Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Phase Change Material for Improving Building Thermal Comfort in Kurdistan

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ARTICLE INFO

Article history:
Received 18 July 2024
Received in revised form 26 October 2024
Accepted 7 November 2024
Available online 20 November 2024

Keywords:
Thermal comfort; phase change material; building energy

ABSTRACT

The Kurdistan region of Iraq suffers from relatively high summer temperature which leads to overheating in office buildings where there is little to no air-conditioning installed. In summer, the temperature rises to around 45-53 °C which can be unbearable to building occupants. The high temperature can affect occupant thermal comfort and causes health issues. Phase chance materials (PCM) are considered as a useful passive cooling method that absorbs excessive heat when the room is relatively hot and releases the stored heat when the room temperature becomes less hot. This research aims to evaluate the effectiveness of using PCM to reduce the overheating of offices in Kurdistan region and to analyze potential factors that will affect the building temperature. The factors include environment-related (location of the building, climate change) and construction related (location of the PCM, insulation, heavyweight/lightweight construction). The potential outcome of this research may provide useful guidance about using PCM in office buildings in Kurdistan region for architects and engineers to decide when and where to use PCM. The building simulation is performed using DesignBuilder software where different types of PCM are investigated. Results from the building simulation show that PCM can reduce cooling energy consumption by about 1% as compared to when no PCM is used.

1. Introduction

Offices in the Kurdistan region of Iraq suffer greatly with overheating in summer to due high summer temperature that can reach 51°C [1]. This poses a risk to buildings with inadequate insulation to protect the occupants from outside heat. Furthermore, most of the buildings in Kurdistan lack mechanical ventilation and good air-conditioning systems, that causes the overheating problem to become even worse. Lack of constant electricity supply also is a major problem that contributes to the overheating problem. While rapid urbanization in the Kurdistan region is pushing demands for office spaces and new buildings to be built, a sustainable and low carbon solution is required to overcome the overheating problem.

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https://doi.org/10.37934/arfmts.124.1.198208

Phase change materials (PCMs) have been acknowledged as an efficient solution for moderating indoor temperature variations, reducing peak temperature in the summer and reducing indoor heat loss in the winter. PCMs are made of the material that solidifies when releasing heat and liquefies when absorbs heat. The specific properties of PCMs make it possible to be used for storing energy and cooling purposes in buildings. Studies in the past have shown the potential of using PCM in construction of buildings. Voelker *et al.,* [2] shows that PCMs could increase the thermal mass of an office building and could also improve thermal protection up to 4 C° reduction of peak indoor temperature. Similar results have been recorded in Cyprus which demonstrates the use of PCMs in reducing the main indoor temperature and increasing the comfort level. By adding 0.15 m thick layer of PCM, the indoor temperature dropped by 1.7 C° in Cyprus [3]. Kusama and Ishidoya [4] investigated the use of PCMs for walls and ceiling of a residential building. PCMs are incorporated in gypsum plaster and tested for basic thermal performance in laboratory environment. The tests are conducted on a larger scale in a residential unit. Both residential units are located in cold and snowy regions. The solar radiation effective utilization rate during the measurement period was approximately 82% which is reflected in the results of the measured room temperature during the heating period. It was observed that the room temperature to be stable at approximately 20 °C. Al-Yasiri and Szabó [5] investigated the optimal thickness of PCM layer incorporated in a composite roof under severe exterior temperatures in Iraq. Three PCM thicknesses of 10, 15 and 20 mm, are embedded inside a roof combination for residential buildings. The performance of the roof with PCMs are compared with the reference roof without PCM. The composite roof is composed of Isogam (4 mm) as a roofing material, concrete (50 mm) as a main roof layer, and gypsum board (8 mm) as a cladding layer. The composite roof with 4mm PCM performed the worst whilst the best thermal performance is reported for the composite roof with 20 mm PCM thickness. The 20cm PCM thickness composite roof obtained a 13.9 % reduction of the maximum temperature reduction. In a related study, Al-Yasiri and Szabó [6] investigate the thermal behavior of a PCM microencapsulated panel and capsules for a building envelope under severe hot climate in Iraq. Two identical rooms are built whereby, one room with PCM material incorporated and the other room with no PCM material incorporated. The test indicated that the PCM was insufficient to maintain an acceptable thermal comfort inside rooms. However, with the PCM can be used for reducing the energy need for cooling the room.

Wang *et al.,* [7] studied the performance of PCM wallboards in air-conditioned lightweight buildings in Shanghai using EnergyPlus commercial software. A 3D model of the room using ASHRAE standard is selected for the simulations. The performance of the PCM wallboards is evaluated for summer and winter climates. The simulation of the room takes into consideration of the different room locations in the middle floor of high-rise buildings. The results of the simulations show that the PCM wallboards improve the indoor thermal comfort in summer and winter by reducing temperature fluctuations. Esbati *et al.,* [8] modelled the effect of using phase-change materials for a building located in Tehran. The aim of the study is to investigate the effect of phase-change materials on the building envelope on the reduction of the cooling and heating load. It is shown that up to 28% of the heating load can be reduced when PCM materials are incorporated in the building. Bai *et al.,* [9] developed a mathematical model for investigating passive buildings utilizing PCM material. The study shows that effectiveness of the depends on both climate and building parameters. PCMs is not effective when the average outdoor air temperature is higher than the boundary of the humans' comfort level. This results in overheating in the building even when PCMs are incorporate. Therefore, the average room temperature should be predicted before the suitable PCM material is chosen. M'ziane *et al.,* [10] performed a numerical simulation to investigate the transient heat transfer performance of a plaster composite with microencapsulated PCM. The results show that the presence of PCM causes the internal temperature of the wall to reduce by 3% as compared to when no PCM is present.

It is evident from the above-mentioned studies that PCMs could be a low carbon solution for the current overheating problem in Kurdistan region. However, some questions need to be answered before PCMs can be fully incorporated in the construction section. Questions such as the efficiency of PCMs in terms of temperature reduction and economic benefit need to be fully understood. In this study, simulations are carried out to understand the effect of different types of PCMs that are available in the market on the building thermal comfort and energy use. The cooling load of the buildings is calculated for each PCM used and compared against a reference case when no PCM is used. The simulation also considers the factor of insulation to prevent the heat exchange between inside the building and the outside surrounding. The amount of fuel savings from using PCM is also analyzed in this study.

2. Methodology

2.1 Case Study Building

Figure 1 shows the building that is used for this simulation. It is a 1st floor office building that consists of 5 offices, a main reception and two restrooms. They are all connected with a corridor and the main reception. The front of the building is all glass windows and it is connected to buildings on the left side and right side. This building is located in Erbil city of Kurdistan, Iraq. The office building consists of 3 main floors which face the North area of 200m2 and height of 3.5m. The windows are fixed and have 40% glazing which covers most of the building, doors are stationed at 2 m height. The 3D mock- up of the building is shown in Figure 2.

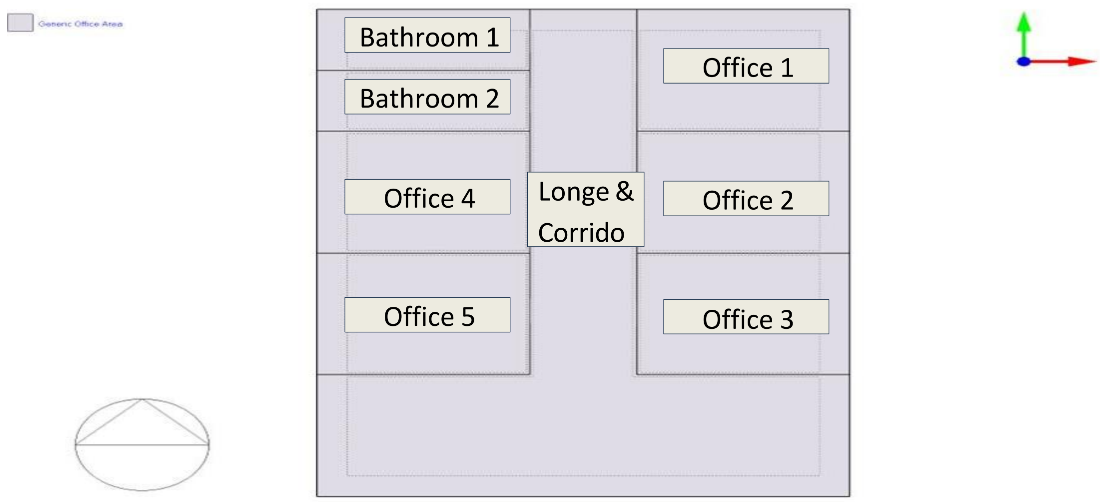

Fig. 1. Layout of the office used in the simulations

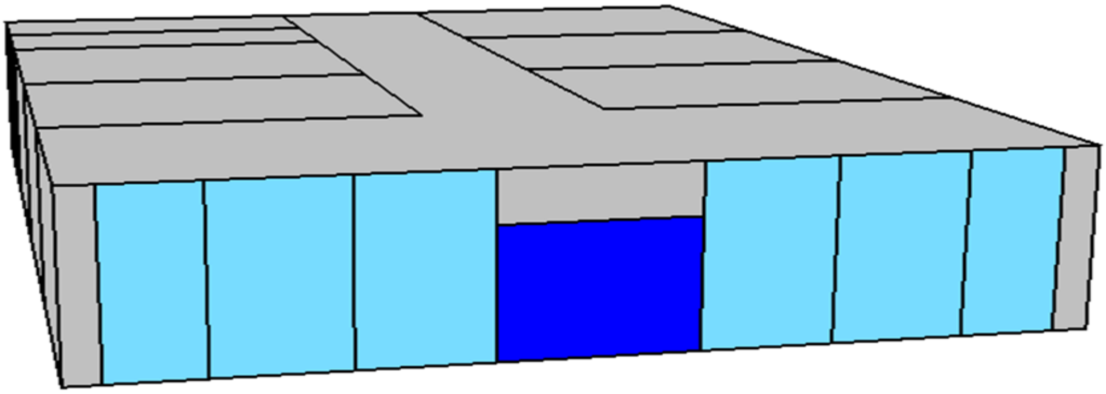

Fig. 2. 3D model of the office used in the simulation

2.2 Building Performance Simulation

The building simulation is simulated using DesignBuilder commercial software. This software can predict the performance of the building under various simulation scenarios. DesignBuilder provides a comprehensive user interface of EnergyPlus, which is a widely used simulation engine developed by the Department of Energy (DOE) in the USA The thermal modeling using EnergyPlus has been validated under various applications, such as in the previous studies [11-17]. In EnergyPlus, PCMs can be used as a separate layer of material and then can be attached to any construction component within the building. This function has been used in some existing studies where its applicability for this study was demonstrated.

2.3 Construction Setting

The construction material used for the model is shown in Table 1. The material selection and thicknesses are based on the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard [18].

Table 1
Construction materials and thickness used in the model

Location	Name of materials	Thickness (mm)		
		Wall with PCM	Medium weight, medium Insulation (No PCM)	Heavy weight, medium Insulation (No PCM)
External walls	Aerated concrete slab	0.100	0.100	0.200
	Brick – reinforced at 50C	0.200	0.200	0.300
	Glass fiber wool	0.25	0.25	0.35
	Infinite RPCM	0.150	-	-
	Gypsum plasterboard	0.200	0.200	0.200
Flat Roof	Cast concrete	0.200	0.200	0.300
	Infinite RPCM	0.180	-	-
Internal Partition	Gypsum plasterboard	0.025	0.025	0.025
	Air Gap	0.100	0.100	0.100
	Gypsum plasterboard	0.250	0.250	0.250

The model that is being used for this study has been implemented into DesignBuilder. These construction materials were inserted into the system and multiple testes were made by using different kind of PCM materials infinite RPCM 18, 21, 23, 25 and 29. The building will be compared with the same one but without using PCM materials to see the comparison. Since we will be using two construction types we will be using different materials beside the change of PCM, we will be conducting studies on (medium weight, medium insulation), (heavy weight, medium insulation) for differences. All the construction material that will be used is based on ASHREA standard, based on the change in materials we will have multiple results and will be compared with each other to see which construction material and PCM is suitable for Kurdistan region weather and heat. The effect of Thickness of PCM is also considered, the best performance for best results we considered thickness between (0.150 to 0.200 mm) in this range the effectiveness of (Infinite RPCM) showed the best results and managed to decrease the cooling load which decreased the electricity consumption.

2.4 Behavior Settings

In the simulation, the office is assumed to have full capacity of employees. Workers only work in the morning and afternoon time which is constantly overheating in summertime. Workers are scheduled to work from 8:30am to 4:00pm from Sunday to Thursday as shown in Table 2. All the rooms are constantly occupied except for the restrooms and elevator and stairs which have been excluded from the simulation. No blinds are considered near the windows since the windows are glazed.

Table 2
Work and activity schedule

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
8:30am to 4:00pm	8:30am to 4:00pm	8:30am to 4:00pm	8:30am to 4:00pm	8:30am to 4:00pm	OFF	OFF

2.5 Weather Data and Location

The weather data has been input into DesignBuilder based on the climate and weather data from Meteonorm. This software provides accurate weather info based on data collected from 8000 weather stations that includes 30 different weather parameters. Weather data from Meteonorm is reliable and has been used by other studies in the past [19-21]. The building is located in the capital city of Erbil, Kurdistan region of Iraq as shown in Figure 3. The weather variation between summer and winter is relatively high whereby in summer, the temperature rises to between 45-53 °C and in winter it goes to as low as -5 C°. The humidity in summer is extremely low humidity in summer as compared to medium to low rate of humidity in winter. The massive change in weather causes discomfort for office workers. Figure 4 shows the recorded daily temperature of Erbil in a week time during summer in August 2023. The maximum recorded temperature reaches more than 45°C during the day.

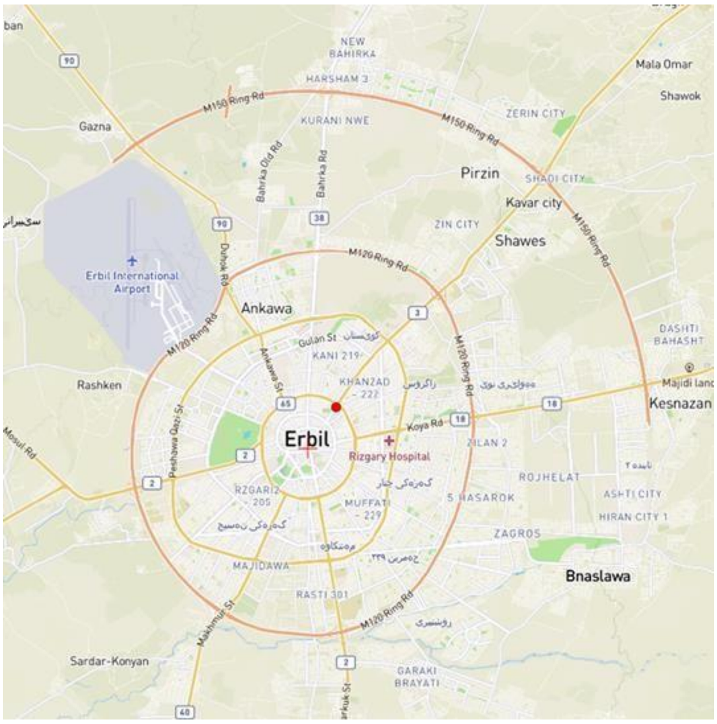

Fig. 3. Location of Erbil based on the GPS coordinates input in Meteonorm

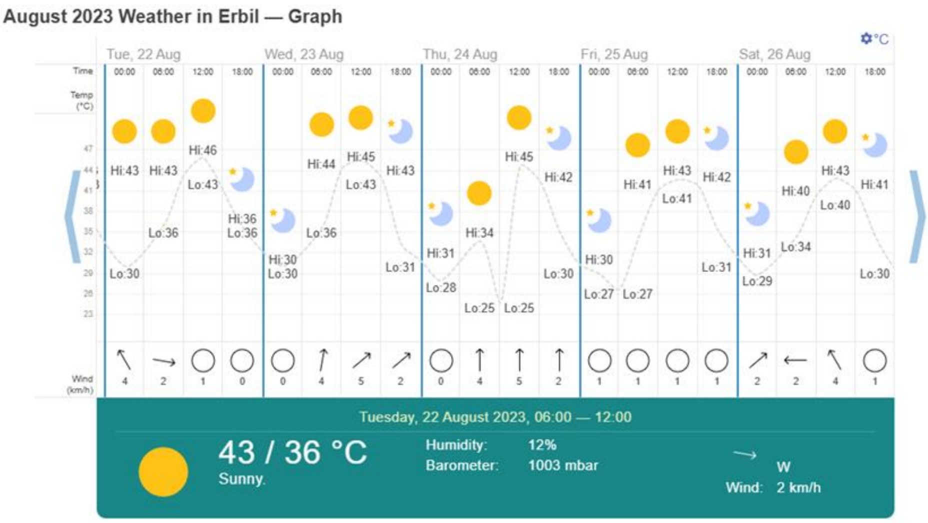

Fig. 4. Recorded daily temperature of Erbil in a week time during summer in August 2023

2.6 Phase Change Material

The PCM material used for this study is based on the PCM manufactured by Infinite R. Infinite R PCM uses salt hydrates as its PCM, which allows room temperature stabilization without relying on conventional energy source. For this study, 5 PCMs from Infinite R are chosen based on the PCM melting temperature. The melting temperature of the PCM are 18°C, 21°C, 23°C, 25°C and 29°C. By melting and solidifying at the phase change temperature (PCT), a PCM is capable of storing and releasing large amounts of energy compared to sensible heat storage. Heat is absorbed or released when the material changes from solid to liquid and vice versa or when the internal structure of the material changes; PCMs are accordingly referred to as latent heat storage (LHS) materials.

There are two principal classes of phase change material: organic (carbon-containing) materials derived either from petroleum, from plants or from animals; and salt hydrates, which generally either use natural salts from the sea or from mineral deposits or are by-products of other processes. A third class is solid to solid phase change. Infinite R uses salt hydrates only.

2.7 Cooling Load Calculation

The cooling load calculation is performed to calculate the energy required for cooling the building. These assumptions are made for the cooling load calculation:

i. Periodic steady-state external temperature calculated using maximum and minimum summer weather conditions.
ii. No wind is added into the calculation.
iii. Includes solar gains through windows and natural ventilation.
iv. Includes internal gains such as occupant activity, lighting and other office equipment.
v. Includes consideration of heat conduction and convection between zones of different temperatures.

The cooling load calculation formula is shown in Eq. (1).

$$Q = 1.08 \cdot CFM \cdot \Delta T \quad (1)$$

Where:
Q represents the cooling load required CFM represents airflow from the blower,
ΔT is the temperature difference between current and desired temperature.

The sensible cooling load, q_w, of windows is calculated by multiplying the area of the windows, A_w, by the glass load factor, GLF as shown in Eq. (2).

$$q_w = A_w(GLF) \quad (2)$$

The sensible cooling load of doors, q_d, is calculated by multiplying the area of the doors by the U-factor (u_d) of the doors and the cooling load temperature difference (CLTD). The formula used is as follow as in Eq. (3).

$$q_d = A_d U_d(CLTD) \quad (3)$$

The sensible cooling load of walls, q_{wall}, is calculated by multiplying the area of the wall (A_{wall}) by the U-factor of the walls(u_{wall}) and the cooling load temperature difference (CLTD) as shown in Eq. (4).

$$q = A_{wall} U_{wall}(CLTD) \quad (4)$$

Eq. (5) shows the sensible cooling load of ceilings and floors, q_{cf} is calculated by multiplying the area of the ceilings (A_c) and floors ((A_f)) by the U-factor of the ceilings (U_c) and floors (U_f) and the cooling load temperature difference (CLTD). The formula used for ceilings and floors is:

$$q_{cf} = A_c U_c(CLTD) + A_f U_f(CLTD) \quad (5)$$

The sensible cooling load of infiltration q_i is calculated by multiplying 1.2 by the specific heat of air, the air change rate per hour (ACH), room volume (V) and the difference between designed indoor (t_i) and outdoor temperature (t_0) as shown in Eq. (6).

$$q_i = 1.2(ACH)(V)(to - ti)\left(\frac{1000}{3600}\right) \tag{6}$$

U-Value in this research is based on the materials that are used in the building, the U-Value is calculated automatically in DesignBuilder when the simulation starts and gives detailed data based on the material that has been chosen.

2.8 Internal Heat Gain

The internal heat gain due to human activity or electric appliance will affect the cooling load of a building based on the occupancy and the amount of equipment that is used daily. Table 3 lists the internal heat sources based on the ASHREA standard [18].

Table 3
Sources of internal heat gain based on the ASHREA standard [18]

Heat source	Heat Gain
People	18.58 W/m^2/people
Computer	5 W/m^2
Electric appliances	5 W/m^2
Light	10.50 W/m^2

3. Results

Figure 5 and Figure 6 compares the fuel consumption required for cooling the building. The fuel consumption is calculated based on the cooling load calculation performed in DesignBuilder software. The unit of the fuel consumption is in $\frac{kWh}{m^2}$. The medium weight, medium insulation with RPCM25C is the best option to decrease the energy consumption.

With the addition of PCM into construction the simulation shows us that the electricity consumption for a building with PCM is far less that a building with PCM due to cool air staying inside far longer. In heavyweight medium insulation we can see that RPCM21C is most suitable however in Iraq heavyweight buildings are not used in construction because it cost too much and not favored by the local business owners.

In Erbil city the fuel consumed for cooling a small office building is around 125 kwh/m^2 per year and the average building with RPCM25C is almost 12% saving each year.

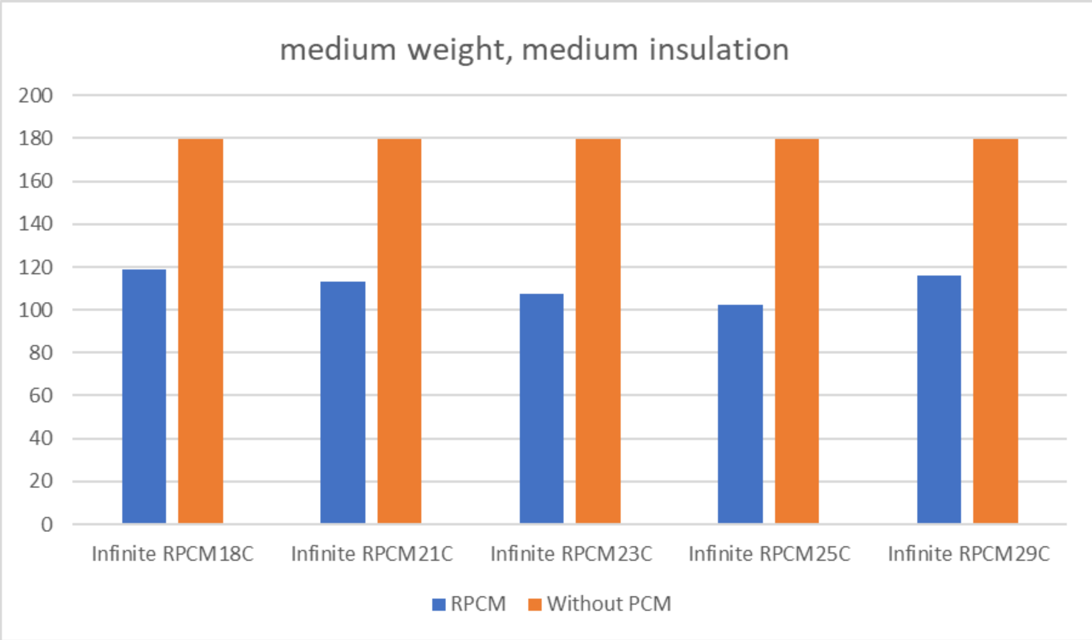

Fig. 5. Medium weight, medium insulation with PCM compared to without PCM

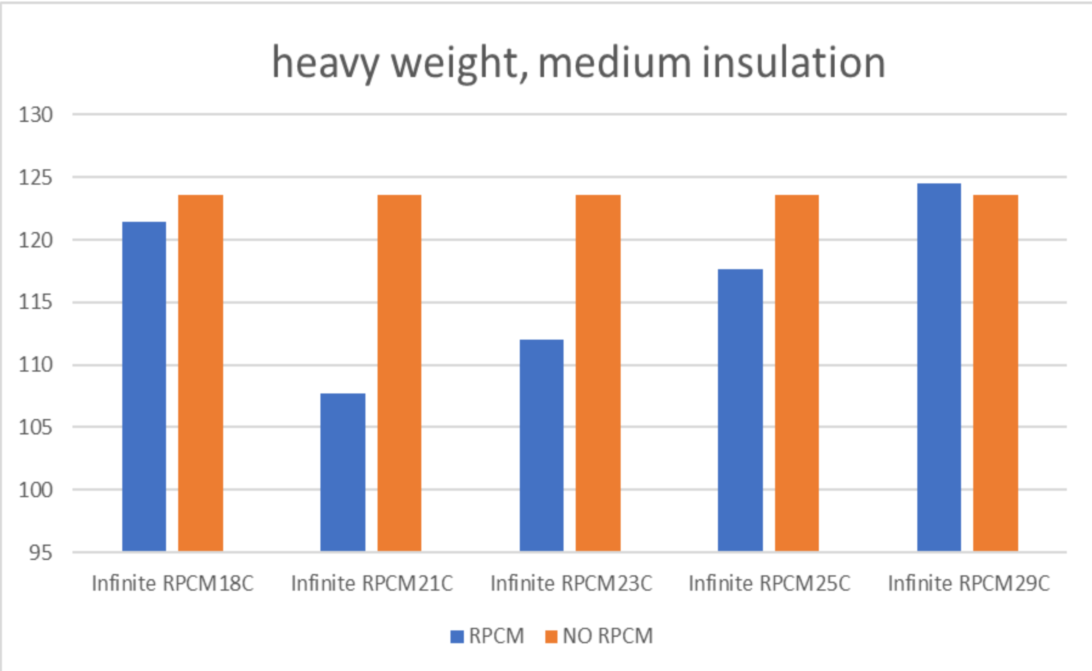

Fig. 6. Heavy weight, medium insulation with PCM compared to without PCM

4. Conclusions

Office buildings in Kurdistan suffer from heat during summertime, it is especially problematic when employees inside the office suffer from overheating and lack of cold air from air-conditions due to electricity shortage in the region. A passive method of fixing this problem is to implement PCMs inside the construction as a low carbon emission solution. This research applied a dynamic building performance simulation to and office building it demonstrated the contributions of PCs to reduce the overheating risks, also identify potential factors that will influence its effectiveness. From the results, the following it has been shown that the PCM material can reduce the energy consumption up to 12% per year.

Acknowledgement
This research was not funded by any grant.

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