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Heat transfer Simulation of solar wall phase chang materials (PCM) for energy storage and optimization

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Abstract

phase change materials have a high capacity in thermal energy storage, these materials can be used to prevent the heat transfer into the building besides optimize and improve the performance of the refrigeration and air conditioning system. Adding phase change materials (PCM) to the building can improve the inside comfort temperature and save consumption energy of the building. In this article the parameters that affect the performance of PCM in the building walls, such as phase change temperature, latent heat, thickness, thermal conductivity, etc., have been investigated using ANSYS software. the numerical simulation of thermal energy storage in the solar walls of the building have investigated using phase change materials in different thicknesses with different heat flux rates. This wall is designed to capture the sun energy during the day, reducing energy consumption and optimizing it during peak times.

Keywords: Phase change materials (PCM), Numerical Thermal energy storage, Computational fluid dynamics (CFD), latent heat

1. Introduction

Energy is essential for human survival as well as economic and social development. Industrialization and urbanization are signs of progress, but basically lead to higher energy consumption [1,2].

According to research the building sector consumes a lot of energy, about 30% to 40% of energy consumption worldwide. There is an increase in CO2 emissions and pollution [3]. The use of renewable energy such as solar energy can be an effective solution to many energy and environmental problems. Also, the main concern for using solar energy is that, the peak energy requirement during the day and night, from evening to night, it is not related with the intensity of the sun radiation at this time, in other words, it can be said exactly when the sun has the lowest intensity It needs more energy [4].

The best solution of use a large energy source like the sun is to use systems that can store energy during the day to use it during the hours of the night when energy is needed. This demand leads to the design of thermal energy storage systems. The functional principles of these systems are based on latent heat of materials [5].

Thermodynamic properties as well as their availability should also be considered choosing phase change materials for melting and freezing temperatures [6]. The higher latent heat of melting of the phase change material, the smaller size of storage chamber, and the amount of heat transfer coefficient is directly related to the amount and time of using energy storage system. Obviously, higher density of phase change material, smaller dimensions of storage system can be [7]. With progress in the building industry, using phase change materials in the walls, ceilings and floors of buildings seems to be a suitable solution for storing thermal energy [8]. which can be considered thermal energy of the sun for heating building or even the loss of thermal energy of the building by using phase change materials to reduce the cooling loads in building. Phase change materials are materials of organic or inorganic compounds that have ability to absorb and store large amounts of thermal energy [9].

Thermal energy storage in these materials occurs during the phase change process. These materials absorb heat from environment or give it back to the environment during phase change [10]. phase change material has ability to sustain latent thermal energy without any change even after thousands of phase change cycles. If these materials are used in building, they are exchanged large amounts of heat with environment through successive cycles during extreme changes in air temperature (for example, between night and day) and in this way provide a more balanced air temperature for space inside the building [11]. By introducing phase change materials as an energy storage system, present research aims to achieve the following goals: 1. Numerical modeling of heat absorption and melting process in a phase change material with the help of numerical methods 2. Use of phase change materials In the cooling system of the building, with aim of reducing the energy consumption of cooling system and increasing the parameters of thermal comfort, such as temperature distribution uniformity.

2. Problem Description and Solution Method

Since these materials store energy in form of latent heat and at the constant temperature, it has received more attention. During the phase change, these materials store thermal energy and release it when will be need, and their proper use will lead to a significant reduction in energy consumption. In this research, one of the applications of phase change materials, i.e. the use of these materials for building cooling, is investigated.

In fact, phase change materials make it possible to store thermal or cooling energy. For example, at night, when the air is cooler, the cooling can be stored in these materials, in such a way that the phase change materials lose their heat by exchanging heat with the ambient air and change from the liquid phase to the solid phase. during the day, they melt by absorbing heat from inside the building and can keep the temperature of the environment inside the building constant (at its phase change temperature) for a period of time (until these materials are completely melted). Due to the fact that these materials absorb or repel a lot of thermal energy during the phase change, it is justified to use them as a storage source of thermal and cooling energy.

2.1. Governing equations

• Conduction heat transfer equation

(3)

By converting the three basic equations governing the fluid flow (equation of continuity or conservation of mass, conservation of momentum and conservation of energy) into algebraic equations discretized by the finite volume method, the numerical solution of these equations is provided.

• Energy equation

(1)

$$\rho \frac{DE}{Dt} = -div(\rho u_i) + \frac{\partial (u_i \tau_{ij})}{\partial x_i} + div(k_c gradT) + S_E$$

(2)

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T$$

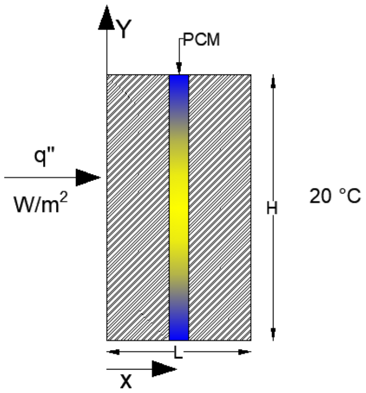

Fig .1. The framework of research

H is the specific enthalpy, h is the Apparent specific enthalpy The latent specific enthalpy that changes from

$$T = T(x,y,t) \quad \frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right)$$

•Boundary conditions

$$\begin{cases} -K \dfrac{\partial T}{\partial x}\Big|_{x=0} = q'' \\ T(x=L, y, t) = 20°C \\ \dfrac{\partial T}{\partial y}\Big|_{y=0} = 0 \\ \dfrac{\partial T}{\partial y}\Big|_{y=H} = 0 \end{cases}$$

•preliminary conditions

(4)

$$E = mc_P(T_1 - T_2) + mh_{sF} \qquad T(x,y,0) = 24°C$$

•Enthalpy formulation from the solved energy equation

(5)

$$\frac{\partial(\rho H)}{\partial t} + \nabla.(\rho v H) = \nabla.(k \nabla T) + S$$

(6)

$$H = h + \Delta H$$

the beginning of the phase change to the end, therefore, during the melting process in the pasty region, is defined as follows:

(7)

$$\Delta H = FL$$

$$F = \begin{cases} 0 \rightarrow if & T < T_s \\ 1 \rightarrow if & T > T_1 \\ \dfrac{T - T_s}{T_1 - T_s} if & T_s < T < T_1 \end{cases}$$

2.2. Assumption of the problem

• Fluid flow is transient.

• PCM is homogeneous.

• Density changes or volume changes are ignored, because phase change materials have a low volumetric expansion coefficient.

• The effect of temperature change on the thermophysical properties of air is insignificant.

• The temperature inside the building is constant and 20°C.

• The inner wall is assumed to be adiabatic

2.3. Problem parameters

• The density of fixed concrete wall is 2300 kg/m^3.

• Specific heat of concrete wall is 880 j/kg.k.
• The conductivity of the concrete wall is 1/7 w/m.k.
• The size of the two sides of the concrete wall is fixed.
• PCM size is variable (1, 2, 5 cm).
• Simple algorithm is used to couple velocity and pressure fields.
• Convergence accuracy is considered for all cases 2-10.

2.4. Characteristics of studied phase change materials

Table 1
PCM material specifications

Manganese Nitrate Hexahydrate	
chemical formula	$H_{12}M_nN_2O_{12}$
density	1820 Kg/m^3
Temperature performance range	7.25-24 °C
Net heat of melting	126000 j/s
C_P	580 j/kg.K
Thermal conductivity coefficient	0.438 w/m.K

3. Results and Discussion

In this research, numerical analysis affect on using phase change materials with different thicknesses on their melting time and also the effect of different heat fluxes on the melting time of phase change materials will be presented. The results of the problem simulation done with ANSYS Fluent[1] software are checked. First, the simulation of the concrete wall containing phase change material with a thickness of 10 cm, which is 1 cm of the phase change material, will be presented with different fluxes and comparison between the outputs will be done. The parameters related to the simulation of the system are presented below: According to Table 2, the heat fluxes are considered to be 1000, 700, 500, 400, 300, 200 and 100 W/m2 for all three thick walls.

Table 2
Complete results of different melting times with PCM thicknesses

q" (w/m^2)	PCB thickness in meters and melting time in seconds		
	0.01m	0.02 m	0.05
100			
200	65000 s		
300	20500 s	35000 s	
400	13400 s	23200 s	
500	10300 s	18100 s	
700	7400 s	13200 s	20500 s
1000	5600 s	9800 s	23000 s

For example, PCM with a thickness of 1 cm with a heat flux of 1000 W/m^2 melts completely in 5600 seconds, and according to the time of sunrise and sunset and its effect on an external wall in the summer season and in the month of August with optimal temperature, we can use PCM with a thickness of 1 cm in areas that have a heat flux of 300, which is the most effective.
Therefore, according to the approximate optimal time of using sunlight, the heat flux 200 which takes 65000 seconds to melt the entire material is not suitable and it is better to use less PCM thickness for the flux 300 to reach the optimal time, and also The heat flux of 100 W/m^2 in different thicknesses has not been calculated, because their melting time is much longer than the time of optimal presence of sunlight.
The obtained numbers, which are distinguished by the yellow highlight, can be said to be in more optimal conditions with regard to heat flux and PCM thickness.
For example, in the figure, we will first examine the results of PCM with a thickness of 1 cm with different heat fluxes. The first output is related to the heat flux of 1000 W/m^2, as it is clear from the graph, the whole PCM has melted completely in 5600 seconds.

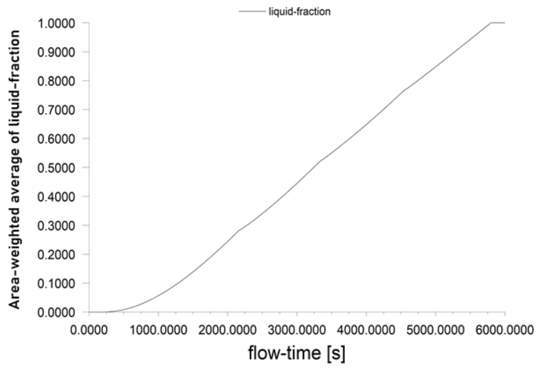

Fig .2. Melting diagram with heat flux of 1000 watts per square meter and PCM thickness of 1 cm

[1] Fluid simulation software is used in industry to predict fluid flow, heat and mass transfer, chemical reactions and other related phenomena.

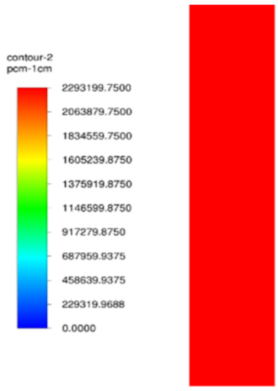

Fig .3. the amount of Energy for complete melting of PCM

According to Figure 3, for all simulation cases, according to the output of the software, 2293200j/s of energy is needed to melt the entire PCM.

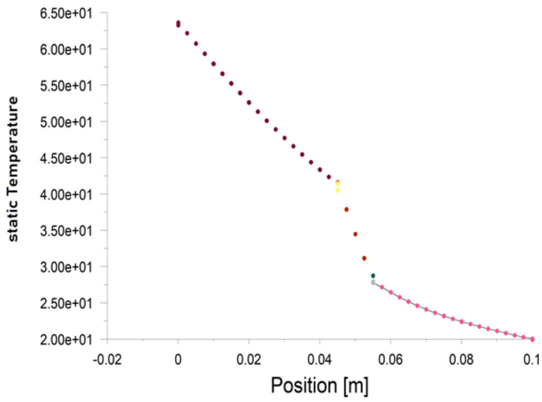

Fig .4. Diagram of temperature changes of the wall containing PCM material

According to Figure 4 of the temperature changes, it is clear that in the location of PCM, the changes in temperature trend have occurred with a greater slope, which is between 4.5 and 5.5cm from the concrete wall. According to the temperature changes due to heat flux, the most suitable position of PCM is between the walls. It can also be said that the wall with PCM has a 41% reduction in heat flux compared to the wall without PCM [13].

4. Conclusions

The results of the research show that numerical investigation of thermal energy storage in solar walls using phase change materials in different thicknesses is different with the amount of heat flux. By using phase change materials in solar walls, radiant energy of the sun can be absorbed and transmitted. heat into the building during the peak hours of the sun, and avoid calculations and selections of larger cooling equipment's that are selected during peak load. This will reduce the consumption of electricity based on fossil fuels. The investigations show that the wall containing phase change material has a better performance in reducing the amount of heat transfer and heat flux compared to the wall without phase change material. Also, the location of PCM in the outer and inner part of the wall has less effect than PCM between the two sides of the wall.

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