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Evaluation of Paraffin based Phase change Material on Thermal Performance in Building

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ABSTRACT

The building sector, which is the primary user of material and energy resources, necessitates the implementation of energy-saving measures and the use of thermally efficient materials. Severe heat waves necessitate a significant level of electricity usage in order to maintain suitable thermal comfort. The current situation poses an economic burden and hinders the progress of sustainable development, unless viable alternative solutions are devised. Hence, thermal energy storage systems are considered a viable choice for the effective and environmentally friendly integration of energy in building design. The objective of this study was to examine the customized thermal mass and heat comfort considerations related to recently developed phase change materials (PCMs) known as local paraffin derived from petroleum. These PCMs were evaluated for their prospective application as thermal energy storage (TES) systems in the specific context of Iraq.

1. Introduction

Furthermore, the heat conductivity of PCM is not as substantial as that of bricks. Therefore, phase change materials (PCMs) have the capability to serve as both storage materials and insulators. In the past decade, the utilization of phase change materials (PCM) as construction materials has gained significant attention owing to its numerous advantages. The inherent characteristics of phase change materials (PCMs) render them very suitable for energy conservation purposes. Phase shift heat-energy storage requires the utilization of materials that possess substantial latent heat capacity and exhibit high thermal conductivity. It is imperative that the melting temperature falls within the operational practical range. The current study aims to explore the application of paraffin produced from petroleum in a country characterized by a hot and dry climate, namely as a building material. In order to assess the thermal efficiency of the paraffin in question, suitable materials are carefully chosen. These materials are then utilized to create test rooms. Experiments are conducted on these test rooms, wherein phase change materials (PCMs) are incorporated. Practical implementations are carried out by constructing prototype models and full-scale test rooms, specifically designed to simulate hot climatic conditions [1].

The need to identify a novel, sophisticated, cost-effective approach for minimizing energy usage in air conditioning systems and mitigating fluctuations in indoor temperature has generated significant interest among researchers. Consequently,

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there is a growing urgency to explore the theoretical application of Phase Change Materials (PCM) in the design of buildings. The employment of phase change materials (PCMs) as thermal storage systems for buildings has garnered significant attention since its initial utilization in the 1940s. Currently, there exist numerous encouraging advancements in the realm of utilizing Phase Change Materials (PCMs) for the purpose of heating and cooling buildings [2].

In their study, **Bel_en Zalba. et al.,** [3] conducted a comprehensive review on the topic of Thermal Energy Storage (TES), specifically focusing on the utilization of solid-liquid phase transition materials. The acquired information was categorized into three distinct sections, namely materials, heat transmission, and applications. The researchers provided a description of the materials that have been identified as potential phase change materials (PCMs), along with an analysis of their thermophysical properties. In addition, there is a mention of commercial phase change materials (PCMs). Various techniques for determining thermal characteristics have been identified. The issues pertaining to the long-term stability of the materials and their encapsulation were deliberated upon. The study of heat transmission has predominantly focused on a theoretical framework, with particular emphasis on exploring various simulation methodologies. There are several uses of phase change materials (PCMs) that can be categorized into various domains, including ice storage, building applications, conservation and transportation of temperature sensitive products, comparison between water tanks and PCM tanks, and other miscellaneous applications..

Heim D and Clarke, [4] made improvements to their ESP-r system through the integration of phase change materials (PCM) modeling (Heim & Clarke, 2014). The behavior of phase change materials (PCMs) is simulated using ESP-r's dedicated materials feature. The energy balance equation incorporates the impact of phase change by include a latent heat generation term, which is determined using the effective heat capacity method. The study involved the implementation of numerical simulations to analyze the performance of a passive solar architecture characterized by many zones, a significant amount of glazing, and a natural ventilation system. The internal room lining consisted of gypsum plasterboard that was impregnated with Phase Change Material. The temperatures of the air, surface, and resulting conditions are compared to the scenario without phase change material (PCM), and the diurnal latent heat storage impact is examined.

P. Lamberg and K.sire, [5] proposed a simplified analytical model that utilizes a quasi-linear, transient, thin-fin equation. This model aims to forecast the location of the solid-liquid interface and the temperature distribution of the fin during the melting process, assuming a constant enforced end-wall temperature. The analytical results are compared with the numerical results, demonstrating a satisfactory level of concordance. It has been determined that the assumptions made in the model indicate that the speed of the solid-liquid interface during the process of melting is marginally slower than anticipated.

K. Ben Nasr et al., [6] conducted a numerical investigation on the laminar natural convection of air within an enclosed hollow. The study specifically focused on the presence of localized heating and cooling on the roof of the cavity. The ceiling is maintained at a consistent temperature, while a certain vertical wall is heated at a uniform temperature, and the rest of the boundary is impermeable to heat transfer. The present investigation in the Cartesian coordinate system employs the control volume approach to address the complete vortex transport equation alongside the stream function and energy equations. The velocity and temperature fields are analyzed for different combinations of Rayleigh numbers and geometrical factors in order to demonstrate certain properties of the flow field. The outcomes are diminished in relation to the Nusselt number as a variable dependent on the Rayleigh number.

The thermal sensitivity of a novel composite building material including natural stone wastes and Phase Change Materials (PCM) was examined by **Mandilaras and M. Founti** [7]. A customized device has been designed at the National Technical University of Athens (NTUA) to assess the transient thermal response of new products under different temperature circumstances. This device has been deployed to investigate the nonlinear heat-transfer characteristics related to the phase-change of the phase change material (PCM). The present study involves the examination and assessment of the thermal performance of three distinct agglomerate marble samples, each containing varying proportions of phase change material (PCM) in their overall mass. The comparative analysis of the findings demonstrates the capacity of the novel materials to effectively maintain their temperature within the melting range of the phase change material (PCM), specifically between 25°C and 30°C. Consequently, these materials have the potential to mitigate heat losses in buildings.

In their investigation on thermal analysis, **Xing Jin and Xiaosong Zhang [8]** employed a double layer phase change material floor. A novel flooring system incorporating a two layer phase change material (PCM) was proposed. The two layers of phase change material (PCM) exhibited distinct melting temperatures. The system was employed for the purpose of storing thermal energy, either in the form of heat or cold, during periods of low demand, and subsequently releasing this stored energy during periods of high demand for heating or cooling purposes. The thermal characteristics of the floor are examined. The findings indicate the presence of ideal melting temperatures for phase change materials (PCMs). The reduction of floor surface temperatures and heat flux fluctuations allows the system to continue supplying a specific amount of heat or cold energy even after the heat pump or chiller has been inactive for an extended period. The floor with phase change material (PCM) exhibits a notable increase in energy release during peak periods, with heating and cooling experiencing a respective rise of 41.1% and 37.9%. This effect is shown when the PCM's heat of fusion is 150 kJ/kg, as compared to the floor without PCM.

Raji et al., [9] investigated the phenomenon of mixed convection heat transfer in a ventilated cavity. The researchers employed numerical methods to solve the mixed convection equations, incorporating the Bous-sinesq approximation. The outcomes of their analysis were presented in the form of streamlines, isotherms, and heat transfer characteristics. Various combinations of the governing parameters, including the Reynolds number ($10 \leq Re \leq 5000$), the Rayleigh number ($104 \leq Ra \leq 106$), and the relative height of the openings ($B = h0/H0 = 1/4$), were considered in the investigation. The numerical findings indicate a significant interaction between the effects of forced and natural convection, as well as the presence of several flow regimes. The regions in question are demarcated inside the Ra-Re plane, and the Re values that distinguish these distinct regions are identified and then compared to the corresponding Ra values.

A. Durmus¸and A. Daloĕlu [10] conducted a study on the unsteady-state natural convection phenomenon within an open rectangular prismatic cavity. The study involved conducting experiments with a table-top refrigerator to investigate a "open-door" scenario. In this experimental arrangement, the movement of air was helped by natural convection, with a specific emphasis on two-dimensional laminar and transition flows. The numerical investigation was performed by utilizing computational fluid dynamics (CFD) software. The rectangular prismatic cavity was expected to possess a vertical aperture, a chilled wall located at the top, and insulated side walls. The process of measuring air velocity involved the utilization of a hot-wire anemometer. The experimentally acquired average Nusselt numbers exhibited a high degree of agreement with the numerically calculated values. As the door is opened, there is an observed increase in the average Nusselt number for the cooling surface. This increase eventually stabilizes over time, reaching a steady-state situation. At the point of peak temperature difference, the Rayleigh number was determined to be 3.2×10^8.

Piia Lamberg et al., [11] conducted a physical validation of the numerical data obtained by the utilization of FEMLAB. The validation process involved doing a comparison examination of empirical data and computational outcomes. The numerical approaches investigated in this study included an enthalpy method and an effective heat capacity method. A collection of experimental phase change material (PCM) storage systems, both with and without features meant to promote heat transfer, were designed and fabricated. The numerical predictions derived from the implementation of FEMLAB simulation software are compared with empirical data. Both numerical methods offer precise estimations of the temperature distribution within the storage units throughout both the melting and freezing processes. However, the effective heat capacity method is considered the most accurate numerical approach when it comes to comparing numerical outcomes with experimental data. This method use a narrower temperature range of ΔT=2°C.

The preceding sections have underscored the significance of phase change materials (PCMs) in terms of their efficacy, efficiency, and cost-effectiveness in the context of energy conservation and reduction. The researchers have predominantly employed the computational fluid dynamics (CFD) technique and the ESR-R program in their numerical investigations. In their experimental studies, they have utilized various types of phase change materials (PCM) under different climatic conditions. Additionally, they have employed diverse methodologies to incorporate the PCM within the construction, including placement in walls, ceilings, and floors. However none of these studies and investigations has used PCM systems in the dry and hot climates. There for present study will focus on the following objects: (1) Determine the possibility of using the PCM in the roof construction in arid climate, especially in IRAQ/Baghdad, (2) Design and installation of a suitable test rig in order to study and analyze the performance of using PCM in the roof and its sensitivity to the ambient conditions, (3) Using the ANSYS FLUENT program in order to numerically simulate the temperature distribution and air flow in the test model room to study the detailed flow and heat transfer of the roof with PCM.

2. Numerical Simulation

Numerical simulations have a crucial role in several industrial applications, particularly in the analysis of fluid flow, heat transfer, turbulence, and related phenomena. This chapter presents a numerical approach for determining the solution to the aforementioned physical phenomena by solving a set of differential equations, including the momentum, energy, and continuity equations, which regulate these processes [12]. Numerical simulations enable the examination of intricate processes without the need for costly prototypes and challenging experimental tests. In recent years, Computational Fluid Dynamics (CFD) has emerged as a highly effective and valuable method for forecasting the distribution of temperature and the behavior of air flow in settings that are conditioned with ceiling Phase Change Materials (PCM). The utilization of numerical modeling techniques to analyze flow, heat transfer, and associated processes holds significant significance in various industrial applications [13].

2.1 Modeling of Phase Change Material

In Iraq, a significant portion of the electricity consumption during the summer season can be attributed to the operation of air conditioning systems in various buildings. Power companies encounter difficulties in fulfilling electricity requirements during periods of high demand, often observed between 12:00 p.m. and 6:00 p.m. In light of the increasing capital expenditures involved in the construction of new power generation facilities, corporations are actively investigating approaches to reallocate a portion of the energy consumption away from peak periods. One potential option entails the use of a phase change material (PCM) within residential attics. In the event that a substance with the ability to undergo phase transition during the periods of highest activity throughout the day is identified, this particular material would absorb a portion of the energy that would otherwise be transferred into the occupied region of the building. By implementing this approach, it is possible to move the maximum energy demand of the household to a later time during the evening. This timing adjustment takes advantage of the lower ambient temperatures during that period, as well as the cooling effect provided by air conditioning, which facilitates the solidification of the material. This process would result in the dissipation of the energy that has been accumulated at the highest point. Extensive research has been conducted in the field of utilizing phase change materials (PCMs) for thermal storage in the context of residential building development. The approach to analysis exhibits significant variation depending on the nature of the material as well as the manner in which it is integrated into the architectural framework. The user did not provide any text to rewrite.

The material under consideration in this context was specifically engineered for installation in the attics of newly constructed residences or as an upgrade to pre-existing structures. Typically, this product is positioned within a resistive, capacitive, and resistive (RCR) arrangement, situated between two layers of insulation. The thicknesses of these different layers play a crucial role in determining the overall effectiveness of the material. The product comprises a phase change material (PCM) of paraffin nature, which is immobilized within a perlite matrix.

2.2 Test Room Geometry

The geometry considered in the present work is a model room equipped with roof containing PCM. Figure (1) with 1:10 scale shows basic dimensions of the CAD geometry model, and its design procedure will be detailed later in Chapter Four. **For the experimental work,** a prototype 1:3 scaled model is used. The model needs some manipulation prior to be tested. This have included the implementation of mean panel temperature and consider it as the main variable in the simulations. The computational model involves the generation of geometry through the utilization of ANSYS FLUENT. This software is employed to construct the room surface as well as other room accessories, resulting in the creation of a three-dimensional solid model.

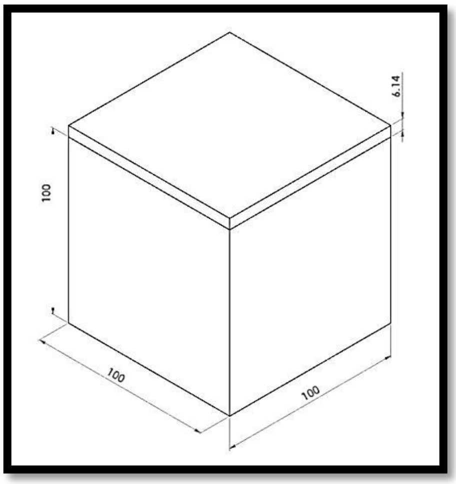

Figure 1 Basic dimensions of the CAD geometry model.

2.3 Development of Numerical Model

2.3.1 One-phase solution

The temperature distribution across the nth layer of the wall is determined by the one-dimensional diffusion equation when the PCM layer is in a state of complete solidity or complete liquidity [15]:

$$K_n \frac{\partial^2 T}{\partial x^2} = \rho_n c_n \frac{\partial T}{\partial t} \quad .... (1)$$

With the boundary condition:

T(0,t)=$T_o(t)$

T(L,t)=$T_l(t)$ .... (2)

An explicit method of numerical solution for a single material node is given by [16]:

$$T_i^{j+1} = T_i^j + \frac{Kn\Delta t}{\rho nCn(\Delta X)^2}(T_{i+1}^j - 2T_i^j + T_{i-1}^j) \quad .... (3)$$

For the inner interface the finite difference equation is:

$$T_i^{j+1} = T_i^j + \frac{2\Delta t\left[K_{ins}\left(T_{i-1}^j - T_i^j\right) + K_{pcm}\left(T_{i+1}^j - T_i^j\right)\right]}{\left(\rho_{pcm}C_{pcm} + \rho_{ins}C_{ins}\right)(\Delta X)^2} \quad .... (4)$$

For the outer interface the finite difference equation is:

$$T_i^{j+1} = T_i^j + \frac{2\Delta t\left[K_{pcm}\left(T_{i-1}^j - T_i^j\right) + K_{ins}\left(T_{i+1}^j - T_i^j\right)\right]}{\left(\rho_{pcm}C_{pcm} + \rho_{ins}C_{ins}\right)(\Delta X)^2} \quad .... (5)$$

The solution will continue to execute in the one-phase subroutine based on the initial state of the phase change material (PCM), whether it is in a fully solid or fully liquid state. The subroutine will terminate when either the maximum temperature at any node within the PCM layer exceeds the melting point, leading to melting, or when the minimum temperature within the material falls below the melting point, resulting in freezing. The temperature distribution at the current time step is subsequently utilized as the beginning condition for the two-phase algorithm.

2.3.2 Two-phase solution

In cases when the phase change material (PCM) layer comprises many phases, it is imperative to maintain the boundary points between the solid and liquid phases at a constant temperature equal to the material's melt temperature.

$T = T_m$ is $T_m - \Delta T < T < T_m + \Delta T$ .... (6)

The movement of the solid–liquid boundary x_{SL} is governed by the Stefan condition [17, 18] which is expressed as:

$$K_{PCM}[lim_{x\rightarrow xsl+}\left(\frac{\partial T}{\partial x}\right)-lim_{x\rightarrow xsl-}\left(\frac{\partial T}{\partial x}\right)]=\frac{\rho_{PCM}\alpha d_{xsl}}{dt} \quad ....(7)$$

Where x_{SL+} and x_{SL-} denote the limits approaching the solid– liquid interface from the right and left, respectively. An explicit numerical solution for a single material two-phase node is given by:

$$T_i^{j+1}=T_i^j=T_m \quad ....(8)$$

$$\lambda_i^{j+1}=\lambda_i^j+\frac{K_{PCM}\Delta t}{\rho_{PCM}\alpha(\Delta x)^2}\left(T_{i+1}^j-2T_m+T_{i-1}^j\right) \quad ....(9)$$

Let λ be the volume percentage of the i^th^ node that undergoes melting during the j^th^ time step. The finite difference equation is adjusted for the two interface locations between PCM and insulation, taking into consideration that each node is divided equally between insulation and PCM. The fully melted state is indicated by a value of λ = 1/2 = λ max for these two nodes. The two-phase finite difference equation is utilized for the inner interface node:

$$\lambda_i^{j+1}=\lambda_i^j+\frac{\Delta t\left[K_{ins}\left(T_{i+1}^j-T_m\right)-K_{PCM}\left(T_{i+1}^j-T_m\right)\right]}{\rho_{PCM}\alpha(\Delta x)^2} \quad ....(10)$$

For the outer interface node the two –phase finite difference equation is:

$$\lambda_i^{j+1}=\lambda_i^j+\frac{\Delta t\left[K_{PCM}\left(T_{i+1}^j-T_m\right)-K_{ins}\left(T_{i+1}^j-T_m\right)\right]}{\rho_{PCM}\alpha(\Delta x)^2} \quad ....(11)$$

The primary objective of the two-phase subroutine is to facilitate the transition between equations (3-3) to (3-5) and equations (3-8) to (3-11) based on the current condition of the node under examination. Figure 2 illustrates a representative temperature distribution upon exiting the one-phase solid solution. In this particular scenario, the material exhibits total solidity, as indicated by a temperature value of zero for all nodes. The outermost node of the phase change material (PCM) is situated at a temperature slightly higher than the melting point (Tm). The temperature of the node is adjusted to the melting point of the phase change material (PCM) and maintained at that level. Equation (3-11) is utilized to ascertain the proportion of the node that has undergone melting. This process persists until the value of λ reaches zero, indicating that the node has fully frozen again, or until λ reaches its maximum value, indicating that the node has entirely melted. Currently, the temperature is once again permitted to vary in accordance with Equation (3-5). The temperatures of the nodes located below the threshold temperature, Tm, are controlled by the one-phase equations until they exceed Tm. At present, the node is acknowledged to exist in two separate phases, and the computational method is modified to utilize Equations (3-8) to (3-11).

Figure 3 illustrates the fundamental logic employed in the two-phase subroutine for transitioning between the two sets of equations. The subroutine consisting of two phases concludes and returns to the main procedure once all nodal temperatures within the phase change material (PCM) layer have reached a state where they are either all above or all below the temperature threshold Tm. The resultant temperature distribution at the end of the process serves as the updated beginning condition when re-entering the subroutine for the one-phase calculation. In the event that the initial temperatures of the phase change material (PCM) in the one-phase method are greater than the temperature at which the PCM transitions into a single liquid phase, the subroutine will terminate if any of the temperatures at the nodes decrease below the melting point. In the scenario where the one-phase method commences with PCM temperatures below the melting point (indicating a solid phase), the subroutine will terminate if any of the nodal temperatures surpass the melt point. The primary procedure will persist in alternating between the two subordinate procedures until the maximum number of time steps is attained. The present study focuses on a physical system consisting of an aluminum box that is filled with phase change material (PCM) and positioned as a roof. During each cycle, the phase change of the phase change material (PCM) in the roof occurs from solid to liquid, specifically during the charging process that takes place during sunshine hours. During the nocturnal discharge phase, the phase transition of the phase change material (PCM) occurs, namely from a liquid state to a solid state by the process of solidification. The process of transitioning is made possible by the phase change material (PCM) dissipating its thermal energy to both the immediate surroundings and the ambient air within the enclosed space. The aforementioned loop endures on a daily basis.

The composite wall is initially held at a constant temperature denoted as "Ti". The boundary condition at the exterior surface of the roof is taken into account as a result of the combined influence of radiation and convection. To account for the impact of radiation, the average monthly solar radiation heat flux in Baghdad, Iraq is utilized on an hourly basis. The estimation of the heat transfer coefficient (h) for convection on the outer surface is achieved by utilizing a heat transfer coefficient correlation that considers the prevailing wind velocity. The user presented a number reference without any associated textual information [19].

$$\overline{Nu}=0.664\,(Re)^{1/2}\,(Pr)^{1/3}$$

The natural convection boundary condition is applied to the inner surface of the concrete slab. Due to the minimal temperature differential observed between the room and the wall, a majority of previous researchers have made the simplifying assumption of considering the bottom wall as thermally insulated. The heat transmission coefficient (h) within a room can be determined through the utilization of the Fortran computer language.

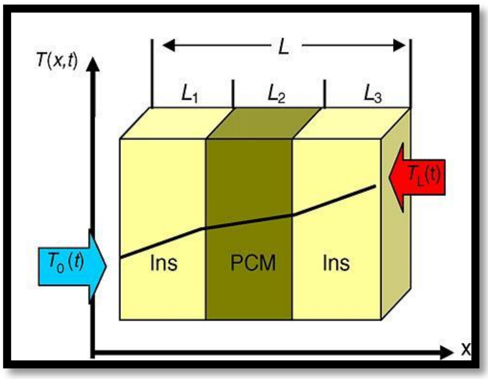

Figure 2 Typical temperature distributions for exiting the one-phase solid subroutine.

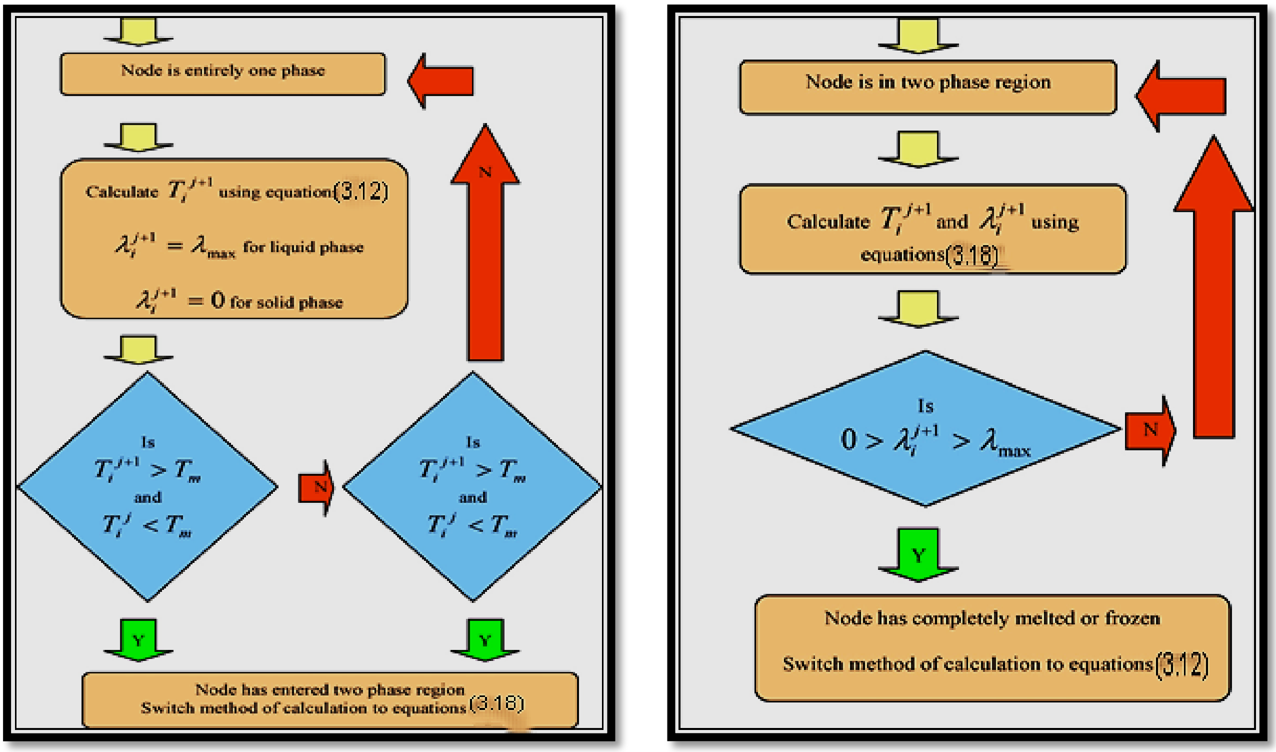

Figure 3 Logic for two-phase subroutine (single-phase node and two phase).

2.4 Heat Transfer Theory

The Energy Equation [20] ANSYS FLUENT solves the energy equation in the following form:

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{v}(\rho E + p)\right) = \nabla.\left(k_{eff}\,\nabla T - \sum_j h_j \vec{J}_j + (\bar{\bar{T}}\text{ eff} \cdot \vec{v})\right) + Sh \quad \ldots(12)$$

Where k_{eff} is the effective conductivity (k + k_t) where k_t is the turbulent thermal conductivity, defined according to the turbulence model being used), and $\vec{J}_j$ is the diffusion flux of species j. The initial three components on the right side of Equation (3-12) correspond to the transfer of energy resulting from conduction, species diffusion, and viscous dissipation, respectively. The calculation encompasses the heat generated by the chemical reaction as well as any other volumetric heat sources that have been specified.

$$E = h - \frac{p}{\rho} + \frac{v^2}{2} \quad \ldots.(13)$$

Where sensible enthalpy h is defined for ideal gases as:

$$h = \sum_j Y_j h_j \quad \ldots.(14)$$

And for incompressible flows as:

$$h = \sum_j Y_j h_j + \frac{p}{\rho} \quad \ldots.(15)$$

In Equations 3.2-3 and 3.5-4, Y_j is the mass fraction of species j and

$$h_j = \int_{T_{ref}}^{T} cp\,.j\,dT \quad \ldots.(16)$$

Where is T_{ref} 298.15 K.

2.4 Mesh Generation and Boundary Condition

The capability of ANSYS FLUENT to adaptively refine or coarsen the mesh in response to geometric and numerical solution inputs is known as solution-adaptive mesh refinement. Furthermore, ANSYS FLUENT offers a range of tools that enable the creation and visualization of adaption fields tailored to specific applications [20]. Traditional computational fluid dynamics (CFD) techniques necessitate the utilization of a mesh that is compatible with the boundaries of the computational domain. The development of a computational mesh that is appropriate for discretizing and solving the three-dimensional Navier-Stokes, continuity, and energy equations has consistently been the focus of extensive research efforts. This particular problem encompasses a broad spectrum of engineering applications. Once the model has been depicted, a mesh is generated, as illustrated in Figure 4. Additionally, Figure 5 displays the closely resembling mesh type. The establishment of appropriate boundary conditions is crucial in achieving a precise solution for the model room. Table 1 presents the thermal boundary conditions.

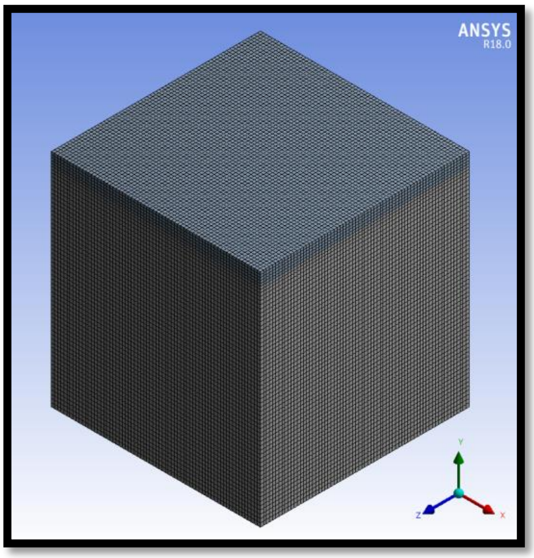

Figure 4 Mesh generated.

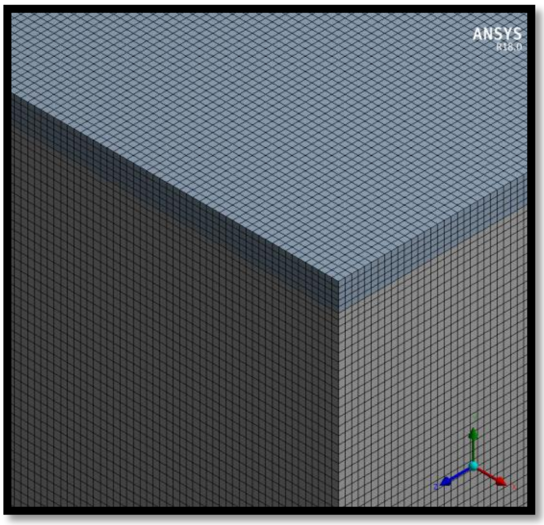

Figure 5 Megascopic mesh section from Figure (4).

Table (1): Thermal boundary conditions.

Part	Type	Thermal Conditions
Top	Wall	- Temperature **(**variable with time**)**. - Heat generation Rate = **0 (W/m^3)**. - Wall Thickness = **0.0007 (m)**.
Wall-part air	Wall	- Heat flux = 0 **(W/ m^2)**. - Heat generation Rate = **0 (W/m^3)**. - Wall Thickness = **0 (m)**.
Plate	Wall	- Heat flux = 0 **(W/ m^2)**. - Heat generation Rate = **0 (W/m^3)**. - Wall Thickness = **0 (m)**.
Plate-shadow	Wall	- Heat flux = 0 **(W/ m^2)**. - Heat generation Rate = **0 (W/m^3)**. - Wall Thickness = **0 (m)**.
Wall-part oil	Wall	- Heat flux = 0 **(W/ m^2)**. - Heat generation Rate = **0 (W/m^3)**. - Wall Thickness = **0 (m)**.

2.5 Solution Methodology

The resolution of the Pressure-Velocity Coupling is achieved through the implementation of the SIMPLE method. This technique contains a Second Order Upwind scheme for the momentum and energy equations, together with a Least Squares Cell Based gradient. It is crucial to exercise control over the manipulation of the primary variable due to the presence of pressure-velocity coupling and nonlinearity inside the equation set that is to be resolved by FLUENT. Under-relaxation is a commonly employed technique that effectively decreases the magnitude of changes in the primary variable that occur throughout iterative processes. The under-relaxation factors employed in the current study for solving the momentum equation and other scalar quantities are provided in Table 2. Residuals refer to the discrepancy between the observed values and the predicted values in a computational model, commonly known as the error. Figure 6 illustrates the convergence history of the static temperature in the uppermost region.

Table (2) Under-Relaxation Factors.

	Under-Relaxation Factor
Pressure	0.3
Density	1
Body force	1
Momentum	0.7
Energy	1

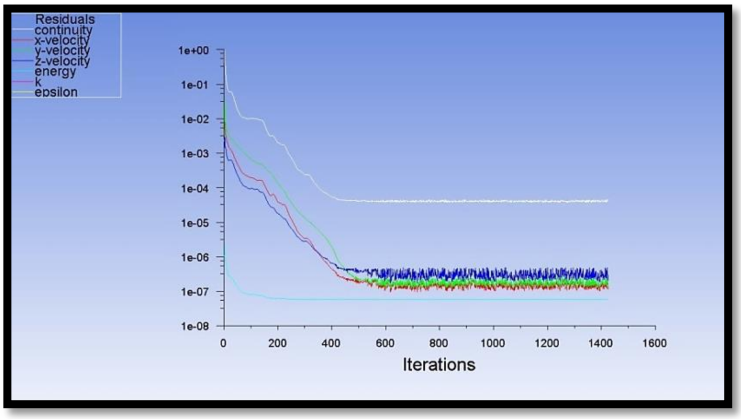

Figure (6): show convergence history of static temperature on top.

3. Results and Discussion

Natural convection flow in enclosures and cavities, has received considerable attention in the recent heat transfer literature that is having continuing and growing interest. The numerical solution of natural convection problems that are too expensive experimental investigations and too complicated for analytical treatment can now be effectively obtained with the availability of high speed computers and advanced computer graphics capability. Recently, the computer has made the mathematical modeling of such processes feasible, based on the fact that the basic equations of the flow, heat transfer, and their coupling must be solved for the two dimensional flow domains. A model size which has the following dimensions (1 m×1 m×1m), was taken in this study. Computational runs were performed at various mean ambient temperatures. One way of presenting data graphically is to show slice (plane) for the room used .All graphic results are plotted on the plane in the middle of the room showed in Figure (7).

3.1 Temperature Contours

The temperature contours for the PCM rooms are presented in Figs. (8, 9, 10, 11, 12, 13 and 14). They represent the temperature contours for PCM room at different hours. The temperature contours can be seen that the room with PCM contains in its roof gives a good temperature distribution in the room along the day. Figure (8) shows the temperature distribution in room at (8AM). Notice that the temperature at ceiling and the room is stable and the temperature range between(32-29)^{0}C. Figure (9) shows the temperature distribution range between (36-30)^{0}C in the room at (10AM). When time increase to (12A.M) an increased fluctuation occurs in the room and the PCM stored energy as shown in Fig (10) with temperature range between (39-31)^{0}C. Figure (11) shows temperature contours for the PCM rooms at (2PM) shows the temperature distribution range between(41.5-32)^{0}C. Temperature distribution in room at (4P.M) shown in figure (12) with temperature range between (40.6-33)^{0}C. PCM worked as heat storage material and the temperature of the material is higher than the inner surface of the ceiling shows in figures (13) and (14) at (8 P.M) and (11 P.M) respectively where the temperature distribution range between (37-33)^{0}C at (8 P.M) and between (32-31.5)^{0}C at (11 P.M). This shows that the temperature distribution in the room makes it a comfort zone. The units in all the figures of the temperature contours are in (ºK).

3.2 Temperature Results and Comparisons

The meteorological data was collected in the city of Baghdad during the month of

July in the year 2002, as depicted in Figure 15. The upper limit of temperatures observed is approximately 480°C, while the lower limit is roughly 280°C. The process of temperature measurement commenced at the onset of sunrise. The temperature distribution across the roof structure is depicted in Figure 16. The observed phenomenon indicates that as time progresses, the temperature within the ceiling rises due to the absorption of a significant amount of heat energy by the phase change material (PCM) as it traverses the roof..

From τ = 6 hr to τ = 12 hr, there is an observed increase in the heat transport characteristics compared to the preceding time period. The curve representing phase change material (PCM) exhibits a minimum value at the lowermost layer and attains its maximum value at the uppermost layer. Initially, the temperature of the layers is almost equal, but as time progresses, the temperature gradually increases.

During the time interval from τ = 12 hr to τ = 18 hr, the thermal energy that has been introduced into the system is transferred within the roof structure. The temperatures at the mid plane exhibit greater values compared to those at τ = 12 hours. During the time interval of τ = 18 hours, the heat flux exhibits a significantly low magnitude, so indicating that convection at the rooftop prevails over other heat transfer mechanisms.

From the time period of τ = 18 hours to τ = 23 hours, there is an absence of solar radiation penetrating the roof. The temperature at the upper and lower sections of the roof exhibits a high degree of similarity. The temperature attains its maximum value at the midpoint and within the vicinity where the phase change material (PCM) is situated. The temperature experiences a rapid decrease to the ambient room temperature as the phase change material (PCM) effectively absorbs all thermal energy that is transferred via the roof. The thermal energy storage capacity of the region where the phase change material (PCM) is implanted causes the temperature to decrease to its minimum value towards the bottom.

Figure 17 illustrates the temperature fluctuations observed within the experimental chamber. The experimental findings revealed a slight reduction in ceiling temperature during daylight hours, while modest elevations in ceiling temperature were recorded during nighttime periods. The objective is to minimize the temperature variation within the phase change material (PCM) room between the hours of 12:00 PM and 2:00 PM. The reason for this phenomenon can be attributed to the significant heat storage capacity exhibited by the phase change material (PCM). The initial row of thermocouples provides measurements in close proximity to the inner surface of the ceiling, exhibiting slight variations. The observed discrepancy is further amplified when comparing the measurements of the second and third rows of thermocouples within the enclosed space, with a discernible difference in values.

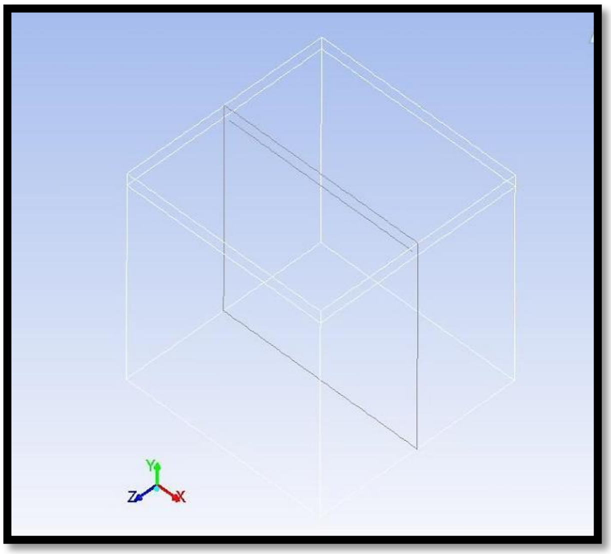

Figure 7 The plane of plot.

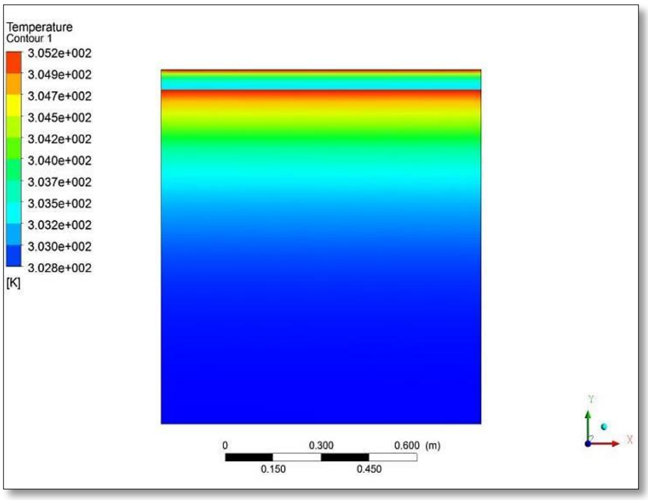

Figure 8 Temperature counters for the experimental room at (8A.M).

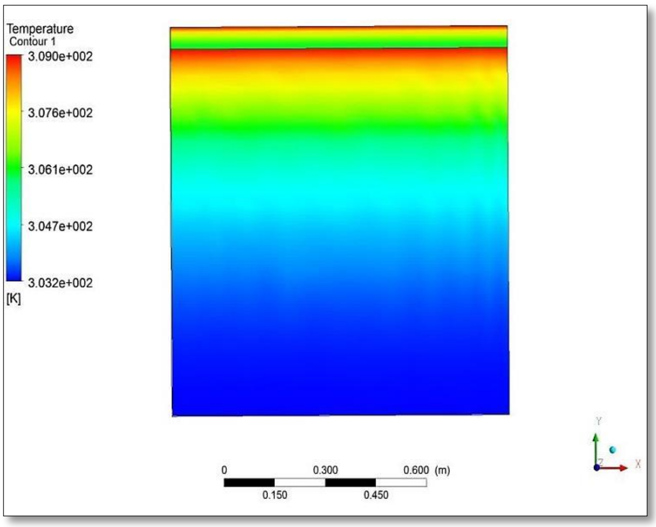

Figure 9 Temperature counters for the experimental room at (10 A.M).

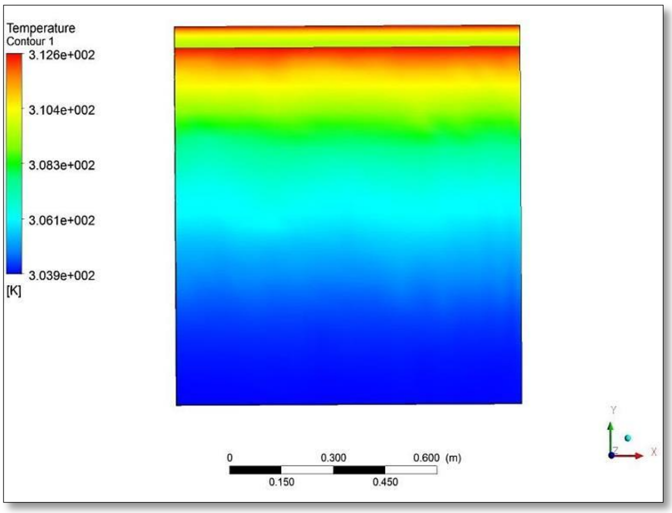

Figure 10 Temperature counters for the experimental room at (12P.M).

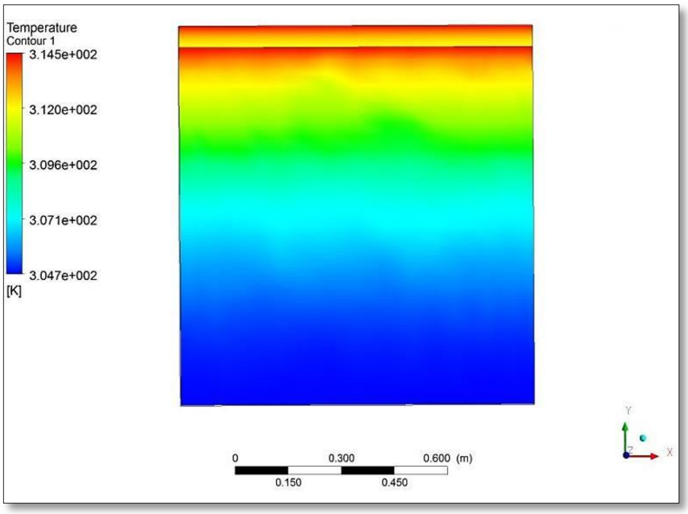

Figure 11 Temperature counters for the experimental room at (2P.M).

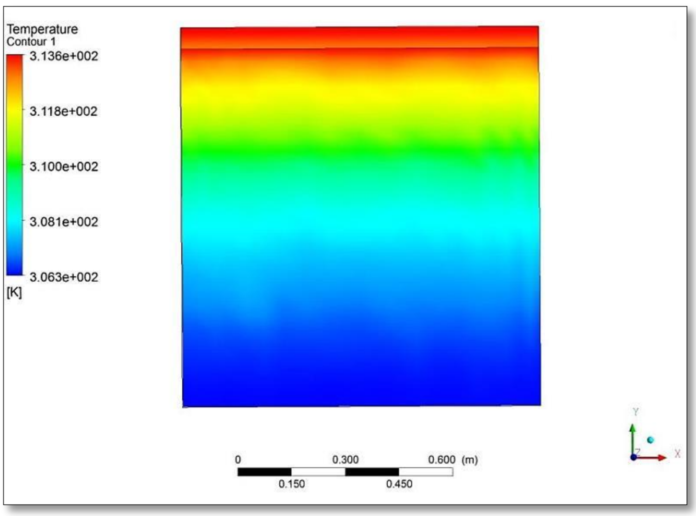

Figure 12 Temperature counters for the experimental room at (4P.M).

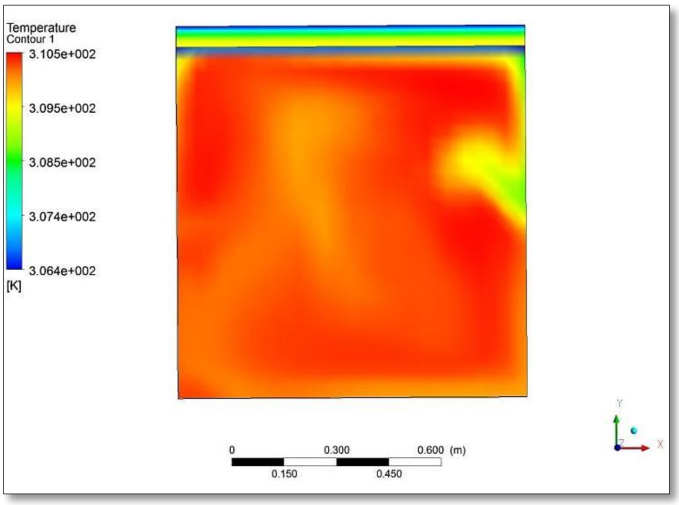

Figure 13 Temperature counters for the experimental room at (8P.M).

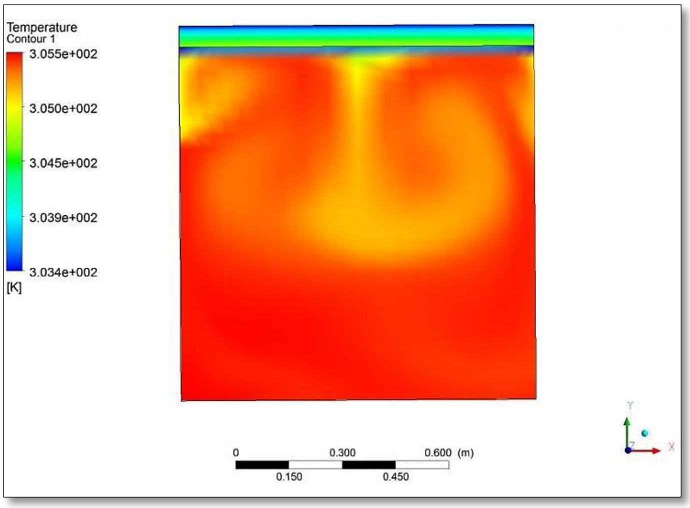

Figure 14 Temperature counters for the experimental room at (11P.M).

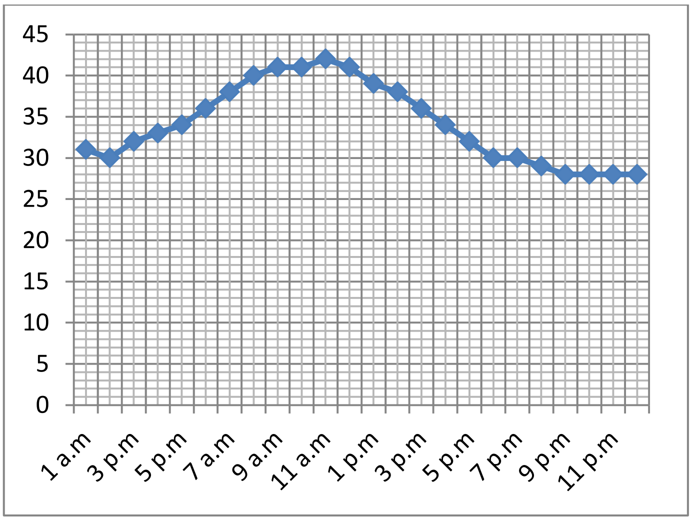

Figure 15 The weather data in Baghdad city during July. 2002.

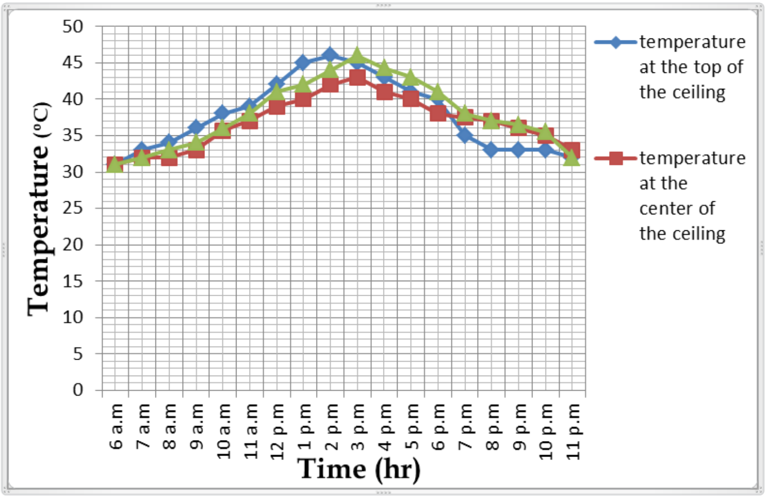

Figure 16 Experimental temperature distributions through the ceiling.

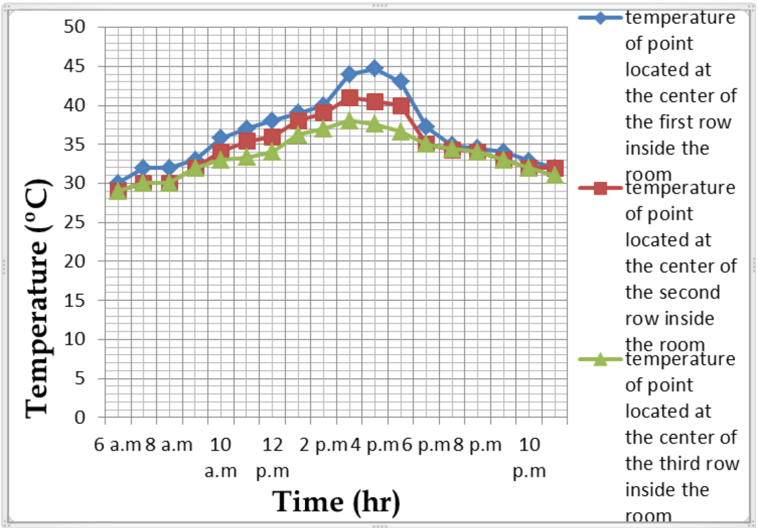

Figure 17 Experimental temperature through the test room.

4. Conclusions

The using of PCM in the building construction especially in the roof has proved to be a successful and energy efficient alternative for air conditioning application in Iraqi climates. A numerical and experimental laboratory has been developed, built, and evaluated for investigating the impact of phase change materials (PCM) on building performance. The unique and versatile facility serves as a comprehensive framework for the examination of room conditions incorporating phase change material (PCM) in the roof. Furthermore, the present study has yielded some key findings regarding the computational modeling methodologies that were examined:

1- The presence of a phase change material (PCM) in the roof structure results in a reduction of heat transfer into the room. Due of its low thermal conductivity, the PCM exhibits a capacity to impede the flow of heat, resulting in a reduction of heat transfer. The architecture of this economic system and the availability of phase change materials (PCM) make it ideal for the arid climate of Iraq.

2- The value of latent thermal substance and melting temperature influence directly the thermal storage process in phase change material that which limit directly amount of gained or lost temperature and rate of gain or loss of temperature for any substance.

3- The relative percentage error compared to the experimental results obtained is very low, hence it can be deduced that they describe the latent absorption phenomenon correctly.

4- Numerical investigations demonstrate a noteworthy decrease in indoor air temperature for structures lacking mechanical cooling systems, together with the potential for downsizing and a decrease in peak-load power and energy consumption for buildings equipped with mechanical cooling apparatus. Nonetheless, The effectiveness of latent thermal storage relies on the consistent discharge of the storage system, which can be achieved through natural cooling or mechanical cooling sources. This is especially important during periods when the demand for cooling is reduced.

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