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Experimental Investigation of an Energy Saving System Using Phase Change Materials in buildings

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Abstract

In this paper, an experimental research has been conducted intended for using Phase Change Materials (PCM) by incorporating it with the building layers walls. The effect of involving PCM volume ratio and orientation on the thermal efficiency and thermal comfort was experimentally studied. Two identical rooms models have been constructed. The first model was used as a standard room as a reference one without using PCM and the second model has the PCM layers and used for all experimental testing works. Both rooms are installed at National Research Center, NRC, Giza, 30.08 °N latitude, Egypt. The PCM used in this experimental work was paraffin wax having a melting point 29 °C. Many cases have been studied based on south wall, east wall and west wall respectively. It was found that using PCM caused a considerable reduction in the indoor air temperature and consequently reduction in the cooling load that minimize the building energy consumed. It is concluded that the Percentage of the cooling load reduction of the zone by using PCM and according to cases and for peak hour in day was 19.2% with PCM for East, West and South walls together, followed by 16.8 % for South wall only, followed by 12.7% with West wall only and followed by 10.5% for East wall only. It is found that the best case in cooling load reduction of the room for peak hour of PCM for South, West and East walls together by 19.2%. The experimental results of the present study were validated with the corresponding experimental study of Mushtaq 2018 with a considerable agreement between the daily cooling load reduction per space volume and the cooling load reduction ratio. It is known that the cooling load reduction ratio is referred to the energy saving which proved that using PCM in building will contribute in energy saving in residential building.

Keywords: Phase change materials, Energy saving, Comfort conditioning, cooling load reduction.

1. Introduction

The demand for energy has increased very rapidly with economic developments. Conventional energy sources such as (gas, coal and oil) are limited in addition to their negative impact on the environment due to the cause of greenhouse gases that lead to climate change and global warming [1]. Heating Ventilation and Air Conditioning (HVAC) is considered one of the most electric energy consumptions in buildings [2]. Therefore, several researches are done to minimize the energy consumption of the HVAC equipment. There are several ways to save the HVAC energy consumption as an example following regularly the operation and maintenance schedule of the equipment, running the system temperature to the comfortable energy efficient temperature zone, using proper ventilation and minimize the infiltration, changing air filter regularly, cleaning the condenser and evaporator coils to reduce the electric energy consumption of the compressor, considering variable speed equipment, and generally implementing the building management system strategy. Beside all the previously mentioned factors to minimize the energy

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consumption of the HVAC systems is to minimize the cooling load of the system. As the cooling load mainly classified into two categories exterior and interior loads. The main factors of the exterior loads are the solar heat gain and temperature difference between the indoor and outdoor space. Therefore, some energy-saving and environment-friendly technologies have got been investigated in latest years. The thermal energy storage techniques used impeded with building's walls to reduce energy consumption were considered a great effective method [3, 4]. Thermal energy storage can be classified as sensible heat storage and latent heat storage systems. The latent heat storage has received substantial attention in recent years due to using PCM that has higher energy storage density plus narrow operating temperature variety [5,6]. In addition, PCM can store and release a large quantity of latent heat throughout the process of melting and solidifying in the narrow phase transition variety [7, 8]. PCM can be used in building for energy saving in two categories. The first one is combining the PCM with the active air conditional technique as a heat source or cold source associated with the air conditioning technique to increase the refrigerating efficiency or the heat efficiency [9, 10]. The second one is to use the PCM as a passive thermal insulation and preservation system, which includes a mix of PCM and building materials to obtain innovative technique to minimize the energy consumption by impeding the PCM with a fixed-shape directly into the structure of the building [11]. The comparison of the thermal efficiency of lightweight buildings with a PCM layer and without being attached to the interior wall panel has been studied and found that the energy consumption to maintain a comfortable temperature can be reduced by 40 - 70% [12]. The effect of thermal control of construction fabrics integrated with PCM in periods of extreme heat waves was previously numerically examined and the result showed that the risks of internal thermal stress can be effectively reduced without the air conditioner function [13]. A researched numerical model based on a modified acceptance model to assess the thermal performance of building conditions that are integrated with PCM and whose result converts to good compatibility with current finite element simulation results [14]. A new double walled PCM board structure was introduced, and a related simplified dynamic model was proposed, and then used to analyze the energy performance of the commercial building under various conditions. The heat transfer process and the effect of PCM parameters on the heat transfer law are very important to the actual design and require more understanding [15, 16]. The experimental evaluation of the built-in phase change brick (PCM) brick for passive conditioning in buildings has been studied and aimed to provide a massive solution to rapidly increasing building energy requirements. PCM bricks were tested under actual conditions, followed by, the effect of different PCM configurations was evaluated. Summer peak experiments were conducted at ambient temperatures above 40 °C during the day. A temperature drops of 4 °C - 9.5 °C was observed of single across and double PCM layer bricks, when compared to conventional bricks. Reduced heat transfer between 40% and 60% [17]. Experimental was studied on the influence of PCM container height on heat transfer characteristics under constant heat flux condition. The effect of changing latent heat storage rectangle variation on the melting process of PCMs under continuous heat flow was studied. The effect of container height on melting process and Nusselt number (Nu) was shown by analyzing the scale. The results showed that although the height of the PCM container positively contributes to accelerating PCM melting in the early stage, it caused more logical thermal accumulation in the top of the container during the solid shrinkage system, which prolongs the time of PCM melting. Therefore, when designing a latent heat storage system, PCM container architecture should be improved [18]

2. Description of the study:

Two identical rooms were constructed with dimensions (2 ×2 ×2.5 m), as demonstrated in Fig.1. The first one is considered as a standard room, and the second one is used as a test room. The rooms are made up of domestic construction materials, according to the building specifications in Egypt. The walls consist of three layers, from outside to inside. the first layer will be a cement mortar with 0.025m thickness and with thermal conductivity (1.4 W/ m K), the second layer will be a hollow brick with dimensions (0.25 × 0.065 × 0.12 m) and with thermal conductivity (0.7 W/ m K), the third layer will be a cement mortar with 0.025 m thickness and with thermal conductivity (1.4 W/ m K). The floor was from concrete with 0.25m thickness and with thermal conductivity (1.91W/ m K). The experimental room was a room equipped with phase change materials. The building material for the experimental room was the same as the standard room material. The PCM layer is installed on the inner side of the walls in an aluminum rectangular frame with dimensions of each plate (8 cm x 1.5 cm x 200 cm) and the number of panels was four panels in each wall in the experiment, as explain in Fig.2. Thermal conductivity of aluminum was (237 W / m K).

Fig.1 a Photo of the experimental apparatus, South and North orientation

Fig.2 Paraffin wax and aluminum boards

3. Mathematical Model:

The cooling load calculation is made for the studied two rooms [19]. The conductive thermal resistance is calculated as shown in eqns. (1-2).

Conduction resistance (R):

$$R = \frac{x}{K} \tag{1}$$

Total Thermal Resistance (R_T):

$$R_T = \frac{1}{h_i} + \frac{x_1}{K_1} + \frac{x_2}{K_2} + \ldots\ldots + \frac{x_n}{K_n} + \frac{1}{h_o} \tag{2}$$

Where: –

R_T: Total Thermal Resistance in (m^2 K/W)

h_i: Inside heat transfer coefficient for enveloping internal wall and equal **(8.3 W/ m^2 K)**

h_o: Outside heat transfer coefficient for enveloping external wall and equal **(16.9 W/ m^2 K)**

x_1: Thickness of first layer for wall in (mm).

x_n: Thickness of last layer for wall in (mm).

k_1: Thermal Conductivity of first layer for wall in (W/ m K)

k_n: Thermal Conductivity of last layer for wall in (W/ m K)

Overall heat transfer coefficient (U):

$$U = \frac{1}{R_t} \tag{3}$$

Where: –

U: Overall heat transfer coefficient (W/ m^2 K).

The heat gain in the building structure is considered as one of the main sources of cooling load calculations. The cooling load through building exterior structure can be calculated by using the (CLTD) method (ASHRAE) [20]

$$Q = U \times A \times CLTDc \tag{4}$$

Where: –

Q: Amount of heat transfer during walls in (W)

U: Overall heat transfer coefficient of wall in (W/ m^2 K)

A: Surface area in (m^2)

CLTDc: Correction cooling load temperature difference (°C) and calculated by equations: –

For walls and ceiling: –

$$CLTDc = [(CLTD + LM) \times K + (25.5 - Tr) + (Tm - 29.4)] \quad (5)$$

Where: –

CLTD: Cooling load temperature difference for walls (°C) which can be taken from special tables ASHRAE depended upon wall construction.

LM: Latitude and month correction factor for wall

K: Color correction factor (Dark = 1, med = 0.83, light = 0.65)

T_r: Indoor temperature of room (°C)

T_m: Outdoor design temperature which refers to ambient temperature (To) and equal:

$$Tm = (To - \frac{DR}{2}) \quad (6)$$

DR: Daily range of outdoor

The reduction in cooling load which is caused by using PCM as insulation materials is calculated as follow:

$$CLR = \frac{CL\ without\ PCM - CL\ with\ PCM}{CL\ without\ PCM} \quad (7)$$

Where: –

$CL_{withPCM}$: Cooling load of room with PCM in (W).

$CL_{withoutPCM}$: Cooling load of room without PCM (W)

Electric consumption cost was calculated at peck hour for all cases of using the PCM (paraffin wax). It has been using the usual default price in Egypt that is 0.5 LE/kWh according to the pricing of the Ministry of Electricity 2019-2020, the price of electrical energy consumption in Egypt on a moderate basis for level three (0-200 kWh).

CS = RCL x EC x NOH (8)

Where: CS: Cost Saving in electricity, LE/day

RCL: Reduction in Cooling Load, kW

RCL = cooling load of room without PCM - cooling load of room with PCM wall.

EC: Electricity Cost, LE/kWh

NOH: Number of Operating Hours, h

The PCM is generally applied in the field of heating and cooling system to reduce thermal loads and integrated with construction materials as plaster, gypsum or concrete and this is usually in the particular form of capsules. In the present work, the energy storage capabilities of PCM are utilized inside aluminium boards attached with the room inside walls. The importance of the PCM position is to offset the maximum load of the cooling by absorbing the heat during melting at peak hours, thereby reducing the heat that passes through the wall towards the room. This heat is then released during the solidification process at night. The used PCM is really a paraffin wax with Honey colour. The cost of paraffin wax was (70 LE/ kg) from local market. The differential scanning calorimeter analysis of the PCM is made as shown in Fig.3 using Differential Scanning Calorimetry DSC131, in the Nanomaterial Investigation laboratory, Central Laboratories Network, National Research Centre (NRC), Egypt.

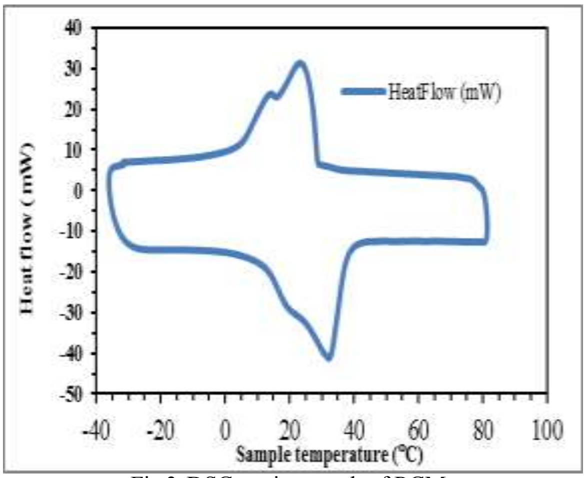


Fig.3 DSC testing result of PCM.

The instrument was calibrated using the standards (Mercury, Indium, Tin, Lead, Zinc and Aluminum). Nitrogen and Helium were used as the purging gases. The test was programed including the heating zone from 0°C to 100°C then cooling from 100°C to 0°C with a heating rate 10 °C / min. The samples were weighted in crucible 120 ul and introduced to the DSC. The thermogram results were processed using (CALISTO Data processing software V.149). Thermal physical properties from the PCM were presented in Table 1.

4.Experimental procedure:

Several tests on PCM were carried out and used in the summer as they were combined with east, west, and south orientation walls. The measuring data for experimental and standard rooms was recorded at the same time. The solar radiation was measured at the exterior wall surface by using solar pyranometer with accuracy ±0.1. The uncertainty of the solar radiation was 0.14. The measuring of temperature and relative humidity of air at the inlet and outlet of rooms was measured with the aid of temperatures- humidity sensor kit with accuracy ±0.1. The uncertainty of the temperature was 0.35 °C and the uncertainty of the relative humidity was 0.32. Each of the two rooms was divided into three zones. Temperature and relative humidity measurements were taken for each of the three zones. Fig.4 shows the division of rooms.

Table 2 explains the composition of the wall with and without PCM boards.

East, West, and South Walls:

In this case, east, west and south walls of experimental room were used paraffin wax, with area of PCM was (0.96 × 2.5 m) with a width of one panel was 0.015 m. The weight of the three walls PCM was 24 kg. The PCM was poured in the aluminum boards after melting process by using gas heater. First the paraffin wax was melted by gas heater and then the molten paraffin wax is poured in the aluminum boards. The test was performed in (11-Jun-2019) from 11 AM to 2.30 PM.

Table1. Properties of the PCM (paraffin wax):

The moist important data	Typical Values	
Melting point	29	[°C]
Heat storage capacity ± 7,5%	165	[kJ/kg] *
Combination of latent and sensible heat in a temperature range of 25 °C to 31 °C.	46	[Wh/kg] *
Specific heat capacity	2	[kJ/kg·K]
Density solid	0.88	[kg/l]
Density liquid	0.76	[kg/l]
Heat conductivity (both phases)	0.2	[W/(m·K)]
Volume expansion	12.5	[%]

East wall only:

The east wall was using PCM with area of PCM was (0.32 × 2.5 m) with width of one board was 0.015 m. The weight of the east wall PCM was 8 kg. The test was performed in (13-June-2019) from 11 AM to 2.30 PM.

West wall only:

The wall was using PCM with area of PCM was (0.32 m × 2.5 m) with width of one board was 0.015 m. with 8 kg per the wall PCM. The PCM was poured in the aluminum boards after melting process by using gas heater. The test was performed in (1-July-2019) from 11 AM to 2.30 PM.

South wall only:

The South wall was using PCM with area of PCM was (0.32× 2.5 m) with width of one board was 0.015 m. with 8 Kg per the wall PCM. The PCM was poured in the aluminum boards after melting process by using gas heater. The test was performed in (10-July-2019) from 11 AM to 2.30 PM.

Table.2. Composition of wall with and without PCM panels.

Wall with PCM					
1	**2**	**3**	**4**	**5**	**6**
Cement mortar	Hollow brick	Aluminium panel	PCM panel	Aluminium panel	Cement mortar
Wall without PCM					
1	**2**	**3**			
Cement mortar	Hollow brick	Cement mortar			

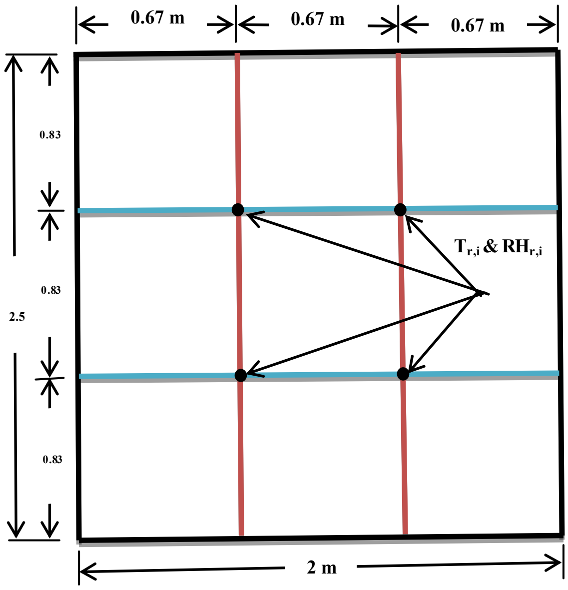
5. Results and Discussion

The following findings are the results of a feasibility study of the use of phase change materials for cooling load reduction in summer. The results were taken in June and July, summer Season the city of Cairo- Egypt at the same time for both the rooms with and without PCM. Many cases were conducted with many orientations

(East, west and south walls):

Figures.5-6 indicate the experimental results of the variation of internal room temperature and relative humidity for two cases with and without PCM. The effect of the direction of the walls (East, west and south) was studied from 11.00 Am to 2.30 PM with a 30-minute interval at (11-Jun-2019).

The intensity of solar radiation in this period ranged from 690 to 840 W/m^2, The ambient temperature during this time was 38.2 to 41 °C and the ambient relative humidity during this time was 30 to 26%. For a room containing PCM, (East, West, and South Walls), it can be seen that. Indoor room temperature with PCM was lower than internal temperature without PCM all hours of the experimental.



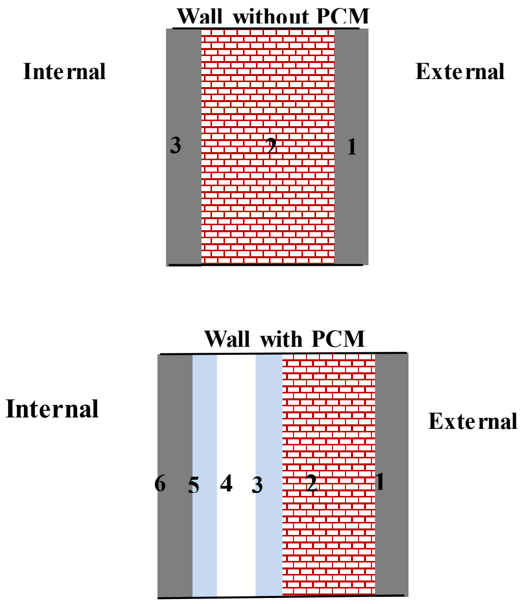


Fig.4. Locations of measurements, internal room

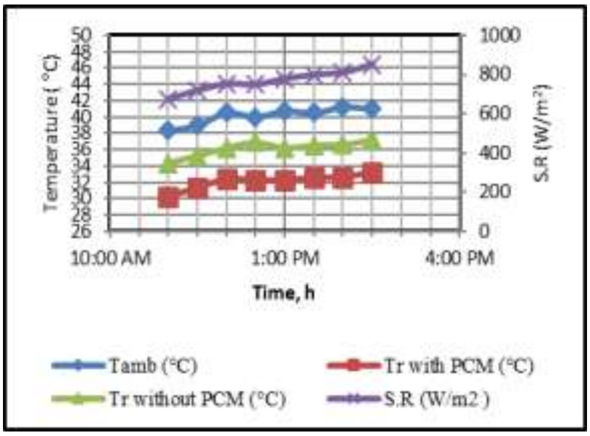


Fig.5. Indoor temperature of rooms at (East, west and south walls) (11-Jun-2019)

As the temperature decreased from 37 to 34.5 °C with a decrease percentage 6.8 %, the decreased in temperature is due to the melting of PCM at daylight hours and absorption of heat and resulting in maintaining the room temperature at low values. Therefore, when a PCM solidify, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs charge /discharge heat as ambient temperatures fluctuate. It is clear also that the indoor room relative humidity with PCM was higher than internal relative humidity without PCM all hours of the experimental. As the relative humidity increased from 32.8 to 34.6 % with an increase percentage 5.5 %, an increase due to the effect of the PCM that led to the provision of heat gain to the room, due to its melting during daylight hours and heat absorption this led to maintaining the relative humidity at the comfort zone values.

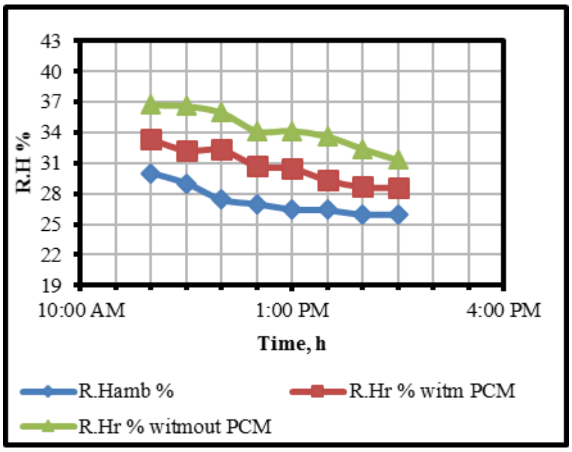


Fig.6. Indoor relative humidity of rooms at (East, west and south walls) (11-Jun-2019)

East wall only:

The effect of the direction of the east wall was studied from 11.00 Am to 2.30 PM with a 30-minute interval at (13-Jun-2019), The intensity of solar radiation in this period ranged from 695 to 851 W/m^2, The ambient temperature during this time was 37 to 40 °C and the ambient relative humidity during this time was 42 to 37%. Figures7-8 showed the variation of internal room temperature and relative humidity for two cases with and without PCM for experimental results. For a room containing PCM, East Wall was combined with PCM (Paraffin Wax). From these figs, it can be seen that, indoor room temperature with PCM was lower than internal temperature without PCM all hours of the experimental.

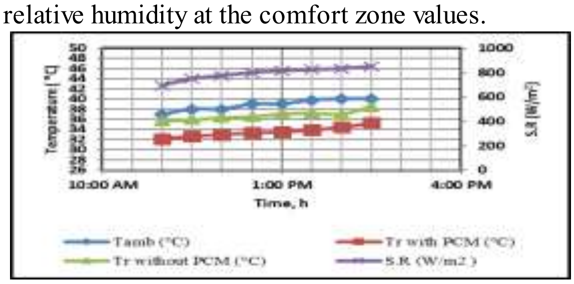


Fig.7. Indoor temperature of rooms at east wall only (13-Jun-2019)

West wall only:

The effect of the direction of the west wall was studied from 11.00 Am to 2.30 PM with a 30-minute interval at (1-July-2019), The intensity of solar radiation in this period ranged from 610 to 950 W/m^2, The ambient temperature during this time was 36 to 40 °C and the ambient relative humidity during this time was 44 to 39 %.

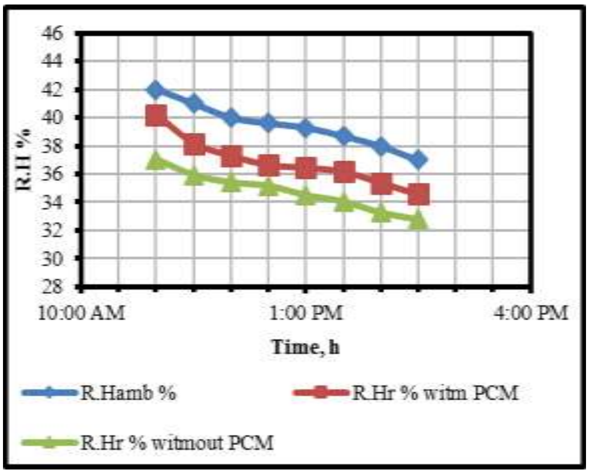


Fig.8. Indoor relative humidity of rooms at east wall only (13-Jun-2019)

Figures 9-10 illustrated the variation of internal room temperature and relative humidity for two cases with and without PCM for experimental results. For a room containing PCM, West Wall was combined with PCM (Paraffin Wax). It can be seen that the indoor room temperature with PCM was lower than internal temperature without PCM all hours of the experimental. As the temperature decreased from 37.6 to 34.5 °C with a decrease percentage 8.2%, this reduction is due to the effect of PCM which resulted in providing heat gain to the room, due to its melting at daylight hours and absorption of heat and resulting in maintaining the room temperature at low values. Therefore, when a PCM solid, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs charge /discharge heat as ambient temperatures fluctuate. It is clear also that the indoor room relative humidity with PCM was higher than internal relative humidity without PCM all hours of the experimental. As the relative humidity increased from 34.3 to 36.5% with an increase percentage 6.4%, an increase due to the effect of the PCM that led to the provision of heat gain to the room, due to its melting during daylight hours and heat absorption this led to maintaining the relative humidity at the comfort zone values.

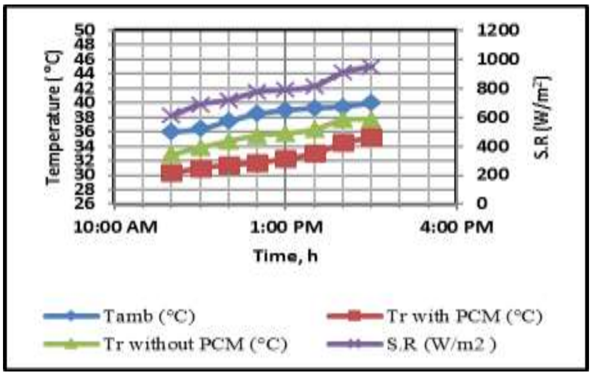


Fig.9. Indoor temperature of rooms at west wall only (1-July-2019)

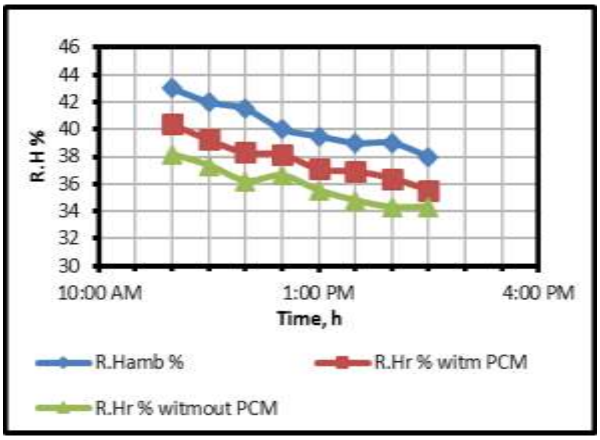


Fig.10. Indoor relative humidity of rooms at west wall only (1-July-2019)

South wall only:

The effect of the direction of the south wall was studied from 11.00 Am to 2.30 PM with a 30-minute interval at (10-July-2019), The intensity of solar radiation in this period ranged from 740 to 990 W/m^2, The ambient temperature during this time was 40.1 to 43.4 °C and the ambient relative humidity during this time was 44 to 39%. Figures 11-12 showed the variation of internal room temperature and relative humidity for two cases with and without PCM for experimental results. For a room containing PCM, South Wall was combined with PCM (Paraffin Wax).

From these figures, it can be seen that, indoor room temperature with PCM was lower than internal temperature without PCM all hours of the experimental. As the temperature decreased from 41 to 36.6 °C with a decrease percentage 10.7%, this reduction is due to the effect of PCM which resulted in providing heat gain to the room, due to its melting at daylight hours and absorption of heat and resulting in maintaining the room temperature at low values. Therefore, when a PCM solidify, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such material melts, it absorbs a large amount of heat from the environment. PCMs charge /discharge heat as ambient temperatures fluctuate. It can be seen also that the indoor room relative humidity with PCM was higher than internal relative humidity without PCM all hours of the experimental. As the relative humidity increased from 30.8 to 32.5% with an increase percentage 7.5%, an increase due to the effect of the PCM that led to the provision of heat gain to the room, due to its melting during daylight hours and heat absorption this led to maintaining the relative humidity at the comfort zone values

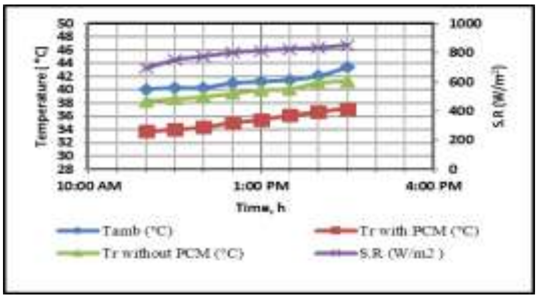


Fig.11. Indoor temperature of rooms at south wall (10-July-2019)

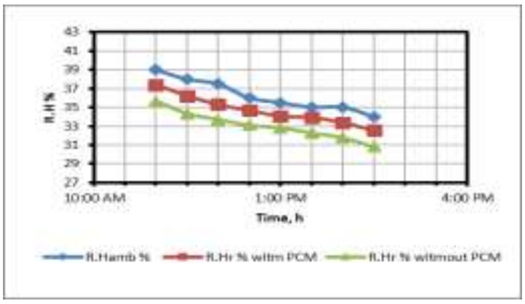


Fig.12. Indoor relative humidity of rooms at south wall (10-July-2019)

Indoor temperature reduction:

Table2. summarizes the difference between the internal temperature between rooms with PCM and rooms without PCM for all cases, which shows that when using PCM, a temperature reduction occurs in all walls. Also, when the East, West and South, walls wall gives maximum reduction in temperature followed by south wall followed by west wall followed by east wall.

Table 2:
Difference of the indoor temperature between rooms with PCM and rooms without PCM for all cases:

Case	TIME	ΔT_r (T_r without PCM -T_r with PCM)	Date
East, West and South, walls	2 P.M	4.7 °C	11 Jun- 2019
East wall only	2 P.M	2.6 °C	13 Jun- 2019
West wall only	2 P.M	3.1 °C	1 July-2019
South wall only	2 P.M	4.4 °C	10 July-2019

Cooling loads (C L): (Jun and July- 2019)

Figures.13-16 showed the variation of percentage of cooling load reduction as a result of using PCM for different studied cases compared with cooling load for standard room. It is important to mention that the tests for different cases of PCM were carried out at different times due to preparation requirements. Table3 summarizes the value of maximum reduction percentages for different cases.

Individual walls with PCM:

Cooling load of the rooms with and without PCM for the south, west and east wall are presented in Figures 13–16 respectively. For the room with PCM the South, West and East wall Individual are merged with PCM (paraffin wax). In these figures, it can be seen that cooling load is reduced at day time which means that the reduction of cooling load is takes place in time which the PCM works and absorbs heat enters to the zone, percentage of reduction in cooling load for all cases and for the individual wall. The effect of PCM reduction is more in south, west and south walls together because they contain of a big mount of PCM, respectively south wall because the main part of heat enters from it to the room, respectively west wall and less effect in east wall, as shown in table3.

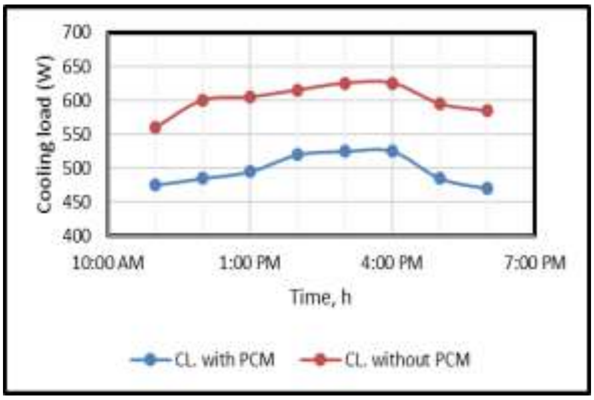


Fig.13. Indoor coaling load of rooms at (East, west and south walls) (11 Jun- 2019)

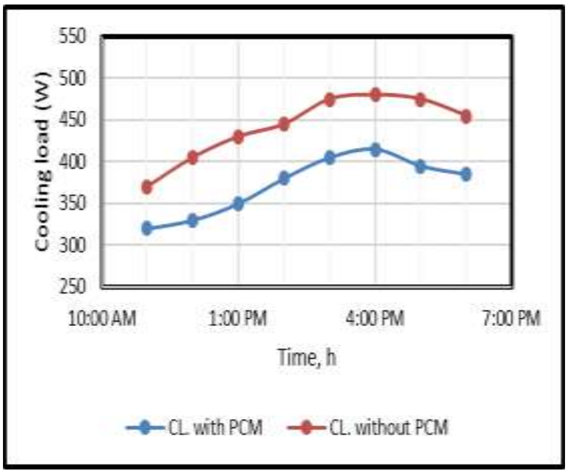


Fig.14. Indoor coaling load of rooms at south wall only (13 Jun- 2019)

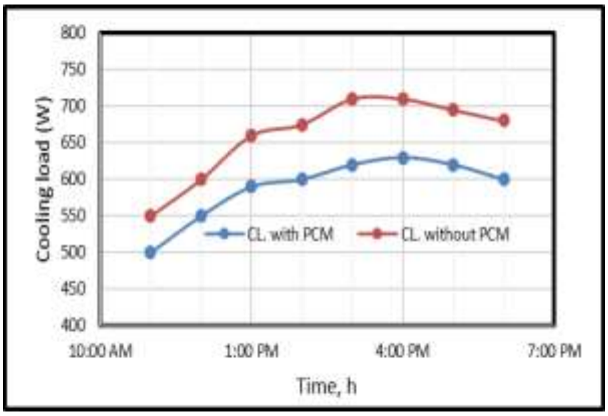


Fig.15. Indoor coaling load of rooms at west wall only (1 July-2019)

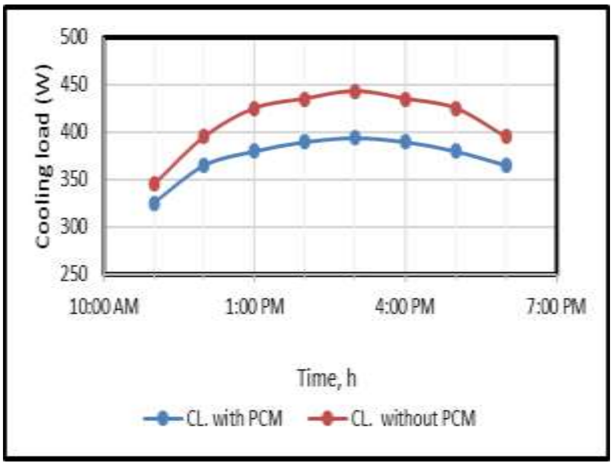


Fig.16. Indoor coaling load of rooms at east wall only (10- July- 2019)

Percentage of cooling load reduction:

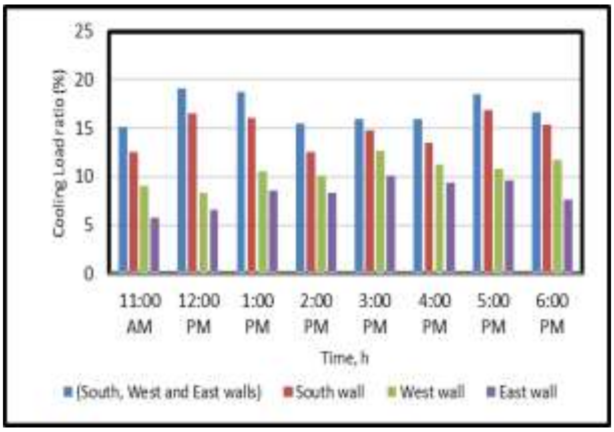
Figure 17 shows the variation of percentage of cooling load reduction as a result of using PCM for different studied cases compared with cooling load for standard room. It is important to mention that the tests for different cases of PCM were carried out at different times due to preparation requirements.

Table3. Summarizes the value of maximum reduction percentages for different cases.

Electric consumption:

Electric consumption cost was calculated at peck hour for all cases of using the PCM (paraffin wax). As shown in table.3.

Table.3. Percentage of the cooling load reduction and electricity saving for rooms with and without PCM for all studied cases



. Fig.17. Reduction of Cooling Load (Jun–July 2019)

Case	Thickness of PCM [mm]	Time	Cooling Load Reduction ratio%	Cooling Load Reduction [kW/m^3 Day]	Date
East, West and South walls	15	2 PM	19.2	2.3	11 Jun-2019
South wall only	15	2 PM	16.8	1.8	13 Jun-2019
West wall only	15	2 PM	12.7	1.6	1 July-2019
East wall only	15	2 PM	10.5	1.03	10 July-2019

6. Validation of experimental present study:

The experimental results of the present study were validated with the corresponding experimental study of Mushtaq 2018 [19]. Figure18. showed a comparison between the daily cooling load reduction per space volume for the present study and Mushtaq experimental study. There is considerable agreement between the two studies and the relative differences shown between the two studies referred to the experimental conditions between the two studied locations. While figure19 showed a comparison between the cooling load reduction ratio for the present study and Mushtaq experimental study. There is significant agreement between the two studies, and it is known that the cooling load reduction ratio is refer to the energy saving which proved that using PCM in building will contribute in energy saving in residential building.

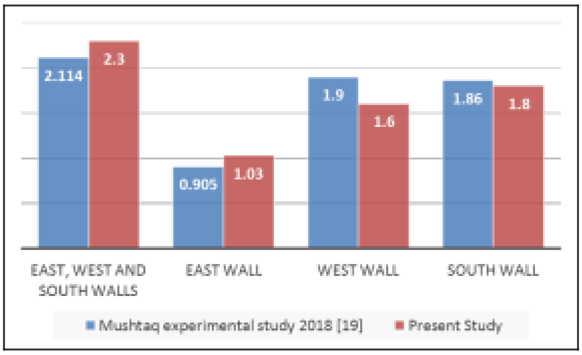


Fig.18 Comparison between the daily Cooling Load Reduction per space volume for the present study and Mushtaq experimental study 2018 [19]

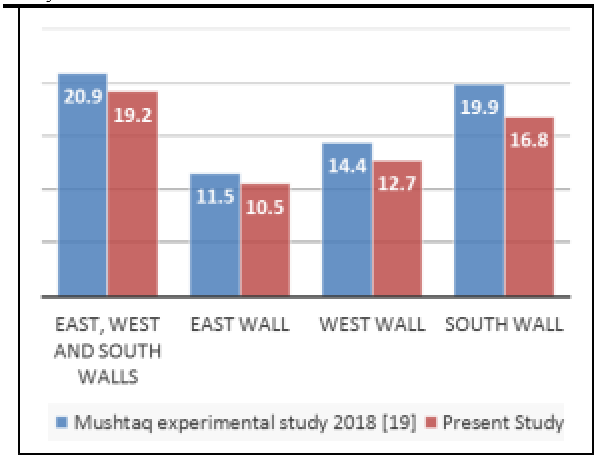


Fig.19 Comparison between Cooling Load Reduction Ratio for the present study and Mushtaq experimental study 2018 [19]

7. Conclusions:

The using of phase change materials in buildings has been studied experimentally. From the results which are obtained can be made the following conclusions:

1- Percentage of the cooling load reduction of the zone by using PCM and according to cases and for peak hour in day was 19.2% with PCM for East, West and South walls together, followed by 16.8 % for South wall only, followed by 12.7% with West wall only and followed by 10.5% for East wall only.

2- The best case in cooling load reduction of the room for peak hour of PCM for South, West and East walls together by 19.2 %.

3- Using PCM in buildings leads to saving of electricity consumption. The saving in electricity consumption was (2300 W/ m^3 Day) with PCM for

South, West and East walls together, followed by (1800 W/ m^3 Day) for South wall only, followed by (1600 W/ m^3 Day) for West wall only and followed by (1030 W/ m^3 Day) for East wall only.

4- The experimental results of the present study were validated with the corresponding experimental study of Mushtaq 2018. It is concluded that there is a considerable agreement between the daily cooling load reduction per space volume for the present study and Mushtaq experimental study. While the comparison between the cooling load reduction ratio for the present study and Mushtaq experimental study proves that there is significant agreement between the two studies and it is known that the cooling load reduction ratio is referred to the energy saving which proved that using PCM in building will contribute in energy saving in residential building.

Nomenclature:

A	Surface area (m^2)
Amb,T	Ambient air temperature (°C)
CLR	Cooling Load Reduction (%)
$CL_{withoutPCM}$	Cooling Load of the room without PCM (W)
$CL_{withPCM}$	Cooling Load of the room with PCM (W)
CLTD	Cooling Load temperature difference (°C)
CLTDc	Correction of cooling load temperature difference (°C)
DR	Daily Range of outdoor (°C)
h_i	Inside heat transfer coefficient for enveloping internal wall and equal (8.3 W/ m^2 K)
h_o	Outside heat transfer coefficient for enveloping external wall and equal (16.9 W/ m^2 K)
k	Color correction factor.
K	Kelvin
k_1	Thermal Conductivity of first layer for wall in (W/ m K)
k_n	Thermal Conductivity of last layer for wall in (W/ m K)
LM	Latitude and month correction factor for wall.
PCM	Phase Change Material.
Q	Amount of heat transfer during walls in (W)
R	Conduction Resistance (m^2 K/W)
T_i	Air design temperature inside the room (°C)
T_m	Outdoor design temperature (°C)
T_o	Air design temperature outside the room (°C)
T_r	Indoor temperature of room (°C)
U	Overall heat transfer coefficient of wall or ceiling in (W/ m^2 K)
x_1	Thickness of first layer for wall in (mm).
x_n	Thickness of last layer for wall in (mm).

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دراسة عملية لاستخدام مواد متغيرة الطور لتوفير الطاقة في المباني

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في هذه المقالة تم إجراء بحث تجريبي مخصص لإستخدام مواد متغيرة الطور (PCM) من خلال دمجها مع طبقات جدران المبنى. تم دراسة تأثير نسبة حجم PCM والإتجاه على الكفاءة الحرارية والراحة الحرارية. تم بناء نموذجين لغرفتين متطابقتين . النموذج الأول تم استخدامه كغرفة قياسية مرجعية بدون استخدام PCM والنموذج الثاني يحتوي على PCM ويستخدم لجميع دراسات الإختبار التجريبي في المركز القومي للبحوث ، NRC، الجيزة ، خط العرض (٣٠.٠٨ ° شمالاً) بمصر. هذا وقد تم استخدام PCM في الاختبارات العملية من شمع البارافين الذي له نقطة انصهار (٢٩ درجة مئوية). تم تقييم اداء المواد متغيرة الطور فى اتجاه الحائط الجنوبى والشرقى والغربى وفى وجود الاتجاهات الثلاثة معا . وقد تبين ان استخدام PCM تسبب في انخفاض ملحوظ في درجة حرارة الهواء الداخلي وبالتالي انخفاض في حمل التبريد الذي يقلل من طاقة المبنى المستهلكة. وقد تم مقارنة النتائج العملية بمثيلتها وتبين وجود تقارب بين الدراسة الحالية والدراسات السابقة مما يعظم استخدام المواد متغيرة الطور فى المبانى السكنية.