Basrah Journal for Engineering Sciences, Vol. 22, No. 2, (2022), 33-40

Original Article

Journal homepage: www.bjes.edu.iq
ISSN (Online): 23118385, ISSN (Print): 18146120

OPEN ACCESS

Effect of Phase Change Material and Roof Shading on Cooling Load of Residential Unit in Basrah

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Received: 24 March 2022; Accepted: 15 May 2022; Published: 24 December 2022

Abstract

In several countries, residential buildings are responsible for high energy consumption. The majority of energy is consumed on air conditioning to ensure maximum indoor comfort. In Iraq, the demand for electricity increases significantly, especially during the summer for cooling purposes. In this paper, two technologies are proposed for buildings to reduce the cooling load. These approaches included the use of phase-changing materials (PCM) in different locations in the walls and roof, in addition to roof shading by galvanized iron. The effects of these proposals were simulated in the latest software tool (designbuilder) and compared with the standard building model. The results were clear when PCM was installed on the outer surface of the wall and roof, which achieved the highest reduction in the cooling load of about 18 %. While the roof shading method using corrugated galvanized iron proved its effectiveness by decreasing the cooling load to 5 % compared to the standard case.

Keywords: Energy consumption, Residential buildings, Cooling load, Phase changing material, Roof shading, Simulation.

https://doi.org/10.33971/bjes.22.2.6

1. Introduction

The demand for energy is increasing dramatically, especially in the hottest areas, due to the use of the cooling system. As the consumption of electricity in the construction sector in Iraq is about (38 %) of the total energy produced, and with the continuous increase in the construction of housing units, this will lead to a significant increase in the demand for electricity. The limited sources of energy require activating the building by providing it with the ability to respond and adapt to the changing external conditions on a daily and seasonal basis. This requires harnessing natural energies and using materials in the best ways while constructing buildings.

Using phase change materials (PCMs) in buildings is one way to improve thermal performance as they are placed in the walls or roofs of the building, which can play a major role in reducing the cooling load, especially during peak hours. Shade methods like overhangs, louvers, and sidfines have a prominent role in reducing heat gain and thus reducing cooling loads. In this paper, the installation of (PCMs) in the walls and roof at different locations and roof shading recently used in Iraq will be simulated. Fig. 1 shows roof shading in Iraq.

Fig. 1 Roof shading in Iraq.

In order to improve the thermal performance of buildings, there are many studies conducted. According to Boehm and Halford [1], an encapsulated PCM was used to shift the cooling demand. They employed laminated PCM in the ceiling and walls, as well as PCM in conjunction with other building materials, including concrete and gypsum wall panels. For simulation, they employed the TRANSYS software. When they compared their results to those of other cases without PCM, they discovered an (11-25 %) decrease in cooling load.

Hussein [2] proposed a method that combines three passive cooling methods: thermal insulation, phase change materials (PCMs), and photovoltaic double glazing. Simulations were carried out using the designbuilder software to determine the most effective proposed strategies among 16 cases. According to the results, utilizing three of these approaches together was the more effective strategy, resulting in a (42.4 %) reduction in energy consumption. Muruganantham [3] studied the performance of BIOPCM in the building of envelopes, roofs, and walls using both experimental and analytical methods. Energy Plus software was employed for simulation. The sliding door, insulation, BIOPCM, gypsum board, and wooden frame on the sides were the wall layers from the outside to the inside. He compared these huts by building door and window sheds. The shed's measurements were (4.876 m long, 3.657 m wide, and 2.436 m). He installed the BIOPCM using the wooden frame. PCM has a melting temperature range of 27-31°C. The results showed the largest energy savings were determined to be around (30 %), and the maximum cost savings were also around (30 %).

Al-Hadithi [4] investigated the influence of PCM on heat transport in a wall using a numerical technique. To construct the treat wall, he combined 25 % paraffin wax with 75 % concrete. Cement 5 mm, treated wall 20 mm, brick 300 mm, and gypsum 20 mm were the layers of the wall from external to interior. The west wall was the one that was treated. When comparison between treat wall and non-treat wall, finding that the treat wall decreased heat transfer about 66 %.

Madhumathi and Sundarraja [5] demonstrated experimentally in hot climatic zones that combining the PCM with traditional construction materials can reduce cooling load and air room temperatures. They utilized organic phase change materials of the polyethylene sort with melting points of 25 and 31 degrees Celsius, which are often used in hollow bricks. They constructed models, each measuring 0.020317 m^3. They discovered that utilizing the PCM increased comfort conditions and decreased the amount of heat entering the room by approximately 33.33 percent.

Nematchoua et al. [6] in tropical coastal climates, studied effect of combining phase-changing materials, shading and thermal insulation on thermal comfort, three different climates were selected (Antsiranana, Mahajuna, and Toamasina). All simulations were done for one year by (designbuilder) program. The results showed the clear significant of phase-changing material on thermal comfort and energy consumption in those different climates. The combination of phase-changing material and thermal insulator was effective in increasing the comfort rate by about 3 % and decreasing energy consumption for cooling purposes by approximately (12 %). While the highest decrease in energy consumption resulted by about (19 %), when thermal insulation and shading were combined.

Al-mudhafar et al. [7] conducted a numerical study on phase change material (PCM) aiming to reduce the use of cooling energy in residential buildings. The heat transfer in the proposed geometric model was calculated using Ansys Fluent software. The results revealed that PCM with a higher melting temperature was more efficient in hotter climates, such as Basra and Baghdad. Incorporating PCM in the external surface of the outer wall can reduce the maximum inner wall surface temperature by 5 %, reducing heat gain and energy consumption.

In the subject of decreasing the heating and cooling loads, Zwanzig [8] examined numerically the incorporation of the PCM with building materials. For the walls and the roof, he used PCM composite wallboard. In a variety of weathers, he tested PCM as an insulation material. The Crank-Nicolson approach was used to solve the model's one-dimensional transient heat equation. He created weather data using TMY3 information. He discovered that PCM's position in building layers is significant, and that it is influenced by the thermal resistance of the layers between the PCM and the outer boundary. He discovered a (19.7 %) reduction in cooling load from the wall, an (8.1) percent reduction in heating load from the wall, and a (6.4) percent reduction in heating load from the roof, when he compared his findings to those without PCM. In a 91 m^2 family residence, Monteiro da Silva and Almeida [9] performed a simulation to employ gypsum plasterboards with micro-encapsulated PCM and macro-encapsulated PCM. For simulation, they utilized software energy plus 7.2. The melting range of PCM (paraffin) was 23-26 °C, while PCM (salt hydrate) was 22-28 °C. The simulation took place on the coldest and warmest days of the year. They used three types of construction materials: concrete walls, single hollow bricks, and double hollow bricks to merge the PCM with the ceiling and walls. They identified a 16 percent reduction in heating demands on the coldest day and a 28 percent reduction in cooling needs on the hotter day, as well as a (16) percent reduction in electricity usage. They also found that on the coldest day, raising the indoor temperature by 0.7 °C and dropping the indoor temperature by 1.4 °C.

Akeiber et al. [10] conducted an experimental and analytical investigation into phase-changing materials. To determine the possibility of implementing PCM in residential buildings in Iraq in order to reduce energy consumption. Experimental and numerical results indicated the reduction of heat flow inside an apartment building using PCM, which consists of oil (40 %) and wax (60 %). PCM (paraffin) is available from waste petroleum products in Iraq. For performing experiments, a two-chamber with identical internal dimensions in the presence and absence of PCM is designed. A two-dimensional numerical transition model of heat was developed and solved using the finite difference method. They observed that the heat flux inside the chamber containing PCM was significantly lower than in the chamber without PCM. This article showed the attractive features, such as the physical and thermal parameters of phase-changing materials, and the possibility of improving the thermal performance of buildings.

Al-mudhafar et al. [11] aimed to investigated the possibilities of adopting phase change material (PCM) to reduce cooling energy usage in residential buildings numerically. The heat transmission in the suggested geometric model was calculated using Ansys Fluent software. Thermal performance, like wall surface temperature, was evaluated, and the applicability of several types of PCMs for specific weather conditions. The findings revealed that PCM with a greater melting temperature was more efficient in hotter climates, such as Basrah and Baghdad. Incorporating PCM into the outer layer of the external wall can lower the maximum inner wall surface temperature in summer, limiting heat gain. This reduces energy consumption to cool the building.

Mohammed [12] focused on the possibility of using modern technologies to exploit renewable solar energy and benefit from the heat of the earth's interior for use in air-conditioning buildings and provide a more suitable environment for living than using traditional sources, thus saving energy in buildings with less or no environmental impact. The study was conducted in a test room that was designed and installed using wood. A glazed structure was connected to an inclined side, then it was connected above the room to collect solar rays above the room and generate convection currents through the principle of reducing air density on all sides except the front end of the glass. At the same time, an underground heat exchanger was connected. The theoretical study included the use of MatLab and ANSYS programs as a result of the FLUENT simulation process for the designed cooling system (heat exchangers and solar chimney). The results proved the importance of technology in order to reduce environmental pollution, reduce operational costs, and rely on renewable energy.

The most important advancements and techniques in evaporative cooling are discussed by Hammdi et al. [13] which result in decreased energy consumption and acceptable cooling comfort. They reached the conclusion that evaporative cooling systems are both efficient and ecologically benign. Evaporative cooling is distinct from other cooling systems in that it delivers effective cooling without the use of a power source.

In comparison with the literature reviewed, this work presents the surface shading research and the use of the EnergyPlus tool in making calculations in the conditioning of buildings in southern Iraq (Basrah City), which is the program adopted in much of the solid research.

2. Building model

A building model included six areas. Fig. 2 and Fig. 3 shows a two-dimensional floor and three-dimensional plans of the building model. The drawing and construction of the model were done using the program designbuilder combined with EnergyPlus software. Basrah (latitude 30.34 and longitude 47.47) was used as the location for this model. In addition, Table 1 indicates the thermal properties of standard model materials (e.g., roofs, walls, floors, windows). The overall heat transfer value (U) was calculated using designbuilder software.

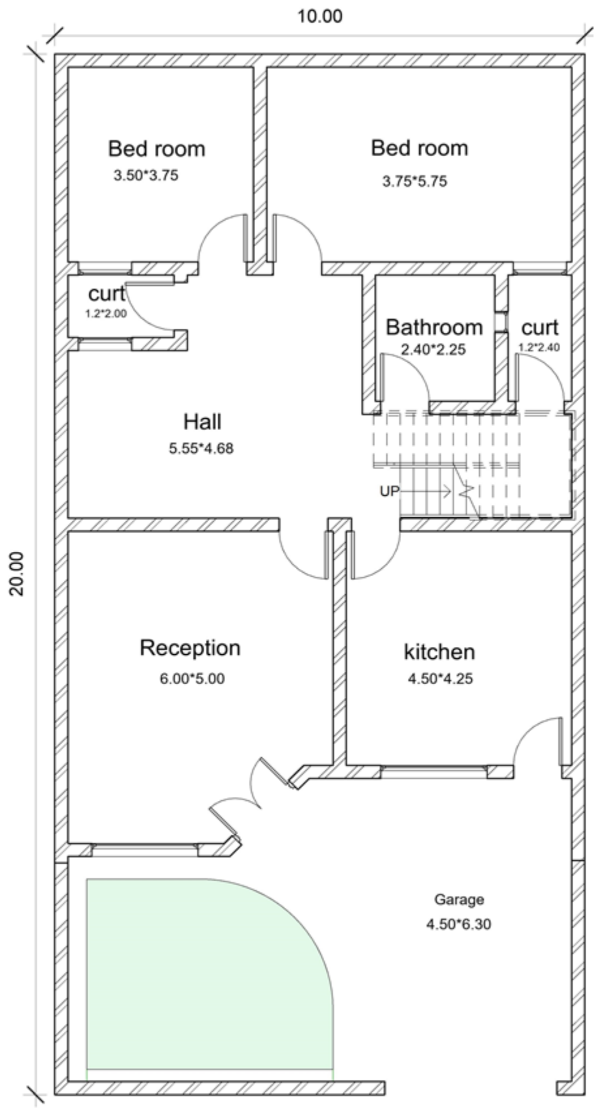

Fig. 2 Two-dimensional floor of building model, all dimensions in meter.

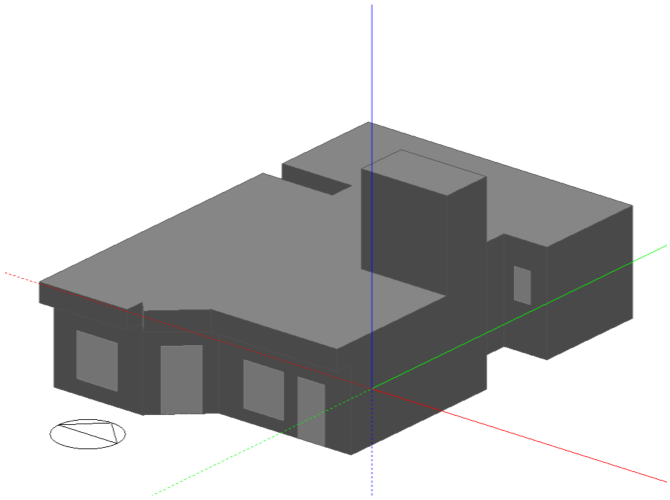

Fig. 3 Three-dimensional plans of the building model.

Table 1. Standard model construction materials.

Part	Details	U value (W/ m^2. K)
External wall	20 mm cement mortar (outside layer) + 240 mm brick + 10 mm cement mortar + 5 mm plaster (inside layer)	1.835
Internal partition	10 mm plaster + 240 mm brick + 10 mm plaster	1.541
Flat roof	40 mm concrete block / tiles (outer) + 20 mm sand layer + 100 mm asphalt and roofing finish + 250 mm cast concrete + 10 mm plaster (inner)	2.347
Ground floor	20 mm ceramic, glass + 15 mm cement screed +100 mm sand layer	4.299
External windows	Single glazing: 6 mm clear glazed Frame: UPVC Material Square windows	5.778
Lighting	LED lights	
Total building area		118 m^2
Total height		3.5 m

3. Cooling loads calculations

For estimating cooling loads, the concepts of the (ASHRAE heat balancing approach) are used. The energy fluxes in the thermal zone are balanced using this heat balancing technology. This required solving energy balance equations for the interior surface, an exterior surface, inside, and air for each building element (roofs, walls, and so on).

3.1. Basis heat balance

Formulating energy and moisture balances for zone air and solving the associated ordinary differential equations with a predictor-corrector approach form the foundation for zone and air system integration. Starting with a heat balance in the zone air, the solution scheme is constructed. (The steady-state system output must be):

$$-\dot{Q}_{sys}=\sum_{i=1}^{N_{si}}\dot{Q}_i+\sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si}-T_z)+\sum_{i=1}^{N_{zones}} m_i c_p (T_{zi}-T_z)+m_{inf} c_p (T_\infty - T_z) \quad (1)$$

Where:

$\dot{Q}_{sys}$ = air systems output.

$\sum_{i=1}^{N_{si}}\dot{Q}_i$ = sum of the convective internal loads.

$\sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si}-T_z)$ = convective heat transfer from the zone surfaces.

$\sum_{i=1}^{N_{zones}} m_i c_p (T_{zi}-T_z)$ = heat transfer due to inter zone air mixing.

$m_{inf} c_p (T_\infty - T_z)$ = heat transfer due to infiltration of outside air.

3.2. Finite difference solution method

A conduction transfer function (CTF) has been used to simulate the surfaces of buildings. The phase change material (PCM) was simulated applying the finite conduction difference (CondFD) algorithm. The CondFD method divides the building's floors, walls, and ceilings into several nodes. It also used an implicit finite difference approach to numerically resolve the relevant heat transfer equations, with the option of using either the fully implicit or the Crank Nicolson formula. Equation (2) shows the method for calculating a fully implicit approach for homogeneous materials with uniform node distance [14]. As equation (2) is used to simulate the phase change material by EnergyPlus under the designbuilder tool.

$$c_p\,\rho\,\Delta x\frac{(T_i^{j+1}-T_i^j)}{\Delta t}=k_w\frac{(T_{i+1}^{j+1}-T_i^{j+1})}{\Delta x}+k_E\frac{(T_{i-1}^{j+1}-T_i^{j+1})}{\Delta x} \quad (2)$$

Where:

$$k_w=\frac{(k_{i+1}^{j+1}+k_i^{j+1})}{2}$$

$$k_E=\frac{(k_{i-1}^{j+1}+k_i^{j+1})}{2}$$

i = node being modeled.

T = node temperature.

Δt = time step.

i +1 = adjacent node to the internal of construction.

i -1 = adjacent node to the external of construction.

Δx = finite difference layer thickness.

c_p = specific heat of material.

ρ = material density.

j = previous time step.

j + 1 = new time step.

With the assistance of equations (3) and (4), which used a space discretization constant (c), material thermal diffusivity (α), and a time step, all of the elements in the CondFD algorithm were automatically divided or discretized. It can be utilizing a default spatial discretization value of 3 (which is equivalent to the Fourier number, F_o, of 1/3) or alternative values can be input.

$$h=h(T) \quad (3)$$

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

Where:

h = Enthalpy.

c_p = Variable specific heat.

T_i = Temperature (iteration scheme).

3.3. Shading calculations

When calculating solar heat gain in buildings, it's important to know how much of each portion of the building is shaded and how much is in direct sunlight. For instance, Fig. 4 shows a flat-roofed, L-shaped building with a window on every one of the visible sides. Since the sun is to the right, walls 1 and 3, as well as windows (a) and (c), are fully shaded, whereas wall 4 and window (d) are completely lit. Wall 2 and window (b) are partially shaded. The amount of sunlight that falls on each surface varies throughout the day as the sun's position changes.

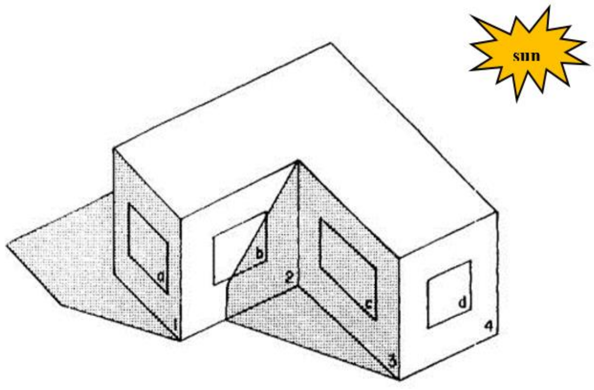

Fig. 4 Overall shading scheme depiction.

The total solar gains on any outside surface are the sum of direct and diffuse solar radiation absorption.

$$Q_{so}=\alpha\left(I_b\ \cos\theta\ \frac{S_s}{S}+I_s F_{ss}+I_g F_{sg}\right) \quad (5)$$

Where:

α = solar absorptance of the surface.

θ = angle of incidence of the sun's rays.

S = area of the surface.

S_s = sunlit area.

I_b = the intensity of a beam (direct) radiation (W/m^2).

I_s = intensity of sky diffuse radiation (W/m^2).

I_g = intensity of ground reflected diffuse radiation.

F_{ss} = angle factor between the surface and the sky.

F_{sg} = angle factor between the surface and the ground.

For a building's surface on a featureless plain

$$F_{ss} = \frac{1+\cos\theta}{2} \quad \text{and} \quad F_{ss} = \frac{1-\cos\theta}{2}$$

Whereas if the surface is shaded, updates by a correction factor that takes into account the light distribution of the sky.

4. Simulation Software

4.1. EnergyPlus under Designbuilder

EnergyPlus software is a rally of several computer modules that operate, together just to compute the energy needed to heat and cool a building that used a range of systems and sources of energy. It achieves this by modeling the building and its related energy systems under various climatic and operating situations. The simulation's nature is a construction model based on basic heat balance theories. The FORTRAN programming language is used to describe the model physically in the EnergyPlus simulation tool. Fig. 5 displays an integrated simulation manager by EnergyPlus.

EnergyPlus software integrates with a variation of building design software, including designbuilder and others. The current attention is on evaluating the impact of phase change material and roof shading on thermal performance using the most recent energy modeling tool, which is designbuildr. Fig. 6 shows the interface of the designbuilder program, including EnergyPlus.

The recently updated climatic data for Basrah city has been entered into the designbuilder tool. The simulation tool software was fed with the basic equations that were previously explained to calculate the cooling load of the building. EnergyPlus calculated the cooling demands using the principles of the ASHRAE heat balancing technique. Fig. 7 shows the overall layout of a building simulation.

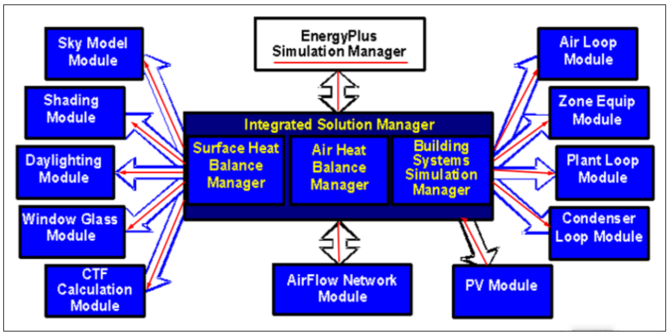

Fig. 5 Diagram of the EnergyPlus program.

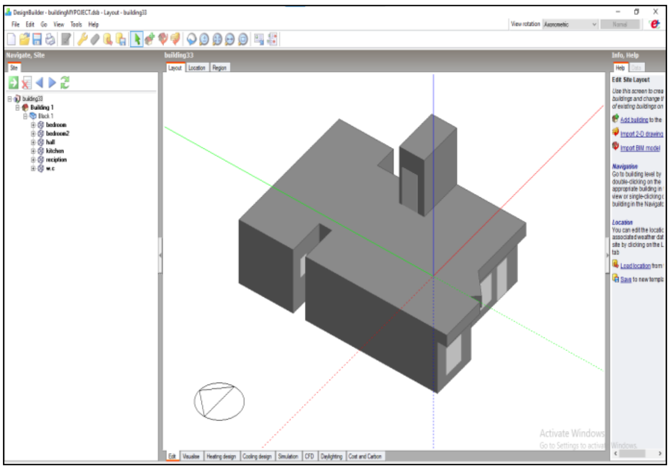

Fig. 6 shows the interface of the designbuilder program.

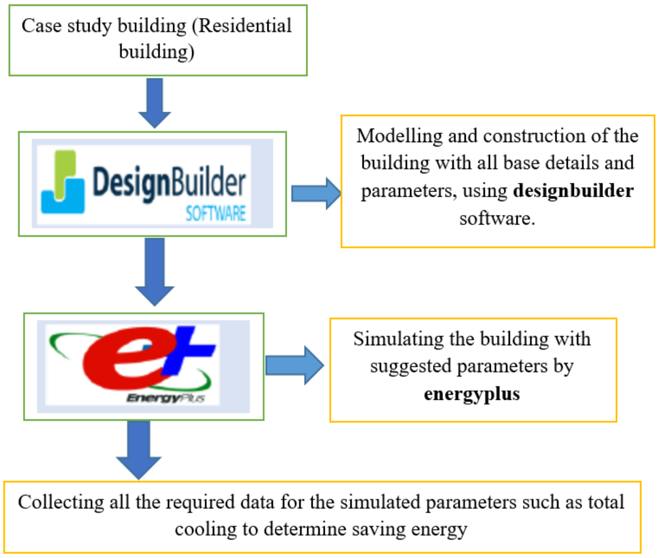

Fig. 7 Displays the overall layout of a building simulation.

5. Improvement of the Building

The building model improvements involved two passive cooling methods (PCM and roof shading) to reduce the cooling load, consumption of energy, inner temperature, and heat gain. Table 2 represents the physical properties of PCM which were selected for the passive cooling method. While Table 3 refers to suggested improvements of the building model.

Table 2. Physical properties of PCM.

Physical properties	Values	Units
Conductivity	0.2	W/m.K
Specific heat	1970	J/kg.K
Density	235	kg/m^3
Vapor factor	150	-
Vapor resistivity	10	MNs/g
Thermal absorptance	0.9	-
Solar absorptance	0.1	-
Visible absorptance	0.5	-
Thickness	74.20	mm
Phase change material (PCM)	Bio PCM M182/Q21	

Table 3. Suggested modifications of building model.

Case	Suggested improvement
	Phase change material
1	Add PCM to roof and external wall (inner side)
2	Add PCM to roof and external wall (outer side)
3	PCM layer is placed in wall from the outside and is topped with cement mortar.
4	PCM layer is placed in wall from the inside and is topped with cement mortar.
	Shading
5	Roof shading by corrugated galvanized iron

6. Results and Discussions

Numerical simulation and analysis are used in this study to estimate the cooling load of a building model using the EnergyPlus software. This estimation comprised a basic case as well as a few of the proposed five cases that are used as passive cooling methods to reduce energy consumed and cooling load. Table 4 presents the cooling load for the standard case and five cases proposed in the north orientation.

As shown in Fig. 8, the simulation results for the standard case recorded that the cooling load was 38.27 kW. When PCM was installed on the inner surface of the wall and roof, it led to a decrease in the cooling load of about 12 %, as in case (1), while placing it on the outer surface of the wall and roof produced the highest drop in cooling load, nearly 18 %, as in case (2). In the case of (3), when PCM was fixed to the outer surface of the wall and topped with cement mortar, a reduction in the cooling load was achieved, about 8 %. In case (4), once PCM was installed on the inner surface of the wall and topped with cement mortar, the cooling load decreased by about 7.5%. Fig. 9 Diagram illustrating the two cases, (3) and (4).

When the method of shading on the roof was used, as in the case (5), this led to a clear reduction of the cooling load by 5 % compared to the standard case. The simulation showed the great effect of shading the roof by decreasing the direct heat gain from the sun, as Fig. 10 shows the difference in the amount of solar radiation with and without roof shading.

Fig. 11 showed a decrease in the total cooling load at noon due to the change in the angle of sunlight, but after this period, the effect of the heat stored in the wall appears, leading to a rise in the cooling load at about 2:30 P.M. According to the results, installing PCM on the outer surface of the wall and roof provided superior performance compared to installing it on the inner surface. Also, the lower the cooling load, the lower the demand for electricity consumption in the hottest Basrah city. Figs. 12, 13, 14 and 15 display the designed annual conditions in Basrah city according to the designbuilder data.

Table 4. improvements in cooling load results.

Cases	Total cooling load (kW) North direction
Standard	38.27
1	33.89
2	31.15
3	35.28
4	35.42
5	36.59

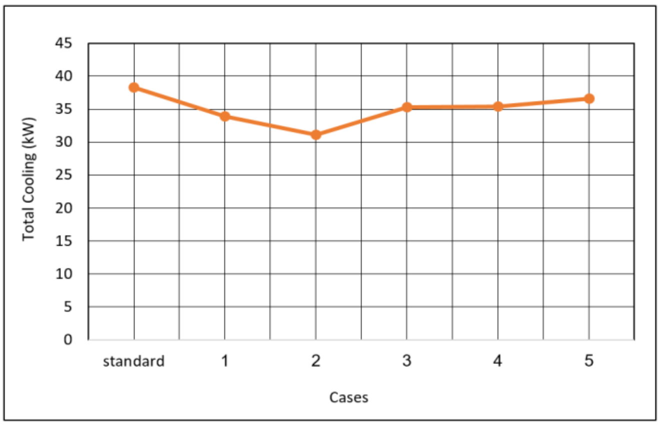

Fig. 8 Effect of PCM and roof shading on cooling load (July).

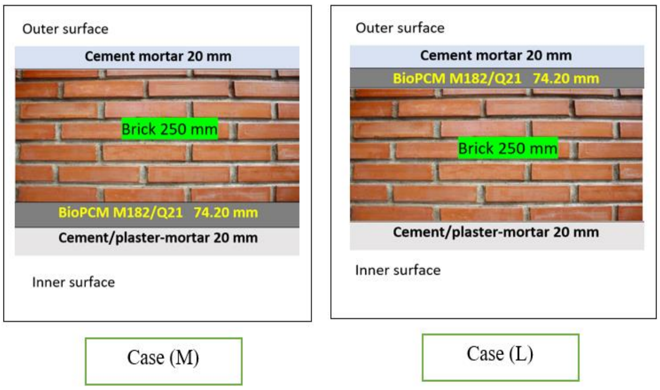

Fig. 9 Fixing the phase change material in the wall in two cases.

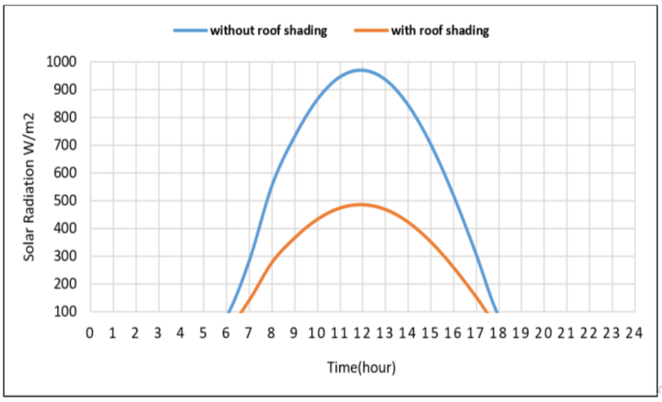

Fig. 10 Solar radiation without roof shading and with roof shading.

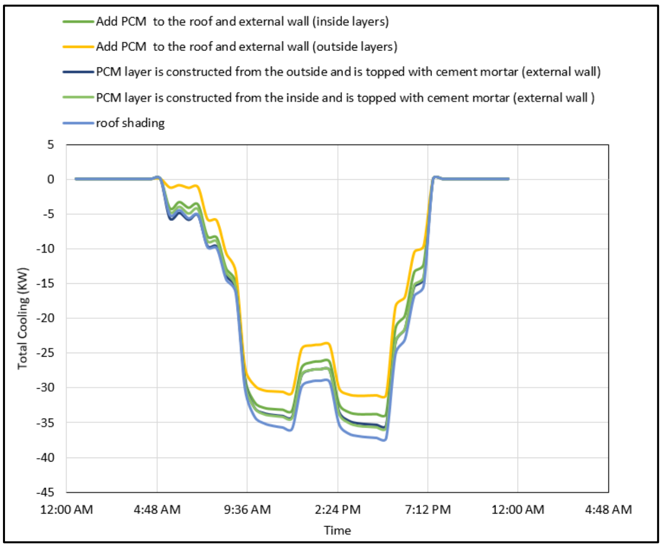

Fig. 11 Total cooling load with time in July.

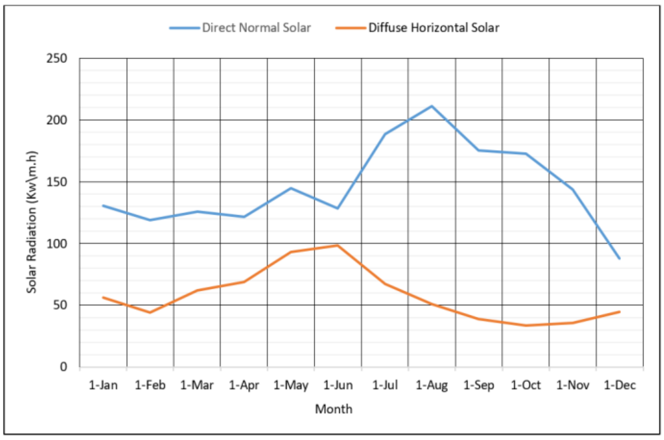

Fig. 12 Annual direct and diffuse solar radiation.

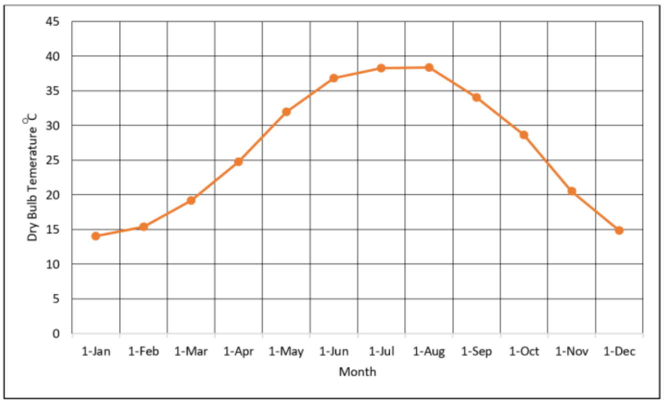

Fig. 13 Annual dry bulb temperature (°C).

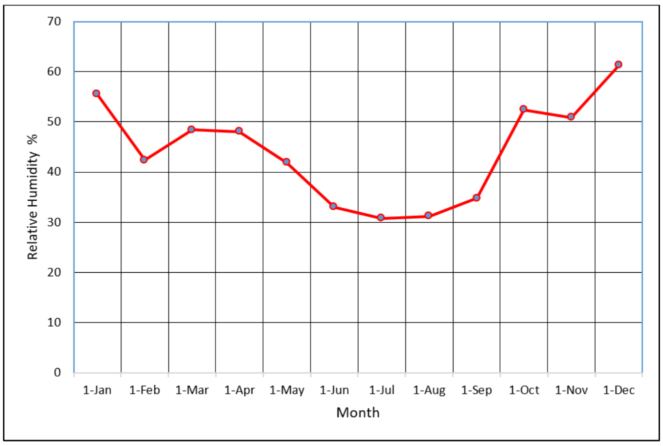

Fig. 14 Annual relative humidity.

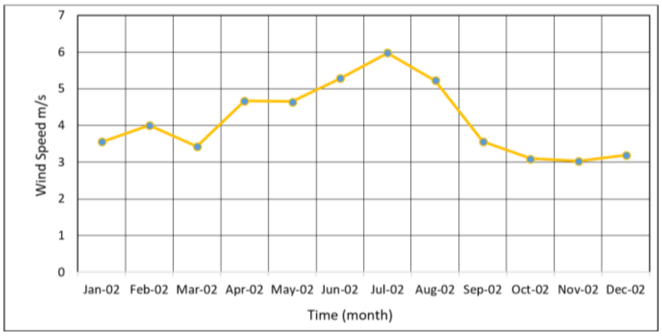

Fig. 15 The mean monthly wind speed over the year in Basrah city.

7. Conclusions

According to the findings of the study, computer-based simulation is an effective approach for calculating energy consumption in buildings and determining optimal design options for energy savings. In this investigation, the cooling loads of a domestic building in southern Iraq were calculated over a year. This study included the following energy-efficient design solutions, which are concluded:

1. The incorporation of PCM with other building materials can contribute to improving thermal comfort.
2. Utilizing PCM results in energy savings and a reduction in cooling load.
3. When PCM was installed on the outer surface of the wall and roof, it resulted in the greatest lessening in the cooling load by about (18 %).
4. Using of roof shading methods will reduce heat gain from solar radiation as the roof is the largest source of this gain.
5. Roof shading was effective in reducing the cooling load by approximately (5 %).

8. Recommendations

1. To improve the thermal performance of a building, roof shading effects can be simulated by utilizing brick tiles or wood rather than corrugated iron sheets.
2. Additional study into phase change materials is essential to discover how to combine thermal mass benefits by utilizing phase change materials instead of concrete or bricks.

Nomenclature		
Symbol	**Description**	**Unit**
A	Surface area	m^2
T	Temperature	K
m	Air system supply mass flow rate	kg/s
Q	Heat transfer during walls or ceiling	W
m	Mass flow rate due to infiltration	kg/s
c_p	Zone air specific heat	J/kg.K
K	Thermal conductivity	W/m.K
h	Enthalpy	kJ/kg
Δt	Calculation time step	sec
Δx	Finite-difference layer thickness	mm
Greek Symbols		
Symbol	**Description**	**Unit**
ρ	density	kg/m^3
θ	angle of incidence of the sun's rays	degree
α	solar absorptance of the surface	-
Subscripts		
inf	Infiltration	
sys	System	
i	Inlet	
Abbreviations		
PCM	Phase change material	
BIOPCM	Bio phase change material	
CondFD	Finite conduction difference	

References

[1] C. K. Halford and R. F. Boehm, "Modeling of phase change material peak load shifting", Energy and Buildings, Vol. 39, Issue 3, pp. 298-305, 2007. https://doi.org/10.1016/j.enbuild.2006.07.005

[2] M. K. Hussein, "Improvements of building envelope using passive cooling techniques to reduce the cooling load in hot-dry regions", Heat Transfer, Vol. 48, Issue 8, pp. 3831-3842, 2019. https://doi.org/10.1002/htj.21570

[3] K. Muruganantham, "Application of phase change material in buildings field data vs EnergyPlus simulation", M.Sc. Thesis, Arizona State University, 2010.

[4] M. B. Al-Hadithi, "Use of phase change material in residential walls to reduce cooling load", Anbar Journal for Engineering Science, Vol. 4, No. 1, pp. 72-74, 2011.

[5] A. A. Madhumathi and B. M. C. Sundarraja, "Experimental study of passive cooling of building façade using phase change materials to increase thermal comfort in buildings in hot humid areas", International Journal of Energy and Environment, Vol. 3, Issue 5, pp. 739-748, 2012.

[6] M. K. Nematchoua, J. C. V. Noelson, I. Saadi, H. Kenfack, A. F. R. Andrianaharinjaka, D. F. Ngoumdoum, J. B. Sela, and S. Reiter, "Application of phase change materials, thermal insulation, and external shading for thermal comfort improvement and cooling energy demand reduction in an office building under different coastal tropical climates", Soler Energy, Vol. 207, pp. 458-470, 2020. https://doi.org/10.1016/j.solener.2020.06.110

[7] A. H. N. Al-mudhafar, M. T. Hamzah, and A. L. Tarish, "Potential of integrating PCMs in residential building envelope to reduce cooling energy consumption", Case Studies in Thermal Engineering, Vol. 27, 2021. https://doi.org/10.1016/j.csite.2021.101360

[8] S. D. Zwanzig, "Numerical simulation of phase change material composite wallboard in a multi-layered building envelope", M.Sc. Thesis, Department Mechanical Engineering, University of Louisville, 2012. https://doi.org/10.18297/etd/1655

[9] S. M. da Silva, and M. Almeida, "Using PCM to improve building's thermal performance", 2nd international conference on sustainable energy storage, June 19-21, Trinity College, Dublin, Ireland, pp. 181-186, 2013. https://core.ac.uk/download/55625078.pdf

[10] H. J. Akeiber, S. E. Hosseini, M. A. Wahid, H. M. Hussen, and A. T. Mohammad, "Phase change materials-assisted heat flux reduction: Experiment and numerical analysis", Energies, Vol. 9, Issue 1, 2016. https://doi.org/10.3390/en9010030

[11] X. Wang, Y. Zhang, W. Xiao, R. Zeng, Q. Zhang, and H. Di, "Review of Thermal Performance of Phase Change Energy Storage Building Envelope", Chinese Science Bulletin, Vol. 54, Issue 6, pp. 920-928, 2009. https://doi.org/10.1007/s11434-009-0120-8

[12] A. H. Mohammed, "A theoretical and practical investigation into the use of an underground heat exchanger and the solar chimney to cool buildings in the city of Basra", Ph.D. Thesis, Department of Mechanical Engineering, College of Engineering, University of Basrah, 2016.

[13] R. H. Hashim, S. H. Hammdi, A. A. Eidan, "Evaporative Cooling: A Review of its Types and Modeling", Basrah Journal for Engineering Sciences, Vol. 22, Issue 1, pp. 36-47, 2022. http://doi.org/10.33971/bjes.22.1.5

[14] The Reference to EnergyPlus Calculations, No. c.2015.

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