# Assessment of embedding phase change materials in heavyweight buildings in Iraq using ESP-r

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## ABSTRACT

The traditional approaches employ massive components to moderate temperature fluctuations. The thermo-physical properties of the construction materials will have a strong influence on a building's energy consumption. Within a passive solar design, the heat capacity of the inner wall layer is dominated. This approach is applicable in locations that have effective daily temperature variations, else that, heavy weight constructions can give rise to problems of excessive thermal mass and cost. The nature of the climate of Iraq can be represented in a two typical seasons; short and cold winter and long, hot and dry summer with short periods of the moderate months. The daily temperature variation is very limited and causes to accumulated heat in the buildings of heavy mass. The use of cooling system, in hot climate, is increased especially with heavy mass constructions. In Iraq, more than 6 million new building unit should be added until 2020, the rapid growth in building sectors become the largest consumer of electric power produced, where the building sector consumes more than 38% from the total energy produced. In this investigation, the phase change materials behaviour was embedded within traditional heavyweight building internal surfaces. The two identical simple single zones modelled and simulated in a professional energy systems program called ESP-r. Global meteorological database software called Meteonorm7 has been used to generate a climate file for Baghdad city (33.3 $^{o}$N and 44.4$^{o}$E) into ESP-r program. The results represent a preliminary investigation into the effect of PCM modelling with heavy structured construction under hot climate. In addition, a comparison of an internal surface with different phase change temperature ranges. It is found that the presence of PCM could have a significant effect on the internal surfaces and thus the zone temperatures. The results encourage a full yearly investigation for the tested model, the simulation under realistic operational loads and with fixed internal boundary conditions underneath control loops using appropriate heating, cooling and ventilation strategies.

**Keywords:** Phase change materials, PCM, Building energy simulation, latent heat storage, Thermal energy storage. Thermal mass. ESP-R.

## الخلاصة

النهج التقليدية المستخدمة في البناء توظف مكونات بأبعاد وكتل كبيرة لمعادلة التقلبات الخارجية في درجات الحرارة وتوفير درجات الحرارة داخلية معتدلة .الخصائص الحرارية-الفيزيائية لمواد البناء يكون لها تأثير قوي على استهلاك الطاقة في المباني . ضمن التصميم الشمسي السلبي، تهيمن خاصية السعة الحرارية لطبقة الجدار الداخلية على الخصائص الاخرى. هذا النوع من التصميم يكون قابلة للتطبيق في المواقع التي لديها اختلافات فعالة درجة الحرارة اليومية، وإلا فأن الإنشاءات الثقيلة الكتلة يمكن أن تؤدي إلى مشاكل ارتفاع درجات الحرارة بسبب الكتلة الحرارية الزائدة وأيضا التكلفة العالية .ان طبيعة المناخ في العراق يمكن أن تكون ممثلة في موسمين نموذجيين، فصل الشتاء القصير والبارد وفصل الصيف الطويل، حار والجاف مع فترات قصيرة من

الأشهر المعتدلة .ان تباين اليومي لدرجات الحرارة محدود للغاية ويسبب تراكم الحرارة المخزنة خصوصا في المباني من الكتلة ثقيلة.ان استخدام نظام التبريد في المناخ الحار هو الشائع، ويزداد بشكل فعال خصوصا مع المنشآت ذات كتلة ثقيلة .في العراق، مع الحاجة الى أكثر من 6 ملايين وحدة بناء جديدة في عام 2020، وبسبب النمو السريع في بناء القطاعات السكنية أصبح قطاع الاسكان أكبر مستهلك للطاقة الكهربائية المنتجة، حيث يستهلك أكثر من 38٪ من إجمالي الطاقة المنتجة .في هذا البحث، تم دراسة سلوك المواد متغيرة الطور داخل الأسطح الداخلية للمباني لمبنى ذو الكتلة الثقيلة. المقارنة تمت مع حيز اخر مطابق لا يحتوي في جدرانه الداخلية على هذه المادة وضمن نفس الشروط التشغيلية عن طريق استخدام برنامج محاكاة تسمى ESP-R. وقد استخدم برنامج قواعد البيانات العالمية للأرصاد الجوية Meteonorm7 لتوليد بيانات المناخ لمدينة بغداد N 33.3 و44.4 E حيث تم إدخال البيانات في برنامج ESP-R. وكانت النتائج تمثل تحقيقا أوليا في تأثير PCM المدمجة مع مواد البناء الثقيلة منظم جيد لدرجات الحرارة للحيز تحت المناخ الحار .وبالإضافة إلى ذلك، يتم إجراء مقارنة بين سطح داخلي مع مواد متغيرة الطور ذات درجات طور مختلفة. أن وجود PCM يمكن أن يكون له تأثير كبير على الأسطح الداخلية وبالتالي درجة حرارة الحيز. ان النتائج تشجع على اجراء تحقيق سنوي الكامل للنموذج واجراء المحاكاة تحت الأحمال التشغيلية الواقعية ومع تثبيت شروط الداخلية ثابتة باستخدام استراتيجيات السيطرة على التدفئة والتبريد والتهوية.

## 1. INTRODUCTION

The distribution of thermal mass within a building is the result of structural and architectural decisions and can greatly influence how the building reacts to internal heat gains, solar radiation entering the building or changes in outside conditions. Lightweight components react quickly to changes in internal gains and radiation. The traditional approaches employ massive components to moderate temperature fluctuations. The thermo-physical properties of the construction materials will have a strong influence on a building's energy consumption. Within a passive solar design, the heat capacity of the inner wall layer is dominated. In this approach is applicable in locations that have effective daily temperature variations, else that, heavy weight constructions can give rise to problems of excessive thermal mass and cost, (**Sara and Mina, 2012**).

The nature of the climate of Iraq can be represented in a two typical seasons, short and cold winter and long, hot and dry summer with short periods of the moderate months. The daily temperature variation is very limited and causes to accumulated heat in the buildings of heavy mass, (**Kazem et al, 2012**). The use of cooling system, in hot climate, is increased especially with heavy mass constructions. In Iraq, with more than 6 million new building unit in 2020 , the rapid growth in building sectors become the largest consumer of electric power produced, where the building sector consumes more than 38% from the total energy produced, (**MOELC**).

Through the integrated of a phase change materials (PCM) to traditional building materials will improve the thermal properties of these materials, especially thermal capacity. The increasing in thermal capacity could shift most of the load coming from residential air conditioners from peak to off peak time periods (**Khudhair and Farid, 2004**). Integrating phase change materials within light construction showed efficient reduction in cooling and heating load especially in cold and moderate climate regions, (**Neeper, 2000**). The present work will assess a building model with heavy structures integrated phase change materials (PCM) within the internal material layers. The model simulated and tested in Baghdad climate conditions using ESP-r (**E**nergy **S**imulation **P**rogram for **R**esearch) program, (**ESP-R**).

## 2. PCM AND FIELD OF APPLICATIONS

The fields of PCM's applications can be divided into high storage density for storage heat or cold, temperature control and thermal resistance contact enhancements. PCM's can be integrated in both building materials and buildings components; implemented in gypsum board, plaster board, mixing with concrete or other wall finishing materials. Thermal storage can be part of the building structure even for lightweight buildings; also can be part in heating ventilation and air conditioning (HVAC) systems, (**Zalba, 2003**). There are several types of organic and inorganic chemical materials that can classified as PCM's according to melting temperature and latent heat of fusion. In general, inorganic materials have almost double volumetric latent heat storage capacity (250–400kJ/m$^3$) than that of the organic materials (128–200 kJ/m$^3$), (**Sharma et al., 2009**). The PCM must encapsulated so that it does not affect or change the function of the building construction material. Three ways are used as means of PCM integration with an any component; direct incorporation, immersion and encapsulation. The first and second types affect the function of the construction material due to the direct contact with construction materials. For examples, concrete blocks impregnated with PCM's and PCM's mixed with heating/cooling system working fluid. The third one can be defined as the containment of PCM within a capsule of various materials forms and sizes prior to incorporation so that it may be introduced to the mix in a convenient manner. In Macro-encapsulation, the inclusion of PCM in some form of containers such as tubes, pouches and spheres in boards, (**Pasupathy et al., 2008**). Microencapsulated of paraffin wax, which work as phase change material covered by polymer was prepared locally in Iraq. The diameter of the prepared capsules was about (170-220) micron, the thermal analysis appears as a best value of enthalpy which was (12 J/gm) when the temperature was (60˚C), (**Mohammed et al., 2012**).

## 3. BUILDING MODEL AND BACKGROUND INFORMATION

### 3.1 ESP-r program

ESP-r is a modelling tool for building performance simulation. In undertaking its assessments, the system is equipped to model heat, air, moisture light and electrical power flows at user specified spatial and temporal resolution. (**ESP-R**). The ESP-r allow to modelling and simulation PCM effect within buildings context using special materials components facilities. In ESP-r, Phase change occurred between melting phase (PCM becomes melts) and solidification phase (PCM becomes solidified) temperatures. Below melting temperature, PCM is considered as a solid and the conductivity of the layer is equal to conductivity in solid phase. Over melting temperature, PCM is considered as a liquid and conductivity of the layer is equal to conductivity in liquid phase. Beyond phase change temperature range, latent heat of material is equal to zero, (Heim and Clarke, 2004).

### 3.2 Weather information

A global meteorological database software called Meteonorm7 used to generate a climate file for Baghdad city (33.3 $^{o}$N and 44.4 $^{o}$E) as input data for ESP-r program, (**Meteonorm**). Meteonorm 7 generate a climate database for long period 1991- 2010. The climate data sets interpolated from the satellite data for nearest climate stations from Baghdad city location. The weather file exported from epw format (**E**nergy **P**lus **W**eather) to binary format (esp-r climate file format) using Meteonorm converter tools facilities (**ESP-R**). The climate data sets interpolated from the satellite data for the nearest climate stations from Baghdad city location. **Fig. 1** and **Fig. 2** shows the dry air temperature in degree-centigrade and the direct radiation in W/m$^2$. Weather data for Baghdad city define the boundary condition for the simulations. Corresponds to the hottest summer between 1991 and 2010. The average ambient air temperature from June to August is 32.49 $^{o}$C and the maximum direct normal solar radiation is 812.8 Watt/m$^2$. The period from the beginning of June to the end of August was selected for the analysis.

### 3.3 Building model

To investigate the effect of PCMs effect, a two identical simple single rooms introduced in ESP-r, as shown in **Fig 3**. The model has dimensions of (5 m * 4 m) and a height of 3m. There is a single window with double glass south facing with 15% the south wall. ESP-r has an adopted database of materials and construction layers that can used directly or modified. In this model a new structure databases created to representing heavy weight structure used in traditional Iraqi's buildings as shown in **Table 1**. PCM layers placed inside the interior surface for three walls only (walls-2, 3 and 4) as shown in **Fig.3**. A typical phase change material is of the liquid-solid type, where energy is stored as latent heat during the phase change of the material. The phase change temperature selected in range 2°C and the latent heat of fusion is 1000J/kg K. The physical properties summarized in **Table.2**. No cooling system used to control the space temperature, only the solar load considerate in this investigation.

## 4. NUMERICAL SETUP AND RESULTS ANALYSIS

The interior layer made from 10 mm of PCM–gypsum composite layer, this applied to all surfaces except the floors, roof and wall-1in the Room and Test-Room zones. Based on the dry bulb ambient temperature and the Room model resultant temperature profile obtained from the initial simulation (no PCM), the melting-solidification temperatures selected to be 24-26, 25-27, 26-28 and 28-30 $^{o}$C respectively. The phase change temperature rang was assumed to be 2$^{o}$C in each case. In addition, each case has the same value of latent heat of fusion given by 24000 J/kg. The simulation period selected between June and August 2007 as shown in **Fig. 2**.

### 4.1 Walls temperatures

The Figure 4, 5 and 6 showing the internal surface temperature of the walls 2, 3 and 4 with PCM. The PCM has a significant effect on the internal surfaces temperature, especially for the days when the PCM temperature reach its phase change range. While, there is no difference for the days with the temperature outside the phase change temperature range (below/above). It is therefore behaving as a regular sensible material. Thus, as long as the phase change materials in charging-discharging continuously, there will be a visible effect on room temperature. Because the two models not supported with a cooling and air ventilation-infiltration systems, the rooms space temperature is allowed to increase, Thus, The PCM reach the full charging state and the temperature of the internal surfaces of the Test-Room increased steadily.

For comparison, all the **Figs. 4-7** taken at the same snapshot in time (June to August). The snapshots chosen to clarify the differences between walls with PCM (Test-Room model) and without PCM (Room model). A PCM layer with phase change rang 24-26 $^{o}$C shown in **Fig. 4**, the temperature profiles for surfaces with PCM diverted from first days of simulation and the temperatures decrease below the surfaces without PCM. The same behaviour is founded in all other phase change ranges while the delay depends on the value of melting temperature.

### 4.2 ROOM TEMPERATUERS

The thermal response of the internal surfaces affects the internal zones temperature. **Figs. 8–11** show the temperature profiles snapshot for Room and Test-Room model over a selected simulation periods. An analysis of these data does not show significant differences in the zone's temperatures profile. The phase change material succeeded in avoid the rise of the internal surfaces temperature in Test-Room's walls, where the reduction achieved compared with the surfaces, which does not contain this materials. Through the figures, it can be noted that the length of this effect depends on the melting temperature and the solidification temperature, because the absence of both cooling and ventilation systems the internal zones temperature continue rising. The other reasons, the floor, glazing, wall-3 and ceiling components receiving solar energy and causing warming the zone space.

Thus, the PCM temperature out of the phase change range. The other reasons, the floor, glazing, wall-3 and ceiling components receiving solar energy and causing warming the zone space. Thus, the PCM temperature out of the phase change range and kept in continuous charging state.

## 5. CONCLUSIONS AND REMARKS

Different strategies can be used for integration PCM within walls, celling and ground compo
The purpose depends on the PCM layer location within the construction, the PCM located an interior layer for controlling zone temperature with cooling or heating processes where the application should be with phase change range. If the PCM located in the external layer, the PCM phase change temperatures should responding with ambient temperature and react as insulation materials with high latent heat capacity. While, if the PCM located in internal layer, the phase change limit equal the comfort temperature range of the users. In this investigation, the effect of phase change material embedded within heavy structured buildings using building energy simulation software called ESP-r. A comparison of an internal surface with different phase change temperature ranges is made. The results represent a preliminary investigation into the effect of PCM modelling with heavy structured construction under hot climate. It is found that the presence of PCM could have a significant effect on the internal surfaces and thus the zone temperatures. The results encourage a full yearly investigation for the tested model, the simulation under realistic operational loads and with fixed internal boundary conditions under control using appropriate heating, cooling and ventilation strategies.

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**Table.1:** Test Roof and walls constructions.

| **Walls** | |
|---|---|
| External/Cement layer (mm) | 25 |
| Brick layer (mm) | 240 |
| Cement layer (mm) | 20 |
| Internal/ Gypsum layer (mm) | 10 |
| **Roof** | |
| Concrete Tile layer(mm) | 25 |
| Sand layer(mm) | 100 |
| Corks layer(mm) | 50 |
| Mastic layer(mm) | 5 |
| Heavy mix concrete layer (mm) | 150 |
| Cement layer (mm) | 20 |
| Gypsum layer (mm) | 10 |

**Table.2:** PCM specification.

| **Property** | **Value** |
|---|---|
| Phase change temperature rang ($^{o}$C) | 2 |
| Conductivity in solid phase J/kg | 0.4 |
| Conductivity in liquid phase J/kg | 0.8 |
| Specific heat (J/kg K) | 1000 |

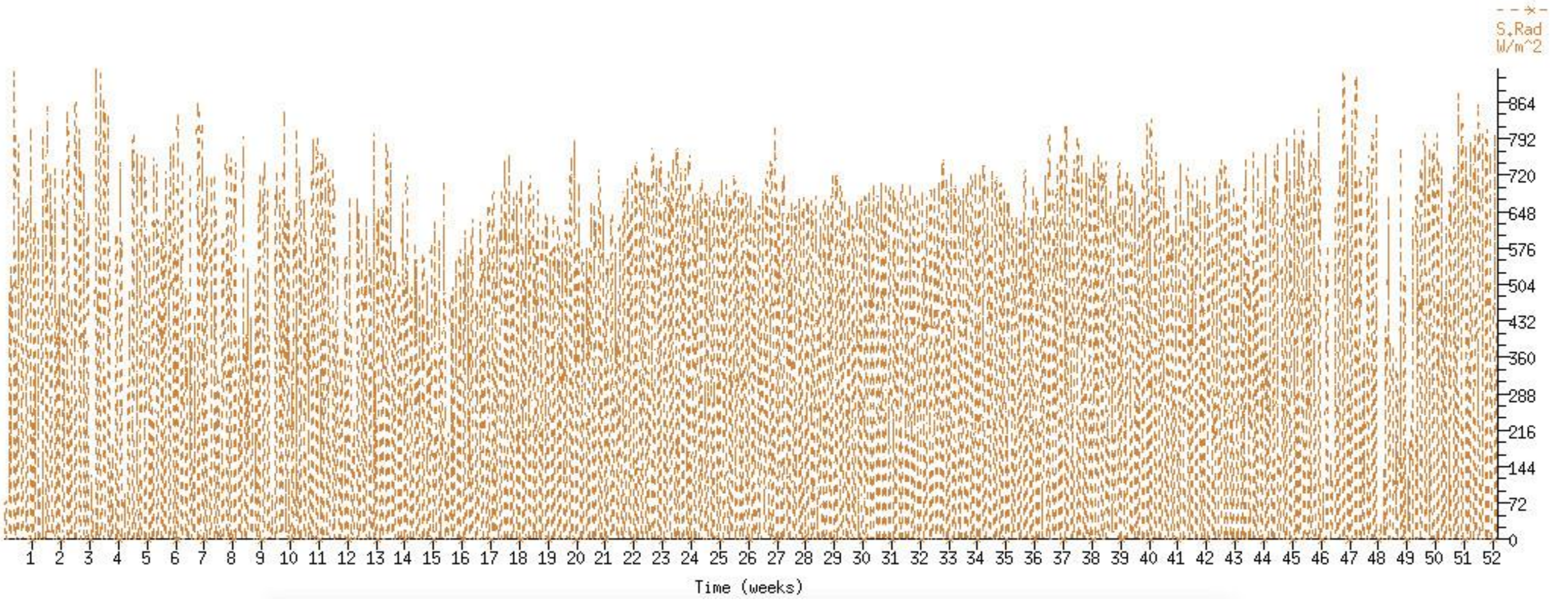


**Figure (1):** Direct normal solar radiation boundary conditions.

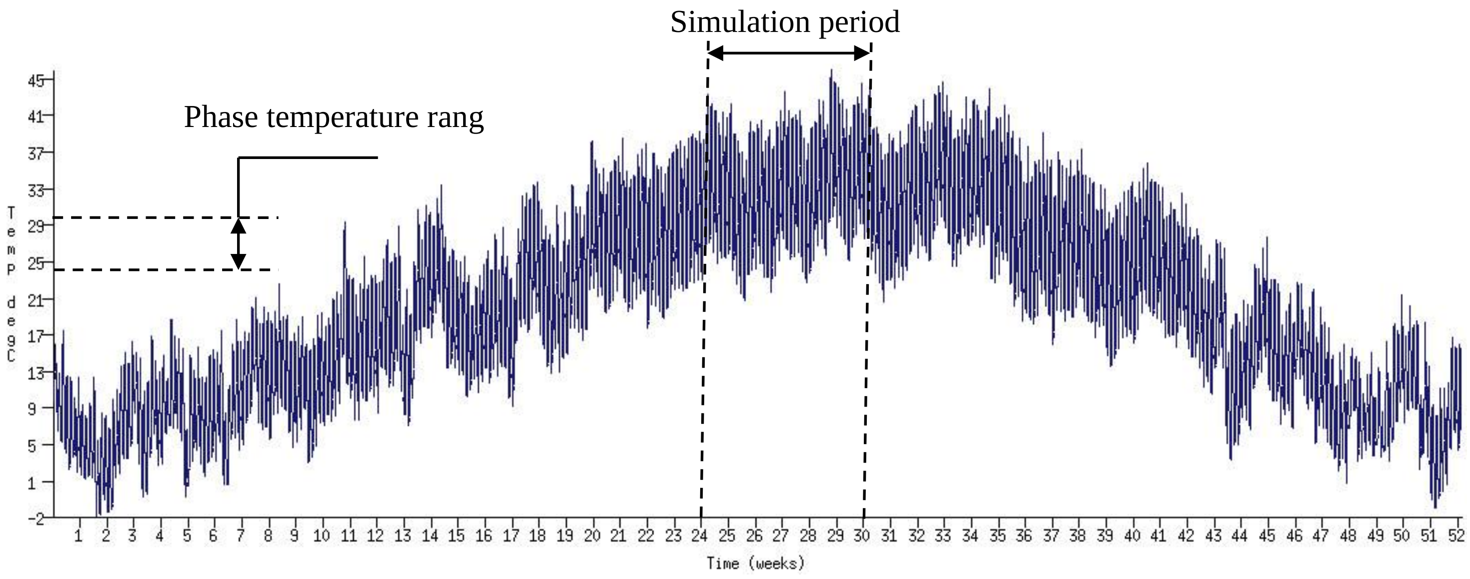


**Figure (2):** Dry bulb air temperature boundary conditions.

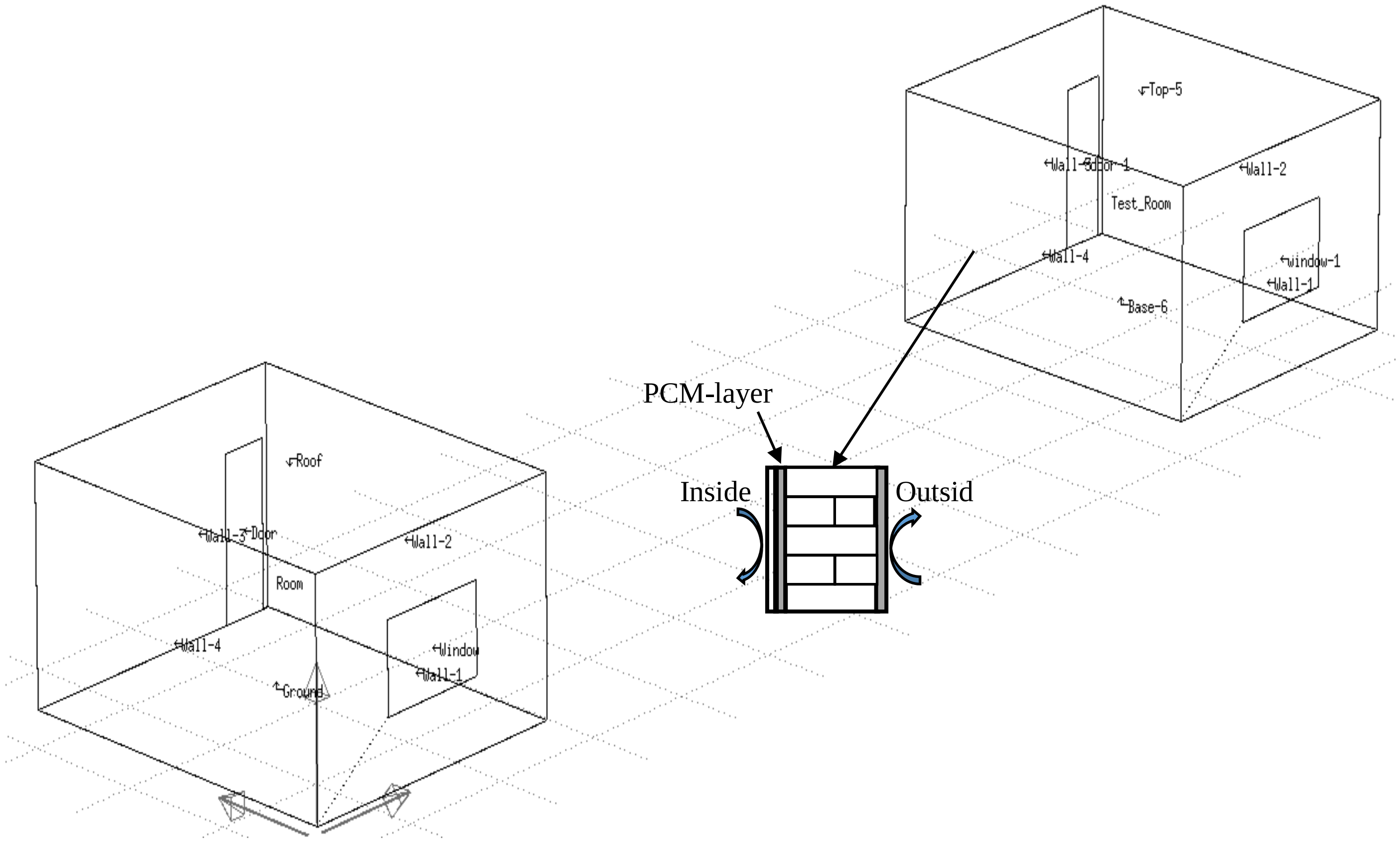
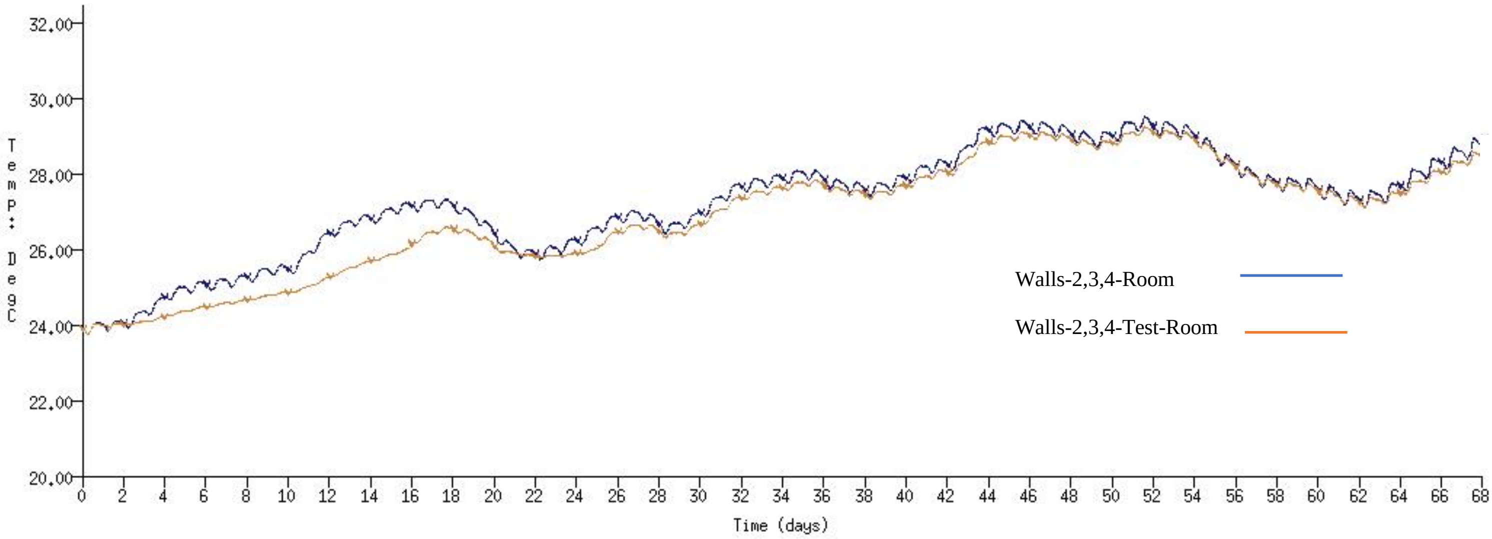


**Figure (3):** Building model (identical rooms with and without PCM).



**Figure(4) :** The internal surface temperature for walls 2, 3 and 4 without PCM and PCM (melting temp. = 24 $^{o}$C and solidification temperature. =26 $^{o}$C) simulation period June-August.

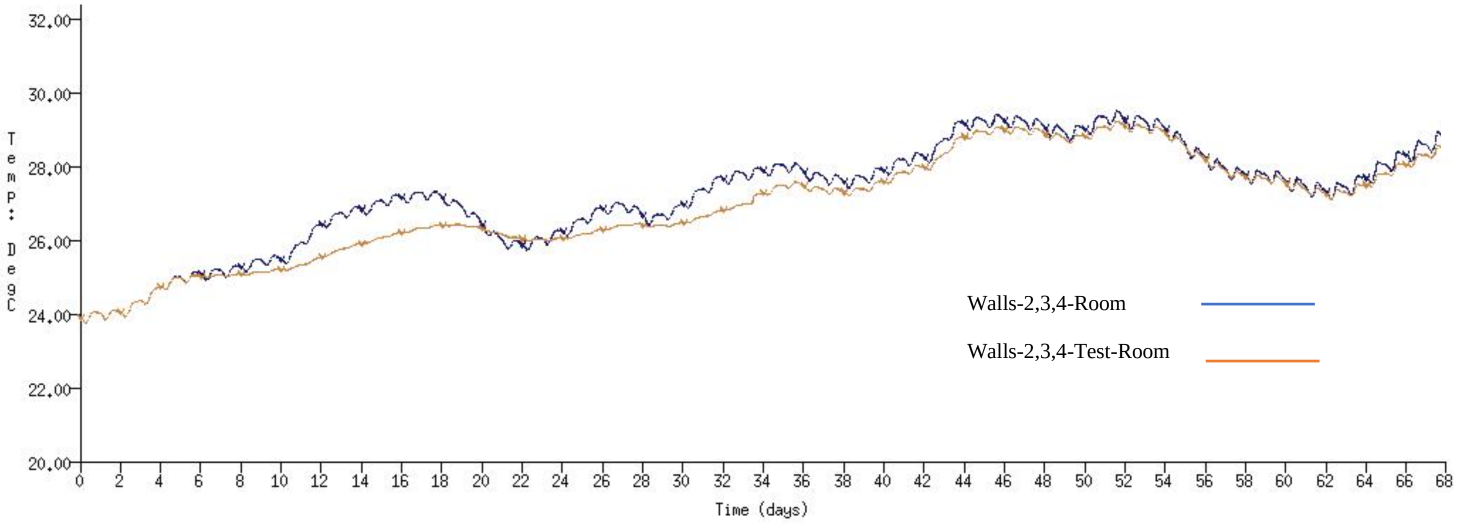


**Figure (5):** The internal surface temperature for walls 2, 3 and 4 without PCM and PCM (melting temp. = 25 $^{o}$C and solidification temperature. =27 $^{o}$C) for period June-August.

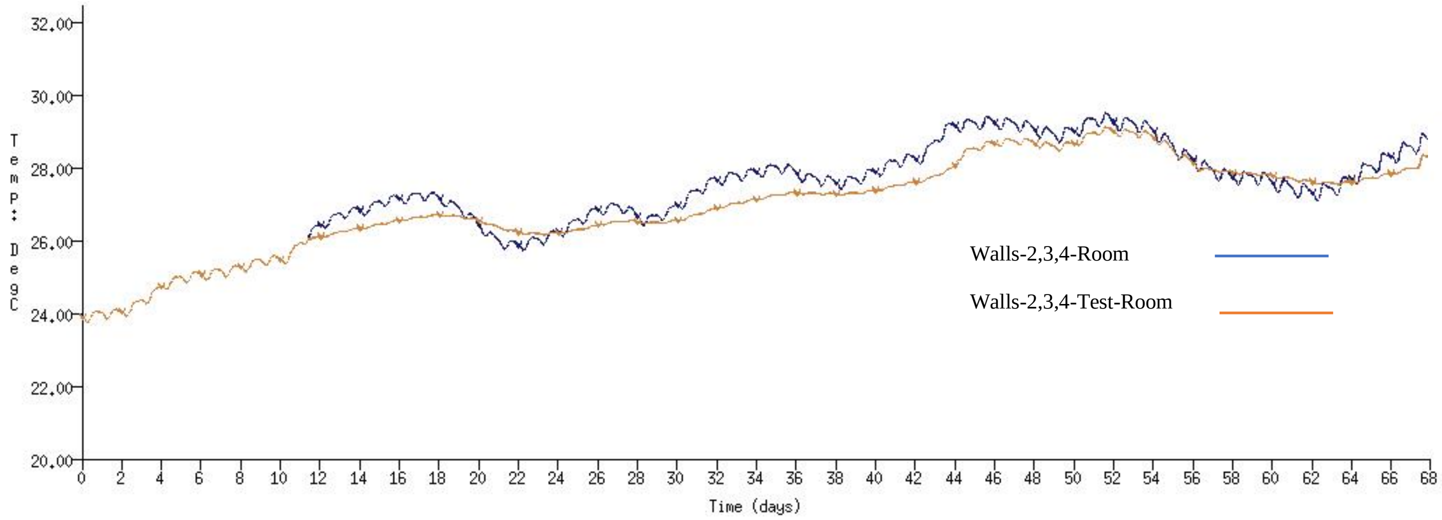


**Figure (6):** The internal surface temperature for walls 2, 3 and 4 without PCM and PCM (melting temp. = 26 $^{o}$C and solidification temperature. =28 $^{o}$C) for period June-August.

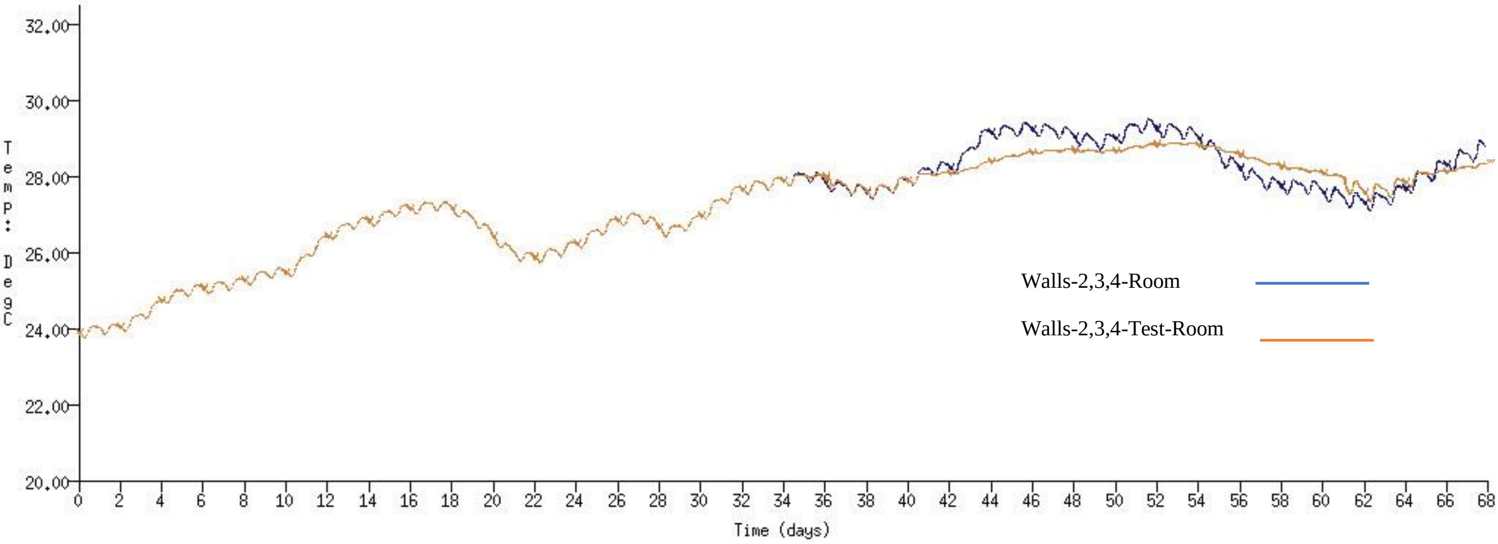


**Figure (7):** The internal surface temperature for walls 2, 3 and 4 without PCM and PCM (melting temp. = 28 $^{o}$C and solidification temp. =30 $^{o}$C) for period June-August.

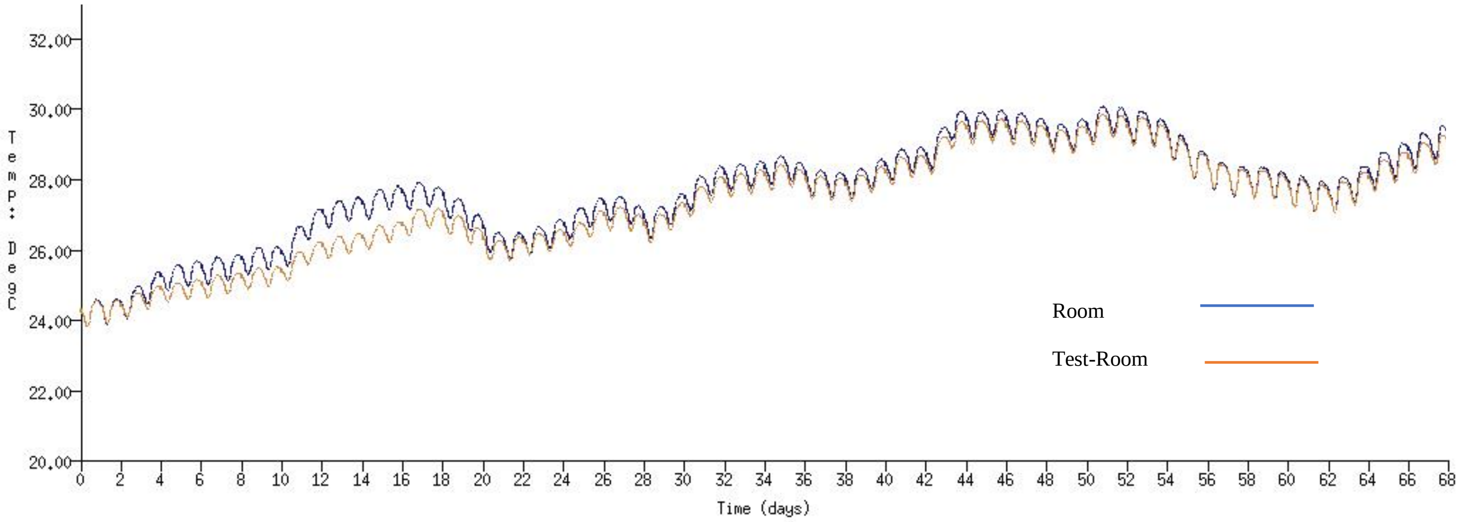


**Figure (8):** Room temperature with and without PCM (melting temp. 24 $^{o}$C and solidification temp. 26$^{o}$C).

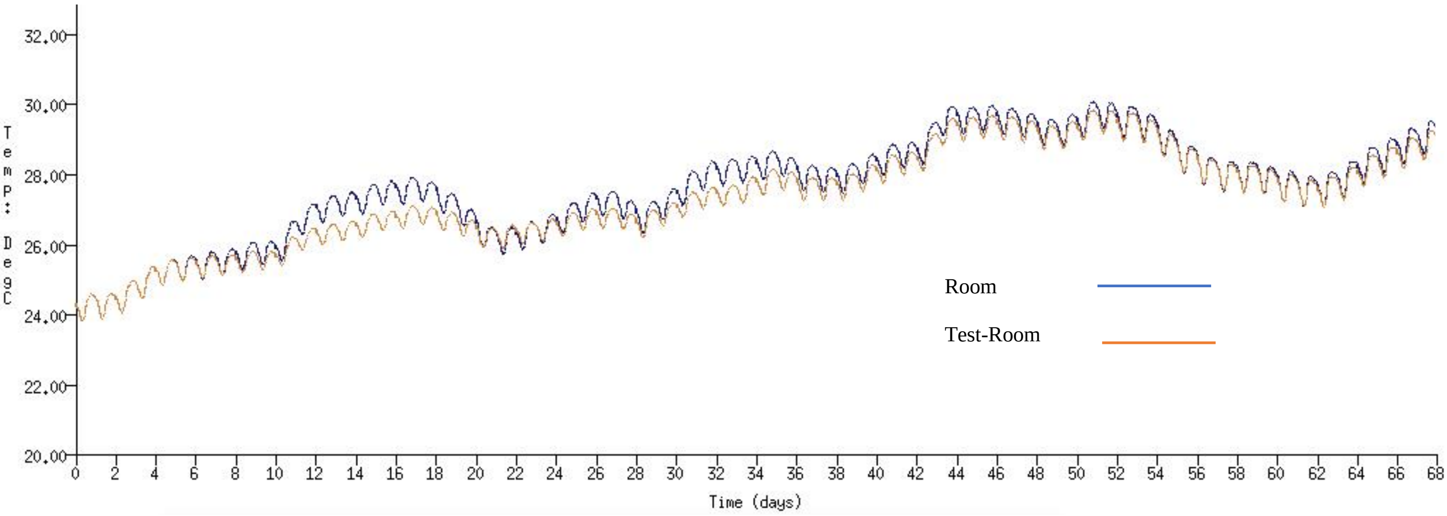


**Figure (9):** Room temperature with and without PCM (melting temp. 25 °C and solidification temp. 27 °C).

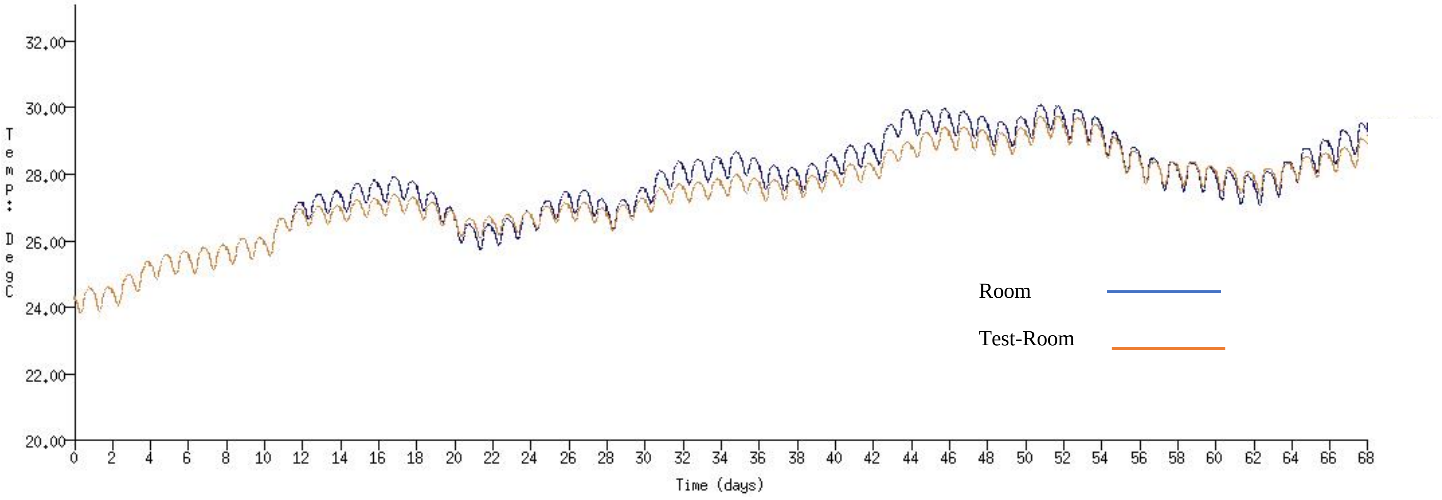


**Figure (10):** Room temperature with and without PCM (melting temp. 26 °C and solidification temp. 28 °C).

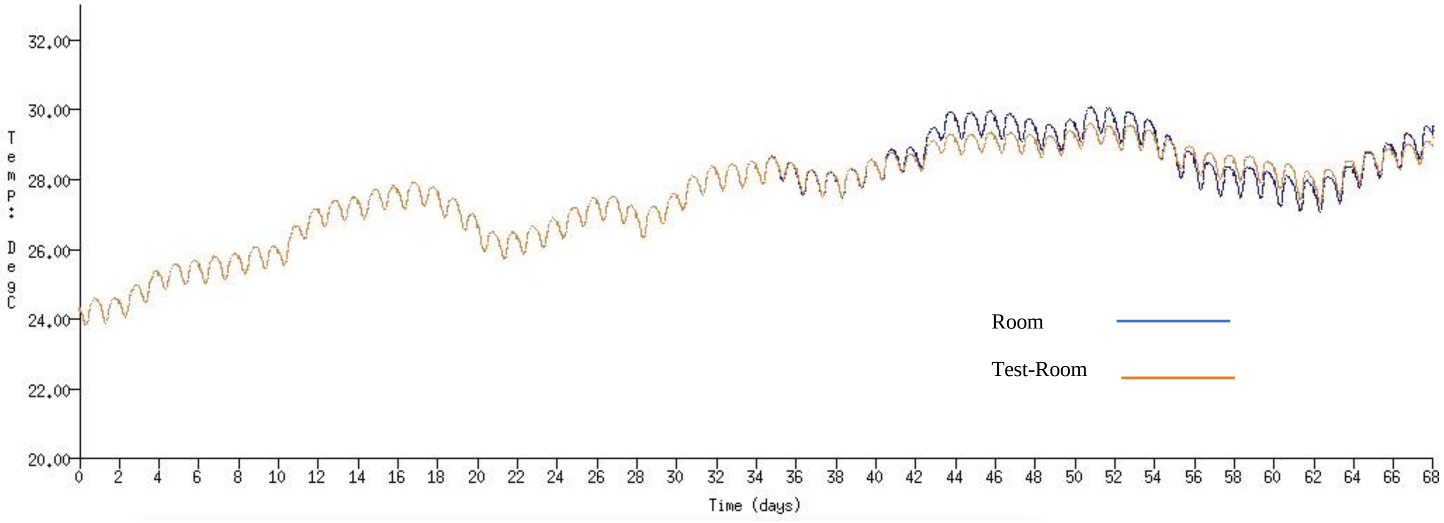


**Figure (11):** Room temperature with and without PCM (melting temp. 28 $^{o}$C and solidification temp. 30 $^{o}$C).