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Passive Cooling Through Natural Ventilation Techniques in Green Buildings: Inspirations from the Past

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Abstract–*Green building concept, in broader terms, involves a building, which is designed, built, operated, maintained or reused with objectives to protect occupant health, improve employee productivity, use wisely natural resources and reduce the environmental impact. It contributes towards lower development costs, lower operating costs, increased comforts, healthier indoor environment quality, and enhanced durability and less maintenance costs. Buildings consume approximately 40% to 50% of total produced primary energy globally. Increasing use of technology & need of thermal comfort with luxury has led to an increasing demand for Cooling in composite. Cooling thus accounts for a significant proportion of the total energy consumption in buildings, and its impact on greenhouse gas emissions is enhanced by the fact that these cooling systems are usually electrically driven and measure part of electrical energy produced in India is by conventional resources & fossil fuels. We have to accept the fact that before invention of mechanical means to provide comfort conditions, people used to make their dwellings in a way, which were comfortable to live in, and were dependent on passive means. but in present scenario people depend more on active means to achieve comfort conditions in their dwellings, and natural means to provide comfort conditions have thus been neglected which were used in past extensively. This paper deals with applicability of passive and low energy cooling technologies & ventilation techniques in the context of composite climate. These techniques are inspired our past. The conclusions arrived from this research suggest direction for further research to explore guidelines for designing green buildings for the present era and future world by following path toward our historic capital.*

Keywords: *passive cooling, natural ventilation, green building, sustainability.*

1. INTRODUCTION

There are many definitions of what a green building is or does. In broader term all definitions include a very important & common consideration which is energy consumption & environmental impacts due to construction & maintenance of building. Both these considerations are dependent & correlated to each other. Fig. 1 represents case of energy consumption in heating ventilation & air conditioning play a major role in energy consumption [1].

In regions of tropical climate such as in India, heat is the major problem that causes thermal discomfort. So Cooling is the basic requirement of building occupants. Cooling is the transfer of energy from a space or from the air, to a space, in order to achieve a lower temperature than that of the natural surroundings.

In modern buildings, mechanical and electrical instruments based air conditioning systems to control the temperature, moisture content, circulation and purity of the air within a space, in order to achieve the desired effects of comfort for the occupants are used majorly. The shortage of conventional energy sources and escalating energy costs have caused the re-examination of the general design practices and applications of air conditioning systems and the development of new technologies and processes for achieving comfort conditions in buildings by passive means.

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 buildings in ancient time was energy efficient & environmentally favorable.

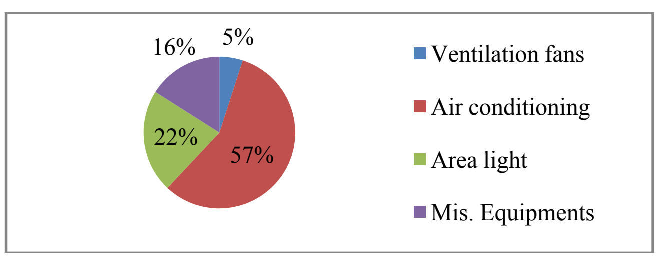

Fig. 1: Energy Requirement In Building

2. ENERGY USE SCENARIO IN BUILDINGS-

During the last 30-40 years we have been sensing the bitter experience of global warming, ozone depletion, resource depletion, energy scarcity, ecological toxicity, human toxicity, acid rains etc.[2]. These have alarmed, rather compelled the mankind to change the way they operate on the earth. Though we cannot avoid affecting the environment, the green buildings & sustainable architecture will aim and contribute towards minimizing the environmental impact. It contributes towards lower development costs, lower operating costs, increased comforts, healthier indoor environment quality, and enhanced durability and less maintenance costs.

Till now we have not perceived a significant contribution in the construction industry towards energy efficient buildings & energy saving. Clients & developers has more often tend to go by cheaper options of construction and ended up in higher operational and maintenance costs in term of energy consumption, adding larger impact on environment because initial investment cost in green building is little higher as compare to conventional building.

Climate change has become the inevitable result of our past actions. According to the United Nations, cities consume two thirds of global energy use. Studies have shown that buildings and construction activities use 40% energy (Fig. 2), 30% mineral resources (Fig. 3) and 20% water of the world's resources (Fig. 4). It also accounts for 40% CO2 emissions (Fig. 5), 30% solid wastes (Fig. 6) and 20% water pollution (Fig. 7) in the world [3].

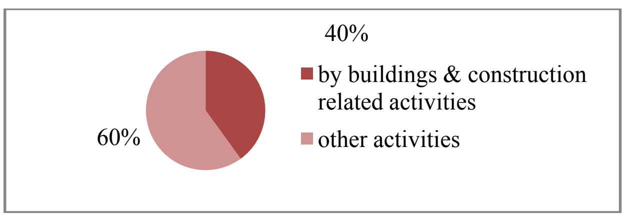

Fig. 2: Global Energy Use

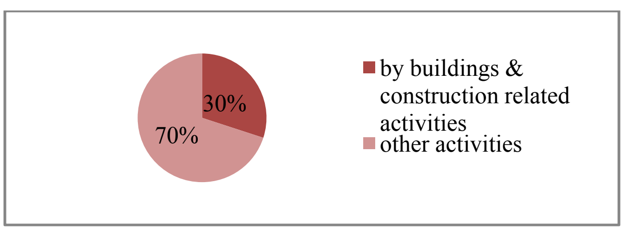

Fig. 3: Mineral & Resource Use

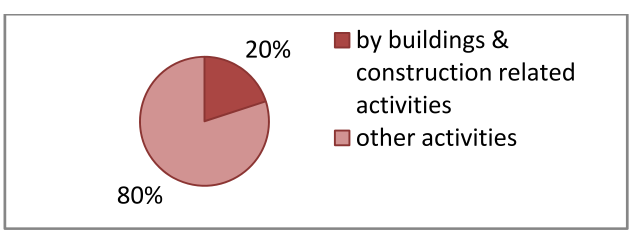

Fig. 4 Water Use

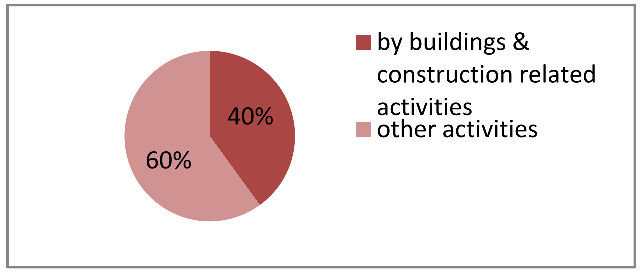

Fig. 5:CO_2 Emission

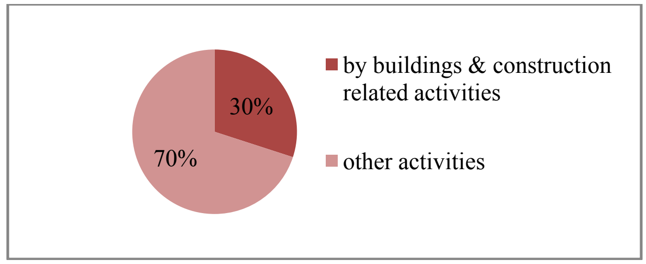

Fig. 6: Solid Waste

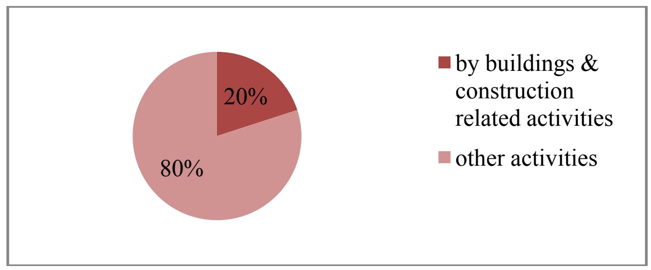

Fig. 7: Water Pollution

When we look to our history, 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).

Before the industrial revolution, emphasis of designers was to develop the techniques which could provide thermal comfort with minimal use of energy because of scarcity of resources. So they got to success in development of passive techniques. during that period there were a very supportive relationship between humans and nature. Later, the industrial revolution influenced the globe and a population explosion in urban areas took place [4]. These factors promoted the use of non-renewable materials and high energy consumption in the building industry. so when we are using conventional system to produce energy for our comfort we are exploiting environmental resources & destroying it by polluting it.

3. NEED OF PASSIVE MEANS FOR COOLING & VENTILATION

Green buildings have been shown to save money through reduced energy and water use and lower long-term operations and maintenance costs. Energy savings in green buildings typically exceed any design and construction cost premiums within a reasonable payback period. but when we look to criteria's related to energy use of green building certification they permit to use anything the developer/user wants to use in building whether it can consumes unnecessary amount of energy but they are focused to compensate this energy demand with the renewable energy resources in spite of removing & reducing this demand by using passive means.

Due to present & upcoming energy crisis there is an need to implement a different option that could provide required thermal comfort at a fraction of the expense of conventional systems, which must respectful of the outdoor environment and socially acceptable. Passive cooling systems offer this opportunity. Because of their simple design, passive cooling systems can be built at lower costs and using local labor and resources, generating income for local entrepreneurs that stays in the community and contributes to local development.

Passive cooling & natural ventilation systems help to establish a closer connection between the dwellers and the environment through the building, ultimately helping to better connect with nature's rhythms. If passive systems are added in existing buildings as the population wishes to improve their life quality, energy consumption will increase very little, while thermal comfort will improve substantially. If passive cooling systems are well integrated and generally accepted by the population, it would be an important step to create a more sustainable architecture globally.

A mechanical cooling & ventilation system has further a considerable shorter service life span than the building structure. A refurbishment or a reinstallation of a new system tends to pull with it a great share of the rest of the building due to the way the systems' plan and its appurtenant network of ducts are shaped and infiltrated in the building structure, thereby reducing the building's average life span [5].

4. IMPORTANCE OF OUR HERITAGE IN TERM OF PASSIVE COOLING & VENTILATION TECHNIQUES-

Energy is the important component for economic development of the country. The modern equipment and materials used in construction and to maintain indoor thermal environment consumes significant amount of our national energy. In view of the shortage of energy it is very much essential to review the historical origin of Architecture &Technology to restore the comfort inside the building. Thermal performance and air quality inside the buildings can be improved substantially and energy can be saved through understanding the ancient design concept.

Traditional architecture is the outcome of centuries of optimization of climate consideration, of material use, construction techniques [6]. Ancient buildings demonstrate the passive architecture of that specific region. Without mechanical means these buildings are better than the newly designed buildings. Natural ventilation and advantages of solar direction was taken in those buildings. Materials are chosen for construction according to the climatic characteristics of the place. The Palaces in Rajasthan also demonstrates the natural ventilation techniques. Water body in temple premises, keeps the environment cool and improve the microclimatic conditions. Havelis of Rajasthan & Gujrat are good examples of passive architecture. The Mughals constructed excellent mausoleums, mosques, forts, gardens and cities. Taj mahal, Agra fort and, Fatehpur Sikri are few monumental buildings near Agra. Mugals laid out many beautiful gardens with water bodies in the centers in the neighborhood of Agra & Lucknow. These buildings are designed in such a way that all people are comfortable inside a building during the hot summer. Landscaping elements water body and trees provided in monumental buildings, temples improves the microclimate of the place and increase the comfort level in the buildings. Courtyard was also an important design element in old residential buildings in hot dry climate called Havelis. It was an element of passive cooling for regular fresh air supply.

5. DESIGN ELEMENT

There are various design elements have been used in different part of world for thermal comfort. like orientation of building, thermal mass, water body, open courtyard, various kind of shading devices, vegetation, lattice screen, domes, jharokhas & wind towers & air vent etc.

From above elements above mentioned mostly perform multiple functions. For example water body behaves like aesthetical feature in the building as well as a source of thermal cooling. open courtyard functions like a source of ventilation as well as a part of integrated indoor- outdoor living area, shading devices provides shade but also capable to change direction of wind at micro level. Lattice screen provides ventilation as well as privacy from outside. Domes causes the high volume in building so stores hot air in it as well as behaves as a ventilation source if vent is provided. with this it causes thermal comfort because of self-shadow produced by dome on itself. With all these features it is a important architectural as well as structural element. All these design elements was used extensively in our ancient buildings of different regions for the purpose of thermal comfort & ventilation.

Here we are going to discuss about four major elements which were used extensively in our past and can play import role in form of a passive strategy to control climate in green building design as well as in conventional designs.

5.1. Jharokha

A jharokha (or jharoka) is a projecting window from the wall, in an upper storey, overlooking a street, market, court or any other open space. it is a type of overhanging enclosed balcony used in Indian architecture.

In Islamic Architecture it is known as 'Mashrabia'. It has monumental scale and make it as a outstanding architectural character. It mainly represents two architectural styles– Mughal Architecture (Combination of Islamic, Persian and Indian Architecture) and Rajasthani Architecture (Western Indian Architecture)[7]. It is most distinctive type of facade decorated with intricate lattice work. It is more formal and ornamental than English or French “oriel”.

Jharokha is used due to the aesthetic appearance, climatic aspects, elevation treatment , privacy to allow royal ladies to observe everyday life in the street below without being seen, since they had to observe strict 'purdah' (face cover) as a viewing platform.

Jharokhas are mainly used in Palaces, Havelis (mansion type structure) and Temples. They brings filtered light into the indoor space. Being a dusty and harsh climate within the area, it brings channeled cool air through its openings and jaalis. Direct wind flow inside the building is not desirable. These openings are shaded with projections covered all around with perforations allows cooling of air. It also helps to shade the building façade.

Fig. 8: Jharokhas In Hawa Mahal Jaipur, India

Purpose of minizing the area of building surface exposed to sun is achieved using this module in repetitive manner. Covering outer layer of the building facade with these kind of projecting overhangs, jaalis and small openings in it works for ventilation purpose. During the day, outer layer gets heated and radiated to immediate environment. When the building have only one layer. Building gets heated up early by transmitting the sun rays directly to primary spaces. But organizing secondary spaces adjacent to outer layer it acts as transitional space keeping comparative cooler inside the primary spaces. Heat enters the secondary space will dissipate in the streets with respected openings in secondary space before it enters inside.

Fig. 9: Jharokha in haveli of jaisalmer

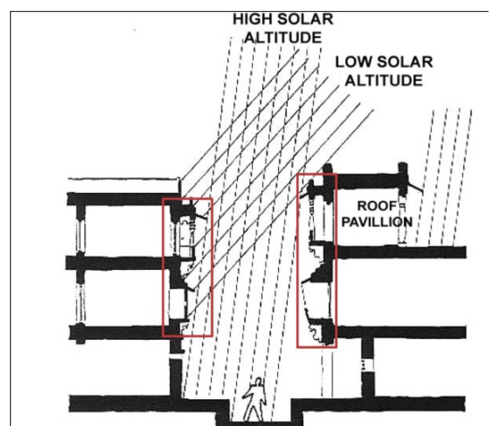

Fig. 10: jharokhas in jaisalmer over narrow streets

5.2. Wind catcher

A windcatcher (badgir in persian) is a traditional Persian architectural device used for many centuries to create natural ventilation in buildings. It is not known who first invented the windcatcher, but it still can be seen in many countries today. Windcatchers come in various designs: uni-directional, bi-directional, and multi-directional. Examples of windcatchers can be found in traditional Persian-influenced architecture throughout the Middle East, Pakistan and Afghanistan[8].

Central Iran has a very large day-night temperature difference, ranging from cool to extremely hot, and the air tends to be very dry all day long. Most buildings are constructed of very thick ceramics with extremely high insulation values. Furthermore, towns centered on desert oases tend to be packed very closely together with high walls and ceilings relative to Western architecture, maximizing shade at ground level. The heat of direct sunlight is minimized with small windows that do not face the sun [9].

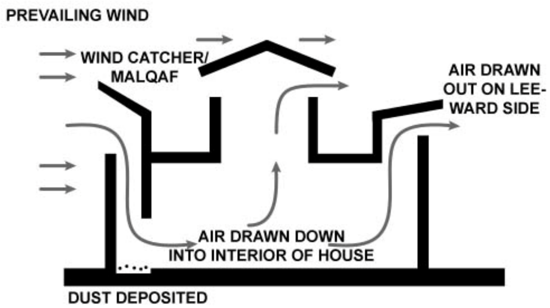

Fig. 11: A windcatcher or malqaf used in traditional persian / arabic architecture

The windcatcher can function by several methods:

One of the most common uses of the badgir is as an architectural feature to cool the inside of the dwelling, and is often used in combination with courtyards and domes as an overall ventilation / heat management strategy. The malqaf is essentially a tall, capped tower with one face open at the top. This open side faces the prevailing wind, thus 'catching' it, and bringing it down the tower into the heart of the building to maintain air flow, thus cooling the interior of the building. This is the most direct way of drawing air into the building, but importantly it does not necessarily cool the air, but relies on a rate of air flow to provide a cooling effect. This use of the malqaf or windcatcher has been employed in this manner for thousands of years, as detailed by contemporary Egyptian architect Hassan Fathy.

The second usage is in combination with a qanat, or underground canal. In this method however, the open side of the tower faces away from the direction of the prevailing wind. (This can be adjusted by having directional ports at the top). By closing all but the one facing away from the incoming wind, air is drawn upwards using the Coandă effect, similar to how opening the one facing towards the wind would pull air down into the shaft.

As there is now a pressure differential on one side of the building, air is drawn down into the passage on the other side. This hot air is brought down into the qanat tunnel, and is cooled by the combination of coming into contact with the cold earth (as it is several meters below ground, the earth stays continuously cool) as well as the cold water running through the qanat. The air is therefore cooled significantly, and is then drawn up through the windcatcher by the same Coandă effect. This therefore brings cool air up through the building, cooling the structure overall, with the additional benefit that the water vapour from the qanat has an added cooling effect.

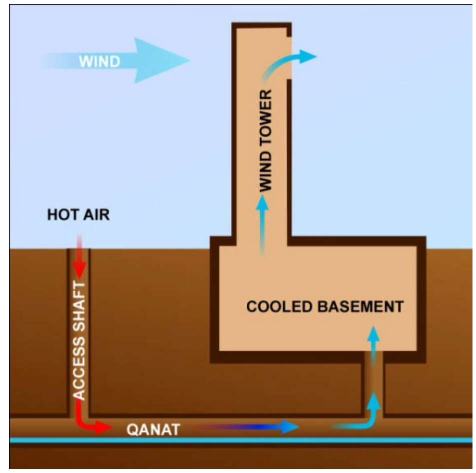

Fig. 12: A windcatcher and qanat used for cooling.

Finally, in a windless environment or waterless house, a windcatcher functions as a solar chimney. It creates a pressure gradient which allows less dense hot air to travel upwards and escape out the top. This is also compounded significantly by the day-night cycle mentioned above, trapping cool air below. The temperature in such an environment cannot drop below the nightly low temperature. These last two functions have gained some ground in Western architecture, and there are several commercial products using the name windcatcher.

When coupled with thick adobe that exhibits high heat transmission resistance qualities, the windcatcher is able to chill lower level spaces in mosques and houses (e.g. shabestan) in the middle of the day to frigid temperatures.

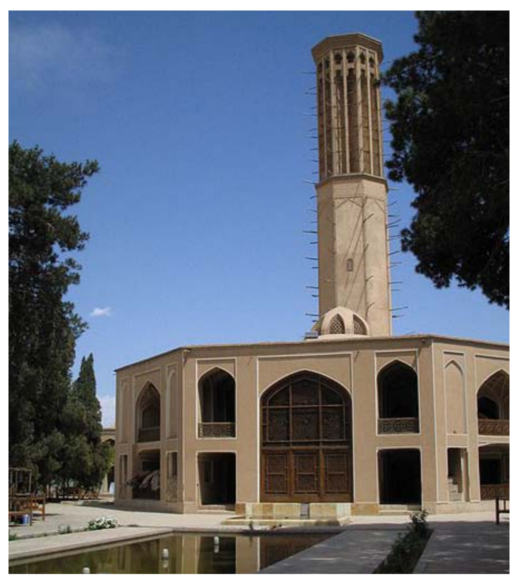

Fig. 13: The windcatcher of Dowlatabad (one of the tallest existing windcatchers) in Yazd, Iran

So effective has been the windcatcher in Persian architecture that it has been routinely used as a refrigerating device (yakhchal) for ages. Many traditional water reservoirs (ab anbars) are built with windcatchers that are capable of storing water at near freezing temperatures for months in summer. The evaporative cooling effect is strongest in the driest climates, such as on the Iranian plateau, hence the ubiquitous use of these devices in drier areas such as Yazd, Kerman, Kashan, Sirjan, Nain, and Bam. This is especially visible in ab anbars that use windcatchers.

With the combination of water tanks and windcatchers, the residents of Yazd – the oldest inhabited city in Iran – were able to keep the lower levels of their buildings cool, providing a place to escape from humid summer days as well as somewhere to store food.

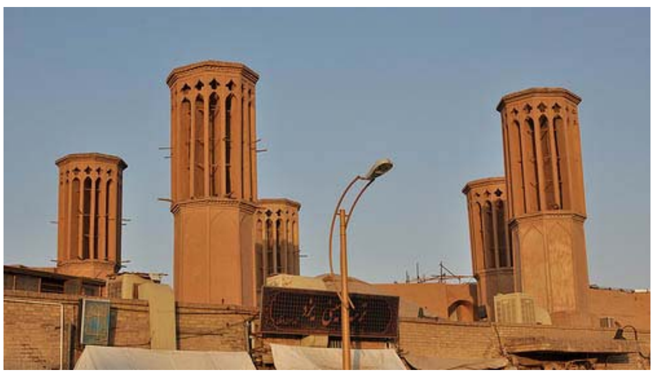

Fig. 14: Windcatchers in Yazd, Iran

Lattice Screen (Jaali)

lattice screens also known as Moroccan latticework , Moroccan wood grills, Moorish screens, is the Arabic term given to a type of projecting oriel window enclosed with carved wood latticework located on the second storey of a building or higher. it is an element of traditional Arabic architecture used since the middle ages up to the mid twentieth century. It is mostly used on the street side of the building; however, it may also be used internally on sahn side [10].

These were mostly used in houses and palaces although sometimes in public buildings such as hospitals, inns, schools and government buildings. They are found mostly in the mashriq – i.e. east of the Arab world, but some types of similar windows are also found in the maghrib (west of the Arab world). They are very prevalent in Iraq, the Levant, Hejaz and Egypt. They are mostly found in urban settings and rarely in rural areas.

Lattice screen with operable windows gives shade and protection from the hot summer sun while allowing the cool air from the street to flow through. The designs of the latticework are usually with smaller opening in the bottom part and larger openings in the higher parts, hence causing the draft to be fast above the head and slow in lower parts. This provides a significant amount of air moving in the room without causing it be uncomfortable. Jaali in Mughal buildings mostly have a low sill or sometimes without sill so that the air could move near the floor. Original lattice screens were made of wood. This wood itself absorbs the extra humidity from the air if it presents in it. if sometime humidity is lesser and air is dry then wood from this lattice humidify the air.

With all these climatic features it also provides privacy from outside. 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.

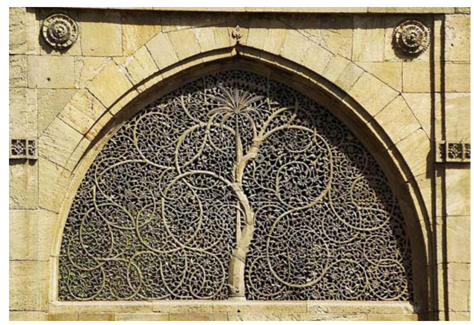

Fig. 15: Common lattice screen of mughal period, india

Fig. 16 Lattice Screen at Amber Fort

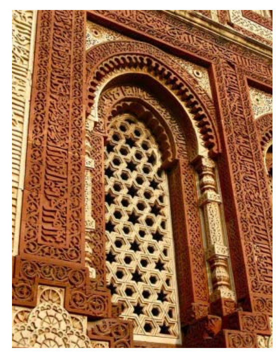

Fig. 17 lattice screen on façade

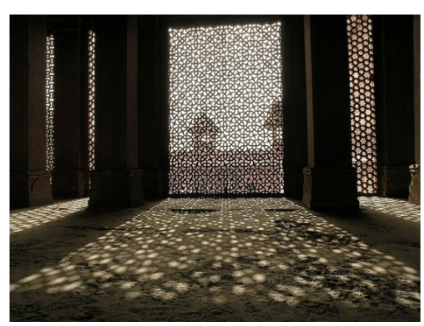

Fig. 18: Lattice screen working as a shading device

Courtyard

There are different definitions of courtyard. According to the Oxford Dictionary, courtyard is "an unroofed area that is completely or partially enclosed by walls or buildings, typically one forming part of a castle or large house". In the past it was used as a traditional element especially in designing the houses. Recently, it is considered as one of the passive design strategies to moderate the climatic conditions (Heidari, 2000). In many regions courtyard is an important and popular architectural space because it involves many daily activities due to its characteristics.

It is a safe place for playing of children or women's activity especially in the third world countries. Moreover, it can be used as a pray place in mosques or as a gathering place in schools, hospital, commercial buildings and even in prisons. Therefore, the courtyard's function is one of the factors to decide on its using as well as its shape and size (Taleghani et al., 2012b). One of the main reasons of using courtyard for more than 5000 years is its environmental effects. In different climates, courtyard can be used as a source of day-lighting for adjacent rooms in deep plans. Further advantage of courtyard in winters is protecting the parent building from harsh conditions of weather such as winds (Upadhyay, 2008). During cold seasons it may increases direct solar heat gain in the rooms which have glazing area on the courtyard. Its performance during summers is different. It can be a solar protector by planting deciduous trees in the courtyard. Furthermore, natural ventilation during hot seasons occurs through the courtyard especially in hot climates. During daytime the air in the courtyard becomes warmer and rises. This draws out the internal warm air into the courtyard through the openings. Consequently, it makes an air movement inside the adjacent building.

Fig. 19: Courtyard in Haveli of Shekhawati Rajasthan

During nights the process is opposite in which the ambient cool air sinks into the courtyard and enters into the internal spaces through the low-level openings. This makes airflows in the rooms and the cooled air becomes warm and then it rises and leaves the rooms through the high-level openings (Fig. 1) (HPCB, n.d.). Bahbudi et al. (2010) point out that the courtyard can be more effective for natural evaporative cooling with the help of vegetation and fountains. Moreover, the shady area can be increased by the high walls around the courtyard and this reduces the temperature of the ground surface. As a result, the courtyard can be used during the daytime [11].

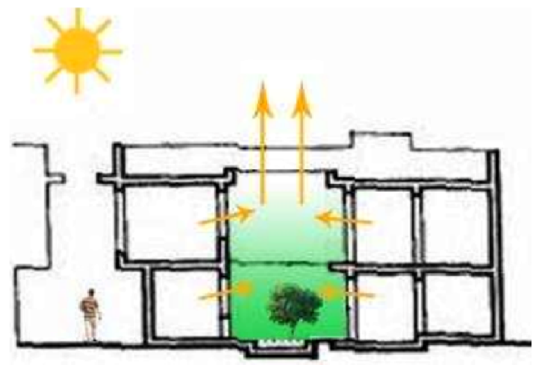

Fig. 20 : Effect of courtyard on ventilation during day

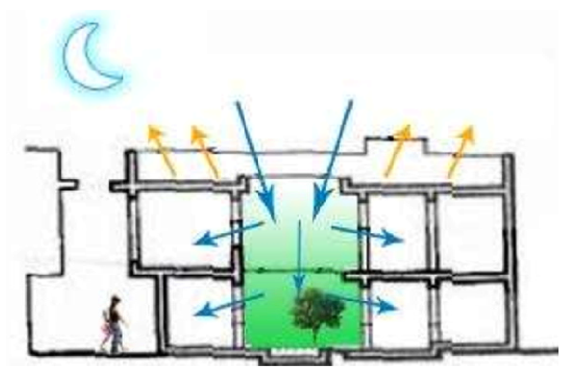

Fig. 21: Effect of courtyard on ventilation during night

6. DESIGN RESPONSE WITH PRESENT CONDITIONS

Very few buildings are designed with the concepts of passive designs inspired from our past. Two case studies of green buildings are given here.

6.1. Pearl Academy Jaipur, India

One of the buildings recognized globally for the passive design is Pearl Academy Jaipur, india, built in the arid suburbs of Jaipur, Rajasthan by Architect Manmit Rastogi.

The Pearl Academy of Fashion combines modern exterior styling with influence of ancient Rajasthani architecture - designed to keep temperatures down without artificial cooling systems. other passive features used are:

- Double skin, derived from traditional "jaali" screen runs the length of the building to provide a cooling outer skin.

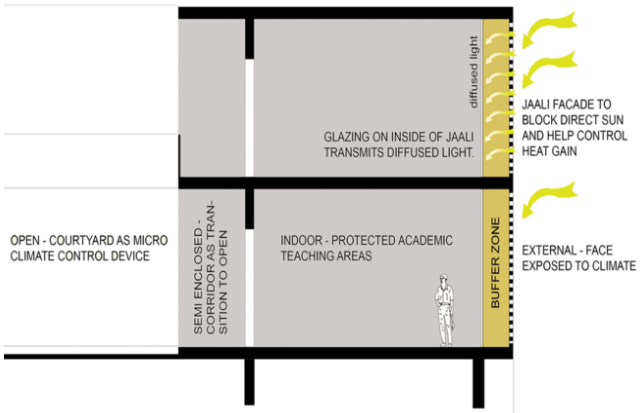

Fig. 22: Double skin by lattice screen

- Traditional step wells often go many stories below ground level, here it is just four meters down where it has a water body for the purpose of evaporative cooling.

Fig. 23: Stepped well form lower ground floor

At the height of summer, in the sweltering industrial suburbs of Jaipur, Rajasthan in north-west India, the Pearl Academy of Fashion remains 20 degrees cooler inside than out -- by drawing on Rajasthan's ancient architecture. Reversed earthen pot kept on the roof to provide thermal insulation from heat. it is a very good ancient technique used in ancient buildings of Rajasthan.

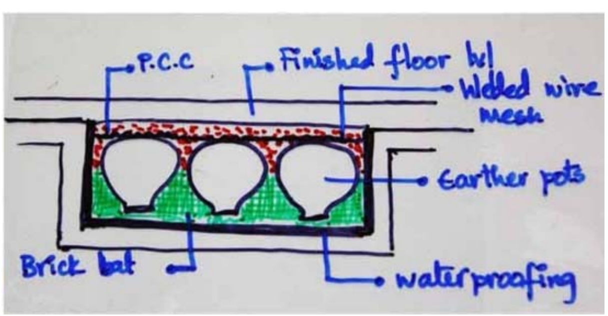

Fig. 24: Reversed earthen pot for roof insulation

Fig. 25: Water body for evaporative cooling

Fig. 26 : Double skin on Exterior by jali

The central water body act as step-well and keeps the surrounding area cool. This modern building is inspired by the traditional passive techniques.

6.2.King Abdullah University of Science and Technology (KAUST):

King Abdullah University of Science and Technology (KAUST) campus is Saudi Arabia's first LEED Platinum rated certified project, the highest rating in the United States green building rating system. The KAUST is a contemporary design paradigm which integrates innovative strategies borrowed from traditional architecture in hot humid climate of Jeddah. KAUST, a world-class research university is situated at Thuwal, near Jeddah having an area of 6.5 million square foot. The master plan encompasses the four million square foot campus, a commercial town center and the entire public realm.

In the Saudi Arabian climate, KAUST applies a delicate balance between controlling solar heat gain and allowing sufficient natural daylight into occupied spaces. The campus buildings utilize overhangs, fixed exterior louvers, dynamic exterior louvers, atria, skylights, and mechanical shading systems to ensure that this balance is achieved. KAUST integrates sustainable measures into the design of the entire community. The design team integrated a series of innovative strategies to create a low-energy, highly sustainable project in the context of an extremely hot, humid climate. They employed five strategies that are borrowed from local culture and traditions to solve environmental issues (Elgendy, 2010). These traditional inspirations included:

- Compact Planning of the Traditional Arab Cities of the Middle East to Minimizing sun exposure to the facades.
- Patio's perforated roof (jaali) that filters light and allows the air to flow emphasized from the traditional Souk (Arab market).
- The Arabic Bedouin tent inspired designers to create a monumental roof system that spans across the campus's building masses to block the sun from building's facades and from the pedestrian spine.
- Passive ventilation strategies of the traditional Arabic house inspired the design of iconic, solar-powered wind towers that harness energy from the sun and wind to passively create air flow in pedestrian walkways.
- Similar to Arabic screening called the Mashrabiya, or wooden latticework screen, inspired the design of the campus's shading devices with an integral shading system that reduces heat load[12].

Fig. 27: KAUST integrates innovative strategies borrowed from traditional architecture of Saudi Arabia (Source: Elgendy, 2010).

7. CONCLUSION

This work has examined various natural ventilation techniques for passive cooling inspired from our glorious past. Traditional buildings are a vital link to the past, an expression of their historical origins and of interest to those who seek to keep in contact with the traditional roots of their society. The study of these dwellings, on the one hand helps to better understand their development, and on the other, provides examples of a sustainable building tradition, from which many lessons can be learned like, their respond to climatic conditions using low-energy design principles to provide human comfort. Incorporation of these sustainable building principles would certainly reduce our dependency on artificial means for thermal comfort and minimize the environmental problems due to excessive consumption of energy and other natural resources.

The recent concept of energy efficient Green buildings attracted all the scientists and building architects to switch over from the present practice of mechanical cooling to ancient methods of passive cooling methods in an efficient modern way. It should be noted that a concept suitable for one place may not be suitable for another, if the climatic conditions are different. Hence, being highly site specific, based on the climatic zones the selection of various ventilation & cooling techniques have to be chosen.

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