International Journal of Advanced Research in
Civil,Structural,Environmental and Infrastructure Engineering and Developing
Volume: 2 Issue: 2 01-Jun-2014,ISSN_NO: 2320-723X

Passive Solar Heating or Cooling for Residential Building Using PCM

R. Velraj[1] , G. Daniel[2]

Professor, Dept. of Mechanical Engineering, Anna University, India [1].
Student, Dept.of Mechanical Engineering, Anna University, India [2]
velrajr@annauniv.edu,danielgnanaselvam@gmail.com

.

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.*

Keywords— PCM, passive architecture, energy savings, green buildings, thermal barrier.

1, 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 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.

2, THERMAL LOAD ON THE BUILDING

2.1 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 $\rho = 80\%$. 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,

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

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

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

S.No	Wind Speed	Position of Surface	Direction of heat flow	Surface Heat Transfer Coefficient (W/m^2K)
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

Table 2.1 Values of surface heat transfer coefficient

2.2 Critical PCM mass

The resistance of the wall cement network is given by,

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

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

$$= 0.4348\ m^2K/W$$

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

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

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

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

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,

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

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

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

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

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

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

The sol-air temperature is given by,

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

$$= 36.5°\mathrm{C}$$

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

$$= 7.5\ °\mathrm{C}$$

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,

$$Q_T = Q_c + Q_s$$

$$= 940.5 + 86.4$$

$$= 1026.9\ W = 20332620\ J$$

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

$$Q_T = Q_{brick} + Q_{cement} + Q_{PCM}$$

$$= \left(\rho_{brick} \times A \times t \times c_{p\ brick}\ \Delta T\right) + \left(\rho_{cement} \times A \times t \times c_{p\ cement}\ \Delta T\right) + (L \times m_{PCM})$$

$$20332620 = (2320 \times .475 \times .2 \times 4 \times 960 \times 2) + (1800 \times .525 \times 0.03 \times 1080 \times 2) + (190 \times 10^3 \times m_{PCM})$$

$$m_{PCM} = 97.78\ kg \approx 100kg$$

3, MODELLING AND THERMAL ANALYSIS

3.1 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.

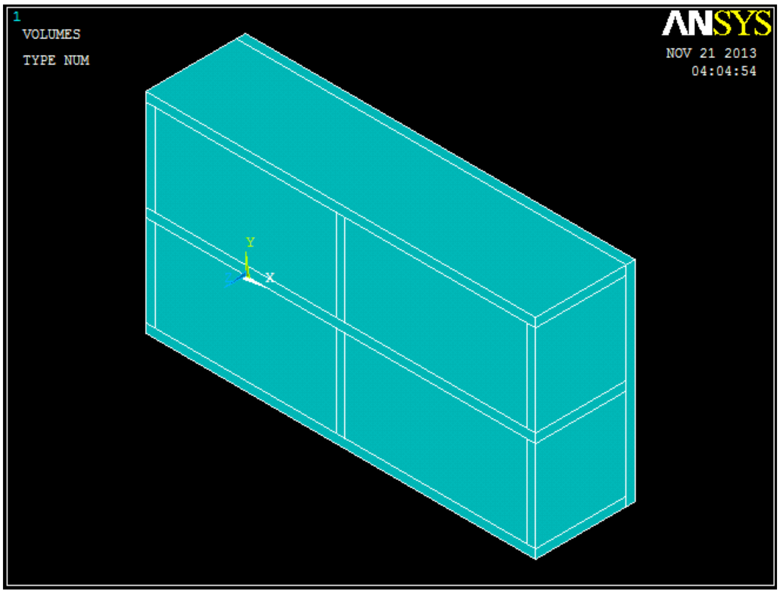


Fig 3.1Modelled wall with ordinary bricks

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

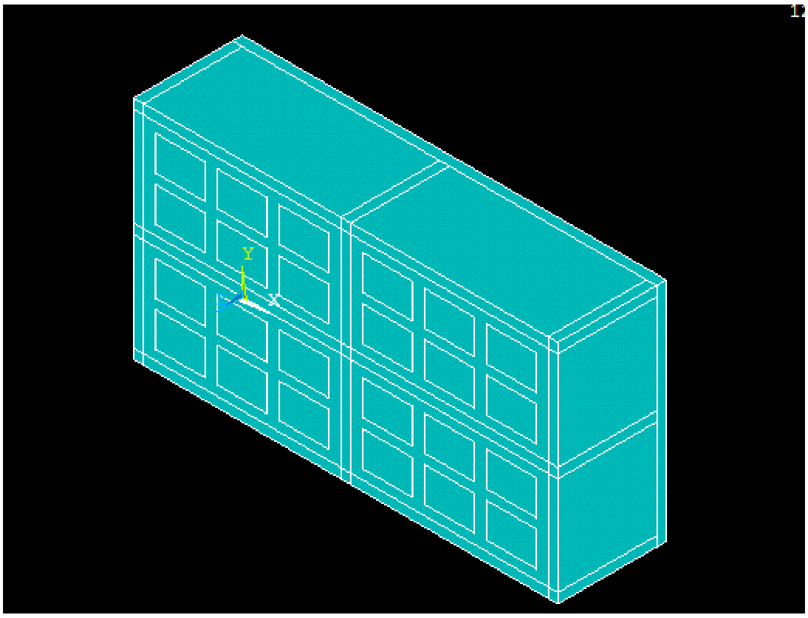


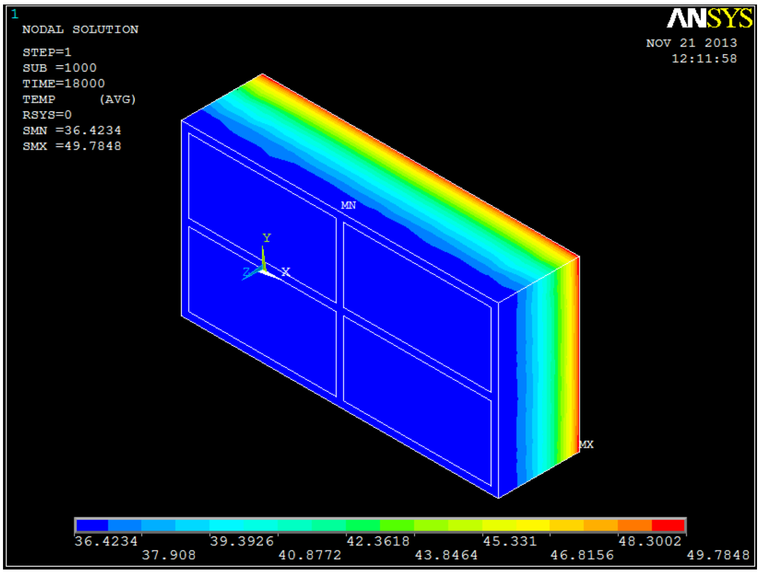
Fig 3.2 Modelled wall filled with PCM

3.2 Thermal Analysis

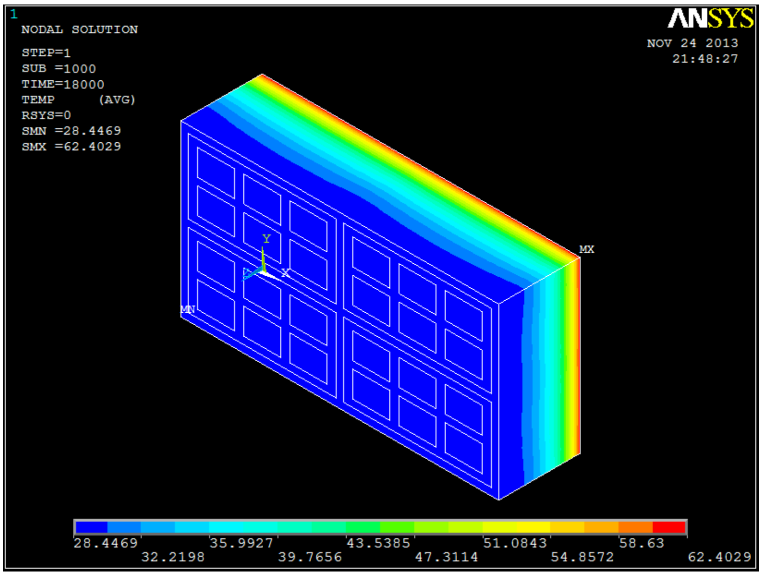
The element chosen is 10-Node Tetrahedral (SOLID 87) as it is capable of handling non-linear transient thermal analysis. A transient thermal analysis is carried out keeping initial conditions with temperature as 25°C. The time interval of analysis has been taken as 5 hours (18000 s). The various assumptions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



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.



VIII. CONCULSION AND FUTUREWORK

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.

References

[1] Bansal N. K., Thomas P. C., “A Simple Procedure for Selection and Sizing of Indirect Passive Solar Heating Systems” Building and Environment Vol. 26, pg. 381-387, 1991.

[2] Garcia-Hansen V., Esteves A., Pattini A., “Passive solar systems for heating, day lighting and ventilation for rooms without an equator facing façade” Renewable Energy Vol. 26, pg. 91-111, 2002.

[3] Bakos G.C., “Improved energy management method for auxiliary electrical energy saving in a passive-solar-heated residence” Energy and Buildings Vol. 34, pg. 699-703, 2002.

[4] Alfredo Ferna´ndez-Gonza´lez, “Analysis of the thermal performance and comfort conditions produced by five different passive solar heating strategies in the United States Midwest” Solar Energy Vol.81, pg. 581-593, 2007.

[5] Chen B., Zhuang Z., Chen X., Jia X., “Field survey on indoor thermal environment of rural residences with coupled Chinese kang and passive solar collecting wall heating in Northeast China” Solar Energy Vol. 81, pg. 781-790, 2007.

[6] Luis Juanico´, “A new design of roof-integrated water solar collector for domestic heating and cooling” Solar Energy Vol. 82, pg. 481-492, 2008.

[7] Rahul Ralegaonkar V., Rajiv Gupta, “Review of intelligent building construction: A passive solar architecture approach” Renewable and Sustainable Energy Reviews Vol. 14, pg. 2238-2242, 2010.

[8] Hoy-Yen Chan, Saffa Riffat B., Jie Zhu, “Review of passive solar heating and cooling technologies” Renewable and Sustainable Energy Reviews Vol. 14, pg. 781-789, 2010.

[9] Suresh Sadineni B., Srikanth Madala, Robert Boehm F., “Passive building energy savings: A review of building envelope components” Renewable and Sustainable Energy Reviews Vol. 15, pg. 3617–3631, 2011.

[10] Krzaczeka M., Kowalczuk Z., “Thermal Barrier as a technique of indirect heating and cooling for residential buildings” Energy and Buildings Vol. 43, pg. 823-837, 2011.

[11] Jacques Michel, Bruno Peuportier, “Comparative analysis of active and passive solar heating systems with transparent insulation” Solar Energy Vol. 54, pg. 13-l8, 1995.

[12] Andreas Athienitis K., “Investigation of thermal performance of a passive solar building with floor radiant heating” Solar Energy Vol. 61, pg. 337-345, 1997.

[13] Xiande Fang, Yuanzhe Li, “Numerical simulation and sensitivity analysis of lattice passive solar heating walls” Solar Energy Vol. 69, pg. 55-66, 2000.

[14] Chandel S.S., Aggarwal R.K., "Performance evaluation of a passive solar building in Western Himalayas" Renewable Energy Vol. 33, pg. 2166-2173, 2008.

[15] Morrissey J., Moore T., Horne R.E., "Affordable passive solar design in a temperate climate: An experiment in residential building orientation" Renewable Energy Vol. 36 pg. 568-577, 2011.

[16] Hassanain A.A., Hokam E.M., Mallick T.K., "Effect of solar storage wall on the passive solar heating constructions" Energy and Buildings Vol. 43 pg. 737-747, 2011.

[17] Olenets M., Piotrowski J.Z., Story A., "Mathematical Modelling of the steady state heat transfer processes in the convectional elements of passive solar heating systems" Archives of Civil and Mechanical Engineering Vol.13, pg. 394-400, 2013.

[18] Enibe S.O., "Performance of a natural circulation solar air heating system with phase change material energy storage" Renewable Energy Vol.27, pg. 69-86, 2002.

[19] Wei Chen, Wei Liu, "Numerical and experimental analysis of convection heat transfer in passive solar heating room with greenhouse and heat storage" Solar Energy Vol. 76, pg. 623-633, 2004.

[20] Murat Kenisarin, Khamid Mahkamov, "Solar energy storage using phase change materials" Renewable and Sustainable Energy Reviews Vol. 11, pg. 1913-1965, 2007.

[21] Yinping Zhang, Guobing Zhou, Xin Wang, Kunping Lin, Wei Xiao, "An assessment of mixed type PCM-gypsum and shape-stabilized PCM plates in a building for passive solar heating" Solar Energy Vol. 81, pg. 1351-1360, 2007.

[22] Yinping Zhang, Guobing Zhou, Qunli Zhang, Kunping Lin, Hongfa Di, "Performance of a hybrid heating system with thermal storage using shape-stabilized phase-change material plates" Applied Energy Vol. 84, pg. 1068–1077, 2007.

[23] Patrice Pinel, Cynthia Cruickshank A., Ian Beausoleil-Morrison, Adam Wills, "A review of available methods for seasonal storage of solar thermal energy in residential applications" Renewable and Sustainable Energy Reviews Vol. 15, pg. 3341-3359, 2011

[24] Soares N., Costa J.J., Gasparb A.R., Santos P., "Review of passive PCM latent heat thermal energy storage systems towards building's energy efficiency" Energy and Buildings Vol. 59 pg. 82–103, 2013.