a building like its shape, form, orientation, size, aspect ratio, layout, fenestrations, etc. (Gupta N, 2017).

Passive cooling concepts channelize the airflow, thus removing the excess heat from the interior spaces. With the help of shading devices, it reduces the solar heat gain in summers and tries to remove the heat from the building with the help of evaporative cooling, conduction, earth coupling, or any other technique suitable for that climate.

1) *Evaporative Cooling:* In evaporative cooling water acts as a cooling agent. It humidifies the air and converts it from warm dry air to cool air. When heat is applied to water it converts into vapour and cooling sensation is felt. This technique is very effective in a hot dry region. Cooling via evaporation is a natural process as water evaporates to cool the body. Water bodies in the centre of palaces and forts are a great example of this technique.

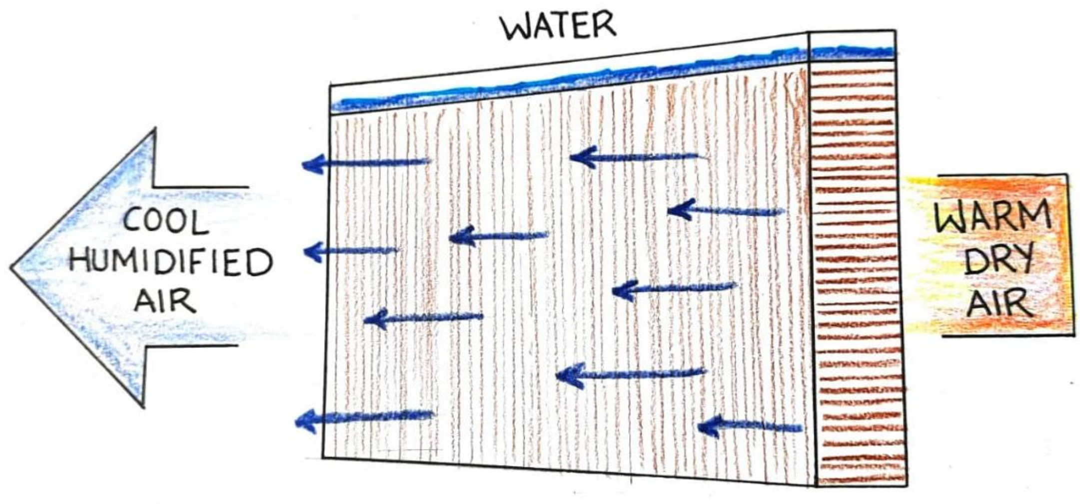

Figure 1: Evaporative cooling

2) *Natural Ventilation/Fenestrations:* The presence of windows and openings is seen in every household. These openings provide a good space for air movement and circulation. Natural ventilation is a basic requirement in the warm-humid regions, where large openings are provided for air circulation. These simple devices depend on wind and temperature to create buoyancy for air movement to flow through a building. In traditional buildings instead of a huge opening lattice screens were used with decorative work for aesthetics.

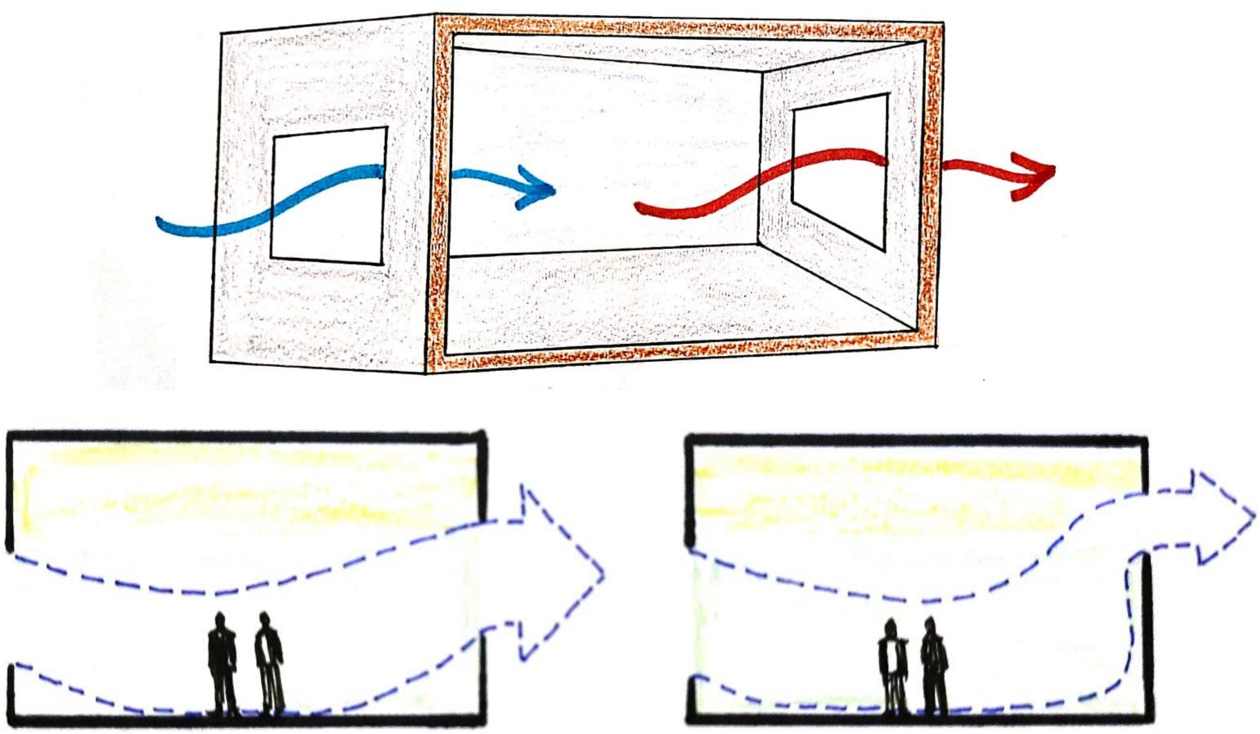

Figure 2: Natural Ventilation/Fenestrations

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3) *Wind Tower:* These towers are around 5 to 8 meters in height. They have a slot corresponding to the prevailing wind direction. They seize the air passing over the building, which is clean and free of dust from the upper layers in the outside space, usually cooler air. They push the air into the building and make it circulate through interior spaces. These wind towers are a prominent feature of Mughal architecture.

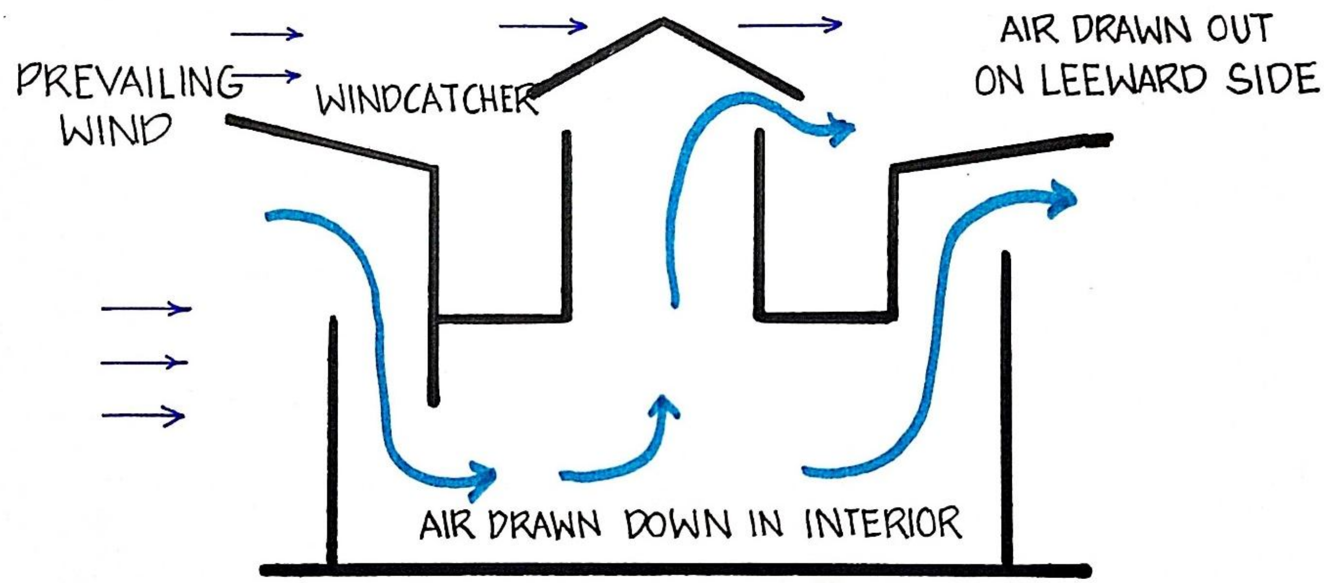

Figure 3: Wind Tower

4) *Courtyard Planning:* Courtyards are small pockets of cut-outs that enhance natural ventilation. In a warm-humid region where buildings are spread out maintaining a good distance, the left spaces are landscaped and converted to courtyards. Even the concept of the central courtyard is very prominent. They are an elegant feature of forts, palaces, and Havelies of Rajasthan. By incorporating water bodies and landscape in the courtyard, it adds to the functionality as well as aesthetics of the place.

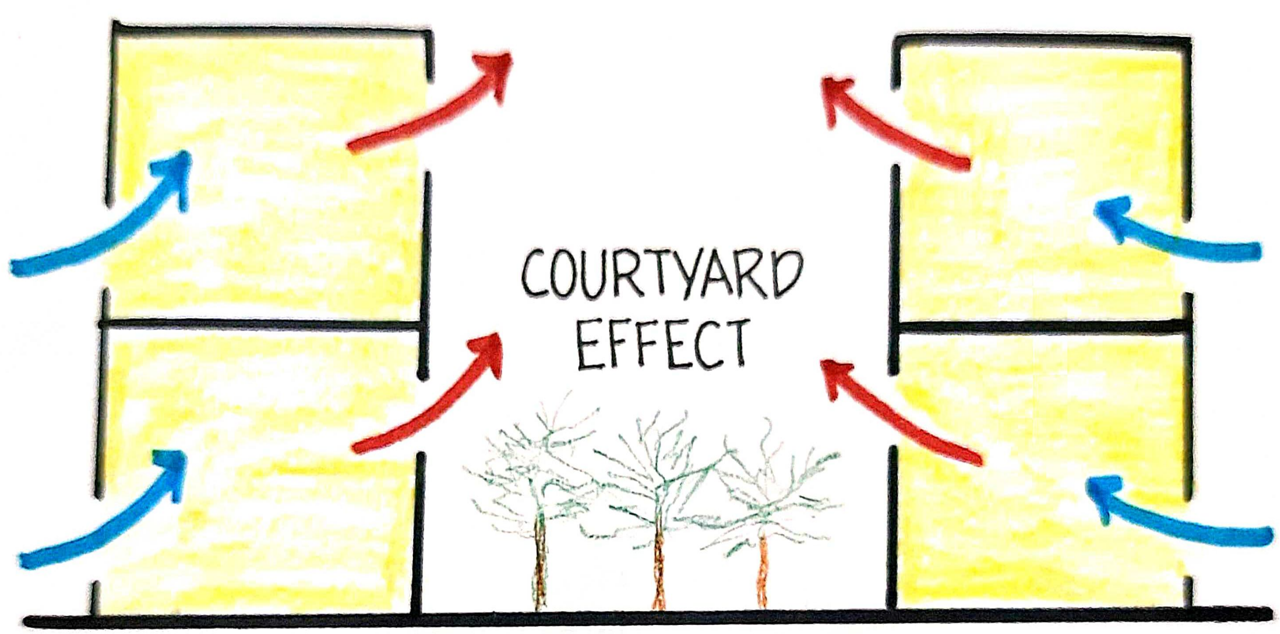

Figure 4: Courtyard Planning

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5) *Roof Pond System:* This passive technique is majorly based upon the increased heat capacity of widely available water. It is covered during the day to prevent heating and opened at night to cool the water. It acts as a barrier that restricts the inlet of heat into the building via the roof. This is a cheap technique and very effective in the region of any climate.

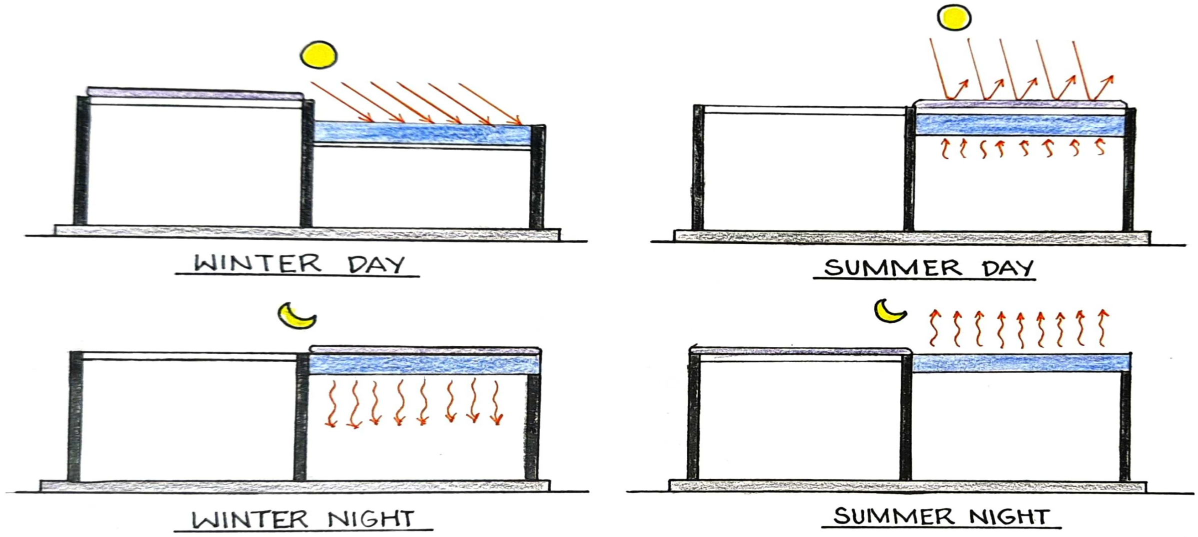

Figure 5: Roof Pond System

6) *Passive Downdraft Evaporative Cooling:* This low-energy technique for cooling and ventilation of buildings works by spraying water in warm dry air. As the water particles come in contact with warm air it turns into vapour, thereby raising the relative humidity of the air while reducing the temperature of the surrounding. This air then occupies a capture zone from where it can be drawn into habitable spaces. In hot-dry zones, this adds as a relief. The long shaft is provided in 2 opposite directions with one to take in cool air and the other to take out hot air.

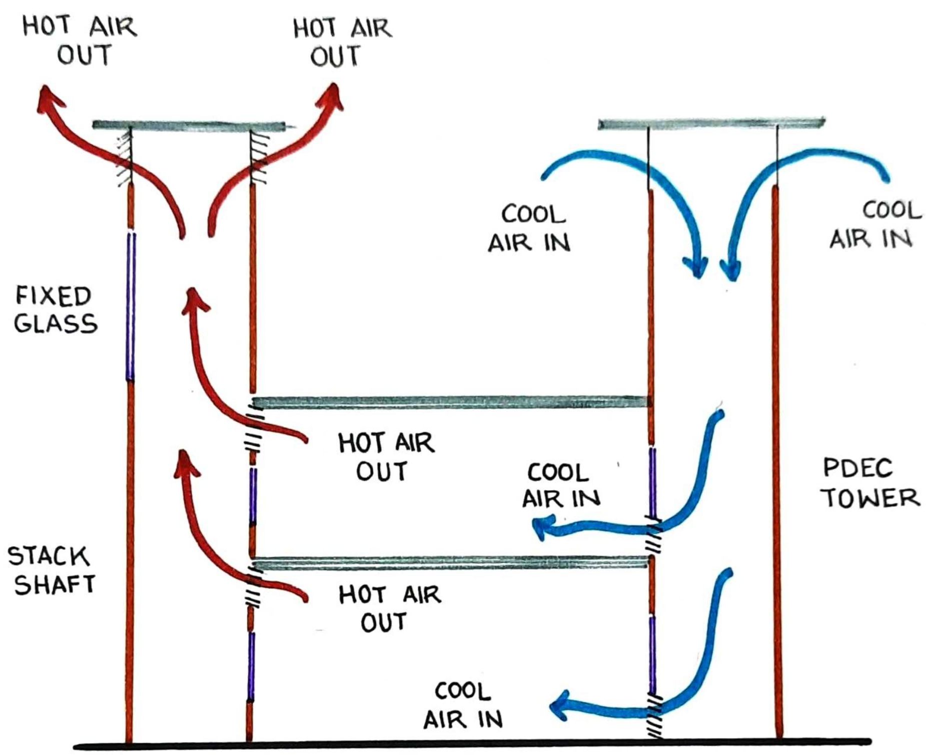

Figure 6: Passive downdraft evaporative cooling

III. ELEMENTS OF PASSIVE COOLING SEEN IN HISTORIC BUILDINGS

The elements of traditional buildings in India are seen to serve both the purpose of an architectural and structural element. The open courtyards function as a good source of air circulation and ventilation, yet blend the outdoor and indoor spaces with each other creating interactive spaces. The water bodies help to increase the aesthetics of the building but also behave as a source of evaporative cooling. The shading devices help to prevent the direct glare of the sun but by providing angles to them they can change the wind direction to a little extent. Lattice screens provide ventilation and protection from dust as well as privacy. Minarets act as an air shaft to suck hot air out and enhance ventilation yet act as an element of aesthetic in design. Every element defines its purpose as well as relates and responds to the climate of that place.

1) *Jharokha:* A jharokha is a wall-mounted window in an upper story that looks out onto a street, market, court, or other open space. It is a type of enclosed overhanging balcony (Sarswat, G., & Kamal, M., 2015). It enhances the aesthetics but is a shading device that protects from direct sun glare and encourages ventilation. The repetitive patterns of jharokhas create punctures in the building envelope giving a direction to airflow. In a hot-dry region, they provide cooling and shade. These are mostly seen in forts, palaces, and havelies of Rajasthan. On the upper stories, they have large openings with perforated jaali, resulting in greater air mass movement to reduce temperature. If water ducts are added just beneath the openings, then due to the evaporative cooling strategy the harmful air from outside converts to a cooler one. In the daytime, the outer layer is heated and radiated to the surrounding environment. When a structure has only one layer, the sun's rays are directly transmitted to primary spaces, causing the building to heat up early. However, by organizing secondary spaces adjacent to the outer layer, it acts as a transitional space, keeping the primary spaces relatively cooler. The heat that enters the secondary space will dissipate in the streets through the secondary space openings before entering the interior (Sarswat, G., & Kamal, M., 2015).

Figure 7: Jharokhas

2) *Wind Catcher:* A wind tower is a vertical ventilating design element that projects above the terrace level of a building with openings on top towards the favourable prevailing winds. Wind catchers take advantage of the pressure difference created in the shaft and try to circulate cooler air inside the building. Due to the stack effect, the hot air rises creating pressure at the bottom, which is then filled with cool air causing air circulation through interior spaces. There are various design types for windcatchers like uni-directional, bi-directional, and multi-directional (Sarswat, G. & Kamal, M., 2015). In a hot-dry region, they act efficiently as very small fenestrations are provided in these areas which obstruct air circulation. The hot air enters through air vents and is allowed to cool down throughout the day, causing the tower to warm up. During the night, the tower releases heat and balances the thermal comfort within the building. This diurnal function capability makes this system lower the temperature up to 12 to 15°C (Gupta N, 2017).

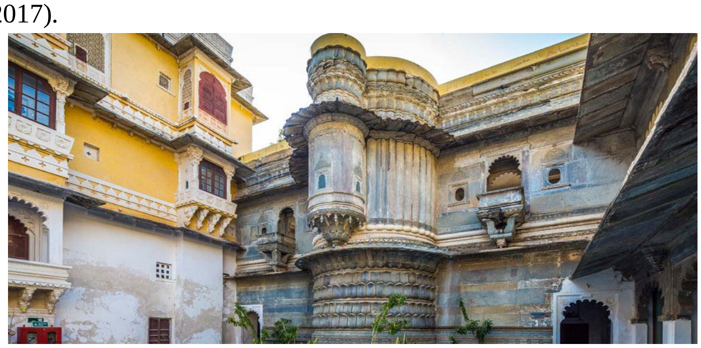

Figure 8: Wind Catcher

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3) *Lattice Screen:* Lattice screens are carved or perforated shading devices used in windows, or balconies to block suns heat and provide cool air at night via convection. These are frequently used in the façade facing the street and are effective for East-West oriented façades enclosed with engraved latticework positioned on a building's upper floors. Lattice screens have been used in some places to maintain privacy, allow air and light to enter the building, and also allow visual connectivity from the inside to the outside surroundings. A wooden lattice screen absorbs the extra humidity present in the air but sometimes humidify the dry air for inner thermal comfort (Sarswat, G. & Kamal, M., 2015). These screens act as a building envelope which can decrease the amount of heat gain in the building when compared to a normal wall.

Figure 9: Lattice Screens

4) *Courtyard:* Courtyards are a basic element of planning in the Indian context. They enhance daylighting and air circulation, concluding to become the best passive cooling strategy to date. Radiation from the sun reflecting off the courtyard exterior warms the air, and the warm light air rises. It allows the cold wind to take its position through windows and openings at night. A stage is reached when a warm surface is cooled by convection and radiation methods and a reverse procedure takes place when its surface temperature equalizes with the ambient air's dry-bulb temperature. In places like Rajasthan, they are a key feature of the design as in every fort, palace, or haveli they act as a central interactive spot. By incorporating the elements of landscaping and water body in a courtyard, they help in stabilizing the enclosed temperature with evaporative cooling techniques.

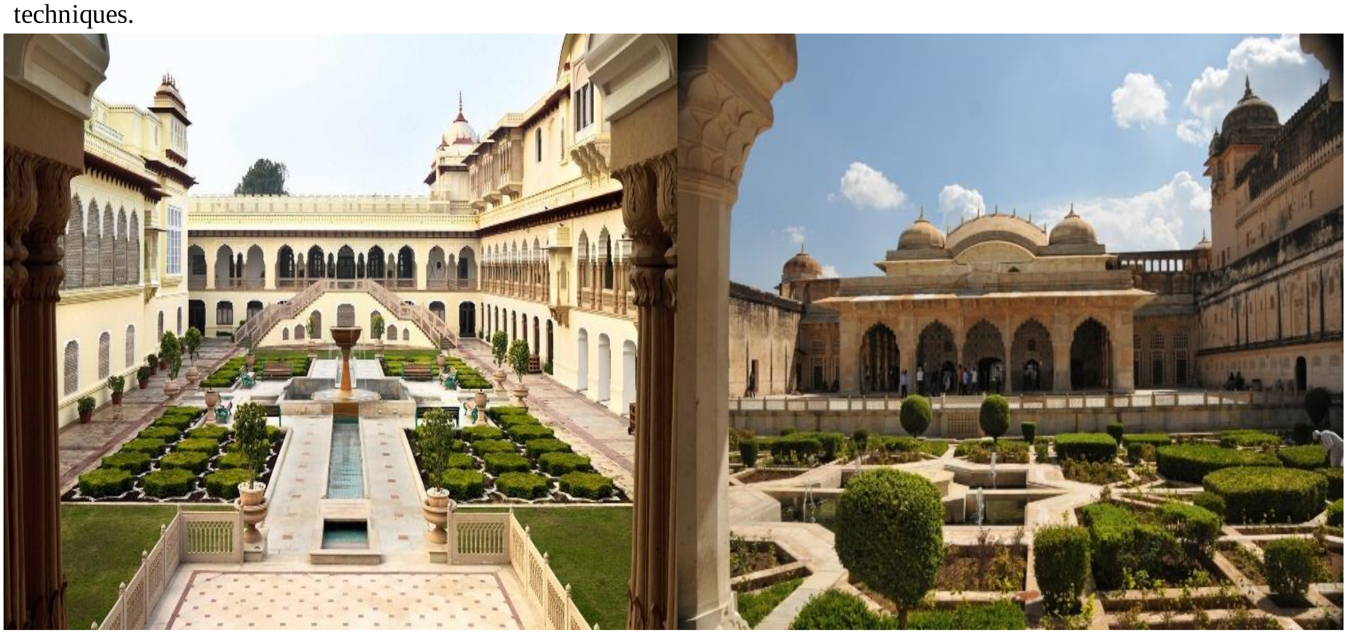

Figure 10: Courtyard

IV. TRADITIONAL BUILDINGS TAKING ADVANTAGE OF PASSIVE COOLING TECHNIQUES

A. Hawa Mahal – Jaipur, Rajasthan

Hawa Mahal also known as the palace of breeze is a prominent example of a passive cooling structure in the hot-dry region of Rajasthan. When the ratio of the facade to the number of punchers in Hawa mahal is compared, it acts as a lattice screen. With 953 windows the air is directed inside, but due to the presence of a water duct the hot air converts into a cooler one. The Hawa Mahal's basic design is similar to that of a honeycomb structure. Lal Chand Ustad designed the Hawa Mahal for Maharaj Sawai Pratap Singh (Hawa mahal – A Natural Cooling System, 2010). The building's original purpose was to allow women to watch processions on the streets below through the intricate jharokhas without jeopardizing their modesty.

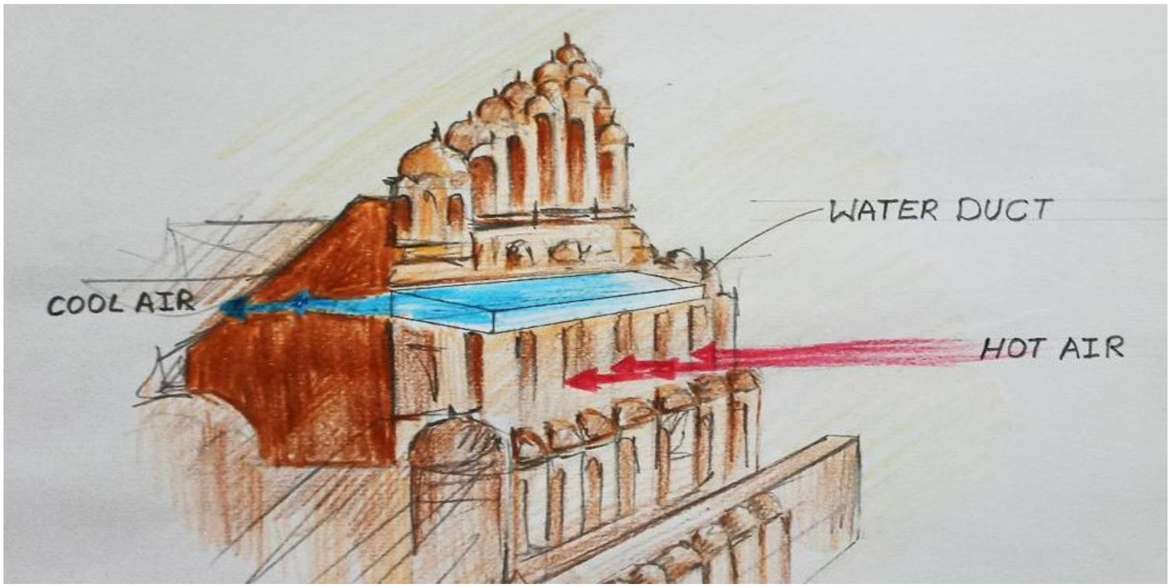

Figure 11: Wind movement through water ducts

It is designed as a natural cooling system, primarily based on the 'Venturi Effect'. The windows and fenestrations in the façade act as wind generators for the interior spaces and corridors. The self-repeating patterns of the punctures with different sizes of windows direct the wind flow to a particular direction. The air blown through is compressed, much like the ordinary laws that govern a modern air conditioner, and is reflected through the curvy linear bay windows. This limestone-constructed structure is a good example of a climate-responsive building as it acts as a natural air-conditioner.

Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section (or choke) of a pipe (Supreme A P, 2021). The lattice windows channel the air in a particular direction because of the geometry used in the construction. In an evaporative cooling system, sensible heat is converted to latent heat, hence the pressure of air is stable and constant even when the air movement is not stable due to weather conditions.

Figure 12: Figure 12: Small windows and cut outs in the facade of Hawa Mahal

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Figure 13: The upper Geometry of Hawa Mahal

The geometry of a structure also plays a very important role in the process of passive cooling. The whole façade is divided into small triangles and sub-triangles with small openings and a lattice screen for the free flow of air. The geometry enhances the wind movement in the structure. The ratio of windows is very large when compared to the façade. The variation seen in the sizes of windows is also very contrasting. There are several large window openings along with detailed smaller lattice screens. When wind passes from these geometric patterns and comes in contact with water present in the water ducts near the openings, the hot air automatically cools down showing a passive cooling effect.

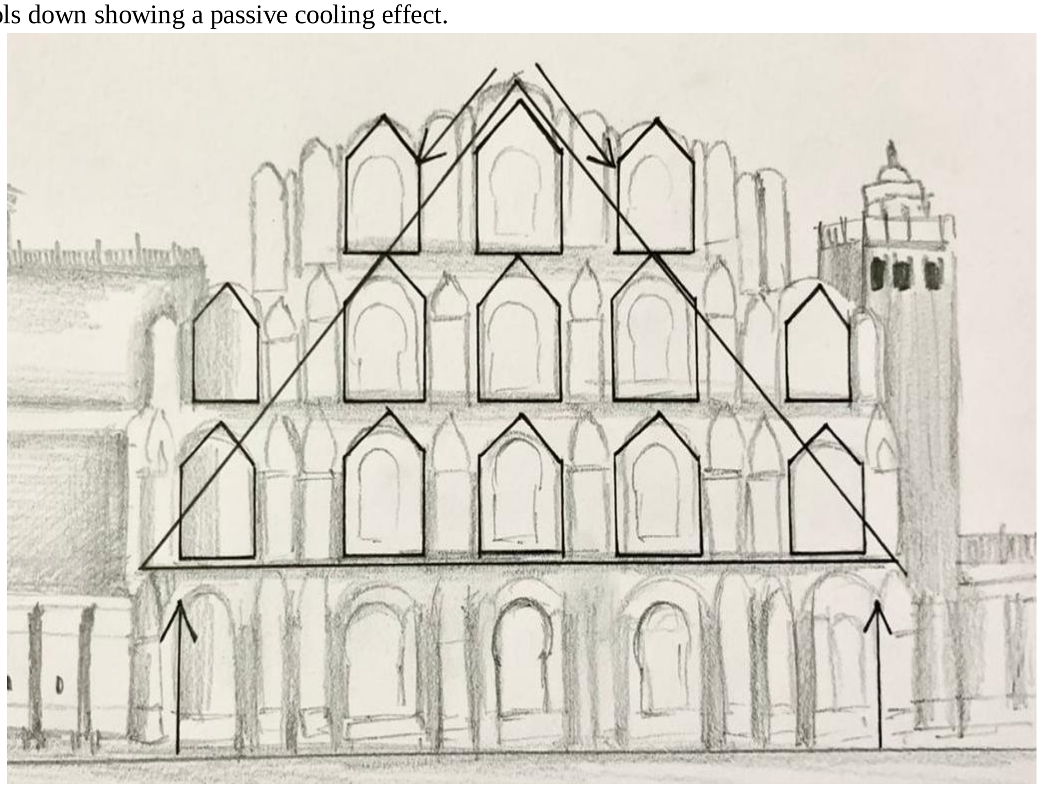

Figure 14: Geometry and pattern easing air flow

*B. Chand Baori – **Village Abhaneri**, Rajasthan*

Chand Baori is a deep four-sided well with a large temple on the structures one face. The monumental well's basic architectural features include a long corridor of steps leading to five or six stories below ground level. Chand Baori is made up of 3,500 narrow steps spread across 13 stories. It extends about 30 m (100 ft) into the ground, making it one of India's deepest and largest step wells. The air at the bottom of the well is 5-6°C cooler than at the surface and Chand Baori was used as a community gathering place for locals during periods of extreme heat (bits & pieces, 2017). A haveli pavilion and royal resting room can be found on one side of the well.

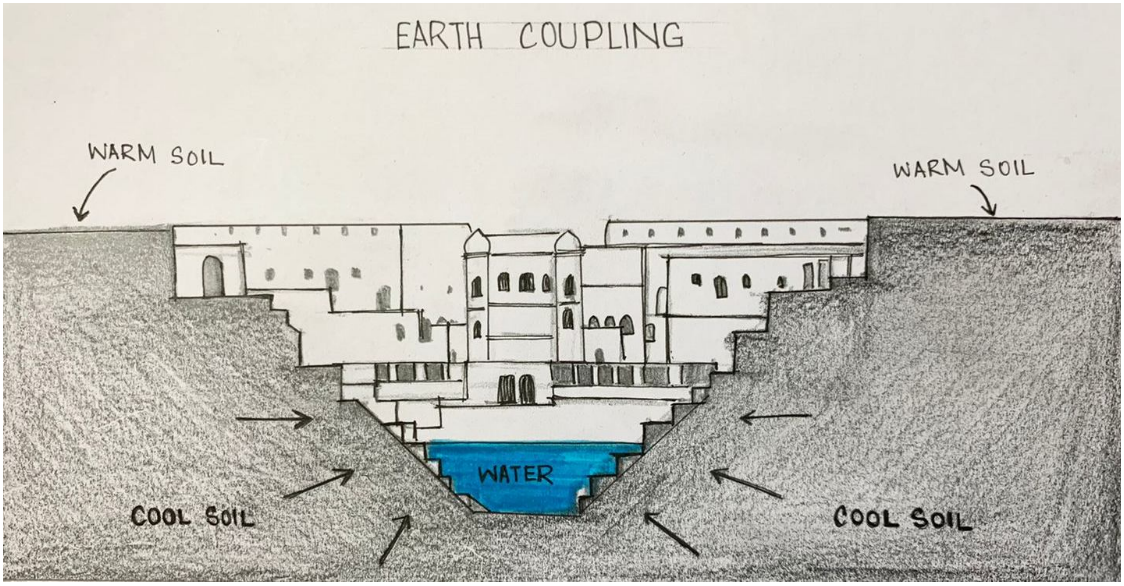

Figure 15: Earth coupling in chand baori

Figure 16: Chand Baori – Village Abhaneri, Rajasthan

The main purpose of the board is water collection but still, it acts as a passive cooling entity. It is an open-to-sky structure with a stone enclosure on four sides and a down water collecting pit at the end. The wide walls used in construction help in thermal insulation and the vaulted roofs restrict the warm air to come inside the structure. The process of earth coupling is seen in the structure. In this process, the temperature of soil acts as a heat sink to cool down the structure by the process of conduction (Subramanian, C. V., & Divya, M., 2016). In a hot-dry climate, this process is very effective. When the earth temperature is cooler than ambient air temperature the denser air which is mostly at the bottom of the surface becomes cooler.

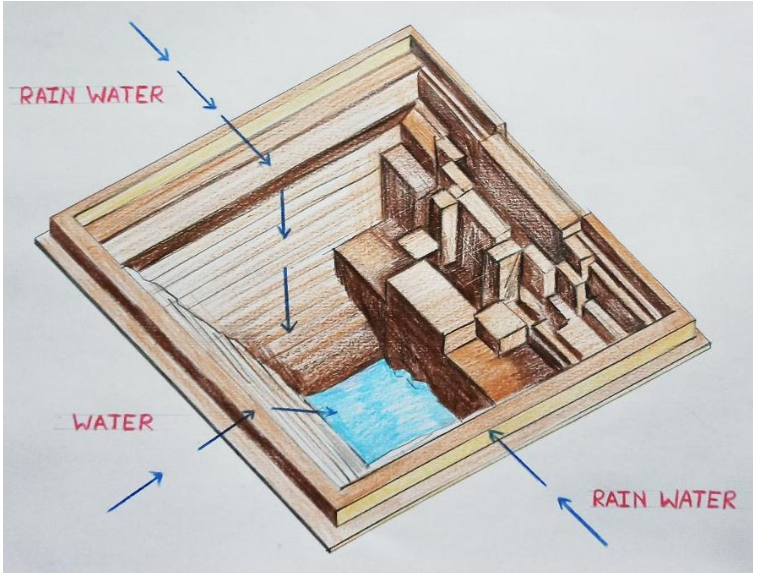

Figure 17: Water collection process - resulting in passive cold winds

In a stepwell system, the earth acts as a heated tank. The topmost layers of the soil are warm but at the deeper end where the water is stored, the soil remains cool. The depth makes the area around it cooler and more comfortable. The stored water by the process of evaporation and condensation changes its state according to the climate and weather conditions giving rise to evaporative cooling. It makes the temperature more comfortable and cool winds are experienced. The design of the structure is a step pattern on 3 sides with private areas later constructed by the Mughals on the north side. At the bottom, the air remains 5-6°C cooler than at the surface of the board (bits & pieces, 2017).

C. Diwan e-Khas - Red Fort, Delhi

Some of the interesting areas of historic structures have been constructed to work with passive cooling techniques. The Diwan-e-Khas in Red Fort, Delhi, would not have been more convenient than an outdoor place without the application of mobile screens and curtains. Two pairs of columns which are around four meters apart surround the throne of the emperor in Diwan-e-Khas (Gupta, V, 1984). Each set of columns could at any time take curtains and displays as needed. Three sets of screens, two of which were grass mats kept moist by water sprinkling are claimed to have been employed in the summer. In winter the strings were heavily quilted and curtains were replaced by these screens. During the day these curtains were raised to permit the sun to warm up the interior of the structure and dropped in the afternoon to keep it warm. A channel of water flows just beneath the throne which helps in cooling the air (Gupta, V, 1984). In Mughal architecture, water was used as an element of design that acted as a passive cooling entity.

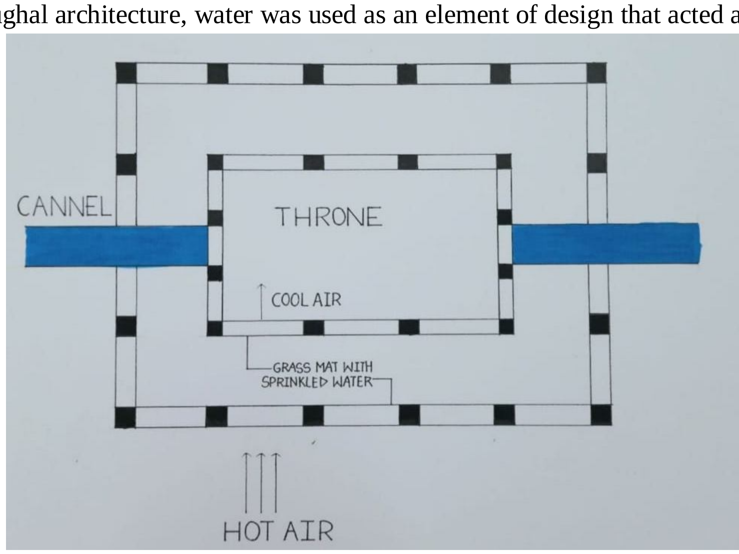

Figure 18: Throne at Diwan e-Khas - Red Fort, Delhi

V. CONCLUSIONS

As the resources are depleting and demands are rising, with no support of resources it becomes difficult to use mechanical modes for cooling a building. The traditional buildings are great examples of climate-responsive structures. Understanding the structures from the past and incorporating those features in the recent construction practices will enhance the productivity of buildings. This will promote energy efficiency, decrease energy use, increase the use of renewable and natural resources, increase thermal comfort and decrease the maintenance cost of the structure. If thermal comfort is achieved in any weather condition, then the structure becomes climate responsive. Taking inspiration from the past and designing energy-efficient structures is a need for today, and by incorporating passive cooling techniques in buildings it can be achieved.

VI. ACKNOWLEDGMENT

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