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Exploring passive cooling potentials in Indian vernacular architecture

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A B S T R A C T

The traditional architecture is known for providing comfortable indoor climatic conditions to its occupants via passive and natural methods. Today, the architecture is completely isolated from the outdoor and completely dependent on artificial means for cooling/ heating of the indoor areas even if the outside conditions are pleasant. It therefore becomes very important to understand the passive methods and apply them in today's buildings for energy conservation. Various passive cooling concepts, their application in the buildings and their respective impact have been reviewed and summarized. This paper, thus makes an effort to review and investigate some examples of vernacular architecture and its building elements from India tracing the respective passive cooling potentials. It has been found that natural ventilation and daylight should be the prime element in building design in order to achieve effective passive cooling and reduce the dependence on artificial means of cooling. Evaporative cooling, courtyard planning with landscaping and water features are the most common elements found in the Indian vernacular architecture.

Keywords: Vernacular Architecture, Day Light, Openings, Passive Cooling.

1. Introduction

Traditional buildings are time tested and well known for energy conservation. It therefore becomes necessary to understand and incorporate the passive technologies used in vernacular architecture in present day architecture since today's buildings are completely dependent on mechanical devices for heating/ cooling and providing comfortable indoor thermal conditions. It has been estimated that about 40 % of the world's energy is dedicated towards the building sector (Development 2009). Lifetime energy requirements of a building include the energy used in that building right from the construction stage to its occupancy and also include the energy that is necessary to sustain and maintain the building throughout its life which is dependent on selection of site, orientation of building, building material, shading devices, façade treatments, openings, windows, form and space utilization, courtyard planning, skylights, structure etc. Hence, incorporating these methods with passive solar techniques will help reduce the lifetime energy requirement of a building substantially. The combination of various passive heating and cooling techniques in order to achieve comfortable thermal temperature conditions has always been visible in vernacular architecture.

Vernacular term refers to the construction done by the local people using traditional technologies, using locally available material in accordance with the environmental context. It offers a good solution to the climatic constraints. With incorporation of passive solar design, about 1-5 % of savings may be achieved without any additional cost in adaptation of such design (building orientation, shape, form, layout, size, aspect ratio, daylight and natural ventilation) (Mingfang 2002). Passive cooling refers to (a) reduction of solar heat gains by using solar shading devices, insulation, appropriate building materials and colors), (b) decrease in thermal heat gains by lighting controls etc., and (c) removal of excess heat from the building via convection, evaporative cooling, air movement, cool breeze, earth coupling, reflection of radiation etc. Passive cooling concepts channelize the air flow, thus removing the excess heat from the interior spaces. Therefore, lessons should be learnt from the vernacular architectural elements, before their demise and to create more appropriate and acceptable environment for present day users and sustainable development. Its

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applicability was already mapped in several studies (Bodach & Werner Lang 2014) (Chandel, Sharma & Marwah 2016) (Gupta & Tiwari 2016). These techniques include Indirect gain (Gupta & Tiwari 2016), evaporative cooling (Gupta & Tiwari 2017), natural ventilation (Ciampi, Leccese & Tuoni 2005), natural daylight (Treado, Gillette & Kusuda 1984)., wind tower (Bouchahm, Bourbia & Belhamri 2011), solar shading techniques (Grynning, Time & Matusiak 2014), landscaping (Kamal 2012), courtyard planning (Hanif et al. 2014), radiative cooling (Gupta & Tiwari 2016), earth shelter (Tiwari et al. 2014), Trombe wall (Gupta & Tiwari 2016). Semitransparent photovoltaic modules can also be used to produce electrical power and daylighting at the same time (Tiwari et al. 2016) (Gupta, Tiwari & Tiwari 2016) (Gupta et al. 2017). Brief description of passive cooling concepts has been tabulated in Table 1 and 2.

Table 1. Passive cooling techniques- Description

No.	Passive cooling techniques	Results	References
1.	Indirect gain	Heating load may be reduced by 25 %.	(Liu & Feng, 2011)
2.	Evaporative cooling	• Reduction of about 9.6 °C may be achieved (Amer, 2006). • With use of fountain, indoor temperature was found to fall within the comfortable zone of 20 °C for hot arid regions (Qiu & Riffat, 2006). • 2- 6.2 ˚C drop in the room temperature may be achieved for hot humid climate (Chungloo & Limmeechokchai, 2007). • Water retaining material (porous roof) laid over roof may reduce surface temperature by 4-6 °C (Chen, et al., 2015). • Indirect evaporative cooling may lead to a reduction of 1 ˚C in mean daily temperature for regions with daily mean temperature ranging between 26.5 °C- 27.6 °C. Also, it may reduce the thermal discomfort due to heat in about 95- 100 % of the year (Cruz & Krüger, 2015). • Indirect evaporative cooling may reduce the energy demand by the HVAC system by 20% in next 20 years (Zhiyin, et al., 2012).	(Amer, 2006) (Qiu & Riffat, 2006) (Chungloo & Limmeechokchai, 2007) (Chen, et al., 2015) (Cruz & Krüger, 2015) (Zhiyin, et al., 2012)
3.	Natural ventilation	• More than 30 % energy savings may be achieved (Ciampi, et al., 2005). • Recommended value of air movement is 0.2 m/s for winters and 0.4 m/s for summers (Tiwari, 2012). • For living rooms, dining areas, mean window to wall ration should be 0.34. The same for bedroom should be 0.27 in high rise buildings (Wan & Yik, 2004). • Artificial mechanical airflow systems should not disturb the natural ventilation (Pfafferott, et al., 2004). • Comfortable indoor thermal conditions may be achieved with air movement of 2-3 m/s (Gupta & Tiwari, 2017).	(Ciampi, et al., 2005) (Tiwari, 2012) (Wan & Yik, 2004) (Pfafferott, et al., 2004) (Gupta & Tiwari, 2017c)
4.	Natural Daylight	• Window to wall and window to ground ratios (0.33-0.58) have a huge contribution to the effectiveness of natural ventilation and daylight (Wan & Yik, 2004). • 10 % additional energy savings may be achieved by changing the size of the windows (Zain-Ahmed, et al., 2002). • Skylights may lead to a reduction in energy savings by 77 % (Treado, et al., 1984). • With integration of semi-transparent photovoltaic systems with buildings, about 7150 W daylight savings may be achieved for cold climatic conditions (Gupta & Tiwari, 2017) • Annual daylight savings of 11233.79 kWh may be achieved by building integrated semi-transparent photovoltaic systems (Gupta & Tiwari, 2017b)	(Wan & Yik, 2004) (Gupta & Tiwari 2017a) (Zain-Ahmed, et al., 2002) (Treado, et al., 1984) (Gupta & Tiwari, 2017a) (Gupta & Tiwari, 2017b)
5.	Wind tower	• About 12-15 °C decrease in the indoor temperature can be achieved (Hughes, et al., 2012). • Reduction of up to 17.6 ˚C in room air temperature may be achieved by using wetted surface design for hot dry regions (Bouchahm, et al., 2011). • With introduction of evaporative cooling concept in terms of 10 m high wet columns may reduce the inside temperature by 12 ˚C and a drop in relative humidity by 22% for hot arid areas (Benhammou, et al., 2015). • For windy areas, new installation of wind towers was introduced which could align itself in the pre dominant wind direction. Also, transparent	(Hughes, et al., 2012) (Bouchahm, et al., 2011) (Benhammou, et al., 2015). (Dehghani-sanij, et al., 2015).

		construction material may be introduced to increase entrance of the natural light (Dehghani-sanij, et al., 2015).	
6.	Solar shading techniques	• Energy demand for south exposing facades may be reduced by about 9 % with proper use of shading techniques (Grynning, et al., 2014). • With additional provision of insulation, about 4.4-6.8 °C decrease in the indoor temperature may be achieved (Bansal, et al., 1994) (Kumar, et al., 2003). • By providing a roof cover from locally available materials like hay, inverted earthen pots, plants, insulation, terracotta tiles etc., indoor temperature may be reduced since roof has the maximum exposed area for solar gains (Kamal, 2012).	(Grynning, et al., 2014) (Kumar, et al., 2003) (Kamal, 2012)
7.	Landscaping	• Presence of a park can reduce the surrounding temperature by 2 °C (Ca, et al., 1998). • Surrounding temperature may be reduce by 2- 5 °C due to the shading effect and evapotranspiration offered by trees (Bansal, et al., 1994) (Kamal, 2012). • Deciduous trees should be planted on the south and southwest of the buildings whereas evergreen trees towards the south and west side of the building (Kamal, 2012). • Due to the presence of a park, the indoor temperature may be reduced by 2 °C (Ca, et al., 1998). • A comparison of shaded (tree buffering) and non-shaded area was conducted and it was observed that the peak solar irradiation at same time was 100 W/m^2 and 600 W/m^2 respectively for a south east oriented building located in Athens (Papadakis, et al., 2001).	(Ca, et al., 1998) (Bansal, et al., 1994) (Kamal, 2012) (Ca, et al., 1998) (Papadakis, et al., 2001).
8.	Courtyard planning	• Potential to save up to 25% of the power consumption for Tropical climate (Hanif, et al., 2014).	(Hanif, et al., 2014).
9.	Radiative cooling	• The cooling power measurements ranges from 20- 80 W/m^2 (Cavelius, et al., 2005). • Specific cooling power of 120 W/m^2 may be achieved by open water based system (Beck & Büttner, 2006). • Cooling load decreases with increase in the elevation with large radiative cooling potential (Zhang, et al., 2002).	(Cavelius, et al., 2005) (Beck & Büttner, 2006) (Zhang, et al., 2002)
10.	Earth Shelter	• About 7.0-8.5 °C decrease in the indoor temperature can be achieved (Tiwari, et al., 2014). • For desert climatic conditions, reduction of 2.8 ˚C in room temperature was observed during summer months (Al-Ajmi, et al., 2006).	(Tiwari, et al., 2014) (Al-Ajmi, et al., 2006)
11.	Trombe wall	• Trombe walls can be seen in the great pyramid of Gizeh to maintain 23 °C in the king's and the queen's chamber throughout the year (Gupta, 1984). • Screened Trombe walls have 18 times lower heat gains when compared to the screened Trombe walls for Mediterranean type of climate (Gupta, 1984). • With introduction of cross ventilation and devices like overhangs, rolling shutters, reduction of 65 % and 72.9 % in cooling energy was observed respectively when compared to unvented Trombe wall (Gupta, 1984). • Reduction of 1.4 °C in the room temperature was observed with reduction of 0.5 MJ/m2 in daily heat gains with additional screening (Stazi, et al., 2012). • 20.7 % reduction in cooling load was observed due to storage capacity of Trombe wall (Soussi, et al., 2013).	(Gupta, 1984) (Stazi, et al., 2012) (Soussi, et al., 2013)

With combination of various passive cooling concepts as listed in in Table 1, energy saving potentials may be increased tremendously as summarized in Table 2.

Table 2. Combination of passive cooling techniques- Description

No.	Passive cooling techniques	Results	References
1.	Trombe wall + Ventilation + glazed walls + green roof + evaporative cooling + thermal insulation.	Size of artificial cooling devices may be reduced by integrating a holistic approach towards energy efficient design in architecture. This will compensate for the supplementary capital investment for energy efficient features.	(Sadineni, et al., 2011)
2.	Thermal wall and roof insulation + fenestration + shadings on south façade.	These variables may lead to a reduction in energy consumption and lifecycle costs by 25.31 % and 11.67 % respectively for Mediterranean type of climatic conditions.	(Jaber & Ajib, 2011)
3.	Building orientation + Trombe wall + infiltration + wall and roof insulation + lighting + windows to wall ratio + glazing type.	About 50 % of the annual energy may be reduced.	(Ihm & Krarti, 2012)
4.	Trombe wall + cool roof + thermal insulation.	When compared to normal building, about 46 % and 80 % of energy savings may be achieved for winter and summer months respectively with reduction of 5.41 W in the peak cooling load.	(Soussi, et al., 2013)
5.	Louvers + double glazing + ventilation + wind towers + green roof + fountains evaporative cooling) + radiative cooling + light interior colors.	An overall reduction of 23.6 % in annual energy consumption was observed.	(Taleb, 2014)

2. Indian Vernacular Architecture

Various passive cooling strategies have been discussed in Table 1 and 2. The following section comprises of few examples from the traditional Indian architecture and how these concepts have been implemented since long.

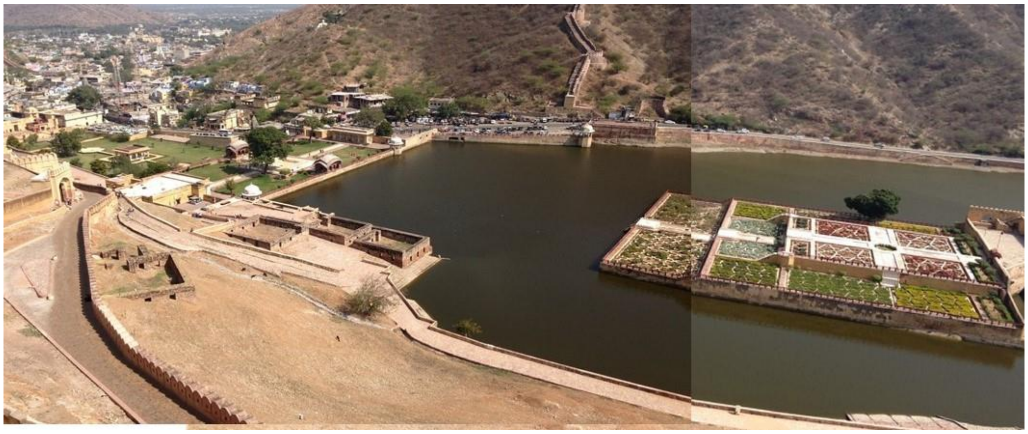
2.1 *Planning type*

Indigenous planning layout was followed for places and simple small dwellings as seen in Shahjahanabad, Jaisalmer and many other cities in India. This type of a dense clustering layout ensured that the buildings were not exposed to the outer sun. This prevents the solar gain and the hot winds from entering the premises and also allows the cold wind to circulate within the building (Figure 1).

Figure 1. Indigenous planning, Jodhpur (Source: Clicked by author)

2.2 *Evaporative cooling and landscaping*

Concept of evaporative cooling is extensively used in ancient architecture for example Amber Fort, Rajasthan, India comprises of a garden which has been positioned just at the center of the lake to modify the microclimate for comfortable outdoor sitting during summers. Also, this concept can be seen in Red Fort, New Delhi where the entire building has been surrounded by water body and landscaping or by a water garden in Deegh Palace, Bharatpur, India or green area in Imambara, Lucknow (Figures 2a, 2b and 5). This was done in order to reduce the surrounding temperatures using landscaping. The small spaces were constructed to keep them sheltered from sun by the neighboring buildings. In case of large open spaces, plantation and water pools were used as landscaping element to protect them from the solar gains.



(a)

(b)

Figure 2. Passive cooling of (a) Amber fort, Rajasthan, India and (b) Imambara, Lucknow (Source: Clicked by author).

2.3 *Radiative cooling and Courtyard planning*

Courtyard planning is visible in havelis and forts of Rajasthan, India for cooling effect (Figure 3). Courtyards were the main architectural element used in planning generally integrated with water bodies, vegetation and usually open to sky to enhance evaporative cooling, provision of shade and infuse maximum daylight in the buildings. In Shahjahanabad, India, the lower floors are used to spend the hot days while the nights are spent on the terrace taking advantage of the radiative cooling. The rooftops are sprinkled with water for evaporative cooling effect. Whereas during the winters, the days are spent on the sunny rooftops and the nights in the enclosed rooms. The buildings in Shahjahanabad, India were designed to allow the heavy cool air to enter the building. There was no provision of parapet wall towards the courtyard and solid parapets were constructed towards the street. Large openings are provided towards the courtyard to take advantage of radiative cooling so that the cool air is passed through the interiors.

Figure 3. Haveli, Shekhawati, Rajasthan (Source: Clicked by author).

2.4 *Solar shading devices*

Solar shading devices is another control medium for solar heat gains in form of horizontal (canopies, awnings, horizontal louvers, overhangs), vertical (vertical louvers, projecting fins), screening (movable insulations, vegetation etc.) or egg crate devices (jalis, grills). These devices reduce the heat gains and thus provides comfortable indoor temperature, reducing the cooling costs. They also act as an aesthetic element and also satisfy daylighting needs if properly designed. Mughal architecture used inclined and deep shades to cover more surface area with deep carvings which creates self-shading effect (Figures 4a and 4b). Horizontal shading devices are best suited for south oriented whereas vertical for east and west facing facades.

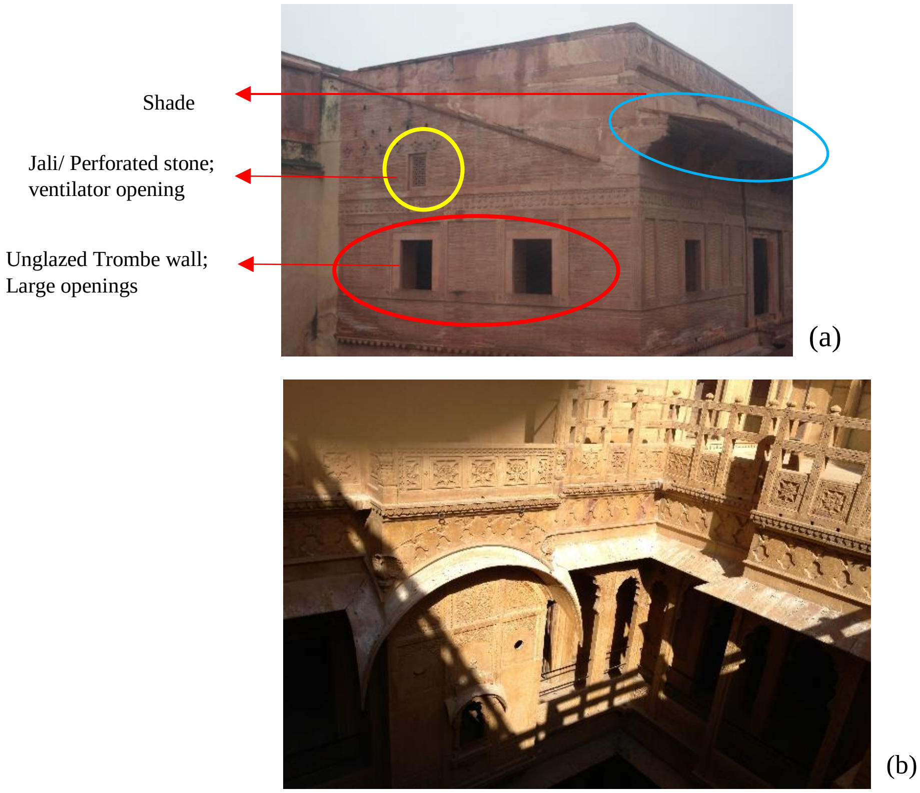


Figure 4. (a) Fateh-pur Sikri, Agra and (b) Jaswant Thana, Jodhpur (Source: Clicked by author).

Ancient buildings were able to keep themselves cool without using the movable screens or curtains rather with the use of some passive techniques as seen in Diwan-e-Khas, Red Fort, Delhi, India (Figure 5). Two sets of columns spaced at 4 m have been placed. The provision of curtains and screens has been provided in these sets for use as per the need. During summers, three screens were used, out of which two were made of sprinkled grass to take advantage of the evaporative cooling. Whereas during winters, these screens were replaced by heavy quilted curtains. During the days, these curtains were rolled up to allow the sun to penetrate and were rolled down in the evening hours to retain the solar gain. These type of screens and curtains are also presently seen in Deegh Palace, Rajasthan, India. Roll up bamboo screens were also used in vernacular architecture as screening device for shading purposes and also for east and west orientations.

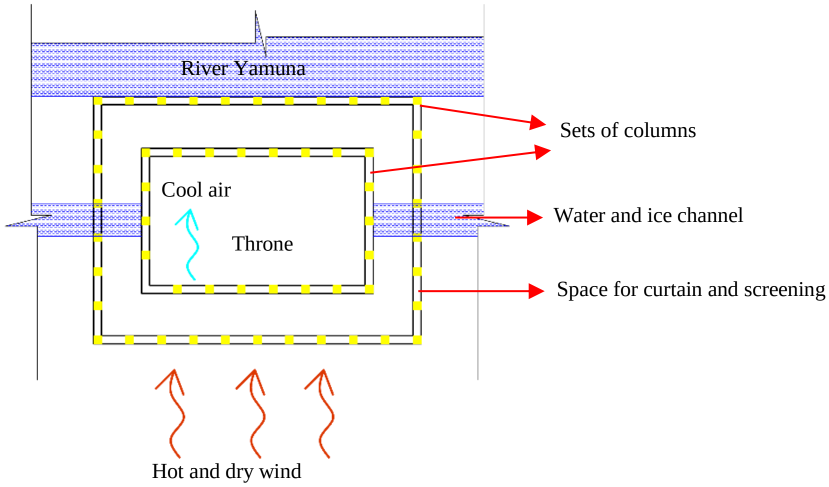
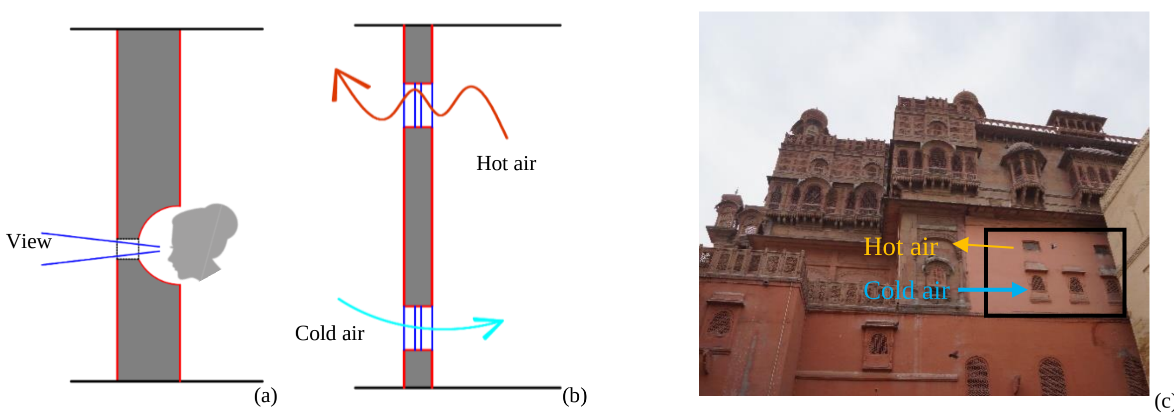
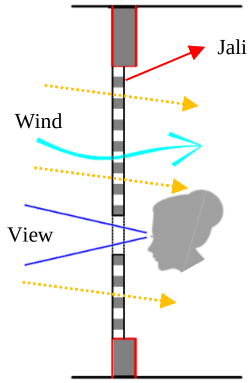


Figure 5. Passive cooling of Diwan-e-Khas, Red Fort, New Delhi.

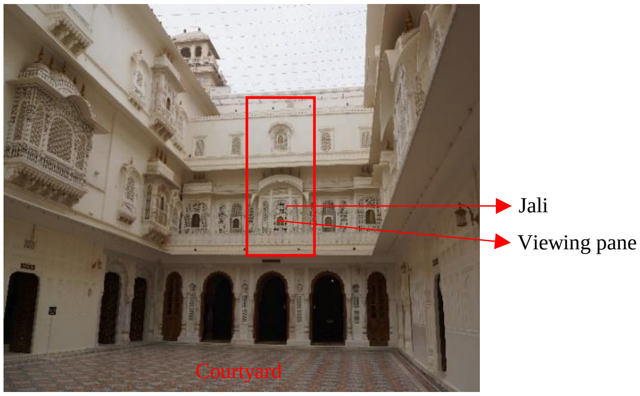
2.5 *Ventilation and daylighting*

The details of the windows and the openings were also taken care of in the vernacular architecture. Examples included small windows (lesser than 100 mm in diameter) used in Amber fort, India in order to ensure the visibility without letting the light or air in (Figure 6a). Openings installed for ventilation purpose were seen in Shahjahanabad, India. These were installed near the floor level and near the roof level in order to let the cool air in from the bottom opening and let the hot air out from the top opening (Figs. 6b and 6c). At some places jalis (perforated stone or latticed screen) have been used to maintain privacy (Figures 4a, 6d and 6e), let the air and light enter the building and also allow the visual connectivity from inside to the outside surroundings (Figures 5d and 5e). Diffused light is allowed to enter the interiors during sunshine hours, and at the same time the interiors are not visible from the outside. For the outside view, small opening is provided at the eye level of the viewer in sitting position (Gupta 1984).





(d)



(e)

Figure 6. Openings (a) Small opening for visual connection, (b) near floor and roof for ventilation (c) Junagarh fort, Bikaner, Rajasthan, India (d) ventilation and visual connectivity with jali and (e) Junagarh fort, Bikaner, Rajasthan, India. (Source: Clicked by author)

2.6 *Trombe wall*

Another planning tool widely seen in vernacular architecture is thick walls i.e., Trombe walls (Figure 4a). They can be seen in Shahjahanabad, Jaisalmer, India. The natural, ventilated air also enters the chambers at the same temperature. The Trombe wall of 600 mm thickness is also seen in all the buildings of Banaras Hindu University, Varanasi. The inside temperature range was found to be about 25-28 °C when the outside temperature was in the range of about 45- 48 °C. (Gupta 1984).

2.7 *Some examples of region specific architecture are:*

- Passive cooling features of vernacular architecture for Kerela, India have been discussed by Dili et al. (Dili, Naseer & Varghese 2010). These included courtyard planning, verandah, scale and proportions, orientation of the building, local building materials (mud, laterite, granite, lime mortar, wood, bamboo, clay roofing, coconut palm leaves etc.,) steep sloped roofs, decorative jalis (for ventilation and daylight), strut comprising walls spaced by slats forming fenestration design thus creating comfortable indoor thermal conditions without input of an external cooling source. The temperature near the courtyards was found to be in the range of 3-8 ˚C lower than the ambient with RH between 50- 80% (while the outside RH= 32-95 %) (Dili, Naseer & Varghese 2010) (Dili, Naseer & Varghese 2010). An example from Kerela of use of local materials like burnt coconut shells, egg whites, plant juices etc. is Padmanabhapuram palace, Kerela. Multiple courtyards are again seen in the palace to facilitate proper air movement.

- Warli house, Maharashtra. These are mud plastered houses on framework of karvi walls. Suitable for hot humid climatic conditions.

- Bhunga, Rajasthan. These are generally mud structures with thatch roof, circular in form planned around atriums or courtyards in clusters with minimum exposure to sun. These structures have controlled entry of light, wind and sun due to small openings. Suitable for hot dry climatic conditions.

- Laterite structures, Goa. These are lime and earth structures with un-plastered sloping roof overhangs to battle sun and rain. Jackfruit wood is usually used as a local material eg. Chapel of Saint Catherine.

Thus, from the above examples it can be clearly stated that to achieve natural harmony between climate, people and buildings, passive cooling concepts should be adopted to make the building self-sustainable.

3. Results and Discussions

- Evaporative cooling is the most economic and the oldest passive cooling concept used.
- Natural ventilation should be the focus of any building design and results in an effective passive cooling technique. This reduces the dependence on artificial means of cooling leading to energy conservation.
- Allowing natural daylight in the buildings leads to reduction in artificial means of lighting. Therefore, the heat generated by the artificial lighting decreases, resulting into an indirect passive cooling concept.
- Vertical shadings should be used for east and west walls whereas horizontal for south facing because of overhead sun.
- Landscaping: Deciduous trees allows summer shading and natural daylight in winter months by shedding their leaves and thus should be planted in south and south-west of the building façade.
- Radiative cooling: The long wave terrestrial radiation shows no correlation with the elevation while the short wave incoming radiation shows a proportionate decrease at the normal lapse rate. Thus, leading to an increase in the value of radiative cooling.
- Courtyard planning: The cooling power decreases with decrease in the difference between the ambient and sky temperature.
- Exterior Trombe walls (thick thermal mass) leads to a reduction in the decrement factor and thus, creates a time lag. The heavy structure is seen in the ancient buildings and is preferred for passive cooling. This mass acts as an insulator and a heat storage medium.

4. Conclusions

Based on the present study, the following conclusions have been drawn:

- It has been seen that passive cooling techniques like ventilation, window and wall shading devices, natural cross ventilation, trees, water bodies, courtyards and verandahs are very effective in maintaining the indoor comfort thermal conditions.
- Indigenous planning, courtyards, landscaping, local materials, movable screens, Trombe walls are the most common passive cooling techniques seen in Indian vernacular architecture and are found to be very efficient.
- Integrating evaporative cooling concept with wind towers is found to be very effective and may lead to a reduction of 12-17 ˚C in the indoor room temperature.
- Combination of Trombe wall, thermal insulation and cool roof may achieve savings of 46 % and 80 % in winter and summer months respectively.
- Evaporative cooling can reduce indoor temperature by 9.6 °C.
- Solar shading techniques alone can provide a fall of 6 °C in the room temperature.

REFERENCES

Al-Ajmi, F, Loveday, DL & Hanby, VI 2006, 'The cooling potential of earth-air heat exchangers for domestic buildings in a desert climate'. *Building and Environment*, vol 41, no. 3, pp. 235-44.

Amer, EH 2006, 'Passive options for solar cooling of buildings in arid areas.', *Energy*, vol 31, no. 8-9, pp. 1332-1344.

Bansal, NK, Hauser, G & Minke, G 1994. *Passive building design- A handbook of natural climate control.*, Elsevier Science, Amsterdam.

Beck, A & Büttner, D 2006, 'Radiative cooling for low energy cold production.', *Proceedings of the Annual Building Physics Symposium*, Hochschule für Technik Stuttgart.

Benhammou, M, Draoui, B, Zerrouki, M & Marif, Y 2015, 'Performance analysis of an earth-to-air heat exchanger assisted by a wind tower for passive cooling of buildings in arid and hot climate.', *Energy Conversion and Management*, vol 91, pp. 1-11.

Bodach, S & Werner Lang, JH 2014, 'Climate responsive building design strategies of vernacular architecture in Nepal.', *Energy and Buildings*, vol 81, pp. 227-242.

Bouchahm, Y, Bourbia, F & Belhamri, A 2011, 'Performance analysis and improvement of the use of wind tower in hot dry climate.', *Renewable Energy*, vol 36, no. 3, pp. 898-906.

Ca, VT, Asaeda, T & Abu, EMA 1998, 'Reductions in air conditioning energy caused by a near by park.', *Energy and Buildings*, vol 29, no. 1, pp. 83-92.

Cavelius, Ralf, Isaksson, Charlotta, Perednis, Eugenijus, Read & F., GE 2005, 'Passive cooling technologies.', *Austrian Energy Agency*, p. 125.

Chandel, SS, Sharma, V & Marwah, BM 2016, 'Review of energy efficient features in vernacular architecture for improving indoor thermal comfort conditions.', *Renewable and Sustainable Energy Reviews*, vol 65, pp. 459-477.

Chen, W, Liu, S & Lin, J 2015, 'Analysis on the passive evaporative cooling wall constructed of porous ceramic pipes with water sucking ability.', *Energy and Buildings*, vol 86, pp. 541-549.

Chungloo, S & Limmeechokchai, B 2007, 'Application of passive cooling systems in the hot and humid climate: The case study of solar chimney and wetted roof in Thailand.', *Building and Environment*, vol 42, no. 9, pp. 3341-3351.

Ciampi, M, Leccese, F & Tuoni, G 2005, 'Energy analysis of ventilated and microventilated roofs.', *Solar Energy*, vol 79, no. 2, pp. 183-192.

Cruz, EG & Krüger, E 2015, 'Evaluating the potential of an indirect evaporative passive cooling system for Brazilian dwellings.', *Building and Environment*, vol 87, pp. 265-273.

Dehghani-sanij, AR, Soltani, M & Raahemifar, K 2015, 'A new design of wind tower for passive ventilation in buildings to reduce energy consumption in windy regions.', *Renewable and Sustainable Energy Reviews*, vol 42, pp. 182-195.

Development, WBCFS 2009, 'Energy Efficiency in Buildings Tranforming the Market.', WBCSD, Geneva.

Dili, AS, Naseer, MA & Varghese, TZ 2010, 'Passive control methods of Kerela traditional architecture for a comfortable indoor environment: comparative investigation during various periods of rainy season.', *Building and Environment*, vol 45, pp. 2218-2230.

Dili, AS, Naseer, MA & Varghese, TZ 2010, 'Passive environment control system of Kerala vernacular residential architecture for a comfortable indoor environment: A qualitative and quantitative analyses.', *Energy and Buildings*, vol 42, no. 6, pp. 917-927.

Grynning, S, Time, B & Matusiak, B 2014, 'Solar shading control strategies in cold climates- Heating, cooling demand and daylight availability in office spaces.', *Solar Energy*, vol 107, pp. 182-194.

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

Gupta, N & Tiwari, GN 2016, 'Review of passive heating/cooling systems of buildings.', *Energy Science & Engineering*.

Gupta, N & Tiwari, GN 2017a, 'Effect of heat capacity on monthly and yearly exergy performance of building integrated semitransparent photovoltaic thermal system.', *Journal of Renewable and Sustainable Energy*, vol 9.

Gupta, N & Tiwari, GN 2017b, 'Energy matrices of Building integrated Photovoltaic Thermal Systems: A case study.', *Journal of Architectural Engineering*.

Gupta, N & Tiwari, GN 2017c, 'A thermal model of hybrid cooling systems for building integrated semitransparent photovoltaic thermal system', *Solar Energy*.

Gupta, N, Tiwari, A & Tiwari, GN 2016, 'Exergy analysis of building integrated semitransparent photovoltaic thermal (BiSPVT) system.', *Engineering Science and Technology, an International Journal*.

Hanif, M, Mahlia, TMI, Zare, A, Saksahdan, TJ & Metselaar, HSC 2014, 'Potential energy savings by radiative cooling system for a building in tropical climate.', *Renewable and Sustainable Energy Reviews*, vol 32, pp. 642-650.

Hughes, BR, Calautit, JK & Ghani, SA 2012, 'The development of commercial wind towers for natural ventilation: A review.', *Applied Energy*, vol 92, pp. 606-627.

Ihm, P & Krarti, M 2012, 'Design optimization of energy efficient residential buildings in Tunisia.', *Building and Environment*, vol 58, pp. 81-90.

Jaber, S & Ajib, S 2011, 'Optimum, technical and energy efficiency design of residential building in Mediterranean region.', *Energy and Buildings*, vol 43, no. 8, pp. 1829-1834.

Kamal, MA 2012, 'An overview of passive cooling techniques in buildings: Design concepts and architectural interventions.', *Acta Technia Napocensis: Civil Engineering & Architecture*, vol 55, no. 1, pp. 84-97.

Kumar, R, Ramesh, S & Kaushik, SC 2003, 'Performance evaluation and energy conservation potential of earth-air-tunnel system coupled with non-air-conditioned building.', *Building and Environment*, vol 38, no. 6, pp. 807-813.

Liu, YW & Feng, W 2011, 'Integrating passive cooling and solar techniques into the existing building in South China.', *Advanced Materials Research*, vol 368-373, pp. 3717-3720.

Mingfang, T 2002, 'Solar control for buildings.', *Building and Environment*, vol 37, no. 7, pp. 659-664.

Neha Gupta, GNTATVSG 2017, 'New model for building- integrated semitransparent photovoltaic thermal system', *Journal of Renewable and Sustainable Energy*, vol 9.

Papadakis, G, Tsamis, P & Kyritsis, S 2001, 'An experimental investigation of the effect of shading with plants for solar control of buildings.', *Energy and Buildings*, vol 33, no. 8, pp. 831-836.

Pfafferott, J, Herkel, S & Wambsganß, M 2004, 'Design, monitoring and evaluation of a low energy office building with passive cooling by night ventilation.', *Energy and Buildings*.

Qiu, GQ & Riffat, SB 2006, 'Novel design and modelling of an evaporative cooling system for buildings.', *International Journal of Energy Research.*, vol 30, pp. 985-999.

Sadineni, SB, Madala, S & Boehm, RF 2011, 'Passive building energy savings: A review of building envelope components.', *Renewable and Sustainable Energy Reviews*, vol 15, no. 8, pp. 3617-3631.

Soussi, M, Balghouthi, M & Guizani, A 2013, 'Energy performance analysis of a solar-cooled building in Tunisia: Passive strategies impact and improvement techniques.', *Energy and Buildings*, vol 67, pp. 374-386.

Stazi, F, Mastrucci, A & Perna, CD 2012, 'Trombe wall management in summer conditions: An experimental study.', *Solar Energy*, vol 86, no. 9, pp. 2839-2851.

Taleb, HM 2014, 'Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings.', *Frontiers of Architectural Research*, vol 3, no. 2, pp. 154-165.

Tiwari, GN 2012, *Solar Energy- Fundamentals, Design, Modelling and Applications.*, Narosa Publishing House Pvt. Ltd., Delhi.

Tiwari, GN, Saini, H, Tiwari, A, Gupta, N, Saini, PS & Deo, A 2016, 'Periodic theory of Building integrated Photovoltaic Thermal (BiPVT) System.', *Solar Energy*, vol 125, pp. 373-380.

Tiwari, GN, Singh, V, Joshi, P, Shyam, Deo, A, Prabhakant & Gupta, A 2014, 'Design of an Earth Air Heat Exchanger (EAHE) for climatic condition of Chennai, India.', *Open Environmental Sciences*, vol 8, pp. 24-34.

Treado, S, Gillette, G & Kusuda, T 1984, 'Daylighting with windows, skylights, and clerestories.', *Energy and Buildings*, vol 6, no. 4, pp. 319-330.

Wan, KSY & Yik, FWH 2004, 'Building design and energy end-use characteristics of high-rise residential buildings in Hong Kong.', *Applied Energy*, vol 78, no. 1, pp. 19-36.

Zain-Ahmed, A, Sopian, K, Othman, MYH, Sayigh, AAM & Surendran, PN 2002, 'Daylighting as a passive solar design strategy in tropical buildings: a case study of Malaysia.', *Energy Conversion and Management*, vol 43, no. 13, pp. 1725-1736.

Zhang, Q, Asano, K & Hayashi, T 2002, 'Regional characteristics of heating loads for apartment houses in China.', *Transactions of AIJ*, vol 555, pp. 67-69.

Zhiyin, D, Changhong, Z, Xingxing, Z, Mahmud, M, Xudong, Z, Behrang, A & Hasan, A 2012, 'Indirect evaporative cooling: past, present and future potentials.', *Renewable and Sustainable Energy Reviews*, vol 16, no. 9, pp. 6823-6850.