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PASSIVE SOLAR HEATING OR COOLING FOR RESIDENTIAL BUILDING USING PCM

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ABSTRACT

Man has tried to improve comfort within buildings by improving the thermal inertia and minimize the equivalent thermal conductivity of the envelope of building from time immemorial. Attempt has been made by engineers by increasing the thickness, changing the geometry of the outer wall and also tried several building materials to reduce temperature fluctuations for indoor environment in both summer and winter. The installation of heating and air conditioning to seek comfort in homes, offices and public places has created high energy consumption and consequently, increased the environmental pollution. The use of passive solar architectural techniques can reduce not only the temperature fluctuations but also can solve the environmental pollution. The use of phase change materials (PCM) in the building along with passive solar techniques is one of the solutions. The integration of a PCM layer into an external building wall diminished the amplitude of the instantaneous heat flux through the wall. In this paper a three-dimensional transient heat transfer model has been developed and solved numerically using the commercial Thermal analysis package ANSYS.

Key words: PCM, Passive architecture, Energy savings, Green buildings, Thermal barrier.

INTRODUCTION

There has been a constant rise in the intensity of energy use reflected in annual per-capita energy consumption mainly in the form of electricity. It is estimated that the residential and service sector, most of which are buildings contribute to more than 40% of energy consumption. Part of the major energy consumption in buildings is the heating, ventilating and air-conditioning (HVAC) system. In order to lessen the burden on the active systems transforming renewable energy into the thermal or electrical energy, a necessary first step is to apply the optimal combination of passive design strategies, foremost among

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them passive solar design strategies. Passive solar design strategies aim to use the solar energy to help to establish the thermal comfort in buildings, without the use of electrical or mechanical equipment. The key to designing a passive solar building is to best take advantage of the local climate. Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading. In general, heat storage is a very interesting technique to decrease energy use in the buildings and to reduce the cost of operation of buildings. Some of the advantages of heat storage in the buildings are as follows:

(a) Reduction of peak power for heating and cooling.

(b) Possibility to shift peak heating and cooling loads to the low tariff hours.

(c) Shifting temperature peaks to non-working hours.

(d) Improvement of indoor environment and

(e) Efficient utilization of passive heating and cooling loads.

The PCM used in builds are either micro-encapsulated or macro-encapsulated to prevent leakage of PCM during melting and also to prevent chemical degradation of PCM by interaction with other building elements.

PCM used in building elements

The PCM used in builds are either micro-encapsulated or macro-encapsulated to prevent leakage of PCM during melting and also to prevent chemical degradation of PCM by interaction with other building elements. The PCM used in LHTES systems based on applications are:

(a) PCM enhanced wallboards

(b) PCM bricksPCM enhanced concrete systems and mortars

(c) PCM Trombe wall

(d) PCM shutters, window blinds and

(e) Translucent PCM walls

PCM enhanced wallboards

Wallboards are very suitable for the incorporation of PCMs. They are cheap and widely used in building applications, especially in lightweight construction. Many studies been carried out to assess the performance of PCM enhanced wallboards.

The efficiency of these elements depends on several factors such as:

(i) How the PCM is incorporated in the wallboard

(ii) The orientation of the wall

(iii) Climatic conditions

(iv) Direct solar gains

(v) Internal gains

(vi) Colour of the surface

(vii) Ventilation rate

(viii) The PCM chosen and its phase-change temperature

(ix) The temperature range over which phase-change occurs

(x) The latent heat capacity per unit area of the wall.

The thermal storage capacity of different construction materials with similar use and position in buildings than PCMs boards were evaluated and compared and it was found that 1.5 cm thick board of gypsum with PCMs stores 5 times the thermal energy of a laminated gypsum board, and the same energy as a 12 cm thick brick wall in a given temperature range (20-30°C).

PCM Bricks

The objective of the PCM brick system is to reduce the heat flow from outdoor space by absorbing the heat gain in the brick before it reaches the indoor space during the daytime. At night, the stored heat is released to indoor and outdoor spaces. The effects of different design parameters such as the PCM's quantity, type, and location in the brick for the best configuration vary from location to location. It is seen that the incorporation of PCM contributes for the attenuation of the indoor space temperature swing, reducing from 5 to 10°C the thermal amplitude, as well as increasing the time delay of about 3 hrs.

PCM Enhanced concrete systems and mortars

PCM enhanced concrete system uses microencapsulated PCM in concrete (with a melting point of 26°C) to enhance its thermal performance. It is found that the concrete reached a compressive strength over 25 MPa and a tensile splitting strength over 6 MPa, and no difference occurred in the effects of the PCM concrete after 6 months of operation. The experimental results also showed that the energy storage in the concrete enhanced walls leads to an improved thermal inertia as well as lower inner temperatures, in comparison with conventional concrete.

PCM Trombe wall

The classical Trombe wall is a massive wall that covered by an exterior glazing with an air channel in between. The massive wall absorbs and stores the solar energy through the glazing. The introduction of PCMs in Trombe wall systems could contribute to the development of light, portable, movable and rotating systems fully adapted to the lightweight buildings category. In this new approach the huge sensible thermal mass of a traditional mass Trombe wall, and the big amount of material could be substituted by the latent heat loads from the PCMs phase-change processes, and less quantity of material will be necessary.

PCM Shutters, window blinds and translucent PCM walls

Exterior PCM shutters containing PCMs are movable structural shading elements associated to windows facades. The PCM shutters system must operate cyclically, reflecting the ongoing daily cycles of 24 hrs. Similarly, the cyclically operation of the system should enable the fusion of the PCM mass during the day and its solidification during the night, enabling the daily cyclic storage and release of thermal energy. The PCM-shutter system is to be opened during the day to maximize the solar direct gains indoors through the glass window and, simultaneously, to allow it's charging. During the night, the system must be closed to minimize the heat losses through the window and to allow its discharging by releasing the thermal energy indoors.

Thermal load on the building

Solar flux on the building

Assuming a constant solar radiation of 800 Wm^{-2} on the building for a duration of 6 hours. Since the building is going to be painted white a reflectivity ρ = 80%. The wall of the building is a composite slab consisting of two layers of bricks and three layers of cement sand aggregate.

$I = 800\ Wm^{-2}$

$\rho = 0.8$

Hence solar flux on the building,

$$S = I \times (1 - \rho)$$

$$= 800 \times (1 - 0.8)$$

$$S = 160\ Wm^{-2}$$

Table 2.1: Values of surface heat transfer coefficient

S. No.	Wind speed	Position of surface	Direction of heat flow	Surface heat transfer coefficient (W/m^{2}K)
1	Still air	Horizontal	Up	9.3
		Sloping 45°	Up	9.1
		Vertical	Horizontal	8.3
		Sloping 45°	Down	7.5
		Horizontal	Down	6.1
2	Moving air 12 (km/h)	Any position	Any direction	22.7
	Moving air 24 (km/h)	Any position	Any direction	34.1

Critical PCM mass

The resistance of the wall cement network is given by –

$$R_{wall} = \frac{1}{h_o} + \sum_{j=0}^{n} \frac{L_j}{k_j} + \frac{1}{h_i}$$

$$= \frac{1}{8.3} + \frac{0.2}{.7} + \frac{0.03}{.3024} + \frac{1}{22.7}$$

$$= 0.4348 \text{ m}^2\text{K/W}$$

The overall heat transfer coefficient of an individual wall is given by –

$$U_{wall} = \frac{1}{R_T}$$

$$= \frac{1}{0.4348}$$

$$U_{wall} = 2.325 \text{ W/m}^2\text{K}$$

The resistance of the roof network is given by –

$$R_{roof} = \frac{1}{h_o} + \sum_{j=0}^{n} \frac{L_j}{k_j} + \frac{1}{h_i}$$

$$= \frac{1}{6.1} + \frac{0.25}{.3024} + \frac{1}{22.7}$$

$= 0.3127\ m^2K/W$

The overall heat transfer coefficient of an individual wall is given by –

$$U_{roof} = \frac{1}{R_T}$$

$$= \frac{1}{0.3127}$$

$U_{roof} = 3.198\ W/m^2K$

Similarly the heat transfer coefficient of glazing and doors are taken as standards.

$U_{glazing} = 5.77\ W/m^2K$\

$U_{door} = 3.18\ W/m^2K$

The sol-air temperature is given by –

$$T_{sol} = T_o + \frac{\alpha S}{h_o} - \frac{\varepsilon \Delta R}{h_o}$$

$= 36.5^oC$

$\Delta T = T_{sol} - T_i$

$= 7.5^oC$

The heat transfer due to conduction and convection is given by –

$$Q_c = \sum_{i=0}^{n} U_i A_i \Delta T$$

$= (2.325 \times 9 \times 4 \times 7.5) + 3.2 \times 9 \times 7.5) + (5.77 \times 2 \times 1.5 \times 7.5) + (3.18 \times 3 \times 7.5)$

$= 940.5\ W$

Solar heat gain due to transparent element is given by –

$Q_s = \alpha_s \times A_g \times S \times \tau_s$

$= 0.2 \times 3 \times 160 \times 0.9$

$= 86.4\ W$

Assuming Heat gain by ventilation and internal heat generation as negligible the total heat transfer is given by –

$$Q_T = Q_c + Qs$$
$$= 940.5 + 86.4$$
$$= 1026.9 \text{ W} = 20332620 \text{ J}$$

For temperature swing to be minimum let temperature rise of building elements should be less than 2°C.

$$Q_T = Q_{brick} + Q_{cement} + Q_{PCM}$$
$$= ((\rho_{brick} \times A \times t \times c_{p\,brick}\,\Delta T) + (\rho_{cement} \times A \times t \times c_{p\,cement}\,\Delta T) + (L \times m_{PCM})$$
$$20332620 = (2320 \times .475 \times .2 \times 4 \times 960 \times 2) + (1800 \times .525 \times 0.03 \times 1080 \times 2) + (190 \times 10^3 \times m_{PCM})$$
$$m_{PCM} = 97.78 \text{ kg} \approx 100 \text{ Kg}$$

Modelling and thermal analysis

Modelling

The ordinary wall consists of a layer of cement-sand aggregate and bricks. The ordinary brick does not have air cavity and is made only of homogenous fire baked clay. The wall is made of repeating units and hence the model has been limited to four bricks and interstitial occupied by cement layer.

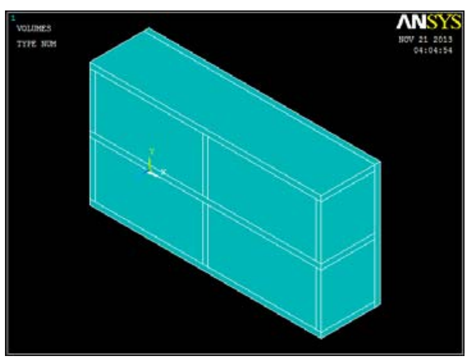

Fig. 3.1: Modelled wall with ordinary bricks

The wall filled with PCM also consists of cement-sand aggregate layer in its interstitials, but the air gaps are replaced with PCM.

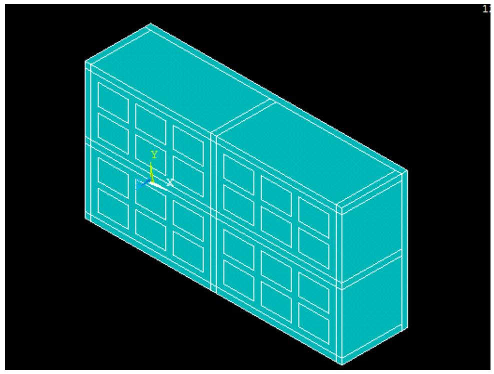

Fig. 3.2: Modeled wall filled with PCM

Thermal analysis

The element chosen is 10-Node Tetrahedral (SOLID 87) as it is capable of handling non-linear transient thermal analysis. A transient thermal analysis is carried out keeping initial conditions with temperature as 25°C. The time interval of analysis has been taken as 5 hrs (18000 s). The various assumptions taken are:

(a) Convective heat transfer is not considered.

(b) Uniform solar radiation is considered.

(c) Surface heat transfer other than solar flux is not considered.

The temperature plot is obtained. It shows that the final temperature internally is about 37°C. The temperature is high because the brick has larger surface area to conduct the heat into the building.

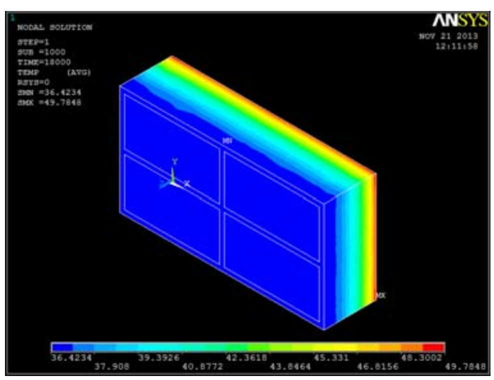

Fig. 3: Thermal analysis of brick

However the final temperature attained in the internal surface is 28°C for the PCM filled wall. This is because the penetrating heat is absorbed by the PCM.

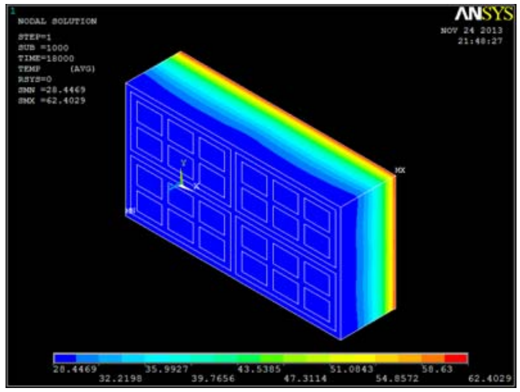

Fig. 3: Thermal analysis with PCM

CONCLUSION

This paper concentrates on the thermal analysis of walls with and without PCM. The ANSYS analysis of the two wall configurations has been carried out. The simulation results showed that the PCM introduced in rectangular holes can improve considerably the thermal inertia of the building, which is very important for improving the heat penetration into the indoor space. Further it is concluded from the numerical analysis that the incorporation of PCM in building elements will reduce the temperature swings. The future work of this paper is to compare the transient thermal analysis with the results from the experimental construction of the cabins in Vellore or similar locations where diurnal variations are high.

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