Thermal analysis of habitat using phase change materials for insulation

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Abstract: This study presents a two-dimensional model with a real size home composed of two levels (ground and first rooms) separated by concrete slab. The building wall with rectangular section containing phase change material PCM in order to minimize energy consumption in the buildings. The main objective of the Wall-PCM system is reducing the heat flow from outdoor space before it reaches the indoor space during the daytime. This goal is achieved by absorbing the heat gain.The numerical approach uses effective heat capacity C_{eff} model with realistic outdoor climatic conditions of Tlemcencity, Algeria. The numerical results show a significant temperature reduction inside the studied solar test room, about 3°C depending on the PCM thickness.

Keywords: Energy storage, PCM, building, solar, dynamic behavior, numerical.

1. INTRODUCTION

One of the most effective means to reduce the energy consumption of the building is to optimize its envelope. Technological solutions have been introduced [1] such as the use of phase change materials (PMC) in active and passive solar buildings which has been subject to considerable interest. The appeal of PCMs is that they can smooth daily fluctuations in room temperature by lowering the peak temperatures resulting from extreme external daily temperature changes. The PCMs can store heat energy in a latent, as well as sensible fashion, leading to greater heat storage capacity per unit volume than that of conventional materials. As the building trends towards overheating, the phase change material melts and absorbs the excess heat due to its phase change from solid to liquid. This heat is only released when the room temperature drops below the specified level and the liquid wax returns to a solid state there by stabilizing the room temperature [2].

A numerical investigation of heat storage device with fins to absorb the solar radiation is developed by Stritih [3]. Athienitis et al. [4] investigated gypsum board impregnated with PCM for thermal storage in a passive solar test room. They found that the utilization of the PCM gypsum board may reduce the maximum room temperature up to 4°C during the daytime. In recent years, a kind of novel compound PCM, the shape stabilized PCM (SSPCM), has been attracting the interests of there searchers [5-7]. De Grassi [8] used statistical approach to evaluate the thermal behavior of the PCM containing walls. Firstly, it demonstrates the existence of statistically significant linear dependencies among the variables used, and, secondly, highlights the improvements in comfort conditions due to the insertion of PCM inside dry assembled walls. Qarnia [9] presented a theoretical model based on the energy equations to predict the thermal behavior and performance of a solar latent heat storage unit consisting of identical tubes embedded in the PCM. A series of numerical simulations were conducted for three kinds of PCM (n-octadecane, paraffin wax and stearic acid) to find the optimum design and also made to study the effect of flow rate on its out-let temperature during the discharging mode

In this work, thermal analysis of a two-dimensional model for building wall with rectangular section containing phase change material PCM is presented. The main objective of the Wall-PCM system is reducing the heat flow from outdoor space before it reaches the indoor space during the daytime. This goal is achieved by absorbing the heat gain.

2. Method of the effective capacity

The equation of energy is given by :

$$\rho C_{eff}\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda\left(\frac{\partial T^2}{\partial x^2}+\frac{\partial T^2}{\partial y^2}\right) \quad (1)$$

C_{eff} : effective heat capacity.
ρ : density
λ : thermal conductivity
u and v : velocity components according to OX and OY .

Initial conditions in fluid domain are: u=v=0, and T_0=15°C.

By making the specific heat of PCM function of temperature, thermal effect of melting and solidification of PCM can be simulated. The geometry of the grid is independent of time, and the liquid/solid interface is tracked by the definition of the specific heat in the governing equations. The specific heat is the rate of change of enthalpy with respect to temperature. In our case, the law of the behavior of MCP used here is that proposed by Kuznik et al. [10]. It is based on the normal curve of the specific heat adapted by experimental measurements (cf. fig. 1 and equation (2)).

$$C_{eff}=\begin{cases}4250+10750\exp\left(-\dfrac{22.6-T}{4}\right)^2 & \text{if } T<22°C\\ \dfrac{C_{pl}+C_{ps}}{2}+\dfrac{L_s}{2.\Delta T} & \text{if } 22°C\leq T\leq 23°C\\ 4250+10750\exp\left(-\dfrac{22.6-T}{3}\right)^2 & \text{if } T>23°C\end{cases} \quad (2)$$

With C_{pl} and C_{ps} are the thermal capacity of the liquid and the solid phases. L_s is the latent heat of phase change. ΔT is the change phase interval (1°C) and must have a minimum value to simulate the pure materials and secondly, it must be of significant value to reduce the nonlinearity caused by the effect of latent heat.

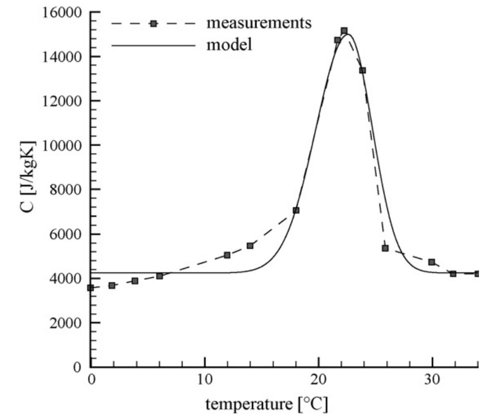

Fig 1. Variation of apparent (effective) heat capacity with temperature.

3. Position of problem

The studied solar test room is a habitat with ground and first rooms, separated by a concrete slab, and a concrete pitched roof of 8%, figure 2. The windows are supposed hermetic and the external walls are composed of concrete and brick. The geometrical properties of the test rooms are represented in table 1.A phase change material is provided between the two materials in the form of sandwich. The PCM used is the paraffin (n-octadecane). The thermal properties of different materials are presented in table 2.

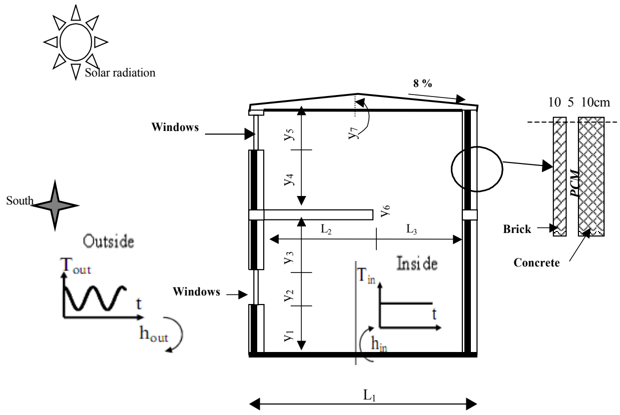

Fig 2. Presentation of the test rooms.

Table 1: Geometrical properties of the test rooms.

y_1	y_2	y_3	y_4	y_5	y_6	L_1	L_2	L_3
1.m	1.m	0.8m	1.m	1.m	0.15m	3.8m	2.1m	1.7m

Table 2 Thermal properties of materials

Materials	ρ (kg/m³)	λ (W/m.K)	Cp (j/kg.K)
paraffin n-Octadecane	765 solid 780 liquid	variable	variable
concrete	2100	1.4	1
Brick	1920	0.72	835
glazing	2500	1.4	720

***Boundary conditions*:**

All walls of the studied rooms are submitted to convective heat transfer with ambient, except the bottom wall. The radiation heat flux is added at the south wall and the pitched roof:

$$Q = h(T - T_a) + \varphi(t) \quad (3)$$

Where $\varphi(t)$ is the solar radiation heat flux according to the typical day of Tlemcen, figure 3-b, and h is the convection heat transfer coefficient due to wind, recommended by McAdams [11]:

$$h = 5.67 + 3.86 v_w \quad (4)$$

The Algerian typical day weather (12) of May in Tlemcen (Altitude 750m, Latitude 35 ° 28'N and Longitude 17° 1') is chosen as the outdoor climate data. The hourly variation of outdoor air temperature and solar radiation on the south wall is shown in Fig. 3. The average outdoor air temperature is 23 _C.

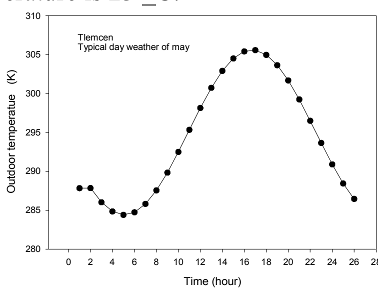

Fig. 3-a Hourly variation of outdoor air temperature .

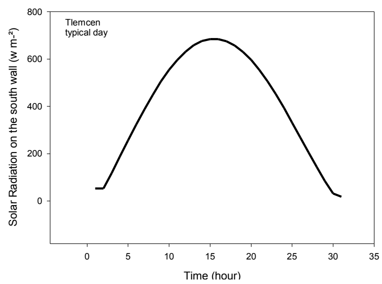

Fig. 3-b. Hourly variation of outdoor solar radiation.

There are two well-known methods for numerically solving the set of governing equations, the finite volume and the finite element approaches. The commercial CFD software package, FLUENT, which is based on the finite volume approach was used for solving the set of governing equations. Fluent provides the flexibility in choosing discretization schemes for each governing equation. The discretised equations, along with the initial and boundary conditions, were solved using the segregated solution method to obtain a numerical solution. Using the segregated solver, the conservation of mass and momentum were solved iteratively and the SIMPLE algorithm was used to ensure the momentum and mass conservation equations. The convergence criterion was set equal to $10^{-6}$for all parameters.

Figure 4 shows the distribution of isothermal contours for different time period. The outside temperature varies from 13°C to 33°C. The interior temperature is stabilized between 19°C and 23°C after 15h. The temperature difference between the lower and the higher level do not exceed 3°C. It can be seen that the maximal temperature reached is 23°C in the higher level after 24 h and 25°C after 48 h, respectively. In the lower level, the maximal temperature reached is 23°C in the higher level after 24 h and 24°C after 48 h, respectively. The PCM can reduce considerably the interior temperature.

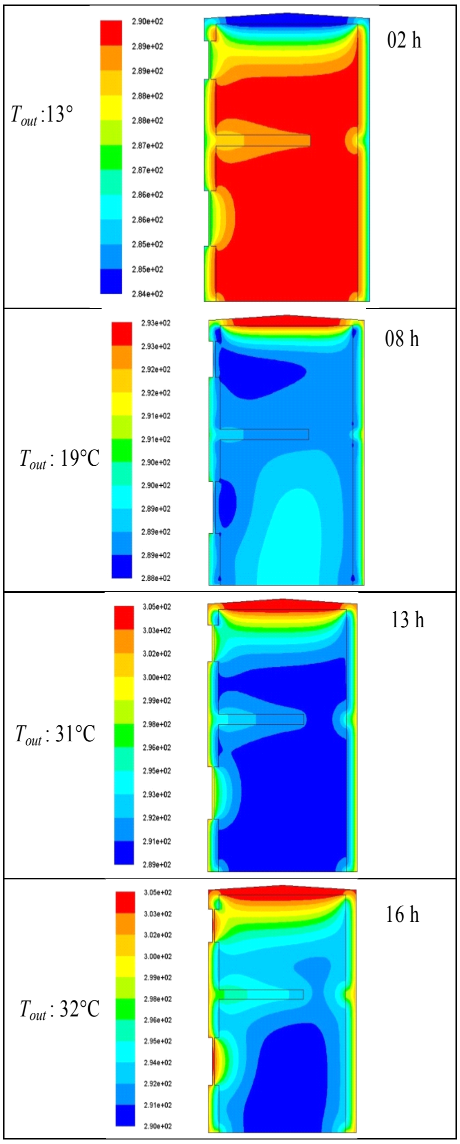

Fig. 4. Temperature contour at various hours.

The Figure 5 shows the temperature evolution at various hours. The MCP material incorporated in the walls of the room builds up heat and then return to the form of a hot or cold heat flux depending on the outside temperature. This can be illustrated by Figure 5 which compares the change in the outside temperature with the inside temperature.

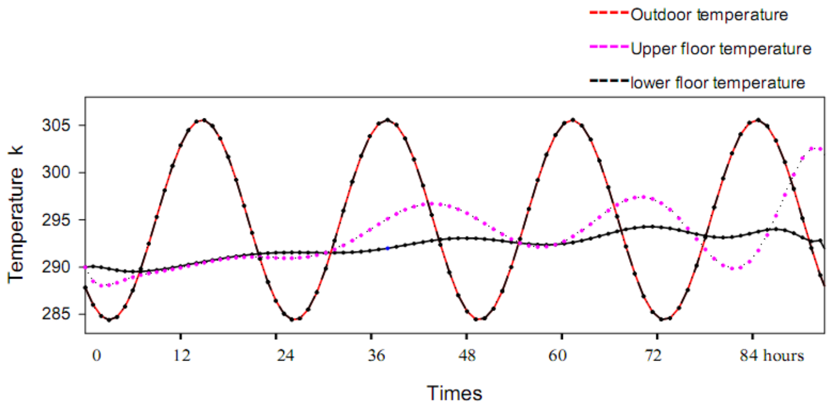

Fig. 5 Temperature evolution at various hours.

The incorporation of an PCM in the walls to smooth fluctuations in internal temperatures and reduces overhead daily up to 6.7°C. The temperature differences calculated on a time interval of four days between the upper and lower level are still less than 3°C.

4. Conclusion

Thermal performance of phase change material (PCM) integrated in wall, has been numerically evaluate in a passive solar building in Tlemcen (nord of Algeria) with an effective heat capacity C_{eff} model. The numerical results shown that by utilizing PCM in wall, the maximum of the inlet heat flux may reduce about 6,7°C of temperature depending on PCM thickness. The other factor that has influence on thermal efficiency of the integrated wall is PCM location. The investigation shows that in the present conditions, the optimal melting temperature is about 23 °C.

5. References

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