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Numerical Investigation of Phase Change Materials for Insulation of Residential Buildings in Hot Regions in Iraqi cities

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Abstract-In this paper, numerical study has been conducted for using PCM as thermal insulation materials by incorporating it with layers of walls and ceiling of buildings. The effect of PCM and its role in improvement of thermal performance and thermal comfort is numerically studied. ESP-r software program has been used for numerical simulation in this paper. Energy plus weather database software was used to create climate date for Kut city (32.٥ ^{o}N ٤٥.8 ^{o}E) that used for simulation in this study. Two identical rooms were inserted in software ESP-r with dimensions (1.5m*1.5m*1m), the first is standard room for comparison and the second is test room for experimenting. Many cases were studied according to the thickness of the PCM and according to the orientation (North wall, South wall, East wall, West wall, and ceiling). Results obtained showed a reduction in indoor temperature of the zone and the reduction in the cooling load and as a result saving in electricity consumption with using PCM as insulation materials.

Keywords: *Phase change materials, PCM, reduce indoor temperature, ESP-r, thickness of PCM, cooling load, numerical simulation.*

(تحقيق عددي لأستخدام المواد متغيرة الطور لعزل المباني السكنية في المناطق حارة الطقس في المدن العراقية)

هادي عبيد بشر، مشتاق اسماعيل حسن ، احمد عمران

الخلاصة -في هذه الورقة، تم إجراء دراسة عددية لاستخدام المواد متغيرة الطور كمواد عازلة للحرارة من خلال دمجها مع طبقات من الجدران والسقف. تم دراسة تأثير المواد متغيرة الطور ودورها في تحسين الأداء الحراري والراحة الحرارية عدديا. وقد استخدم برنامج ESP-r للمحاكاة. تم استخدام برنامج قاعدة بيانات Energy Plus Weatherلخلق بيانات المناخ لمدينة الكوت (32.5 ^{o}N,45.8 ^{o} E) التي استخدمت للمحاكاة في هذه الدراسة. تم إدراج غرفتين متطابقتين في برنامج ESP-r مع أبعاد(1.5m * 1.5m * 1m) ، الأولى هي غرفة قياسية للمقارنة والثانية هي غرفة اختبار لتجريب. تم دراسة العديد من الحالات وفقا لسمك المواد متغيرة الطور ووفقا للاتجاه (الجدار الشمالي، الجدار الجنوبي، الجدار الشرقي، الجدار الغربي، والسقف). وأظهرت النتائج التي تم الحصول عليها انخفاض في درجة الحرارة الغرفة وانخفاض في حمولة التبريد ونتيجة لذلك توفير في استهلاك الكهرباء باستخدام المواد متغيرة الطور كمادة عازلة.

I. INTRODUCTION

The apportionment of thermal mass inside a building is the consequence of constitutional and architectural resolutions and can highly affect how the building interacts to internal heat gains, solar radiation or changes in outdoor conditions. Lightweight components interact readily to changes in interior gains and solar radiation. The conventional approaches employing enormous components to temperate temperature inconstancy. Thermo-physical properties of the construction materials will have a direct effect on energy consumption of the building. Within a negative solar purpose, the heat capacity of the internal wall layer is governing. This approach it is applicable in sites that have an efficacious daily temperature variance, that, heavy weight building can give rise to problems of excrescent thermal mass and cost.

The nature of Iraq's climate can be described in two basic seasons, hot dry and long summers, and cold short winter. Difference Daily range temperature is limited and causes the assemblage of heat in the building layers.

The consumption of electrical demand is increasing, especially in hot regions due to using the cooling system where the consumption of electric energy in the building sector in Iraq reach about 38% of total energy produced, where in 2020 it will be built more than six million building unit and this will increase in electric demand [8].

The phase change materials and its used in building material considers one of methods to improve the thermal properties of the construction material where integrate these PCM with layers of the building material play important role in shifting the cooling load especially in peak load and Contributes to reducing cooling load. In this research, we will study numerical integration the PCM with layers of local construction material in Kut city in Iraq.

In the field of using the PCM as insulation materials and its incorporating with building materials there are many experimental and numerical studies were conducted.

Halford and Boehm (2006) [1] conducted simulation for using encapsulated PCM to shift the cooling load. They used encapsulated PCM in ceiling and walls and incorporated the PCM with construction materials like concrete and gypsum wallboard. They used TRANSYS program software to simulate. By comparting their results with other cases without PCM, they found 11-25% reduction in peak load compared with the case without PCM. Karthik Muruganantham (2010) [2] conducted experimental and numerical study about using BIOPCM in envelope building, ceiling and walls. He used energy plus program in the simulation. Layers of the wall were, from outside to inside, sliding door, insulation, BIOPCM and gypsum board as well as wood frame at two sides. BIOPCM was as small block. He made shed contain door and window and conducted comparative between these sheds. Dimension of the shed was (4.876m length, 3.657 m width and 2.436m height). He used wood frame to install BIOPCM. The melting range of the PCM was (27-31 ^{o}C). He found that maximum energy saving about 30%, and maximum cost saving was 30%. Mustafa B. Al-Hadithi (2011) [3] studied numerically the effect of using PCM in the wall. Mixed paraffin wax (25%)with concrete (75%) to made treat wall. Layers of the wall were, from external to internal, (cement 5mm, treat wall 20 mm, brick 300 mm and gypsum 20 mm) treated wall was West wall. He compared between treat wall and no treat wall and showed that treat wall reduced heat transfer by 66%. Madhumathi and Sundarraja (2012) [4] proved experimentally of using the PCM with traditional construction materials in hot climatic zones to reduce the cooling load and air room temperature. They used organic phase change materials of Polyethylene type with melting point (25 ºC and 31 ºC) where it was used in hollow brick. They built models each model was one cubic feet. They concluded using the PCM to improve thermal comfort and reduce in entering heat into room by 33.33%. Stephen David Zwanzig (2012) [5] evaluated numerically incorporating of the PCM with building material in field of reducing of the heating load and the cooling load. He used PCM composite wallboard into walls and roof. He checked of using of PCM as insulation material in many weathers. He used model one - dimension transient heat equation and used the Crank-Nicolson scheme to solve this equation. He used TMY3 data for create weather data. He found the optimizing location of the PCM in layer of building is important and it depended on thermal resistance of layers between the PCM and outside boundary. He compared results with cases without PCM and he found reducing in cooling load from the wall by 19.7% and from roof by 8.1% and reducing in heating load from walls by 6% and from roof by 6.4%. Monteiro da Silva and Almeida (2013) [6] conducted simulate to using of Gypsum plasterboards with micro-encapsulated PCM and macro-encapsulated PCM into family house has area 91m^2. They used software energy plus 7.2 to simulate. Rang of melting of PCM (paraffin) that used was (23 - 26ºC) and PCM (salt hydrate) (22°C - 28°C). The simulation was in the coolest and the hottest days. They integrated the PCM with ceiling and walls and used three type of construction materials concrete wall, single hollow brick and double hollow brick. They concluded the PCM reduced heating needs by 16% in coolest day and reduced cooling needs by 28% in hottest day and reduced 16% total energy needs. Also, they found increase indoor temperature by 0.7 ºC in coolest day and decrease indoor temperature by 1.4 ºC in hottest day. Mushtaq et al (2013) [7] investigated experimentally and numerically using of PCM in ceiling with cooling system for cold PCM. They used two rooms with and without PCM, dimensions of rooms were (1.8m*1.8m*2.44 m). Layers of roof, from bottom to top, without PCM were (concrete 12cm and brick mixture+ mortar 10cm) and with PCM were (concrete 12cm, light structure panel from aluminum with PCM 2.5cm and brick mixture+ mortar 10cm). Melting rang of PCM was (36.7-37 ^{o}C). They noted that reduction in heat transfer was by 46.71%. Alaa L. Hashem (2015) [8] checked the simulation of the PCM effect in the heavyweight buildings in Iraq. He inserted two models of rooms in the ESP-r software program with dimensions (4 m*5 m*3 m*). He tested many ranges of melting temperature for PCM include (24-26, 25-27, 26-28, 28-30 ^{o}C). He used PCM-gypsum composite layer at the internal side of the wall. The period of the simulation was at June, July, and August. He found that PCM influenced on the indoor temperature and these results encourage to conduct the annual comprehensive investigation of the effect of the PCM on the temperature fluctuations of the zone.

In literature that reviewed the PCM is usually used in the field of heating and cooling system to reduce thermal loads and it incorporated with construction materials like plaster or gypsum or concrete and it may be in the form of capsules. In the present work, the PCM was used as an insulation layer with aluminum structure.

II. PROBLEM DESCRIPTION AND BUILDING MODEL

A. Building Model

Two identical rooms were inserted in ESP-r with dimensions (1.5m*1.5m*1m), as shown in figure (1). ESP-r was contained a database of materials and construction layers which can be used directly or modified as required. Local building materials have been used and entered into the program database for simulation. The first room is standard room and consisting of domestic construction materials, according to the construction specifications in Iraq. The walls consist of two layers, from outside to inside, first layer from bricks with 12 cm thickness, the second layer from cement mortar with 1 cm thickness. The ceiling was from sandwich panel with 5 cm thickness. The floor was from the direct ground. The second room is test room and its construction materials are the same for that of the standard room in addition to the PCM layer. The PCM placed in the internal side of the walls and ceiling in the frame of the aluminum. The additional layer is the aluminum frame where it consists of two layers of aluminum with the thickness of (0.7 mm) for each one.

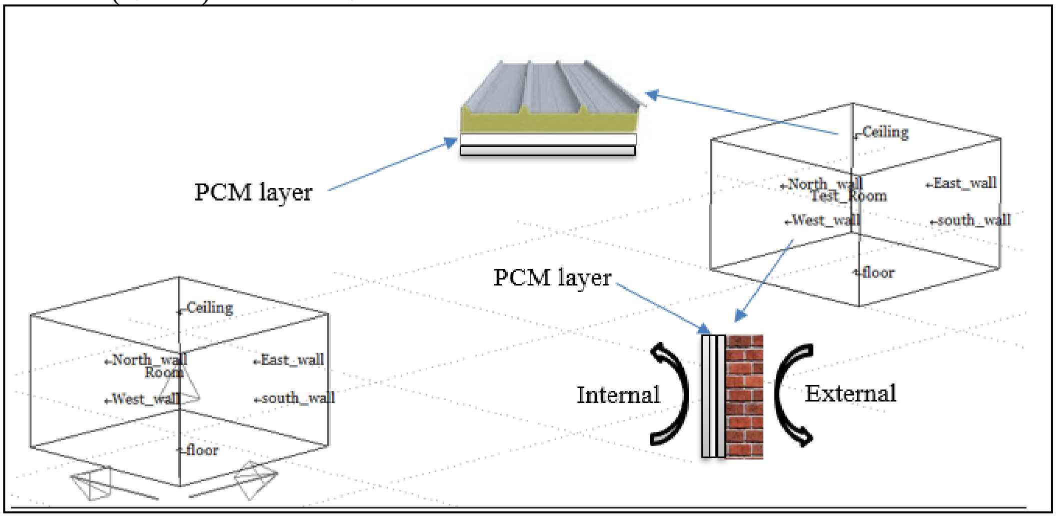

Fig. 3: Room Models

B. Boundary Conditions:

Energy plus weather database software was used to create climate date for Kut city (32.٥ ^{o}N ٤٥.8 ^{o}E) for simulation in this study. Climate data considers as input data for ESP-r. Energy plus weather created a climate data for long period (1991-2010). Meteonorm adapter tools was used to export the weather file from epw format (Energy Plus Weather) to bilateral format (esp-r climate file format) [9]. Dry bulb air temperature in (^{o}C) and direct normal solar radiation in (W/m^{2}) were presented in figures 2&3 respectively.

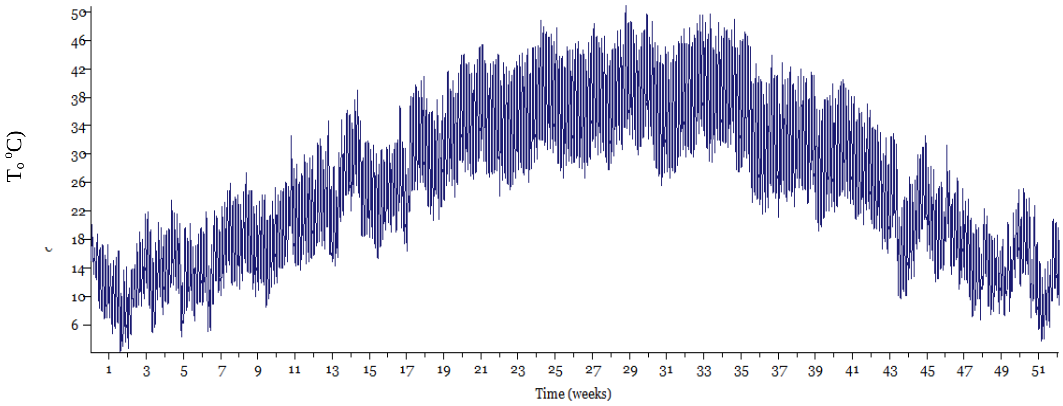

Fig.2: The annual ambient temperature in Iraq (Kut city)

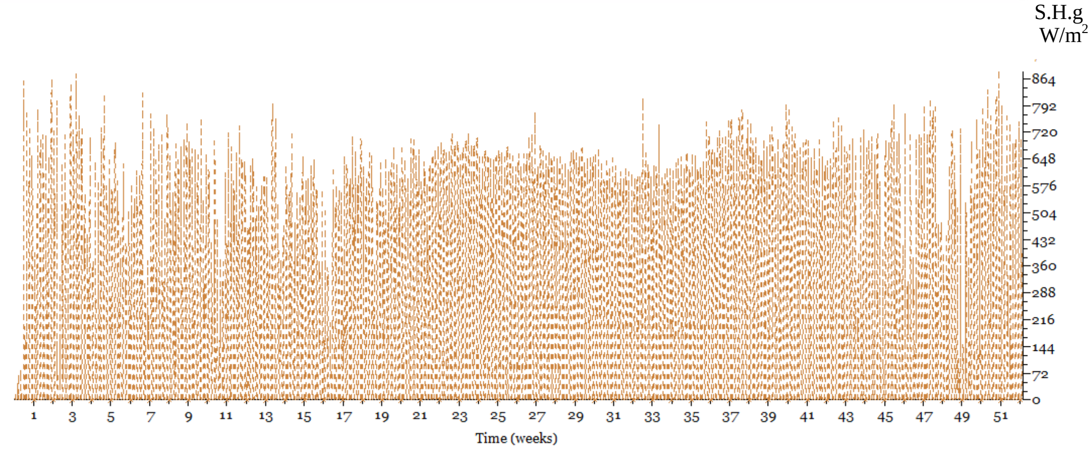

Fig .3: The annual solar irradiation in Iraq (Kut city)

August and September was period of simulated. Maximum normal solar radiation in August And September was (811 W/m^2) and average dry bulb temperature was (35.6 ^oC). the governing equation was the general energy equation:

$$\frac{\partial^2 Ts}{\partial x^2}+\frac{\partial^2 Ts}{\partial x^2}+\frac{\partial^2 Ts}{\partial x^2}=\alpha_s\frac{\partial Ts}{\partial t} \quad \text{for brick and aluminum} \tag{1}$$

$$\frac{\partial^2 Tp}{\partial x^2}+\frac{\partial^2 Tp}{\partial x^2}+\frac{\partial^2 Tp}{\partial x^2}=\alpha_p\frac{\partial Tp}{\partial t} \quad \text{for PCM} \tag{2}$$

$$C.L=q=A.U.\Delta T \tag{3}$$

The boundary conditions were represented the weather of Kut city and inlet dimensions of the rooms and the initial condition were for 24 hours and interval time of the simulation was every 10 minutes.

C. ESP-r software program:

ESP-r is a modeling tool for evaluating performance simulations. To carry out an assessment of performance in the program to make the system models the air flow, heat, electric power, light moisture, and modulated by the spatial and temporal user and it used finite volume method for analyses, the release of the program was 12.0 [9]. ESP-r is permitted to simulate the effect of the PCM in the interior building with special materials components. Behavior of the PCM in ESP-r described in two phases, melting phase and solidification phase, in melting phase PCM becomes melts and in solidification phase PCM becomes solidify. Under melting point, the PCM is treated as a solid material and its thermal conductivity equal to the solid phase conductivity. Above the melting point, the PCM is treated as liquid and its thermal conductivity equal to the liquid phase conductivity. Between the melting temperature and solidification temperature, the latent heat is zero as shown in the following equation:

$$k_{pcm}=\begin{bmatrix} K_s & T<T_m & \\ & \frac{k_S+k_L}{2}+\frac{H}{2\delta T} & T_m<T<T_{sof}\quad H=0 \\ k_l & T>T_m & \end{bmatrix} \tag{4}$$

$$C_{pcm}=\begin{bmatrix} C_s & T<T_m & \\ & \frac{C_S+C_L}{2}+\frac{H}{2\delta T} & T_m<T<T_{sof}\quad H=0 \\ C_l & T>T_m & \end{bmatrix} \tag{5}$$

$$\rho_{pcm}=\begin{bmatrix} \rho_s & T<T_m & \\ & \frac{k_S+k_L}{2}+\frac{H}{2\delta T} & T_m<T<T_{sof}\quad H=0 \\ \rho_l & T>T_m & \end{bmatrix} \tag{6}$$

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D. Simulation Method in ESP-r

Figure (4) shown the window of the ESP-r, there are three main steps to use ESP-r: - Creation new model, simulation andesults analysis.

- *Creation new model:*

Before starting in this step, climate file was inserted, as shown in figure (5), created new model involves three steps: -

A-Geometry and attribution.

B-Construction materials.

C-Operation details.

- *Simulation:*

Figure (6) shows the steps of the simulation.

- *Result Analysis*

Figure (7) shows the steps of the result analysis.

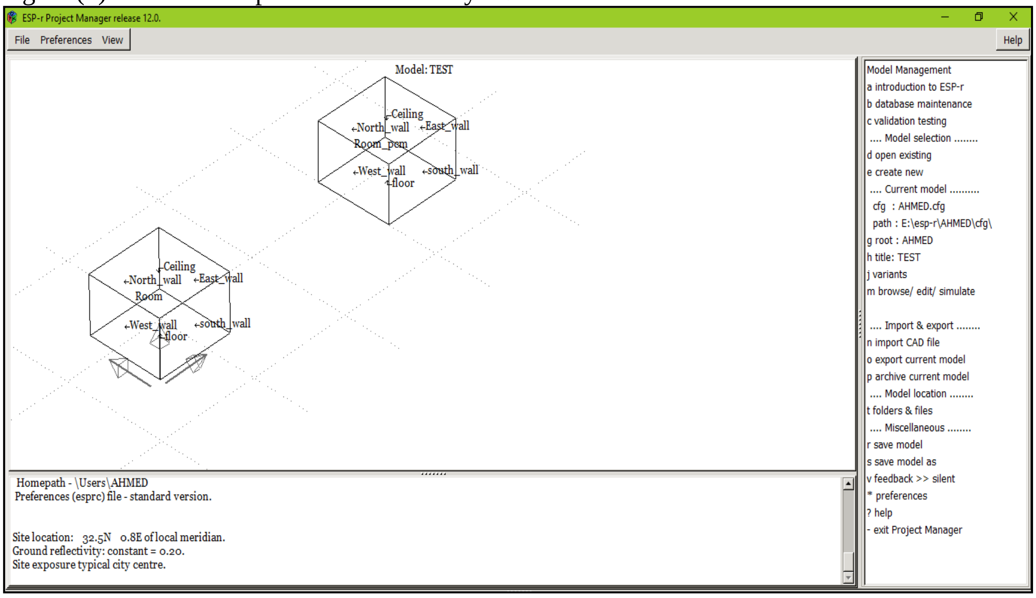

Fig.4: The main window of ESP-r program

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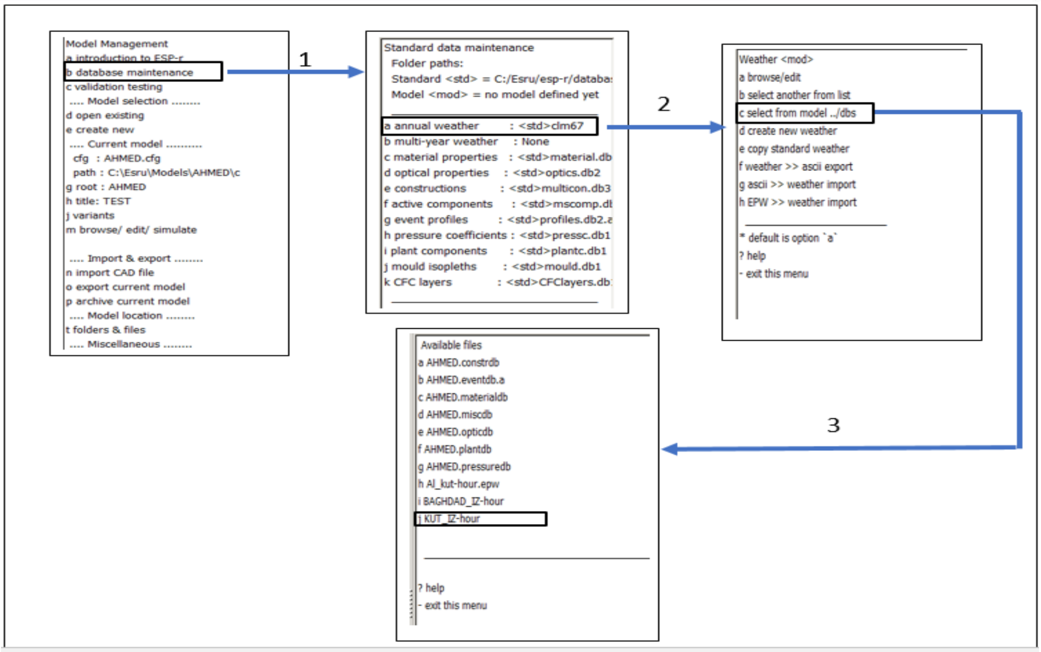

Fig.5: Selection of the climate file.

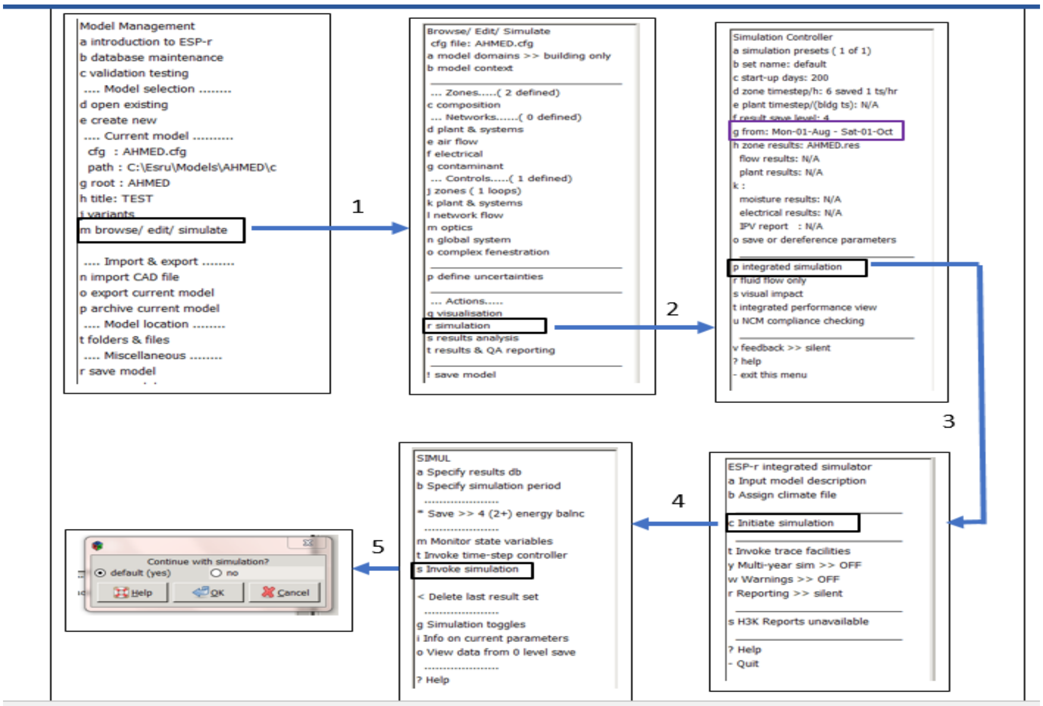

Fig. 6: Steps of the simulation.

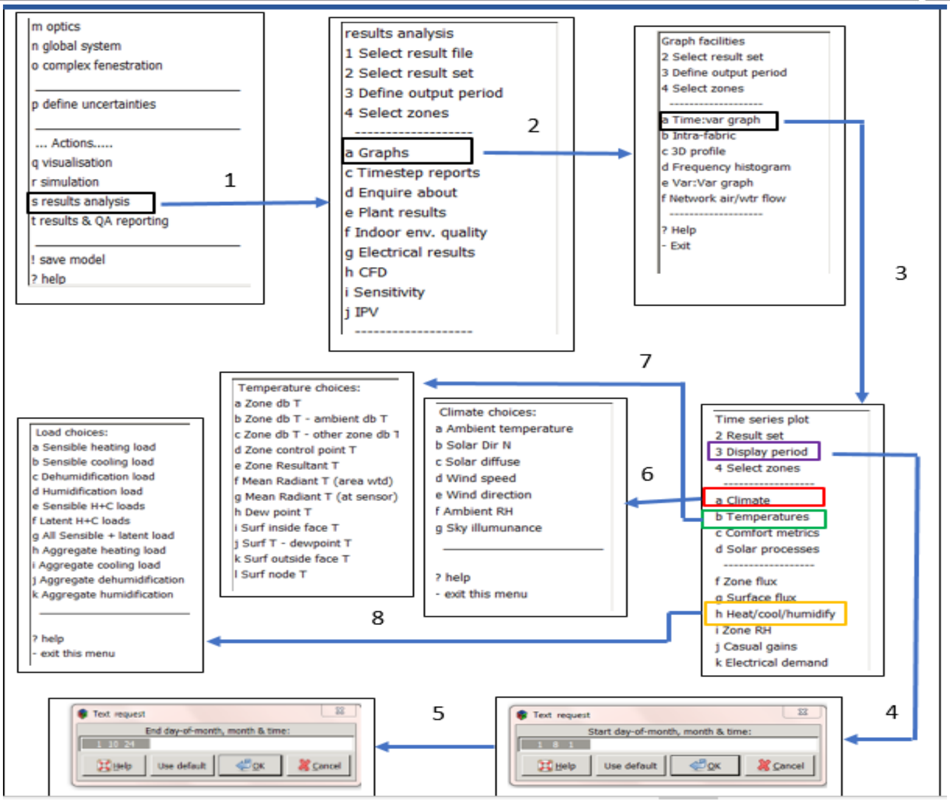

Fig. 7: Steps of the result analysis.

E. Properties of the Phase Change Materials (PCM)

The phase change materials are thermal storage materials and it is used as thermal insulation material due to its properties in thermal storage and to curb the heat. The PCM has a wide application in buildings, including in the field of integrated heating and cooling systems, as well as in the field of heating and cooling together. It is also used in air conditioning and in the ceiling panels of thermally activated and incorporated into building materials [11]. The PCM is usually used in the field of heating and cooling system to reduce thermal loads and integrates with construction materials as plaster or gypsum or concrete and it is may be in the form of capsules [12]. In this paper, the PCM was used as insulation layer for residential building inside aluminum frame attached to the room inside walls and ceiling. The physical properties of the PCM that the program just need were presented in Table I

TABLE I:- PROPERTIES OF THE PCM THAT THE PROGRAM JUST NEED [9]

Property	Value
Melting range (^{o}C)	2-3
Conductivity in solid phase (J/kg)	0.4
Conductivity in liquid phase (J/kg)	0.8
Specific heat (J/kg.K)	1000

III. NUMERICAL SOLUTION

In this study, the PCM-gypsum composite layer placed between two layers of aluminum in test room. Many thicknesses and many cases depended on orientations have been studied. Different melting temperature ranges were used according to base on initial simulation of the internal surface temperature of the room without PCM. August and September was the period of the simulation and it has been chosen special days for simulation.

A. All walls with PCM with thicknesses (1 cm- 4cm)

In this case, all walls of test room were insulated by PCM-gypsum composite layer. As maintained before the PCM is used inside aluminum frame with area equal to the wall area. The melting range of temperature that used in this case was (45-48 ^{o}C). The test was performed in the period from (16-Aug-2016) at 12 a.m. to (17-Aug-2016) at 12 a.m. The results were compared with standard room at same test time.

B. The ceiling with PCM with thicknesses (1 cm- 4cm)

The ceiling was insulated by using PCM-gypsum composite layer with area was (1.5m*1.5m). The melting range of temperature that used in this case was (27-29 ^{o}C). The probationary period was from (8-Sep-2016) at 12 a.m. to (9-Sep-2016) at 12 a.m. The results were compared with standard room at same test time.

C. Individual walls with PCM with thicknesses (2cm- 4cm):

In this case, the different walls were tested individually by insulating them. The West wall, South wall, North wall and East wall were insulated by using PCM-gypsum composite layer with area (1m*1.5m). The results were compared with standard room at same test time.

- The West wall with PCM with thicknesses (2cm- 4cm)
  The melting range of temperature that used in this case was (45-47 ^{o}C). The probationary period was from (22-Aug-2016) at 12 a.m. to (23-Aug -2016) at 12 a.m.
- The South wall with PCM with thicknesses (2cm- 4cm)
  The melting range of temperature that used in this case was (35-37 ^{o}C). The probationary period was from (21-Sep-2016) at 12 a.m. to (22-Sep -2016) at 12 a.m.
- The North wall with PCM with thicknesses (2cm- 4cm)
  The melting range of temperature that used in this case was (40-43 ^{o}C). The probationary period was from (31-Aug-2016) at 12 a.m. to (1-Sep -2016) at 12 a.m.
- The East wall with PCM with thicknesses (2cm- 4cm)
  The melting range of temperature that used in this case was (35-37 ^{o}C). The probationary period was from (24-Sep-2016) at 12 a.m. to (25-Sep -2016) at 12 a.m.

IV. RESULTS AND DISCUSSION

The following findings are the results of a numerical simulation for using of phase change materials as thermal insulation materials for reduce indoor temperature in summer. The results were taken in August and September in the Kut city - Iraq. In this study, ESP-r software program has been used for simulated in the same time for both the rooms with and without PCM. Many cases were conducted with many thicknesses and orientations.

A. Indoor Temperature

- All walls with PCM with thicknesses (1cm- 4cm)

Figures. (8 and 9) show the variation of room indoor temperature for two cases with and without PCM for numerical results for all walls for thicknesses 1cm and 2 cm respectively. For room with PCM all walls are insulated with PCM. From these figures, it can be seen that the indoor temperature of room with PCM is lower than the indoor temperature of room without PCM around all day hours due to the insulation effect of PCM which reduce the heat gain to the room, due to its melting in day hour and absorbing the heat and lead to maintain the temperature of room at low values. While at night hours it can be observed that the indoor temperature of room in case of using PCM as insulation material become higher than that for similar room without PCM which is due to discharging effects, since the PCM start discharging heat through solidification process in night time. Also, it can be seen from these figures that there is a fluctuation in temperature of room for two cases with and without PCM due to effect of outside temperature fluctuation. The difference between the indoor temperature room with PCM and without was presented in table II.

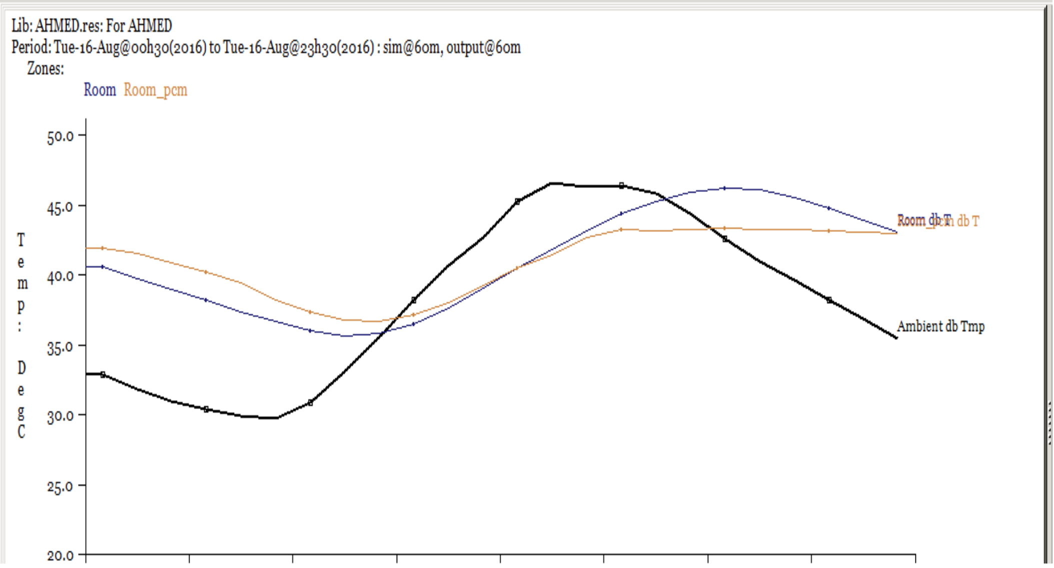

Fig. 8: indoor temperature of rooms with and without PCM using 1cm of PCM at all walls (16-Aug-2016).

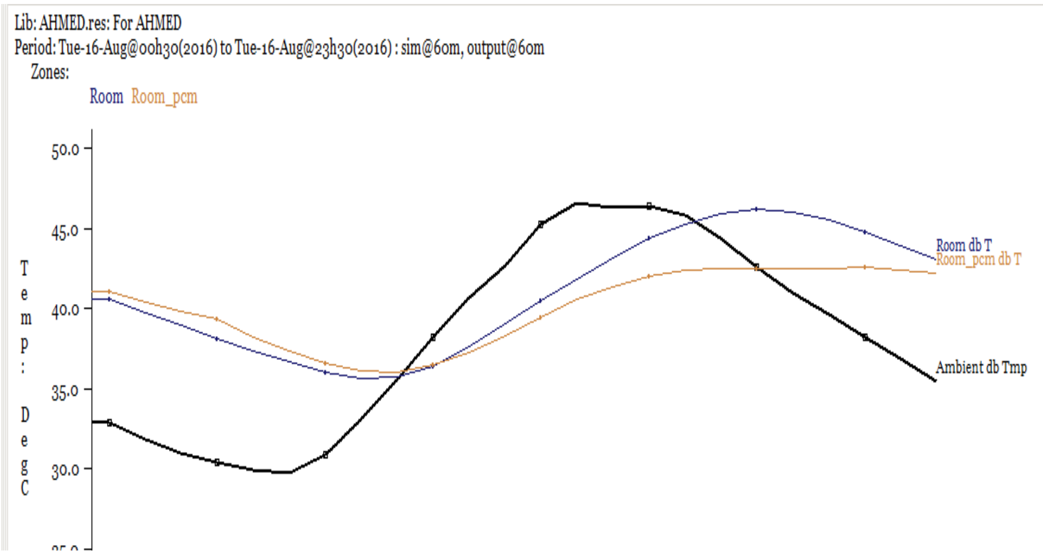

Fig.9: indoor temperature of rooms with and without PCM using 2cm of PCM at all walls (16-Aug-2016).

TABLE II:- SHOW DIFFERENCE OF INDOOR TEMPERATURE BETWEEN ROOM WITH PCM AND ROOM WITHOUT PCM FOR ALL WALLS CASE WITH DIFFERENT THICKNESSES OF PCM.

Case	**Thickness of PCM**	**TIME**	**ΔT (T_r without PCM-T_r with PCM)**	**Date**
All walls	1cm	6 p.m.	2.12 ^oC	16-Aug-2016
All walls	2cm	6 p.m.	3.63 ^oC	16-Aug-2016
All walls	3cm	6 p.m.	4.16 ^oC	16-Aug-2016
All walls	4cm	6 p.m.	4.32 ^oC	16-Aug-2016

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- *The ceiling with PCM with thicknesses (1 cm- 4cm)*

Figures. (10 and 11) show the variation of room indoor temperature for two cases with and without PCM for numerical results for ceiling only for thicknesses 1cm and 2cm respectively. For room with PCM the ceiling only is insulated with PCM. From these figures, it can be seen that the indoor temperature of room with PCM is lower than the indoor temperature of room without PCM all day hours due to the insulation effect of PCM which reduce the heat gain to the room, due to its melting in day hour and absorbing the heat and lead to maintain the temperature of room at low values. While at night hours it can be observed that the indoor temperature of room in case of using PCM as insulation material become higher than that for similar room without PCM which is due to discharging effects, since the PCM start discharging heat through solidification process in night time. Also, it can be seen from these figures that there is a fluctuation in temperature of room for two cases with and without PCM due to effect of outside temperature fluctuation. The difference between the indoor temperature room with PCM and without was presented in table III.

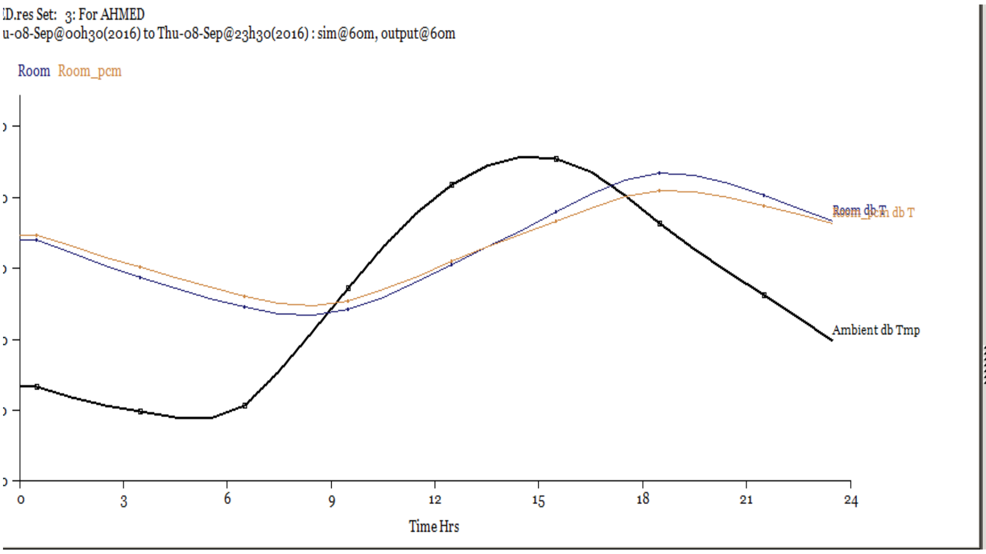

Fig.10: indoor temperature of rooms with and without PCM using 1cm of PCM at ceiling only (8-Sep-2016).

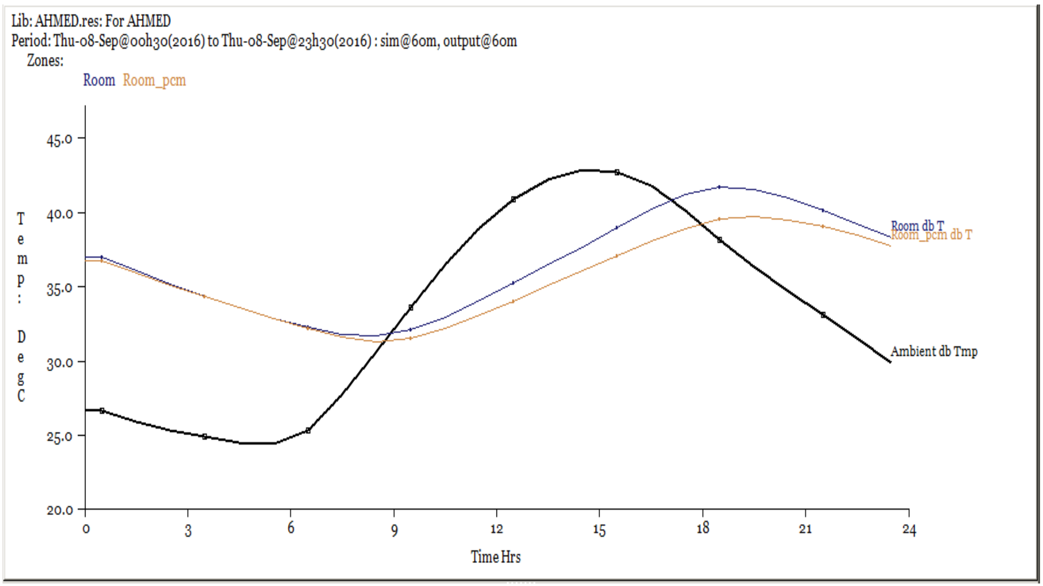

Fig. 11: indoor temperature of rooms with and without PCM using 2cm of PCM at ceiling only (8-Sep-2016).

TABLE III..SHOW DIFFERENCE OF INDOOR TEMPERATURE BETWEEN ROOM WITH PCM AND ROOM WITHOUT PCM FOR CEILING CASE WITH DIFFERENT THICKNESSES OF PCM.

case	Thickness of PCM	TIME	ΔT (T_r without PCM- T_r with PCM)	Date
Ceiling	1cm	6 p.m.	1.3°C	8-Sep-2016
Ceiling	2cm	6 p.m.	2.1 °C	8-Sep-2016
Ceiling	3cm	6 p.m.	2.17 °C	8-Sep-2016
Ceiling	4cm	6 p.m.	2.26 °C	8-Sep-2016

- *Individual walls with PCM with thicknesses (2cm- 4cm)*

Figures 12-19 show the variation of room indoor temperature for two cases with and without PCM for numerical results for West, South, North and East wall respectively for thicknesses 2cm and 3 cm respectively. For room with PCM the West, South, North and East wall individual are insulated with PCM. From these figures, it can be seen that the indoor temperature of room with PCM is lower than the indoor temperature of room without PCM all day hours due to the insulation effect of PCM which reduce the heat gain to the room, due to its melting in day hour and absorbing the heat and lead to maintain the temperature of room at low values. While at night hours it can be observed that the indoor temperature of room in case of using PCM as insulation material become higher than that for similar room without PCM which is due to discharging effects, since the PCM start discharging heat through solidification process in night time. Also, it can be seen from these figures that there is a fluctuation in temperature of room for two cases with and without PCM due to effect of outside temperature fluctuation. The difference between the indoor temperature room with PCM and without for individual walls was presented in tables (IV, V, VI and VII) respectively

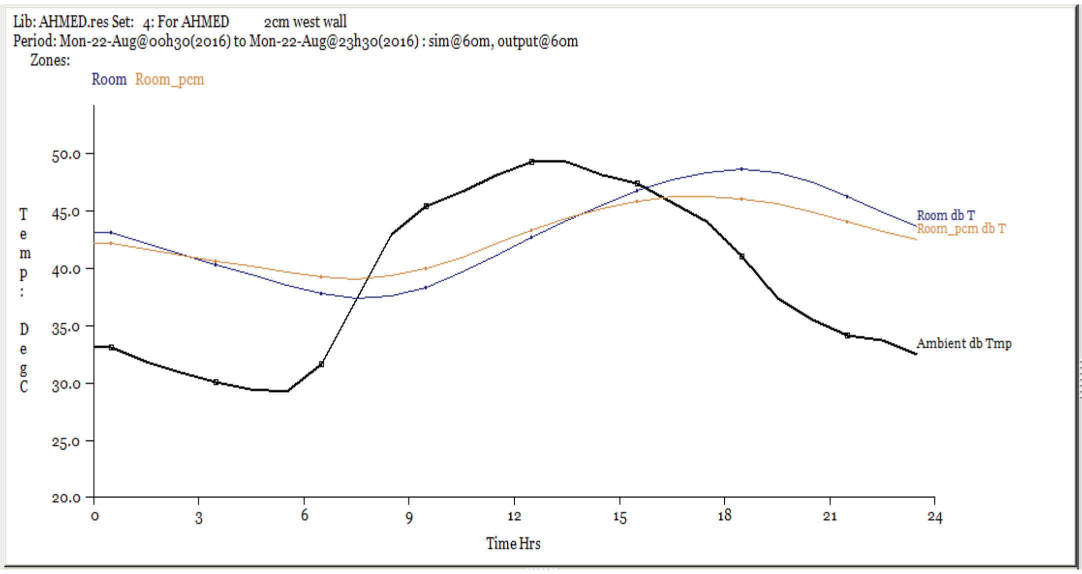

Fig.12: indoor temperature of rooms with and without PCM using 2cm of PCM at West wall (22-Aug-2016).

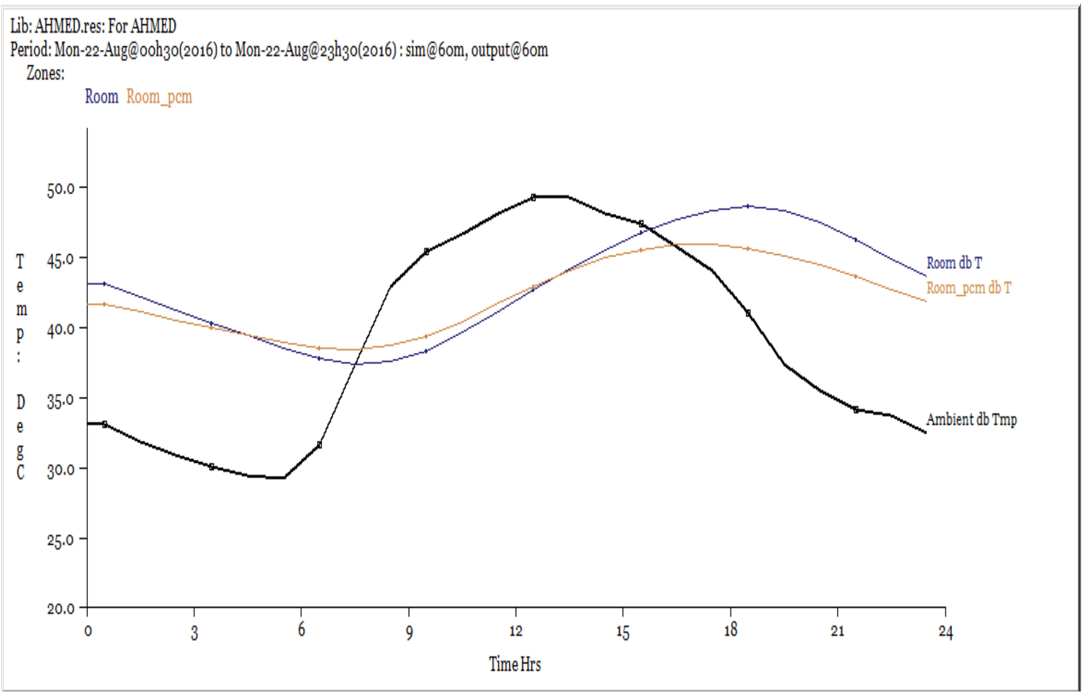

Fig.13: indoor temperature of rooms with and without PCM using 3cm of PCM at West wall (22-Aug-2016)

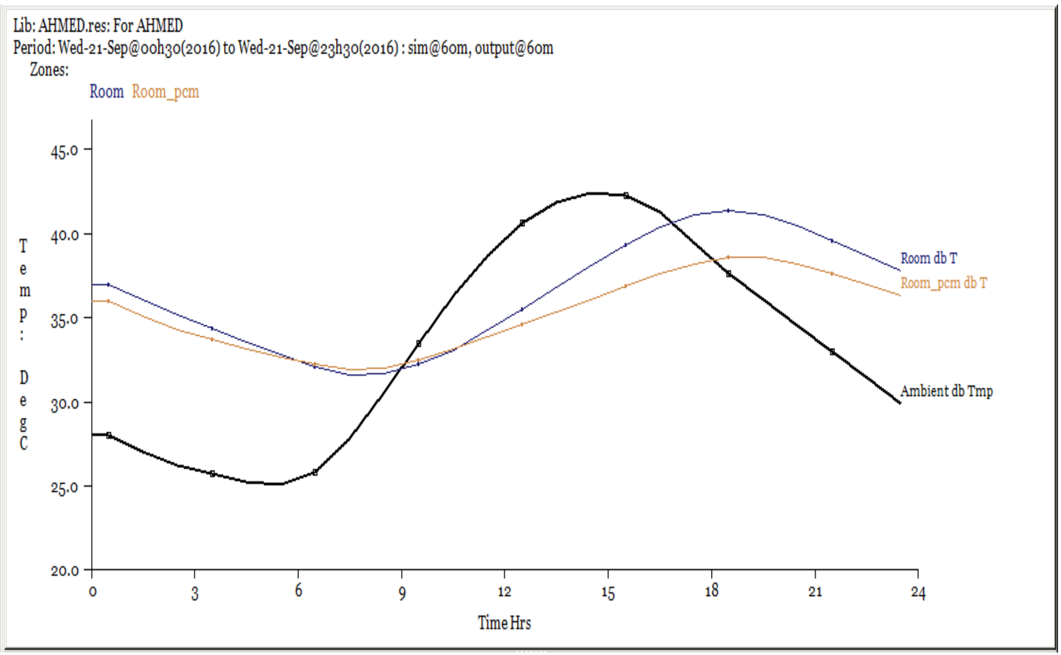

Fig..14.: indoor temperature of rooms with and without PCM using 2cm of PCM at South wall (21-Sep-2016).

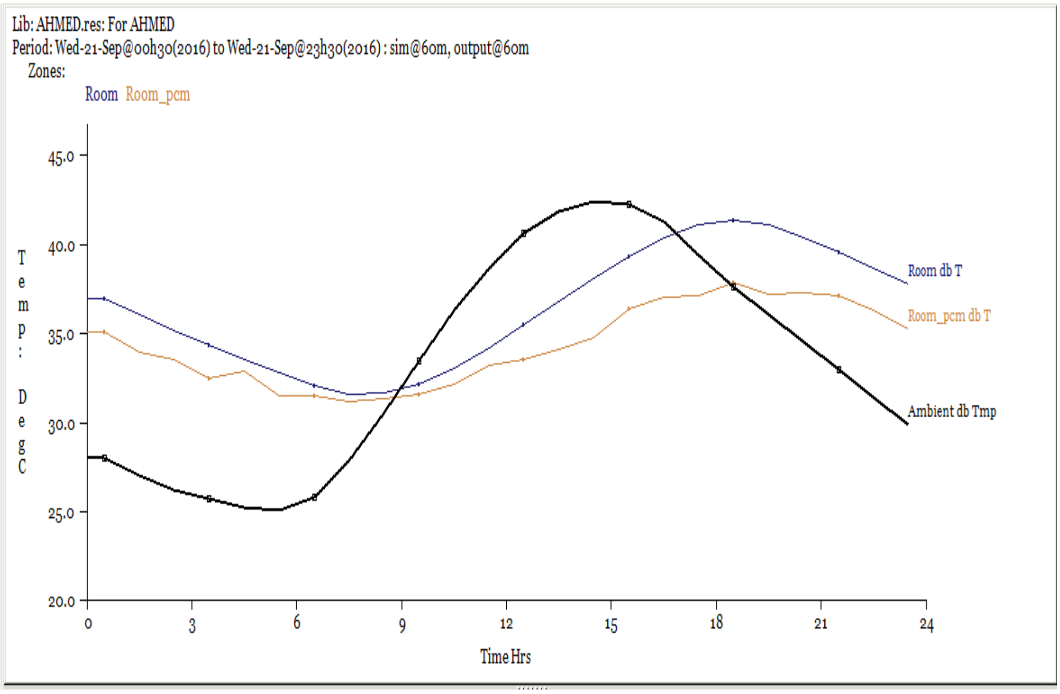

Fig..15: indoor temperature of rooms with and without PCM using 3cm of PCM at South wall (21-Sep-2016).

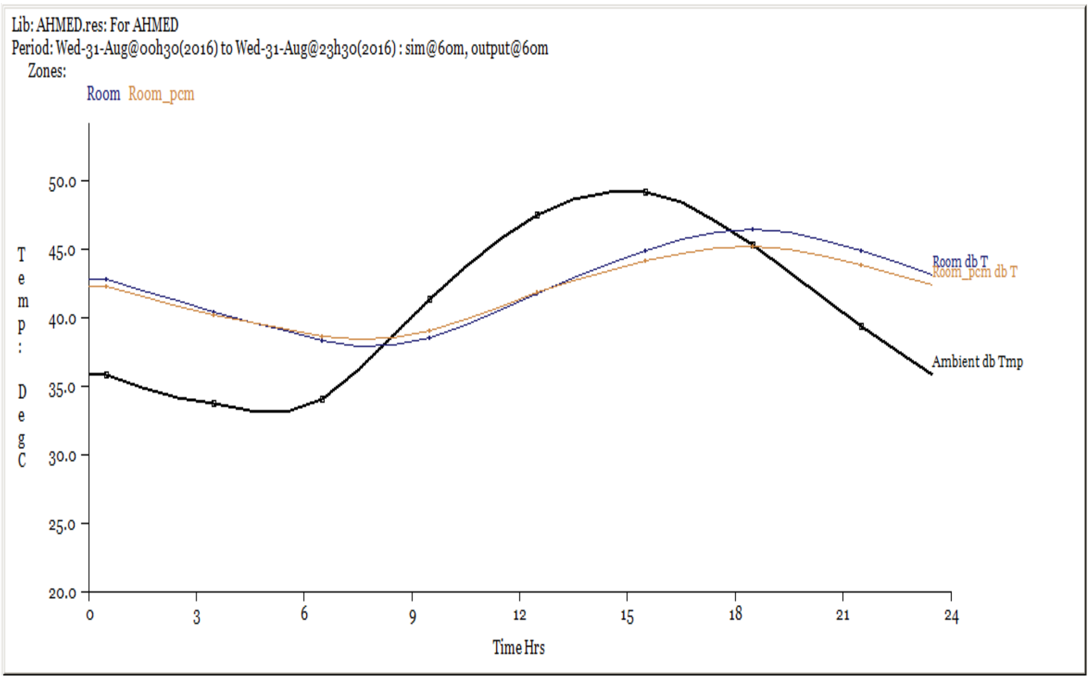

Fig.16: indoor temperature of rooms with and without PCM using 2cm of PCM at North wall (31-Aug-2016).

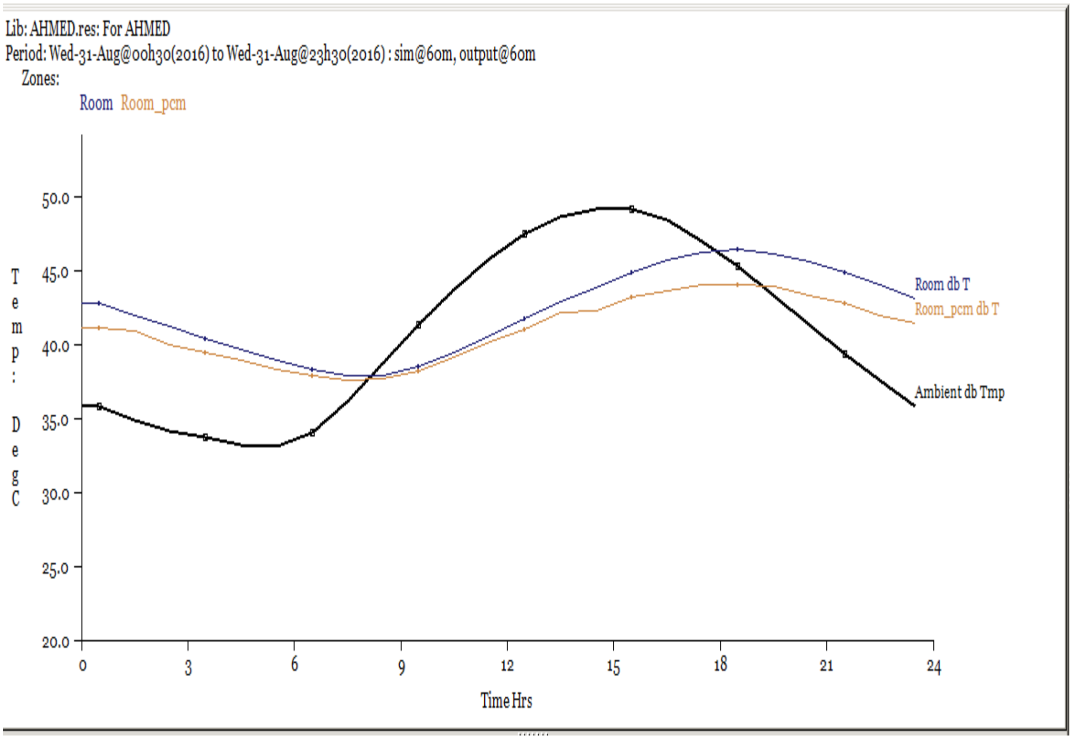

Fig.17: indoor temperature of rooms with and without PCM using 3cm of PCM at North wall (31-Aug-2016).

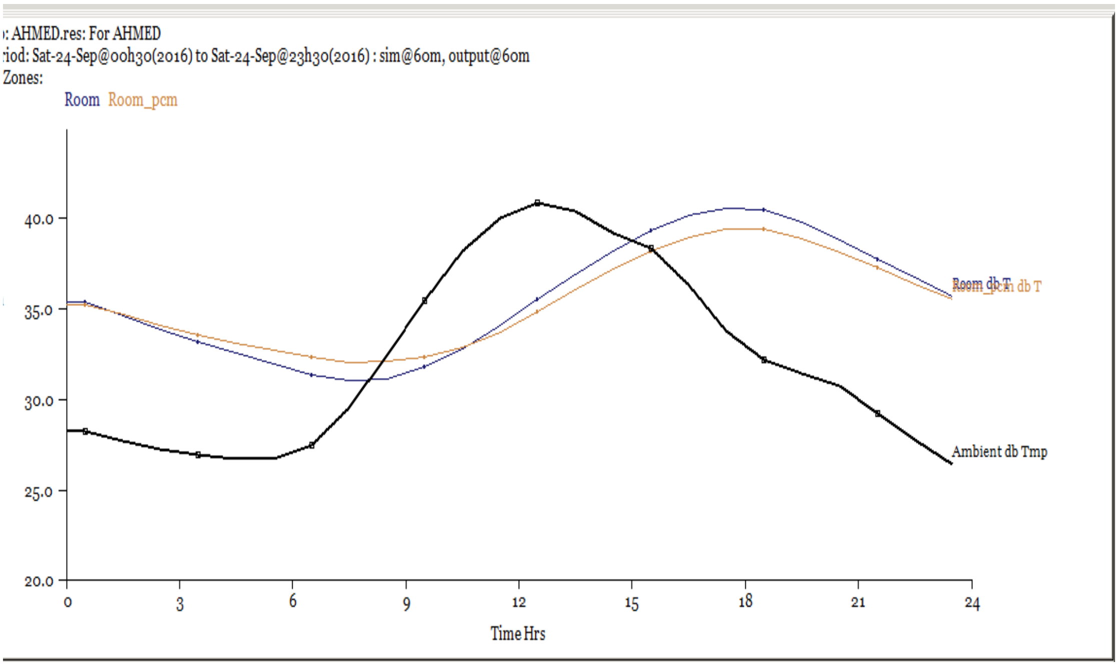

Fig.18: indoor temperature of rooms with and without PCM using 2cm of PCM at East wall (24-Sep-2016).

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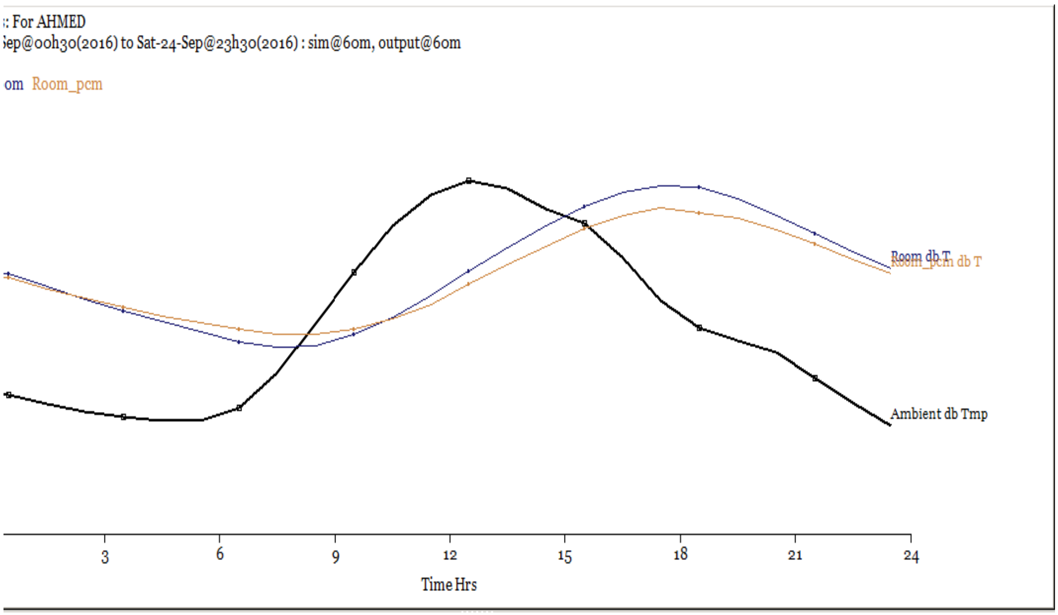

Fig.19: indoor temperature of rooms with and without PCM using 3cm of PCM at East wall (24-Sep-2016).

TABLE IV. SHOW DIFFERENCE OF INDOOR TEMPERATURE BETWEEN ROOM WITH PCM AND ROOM WITHOUT PCM FOR WEST WALL CASE WITH DIFFERENT THICKNESSES OF PCM.

case	**Thickness of PCM**	**TIME**	**ΔT (T_r without PCM- T_r with PCM)**	**Date**
West wall	2cm	6 p.m.	2.6 °C	22-Aug-2016
West wall	3cm	6 p.m.	3.1 °C	22-Aug-2016
West wall	4cm	6 p.m.	3.25 °C	22-Aug-2016

TABLE V. SHOW DIFFERENCE OF INDOOR TEMPERATURE BETWEEN ROOM WITH PCM AND ROOM WITHOUT PCM FOR SOUTH WALL CASE WITH DIFFERENT THICKNESSES OF PCM.

case	**Thickness of PCM**	**TIME**	**ΔT (T_r without PCM- T_r with PCM)**	**Date**
South wall	2cm	6 p.m.	2.78°C	21-Sep-2016
South wall	3cm	6 p.m.	3.95 °C	21-Sep-2016
South wall	4cm	6 p.m.	4.09 °C	21-Sep-2016

TABLE VI. SHOW DIFFERENCE OF INDOOR TEMPERATURE BETWEEN ROOM WITH PCM AND ROOM WITHOUT PCM FOR NORTH WALL CASE WITH DIFFERENT THICKNESSES OF PCM.

case	Thickness of PCM	TIME	ΔT (T_r without PCM- T_r with PCM)	Date
North wall	2cm	6 p.m.	1.25 °C	31-Aug-2016
North wall	3cm	6 p.m.	2.34 °C	31-Aug-2016
North wall	4cm	6 p.m.	2.74 °C	31-Aug-2016

TABLE VII. SHOW DIFFERENCE OF INDOOR TEMPERATURE BETWEEN ROOM WITH PCM AND ROOM WITHOUT PCM FOR EAST WALL CASE WITH DIFFERENT THICKNESSES OF PCM.

case	Thickness of PCM	TIME	ΔT (T_r without PCM- T_r with PCM)	Date
East wall	2cm	6 p.m.	1.1°C	24-Sep-2016
East wall	3cm	6 p.m.	1.48 °C	24-Sep-2016
East wall	4cm	6 p.m.	2.51 °C	24-Sep-2016

B. *Cooling Load*

- *All walls with PCM with 1cm thickness*

Cooling load of the rooms with and without PCM is presented in Figure (20). For the room with PCM, all walls are coated with PCM (paraffin wax). In this figure, it can be seen that cooling load is reduced at day time which means that the reduction of cooling load takes place in time which the PCM works and absorbs the heat enters to the zone, reduction in cooling load is 22.9% at peak hour. As concerning in night hours, the cooling load is increased due to discharging process where the PCM rejected the heat inside the room.

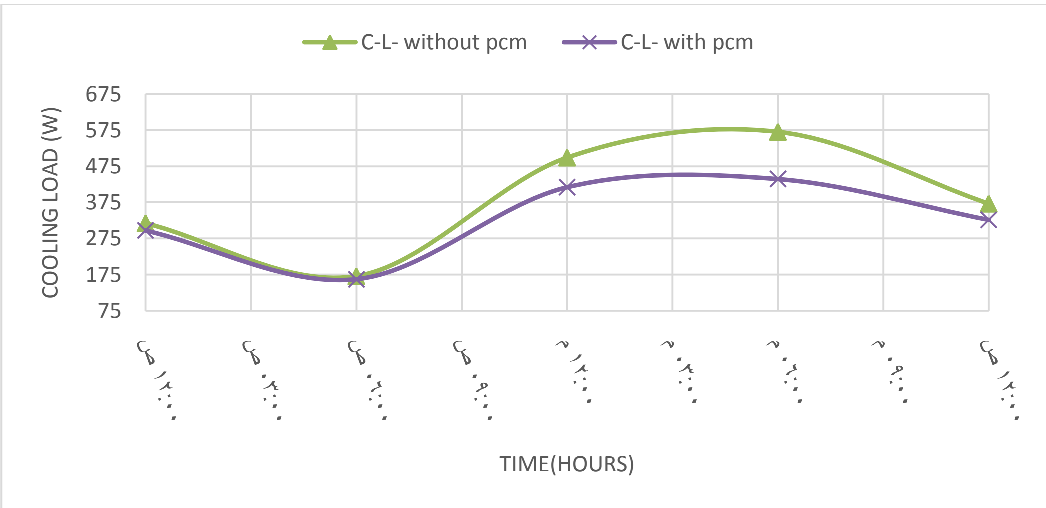

Fig. 20: Cooling load of the rooms with and without PCM using 1 cm of PCM at all walls (16-Aug-2016).

- *The ceiling with PCM with 1cm thickness*

Cooling load of the rooms with and without PCM is presented in Figure (21). For the room with PCM, the ceiling is only coated with PCM (paraffin wax). In this figure, it can be seen that cooling load is reduced at day time which means that the reduction of cooling load takes place in time which the PCM works and absorbs the heat enters to the zone, reduction in cooling load is 8.2% at peak hour. As concerning in night hours, the cooling load is increased due to discharging process where the PCM rejected the heat inside the room.

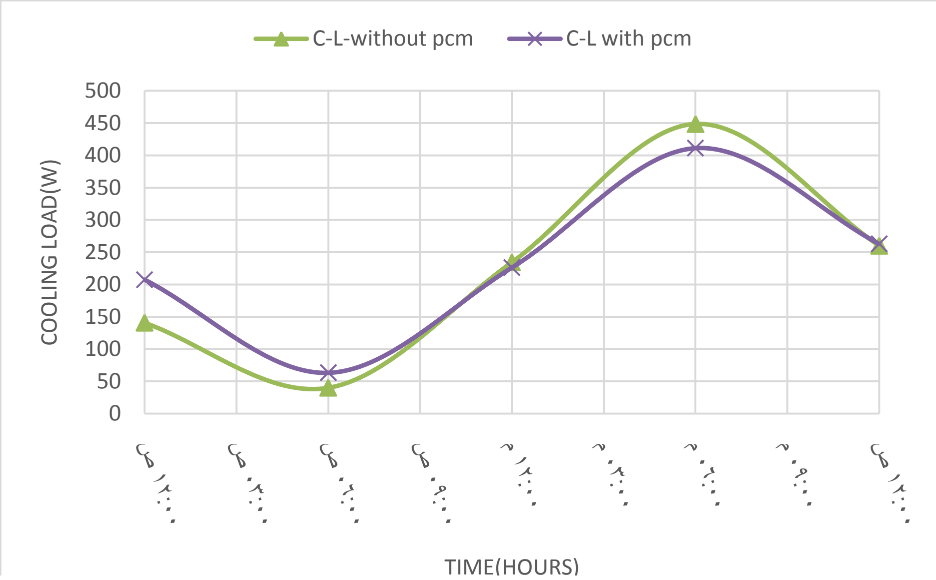

Fig. 21: Cooling load of the rooms with and without PCM using 1 cm of PCM at only ceiling (8-Sep-2016).

- *Individual walls with PCM with 2cm thickness*

Cooling loads of the rooms with and without PCM for the West, South, North, East wall are presented in Figures (22, 23, 24 and 25) respectively. For the room with PCM the West, South, North, East individual walls are coated with PCM (paraffin wax). In these figures, it can be seen that the cooling load is reduced at day time which means that the reduction of cooling load takes place in time which the PCM works and absorbs the heat enters to the zone, percentage of reduction in cooling load for all cases and for the individual walls are presented in table (8). As concerning in night hours, the cooling load is increased due to discharging process where the PCM rejected the heat inside the room.

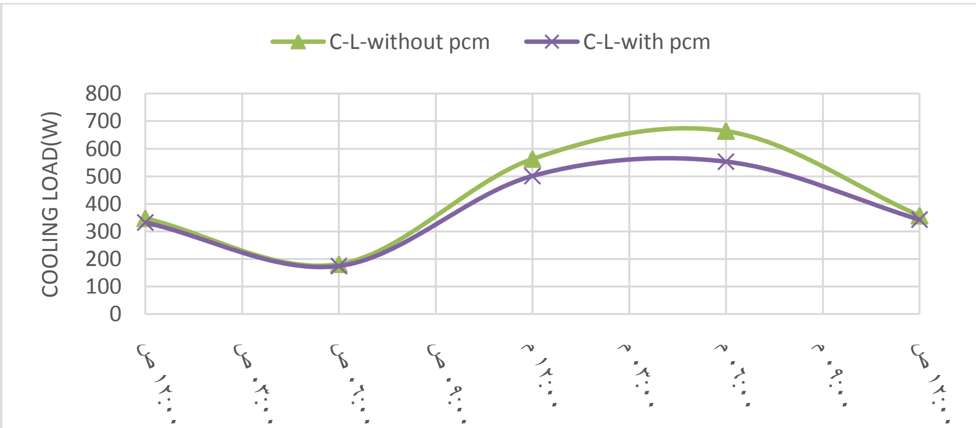

Fig. 22: Cooling load of the rooms with and without PCM using 2 cm of PCM at West wall (22-Aug-2016).

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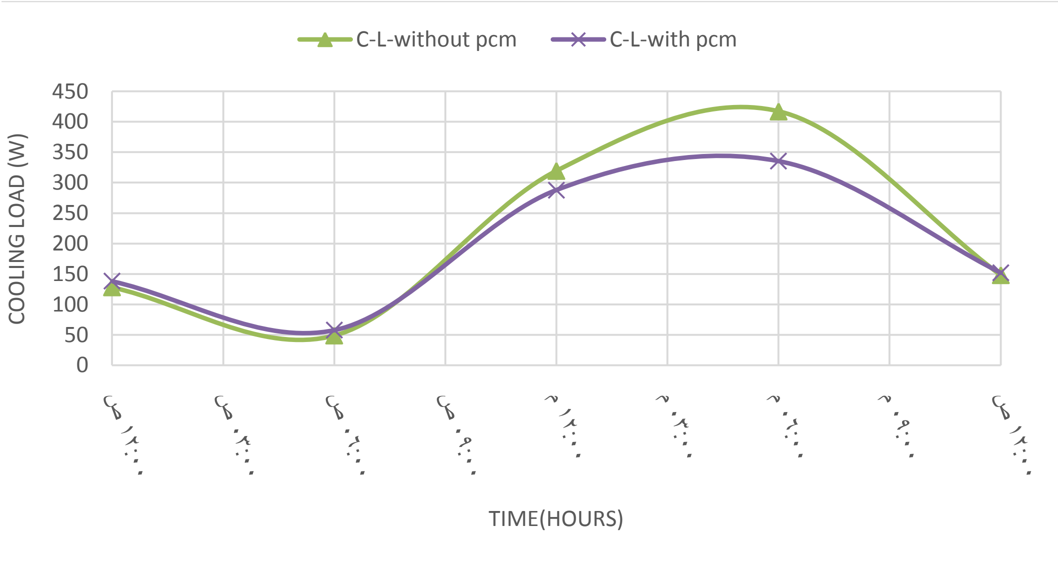

Fig. 23: Cooling load of the rooms with and without PCM using 2 cm of PCM at South wall (21-Sep-2016).

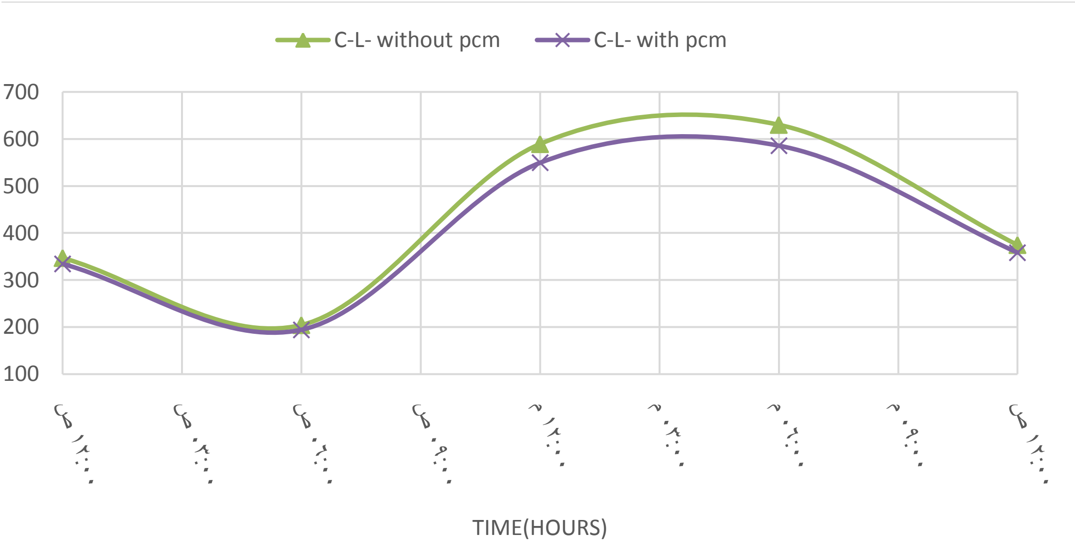

Fig. 24: Cooling load of the rooms with and without PCM using 2 cm of PCM at North wall (31-Aug-2016).

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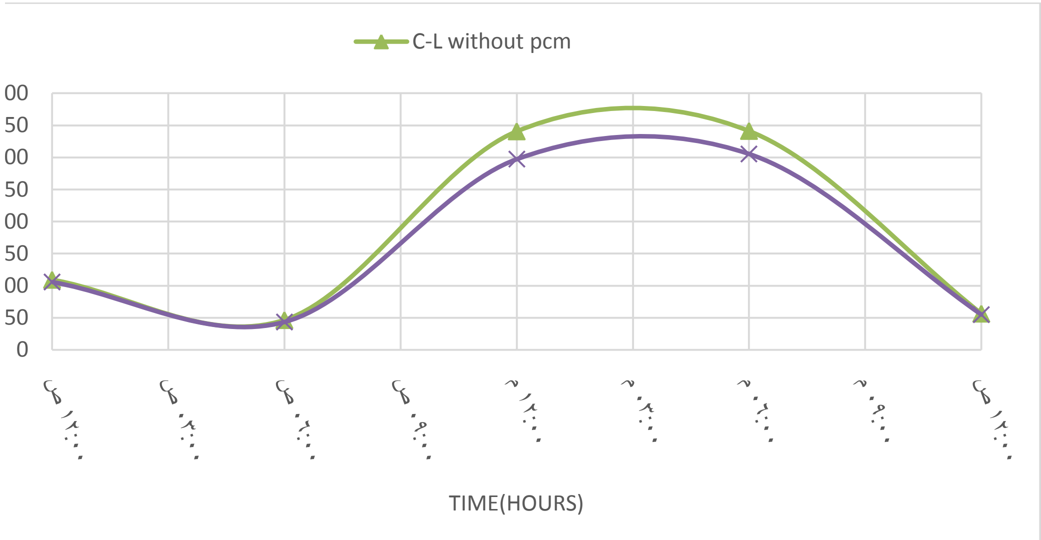

Fig. 25: Cooling load of the rooms with and without PCM using 2 cm of PCM at East wall (24-Sep-2016).

TABLE VIII .PERCENTAGE OF THE COOLING LOAD REDUCTION FOR ROOMS WITH AND WITHOUT PCM FOR ALL STUDIED CASES.

Case	Thickness of PCM	TIME	% Reduction of C-L	Date
All wall	1 cm	6 p.m.	22.9%	16-Aug-2016
Ceiling	1 cm	6 p.m.	8.2%	8-Sep-2016
South wall	2 cm	6 p.m.	19.66%	21-Sep-2016
West wall	2 cm	6 p.m.	16.7%	22-Aug-2016
North wall	2 cm	6 p.m.	7.14%	31-Aug-2016
East wall	2 cm	6 p.m.	10.5%	24-Sep-2016

Increasing the effect of the PCM with increase the thickness this because increasing the heat capacity of PCM, also effect of the PCM is appeared at evening due to time lag of heat.

C. Comparison with previous studies

The results compared with Mushtaq et al [7] the dimensions of the rooms were (1.8m*1.8m*2.44 m). the roof of PCM room was (concrete 12cm, light structure panel from aluminum with PCM 2.5cm and brick mixture+ mortar 10cm). Melting rang of PCM was (36.7-37 ^{o}C). They noted that reduction in heat transfer was by 46.71%.

In the present work, the dimensions of the rooms were (1 m*1.5m*1.5 m). the roof of PCM room was (sandwich panel 5 cm, light structure panel from aluminum with PCM 1cm). Melting rang of PCM was (27-29 ^{o}C). it was noted that a reduction in the cooling load was by 8.2%.

V. CONCLUSIONS

The using of phase change material as thermal insulation material has been studied numerically. From the results which are obtained can be made the following conclusions: -

- Using the PCM as thermal insulation material in buildings contributed to the improvement of thermal comfort.
- Using the PCM lead to reduce the indoor temperature of zone and reducing the cooling load.
- Reduction in the indoor temperature of the zone by using PCM and according to cases was 2.12 ^{o}C with 1 cm thickness of PCM for all walls, 1.3 ^{o}C with 1 cm thickness of PCM for ceiling, 2.78 ^{o}C with 2 cm thickness of PCM for South wall, 2.6 ^{o}C with 2 cm thickness of PCM for West wall, 1.25 ^{o}C with 2 cm thickness of PCM for North wall, 1.1 ^{o}C with 2 cm thickness of PCM for East wall.
- Insulating the South wall lead to higher reduction in indoor temperature.

- Percentage of the cooling load reduction of the zone by using PCM and according to cases was 22.9% with 1 cm thickness of PCM for all walls, 8.2% with 1cm thickness of PCM for ceiling, 19.66% with 2 cm thickness of PCM for South wall, 16.7% with 2 cm thickness of PCM for West wall, 7.14% with 2 cm thickness of PCM for North wall, 10.5% with 2 cm thickness of PCM for East wall.
- The best case in cooling load reduction of the zone was 1 cm thickness of PCM for all walls.
- The effect of PCM as insulation materials increases with increasing thickness of PCM layer and must be taking into account period of the simulation suitable with melting temperature range.
- Using PCM as insulation materials lead to saving in electricity consumption.

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