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Numerical analysis of Phase Change Materials utilization for energy saving in Egyptian buildings

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Abstract

The storage of thermal energy is one of the economic ways to achieve a rationalization of energy consumption in buildings and to ensure comfort conditions. The effect of using phase change materials on the room structure located in Egypt was studied using the PCM Express modeling and simulation program. The theoretical calculations were based on the PCM boards were impeded inside the walls. The study showed the importance of using phase change materials in the building structure compared to the traditional room due to the thermal efficiency of these materials and the storage and release of heat energy, which contributes to reducing thermal loads and good internal comfort conditions. Where five different cities were studied in Egypt (Cairo, Alexandria, Asyut, Aswan and Suez) and the study concluded that the city of Alexandria achieved the highest rise in energy saving by 2.59 kW/m^3 day. The current study also demonstrated the effect of use of phase change materials with different thicknesses (5 mm, 10 mm and 15 mm). It is found that the thickness of 15 mm achieved higher energy saving by 2.34 kW/m^3 day. Walls orientation (East, North, South, and West) were also studied, and it is found that the south wall achieved higher energy saving by 1.92 kW/m^3 day. Different PCM types was studied (Paraffin PCM, fatty acid PCM and hydrated salts PCM) and it is concluded that the higher energy saving was achieved by the values of 2.1 kW/m^3 day, 1.7 kW/m^3 day, 0.6 kW/m^3 day for Paraffin PCM, fatty acid PCM, and hydrated salt PCM respectively. The conditions of internal comfort for the study rooms obtained the highest average increase in annual comfort temperature and energy saving by 38.9%

Keywords: Phase change materials, Energy saving, Comfort conditioning.

1. Introduction

The building sector in countries is estimated to be responsible for more than 40% of global energy consumption (more than transports or industry) and 24% of greenhouse gas emissions [1]. An increase in the emissions of greenhouse gas resulting from human activities is responsible for the rise of the average global temperature. When there is an increase of 2 ºC (compared to pre-industrial times) in the global temperature that lead to negative impact on the environment will occur. It is crucial to maintain global warming below 2ºC (European Union, Climate Action). This means that, according to the 2-degree scenario, until 2050, the building sector must reduce its total CO2 emissions by 60% [2]. Space heating and cooling is the most relevant energy service in buildings and it's responsible for about 60% of the total energy consumption in buildings [3]. An increase in Heating, Ventilation and Air Conditioning (HVAC) systems efficiency has also been responsible for a reduction in energy consumption; however, energy efficiency

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improvements should not be limited to these approaches. Increasing the building's thermal inertia was a best way to decrease the amount of energy used for cooling and heating [4]. Phase Change Materials (PCM) undergo phase change at temperatures within the thermal comfort range, so they work as a Thermal Energy Storage (TES) system, storing great amounts of latent heat and thus increasing the building's thermal inertia. TES is an essential tool for designing Nearly Zero Energy Buildings (NZEB), that have very high energy performance and where the small amount of energy demand is provided mostly by local renewable sources. The energy performance of buildings directive requires all new buildings or submitted to large renovations to be nearly zero-energy by the end of 2030[5]. The incorporation of phase change materials has been studied as an effective layer in a home floor heating system. A set of design criteria for phase change materials to efficiently store heat energy has been proposed. The material was a change in the paraffin wax stage with a 40 ° C phase change. Luisa et al. proposed an efficient system using microencapsulated PCM in concrete walls for energy savings [6]. The use of PCM with small capsules in concrete walls has been studied to save energy. The new innovative concrete with phase change materials (PCM) was studied on the thermal aspects. The aim was to develop a product that achieves significant energy savings in buildings. The work was the construction and experimental installation of two real-sized cement cubes to study the effect of PCM insertion with a melting point of 26°C. The results of that study showed energy storage in walls by laminating PCMs and comparing with conventional concrete without PCMs which leads to thermal inertia as well as lower internal temperatures [7]. Available numerical technique and diagram solution are documented in PCM modeling. For modeling an enhanced wall boards using PCM, two methods were proposed to address variable parameters as well as the mobile interface within PCM [8]. The thermal nebulization of the gypsum board with acidic acid and paraffin wax was studied as an external or internal wall and was subject to daily change in internal and external temperature. Focus on the effect of both the melting temperature of the phase change material and the latent heat of the phase change material. Phase change material with a melting temperature equal to the average room temperature and with a melting area of no more than ± 2°C [9]. A new method for preparation of microencapsulated phase change materials (PCMs) for low coast energy in cooling of building was studied and the prepared microencapsulated of paraffin wax acts as core material of phase change material covered by polymer was prepared by using rabid (physical-chemical) with lower energy (green) method. Pre-polymer of condensed Melamine-Formaldehyde resin was solidified by heat effect gradually and surrounds the Paraffin wax as microcapsules. The diameter of the prepared capsules was about (170-220) micron which has a proportion with the pre-polymer temperature, otherwise the thermal analysis appears as a best value of enthalpy (ΔH) which was (12 J/gm) when the pre-polymer temperature was (60˚C) [10]. The investigated experimentally the influence of (PCMs) in Mediterranean buildings they were described as an experimental set-up to test phase change materials with conventional and alveolar brick for insulated construction under real conditions. They showed that the experimental results of the winter period showed a positive effect of the PCM. The increase of the insulation effect introduced by the PCM results in warmer temperatures inside the PCM cubicles, especially during the cold hours of the day [11]. Experimental and theoretical analysis of a cement mortar containing microencapsulated PCM was investigated and tested cement mortar containing microencapsulated PCM. In Moderate climates, the relatively large thermal mass of the concrete walls and floors can be an advantage, as they store up energy during the day and release it at night, thereby reducing the need for auxiliary cooling/heating [12]. Investigation of the impact of the control strategy on the energy consumption transformation in a building integrated with the PCM board was studied. Five operating room temperature ranges were chosen in the context of charging the system during the peak period. The thermal energy consumption in a room furnished with a PCM material was simulated and determined during the charging period and the whole day. Also, the shift in energy demand for each strategy was calculated for three different climate conditions. It was concluded that having a greater range of operating room temperature leads to higher energy consumption during the charging period and the whole day. Moreover, a larger range of operating temperature avoids the operation of the air conditioner for a longer period after hours of charging. It has been indicated that a higher latent thermal power is used for PCM, and a longer energy transition is obtained [13]. The effect of using phase change materials on a flat structure located in the city of Homs was investigated using the PCM Express modeling and simulation program. PCMs have been chosen to have a phase transition temperature equal to the interior design temperature installed on the inside of the walls and ceiling. That study found that 15mm PCM panels achieved 43% annual thermal load savings compared to a layer of polyurethane thermal insulation of the same thickness and composition at the same location [14]. The TABS application was examined with control strategies for storing thermal energy in conventional building materials as reasonable heat to enable reduced energy consumption during peak hours. Besides traditional building materials, concrete and bricks, the incorporation of PCM into the building elements provides the opportunity to store both sensible and latent heat. The latent heat is more preferred than sensible thermal storage due to its high energy storage density and the semi-thermal nature that occurs around the melting temperature. Therefore, a PCM envelope mixture in the building envelope and control strategy for PCM charge and discharge management can provide storage capacity to reduce the air conditioning load off-peak [15,16]. A new tile was experimentally tested including PCM to supply the floor for energy savings during heating and cooling seasons. A mixture of paraffin composition was tested inside the tiles. It was found that the application of this new tile fixes room temperature in winter and absorbs heat inside the room in summertime when the PCM melting point is below average room temperature. Moreover, the results showed that tiles receiving direct solar radiation are more effective in heating space in winter [17]. Novel concept of composite phase change material wall system for year-round thermal energy savings was investigated. A novel composite wallboard consisting of an insulation sandwiched between two PCM layers to save heating and cooling energy in continental climate areas. A year-round simulation was conducted to model the thermal performance of the wallboard using the enthalpy method with effective heat capacity. The outer PCM layer was proposed to reduce the solar heat flux in the cooling season, while the inner PCM layer was applied to reduce the indoor temperature swing and shift the peak. The design specified that the outer PCM layer required a higher melting temperature than the inner PCM layer. They concluded that the suggested two-layer PCM may have a peak load reduction up to 36% for both heating and cooling seasons. The total heating load saving was 12.8%, while the cooling load reduction was only 1% [18]. The present study focused on testing the efficiency of the application of passive PCMs in different climatic zones in Egypt, starting out with the premise that the high thermal storage capacity in paraffin wax board (PCM) would help to control the internal temperature of the study space, reduce temperature peaks, and improving thermal balance. A passive system was chosen as it didn’t require any additional energy, it´s the simplest method of application, and according to the recent studies, the most cost-effective and environmentally sound means of using PCM [19]. A comparative study was carried out using dynamic energy simulations of all the possible combinations of study variables. For each simulation, two rooms studies were always used, the “Reference room” without PCM and the “Test room” with PCM incorporated, in order to verify the benefits of the incorporation of phase change materials. The key issues for improving the interior thermal conditions by means of PCM that were analyzed are:

1- Reduction of peak temperature.

2- Reduction of temperature swing.

3- Reduction of hours with temperature out of the comfort zone (21 ºC - 26 º C).

2. PCM selection

The study was carried out using paraffin wax boards. The ease of installation and the possibility of passive use were also key in its selection. The paraffin wax boards were used as phase changing material. When the temperature rises, the paraffin wax inside the aluminum boards begins to melt, and as it changes phase it absorbs and accumulates a great amount of heat. When the temperature drops, the paraffin wax begins to solidify and emit heat as it changes phase. During the change from solid to liquid or vice versa, their physical and thermal properties are showed in table (1).

3. Study variables

The following study variables can be summarized as; the influence of PCMs in building in different Egyptian climates, PCMs thicknesses, orientations of room building, different types of PCM. The climatic data for the city of Cairo (Egypt) were obtained based on Meteonorm 7. This program handles data in standard format TMY (typical Metrological Year files are read by the PCM Express program [20].

The simulations were carried out using PCM Express program. It is a simulation program that developed in the "Development of a user-friendly planning and simulation program" within framework "PCM Thermal Storage Active Systems in Buildings". The mathematical models and algorithms were developed by the Fraunhofer Institute of Solar Energy Systems (ISE) in Freiburg, Germany, with the support of the industrial sector and the Federal Ministry of Economy and Technology (FMET) and its interface was designed by Valentin Energy software.

4. Phase Change Material Simulation program

PCM express1.0 can simulate PCMs only with the Conduction Finite Difference (CondFD) solution algorithm. CondFD divided walls, floors, and ceilings into several nodes and used an implicit finite difference scheme to numerically solve the appropriate heat transfer equations. The CondFD algorithm in PCM express1.0 uses an implicit finite difference scheme, where the user can select Crank-Nicholson or fully implicit. Equation1 shows the calculation method for the fully implicit scheme for a homogeneous material with uniform node spacing.

$$\mathbf{Cp\ \rho\ \Delta x\ \frac{T_i^{j+1}-T_i^{j}}{\Delta t} = Kw\ \frac{(T_{i+1}^{j+1}-T_i^{j+1})}{\Delta x} + K_E\ \frac{(T_{i+1}^{j+1}-T_i^{j+1})}{\Delta x}} \quad \textbf{(1)}$$

Where:

$$\mathbf{Kw = \frac{(T_{i+1}^{j+1} - Ti^{j+1})}{2}}$$

$$\mathbf{K_E = \frac{(T_{i+1}^{j+1}-T_i^{j+1})}{2}}$$

$\boldsymbol{k_i} = (\mathbf{T_i^{j+1}})$, if thermal conductivity is variable, [W/m K]

T = temperature, [°C]
i = node being modeled
i+1 = adjacent node to interior of construction
i-1 = adjacent node to exterior of construction
j+1 = new time step
j = previous time step
Δt = time step
Δx = finite difference boards thickness, mm
Cp = specific heat of material, [J/kg K]
ρ = density of material, [kg/m^3]

In the CondFD algorithm, all elements are divided or discretized automatically using Equation 2 [21], which depends on a space discretization constant (c), the thermal diffusivity of the material (α), and the time step. It can be leaved the default space discretization value of 3 (equivalent to a Fourier number (Fo) of 1/3) or input other values.

$$\mathbf{\Delta x = \sqrt{c\ .\ \alpha\ .\ \Delta t} = \sqrt{\frac{\alpha\ .\ \Delta t}{Fo}}} \quad \textbf{(2)}$$

For the PCM algorithm, the CondFD method is coupled with an enthalpy-temperature function Equations 3, 4 [21] that the user inputs to account for enthalpy changes during phase change. The enthalpy-temperature function is used to develop an equivalent specific heat at each time step.

$$\mathbf{h = h\ (T)} \quad \textbf{(3)}$$

$$\mathbf{Cp(T) = \frac{h_i^{j} - h_i^{j-1}}{T_i^{j} - T_i^{j-1}}} \quad \textbf{(4)}$$

Where:
h = enthalpy, [kJ/kg]

5. Simulations

The thermal performance of the reference room was simulated and studied in dynamic regime on hourly basis. This process was repeated with each of the possible combinations of variables established in the study. From the results, daily and annual charts were generated with the evolution of the interior temperature of the reference rooms and test room as shown in Figs.1-5. It presents interior room temperatures for the summer months (May, Jun, July, August and September) in 2019, for both rooms with and without PCM. In figures 1-5, interior room temperature with PCM was lower than interior temperature without PCM throughout the study. The reduction is due to using PCM in building 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,

Table1. physical and thermal properties of the room:

			Use	**living**
GENERAL DATA	**Length**	2 m	**Furniture**	Normal
	Width	2 m	**Orientation**	Exterior wall south facing
	Height	2.5 m	**Internal load**	20 w/m^2
	Floor Area	4 m^2	**Free ventilation**	0,6 l/h
	Volume	10 m^3	**Natural ventilation**	with windows possible

CEILING (4 m^2)	**Construction**	**Material**	**Thickness (mm)**	**Thermal Conductivity (W/mK)**
		Hard Wood Panel	7	0,173
	Situation	Interior (Adiabatic)		
NORTH WALL (5 m^2)	**Construction**	**Material**	**Thickness (mm)**	**Thermal Conductivity (W/mK)**
		Cement mortar	20	0.14
		Hollow brick	65	0.7
		Cement mortar	20	1.4
	Window	Glass with frame of wood single Glass G-value = 50 Glass/Frame Ratio = 70	3	0.8
	Situation	External Wall (to outside air)		
SOUTH, WEST and EAST WALLS (5m^2, 5 m^2 and 5 m^2)	**Construction**	**Material**	**Thickness (mm)**	**Thermal Conductivity (W/mK)**
		Cement mortar	20	1.4
		Hollow brick	65	0.7
		Cement mortar	20	1.4
	Situation	External Walls (to outside air)		
FLOOR (4 m^2)	**Construction**	**Material**	**Thickness (mm)**	**Thermal Conductivity (W/mK)**
		Sand	20	0.9
		Concrete	25	1.91
		Cement plaster	20	1.4
	Situation	Interior (Adiabatic)		
PCM	**Construction**	**Material**	**Thickness (mm)**	**Thermal Conductivity (W/mK)**
		paraffin wax	5. 10 and 15	0.2
		Melting temperature 29 °C		
	Situation	Internal		

when such material melts, it absorbs a large amount of heat from the environment. PCMs charge /discharge heat as ambient temperatures fluctuate. During night hours, the interior temperature of the test room becomes higher than that in reference room because of discharge, as the PCMs begins to discharge heat through the discharging process at nighttime. Also, it can be seen from these figures that there is a fluctuation in room temperature for two cases with or without PCM because of external temperature fluctuation. The reduction ratio of indoor room temperature and energy saving as shown in table 2.

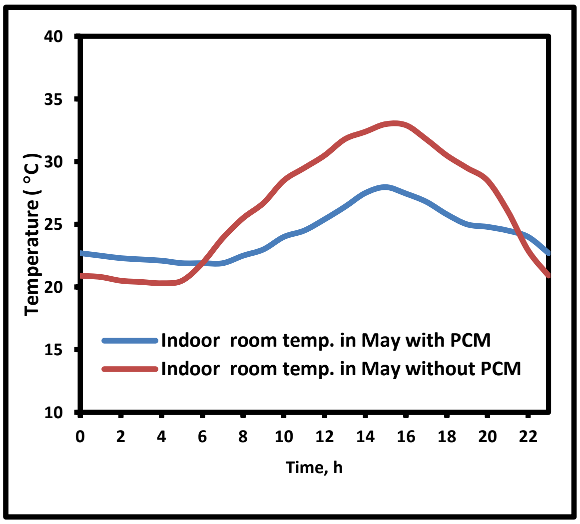

Fig.1. Indoor room temperatures with and without PCM 15/ May/2019

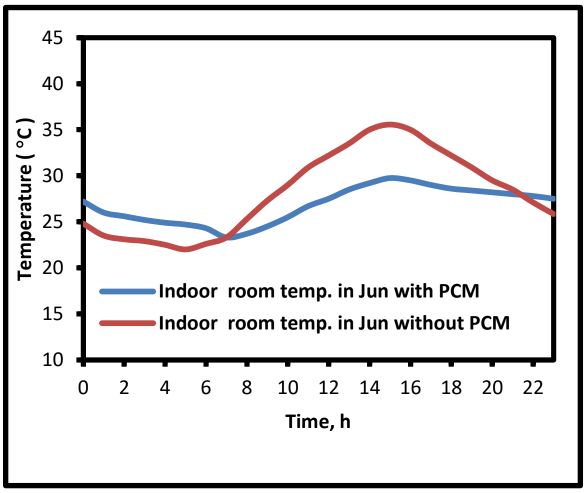

Fig.2. Indoor room temperatures with and without PCM 8/ Jun/2019

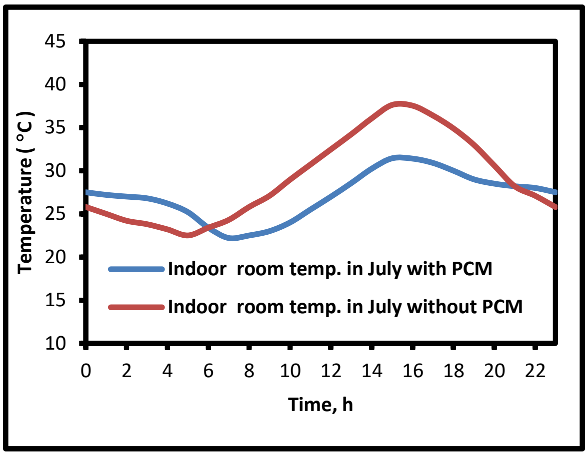

Fig.3. Indoor room temperatures with and without PCM 10/ July/2019

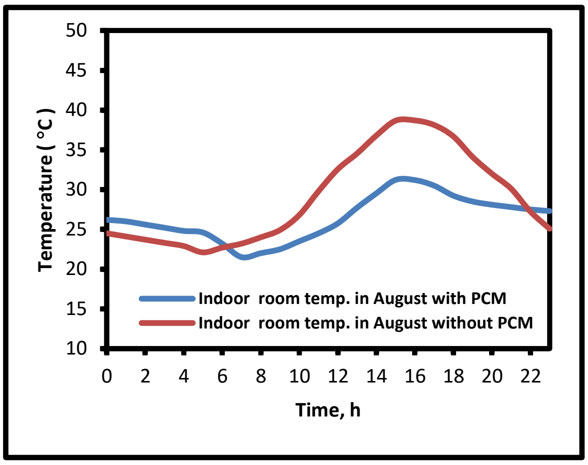

Fig.4. Indoor room temperatures with and without PCM 22/ August/2019

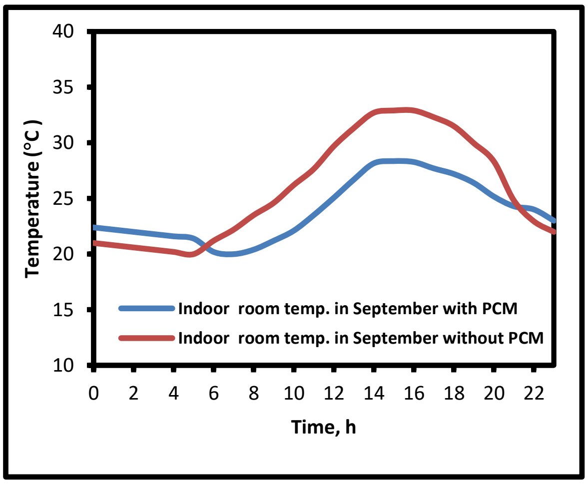

Fig.5. Indoor room temperatures with and without PCM 12/ September/2019

Table2. Reduction of temperature and energy saving in summer months:

Months	$T_{withoutPCM - withPCM}$ (° C)	Energy saving (kW/m³ day)	Date
May	5.4	2.037	15/ May/2019
Jun	5.7	1.943	8/ Jun/2019
July	6.2	2.142	10/ July/2019
August	6.5	2.368	22/ August/2019
September	4.6	1.677	12/ September/2019

6. Results and discussions

All the information generated by the simulations (data, results and figures) were organized in figures in order to make the data analysis easier and more effective. The results obtained show a lot of information referring to achieve interior comfort, however, this study focus on the key issues related to the improvement of interior thermal conditions and energy saving as a result of the incorporation of PCM in the study rooms.

6.1 Effect of different climatic zones in Egypt:

• Cairo city climate (30.08° N) latitude:

In the test room of temperature within comfort range (21ºC - 26 ºC), it is found that the highest increase in comfort hours was achieved with (2304 h) with a percent of 26.3%, and energy saving by 2.34 kW/m3 day. While in the reference room was (1384 h) with a percent of 15.8%. In the test room reductions in temperature peaks were achieved up to 7.1 ºC compared to the reference room as shown in Fig. 6 and table 3.

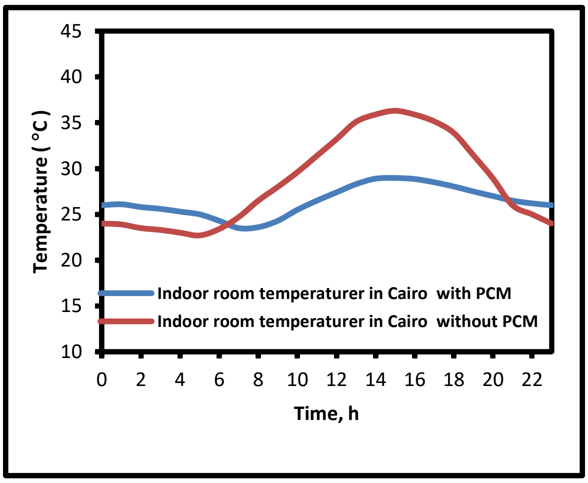

Fig.6 Daily results of indoor room temperatures in Cairo. 18/ July/2019

• Alexandra city climate (31.20° N) latitude:

In the test room of temperature within comfort range (21ºC - 26 ºC), it is found that the highest increase in comfort hours was achieved with (2479 h) with a percent of 28.5%, and energy saving by 2.59 kW/m3 day. While in the reference room was (1489 h) with a percent of 17%. In the test room reductions in temperature peaks were achieved up to 7.6 ºC compared to the reference room as shown in Fig. 7 and table 3.

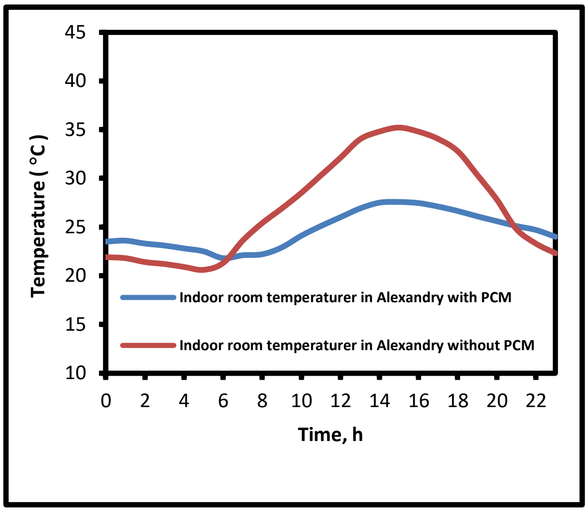

Fig.7 Daily results of interior room temperatures in Alexandra. 18/ July/2019

• Asyut city climate (27.05 ° N) latitude:

In the test room of temperature within comfort range (21ºC - 26 ºC), it is found that the highest increase in comfort hours was achieved with (1892 h) with a percent of 21.6%, and energy saving by 1.98 kW/m3 day. While in the reference room was (1139 h) with a percent of 13%. In the test room reductions in temperature peaks were achieved up to 6.2 ºC compared to the reference room as shown in Fig. 8 and table 3.

•Aswan city climate (23.97 ° N) latitude:

In the test room of temperature within comfort range (21ºC - 26 ºC), it is found that the highest increase in comfort hours was achieved with (1183 h) with a percent of 13.5%, and energy saving by 1.53 kW/m3 day. While in the reference room was (718 h) with a percent of 8.2%. In the test room reductions in temperature peaks were achieved up to 5.1 ºC compared to the reference room as shown in Fig. 9 and table 3.

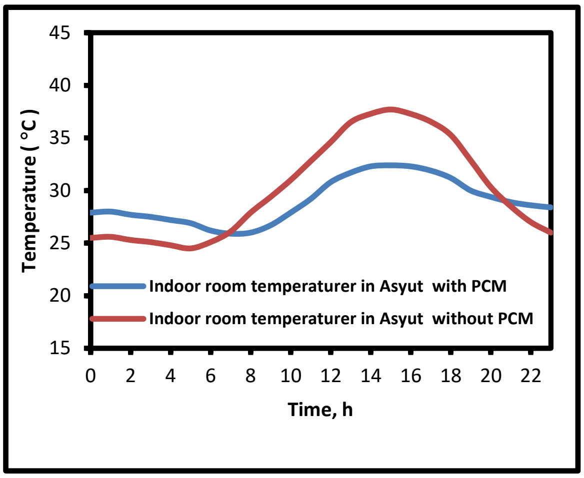

Fig.8 Daily results of interior room temperatures in Asyut. 18/ July/2019.

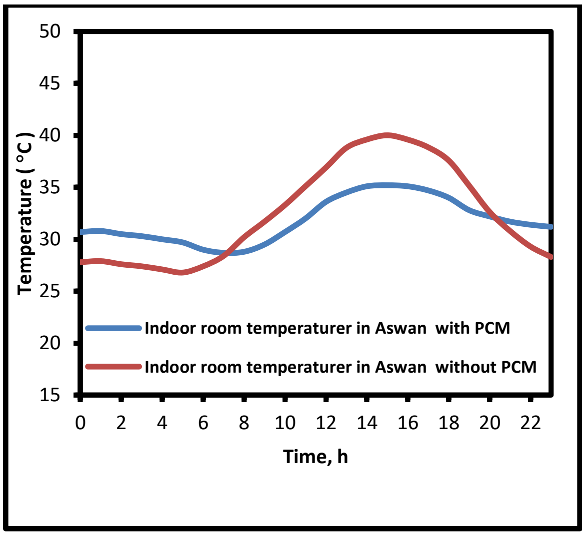

Fig.9 Daily results of interior room temperatures in Aswan. 18/July/2019

•Suez city climate (29.87 ° N) latitude:

In the test room of temperature within comfort range (21ºC - 26 ºC), it is found that the highest increase in comfort hours was achieved with (1945 h) with a percent of 22.2%, and energy saving by 2.26 kW/m3 day. While in the reference room was (1235 h) with a percent of 14.1%. In the test room reductions in temperature peaks were achieved up to 6.8 ºC compared to the reference room as shown in Fig. 10 and table 3. The PCMs increase the capacity of thermal storage in construction building in Egypt as shown in Fig. 11[a & b].

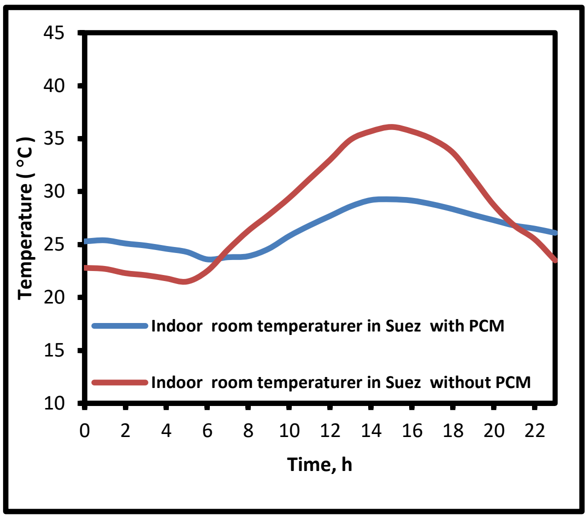

Fig.10 Daily results of interior room temperatures in Suez. 18/July/2019

Table3 Comfort hours and max. temp. reduction:

Cities	**Comfort hours (21 °C - 26 °C)**		**$T_{withoutPCM - withPCM}$ (°C)**	**Energy saving (kW/m^3 day)**
	Convential system	PCM system		
Cairo	1384 h (15.8 %)	2304 h (26.3 %)	7.1	2.34
Alexandry	1489 h (17 %)	2479 h (28.3 %)	7.6	2.59
Asyut	1139 h (13 %)	1892 h (21.6 %)	6.2	1.98
Aswan	718 h (8.2 %)	1183 h (13.5 %)	5.1	1.53
Suze	1235 h (14.1 %)	1945 h (22.2 %)	6.8	2.26

The test room in Alexandria obtained the highest average increase in annual comfort hours. The values of comfort hours and its percentage were 2479 h (28.3%), 2304 h (26.3%), 1945 h (22.2%), 1892 h (21.6%), 183 h (13.5%) for Alexandria, Cairo, Suez, Asyut and Aswan respectively. It is found that, the city of Aswan recorded the least hours of comfort when using PCM. This is because during the summer in Aswan, the ambient temperature at night is relatively hot, so the chance to change the full phase from liquid to solid is less when compared to cooler places such as Alexandria that recorded the highest hours of comfort when using the PCM, because in Alexandria the ambient temperature is lower than that of other cities and thus the phase change occurs more frequently when using PCM.

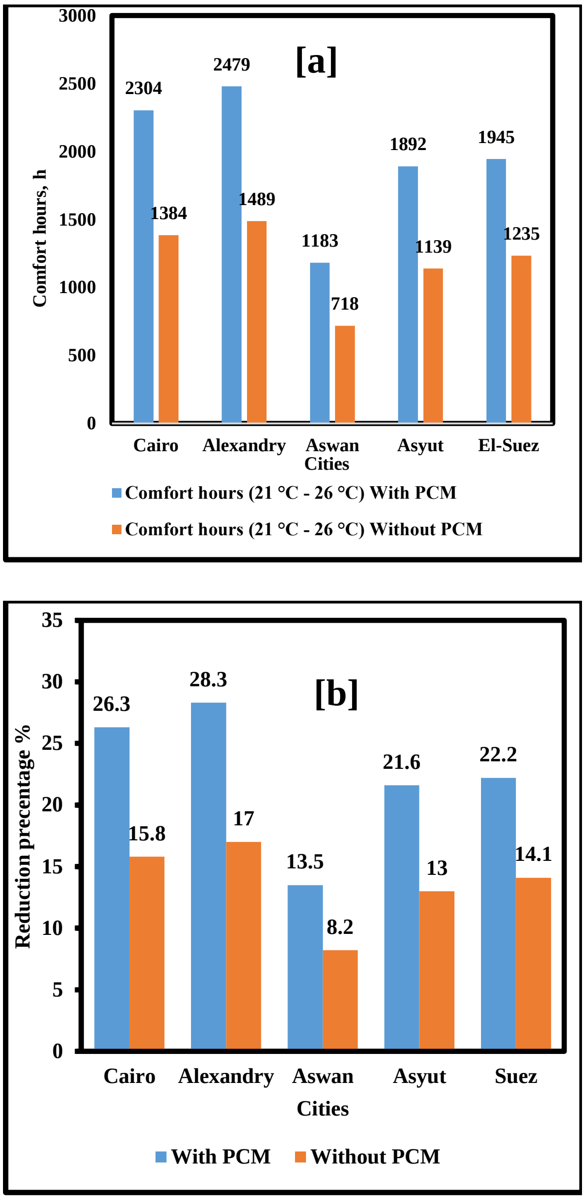

Fig.11. [a & b] Comparison of the current study cities with comfort hours and the rate of reduction when using PCM

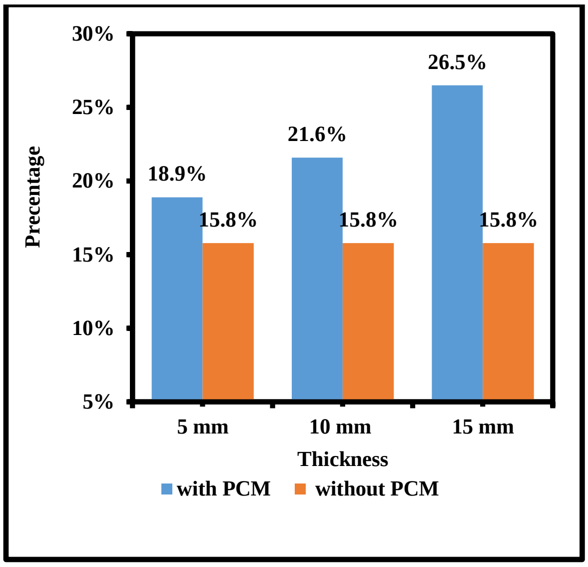

Fig.12 [A] Effect of PCM thicknesses. 18/Jun/2019

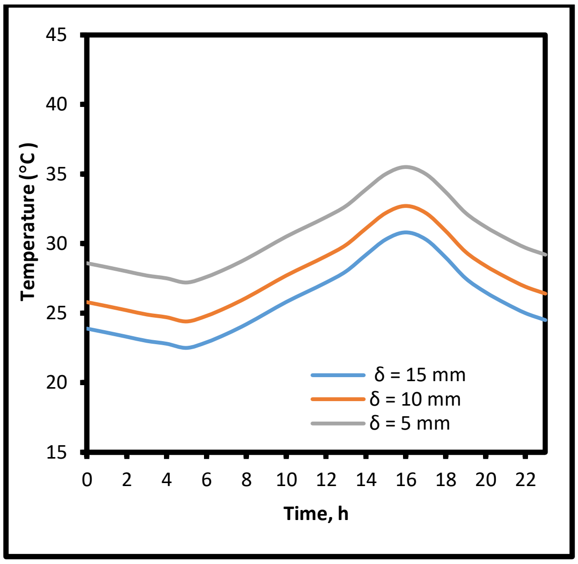

Fig.12 [B] Reduction percentage of PCM thicknesses

6.2 PCM thickness effect

Figure 12 [A and B] illustrate a decrease in the temperature of the condition in which PCM boards are integrated onto internal walls of various thicknesses (5, 10, and 15 mm) for PCM boards of fixed area. The presence of PCM boards reduced temperature by increasing the thickness of PCM. The usage of PCM with 15 mm recorded the highest energy saving and temperature reduction in the current study. The energy saving compared to the reference room was recorded 2.34 kW/m^3 day with 26.5%, 1.44 kW/m^3 day with 21.6%,1.04 kW/m^3 day with 18.9% for a thickness of 15 mm, 10 mm and 5 mm respectively. This is because the energy that can be stored is directly related to the amount of PCM in the boards and then to the thickness of the PCM boards. Whenever the amount of PCM is relatively large, this leads to the time of its melting process, to absorbing a greater amount of latent heat from the room, which leads to a reduction in the temperature inside the place by large proportions, and in turn leads to a large amount of energy saving.

6.3 Effect of PCM types

A comparative study of different types of PCMs was studied in the current research like (paraffin PCM, fatty acids PCM and hydrated salts PCM) whose physical properties are shown in the table 4 and the impact of each of them to reduce the temperature inside the room and energy saving when combined with the building walls of the rooms. Through the analysis, it was found that the best type to reduce indoor room temperature and saving energy is paraffin PCM. The results were estimated as 2.14 kW/m^3 day, 1.7 kW/m^3 day and 0.6 kW/m^3 day for paraffin PCM, fatty acids PCM and hydrated salts PCM respectively. Figures 13 and 14 showed described the reason that paraffin PCM is more energy saving because paraffin mixtures of different mass proportions have a wider phase change temperature range and higher phase change latent heat. Therefore, paraffin can be used in different thermal storage areas by adjusting the mixed ratio. On the other hand, paraffin is the most commercially available and the maximum frequency of use is 87.5% [22]. Fatty acids are also a type of PCM task and can reach 27%. While PCM of hydrated salts recorded less energy saving, compared to paraffin PCM and fatty acids PCM, probably due to the aqueous properties of the absorption of aqueous salt with its high conductivity.

6.4 Orientation effect of room building

Figure 15 [A and B] show the energy saving by incorporating PCMs boards in all walls in the test room. The simulation results of the test room obtained the values of annual comfort temperature and (energy saving) as 26.3%, (1.92 kW/m^3 day), 22.8%, 1.64 kW/m^3 day, 21.9%, (1.48 kW/m^3 day), 18.8%, (1.14 kW/m^3 day) for South, West, East and North wall orientation respectively. It is found that the south wall recorded the best reduction in the indoor room temperature as well as the best energy saving, because the south wall is more exposed to sunlight during daylight hours, which leads to melting process of the PCM better, which works to withdraw a large amount of latent heat from the place that keeps the room interior temperature low during daylight hours as shown in table 5.

Table 4 Properties of the PCM types:

Type of PCM	Heat of fusion [kJ/kg]	Thermal conductivity [W/m K]	Density [kg/m^3]
Paraffin	179	0.2	880
Fatty acid	142.7	0.12	752
Hydrated salts	752	1.0	1490

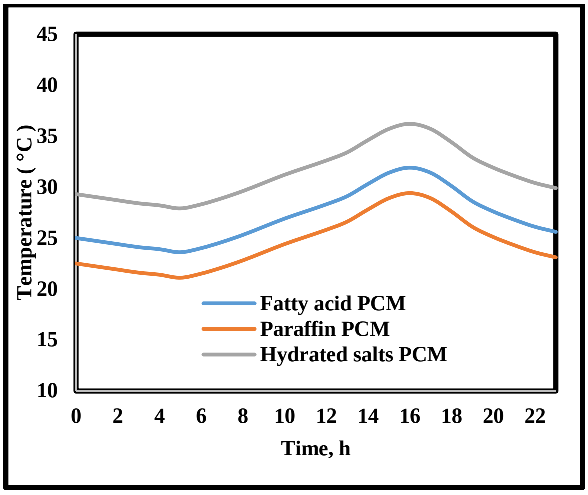

Fig.13. Comparison between PCM types effect of indoor room temperature

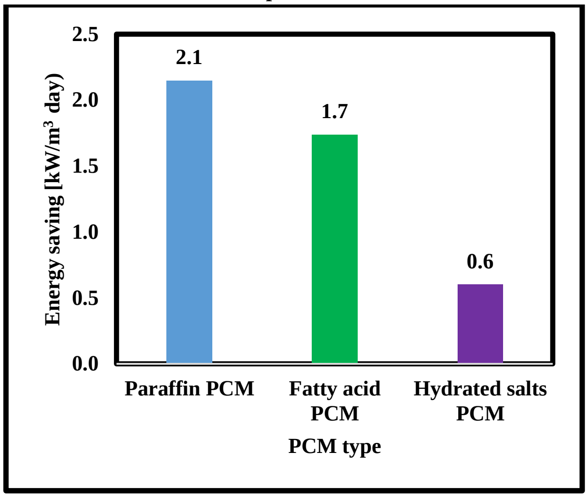

Fig.14 Comparison between PCM types effect of energy saving

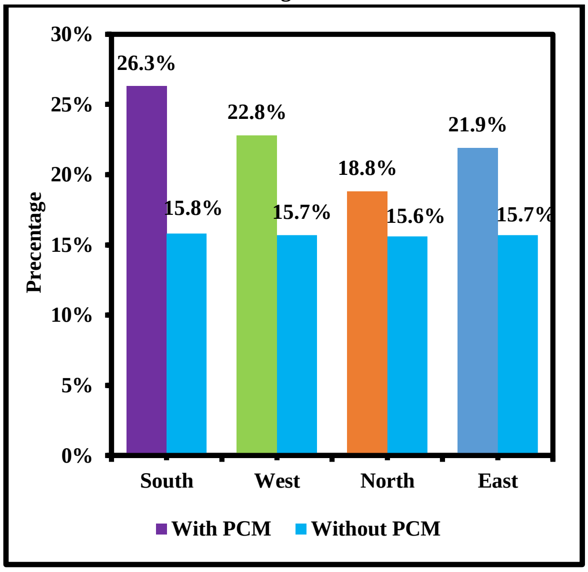

Fig.15 [A] Energy saving indoor room temperature with PCM by orientation of walls

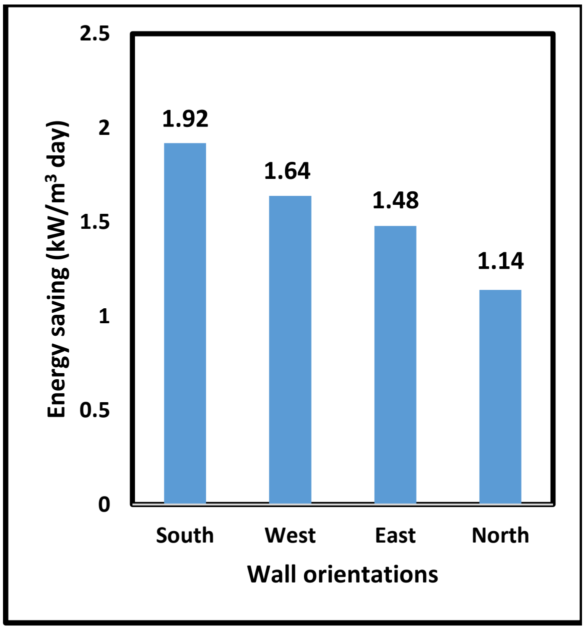

Fig.15 [B] Reduction percentage of PCM orientation of walls

Table 5 Reduction of temperature and energy saving with orientation of walls:

Orientation of wall	$T_{withoutPCM - withPCM}$ (° C)	Energy saving (kW/m³ day)
South	6.8	1.92
West	5.2	1.64
East	4.7	1.48
North	3.6	1.14

6.6 The air conditioning system

Several simulation runs are made to find out the comfort hours and its percentage in case using air conditioning system in both test and reference rooms. It is found that the comfort hours and its percentage were 3408 h (38.9%) and 1927 h (22%) for test and reference rooms respectively. In the test room, reductions in temperature peaks were achieved up to 10.7 °C. From the simulation results in case of using air conditioning system, it is found that the PCM has achieved annual conditioning in the test room 704.33 kWh while in the reference room was 846.85 kWh. This is due to the reduction of thermal loads in case of test room than that of reference room. Using PCM in air-conditioned space improved the conditions of internal comfort and that led to energy saving in summer months as shown in Fig.16 and tables 6 and 7.

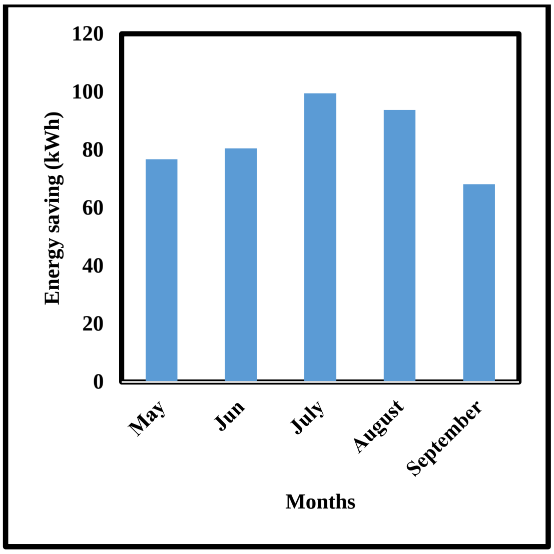

Fig.16 Monthly energy saving with conditioning system

Table 6 Annual total cooling energy and Comfort hours with air conditioning system:

Annual total cooling energy [kWh]		Comfort hours [21 °C - 26 °C]	
Reference room	Test room	Reference room	Test room
846.85	704.33	1927 h (22 %)	3408 h (38.9 %)

Table 7 Monthly energy saving and temperature reduction with air conditioning system:

Month	$T_{withoutPCM - withPCM}$ [° C]	Energy saving [kWh]
May	8.1	76.7
Jun	8.5	80.5
July	10.5	99.5
August	9.9	93.8
September	7.2	68.2

Validation of a numerical present study vs Authors experimental previous work [23]:

The numerical results of the present study were validated with the corresponding authors experimental previous work Figure 17. showed a comparison between the daily cooling energy saving per space volume for the numerical present study and experimental study made the authors [23]. There is a considerable agreement between the theoretical and experiment works.

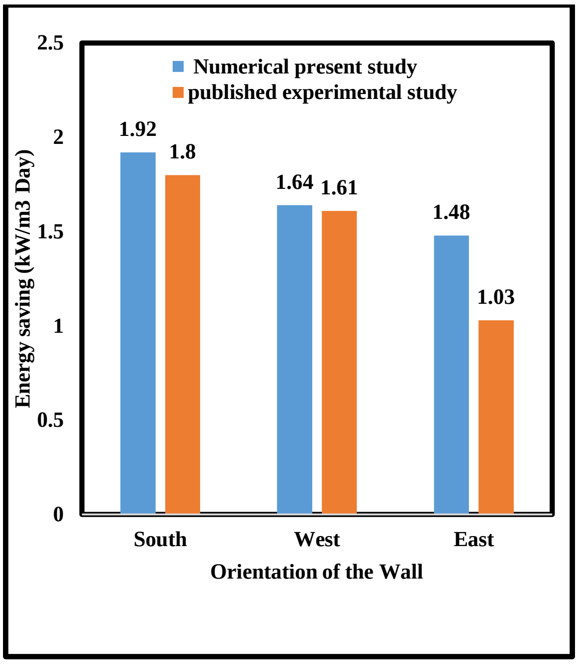

Fig.17 Comparison between the energy saving for the numerical present study and published experimental study

7. Conclusions

After simulating the test and reference rooms to study the effect of PCM boards on comfort conditions and energy saving, some concluded remarks can be listed as follows:

• The test room in Alexandria obtained the highest average increase in annual comfort hours. The values of comfort hours and its percentage were 2479 h (28.3%), 2304 h (26.3%), 1945 h (22.2%), 1892 h (21.6%), 183 h (13.5%) for Alexandria, Cairo, Suez, Asyut and Aswan respectively

• The usage of PCM with 15 mm recorded the highest energy saving and temperature reduction in the current study. The energy saving compared to the reference room was recorded 2.34 kW/m^3 day with 26.5%, 1.44 kW/m^3 day with 21.6%,1.04 kW/m^3 day with 18.9% for a thickness of 15 mm, 10 mm and 5 mm respectively.

• it was found that the best type to reduce indoor room temperature and saving energy is paraffin PCM. The results were estimated as 2.14 kW/m^3 day, 1.7 kW/m^3 day and 0.6 kW/m^3 day for paraffin PCM, fatty acids PCM and hydrated salts PCM respectively.

• The simulation results of the test room obtained the values of annual comfort temperature and (energy saving) as 26.3%, (1.92 kW/m^3 day), 22.8%, 1.64 kW/m^3 day, 21.9%, (1.48 kW/m^3 day), 18.8%, (1.14 kW/m^3 day) for South, West, East and North wall orientation respectively.

• From the simulation results in case of using air conditioning system, it is found that the PCM has achieved annual conditioning in the test room 704.33 kWh while in the reference room was 846.85 kWh.

8. Abbreviations:

HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
ISE	Institute of Solar Energy Systems
NZEB	Nearly Zero Energy Buildings
PCM	Phase Change Materials
TES	Thermal Energy Storage

Nomenclature:

C_p	Specific heat temperature, [J/kg K]
h	Enthalpy, [kJ/kg]
i	node being modeled
j	previous time step
K	Thermal conductivity, [W/m K]
T	Temperature, [°C]
ρ	Density [kg/m^3]
δ	PCM thickness, [mm]
Δx	finite difference boards thickness, mm
Δt	time step

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