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Thermal performance of compound solar radiant floor heating with PCM insulation in green building

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***Abstract*—Different types of compound radiant floor heating systems are used in residential buildings and their thermal and economic performance varies largely by many factors. One of the most influential factors on performance of a system is envelopes insulation. The aim of this study was to investigate the effect of insulation in thermal and economic performance of a radiant floor heating system. Using different insulation approaches – poor or no insulation, conventional insulation according to national regulations and with BioPCM boards- heating loads and system sizing's were analyzed and calculated by Design Builder software and system and components were compared in each case. The results showed that the heating loads and component sizes decreased significantly with PCM insulation. As a result, using BioPCM boards for envelope insulation can be considered as an energy and money saving constructing approach for a residential buildings using radiant floor heating system. Due to it's at least 11% reduction in heating loads.**

***Keywords*—PCM Insulation, BioPCM, Solar Radiant floor, heating system, Energy conservation, DesignBuilder software, Co_2 emission, payback period time**

I. Introduction

The building sector is known to contribute significantly to total energy consumption and Co2 [1, 2] as in 2002, buildings were estimated to account for about 3% of global greenhouse gas emissions [3]. The study of Kwak and Rajkovich reported that 38.9% of total energy requirement of USA is related to buildings, of which 34.8% is used for heating, ventilation and air conditioning [4]. Both compound solar radiant floor heating and latent heat storage are considered to be ways of decreasing heating demands and increasing comfort and energy saving. Different studies are made around these two subjects .Strand [5] summarized radiant system model with a popular building energy simulation program. Sattari and Farhanieh [6] studied the effects of design parameters on performance of radiant floor heating systems. Zhang and Wang [7] analyzed a lightweight radiant floor heating system both experimentally and numerically, and several other papers addressed the thermal performance of radiant floor heating system [8-10].

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Radiant floor heating has become a common trend these days and is widely used around the world because of its energy savings and health benefits [11].As mentioned earlier building sector and residential building's energy consumption is known to contribute a large proportion of the total energy consumption. Therefore, reducing energy consumption and energy savings has come to the center of attention. Many different ways have been examined, including the use of vacuum insulation panels, high performance window systems and high performance ventilation systems. Thermal energy storage is a useful tool for improving energy efficiency and increasing energy savings. Among ways of thermal energy storage, latent heat storage is the most appealing due to its high storage density and small temperature variation from storage to revival [12, 13]. The energy is stored during melting and recovered during the freezing of a phase change material. A great variety of PCMs have been investigated to be used in building applications [14-17]. Qiu and Wu have numerically simulated the thermal performance of a radiant floor heating system with enclosed phase change material located in the floor slab [18]. Barbour and Hittle [19] modeled phase change materials with conduction transfer functions for passive solar applications. However, the lack of sufficient researches on the application of phase change material in residential buildings using compound solar heating system can be easily sensed. The most important aspects to investigate are the effect of applying PCMs and compound solar heating system on building's heating demand and comparing the results with more conventional and less expensive trends. This study aims to investigate simultaneous application of PCMs and compound solar radiant floor heating systems. To do so, a sample building in Tehran has been considered to be heated by compound solar radiant floor system. Heating load will be calculated by Design Builder software and components will be sized in three different conditions. 1- With using BioPCM boards on walls. (BioPCM wall above grade as listed on ASHRAE 90.1 2007-Steel-framed) 2- with using conventional envelope insulation according to local regulations and 3- with poor or no insulation.

II. Parameters and procedure

A. *Test room layout*

Single family houses are very popular in Iran, therefore a schematic regular layout of a single family house is chosen. Fig.1 shows the test rooms' layout, heating loads, annual

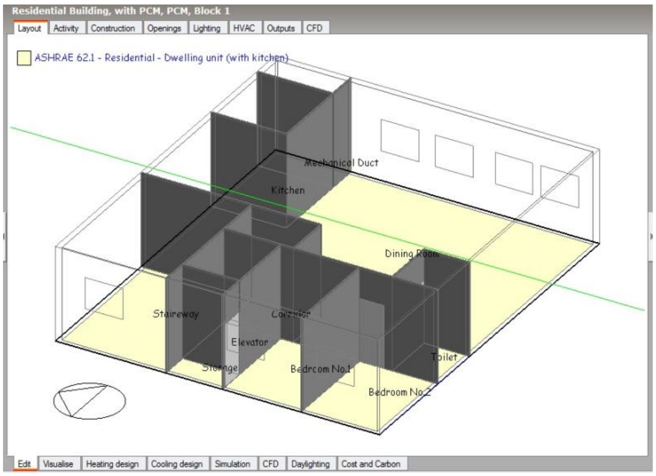

Fig.1. Test room layout

energy consumption and solar conservation factor is calculated in three different conditions using Design Builder software, then the components are sized and annual costs and payback period time of each condition have been compared.

B. *Design parameters*

As mentioned earlier three different conditions have been considered, and other influential parameters are considered to be fixed. The focus of this work was on the Effect of envelope insulation in energy consumptions, though the building is considered to be a residential dwelling unit (with kitchen) according to ASHRAE62.1 and residents' activities are standing and walking. The building is equipped with compound solar radiant floor heating system. Fixed design parameters are shown in table.1. And parameters of envelope insulation for all three different conditions are shown in table.2.

III. Results and discussion

A. *Thermal performance*

It was necessary to investigate the effect of PCM insulation on the heating loads, heat gains and component sizing's. Thermal properties of the test room were calculated. First the test room has been modeled in the Design Builder software and variable and fixed data's (see tables 1, 2.) were assigned on it, heating load of each space and the total heating load was calculated.

TABLE I. FIXED PARAMETERS

Parameter	Properties
Building Type	Residential, dwelling unit
Occupancy	0.04 people/m^2
Activity	Light work: Standing/walking
CO_2 generation	0.0000000382
DHW daily consumption	1.5 Lit/m^2
Heating setpoint	20 C

The results are shown in Fig. 2 &3.

TABLE II. PARAMETERS OF ENVELOPE INSULATION

condition	Parameters of envelope insulation			
	Building envelope	***Construction***	***Thickness (m)***	***Overall heat transfer coefficient***
PCM insulation	Exterior wall	BioPCM wall	0.1327	0.341
Conventional insulation	Exterior wall	Standard wall construction	0.265	0.502
Poor insulation	Exterior wall	Uninsulated brick/block wall	0.265	1.487
All conditions	Internal partition	Lightweight gypsum plaster board	0.15	1.639

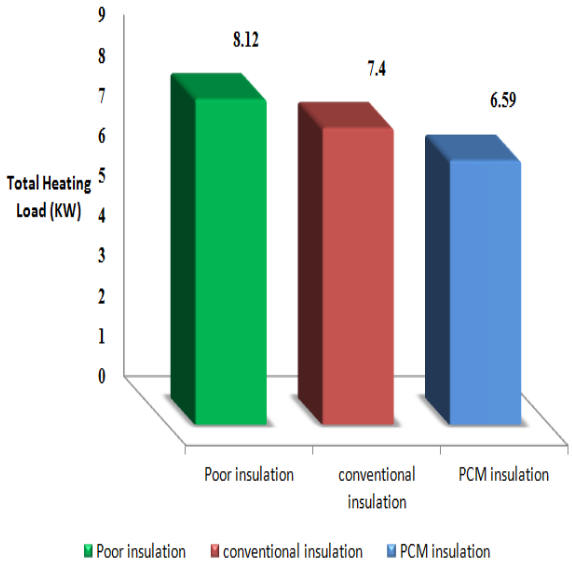

Fig.2. Total heating load comparison

B. *Energy analysis*

Define the annual energy needed for heating and domestic hot water is calculated in each condition by day-degree method. The energy needed for one day is calculated by eq. (1).

$$Q/_{DD} = UA \qquad (1)$$

Where DD is the day-degree, this quantity is then modified for inside temperature by eq. (2) & (3).

$$DD = [1 - K_d(65 - T_i + \frac{q}{UA}]DD_{65°\text{F}} \qquad (2)$$

$$K_d = 6.398DD_{65°\text{F}}^{-0.577} \qquad (3)$$

Where $DD_{65°\text{F}}$ is the annual degree-day which is calculated at 65˚F.The monthly and yearly energy needed in each condition is shown in Fig.4.

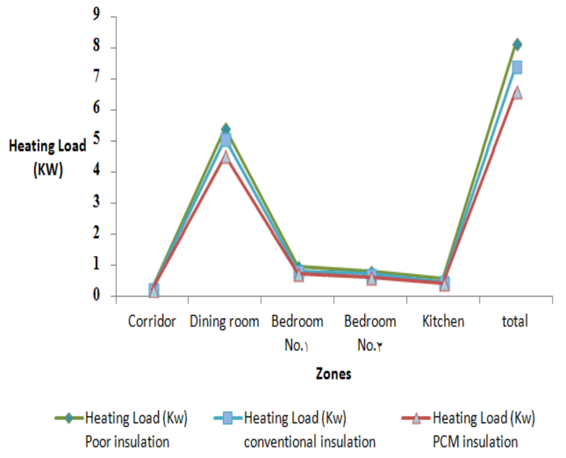

Fig.3. Zones heating load in different conditions.

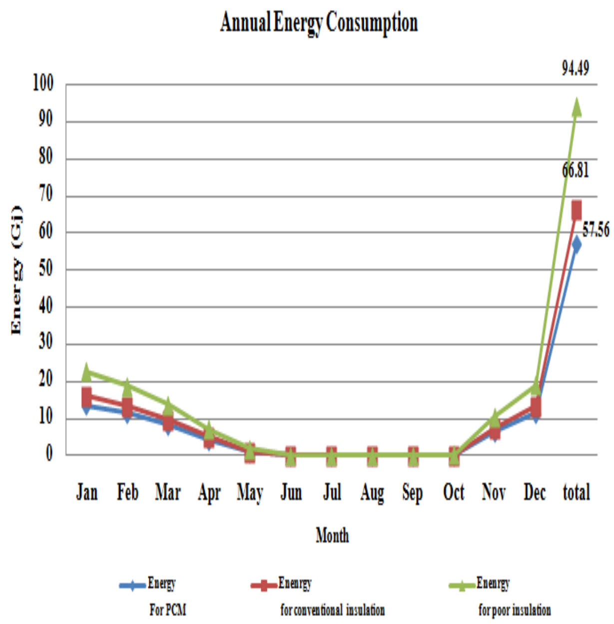

Fig.4. Annual energy consumption in each condition.

Solar conservation factor is calculated by eq. (4).

$$SCF = \frac{E_{co}+E_{win}}{Q_H+Q_{DHW}} \quad (4)$$

Where E_{co} the energy is absorbed by solar collectors and E_{win} is windows heat gain.

The optimized area of a collector is chosen based on the heating load and the energy needed for supplying domestic hot water. But from a certain point the increase in total collector area won't have a significant effect in improving the SCF and increases the both initial and maintenance cost of the system. Total collector area and the number of collectors are calculated by eq. (5) & (6) for each condition and then the number of collectors are optimized based on costs and other parameters.

$$A_c = \frac{((Q_H+Q_{DHW})-Q_{win}}{q_c \times 31} \quad (5)$$

$$n = \frac{A_c}{2} \quad (6)$$

Solar energy conservation for each condition is then calculated by eq. (4). The results are shown in Fig.5.

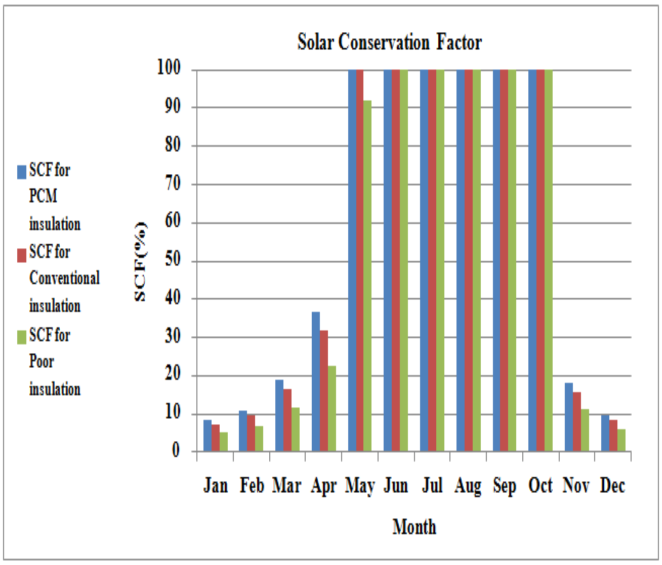

Fig.5. Solar conservation factor

C. *Fuel consumption and CO_2 emission*

The Fuel consumption of each condition is calculated by eq. (7) and then compared with the consumption of fossile fuel system with no solar collectors. The results are shown in Fig.6.

$$Gas(m)^3 = \frac{Q_t(Btu)}{1055\frac{Btu}{ft^3}\times 0.75\times 35.31\frac{ft^3}{m^3}} \quad (7)$$

Where the efficiency of burner is considered to 75%.

Co_2 emission also is calculated; the results for a test room with PCM insulation show a significant reduction in both Co_2 emission (about 3.41 ton/year) and gas consumption (about 1.24 ton/year) of the test room in comparison with fossil fuel system with no solar collectors.

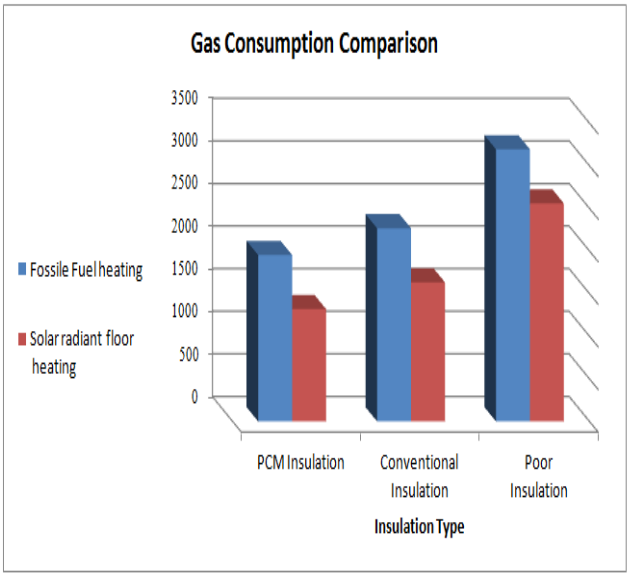

Fig.6. Gas consumption comparison

D. Conclusions

In this paper thermal performance, energy and gas consumption of a test room with different types of envelope insulation were investigated by popular software. The influence of using BioPCM boards on exterior walls of a test room was analyzed and the results were compared with other conditions.

In summary

- PCM envelope insulation can decrease the total heating load about 11% in comparison with conventional insulation practices and about 19% in comparison with poor insulation practices.
- With considering the optimal collector area constant in each condition, the results show a significant improvement in solar conservation factor by using PCM insulation.
- Co_2 emission and gas consumption show great reduction in comparison with fossil fuel systems.
- If the numbers of building stories increases, this reduction in heating loss and energy consumption can also affect the HVAC systems' sizing's and component choosing and also the number of collectors and therefore it can reduce the energy costs in a great deal.

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