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A comprehensive review on passive building designs retrofitting solar energy

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Abstract
In this report, an effort has been made to highlight passive solar cooling and heating techniques and their benefits and limitations. We can analyse their performance on the building thermal and visual management. The concepts of bionic buildings, CABS, Trombe wall, PCM wall, radiative cooling, roof pond, evaporative cooling, solar chimney, earth-air heat exchanger, solar shading and window design have extensively covered this report. A comparison of results of various passive concepts has been made after a survey of the literature. This report aims to find the best cost-effective, environment-friendly passive techniques to easily integrate with the building design to give thermal and visual comfort to the occupants and reduce greenhouse house emissions.

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NOMENCLATURE

WBCSD	World Business Council for Sustainable Development.
CO_2	Carbon dioxide
HVAC	Heating Ventilation and Air Conditioning
CABS	Climate Adaptive Building Shells
PCM	Phase Change Material
MCA	Multi- Criteria Analysis
TES	Thermal Energy Storage
GH	Greenhouse
PV	Photovoltaic
LH	Latent Heat
BIPV	Building Integrated Photo voltaic
DSF	Double Skin Facades
CFD	Computation Fluid Dynamics
PCMVW	Phase Change Material Ventilated Windows
CFM	Ca0.5Mg10.5(HPO3)8(OH)3F3
SHETRE	Hydrodynamics Cool Roofs System with Energy Recovery
WAHE	Water-to-Air Heat Exchanger
EAHE	Earth Air Heat Exchanger
ANSYS	Analysis of Systems
ETFE	Ethylene Tetra-fluoroethylene
OPV	Organic Photovoltaic
PVC	Polyvinyl Chloride
VCRS	Vapour Compression Refrigeration System
CFCs	Chlorofluorocarbons
EM	Electromagnetic

I. Introduction

According to the survey conducted by WBCSD, buildings consume around 40% of the world's total energy and produce carbon emissions of 35-40 % of the total amount of CO2 emitted worldwide, even more than that of the transportation sector achieving thermal comfort. This percentage may vary from country to country because of their different social and economic conditions, available energy resources, and climatic conditions. Out of this 40%, a major part of it, nearly 60% of the energy is mainly used for HVAC purposes [1].

This energy demand is increasing rapidly year by year. It may double or even triple by 2050 because of many reasons such as urbanization, growing population, migration of people, depleting environmental conditions. The main challenge for building design nowadays is to reduce energy consumption and greenhouse emissions without compromising with thermal comfort requirements. Here, thermal comfort means controlling the temperature and covering environmental, human and psychological factors, as shown in figure [1]. Building energy efficiency depends upon the performance of active and passive technology. Active technology is related to building services, while Passive techniques cover structural and architectural design prospects.

Passive HVAC has gained much attention among researchers in recent years because of increasing energy demand, energy prices, and growing pollution. According to many works of literature, passive HVAC can reduce heat and cooling load, decrease greenhouse emissions, improve air quality and provide thermal comfort conditions. L.F. Cabeza and M. Chàfer [2] studied and classified the technologies to contribute to the building climate change mitigation, achieving zero-energy buildings. They analysed the building geometry, natural lighting, natural ventilation, and heat storage system. Then, suggested different ways to achieve the needed energy using renewable energy sources (solar, geothermal, biomass, etc.) and storage or backup systems such as thermal/electrical energy storage, fuel cells with their merits and demerits. That's why passive building design techniques become very important for the energy-efficient and sustainable development of the building. For this purpose, incorporation of renewable sources of energy such as solar energy, wind energy, geothermal energy should be done in building passive design for achieving thermal and physiological comfort.

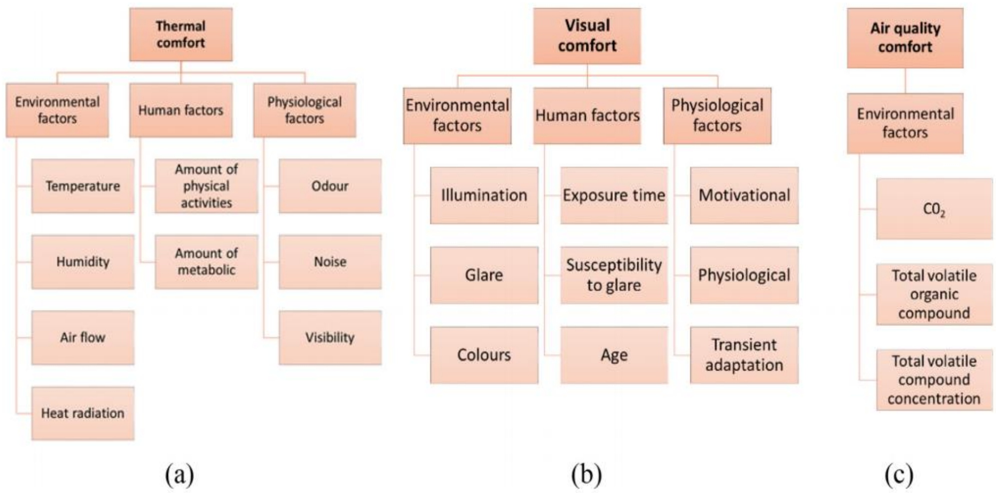


Fig.1 Factors influencing (a) thermal, (b) visual, and (c) air quality comfort of building occupants[2].

II. Passive concepts replacing mechanical heating, cooling, and ventilation load

2.1 Bioclimatic strategies

Bioclimatic strategy is the first technique and plays a crucial role in reducing HVAC requirements and energy costs. This strategy focuses on improving the building envelope and the window material, shape, size, orientation as per the climate conditions and location taking inspiration from adaption strategies of different living organisms and ancient building techniques.

Y. Yuan et al. [3] observed the architects of different bionic architecture, who took inspiration from the physiological, mechanical, and behavioural and structural adaptation strategies of other living organisms and tried to implement these strategies in the bionic building for achieving energy-efficient, sustainable development of the building. Their study focused on the bionic function, bionic structure, and bionic material of different organisms to develop bionic green architecture. They designed transparent heat insulation material for the exterior surface of a building by imitating the polar bear's fur and skin structure. They found that inside room temperature stayed at 20°C without any central heating, although the outside environment temperature was 8°C.F. Manzano Agugliaro et al. [4] studied the bioclimatic diagram proposed by Givoni B. [5], in which 14 zones are defined based on the region's dry bulb temperature and air humidity as depicted in figure [2]. They found that building design requirements (heating and cooling load requirement) varied depending on location, climate, population, and environmental conditions. Then, they recommended the best possible bioclimatic architectural strategies to meet the heating, ventilation and air conditioning load of the zone. They concluded that the implementation of these bioclimatic architectural systems achieve thermal comfort and reduce energy consumption. X. Xie et al. [6] monitored the microclimate characteristics of various building forms such as street canyon, courtyard, semi-closed courtyard, and large courtyard with open space. They observed that various building forms of a building with the same neighbourhood scale resulted in different heating load and ventilation cooling potential because of the variation of solar radiation and wind pattern. They found that in summer, solar radiation in the street canyon and the courtyard was lower than other forms due to the shading effect during daytime and thermal trapping at night. In winter, heating demand was highest in a large courtyard with open space, whereas the courtyard form showed the day's peak temperature due to lower aspects ratio. They concluded that out of the four building forms discussed above, the courtyard had the least heating demand in winter and relatively higher ventilation cooling potential in summer.

Proper selection of bioclimatic strategy for buildings helps us provide the required visual, thermal and air quality comfort to the building occupations at a lower cost and reduce the heating and cooling load and greenhouse emissions.

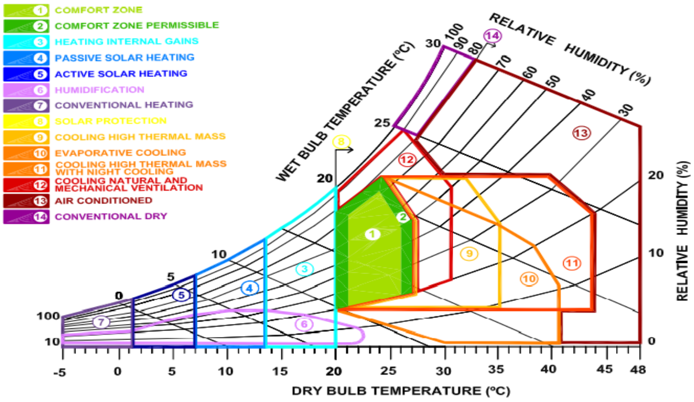


Fig. 2 Psychometric chart adapted from Givoni [4,5]

2.2 Building envelope

2.2.1 CABS

CABS is a significant development in the field of passive building design and sustainability. CABS consists of a group of variable roofs and facades that respond to the changing weather conditions and improve building performance. These building envelopes alter their behaviour, features, and functions with time to versatile climate conditions and improve building energy efficiency. The three main benefits associated with CABS are adaptability, multi-ability, and evolvability. Toms Mols et al.[7] generated seven different CABS: Active window, Deployable External Insulation, Glass X crystal PCM, Living walls and roofs, Liquid façade, Skytherm solar roof pond, Solar barrel wall and analysed with MCA using a weighting of criteria. They concluded that solar barrel wall with PCM technology for the application in CABS was most appropriate. Ruta Vanaga et al.[8] analysed four nature strategies, namely: blubber, blood vessel system, animal skin, vegetation surviving winter properties, concerning seven thermodynamic criteria: (1) heat losses in thermal envelope, (2) air exchange, (3) thermal inertia, (4) solar heat gains, (5) energy storage, (6) energy production and (7) changing building surface parameters. The objective of this analysis was to choose the best nature's strategy with the highest thermodynamic potential for application in building thermal envelopes using MCA analysis. They concluded that the best nature-inspired alternative to overtake for the CABS is blubber. Its inspiration model comes from the Atlantic bottlenose dolphin (Tursiops truncates), the blubber of which absorbs heat. It is found out that the dolphins have a layer of fatty acids which are classified as phase change material (PCM) with melting temperature close to mammalian body temperature. So the layer has high latent heat storage – about180 kJ/kg.

CABS helps us reduce the heating and cooling load of a building and achieve sustainability by improving environmental quality. The leading cause that hinders its development and popularity is its complexity and higher operational and maintenance cost than the static building—also, due to lack of software available which can analyse the temporal variation of CABS technology.

2.2.2 Air tightness

Increasing the airtightness of a building is one of the best ways of reducing building energy demand. According to the literature air leakage accounts for about 40% of the total heat loss from a building. Airtightness improves air quality and occupant comfort. For this purpose, several insulation materials have been analysed in recent years. Some commonly used organic, inorganic and combined insulating materials have been listed in the table [1]. These insulating materials can maintain a temperature difference of 4-8°C between indoor and ambient temperature if appropriately used.

Table 1: Commonly used insulation materials

S. No.	Insulating material	Description
1.	Organic	Foamy: Foam Fibrous: Glass-wool; Stone -wool
2.	Inorganic	Foamy: Polystyrene; Polyurethane Foamy expanded: Cork ; Phenol; Melamine Fibrous: Sheep-wool; Cellulose ;Cotton-wool;
3.	Combined	Siliconated calcium Gypsum foam Wood-wool

2.2.3 PCM

Solar energy is intermittent. So there is a need for a T.E.S. system for heating buildings during the night. Researchers have realised that thermal energy storage employing L.H. is an excellent approach for providing thermal comfort to the occupants. Phase change materials have proved out to be an effective and powerful tool in this regard. P.C.M. increases the thermal inertia and reduces temperature fluctuations of the building envelope. Generally, encapsulated P.C.M. are used for buildings application to manage volume variation avoid leakage during phase change.

H. Akeiber et al. [9] investigated the properties of different types of Phase change material to find the best one for building heat energy storage requirements. They concluded that paraffin (organic P.C.M. with lesser fatty acid), because of its high heat of fusion, chemical stability, compatibility with most building envelop material is most suitable. P.K.S. Rathore and S.K. Shukla [39] experimentally analysed the peak temperature, thermal amplitude, and time lag of the building envelope macro encapsulated P.C.M. to evaluate its thermal behaviour, cooling load reduction, and energy savings. For this, they developed two identical cubicles (experimental and reference cubicle), each of dimensions: 1.12 m ×1.12 m× 1.12 m at Mathura (India) as shown in figure [4**].** The tubular macro capsule of Al alloy 8011 was filled with paraffin OM37 PCM and embedded in the concrete walls and roofs of the experiment cubicle because encapsulated P.C.M. prevents leakage, direct contact with a matrix material, enhances strength, and provides more heat transfer area as shown in fig [3]. They compared the performance of experimental and reference cubicles. They found that experimental cubicles reduced the maximum peak heat flux by 41.3%, peak temperature by 7.2- 9.2% and cooling load by 38.8%, which resulted in energy savings of 28.3 Rupees/day with good thermal comfort.Gopal Nandan et al. [10] studied the various domestic applications of P.C.M., including solar water heater, solar air heater, solar cooker, solar greenhouse, and buildings. They found that smaller thickness P.C.M.s walls were more thermally efficient storage than the ordinary masonry wall. The thermal performance was better for 8.1 cm P.C.M.s wall than 40 cm thick masonry wall in Trombe wall when subjected to the same ambient condition. N. Yu et al. [11] studied the concept of a passive solar precast concrete curing building integrated with a P.C.M. thermal storage system. It evaluated the optimum thickness of the best-suited P.C.M. for application in building walls. Steam curing requires a temperature level equal to or above 35°C with 90% humidity for a long time so that the building can achieve the necessary hardening. According to them, G.H. series P.C.M.s such as GH-33, GH-35, and GH-37 satisfied the building's minimum curing temperature and sufficient humidity criteria. They found that the application of P.C.M. walls increased the average monthly temperature by 2.7 °C and reduced the heating load by 5.8, 3.4, 2.9, and 6.4 GJ in the autumn, summer and winter, spring, respectively. Out of three, GH-37 PCM board with a thickness of 50 mm had optimal cumulative time rate and phase change rate because of its phase transformation between 37.4 and 43.5 °C and latent heat of 227.5 KJ/Kg.

P.C.M. can be incorporated in building roof, windows and floor. Nowadays, P.C.M. has gained much popularity and is used for various applications: building thermal energy storage, solar cooling systems, P.V. electricity generation systems, solar dryers, solar chimneys and the space industry.

Fig. 3 Prepared macro capsules of PCM [39]

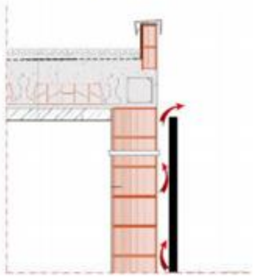
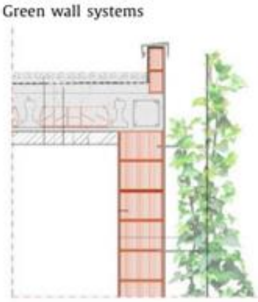
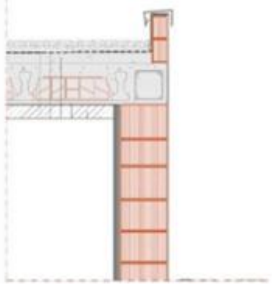
Fig. 4Developed reference and experimental cubicle [39]

2.2.4 Trombe wall

Trombe ball is popularly known as solar heating wall or storage wall. It is made up of concrete, stones, bricks of high thermal inertia and one side are blackened. A Trombe wall is referred to as a passive, indirect heat gain system. Here, sunlight is first absorbed by the thermal mass located between Sun and the living space, then converted heat is transferred into the living space. This system works on the greenhouse effect and traps solar heat between glazing and the thermal mass. Glazing allows shorter wavelength radiations to pass through them but does not allow longer wavelength radiations to escape. Also, due to the Trombe wall material's high heat capacity, it shows in the time lag phenomenon. It stores heat during the daytime, releases it during the night for indoor heating space, and avoids many temperature fluctuations. In the current design, practice vents have become an integrated part of the Trombe wall, which increases the buoyancy effect and help in satisfactorily reducing the heating load in winter and cooling load in the summer.Z. Yilmaz et al. [12] compared three different Trombe wall façade with single glass, double glass, integrated semi-transparent P.V. modules by both experimental and C.F.D. Simulation Model. They found that the Trombe wall with single glass gives the best solar radiation gain due to its higher solar heat gain efficiency. They suggested using a single glass with a shutter to offset its heat losses during the evening and night-time. The impact of insulation thickness for decreasing the heating energy needs and increasing the bioclimatic gap changes significantly with insulation thickness. It can also reach 1% for a particular thickness value. Therefore, the selection of optimal thickness value of the insulation should be made for effective working.

A step further in the Trombe wall is the inclusion of P.C.M., which provides more energy storage and saving. It enhances the overall performance of the building and reduces HVAC costs. Lone et al. [13] studied the various application of P.C.M. and reviewed that the efficiency of P.C.M. filled glass window and wall in maintaining room temperature is much better than the window and wall without P.C.M. They proposed that replacing masonary with Organic P.C.M. (with some additives for increasing conductivity) in a Trombe wall made them more efficient and productive.

Table 2: The advantages and disadvantages of several passive walls are listed in the table [2,14].

Passive wall strategy	Advantages	Disadvantages	Cost estimation
Trombe wall 	Capability to be integrated with new technologies such as PV systems	In region with mild winters and hot summers, overheating problems may outweigh the winter benefits	Medium
	Reduction of building energy consumption and decrease of moisture and humidity of interior spaces in humid regions	In a climate with extended cloudy periods, without employing the adequate operable insulation, the wall may become heat sink	
	The indoor temperatures are more stable than in most other passive systems. Prevention of excessive sunshine penetration into the inhabited space	They have low thermal resistance causing to transfer the heat flux from the inside to the outside of a building during the night or prolonged cloudy periods	
	Installation is relatively inexpensive, where construction would normally be masonry, or for retrofitting existing buildings with uninsulated massive exterior walls	The amount of heat gained is unpredictable due to changes in solar intensity	
	The time delay between absorption of the solar energy and delivery of the thermal energy to the living space can be used for night-time heating	They are aesthetically appealing	
	It not only provides thermal comfort in the spaces connected to itself, but it also contributes to the enhanced thermal comfort conditions of adjacent spaces		
Passive wall strategy	Advantages	Disadvantages	Cost estimation
Green wall systems 	Enhancing building aesthetics	Providing a living environment for mosquitoes, moths, etc.	High
	Improving acoustic properties	Requirement of significant maintenance	
	Reduction of heat gains and losses	Water drainage can involve complexities and difficulties	
	Ability of integration with existing buildings		
PCM wall systems 	Availability at different temperatures	Low thermal conductivity	High
	High volumetric energy storage	Flammability	
		Low thermal and chemical stability	

Greenery wall is another extensively used building envelope system widely used nowadays worldwide. Researchers have studied different building envelope systems in recent years and compared them to select the best one suited for building walls and achieve thermal and visual comfort at a low cost. H. Omrany et al. [14] reviewed different passive wall systems and analysed the effect of these walls on building indoor climate and environment. Their study included: Trombe wall, P.C.M. wall and Green wall. The advantages and disadvantages of several passive walls are listed in the table [2]. They found that the Trombe wall alone cannot decrease the heating and cooling load much, for this chimney of suitable dimension and orientation or BIPV should be integrated with it to improve its performance. Critical design factors such as distance between two skins, depth of the cavity, glazing material play significant roles in the maximum utilisation of D.S.F.s.

2.3 Windows

From an energy-efficient building design perspective, a window is the crucial element of building design. Windows are considered helpful multifunctional devices for buildings that provide passive solar gain, air ventilation and visual comfort. About 60% of the total heat loss by residential buildings can be attributed to the glazed areas. Window area, glazing Material, position, shape, facades orientation, climate affects the heating, cooling, lighting load requirements, and thermal and visual comfort. A. Aflaki et al. [15] found that radiation cooling fails to work well in tropical climate regions because of lack of temperature fluctuations, high humidity, and cloud cover dominance. It reduces heat transfer rate and causes an uncomfortable thermal situation. Evaporative cooling also losses its efficiency because of high levels of humidity. Natural ventilation through building facades and openings is the best technique for achieving thermal comfort and maintaining humidity levels inside buildings. Their analysis showed that wind force and stack effect plays a key role in air movement inside buildings. Their study revealed that building facades, building orientation, building layout, window to wall ratio (with every 10% increment in the window to wall ratio, cooling load increases by 1.3%), window to floor ratio, ventilation shaft are essential for natural ventilation. T. Kaasalainen et al. [16] studied various architectural window design parameters such as window areas, glazing, shape, position, properties, proportion, internal shading, window shading length and observed its impact on heating, lighting and cooling load requirements in the Finland climate. They found that window proportion and horizontal window position had no significant effect on calculated energy consumption while increasing the window area from 2 to 4 meter-square decreased lighting load by 18.9% of the total increased heating and cooling load. They suggested that increasing window size can be advantageous only if other dependent properties such as glazing properties, shading devices are correctly adjusted. Additional window shading length reduces cooling need but at the same time increases heating and lighting need, as a result, cause a minimal effect on building total energy demand. Hence, Additional window shading is advantageous in the region, which requires a high cooling load. Adjustable exterior shading can adapt to different environmental conditions and achieve the best benefit of shading in all areas.

M. Rabani et al. [17] performed the optimization of envelope, shading devices and energy supply systems for providing both visual and thermal comfort. They observed that visual comfort and thermal comfort are two conflicting factors for achieving low building energy use. This optimization reduced the building energy requirement for heating and cooling significantly, up to 77%. Suitably placed deciduous tree performs well the function of adjustable shading. Internal shading with louvre, blinds or curtains provides similar results to external shading and avoids glare and overheating. Y. Hu, P.K. Heiselberg, and R. Guo [18] experimentally studied a PCM enhanced ventilated window (PCMVW) and its performance in both ventilation pre-cooling and ventilation pre-heating applications. The night cooling experiment with PCMVW decreased the room inlet air temperature by an average of 1.4 °C in 7.0 h and enhanced the energy savings by 0.7 MJ/day than the ordinary VW. The solar energy storage experiment with PCMVM increased the inlet air temperature of the VW by two °C for 12.0 h. It resulted in an energy saving of 1.6 MJ/day compared with an ordinary VW. Zinzi et al. [19] conducted the thermal and numerical analysis of cool painted aluminium windows shutters in Palermo in southern Italy, Rome in central Italy, and Venice in northern Italy. They studied its effect on cooling and thermal comfort. They found that shutters with cool tint have decreased the energy requirement by 38 kWh, 15 kWh, and 17 kWh per year in Palermo, Rome, Venice, respectively. Net cooling demand for the house configuration equipped with conventional and cool shutters in Palermo, Rome and Venice is shown in figure [5]. They concluded that the shutters equipped with cool tints decreases the building mean surface temperature by 5° and enhances the cooling performance of the building. M. Vaseghi et al. [20] constructed a building in Tehran, Iran, with the latitude and longitude of 35.7°N and 51.38°E. The main objective of their study was to evaluate the heating load of a museum in winter and provide thermal comfort in summer during the daytime. They found that the sun's heat absorbed by the building ceiling in wintertime was enough to reach thermal comfort. At 10 AM and 5 PM, Due to a decrease in the sun's heat flux, the museum needed additional heating through spiral piping to meet comfort temperature.

Similarly, in summer, windows installed on the top and bottom of the museum reduced the temperature up to 4° via Natural ventilation using stack effect and provided thermal comfort in some hours. But at 2 PM and 3 PM, they needed additional forced ventilation or air conditioning to provide thermal comfort from the sun's intense heat. They concluded that both passive and active heating and cooling are required for museum buildings to reach thermal comfort and reduce CO2 emission and environmental pollution.

There are so many studies on how window area and glazing material affects building energy consumption. In the future, studies will be focused on Window shape and positioning with their combinations.

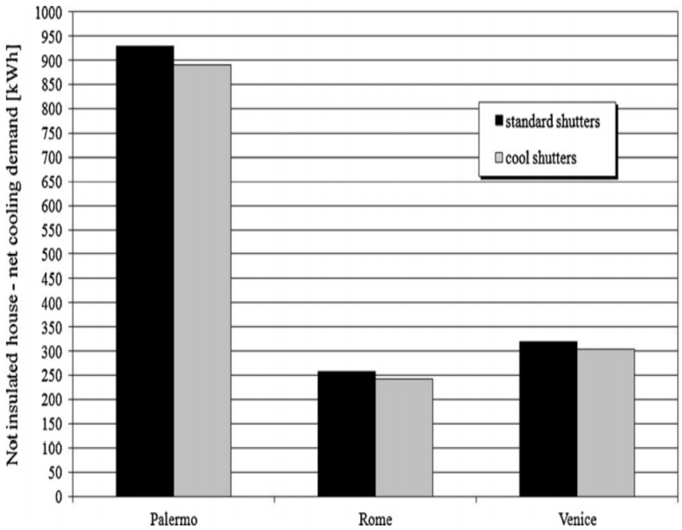


Fig. 5Net cooling demand for the house configuration equipped with conventional and cool shutters in Palermo, Rome and Venice [19].

2.4 Radiative Cooling

Passive radiative cooling is an emerging field of futuristic research and development. Passive cooling is becoming popular because it can reduce water, electricity demand and the adverse environmental effects of the conventional cooling system. Passive radiative cooling is an environment-friendly cooling technique due to zero emissions of CO2, harmful chemicals and can provide temperature below ambient temperature without any water or energy consumption. J.P. Bijarniya et al. [21] extensively reviewed the passive daytime radiative cooling with fundamentals of EM waves and material interaction, categories of different radiative materials, the environmental effect on their performance and various challenges researchers face in developing radiatively cooled buildings. They found that for optimised radiative cooling, the ideal radiative surface emits in the atmospheric window (8-13 μm wavelength) only and reflects other wavelengths. The radiative behaviour of multi-layer media, randomly distributed media, and porous polymer structure, as shown in fig [6], was tested. They concluded that layered material, porous polymer material, random and pigmented material could give the cooling effect of up to 10°C, 6.1°C, and 7.3°C, respectively. Their performance depends on environmental factors such as humidity, cloud fraction, wind velocity, etc., of the region. Multi-layered structures give the highest temperature drop in radiative cooling, but it is costly. The researchers can focus on developing cost-effective and easy to manufacture random and porous material as daylight radiative cooler in the upcoming future. The research area related to the life cycle and stability of radiative cooler, when exposed to environmental factors such as sunlight, humidity, cloud, rain, can be explored.

The way radiative cooling reduces the temperature of the building is intense work. Radiative cooling can only be achieved when the structures coated on Wall and window can reflect the incident sunlight or absorb and re-radiate far infrared lights. Therefore researchers are focusing on complex photonic crystals and bulk materials for building passive cooling. X. Huang et al. [22] Prepared a highly efficient passive cooling powder of Ca0.5Mg10.5(HPO3)8(OH)3F3 (CFM). They mixed it with polyvinylidene fluoride (a film-forming agent) in the proportion of 85:15 by weight. They observed that CFM has average reflectivity of 0.98 and an average emissivity of 0.91. To analyse CFM's thermal performance, they applied 160 um thick CFM coating on aluminium foil and stuck a heating sheet to the back of the foil. This arrangement was wrapped with polystyrene foam and a silica aerogel and placed inside a box, as shown in fig [7]. They concluded that CFM coating reduced the ambient temperature by 5.1°C at noon and 2-5.3°C at night. In the future**,** researchers can study the behaviour of CFM coating in different climatic and natural conditions. Hence, determine the optimum thickness of CFM coating required for producing an efficient cooling effect.

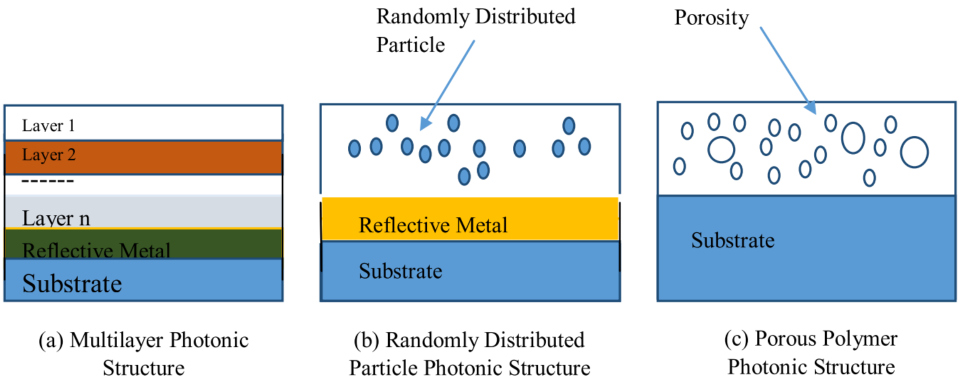


Fig.6Different material structures for daytime radiative cooling[21].

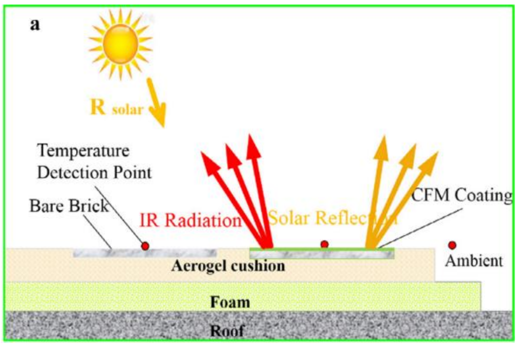


Fig. 7 Working of CFM coated power test equipment for passive cooling[22].

J.Liu et al. [38] analysed the recent advancements and challenges of the passive radiative cooling technique. Their literature survey found that minimising solar absorption and maximising mid-infrared emissions are the two key functions performed by the Radiative surface for achieving effective cooling. For minimising solar absorption, radiative coolers are made of highly solar reflective metal or porous structures. For maximising mid-infrared emissions, a photonic structure of size closer to wavelength is preferred. Other ways of decreasing solar absorption are: coating the surface with nanoparticles (ZnS,TiO2) to enhance reflectivity, using sunshade, and developing nano-photonics material. Use of 1-D and 2-D photonic structure, meta-material and meta-surface, scalable radiative cooling materials maximises infrared emissions. Since Radiative cooling provides low- cooling costs, high energy saving, and negligible environment polluting CFCs compared to traditional VCRs refrigerators. Therefore, it has gained the focus of several researchers.

Out of different passive roof technology, cool roof, roof pond, evaporative cooling, and combination have shown better results in the cooling building. Cool roofs consist of external coating with high albedo material, which increases the roof surface's reflectance and reduces solar heat gain. The cool coating improves the indoor and outdoor thermal conditions in summer and decreases building energy demand by 7- 57%, depending upon the building type and climatic conditions. Ulises Chávez et al. [23] evaluated the performance of an environment conditioning system, so-called Hydrodynamics Cool Roofs System with Energy Recovery (SHETRE), both analytically and experimentally. They found that SHETRE decreased the indoor temperature by 8°C in the study case test building compared to the bare roof when ambient air temperature reached 35 °C and increased the comfort hour by 68.1%.

Evaporative is the conventional air conditioning technology that dissipates heat using water as a sink. It makes air cool by increasing its water vapour content. It can be integrated with other passive techniques such as natural ventilation for better performance. Gopal N. Tiwari et al. [24] studied different passive heating and cooling concepts and found that evaporative cooling and wind tower together can reduce the temperature by up to 12-17 °C. They observed that a double glazed system reduces 9% of heat gain but reduces the heat losses by 28% compared to single- glazed system. Evaporative cooling offers a high-efficiency range, attractive payback period and require little maintenance. The main disadvantage of direct evaporative cooling is that it can attain a minimum temperature equal to the wet-bulb temperature of ambient. Therefore indirect evaporative cooling is needed to overcome this disadvantage.

A roof pond is a combination of indirect evaporative cooling and radiant cooling processes. J.M. Almodovar et al. [25] evaluated the cooling performance of two roof pond configurations with WAHE system: a roof pond with a floating insulating panel and spray system operating at night, and a roof with a sealed flat aluminium plate separated from the water by an air gap. The performance of both the configuration with the WAHE system was better than the ordinary roof pond. However, the former roof pond with the WAHE system gave the best performance. This roof configuration was able to keep the indoor temperature under 24°C even with outdoor temperatures above 35°C, a difference of more than 10°C. Rubing Han et al. [26] developed water-retaining brick of dimension 300mmX300mmX240mm and compared three different configurations; roof with water retaining brick, roof with a radiation shield and an ordinary roof Mianyang (China). They observed the diurnal variations of the temperatures tested inside and outside, the total solar radiation intensity, outdoor wind velocity and relative humidity of outdoor air in summer and winter. They concluded that out of the three configurations above mentioned, the maximum cooling effect is achieved on a roof with water retaining brick during summer.

A roof pond technology is helpful for both passive cooling and heating. During daytime ponds, water can store solar energy as sensible heat. This stored heat is transferred to the ceiling by conduction and then carried to the indoor space by convection and radiation to give thermal comfort. Furthermore, the permanent humid conditions of roof ponds may lead to the growth of mosquitoes and virus-like Chikungunya.

2.5 Solar chimney

A Solar chimney is used to increase the natural ventilation in a building envelope. It is a solar-based passive ventilation system that improves the thermal comfort of the occupants. P.C.M. enhanced solar chimney improves the temperature uniformity and thermal comfort of the room.M.E. Tiji et al. [27] performed a numerical simulation of a PCM-enhanced solar chimney with a finned absorber to investigate the influence of using P.C.M. on the temperature and velocity distributions inside a guardroom compared with the non-PCM system. They observed that the use of P.C.M. storage in the chimney enhances the thermal uniformity in the room but achieved a room mean temperature of about 14.7◦C, which was relatively less than thermal comfort temperature. By adding a rectangular-shaped fin with the aluminium absorber resulted in a significant recovery in energy dissipation. It increased the room mean temperature to 17.6◦Celcius, but it increased the airflow rate inside the room and made it non-uniform inside the room.Passive ventilation systems are among the best low-cost, low-energy solutions that can help in energy conservation. A Buoyancy-driven system, the solar chimney has gained popularity among researchers because of its synchronous HVAC functions. A solar chimney can easily integrate into the existing building envelope, provide the desired airflow, and have fewer space requirements. PCM integrated solar chimneys can store solar energy during the daytime and release it at night. As a result, it enhances the temperature uniformity and ventilation capacity of the system. Two modes in which solar chimney can work in the summer and winter season is shown in figure [8]. Haihua Zhanget al.[42] studied different controlling parameters that influence solar chimney performance and ventilation capacity at RMIT University, Melbourne. They observed that the performance of solar chimneys depends on Room configuration, chimney configuration, installation conditions, occupants behaviours, external environment, and the material used in the building envelope, glazing wall, Solar absorber. External environment factors include solar radiation intensity, external wind intensity and direction, relative humidity and ambient temperature. They suggested that with the growing population, demand for energy-saving and thermal comfort is also increasing rapidly. For this, a double combination or triple combination of different ventilation strategies such as a windcatcher, a solar chimney, and EAHE should be given attention and analysed. L. Moosavi et al. [28] performed simulation and experimental analysis of a two-storey prototype building with three different experimental setups and analysed its thermal and ventilation performance. They noted the average value of temperature and airflow of the three cases, as shown in the table [3]. They found that the experimental setup of case 3 can reduce an average temperature of 5.2°C and save 75% of cooling load in extreme climate conditions. They concluded that a solar chimney, when integrated with a windcatcher and water spray, gives favourable thermal and airflow in the entire building. In the future, the Effect of other parameters such as wind force, climate condition, chimney height, and opening area on chimney-integrated windcatcher performance needs to be investigated.

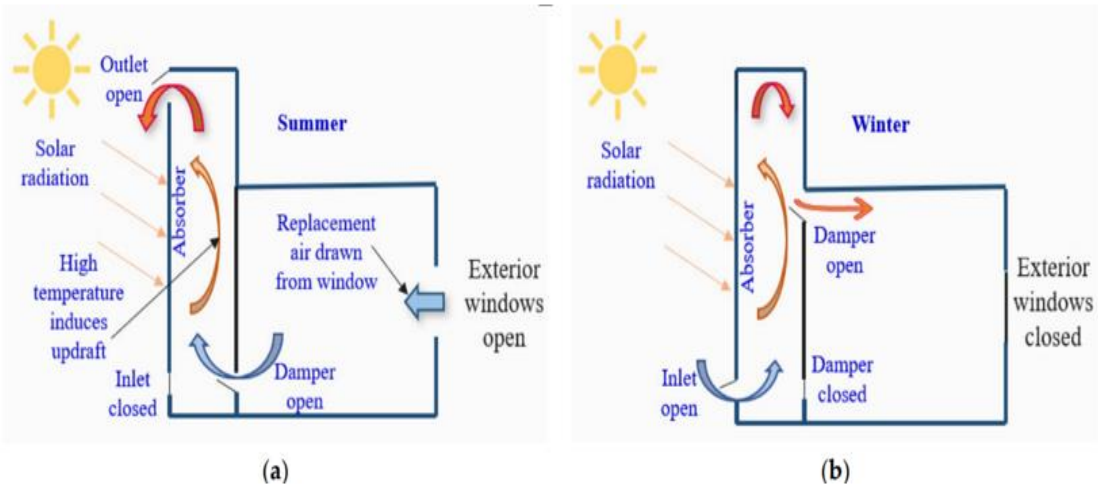


Fig.8Schematic of cooling mode (a) and heating mode (b) of solar chimney[42].

2.6 Earth-air heat exchanger

The earth-air heat exchanger is a non-conventional technique that uses underground earth heat for space heating and cooling. It can be integrated with the buildings as passive systems as well as integrated with active systems. In recent years EAHE systems have been combined with other passive techniques to provide better energy-saving and thermal comfort.A. Serageldin, et al. [29] performed experimental and numerical investigations to analyse the performance of solar chimneys when combined with EAHE under the meteorological condition of Egypt. They found that the airflow was optimum when the inclination of the solar chimney with the horizontal was in the range of 45-70°. They used TRNSYS simulation for long term performance and noted the transient behaviour of it. They concluded that combining solar chimneys with EAHE can increase the zone temperature by 10°C in winter and decrease the zone temperature by 5°C in summer compared to ambient in the meteorological condition of Egypt and provides necessary thermal comfort. Moreover, this combination can payback within 6-10 years by saving the annual heating and cooling power.

M. Dabaieh and A.A. Serageldin [30] proposed the combination of three passive solutions, i.e. EAHE, Trombe wall, and green wall, for developing low- energy consumption, low environment polluting refugee houses. This concept aimed to reduce the heating and cooling loads and fulfil the energy needs by utilising renewable sources. For this, they took 8 possible combinations of these passive heating and cooling concepts as listed in table [4] and analysed each case's behaviour. The modelling, simulation and computation of their model were performed using TRNSYS and ANSYS software to assess the feasibility and efficiency of this proposed building passive combinations. They verified simulation results by constructing a passive refugee house prototype in Sweden, and year-long monitoring was done. They concluded that these three passive techniques collectively reduced the heating and cooling demands of the prototype house to 7.9 kWh/m2 /annum and 2.8 kWh/m2 /annum, respectively. It also reduced the CO_2 emissions by 242.2 kg per annum and reported the expected payback time of the system as 7.5 years. Building heating and cooling loads of different cases in kWh/m2 is listed in the table [5].

Table 3: Different experimental set up with their average predicted temperature and air velocity values of the occupant space.

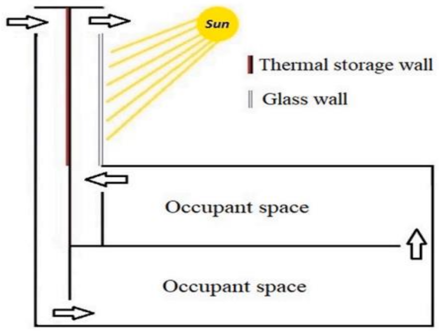
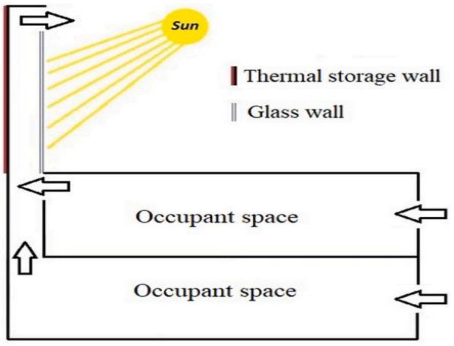
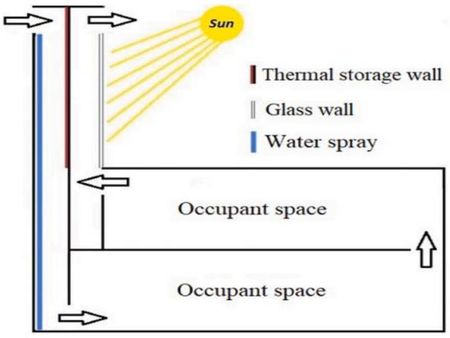
<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Strategies implemented</th><th rowspan="2">Experimental setup</th><th colspan="2">Average Temperature (C)</th><th colspan="2">Average Air velocity (m/s)</th></tr>
<tr><th>Down floor</th><th>Top floor</th><th>Down floor</th><th>Top floor</th></tr>
<tr><td>1.</td><td>Windcatcher
Solar chimney</td><td>
Case 1</td><td>30.7</td><td>32.2</td><td>0.11</td><td>0.05</td></tr>
<tr><td>2.</td><td>Solar chimney</td><td>
Case 2</td><td>30</td><td>30.2</td><td>0.23</td><td>0.15</td></tr>
<tr><td>3.</td><td>Windcatcher
Solar chimney
Water spray</td><td>
Case 3</td><td>29.2</td><td>30.7</td><td>0.12</td><td>0.05</td></tr>
</table>

Table 4: Eight different cases (individually, in pairs and combine) by using the three passive systems [30].

Case 1	Base case
Case 2	Base case + green wall
Case 3	Base case + three Trombe walls
Case 4	Base case + green wall + three Trombe walls
Case 5	Base case + EAHE
Case 6	Base case + EAHE + green wall
Case 7	Base case + EAHE + three Trombe walls
Case 8	Base case + EAHE + green wall + three Trombe walls

Table 5: Building heating and cooling loads in kWh/m2 obtained are [30].

Case	Heating, (kWh/m^2)	Cooling, (kWh/m^2)
Case 1	16.0	10.4
Case 2	14.4	10.9
Case 3	13.3	12.2
Case 4	9.3	13.6
Case 5	12.7	8.6
Case 6	11.6	4.9
Case 7	8.7	9
Case 8	7.9	2.8

2.7ETFE

The use of ETFE (ethylene tetrafluoroethylene) foils in transparent buildings has drawn the attention of several researchers in recent years. It has become popular among researchers because of its excellent material properties, architectural performance and better structural behaviour than glass materials. **J.** Hu et al. [31] reviewed the buildings with ETFE foils and noted the material properties, architectural performance and structural behaviour. They found that ETFE is a cheaper, better insulator and has a higher light-transmitting ability than glass. Also, it is 1/100 the weight of glass. In transparent roofs, ETFE material offers self-cleaning effect, elasticity, long service life, UV resistance and chemical resistance invasion, which lead to the reduction of maintenance cost. It contributes to green and sustainable building construction since it is 100% recyclable and requires minimal energy for its transportation and installation. Therefore it is considered the best alternative for glass and PVC in transparent building materials. The performance of ETFE cushion building enhances when the PV system is integrated with it. Typical ETFE cushions integrated photovoltaic/thermal systems are shown in figure [9]. This system utilises solar energy to generate electricity and thermal energy and contribute to self-sufficient, sustainable building. J. Hu et al. [32] performed one parameter and two-parameter analysis of the ETFE foils integrated with organic PV. They found that thermal and mechanical properties are dependent on each other, but electrical properties are independent under normal working conditions. They concluded that the performance of double OPV specimens was better than that of single OPV specimens.

(a) (b)

Fig. 9 Typical ETFE cushions integrated photovoltaic/thermal systems. (a) Two-layer ETFE cushions with photovoltaic integrated on top layer. (b) Three-layer ETFE cushions with photovoltaic integrated on middle layer [31].

III. Optimization studies

The parameters such as building orientation, glazing type, insulation of walls, windows to wall ratio, opaque envelope, and shading system etc., have a critical impact on the performance of passive building design. Therefore, using an optimization method coupled with the building energy simulation plays a crucial role in choosing an optimal combination of passive solar design strategies for a given climate condition. S. Stevanovic [33] reviewed parametric study of different optimization methods coupled with the building energy simulation to reach energy-efficient and cost-effective passive building designs. They found that optimal selection of design parameters affecting the performance of the passive building can lead to the reduction of life cycle cost of building by 10- 25%, depending upon the location and climatic conditions. P.G. Loutzenhiser et al. [34] Constructed daylight models in EnergyPlus and DOE-2.1E, then compared the predicted value of illuminance and light power with the original measured value. Their analysis aimed to check the empirical validation of daylight algorithm incorporated building energy simulation programs. The predicted value of the reference point by algorithm integrated building simulation programs is shown in the table [6]. They concluded that building simulation programs are an essential tool for assessing daylight control savings in the design phase of a building.

Table6: The predicted value of the reference point by algorithm integrated building simulation programs.

S. No.	Parameters	The predicted value of the reference point by EnergyPlus, were within limit	The predicted value of the reference point by DOE-2.1E, were within limit
1.	illuminance	119.2%	114.1%
2.	Light power reductions	16.9%	26.3%
3.	Reheat coil power	17.3%	25.4%

The Trombewall has gained a wide range of attention from researchers due to its low operating cost, simple structure and high thermal performance. T. Zhou et al. [40] compared the performance of three configurations of the wall, namely: TW (Trombewall), WTW (Water Trombewall), GWTW (Glass Water Trombewall), by CFD method and validated the results with several literature references. They performed thermal analysis to evaluate the effect of various parameters such as influence of irradiance, Water mass flow rate, the inlet water temperature on the energy efficiency, exergy efficiency and heat loss performance of TW, WTW and GWTW. They found that WTW gives the best thermal performance in terms of energy and exergy efficiency compared to other configurations and reduces heat loss by 31% compared to TW. Based on weather data of Belgrade, Serbia, T. Bajc et al. [41] constructed a model house for CFD analysis of temperature and velocity field. They optimised the construction of Trombewall using different glassing, opening with flaps and climatic conditions. Their simulation found that Trombewall, when used with closed flaps both in concrete core and glassing during winter, can result in average temperature variations of 4.52°C at 8 p.m. to 14.7°C at 1 p.m. In summer, the cooling performance improved by using PV strip cover outside the Trombewall. PV strips contributed to electricity production, which was used for running cooling devices**.**

Y. Tao et al. [37] constructed the porous structure in PVC by chemical etching with CaCO3 particle as pore template and compared its properties with PVC/titanium dioxide (TiO2) composite films with 10 v% TiO2. They investigated that the thermal conductivity of sample 67 v% is 0.0868 W/m-k, 46.2% lower than that of PVC films. The total solar reflectance of sample 67 v% is 96.34%, 454.9% higher than that of PVC film. They concluded that PVC porous material has the advantages of low thermal conductivity (or high thermal insulation), good solar reflectance and simple preparation over others, which is desired for the application prospects in passive cooling materials.K.M. Al-Obaidi et al. [35] performed experiments and simulation tests to evaluate the design efficiency of different passive cooling techniques to control heat gain and heat dissipation in buildings and achieve maximum comfort while minimising energy use. They developed a green and sustainable solution for existing concrete flat roofs with no significant interventions. They found that a perforated device with an opening percentage of 88% and cavity of 0.05 m gives lower operative temperature within a range of mean value between 0.8 to 0.91 °C compared to a roof with full shade cover.I.L. Wong [36] studied different Daylighting systems with the help of various methods (models) and computer simulation programs. They noted the strength and weaknesses of each model and found that the scale model was most effective, but it was most expensive. They suggested that advancements in computer-based simulation such as Dialux, Energy plus, RADIANCE, CODYRUN etc., can provide cost-effective solutions and accurate predictions to daylighting performance.

IV. Conclusions

After a thorough survey of several literature reviews, it has been found that researchers have worked on window dimension, orientation, and Louvre angle. Still, there are very few papers on climate adaptive windows. A window with an adjustable shutter or sliding curtain can be a good option for passive heating and cooling. Since Windows glazing contributes to about 60% of the total heat loss of a residential building, so windows and their glazing materials need more attention. Many researchers have claimed ETFE as the best replacement for glass glazing. So The ETFE integrated building roof, windows need attention. Thermal Energy Storage through high-density PCM is an effective way of improving the thermal performance of the building. PCM enhanced window curtains can provide good thermal storage and control temperature fluctuations.

Solar shading can provide 6°C temperature drop with proper insulation and a controlled airflow channel. Airtightness may lead to 9.4% of cooling load. So During building design, adjustable shading and infiltration should be considered, and their combination with other passive techniques such as radiative cooling, Trombe wall, and solar chimney needs further studies.

Analysis of the impact of Trombe wall, Trombe wall with adjustable vents, P.C.M. wall on the thermal performance of the building have been done separately. But the combination of P.C.M. wall and Trombe wall wall with other passive techniques such as EAHE, radiative cooling needs further research. Most researchers have combined two passive techniques in their analysis, but the combination of three, such as Trombe wall with Solar chimney and adjustable glazing/shading elements or more, is also possible. A combination of three or more passive techniques will improve the thermal performance of the building.

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