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Passive Cooling System to Provide Thermal Comfort

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Abstract: In a country like India, where temperatures may reach 40 degrees Celsius, everyone wants relief from the sweltering heat, but only a few can afford it. As a result, passive cooling is a low or no energy approach that relies on heat gain management and heat dispersion to offer thermal comfort. Heat Protection, Heat Modulation, and Heat Dissipation are the three basic types of passive cooling systems. The combined effect of approaches from each category on a prototype room is examined in this research, which includes shading and green roofs for heat protection, thermal mass (PCM) for heat modulation, and cross ventilation for heat dissipation. Thermal mass is a term that describes a substance's ability to store heat. The three primary phases of a Thermal Energy Storage (TES) system are thermal charging, thermal storage, and thermal discharging. Phase Change Materials or PCM are latent heat storage materials. The roof is one of the most exposed parts of a house to the sun, accounting for over half of the heat gain in a single-story home. As a result, heat protection might be a viable option for lowering heat gain via the roof. A green roof, or a roof with vegetation, is one such system that operates on the principle of evapotranspiration, which is the combined action of soil evaporation and plant transpiration. Another effective method of heat shielding that is used in everyday life is shading. Shading is a basic technique for blocking sunlight before it enters a structure by using structural components such as overhangs, light shelves, horizontal louvres, or blind systems. Cross ventilation is a natural cooling method that uses wind to force cold air into a structure through an opening while driving warm air out. Natural ventilation of this sort is low-cost and ensures that a structure is suitably cooled. There are many such different passive cooling techniques used in different regions of the world in the form of individual as well as hybrid system. This project focuses mainly on Hybrid Systems. Thus, the objective of this project is to integrate PCM and other secondary passive cooling techniques for creating a hybrid passive cooling system to provide thermal comfort.
Keywords: Passive Cooling, Phase Change Material, Green Roof, Shading, Cross Ventilation.

I. INTRODUCTION

The global population is rapidly increasing, which is accompanied by expansion in the industrial, transportation, agricultural, and infrastructural sectors, among other areas. Heating, air conditioning, ventilation, cooling, and others are the most significant elements of energy use in the construction industry. As a result, passive cooling techniques and systems must be designed to eliminate energy consumption, maintain the ecosystem and environment, and provide enough comfort. Thus, the current study outlines a hybrid passive cooling system that provides thermal comfort.

Passive cooling strategies reduce the rise in the building temperature caused by heat sources such as surrounding air, building internal heat gain and direct solar heat gain by using surrounding cooling sinks such as building material, air, night sky, water and so on. Passive cooling techniques are divided into mainly 3 types - Heat Protection, Heat modulation and Heat Dissipation.[1]

1) Heat Protection, which shields the structure from direct solar heat gain.[1]
2) Heat Modulation, in which the heat gain of a structure is regulated using the thermal energy storage capacity of the structure.[1]
3) Heat Dissipation, in which surplus heat from the building is rejected to a lower temperature ambient heat sink.[1]

The hybrid system being studied has techniques from each of the above types-

a) Green Roof and Shading for Heat Protection.
b) PCM for Heat Modulation.
c) Cross Ventilation for Heat Dissipation.

During phase transition, latent heat storage materials, commonly known as PCM (Phase Change Material), store and reject heat. During the day, PCM gathers heat in the form of latent heat from the building's glazed and opaque surfaces and melts at a steady temperature. As a result, the building's internal temperature is controlled and decreased. PCM's accumulated latent heat is removed

throughout the night. Passive cooling achieves heat dissipation from PCM by natural mechanisms, whereas active cooling achieves heat rejection with the use of air conditioning equipment, which comes at a cost in terms of power.
Planting vegetation on and around the building envelope is a very ancient practice for lowering elevated temperatures around structures. Green roofs or planted roofs, employ vegetation to enhance the appearance, performance, or both of a roof's components.[1]

Green roof can be divided into two types
- Extensive roofs which are light and are covered by a thin layer of plants.
- Intensive roofs which are heavier and can support small trees and shrubs.

Green Trees and plants aid in the cooling impact by absorbing heat from the environment via the process of evapotranspiration.[1]
With the employment of architectural components such as overhangs, horizontal louvres, light shelves, blind systems, or façade and fenestration, shading reduces insolation and heat gain in structures. Shading is a simple technique to block sunlight before it enters the building. Various shading systems can be used to shade the building, reducing incident solar radiation and efficiently cooling it, which has an impact on the building's energy efficiency.[1]
Cross ventilation is the utilization of openings on different sides of a room to induce a circulation of air throughout the space. If both sides of the room are open, the high pressure on the exposed side and/or the low pressure on the other, sheltered side will cause a stream of air to flow from the exposed to the protected side. [19]

Thus, the objectives of this project are-
- ✓ To understand and research the variable properties of PCMs which would give effective cooling in the residential houses.
- ✓ To select an effective PCM (phase change material) which would be ideal for providing cooling comfort.
- ✓ To use a secondary passive cooling technique in unison with PCM to provide thermal comfort at a lower cost.
- ✓ To analyze, design and build a prototype of a small room with PCM and the supporting passive techniques.

II. DESIGN AND FABRICATION OF PROTOTYPE ROOM

A. *Design of Prototype Room*

1) *Dimensions of Prototype Room*

- A normal room in India is considered to be of area 10 ft X 10 ft.
- So, the actual dimensions are scaled down and a small room with inside dimensions 3.5 ft X 3 ft, with a height of 3ft is finalized.
- This Room is then designed in solidworks software with dimensions as mentioned below -

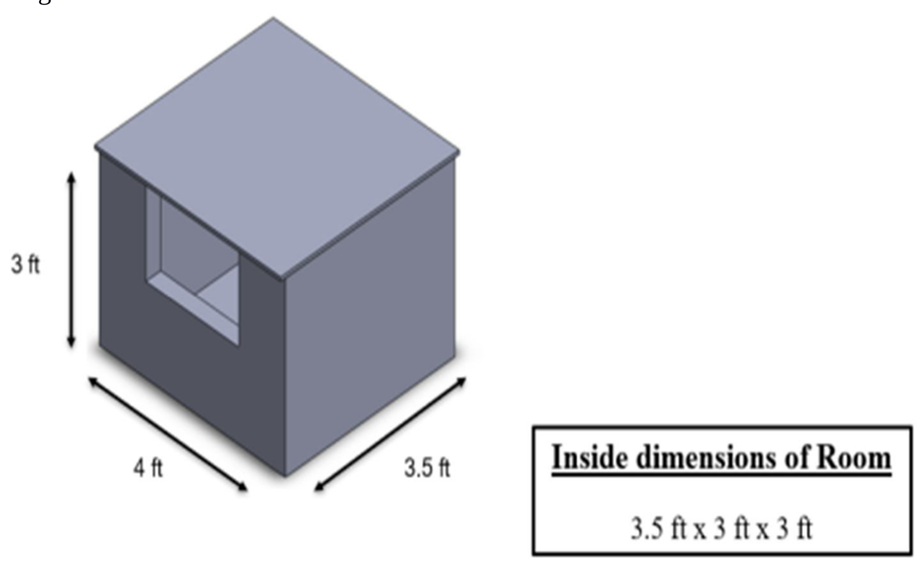

Fig. 1 Design of Prototype Room with dimensions

B. *Construction of Prototype Room*

For feasibility and easy handling of the room for carrying out the experimentation, the room has been constructed on a movable trolley

Fig. 2 The room ready with plastering

C. *Incorporation of PCM*

1) *Selection of PCM*

PCMs can minimize cooling system energy consumption and interior temperature changes; however, various selection criteria must be addressed before.

PCMs can be efficiently applied in the building structure for passive cooling. To ensure thermal comfort for occupants,

- The freezing temperature of the PCM must lie in between 10°C to 30°C from a physical standpoint.
- It should possess a high latent heat per unit volume thermodynamically, which is necessary in construction purposes since it means the PCM can absorb/release more energy with less volume, resulting in a lighter built environment.
- It must have a high specific heat capacity (Cp). Its ability to transmit heat is another key thermodynamic property (conductivity).
- It should have low volume expansion, chemical stability, and minimum or no super-cooling while freezing.
- PCMs must also be non-corrosive, non-toxic, non-explosive and non-flammable.
- It should be stable across a number of melting/freezing cycles or have strong cycling stability. Long-term stability is another phrase for this.
- The last criteria, which takes precedence over all others, is economics. A PCM must be affordable and readily available in the market.

PCMs are categorised into three groups in general, as illustrated below:

- ✓ Organic PCMs - Organic PCMs are those with C-H bonds and are categorized into two groups: Paraffins (Alkanes) and Non-Paraffins.
- ✓ In-organic PCMs - There are no C-H bonds in these PCMs. Metallic PCMs and Salt hydrates are the two types.
- ✓ Eutectic PCMs are made up of at least two different PCMs.

Organic PCMs, such as paraffins, and non-organic PCMs, such as salt hydrates, are the best candidates for thermal energy storage. Inorganic PCMs possess a greater heat of fusion per unit mass, but they are less costly and flammable in comparison (usually). As a result, salt hydrate PCM is used for this investigation. In comparison with organic PCMs, salt hydrates are promising for heat storage in buildings because of their high volumetric storage density (350 MJ/m3), strong thermal conductivity (0.5 W/mK), and low cost. The PCM should be chosen such that its melting point falls within the range of the daily average temperatures of the site under consideration. For Mumbai, the daily temperature ranges from 25°C to 35°C (and can even reach 40°C in summer). Hence PCM having melting point around 27-29 °C will be more suitable. From the available PCMs, $CaCl_2.6H_2O$ is selected because of the easy availability.

TABLE I
PROPERTIES OF PCM

Property	Value
Appearance	Transparent Liquid with white suspension
Melting point	29 °C
Latent Heat	190 kJ/kg
Liquid sp. Heat	2.3 kJ/(kg K)
Thermal Stability	2000 cycles (approx.)

2) Encapsulation of PCM

Although $CaCl_2.6H_2O$ is a good Phase change material in terms of cost, temperature and safety, it is known to be very corrosive because it is a chloride-based salt. Hence encapsulation of PCM is necessary before applying. For encapsulation, used milk pouches made of LDPE are used. LDPE provides excellent puncture resistance, superior seal strength and is also amenable to low temperature storage. This way also helps in the waste management of the plastic bags. Empty milk pouches are first cleaned thoroughly and dried. Then the pouches are cut open from one side. Heat sealer is used to seal the pouch from the middle in the vertical direction to form two partitions within the pouch. 10 mL of PCM is then poured in both the partitions. Again, the pouch is sealed from the middle but in a horizontal direction which creates 4 partitions in the pouch. Same volume of PCM is poured in the above partitions and finally sealed from top. A curtain containing 4 PCM filled pouches is made by attaching an empty pouch between two PCM filled pouches. Four such curtains are placed on the south wall with some spacing between them. The figure 3 shows the encapsulation of PCM in a milk pouch.

3) Experimental Setup for PCM

The wall where PCM is mounted has a considerable effect on the room's cooling load. When compared to other walls of the construction, PCM, when applied on the south and west walls has a larger cooling load reduction.[4]. PCM cooling will be done by cross ventilation and windows for cross ventilation are made on east and west walls. Hence, the curtains made as mentioned in the previous subchapter are applied to the south wall of the constructed prototype room. Four such curtains are placed on the south wall with some spacing between them.

Fig. 3 PCM filled Milk Pouches

Fig. 4 Actual Experimental Setup for PCM

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D. Green Roof

1) Layers of Green Roof

TABLE II
FUNCTIONS OF DIFFERENT LAYERS OF GREEN ROOF

Layer	Function
Greenery	Plants and vegetation
Soil	Growing medium for the plants
Filtration Sheet	It filters the tiniest soil particles while allowing water to pass through.
Drainage layer	The drainage layer's purpose is to recreate natural conditions for growth of vegetation. It collects water through small tanks on the upper side, but it also allows surplus water to flow through tiny holes.
Retention sheet	Particles that have dropped down from the top layers are collected in this layer.
Anti-Root barrier	Prevents growing of roots that may damage the structure.
Waterproofing layer	Prevents water from damaging the roof, leakage.

2) The Actual Roof

Based on the size of the room and the working conditions, some of the layers explained in the previous sub chapter are incorporated in the prototype room. For construction of the Actual Green Roof, a square wooden frame is made using wooden planks in order to hold all the layers i.e., soil, stones, etc. in place. The layers are added one over the other in the order mentioned in figure 5.

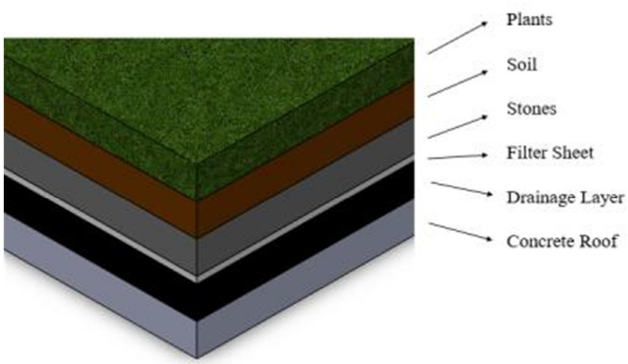

Fig. 5 Actual Layers Used in the green roof

Fig. 6 Actual Green Roof

E. Shading

For the testing of the shading technique, we have two windows of dimensions - length 24 inch and a height of 18inches. Both of them will have an overhang of length 25 inch and breath of 12 inch. The dimension of the overhang is considered by considering the solar azimuth and solar altitude angles for Mumbai of the month of highest temperature i.e., May and lowest temperature i.e., December.

F. Cross Ventilation

For the testing and implementation of Cross Ventilation in our prototype, we have kept two windows of dimensions – length 24 inches and height of 18 inches exactly opposite to each other. Summer winds blow from the south-west to the north-east, whereas winter winds blow to south west from the north east. The windows in our prototype are on the east and west facing in opposite directions. Thus, proper cross ventilation can be adopted in our prototype and necessary drop in temperature can be achieved.

Fig. 7 Prototype room with all passive cooling techniques

III. EXPERIMENTATION

A. Instrumentation

1) Sensors and Temperature Indicator

- Thermocouple wire bundle of 30 meters is brought and the wires are cut according to length from each wall.
- Thermocouple wires used are of K-type (Chromel-Alumel) along with temperature indicator.
- The 2 ends of the wire are attached to the wall and across the terminals of the temperature indicator respectively.
- Temperature indicator – ES POINT Model TXI-01 Digital temperature indicator.

2) Calibration

The Thermocouple wires are calibrated using two-point method by comparing the output of the thermocouple wires with that of a calibrated thermometer in two cases –

- ✓ Temperature of Ic
- ✓ Temperature of Boiling Water.

B. Temperature Measurement

Temperature was measured at 12 points:

1) Inside and outside of all the 4 walls (8).
2) Above and below the roof (2).
3) Centre of the room (1).
4) Ambient temperature (1).

C. Experimentation Procedure

The steps followed for measurement and recording of temperature are mentioned below-

5) The Prototype room is built on a trolley and kept inside a shed. So, it is first pulled out of the shed to the selected location where the room is exposed to sun properly without any shade falling on it for accurate results.
6) Extension boards are set up for providing power supply to the temperature indicator.
7) Thermocouple wires are already connected to the temperature indicator. The temperature indicator is placed at a suitable position such that length of wires is perfect to reach the designated wall.
8) The ends of thermocouple wires are fixed to the walls and the temperature indicator is switched on.
9) The knob of temperature indicator is switched to position 1 and the temperature at other end of thermocouple wire connected to port 1 is displayed on the indicator.
10) After the fluctuation in temperature stops and constant temperature is displayed, that temperature is recorded for the respective wall or location in the observation table.
11) The knob of temperature indicator is then turned to position 2 and same steps are followed.
12) The above procedure is followed for 6 readings from 12:00 PM to 05:00 PM with an interval of 1 hour after every reading.

The above procedure is followed for recording temperatures in 3 cases:

- ✓ Prototype room without any passive cooling technique
- ✓ Prototype room with Cross Ventilation.
- ✓ Prototype room with all the passive cooling techniques i.e., hybrid model.

IV. RESULTS AND DISCUSSION

A. Room Centre vs ambient temperature

The following tables shows the Temperature of room centre and the ambient temperature in all the three cases-

1) Prototype Room Without Windows

TABLE III
ROOM CENTRE AND AMBIENT TEMPERATURES
(PROTOTYPE ROOM WITHOUT WINDOWS)

Centre	T11	38	38	37	37	37	34
Ambient	T12	41	40	39	39	38	34

2) Prototype Room with Windows

TABLE IV
ROOM CENTRE AND AMBIENT TEMPERATURES
(PROTOTYPE ROOM WITH WINDOWS)

Centre	T11	34	34	36	32	32	32
Ambient	T12	34	36	36	34	32	34

3) Prototype Room with All Passive Cooling Techniques

TABLE V
ROOM CENTRE AND AMBIENT TEMPERATURES
(PROTOTYPE ROOM WITH ALL PASSIVE COOLING TECHNIQUES)

Centre	T11	29	29	33	33	33	32
Ambient	T12	33	33	34	34	34	33

The following figure shows a graph comparing the Temperature of room centre and the ambient temperature in all the above cases-

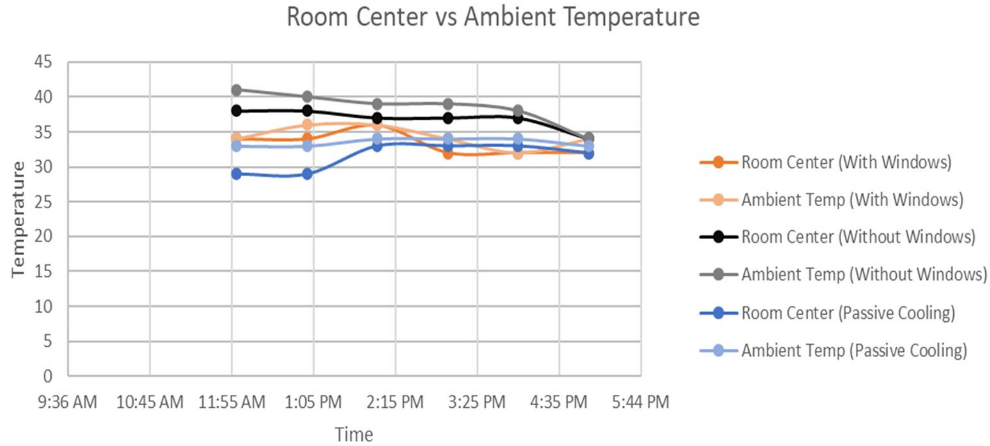

Fig. 8 Room Centre vs Ambient Temperature

B. Outside Surface vs Inside surface of the wall (South Wall)

The following table shows the Temperature on the outside surface and inside surface of the south wall in Case 1(Room without Windows) and Case 3 (Room with all Passive Cooling Techniques)-

1) Prototype Room Without Windows

TABLE VI
OUTSIDE AND INSIDE TEMPERATURES OF SOUTH WALL
(PROTOTYPE ROOM WITHOUT WINDOWS)

South Outside	T2	41	42	40	40	40	38
South Inside	T6	35	37	38	39	38	36

2) Prototype Room with All Passive Cooling Techniques

TABLE VII
OUTSIDE AND INSIDE TEMPERATURES OF SOUTH WALL
(PROTOTYPE ROOM WITH ALL PASSIVE COOLING TECHNIQUES)

South Outside	T2	34	34	39	38	37	35
South Inside	T6	30	30	33	33	33	33

The following figure shows a graph comparing the Temperature on the inside surface and outside surface of the south wall in the Case 1 (Room without Windows) and Case 3 (Room with all Passive Cooling Techniques)-

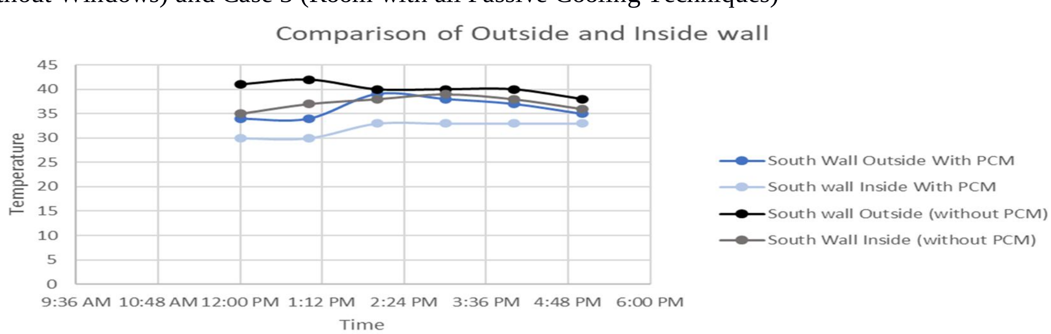

Fig. 9 Graph of Inside vs Outside surface temperature of south wall

V. CONCLUSION

A. Different types of Passive cooling techniques are Researched and studied and Phase Change Material is selected as the Primary passive cooling technique.
B. Along with Phase Change Material, Green Roof, Shading and Cross Ventilation are selected as Secondary Passive Cooling Techniques.
C. Variable properties of PCM are studied and an effective PCM is selected which would be ideal for providing cooling comfort.
D. A prototype of a small room with PCM and the supporting passive techniques is designed and built and the difference before and after applying passive cooling is noted.
E. From the observations in table III, IV and V and graph in figure 8, it can be observed that in case of temperature measurement with Passive Cooling, a temperature drop of up to 3^oC is observed as compared to that without any Passive Cooling Method.
F. As a result, the Hybrid system of multiple Passive Cooling Techniques is successful in lowering the prototype room's interior temperature.
G. From the observations in table VI and VII and graph in figure 9, it can be observed that there is a difference in temperature of 4-5^oC between the inside surface and outside surface of the South Wall (The wall on which PCM is applied).
H. Thus, the Primary Passive Cooling Technique i.e., Phase Change Material is successful in lowering the interior wall temperature of the prototype room.

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