Passive Design Techniques as a Sustainable Solution for Thermal Comfort in Transitional Spaces of an Institutional Building (A Case of Jaipur)

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Abstract: ***The use of passive technologies in the buildings are emerging since last few years as sustainable design solution. Architects are using many passive techniques like evaporative cooling, wind towers, adaptive fenestrations etc., to create sustainable buildings. Presently there are many examples available in India in this regard. Many buildings are especially designed with the fusion of modern and passive technologies in the hot and dry climate of Indian subcontinent. This paper compares the various passive strategies used in the transitional spaces of institutional building of Jaipur. It also recommends various design considerations to be preferred while designing the transitional spaces in institutional buildings. It is observed that the use of passive technologies in the transitional spaces helps in lowering down the temperature and providing thermal comfort within the spaces.***

Keywords: thermal comfort: transitional spaces; passive technologies

1. Introduction

Educational buildings accounts for a large portion of building stock in which there is also high energy consumption that needs to be reduced and thermal comfort to be achieved with minimum energy consumption. An institutional campus can be regarded as a small city due to its large educational building's coverage, population size, and various complex activities, which may have serious direct and indirect impacts on the environment. Transitional spaces refer to those spaces located in-between interior and exterior environments acting as both buffer spaces and physical links, such as entrance canopies, foyers, lift lobbies, corridors, stairwells, atrium, etc. They account for 10% to 40% of total volume in different types of buildings and are considered as one of the alternative means for optimizing building performance. For any transition space to function effectively in terms of providing thermal comfort, there are parameters such as location, as well as social and physical environment that all play primary roles. Passive design concepts are used throughout the world in traditional structures. It can be described as a manner to design buildings to obtain a comfortable environment that minimizes mechanical system energy use and dependence as they contribute to serious environmental problems because of excessive consumption of energy and other natural resources. Factors affecting thermal comfort in buildings can be classified into two groups. The first group of factors include local climatic conditions, which are outdoor temperature, relative humidity, solar radiation, geographical location and the effect of neighboring buildings *etc*. The second group of factors comprise materials of the building envelope, glazing type and size, orientation, thermal mass, surrounding vegetation, thermal insulation, ratio of transparent and opaque components, shading tools, building form etc. As can be realized, architects have a chance to control and regulate the second group of factors in achieving better thermal comfort in their designs.Basically, modern buildings can incorporate the methods employed in traditional buildings to attain thermal comfort in a passive way.

2. Need for Study

Climate change is the most recent talked issue in today's time. In the coming decades, climate change is likely to become very evident. Now that climate is changing, our built environment also faces the challenge to reflect a new & developing set of guidelines. The buildings should be designed in accordance with the user satisfaction & making it thermally comfortable using passive techniques.Prior to the development of mechanical air conditioning systems, societies used natural heating and cooling methods – such as shading, thermal mass, and natural ventilation – to achieve thermal comfort. Such methods have been used for thousands of years. Ancient Indians would hang wet grass mats on the windward side of their homes to achieve a cooler indoor temperature. Society moved away from these methods when mechanical cooling became available in the early 1900s. In 1902, the first mechanical cooling system was built [1].The emergence of air conditioning has made it possible to have a comfortable indoor environment in any climate, and has also led to designs that have totally ignored variable climatic circumstances. This results in serious consequences that ultimately teach the importance of passive concept. The current study is limited to the transitional spaces of institutional buildings at Jaipur.

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3. Common passive design elements

A few common design elements that directly or indirectly affect thermal comfort condition and thereby the energy consumption in a building are listed below:

3.1 Landscaping

The microclimate of the site needs to be studied in which landscaping plays an important role. It helps in reducing direct sun from heating building surfaces. Tree shade helps in reducing air temperature about 2 to 2.5°C and provides evaporative cooling. Deciduous trees are beneficial on the southern side of the building (Majumdar, 1997).

3.2 Building plan &form

The form of the building in hot and dry climate must minimize east and west walls to reduce heat gain. In these regions, buildings are compact in form to reduce heat gain and loss. Maximizing building depth would help in increasing thermal capacity (Kamali, 2014). Greater the perimeter - to - area ratio, greater is the heat gain by the building. Planforms with greater P/A ratio may be applied in certain cases to include features like water bodies & vegetation which can modify the micro-climate. The intermediate spaces can also be effective as interaction spaces.

3.3 Location of water bodies

In hot & dry regions, water bodies would help in significant cooling by evaporating a large amount of heat. Water acts as a modifier of climate.

3.4 Orientation

In the hot and dry climate zones, the optimum orientation is north-south. West and east side of the building receives maximum heat. The buildings should be oriented facing the prevailing cool wind direction to allow maximum cross ventilation during the night, and avoid hot dusty winds during the day.

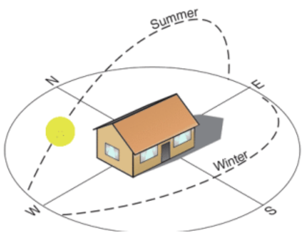

Figure 1: Orientation
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3.5 Building envelope

The primary elements of a building envelope are materials used in construction, roof, walls, fenestration and shading. Low energy materials are preferred. In hot climates, insulation is placed on the outer face so that the thermal mass of the wall is weakly coupled with the external source and strongly with the interior(Majumdar, 1997). In hot regions, insulation on roofs can be provided using earthen pots, cover of deciduous plants or creepers. Blinds, curtains and louvers can be provided for shading. The window size should be kept minimum in hot and dry regions(Majumdar, 1997).

3.6 Courtyard

Courtyards are important for daylight & ventilation and has a cultural significance too. Ventilation in hot dry climate is useful if the air is cool. Thus, the courtyard should (a) be proportioned to be mostly shaded, and (b) contain cooling elements like trees, soft paving and water bodies if water is available.

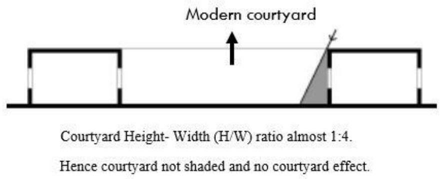
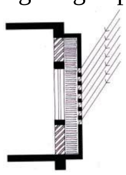


Figure 2: Courtyard ratio
(Source:https://cpwd.gov.in/Publication/IGDBooklet.pdf)

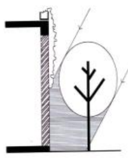
Figure 3: Cooling elements in courtyard
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

3.7 Shading strategies for buildings & openings

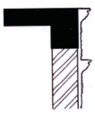
Shading is the most important building design strategy for comfort in the hot-dry climate. Shading of openings like windows is very important. The Window-Wall-Ratio (WWR) should not be more than 60%. Effective day lighting is possible with a much lower WWR.



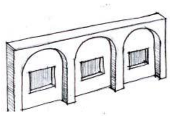
Shading of window and Wall surface by jaali screens.



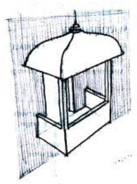
Shading of building surface by vegetation.



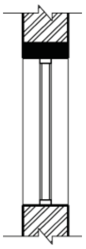
Shading of building surface by surface texture



Shading of building surface by architectural projections.



Jharokhas of the region provide effective shading. A Jharokha window on the south also cuts out the east-west sun.



Double Glazed Units (DGUs) help insulate the window panel and reduces large heat ingress which would otherwise enter the living space.

4. Passive Cooling Strategies

Passive cooling techniques derive cooling directly from evaporation, convection and radiation without using any intermediate electrical devices. All these design strategies described below helps in reducing heat gain to internal spaces(Majumdar, 1997).

4.1 Evaporative cooling

Water body
Evaporative cooling works well in the hot-dry climate as humidity is low in this zone. But water availability needs to be checked.

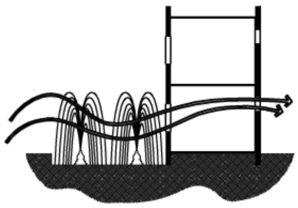


Figure 4: Water fountains
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

Water bodies outside or in courtyard for cooling the air. Water bodies should be shaded to minimize evaporation losses.

Wind Tower
The wind tower is a ventilating shaft which projects above the roof of a building with openings towards the favorable prevailing winds. Its main function is to capture air from above and transmit it indoors, thereby providing the living spaces with ventilation.

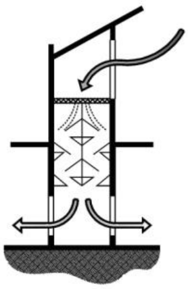


Figure 5: Wind tower
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

4.2 Earth air tunnel

This system is viable if the ground below has good thermal capacity, for. e.g. soil with adequate water content. The design basics generally followed are (from various existing systems):

- Pipe depth 4m
- Pipe diameter 0.3 to 0.7m
- Distance between pipes 3m Centre to Centre

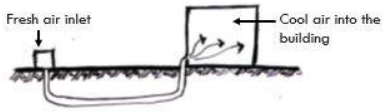


Figure 6: Earth air tunnel
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

4.3 Natural Ventilation

Night ventilation works well in this climatic zone as diurnal variations are high. In this process, buildings are ventilated at night when ambient temperatures are lower to resist heat build-up.

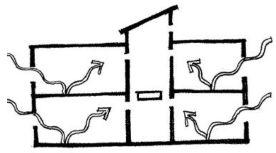


Figure 7: Daytime building heat gain
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

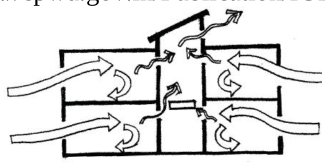


Figure 8: Night ventilation removes heat gain
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

4.4 Earth berming

Earth berming reduces outside air infiltration, keeps temperatures cool in summer and warm in winter as the earth's temperature at a depth of a few meters remains almost stable throughout the year. Berms may cover a part of the ground floor, sometimes entire buildings, provided daylight and ventilation requirements are taken care of. Needs adequate water-proofing measures. Basements are similarly cool and preferred spaces.

4.5 Thermal Mass

A building envelope with higher thermal mass will retard heat transfer from the exterior to the interior during the day. When temperatures fall at night, the walls re-radiate the thermal energy back into the night sky. Extensively used in traditional buildings in the region.

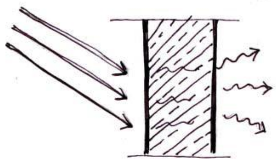


Figure 9: Thermal mass
(Source: https://cpwd.gov.in/Publication/IGDBooklet.pdf)

5. Passive design responsive buildings

Very few buildings are designed with the concept of passive design inspired from our past. Two case of such buildings are discussed here:

5.1 Pearl Academy of Fashion, Jaipur

- Location- Jaipur
- Client- Pearl Academy of Fashion
- Climate- Hot & Dry
- Architect-Morphogenesis
- Building type- Institutional
- Area of site- 11745sq.m (3 acres)
- Year of establishment-2008

The main goal was to build a low-cost, environmentally sustainable campus. The campus reflects the local vernacular architecture of the city with contemporary building techniques. The adverse climate of the site makes it a challenge in controlling the micro-climate and thus various passive climate control methods becomes unavoidable.

The building is simply rectangular that minimizes the exposed surface area. The longer façade of the building is facing north and south direction to reduce heat gain.The materials used for construction are a mix of local stone, steel, glass, and concrete chosen keeping in mind the climatic needs of the region while retaining the progressive design intent. The building is protected from the environment by a double skin which is derived from a traditional building element called the 'Jaali' which is prevalent in Rajasthan architecture. The double skin acts as a thermal buffer between the building and the surroundings. The density of the perforated outer skin has been derived using computational shadow analysis based on orientation of the façades.

Figure 10: Jaali
(Source: author)

Roof receives significant solar radiation and plays an important role in heat gain/losses day lighting and ventilation. Hence the entire roof surface is covered with inverted earthen pots. it is also an insulating cover of still air over the roof. The whole building is lifted above the floor and the stilt floor forms a thermal sink which is cooled by evaporative cooling. This lower ground floor dissipates the heat to the environment during the night when the temperature falls, keeping the region thermally comfortable. The whole building is on a 9m grid, singly loaded corridor, lit and cross-ventilated. This configuration of grid allows for day lighting and ventilation.

Figure 11: Stepwell
(Source: author)

The campus achieves temperature of about 27°C with the help of passive environmental designs inside the building when the outside temperatures are at 47° C.

5.1 Manipal University, Jaipur

- Location- Jaipur
- Client- Manipal University
- Climate- Hot & Dry
- Architect- Hafeez Contractor
- Building type- Institutional
- Area of site- 20 acres
- Year of establishment-2014

Manipal University's Jaipur campus is being designed to be a LEED Platinum and GRIHA 5-star rated project. The building integrates all the passive design strategies such as improved day lighting, optimizing external design solutions, better natural ventilation, maximized mixed mode ventilation and night cooling etc.

The building is simply rectangular that minimizes the exposed surface area. The longer façade of both the building is facing south-west direction. Local stone, steel and hollow concrete blocks for better insulation and lower embodied energy. Solar panels are being used on the roof of the south facade of the academic as well as administrative blocks. Double wall with insulation in the cavity provides both thermal mass and insulation to maximize thermal lag.

Figure 12: Roof
(Source: author)

All the walls are painted with light orange color which reflects most of the sunlight. All fenestration intended to provide usable daylight free of glare in most areas. On the east and west facades, GRC jaalis are used to maximize shading. Various kind of glazing used in different parts of the building based on shading and orientation ensuring a balance between solar gain and day light. Number of openable windows calculated based on space usage and orientation. Low level and high-level openable windows provide ventilation on both sides of the room.

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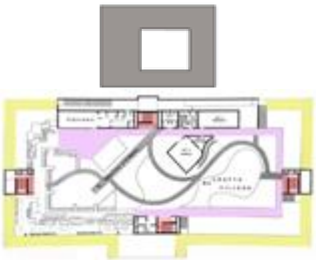
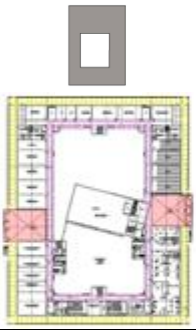
Figure 13: GRC Jaalis
(Source: author)

The campus achieves a temperature of 29°C with the help of these strategies in this hot & dry weather of Jaipur.

6. Comparative analysis of the selected buildings

Table 1: Comparative analysis

Parameters	Case Study 1 Pearl Academy Of Fashion, Jaipur	Case Study 2 Manipal University, Jaipur	Inferences	Design Recommendation
Building Plan & Form Orientation	Rectangular plan with a greater perimeter to area ratio with courtyard. Longer facade facing north and south direction. 	Rectangular plan with a greater perimeter to area ratio with courtyard. Longer facade facing south-west direction. 	Planforms with greater P/A ratio may be applied in certain cases to include features like water bodies & vegetation which can modify the micro-climate. The intermediate spaces can also be effective as interaction spaces. Buildings should be oriented towards North & South direction also keeping in mind the prevailing wind direction.	Planforms with greater P/A ratio and a central courtyard is preferred. Building blocks will be oriented towards South West direction to take advantage of the prevailing wind and avoiding maximum solar radiation.
Thermal Insulation	**Roof:** Earthen pots which are 35cm in dia are placed on flat roof, 2.5cm apart.	**Roof:** Solar panels & terracotta tiles are used.	**Roof:** (a) Using solid cover: A cover made of concrete or galvanized iron sheets. Sandstone roofing can be done.	**Roof:** Solar panels, terracotta tiles and cool roofs will be used.
			(b) Using plant cover: A cover of deciduous plants & creepers can be used.	
	Walls: Local stone and concrete walls.	**Walls:** Hollow concrete and AAC blocks with lower embodied energy.	(c) Using earthen pots: It increases the surface area for radiative emission. Broken china mosaic or ceramic tiles can also be used.	**Walls:** AAC blocks, Ferrocement or Fly ash gypsum blocks can be used.
			Walls: Ferrocement, Cellular light weight concrete (CLC), Aerated Autoclave Concrete blocks (AAC), Perforated brick masonry, 3D Eco wall, Compressed stabilized earth blocks (CSEB), Fly Ash-Lime gypsum blocks, Pre cast stone blocks can be used for thermal insulation.	
Fenestration	Jaalis are used which are 4 feets away from the building.	GRC Jaalis on the east and west facade.	The Window-Wall-Ratio (WWR) should not be more than 60%.	Shading will be done using traditional elements like Jaali and Jharokhas using shadow analysis.
	The double skin acts as a thermal buffer between the building and the surroundings.	Various kind of glazing used in different parts of the building based on shading and orientation ensuring a balance between solar gain and day light.	Shading of window and wall surface by jaali screens.	
			Shading of building surface by vegetation.	
			Shading of building surface by surface texture.	
			A Jharokha window can be used on the south that cuts out the east-west sun.	
			Double Glazed Units (DGUs) help insulate the window panel.	
Landscaping	Khejri, Babool, Bouganvillea, Neem, Ber and Thor are used for the landscaping.	Drip irrigation and micro sprinklers are used.	Ronjh, Khejri, Babool, Bouganvillea, Salai, Baheda, Ber, Farash, Rohida are some of the trees that are used in the hot and dry climatic regions of India.	Landscaping will be done according to the irradiation and wind studies.
		Neem, Bouganvillea, Neem, Ronjh, Kher and Rohida are the type of trees used.		Trees that are native, deciduous and low water consuming will be used.
Vegetation	Ker, Sewan, Thor, Bouganvillea	Khair, Bundi, Bui are	**Roof:** A cover of deciduous plants and	Ornamental, edible and

	are used as shrubs and grasses.	used for vegetation within the campus.	creepers can be used. **Walls:** Ornamental plants such as Blue trumpet vine, Ivy gourd can lower the air temperature by max. 4.71°C. **Ground:** Vegetation native to Rajasthan Shrubs- Bouganvillea, Ker, Thor Grass- Sewan Small tree- Khair, Kankera, Ber, Peelu	medicinal plants will be used in the transitional spaces to achieve comfort and comfortable temperature.
Courtyard	The self-shading courts on the internal areas help to control the temperature of internal spaces. Open courtyards allow sufficient day lighting inside studios and classrooms.	Courtyard planning has been done with certain trees to lower down the temperature and creating stack effect.	Ventilation in hot dry climate is useful if the air is cool. Thus, the courtyard should- be proportioned to be mostly shaded and contain cooling elements like trees, soft paving and water bodies if water is available.	Courtyard planning will be done using certain passive cooling elements.
Evaporative Cooling	A traditional baoli concept is used. During the night when the desert temperature drops this floor slowly dissipates the heat to the surroundings keeping the area thermally comfortable.	No water body present.	**Water body**- Water bodies outside or in courtyard for cooling the air. Water bodies should be shaded to minimize evaporation losses. **Wind tower**- The wind tower function is to capture air from above and transmit it indoors. Useful for cooling double loaded corridors.	Wind towers will be used for cooling the doubly loaded corridors
Natural Ventilation & Daylighting	Singly loaded corridors allowing day light into the classrooms.	Low level and high level openable windows provided on both sides of the rooms to both cross ventilation and stack ventilation.	The structural grid of the building block should be such that it helps in natural ventilation and day lighting.	The structural grid would be made accordingly to the transitional spaces of the block allowing day light and ventilation.

(Source: author)

7. Conclusion

This study has examined various natural ventilation techniques for passive cooling in the transitional spaces. The above-mentioned data from the table helps in evaluating design considerations for transitional spaces to achieve thermal comfort. All these strategies would help in designing spaces that are naturally ventilated and thermally comfortable. Incorporation of these sustainable design principles would help in reducing the dependency on the artificial means for thermal comfort and minimize the over consumption of energy and natural resources.
However, more research on this topic needs to be undertaken and practical solutions must be designed for developing countries.

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Author Profile

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