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Analysis of thermal comfort in a prototype residential model building - A Novel PCM Composites

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Abstract : Phase Change Materials (PCMs) are ideal products for thermal management solution. It is a substance with a high heat of fusion which melting and solidifying at a certain temperature. In view of the efficient thermal behavior of the PCMs towards the diversified engineering applications, the work has been carried out to study the thermal comfort in prototype housing models. A series of PCM composites of Magnesium Chloride, Alumina, Silica, Sodium Silicates are proportionated on the bases of lime. The thermo-cool properties of these composites are studied over the day time between 6 am and 6 pm for three days per composite. The results shown that the PCM of Sodium Silicate and lime composite is remarkably reduced the temperature of four degree centigrade with respect to base model.
Key words: Prototype housing model, PCM, Sodium Silicate, Temperature and lime.

1. Introduction

Electrical energy consumption varies significantly during the day and night according to the demand on the industrial, commercial and residential activities. In hot and cold climate countries, the major part of the electrical load variation is due to the air conditioning and space heating respectively. These variation leads to a differential pricing system for peak and off peak periods of energy usage. Recent discussions on topics like global warming and heat waves have brought attention to develop the energy efficient cooling systems from renewable energy sources. Significant economic benefit can be achieved by thermal energy storage for heating and cooling in residential and commercial buildings. Buildings that have large mass reacts slowly for heating and cooling demands. Thermal storage plays an important role in building energy conservation, which is greatly assisted by the incorporation of latent heat storage in building products [1]. In the world where there is a continuous increase in the emission of greenhouse gases into the atmosphere and increase in global temperature exponentially it is necessary to use technologies to find a way to reduce the temperature of the buildings inside. Phase change materials (PCMs) or latent heat storage materials are suggested to be used along with the insulators in the building construction to reduce the inflow of heat into the building [2]. The total heat storage in a material [3] is given by equation (1)

$$E = mc\Delta T_1 + mL + mc\Delta T_2 \qquad (1)$$

Where, ΔT_1 is the difference between the melting point temperature and the initial temperature ΔT_2 is the difference between the final temperature and the melting point temperature and mL is the latent heat storage (Energy storage considering the phase transformation).

2. Literature Review

The phase change materials can manage the fluctuations of the external temperatures, wind, solar load, and heating or cooling processes in indoor climate conditions Yvan Dutil et al [4] described 10-15 % of energy gain can achieved in building applications by the utilization of PCMs. Bernardi et al [5] investigated the application of PCM technology to cultural heritage in a European MESSIB (Multi-source Energy Storage System Integrated in Buildings) and pointed out the strong and weak points, the technical and non-technical barriers and the possible solutions to apply PCM_S in a buildings. Mettawee and Ead [6] presented an experimental analysis of peak load shifting for air conditioning system using PCM in a room. The melting point of used PCMs are lie between 20 and 25°C. As a result, during the peak load shifting time, which is within 2 hours, the decrease of the room temperature is between 7^{o}C and 10 °C by using PCM ceiling system. Vineet Veer Tyagi and Buddhi [7] presented a comprehensive review for heating and cooling system in buildings through PCM thrombi wall, PCM wallboards, PCM shutters, PCM building blocks, air-based heating systems, floor heating, ceiling boards, etc. Belen Zalba et al [8] discussed the thermo-physical properties of commercial PCMs using solid–liquid phase change materials in the review of Thermal Energy Storage (TES). Joseph Stalin et al [9] discussed the cooling of room by PCMs in respect to ceiling fan usage. This system reduces the usage of power to a great extent thereby saving energy. With the increasing demand of Air Conditioning systems, this system would give better and a perfect replacement with better efficiency and reduced cost. Suil and Zhang [10] presented a residential floor cooling system by considering the indoor thermal environmental parameters and human thermal comfort. It increases the great interest to maintain the room temperature below to the ambient temperature by coating of PCMs. In view of the literature reviews, it has been carried out for PCMs modelling, characteristics and method of analysis.

3. Materials And Methods

The Phase Changing Materials hydrated Magnesium Chloride, Aluminium Oxide, Silica and Sodium Silicate are purchased from commercial chemical agents. The lime is purchased from road side shops. The two prototype housing models are built in the size of 540mm X 320mmX 320 mm consisting of 430 mmX230mm X135 mm room size by using ordinary brick and cemented by 55 grade cement proportionated with sand mortar. The top house is closed by concrete cement slab with 350 mm thickness. The entrance door is made of thermocool. The mercury thermometers with 110^{0}C are fitted inside of houses. The housing model No.1 (Figure 1) is chosen for base model and white lime without any PCMs. The housing model No.2 (Figure 2) is used for experimental purposes, where the PCM blended lime is coated over the entire house of the model.

Figure 1 Base Model (BM) **Figure 2 Experimental Model (EM)**

3. Results and Discussion

The various compositions of lime and PCMs are prepared and applied over the experimental prototype housing models. The Magnesium Chloride, Aluminium Oxide, Silca and Sodium Silicate are individually charged in to lime at rate of 10%, 20%, 30%, 40%, and 50% on the bases of weight by weight proportions. Among them, Magnesium Chloride and Aluminum Oxides are not played any vital role in reduction of indoor temperature. The different compositions of silica and lime are prepared and applied over the housing model. There is a little improvement in reduction of temperature but does not play any significance role in indoor cooling. The sodium silicate compositions are found to be used an excellent phase changing materials for numerous engineering applications. Hence, it is decided to apply the lime and sodium silicate composites over the experimental housing model. Among the various compositions, the 50:50 lime and sodium silicate proportions significantly reduced the room temperature. The temperature difference between the base and experimental models are noted for every two hours period between time 6am to 6pm and result of experimental and base housing models are given table 1.

Table 1 Temperature Measurement in Base and Experimental Models

Day	Temperature in °C													
	6 am		8 am		10 am		12 am		2 pm		4 pm		6 pm	
	BM	EM	BM	EM	BM	EM	BM	EM	BM	EM	BM	EM	BE	EM
08.03.2015	25.5	25	26	26	28	26	37	34	36	32	35.5	31	34	30
09.03.2015	26	26	27	27	29	27	36.5	33	36	32	35	31	34	30
10.03.2015	25.5	25	27	26.5	28	26	36	34	35	32	35.5	31	33	31.5

In general, the forenoon sessions have shown meager cooling processes whereas an afternoon session shown 3-4 degree centigrade temperature reductions with respect to the base model. The temperature of housing models are plotted against time. On first day of the observation, the temperature of experimental housing model constantly maintained at 26 °C between 8 to 10 am, even indoor temperature of base model gets steep increases according to the prevailing the hot environmental climate. The temperature is increased further on base and experimental models, during hot sun irradiations (see fig .3).

The maximum temperature of the day falls at 37°C and the peak temperature is maintained between 12 noon and 2 pm. The cooling effect (i.e reduction of indoor temperature) of experimental housing model is proportionate with respect to the sun irradiations. The temperature difference between base and experimental housing models are gradually increases from 10 am to 2pm. At 10 am, the temperature difference between composite coated and lime coated housing models are 2°C, whereas, it remarkably differ at 3°C on 12 noon of the session.

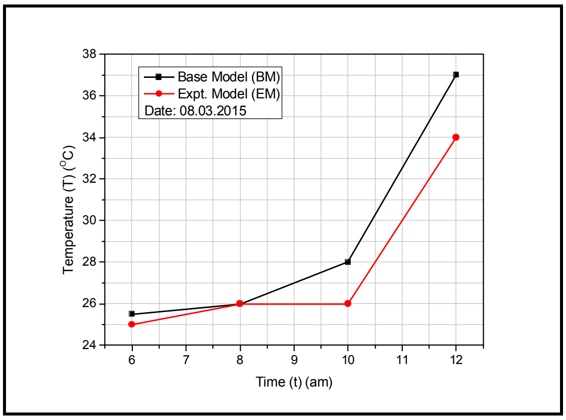

Fig.3. Indoor temperature of housing model between 6am to 12 noon.

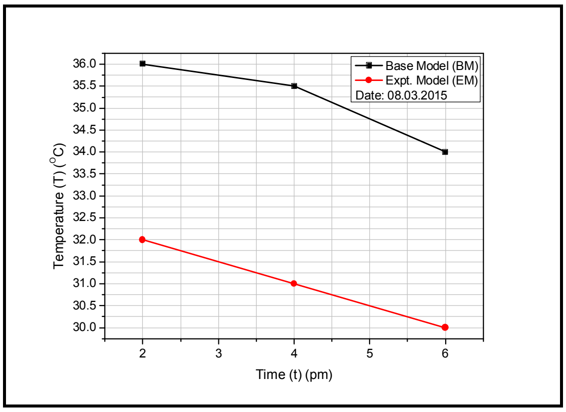

Fig.4. Indoor temperature of housing model between12 noon to 6pm.

The indoor temperature of experimental model has get reduced further one degree centigrade on 2pm. The same temperature difference is found, up to 6 pm (fig.4). It is inferred that the sodium silicate and lime 50; 50 composite have played a vital role in absorption Infrared radiations (IR) emitted from earth, after 2 pm. The PCMs also effectively performed against the sun radiations even in forenoon sessions, after 10pm.

On the second day observations, the PCM played the same performance as found in first day. It is found that there is no temperature fall during 6am to 8am. It could be reason out that the climate of the day was cloudy and the hot sun irradiations perhaps discharge less UV radiations. Usually, the PCM incorporated composite housing model maintain 27°C temperature between 8am and 10am.The difference in temperature between the housing models are 2°C at 10 am and it is gradually improved, finally fall by 3°C at 12 noon (see fig .5).

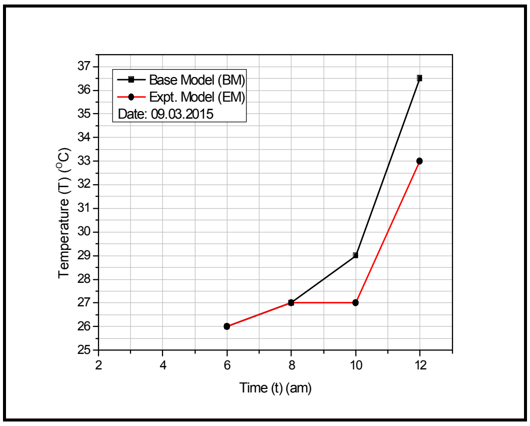

Fig.5. Indoor temperature of housing models between 6am and 12 noon.

After 2pm the temperature difference of housing models was fallen on degree Celsius from the 12 noon sessions and be extended the same performance still 6pm (see fig 6).

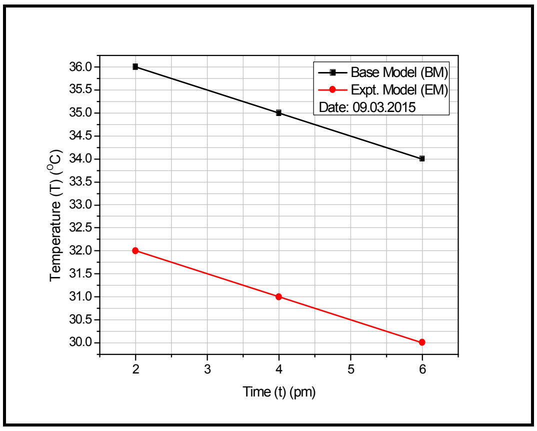

Fig.6. Indoor temperature of housing models between 2pm and 6pm.

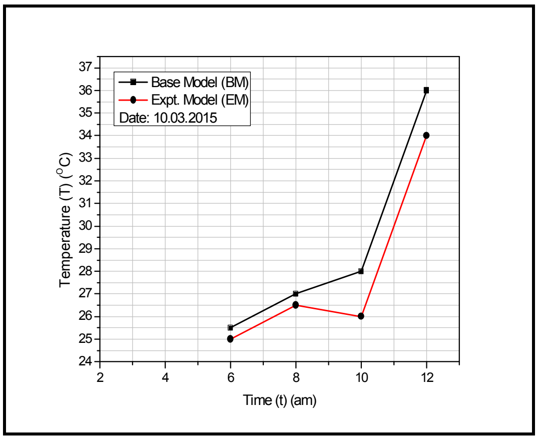

Fig.7. Indoor temperature of housing models between 6am and 12 noon.

On third day of the experiment, the temperature run in prototype housing models shown the same effect against PCM. In forenoon session, there a meagre temperature differences between the housing models are observed from 6am to 8am. Two degree temperature differences were found between the housing models at 10am and it was gradually improved 3^{o}C up on 12 noon (fig.7).

Unexpectedly on the day, the indoor temperature of the base model is get raised up on sun radiations. The maximum temperature of the day is 35.5^{o}C and it is found only at 4 pm. The PCM composite is effectively reduced 5^{o}C on the indoor temperature of experimental housing model at 4pm, where the highest sun irradiations(fig.8).

The steep fall in temperature of the base model is observed after 4pm and the temperature difference of housing model is fallowed narrow.

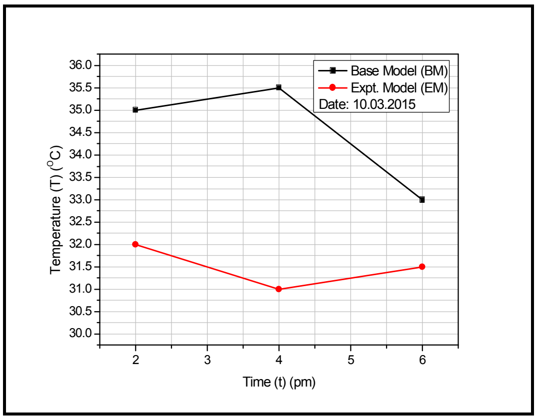

Fig.8. Indoor temperature of housing models between 2am and 6 pm.

Though the temperature of the experimental model lesser than base model, the gap is narrow. The decrease in temperature difference between the housing models could be understand by the prevalence of sudden cloud formation and poor UV irradiations.

4. Conclusion

The composites of sodium silicate and lime with 50:50 found to be the suitable composite for reduction of temperature through absorption of infrared radiations emitted by earth. These PCM composite effectively perform against peak hot hours between 10am-4pm. In general, the absorbed UV radiations at the forenoon sessions will be remitted back at afternoon sessions. The defined composite played a vital role in reduction of temperature during the afternoon session. Thus, sodium silicate could be ideal ingredient for paints to prevent hot UV radiations. It is worthwhile to use in hot zone countries since it is economical viable and improve sustainable environment.

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