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Thermal Management Components and their Significance in Energy Efficient/Green Buildings in India: A Review

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A growing world-wide concern for the conservation of energy and depletion of natural resources leads to a renewed interest in those aspects of architecture, which leads to thermal comfort in buildings with minimum consumption of conventional energy and depletion of natural resources. These aspects are termed as energy efficient design strategies. Various strategies for designing green buildings are (i)Building design parameters (iii) Efficient selection of HVAC equipments (iii) lower embodied energy of building material and (iv) Soil & water conservation. In this review various aspects like social, economical, energy, environment and sustainability of buildings with their labeling in terms of Bureau of Energy Efficiency, India has been presented.

Keywords: Thermal Comfort, Green Building, HVAC (Heating, Ventilation and Air Conditioning).

1. INTRODUCTION

The main function of buildings is to provide a comfortable indoor environment and to protect the mankind from the extremities of climates. Traditional buildings, therefore, were built with considerations to climatic conditions for keeping the inside building spaces cool in summer and warm in winter. These aspects have been forgotten in the modern architecture, which essentially relies on mechanical methods of heating and cooling involving large amount of energy expense. The construction sector poses a major challenge to the environment. Globally, buildings are responsible for at least 40% of energy use.

These aspects of architecture leads to thermal comfort in buildings with minimum consumption of conventional energy. These aspects are termed as energy efficient design strategies [1-7]. Various energy efficient strategies for heating and cooling of the buildings are (i) Building design parameters viz. Orientation, reflecting components, absorbing surfaces, glazing, minimum surface to volume ratio, thermal insulation, reduction of air infiltration, shading, air cavities etc. and (ii) Efficient selection of HVAC equipments. As we chart our development path, it is important for us to keep our eyes on the environmental damage that we create. It is well established fact that green buildings offer immense potential to reduce consumption and regenerate resources from waste and renewable sources. The aim of a green building is to minimize the demand on non-renewable resources, maximize the utilization efficiency of these resources when in use and maximize the reuse, recycling and utilization of renewable resources. India exhibits

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a vast variety of climates. The climate ranges from warm and humid in the coastal areas, hot and arid deserts of Rajasthan and there is dry and cold at the higher altitudes of Ladhakh and Leh region. However, the composite climate, which is a dominant factor in most of the mid latitudes of India, where no single season predominates, poses a challenge to the designer.

The major components of a green building include:

a) The walls and roof which protect man from the extremities of the environment outside.
b) The windows and ventilators for daylight, solar heat gain and ventilation and
c) The doors that cause infiltration.

Buildings, as they are designed and used today, contribute to serious environment problems of excessive consumption of energy and other natural sources. Energy resources efficiency in new construction can be affected by adapting an integrated approach to building design and use. The primary steps in this approach are listed below.

- Incorporate solar passive techniques in a building design to minimize load on convention system(heating, cooling, ventilation, and lighting) passive system provide thermal and visual comfort by using natural sources and sinks, e.g. solar radiation, outside air, sky wet surfaces, vegetation and internal gains. Energy flow in these system are by natural means such as radiation, conduction and convection with minimal or no use of mechanical means.

- Design energy-efficient lighting and HAVC (heating, ventilation, and air-conditioning) system. Once the passive solar architectural concepts are applied to design, the load on conventional systems (HVAC and lighting) is reduced. Further energy conservation is possible by judicious design of the artificial lighting and HVAC system using energy efficient-equipment, controls, and operation strategies.

- Use renewable energy systems (solar photovoltaic system/solar water heating system) to meet part of building load. The pressure on the earth’s non-renewable resources.

- Use low energy materials and method of construction and reduce transportation energy an architect should also aim at efficient structural design, reduce use of transportation energy and high energy building materials (glass, steel, etc.) and use of low energy building materials.

Thus in brief, an energy-efficient building balances all aspect of energy use in building-lighting, space-conditioning, and ventilation-by providing an optimized mix of passive solar design strategies, energy-efficient equipment, and renewable sources of energy. Use of materials with low embodied energy also form a major component in energy-efficient building designs.

With the trend growth in the world’s population and the requirement of building for habitation, education, industry and business, construction sector poses a major challenge towards the energy and environment. There is a need to go for sustainable building which is economic viable, energy efficient, environment friendly and socially acceptable.

A multidimensional integrated building design approach adopting of these features would result in (i) Less material usage (ii) Reduced operational energy (iii) Lower maintenance cost (iv) Environment friendly. Building having such features is called green building.Green buildings [1] may be categorized as those which are "Environment Friendly" in terms of the impact they make on nature and its resources. The characteristics of Green Building are as follows

a) They are made of building materials that have relatively lower "embodied energy".
b) They consume less energy in providing shelter and thermal comfort to its occupants.
c) They would incorporate the best principles of 'climate responsive' and 'passive solar design'.
d) They would integrate the most energy efficient lighting fixtures, mechanical and electrical equipment as also building management systems wherever so required, in order to minimize energy consumption.
e) They would harvest rain-water and also recycle waste-water for use in secondary purposes.
f) They would harness renewable energy applications (such as Solar, Wind and others) for their own require.

The above mentioned green building characteristics and desirable sustainability can be achieved with the help of the following

(a) Learning from the past traditions of Vernacular Architecture.
(b) Integrating the knowledge from modern science and technology.
(c) Adapting both the above, with a deep understanding of the human metabolism and acclimatization capabilities, as well as socio-economic and cultural factors.

National commercial benchmarking initiative was taken up with a goal to establish a framework to standardize energy performance target setting for buildings as star label. The star rating for buildings would help in towards the performance of the building in terms of specific energy usage. Energy Performance Index (EPI) in kWh/sqm/year will be considered for star rating of the building [2]. From it, the main components and parameters which are considered for the performance of a green building are (i) building material (ii) design (iii) energy usage and (iv) sustainability. The state of development of green buildings still remains inadequate due to the lack of knowledge, information and capital cost.

There is a close connection between energy use in building and environmental damage arises because energy-intensive solution sought to construct and meet its demand for heating, cooling, ventilation, and lighting cause severe depletion of invaluable environment resources. An estimated 42% of the global water consumption and 50% of the global consumption of raw materials is consumed by buildings when taking into account the manufacture, construction, and operational period of buildings [3]. In addition, building activities contribute an estimated 50% of the world's air pollution, 42% of its greenhouse gases, 50% of all water pollution, 48% of all solid wastes and 50% of all CFCs (chlorofluorocarbons) to the environment by heating and cooling of buildings [8]. India too faces the energy and environmental challenges of the construction sector as the trends show a growth of 10% [8].

Based on the above, suitable Green Building Codes and Rating Systems need to be evolved and made mandatory for application in all development processes of building industry and experts viz. architects & consultants, building contractors, as well as building technology, building materials and equipment manufacturers etc. Green building can be designed for various climate zones as per requirement. India is divided into six climatic zones [3].

Based on the climatic conditions, the various factors to be considered during design of green buildings are listed below [1,4]

a) An analysis of the socio-economic context and location of site.
b) A site and climatic analysis of location and context of its environment.
c) An understanding of the traditional and vernacular architecture of the place.
d) Availability of local building materials, technologies and skills.
e) An understanding of the nature and use of building and its functioning hours. Whether residential, commercial, institutional, hotel, hospital or others.
f) An understanding of the applicable building codes, and local bye-laws for energy efficiency and others.
g) An evaluation of overall project costs, as well as life-cycle costs of project.
h) Study of various parameters related to thermal energy.

Normally, the major part of energy consumed by air conditioning system and lighting in commercial buildings and this energy consumption can be reduced by adopting following design parameters in the building components and usage practices [5,6].

a) **Orientation:** Orientation of building play very important role mainly with regard to solar radiation and wind. For hot regions, building should be oriented to minimize solar gain and vise versa for cold regions. In India, the recommended orientation is E-W axis.

b) **Use of glass:** Type of glass is very important for green buildings. Windows transfer direct heat gain inside the building and hence become critical in hot weather. The windows sizes should be minimum in composite climate. To reduce the heat load of building we should use triple glass or double glass based on cost difference. Internal shading devices such as venation blinds can reflect back some part of heat outside the building.

c) **Use of Walls & Roof:** The amount of heat conducted into the structure through the building fabric is dependent on the thermal resistance of the material and its heat storage capacity. Discomfort is caused by solar radiation, which is absorbed by the outside surface and transmitted through the roof or walls to the inside surface. Walls are major portion of building which transfer solar heat gain from outside ambient to inside the building, amount of heat transfer is depend on heat storage capacity and heat conduction property of wall material. Generally, in conventional building fire clay bricks are used in the walls but thermal conductivity of fire clay brick is higher as compared to ash block, hence, it effect the overall heat transfer coefficient of the wall component. So one can use of ash block walls with insulation for the reduction of thermal load.

   Roof receives lot of heat through solar radiation and play very important role in heat gain inside the building. Based on the climatic condition, proper roof treatment is required. For green building application use of insulation over or below the exposed roof would help to reduce the heat gain/loss. Energy Conservation Building Code (ECBC) has defined the maximum value of over all heat transfer coefficient which can be achieved by using low thermal conductivity building material and insulation on it.

d) **Lighting:** As per the guidelines of green building, lighting inside the building should not be more than 10 watts/ sq m, and it can further be reduced by utilizing daylighting and efficient lighting system.

e) **Indoor conditions:** Indoor conditions plays important role in reduction of heat loads. In some conventional commercial building inside temperature defined 22 °C but as per study human feels comfortable at 24 °C.

f) **Fresh air:** Normally fresh air is inducted inside the building and same amount of inside air is being exhausted in to the atmosphere and by doing it energy is being wasted because in summer we take fresh air from ambient temperature at 43.3 Deg C and we are exhausting equivalent amount of air from 24 °C. Recovery and use of this coolness would help to cool the fresh air hence, reduce the heat load on air conditioning machines.

g) **Free air cooling system:** Internal heat load generated in side the building due to use of computers, photo copy machines, internal lighting load, occupants and other equipment. Due to this air conditioning also required throughout the year. However, during certain days of the year the ambient temperature is much lower than the indoor requirement, therefore, this ambient air can be used directly for air conditioning applications and no need to run the compressor. Use of ambient air to remove the heat load is known as free air cooling.

h) **Earth air Tunnel:** Daily & yearly temperature fluctuation decrease with the increase in depth below the ground level. The temperature remains constant round the year below 4 meter depth from ground level and is nearly equal to the yearly average temperature of the place. The earth can be used as heat source or a sink for heating/cooling air in underground pipes as the earth-air heat exchanger system utilize the stable temperature and large thermal capacity of the earth. Air that is passed through the pipes 4 m below ground level is cooled in the summer and heated in the winter. The amount of heat exchanged between the air and surrounding soil depends on various parameter of surface area, the length of pipe, velocity of air, etc. This air can be circulated inside the building using fans [9-11].

i) **Evaporative Cooling:** Evaporating cooling lowers indoor air temperature by evaporating water. It is effective in hot and dry climate where the atmospheric humidity is low. In evaporating cooling, the sensible heat of air is used to evaporate the water, thereby cooling the air, which, in turn, cools the living space of building. Increase in contact between water and air increase the rate of evaporation. The presence of water body such as a pond, lake, and sea near the building or a fountain in courtyard can provide a cooling effect. The most commonly used system is a desert cooler, which comprises water, evaporative pads, a fan, and pump [12].

j) **Day lighting:** Day lighting has a major effect on the appearance of space and can considerable reduce the load due to light, if used properly [13]. Its variability and subtlety is pleasing to the occupants in contrast to the relatively monotonous environment produced by artificial light. It helps to create optimum working condition by bringing out the natural contrast and colour of object. The presence of natural light can bring a sense of well being and awareness of the wider environment. Day lighting is important particularly in commercial and other non-domestic buildings that function during the day. Integration of day lighting with artificial lighting brings about considerable saving in energy consumption. A good day lighting system has a number of elements, most of which must be incorporated into the building design at an early stage. This can be achieved by considering the following in relation to the incidence of daylight on the building.

- Orientation, space organization, and geometry of the space to be lit.
- Location, form, and dimension of the fenestrations through which daylight will enter.
- Location and surface properties of internal partitions that effect daylight distribution by reflection.
- Location, form, and dimensions of shading devices that provide protection from excessive light and glare.
- Light and thermal characteristics of the glazing materials.

As per the survey conducted [7] of energy efficient buildings, major design parameter considered for composite climatic conditions are (i) Orientation (ii) Proper window shading (iii) Solar chimney (iv) Insulation (v) wind tower (vi) Thermal mass of floor slabs moderates diurnal swings (vii) House from developed around courtyard (act as heat sink) (viii) Large volumes' of spaces coupled with courtyard for ventilation (ix) Buffer spaces located on the over headed south-western exposure (x) Optimization of structure and reduction of embodied energy by use of less energy-intensive materials (xi) Terrace with skylights (xii) wind-driven vaporative cooler (xiii) earth berming (xiv) landscaping (xv) earth-air tunnel system (xvi) Air cavity in walls and roofs (xvii) East and west walls devoid of openings and are shaded (xviii) Underground construction (xix) Thermal storage walls.

Energy Performance Index (EPI) in kWh/sqm/year considered for rating the building with star label under the major climatic zones are tabulated in Table 1.

Table 1: Star rating for office buildings as per Bureau of Energy Efficiency, Government of India for major climates of India.

Climate Zone: Composite

Air conditioned area > 50% of building area	**Air conditioned area <50% of building area**	**Star Label**
EPI (kWh/sq m/year)	EPI (kWh/sq m/year)	
190-165	80-70	*
165-140	70-60	**
140-115	60-50	***
115-90	50-40	****
Below 90	Below 40	*****

Climate Zone: Warm and Humid

Air conditioned area > 50% of building area	**Air conditioned area <50% of building area**	**Star Label**
EPI (kWh/sq m/year)	EPI (kWh/sq m/year)	
200-175	85-75	*
175-150	75-65	**
150-125	65-55	***
125-100	55-45	****
Below 100	Below 45	*****

Climate Zone: Hot and Dry

Air conditioned area > 50% of building area	**Air conditioned area <50% of building area)**	**Star Label**
EPI (kWh/sq m/year)	EPI (kWh/sq m/year	
180-155	75-65	*
155-130	65-55	**
130-105	55-45	***
105-80	45-35	****
Below 80	Below 35	*****

2. ADVANCE THERMAL MANAGEMENT SYSTEM

The above star rating is mainly covering the energy consumed in creating the thermal comfort and lighting in the space utilizing conventional and existing building materials. More than half of the energy is utilized specifically for space conditioning. An effective way of achieving building energy conservation is through solar thermal space conditioning using passive solar design [3,6]. The proper implementation of passive solar building design has been found to yield significant improvements in energy conservation due to the decreased demand of conventional space heating and cooling. For heating and cooling of the space using solar energy, the solar energy is to be collected, stored, and distributed properly in the space. The building materials, like brick, stone concrete, glass, iron etc., form the building envelope but if these materials are heavier (thick, walls, roofs, etc.) then they may store sufficient energy and may help in time delay and lowering the heat wave amplitude. During daytime, the excess heat may be stored in these materials, which may be released during night time. The area of the house thus heated tends to get very hot in the day unless storage mass is provided in the room. The fluctuations in the room are usually higher than tolerated by man for the designed, comfort level. Another effective method for reducing the swing in the room temperature is to introduce a thermal storage wall between direct solar radiation and the living place. The concept is called indirect gain. Passive heating concepts used for indirect gain are: (a) Trombe wall, (b) water wall, (c) Trans wall, and (d) Solarium. The storage systems for passive heating and cooling of buildings practiced are vary therm wall, earth sheltered/bermed structures, earth air tunnels, etc. Presently, the storage for heating and cooling of the building/space is mainly based on sensible heat storage materials. There are certain limitations, however, in adopting passive solar design to a typical building, since the requirement of large mass structures for sensible heat storage may not be practical in typical light-construction houses.

Another type of thermal storage system for the management of thermal load were tried for heating, and cooling of buildings, is based on the concept of latent heat storage through phase change material (PCM). Unlike sensible storage materials, such as water, masonry or rocks, phase change material stores much more heat per unit volume and another key advantage with the use of a PCM is that heat storage and its recovery occurs isothermally, which makes them ideal for space heating/cooling applications and reducing/shifting the heat load, hence, the management of thermal load an the size of air conditioning machine [14].

2.1. PCMs for Space Heating and Cooling

PCMs are ‘‘latent’’ heat storage materials. They use chemical bonds to store and release the heat. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state or phase. PCMs, having melting temperature between 15°C and 32°C, were used/recommended for thermal storage in conjunction with both passive storage and active solar storage for heating and cooling in buildings. A large number of PCMs are known to melt with a heat of fusion in the required range. However, for their employment as latent heat storage materials these materials must exhibit certain desirable thermodynamic, kinetic and chemical properties. Moreover, economic consideration and easy availability of these materials has to be kept in mind. A list of few selected phase change material in the range is given in Table 2.

Table 2: List of few potential PCMs in the temperature range of 15°C to 32°C.

Compound	Melting point (°C)	Heat of fusion (kJ/kg)
Butyl stearate	19	140
Paraffin C16–C18	20-22	152
Dimethyl sabacate	21	143
Polyglycol E 600	22	127
Paraffin C13–C24	22-24	189
$KF. 4H_2O$	18.5	231
$CaCl_2 .6H_2O$	29	190.8
$Na_2SO_{4.}10H_2O$	32	251
Capric acid	32	157
n-Octadecane	27.7	243.5

2.1.1. Major applications of PCMs as building components for the management of thermal load

The application of PCMs in building can have two different goals. First, use of natural heat that is solar energy for heating or night cold (ambient energy) for cooling. Second, use of manmade heat or cold sources. In any case, storage of heat or cold is necessary to match availability and demand with respect to time and also with respect to power. Basically three different ways to use PCMs for heating and cooling of buildings are:

(i) PCMs in building walls.
(ii) PCMs in other building components other than walls.
(iii) These are passive systems, where the heat or cold stored is automatically released when indoor or outdoor temperature rises or falls beyond the melting point.

2.1.2. Properties of PCM

The PCM to be used in the design of thermal storage system should posses desirable thermophysical, kinetic and chemical stability, which are recommended as follows [14,15].

2.1.2.1. Thermo physical properties

(i) Low melting temperature (ii) High latent heat of fusion (iii) High specific heat (iv) High thermal conductivity (v) Small volume change on phase transformation (vi) Congruent melting.

2.1.2.2. Kinetic properties

(i) High nucleation (ii) High rate of crystal growth.

2.1.2.3. Chemical stability

(i) Complete reversible freeze/melt cycle (ii) No degradation after a large number of freeze/melt cycle.

2.2. Passive Storage System

2.2.1. PCM Trombe wall

A Trombe wall is a primary example of an indirect gain approach. Traditionally Trombe walls relay on sensible heat storage, but because of the potential for greater heat storage per unit mass, the PCM Trombe wall is an attractive concept still awaiting successful implementation. A wall filled with PCM is constructed on the south-side window of a house. The wall is heated during the day by incoming solar radiation, melting the PCM. At night the heat is withdrawn to warm the house. For a given amount of heat storage, the phase change units require less space than mass Trombe walls and are much lighter in weight. These are, therefore, much convenient to make use of in retrofit applications of buildings.

It was observed [15-17] that if the PCM wall is designed properly, it eliminates some of the undesirable features of the masonry walls with comparable results. Schematic diagram of PCM Trombe wall is shown in Fig. 1.

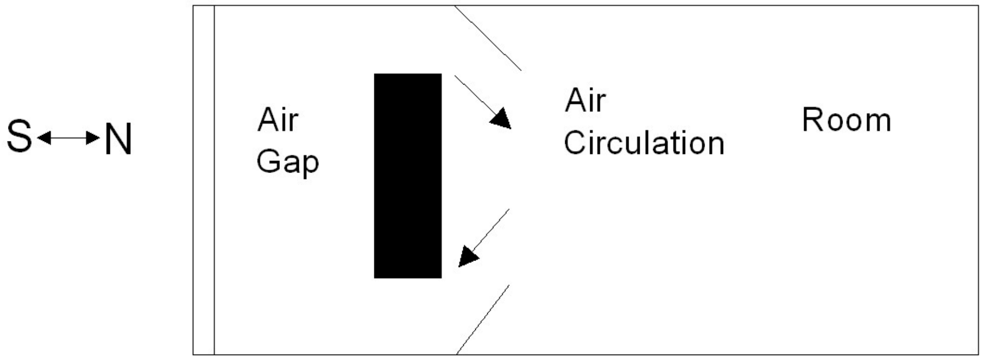

Fig. 1: Schematic Diagram of PCM Trombe Wall.

Buddhi and Sharma [16] measured the transmittance of solar radiation through phase change material at different temperatures and thickness. Stearic acid was used as a phase change material. They found that transmittance of the phase change material was more than the glass for the same thickness and suggested a new application of phase change material in windows/walls as a transparent insulating material.

2.2.2. PCM wallboards

The wallboards are cheap and widely used in a variety of applications, making them very suitable for PCM encapsulation. However, the principles of latent heat storage can be applied to any appropriate building materials. Kedl and Stovall [17] and Salyer and Sircar [18] used paraffin wax impregnated wallboard for passive solar application. The immersion process for filling the wallboards with wax was successfully scaled up from small samples to full size sheets. Processes where by this PCM could be incorporated into plasterboard either by post-manufacturing imbibing of liquid PCM into the pore space of the plasterboard or by addition in the wet stage of plasterboard manufacture were successfully demonstrated.

2.2.3. PCM shutter

In this concept, shutter-containing PCM is placed outside of window areas. During daytime they are opened to the outside the exterior side is exposed to solar radiation, heat is absorbed and PCM melts. At night we close the shutter, slide the windows and heat from the PCM radiates into the rooms. Buddhi et al. [19] studied the thermal performance of a test cell (1 m x 1 m x 1 m) with and without phase change material. Commercial grade lauric acid (melting point, 42°C) was used as a latent heat storage material. He found that the heat storing capacity of the cell due to the presence of PCM increases up to 4°C for 4–5 h, which was used during nighttime.

2.2.4. PCM building blocks

Building blocks or other building materials impregnated with a PCM are used in constructing a building, resulting in a structure with a large thermal inertia without the large mass associated with it. Collier and Grimmer [20] showed that a macro-encapsulated PCM material cemented within masonry building blocks results in significant increase in the system performance over an equivalent volume of concrete. Hawes et al. [21] and Hawes and Feldman [22] studied the thermal performance of PCMs (Butyl stearate, Dodecanol, Paraffin, Tetradecanol) in different types of concrete blocks. Lee et al. [23] studied and presented the results of macro-scale tests that compare the thermal storage performance of ordinary concrete blocks with those that have been impregnated with two types of PCMs, butyl stearate and commercial paraffin.

2.2.5. Floor heating

Floor is also the important part of a building and heating and cooling of buildings were tried using it. Athienities and Chen [24] investigated the transient heat transfer in floor heating systems. His study focused on the influence of the cover layer and incident solar radiation on floor temperature distribution and on energy consumption. Complete and partial (area) carpets were considered as well as hardwood cover layers over concrete or gypcrete (gypsum–concrete mixture) thermal storage.

2.2.6. Ceiling boards

Latent heat solar roof was tested in a Peruvian village to maintain near isothermal conditions in an experimental chicken brood. The brooder house was divided into two connecting parts, a patio and a heated enclosure. Two semi-circular tanks with upper face closed with glass, containing 42 kg of paraffin wax each were located below a glass roof, which was airtight. At night thick polyurethane insulators were placed between the glass roof and paraffin tanks to regulate the enclosure temperature between 22 and 30°C [25].

2.3. Active Storage Systems

2.3.1. Floor heating

Mostly active floor system can be used for off peak storage of thermal energy in buildings [26-33]. Thus, peak loads may be reduced and shifted to nighttime when electricity costs are lower. An electrical under floor heating system having paraffin wax (melting point, 40°C) as the PCM was proposed by Farid and Chen [26]. They placed 30-mm layer of PCM between the heating surface and the floor tiles. Using computer simulation they found that the heat output of the floor could be raised significantly from 30 to 75W/m^2 if PCM storage was used. Nagano et al. [27] presented a floor air conditioning system with latent heat storage in buildings. Floor size of the experimental cell was 0.5 m^2. Granulated phase change material was made of foamed waste glass beads and mixture of paraffin. The PCM packed bed of 3 cm thickness was installed under the floorboard with multiple small holes. The change in room temperature and the amount of stored heat were measured and results showed the possibilities of cooling load shifting by using packed granulated PCM.

2.3.2. Ceiling boards

Ceiling boards are the important part of the roof, which are utilized for the heating and cooling in buildings. Bruno [29] developed a system, which stored coolness in phase change material in off peak time and released this energy in peak time. The effects of the peak-cut control of air-conditioning systems using PCM for ceiling board in the building were also tried. The melting point of the PCM used was of the range 20–30°C, which was almost equal to the room temperature suitable for the purpose. Kodo and Ibamoto [30] made an effort to reduce the peak load of air conditioning system using the PCM in the ceiling board. The melting point and latent heat of fusion of used PCM was 24.5°C and 174.4 kJ/kg respectively. The system was basically same as the ceiling chamber system. At the cooling time, the cool air from the air-handling unit (AHU) was passed through the ceiling chamber space to store the coolness in the PCM ceiling board. The coolness was recovered during 2 h of the peak to cool the room. It was found that the rise in the room temperature was only about 2°C as compared to the 6°C rise in the room temperature, if PCM was not used. Schematic diagram showing outline of ceiling board system having PCM is shown in

3. CONCLUSION

This review paper presents the state of art of various components of building contribution towards thermal load management and possible PCM-based technologies for heating and cooling load management of buildings. Materials used by researchers as potential PCMs (lying in the range of 15–32°C) for human comfort in buildings are tabulated. The systems discussed in this review paper have predicted a potential for reducing the heating and cooling load in building through thermal management system with and without phase change material. These thermal management systems were studied in an isolated manner as building components and were not studied as integrated component of green buildings which can further help to redefine the energy performance index for star labeling of buildings. Therefore, as per the today's need of energy and environment context with reference to buildings, the following points remain to be explored for

a) Alternative, cost-effective, "low embodied energy", and natural building materials, with adequate thermal performance, which may be locally available.
b) Socio-economic and cultural factors for determining a wider range of acceptable thermal comfort parameters.
c) Development of climate responsive buildings using thermal management system and efficient design strategies.
d) Energy and environmental security for sustainable development.

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