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A NEW COOLING TECHNIQUE USING PHASE CHANGE MATERIAL IN A CAR CEILING AND WALL BUILDINGS

A. F. Khadrawi, A. Balabel and Ali S. Al-Osaimy

Advanced Research Center for Nanotechnology and Renewable Energy (ARCNR), Taif University
Mechanical Engineering Dept., Faculty of Engineering, Taif University, Al-Haweiah, P.O. 888, Z.C. 21974, Taif, Saudi Arabia
Email: khadrawi99@yahoo.com, Email: ashrafbalabel@yahoo.com, Email: alosaimy@tu.edu.sa

ABSTRACT

In the present work a new cooling technique for buildings or car ceiling has been presented and investigated analytically. The new cooling technique uses several types of phase change materials (PCM) that is filling an enclosure that surrounds the wall buildings or car ceiling completely. It is found that the new phase-change cooling technique is more appropriate for cooling especially in hot climate countries. This can save much of electrical power used for cooling process of buildings and autos and in turn solves many environmental problems. The new phase-change cooling technique shows much better cooling performance when compared with the conventional sensible cooling one. Advantages can be also taken from the latent heat stored within the PCM in its liquid phase. This occurs when the PCM releases its latent heat of solidification. The new technique of using PCM can save much cooling energy that required for cooling the interior space of rooms or cars. The saving energy is about 78.6% from the initial energy required for cooling without PCM. It is found that the cooling operational time increases as both the melting temperature and the enthalpy of melting increase. Also, the PCM Paraffin (RT26) gives the optimum results for cooling.

Keywords: Cooling process, Energy saving, Phase change material, Wall insulation.

1. INTRODUCTION

Manuscripts not complying with present instructions may not be published. Heat and cold to be stored by Thermal Energy Storage can be used later. Two methods of storage are available: physical methods (sensible and latent heat storage) and chemical methods. Sensible heat is the most commonly observed thermal energy storage which is the amount of heat released or absorbed by a substance during a change of temperature. It can be calculated as:

$$Q_{sensible} = \dot{m} c_p \Delta T$$

where $\dot{m}$ is the mass flow rate, c_p is the specific heat and ΔT is the temperature difference. On the other hand, latent heat is the amount of heat released or stored by a substance during a change of state that occurs without much change in temperature. Latent heat storage can occur by several methods: solid-liquid phase change, liquid-vapor phase change, and solid-solid phase change. For solid-liquid phase change material, the latent heat stored and due to the small volume, the latent heat can approximately be written as [1]:

$$Q_{latent} = \dot{m} \Delta h$$

where Δh is the enthalpy difference between the solid and the liquid phase. The storage media employing the solid-liquid phase are commonly known as phase change material (PCM). PCM can be used to store or extract heat without substantial change in temperature. The main advantage of PCM is that it can store about 3 to 4 times more heat per volume than sensible heat in solids and liquids at an approximate temperature of 20 °C [1].

Phase Change Material (PCM) is a good applicable when there is a mismatch between the supply and demand of energy. In the literature some applications of PCM investigated by Salyer et al. [2] and Fatih Dermirbas [3]. They investigated the thermal protection of flight data and cockpit voice recorders, hot and cold medical therapy, transportation and storage of perishable foods, medicine and pharmaceuticals products, thermal management systems, solar power plants to store thermal energy during day time and reuse it during the later part of the day, electronic chips to prevent operation at extreme temperature, photovoltaic cells and solar collectors to avoid hot spots, miscellaneous use like solar-activated heat pumps, and waste heat recovery. Dincer and Rosen [4] studied the Thermal Energy Storage Systems and Applications. Energy consumption in buildings varies significantly during the day and night according to the demand by business and residential activities. Most of the energy is consumed during the day time in hot climate areas due to high ambient temperatures and intense solar radiation. This has led to varying pricing system for the on-peak and off-peak periods of energy use. Potential cost savings by reduction in energy consumption and by shift of peak load during the day can be achieved by incorporating PCMs in the envelope of residential and business building establishments.

There are several applications in the field of PCM for heating and cooling of buildings. Using PCM in the walls and in the ducts of the cooling units of a building to provide both heating and cooling effects and a storage system for both heating and cooling seasons that comprised two different PCMs integrated into a reverse cycle refrigeration heat pump system was reviewed and studied by Frank [5]. Pasupathy et al. [6] performed experimental measurements and simulation analysis of incorporating PCM in the roofs of buildings. An experimental work on a new kind of PCM was carried out by Guo [7] and found that its heat storing releasing ability was significantly higher than other PCMs. He also performed a simulation and calculation based on the effective heat capacity method to verify the results. Huang [8] applied a validated model to predict the energy conserving capability of the PCM by fabricating them in walls of buildings. Takeda et al. [9] was conducted an experimental study to analyze PCM usage on floor supply air conditioning systems to enhance building thermal mass. Also, Farid and Chen [10] presented a simulation of under-floor heating with and without the presence of a PCM layer. A simplistic way for cooling an intermittent operating internal combustion engine is investigated by Khadrawi and Al-Nimr [11]. Jamekhorshid and Sadrameli [12] studied the application of Phase Change Materials (PCMs) in Maintaining Comfort Temperature inside an Automobile. The heat conduction model for different applications was investigated by Khadrawi et al. [13-18].

The aim of the present work is to find a new cooling technique for wall building and car ceiling using phase change material. This technique will be more efficient for cooling than others. It will be much better than the conventional cooling methods because the phase change material absorbs much more heat in the form of latent heat which is much larger than the sensible heat. Also, this method will be much better for heating since phase change material release heat through the solidification process.

In further future investigations, the complet phase change process will be numerically simulated using a developed numerical method based on the level set method [19-24].

2. ANALYSIS

Consider the wall building or car ceiling as shown below in Fig. 1. The wall is considered to have a finite wall thickness. The room temperature is assumed to be constant at 22 oC and the ambient temperature is assumed to be constant at 50 oC. The characteristics of the air- PCM-wall system are given as following:

$h_\infty = 400 W/m^2 K$, $k_1 = k_2 = 35 W/mK$,

$L_1 = L_2 = 0.05 m$.

From the energy balance

$$\frac{T_R - T_m}{R_3 + R_4 + R_5} = \dot{m} h_{sf} + \frac{T_m - T_\infty}{R_6 + R_7 + R_8} \tag{1}$$

where $\dot{m}$ is the rate of change of melting material from solid to liquid and is given by:

$$\dot{m} = \left[\frac{T_R - T_m}{R_3 + R_4 + R_5} - \frac{T_m - T_\infty}{R_6 + R_7 + R_8} \right] \Big/ h_{sf} \tag{2}$$

Also, $\dot{m}_m \tau = V_m \rho_m$, where τ is the operational time of the system and is given by:

$$\tau = \frac{V_m \rho_m}{\dot{m}_m} \tag{3}$$

where V_m is the volume of melting material and τ is the time required by the phase-change solid material to be completely melted, and

$$R_3 = \frac{1}{h_\infty A}, \quad R_5 = \frac{1}{h_{sf} A}, \quad R_6 = \frac{1}{h_{sf} A}, \quad R_7 = \frac{L_2}{k_2 A},$$

$$R_8 = \frac{1}{h_\infty A}$$

The surface temperature for conventional air cooling and for phase change cooling, is given by:

- For conventional air cooling (Fig. 1b)

$$\frac{T_R - T_s}{R_3} = \frac{T_s - T_\infty}{R_4 + R_8}$$

$$T_s = \frac{R T_\infty + T_R}{(R+1)} \quad \text{where} \quad R = \frac{R_3}{(R_4 + R_8)} \tag{4}$$

- For phase change cooling (Fig. 1a):

$$\frac{T_s - T_R}{R_3} = \frac{T_m - T_R}{R_3 + R_4 + R_5}$$

$$T_s = R_3 \left[\frac{T_m - T_R}{R_3 + R_4 + R_5} \right] \tag{5}$$

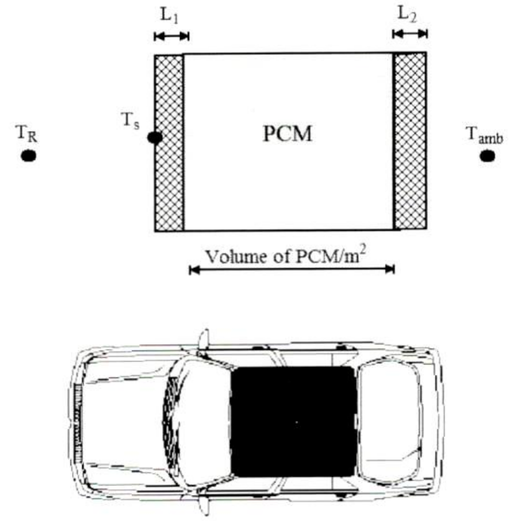

Fig.1a. Schematic diagram of the problem under consideration (with cooling).

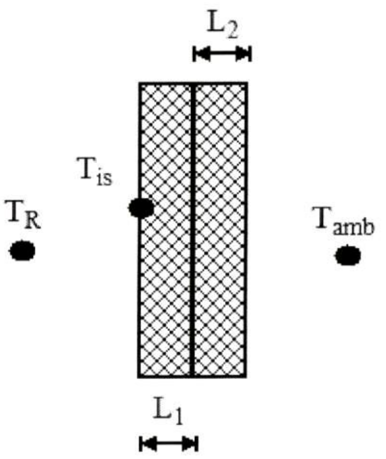

Fig.1b. Schematic diagram of the problem under consideration (without PCM cooling).

3. RESULTS AND DISCUSSION

Figure 2 shows the effect of phase change material, described in Table 1, on operating time and surface temperature. It is obviously from this figure that the PCM (Paraffin-RT26) give the maximum operating time and minimum surface temperature. Therefore, this material is preferred in our analysis and it is considered in our calculations.

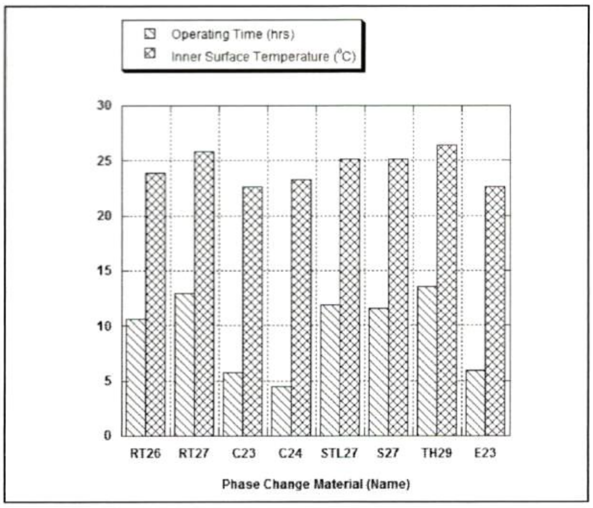

Fig. 2. Effect of phase change material on operating time and surface temperature.

Figure 3 shows the effect of PCM volume on the operating time. It is clear that as the volume of PCM increases the melting operating time increases. The effect of the ambient temperature and thermal conductivity on the operating time is shown n Figs. (4&5). It can be seen from these figures that as the ambient temperature and the thermal conductivity increase the operational time decrease. Which means that as the thermal conductivity increases the thermal resistance decreases which in turn leads to decreasing in the operational time.

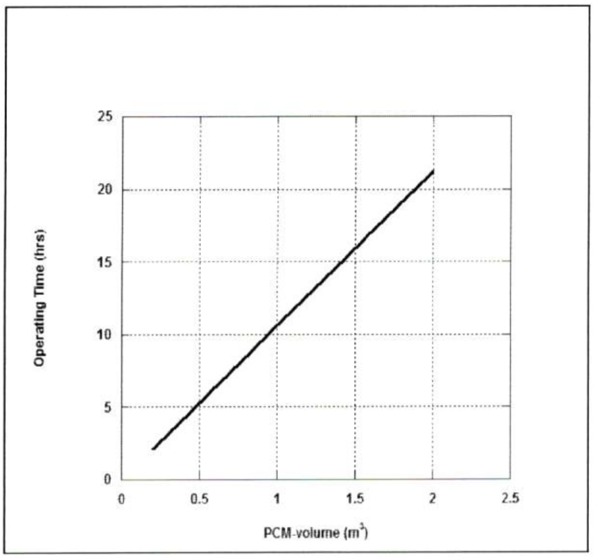

Fig.3. Effect of phase change material volume on operating temperature for $h_{sf} = 232kJ/kg \;\; \rho_m = 920kg/m^3$ $, h_\infty = 400W/m^2K, T_R = 22\,^oC,\; T_\infty = 50\,^oC,$ $k_1 = k_2 = 35W/mK$.

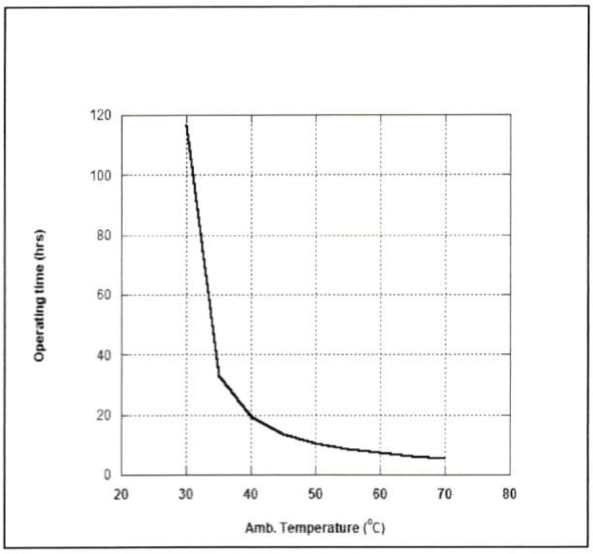

Fig.4. Effect of ambient temperature on operating temperature for

$$h_{sf} = 232kJ/kg,\ \rho_m = 920kg/m^3$$
$$, h_\infty = 400W/m^2K, T_R = 22\,^oC,$$
$$k_1 = k_2 = 35W/mK.$$

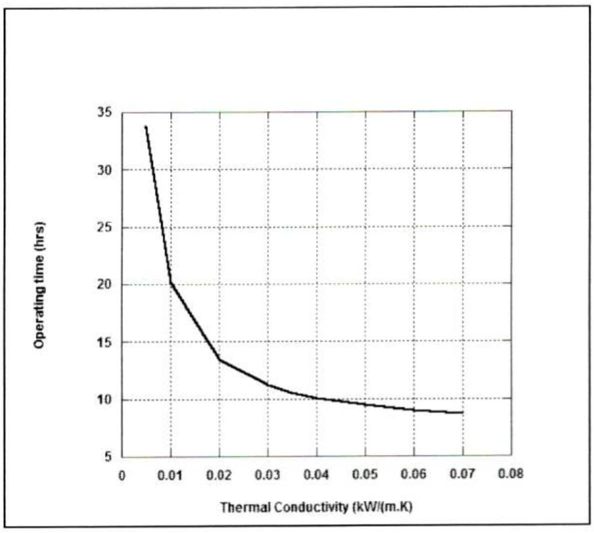

Fig.5. Effect of thermal conductivity on operating temperature for $\rho_m = 920 kg/m^3$ $, h_\infty = 400 W/m^2 K, T_R = 22\,^oC,$ $T_\infty = 50\,^oC . h_{sf} = 232 kJ/kg$

Effect of the thermal conductivity on the inner surface wall temperature is shown in Fig.6. It is clear that as the thermal conductivity increases the surface temperature increases because as the thermal conductivity increases the thermal resistance decreases so the surface temperature will increase.

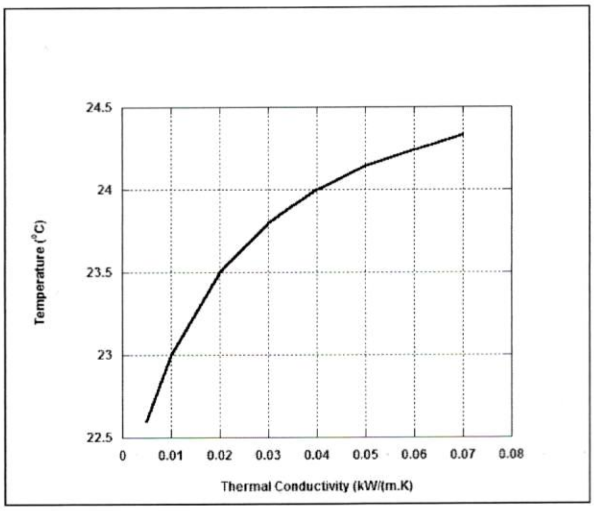

Fig.6. Effect of thermal conductivity on operating temperature for $\rho_m = 920 kg/m^3$ $, h_\infty = 400 W/m^2 K, T_R = 22\,^oC, T_\infty = 50\,^oC,$ $k_1 = k_2 = 35 W/mK . h_{sf} = 232 kJ/kg$

Fig. 7 shows the effect of melting temperature on the operating time of the system. It is clear that as the melting temperature increases the operational time of the system increases. This implies that as the melting temperature increases the melting rate decreases then the operational time of the system increases.

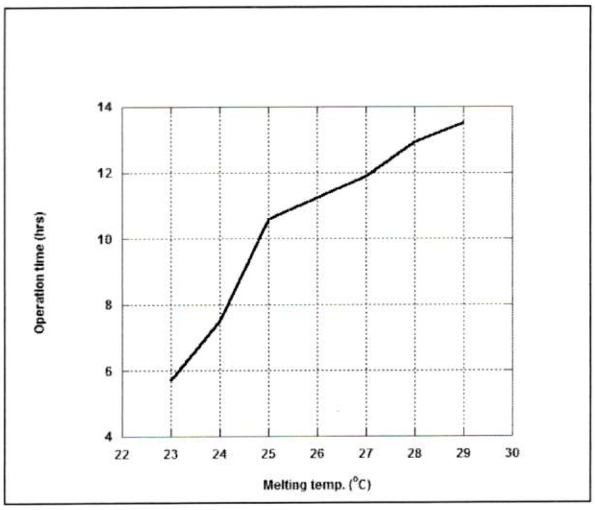

Fig.7. Effect of melting temperature on operating temperature for different phase change materials.

4. CONCLUSION

A novel cooling technique to cool the building walls and car ceiling is investigated. The new cooling technique uses a phase change material that melts when it is in contact with temperatures equal to or higher than the melting temperature and solidifies when it is in contact with temperatures equal to or less than the solidification temperature. It is found that the new latent (phase-change) cooling technique gives much better cooling performance than the conventional sensible one. It is found that the cooling operational time increases as both the melting temperature and the enthalpy of melting increase. The effect of the enthalpy of melting on the cooling operational time is found to be more pronounced at large values of melting temperatures. It should pointed out that, the above new technique of using PCM can save much cooling energy that required for cooling the interior space of rooms and cars. By using a simple analysis for cooling load calculations on both cases, with and without PCM, it is found that the energy saving is about 78.6% from the initial energy required for cooling without PCM.

In our future work, this new cooling technique is simulated numerically under different operating conditions to investigate such process in more details.

Table 1. Effect of PCM material propertie

PCM- Name	Type of Product	Melting Temp. (°C)	Heat of Fusion (kJ/kg)	Melting Mass	Operating Time (hr)	TSW	TSWO
RT26	Paraffin	25	232	2.4E-2	10.6	23.9	30.9
RT27	Paraffin	28	206	1.97E-2	12.94	25.8	30.9
Climsel C23	Salt Hydrate	23	148	4.46E-2	5.72	22.63	30.9
Climsel C24	Salt Hydrate	24	108	5.64E-2	4.52	23.26	30.9
STL27	Salt Hydrate	27	213	2.14E-2	11.89	25.17	30.9
S27	Salt Hydrate	27	207	2.21E-2	11.55	25.17	30.9
TH29	Salt Hydrate	29	188	1.89E-2	13.5	26.44	30.9
E23	Plus ICE(Mixture of Non-Toxic Eutectic Solution)	23	155	4.26E-2	5.99	22.63	30.9

5. NOMENCLATURE

A surface area, m^2
h heat transfer coefficient, $W/m^2\,K$
h_{sf} enthalpy of melting, J/kg
k thermal conductivity, W/m K
L wall thickness, m
$\dot{m}_m$ rate of change of melting material from solid to liquid, kg/s
R thermal resistance, K/W
T_R room temperature, K
T_m melting temperature, K
T_s surface temperature, K
T_∞ ambient temperature, K
V_m volume of melting material, m^3

Greek symbols

ρ density, kg/m^3
τ operational time of the system or time of melting, s

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