The Effect of PCMs in the Building Shell on Energy Consumption Storage

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The performance of the building shell has a significant effect on the cooling and heating load of the building. One of the things that have a significant effect on storage and improving thermal comfort conditions are PCMs because they can store thermal energy in both tangible and latent thermal energy in materials. The thermal performance of the building shell can be improved by using PCMs. The purpose of the present study was to examine the effect of using four types of PCMs with different melting temperatures and specific latent heat in the external and internal walls of the building on reducing the energy consumption of the studied building in Tehran climate using building information modeling and Energy Plus software. The simulation results show a significant reduction in heat transfer using PCMs in the building shell and a reduction in annual energy consumption of up to 3.97%.

keywords: *Energy storage, Thermal load, Energy Plus.*

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1. INTRODUCTION

The most important threats of the present century are climate change, increasing greenhouse gas emissions, and increasing global energy consumption, which follows the development of industry and the daily increase in the population [1, 2] where buildings play a role in it with about 40% of global energy consumption [3, 4].

Estimates show that by 2050, energy consumption and carbon dioxide emissions will grow by 1.8% per year [1]. Therefore, the effect of using energy storage systems can not be ignored.

A review of past studies has shown that PCMs can be used on various building components such as walls, ceilings, floors [5, 6].

The performance of the building shell has a significant effect on the cooling and heating load of the building [7–9].

Since PCMs can store thermal energy in both tangible and latent thermal energy in materials, they significantly affect storage and improve thermal comfort conditions.

This research, it is tried to study energy consumption changes by modeling a studied building according to the climatic conditions of Tehran and using four types of PCMs in the internal walls, ceiling, and floor of the building.

2. THEORETICAL FOUNDATIONS

A. Objective:

The objective of energy simulation in this study is to examine the effect of using four types of PCMs with different melting temperatures and specific latent heat in the external and internal walls of the building to reduce the energy consumption of the studied building in Tehran.

B. Energy storage:

Thermal energy storage is a useful method in promoting energy efficiency in buildings. This storage can be done as tangible or latent energy or as a combination of both [10, 11]. The latent state requires less mass of matter than the tangible state to store the same amount of energy, resulting in a smaller temperature difference during energy storage or release. Materials that can change the phase of the liquid to solid and vice versa for the latent storage of energy are called PCMs [12]. These materials are organic or inorganic compounds that can absorb and store large latent amounts of heat energy. The storage of thermal energy in these materials occurs during the process of the phase change (change of state from solid to liquid or vice versa). When materials change phase from solid to liquid or from liquid to solid, they absorb or return this heat to the environment in a constant temperature process [12]. Today, PCMs are used in many applications, including medical, military, electronics, heating and cooling applications, food preservation, textiles, buildings, and so on. The use of these materials in buildings can reduce temperature fluctuations, especially fluctuations due to loads caused by direct sunlight, which has been proven in various numerical studies [13, 14].

C. Classification of PCMs:

Over the years of research, a large number of potential PCMs have been identified. Most of which can be classified into four groups, the first group of organic materials including paraffins and non-paraffins (fatty acids and sugar alcohols), the second group of inorganic (mineral) materials including water, hydrates of salts and metals, the group of sumiotectics and the fourth group of various materials such as clathrates.

C.1. Organic materials:

The phase change temperature of this group of materials is in the range of -30 to 200 °C; at high temperatures, their covalent bonds are broken and cause instability. Also, the density of most of them is less than 1000 $\frac{Kg}{m^3}$, which is less than the density of most inorganic materials such as water and salt hydrates. This reduces the enthalpy values of phase change per unit volume compared to inorganic materials [10].

C.2. Paraffins:

The most widely used organic PCMs are paraffins, which are alkanes with the chemical formula CnH2n + 2. As the number of carbon atoms increases and the length of the chain expands, the melting temperature of these materials increases, commercial paraffins are obtained from the distillation of petroleum products, and yet they are still not pure materials and are a combination of different hydrocarbons. These materials are available from different manufacturers but are offered at a much higher price than similar salt hydrates. Commercial paraffin storage capacity varies between 120 and 210 (J/Kg) [10]. These materials have a relatively low degree of sub-cooling, so they do not need to add nuclear ingredients. Paraffins are safe and non-reactive materials compatible with most metal containers holding PCMs but tend to soften and perforate plastic containers. Other forms of paraffinic materials have low thermal conductivity (about 0.2 ($W/m°k$)), especially in the solid-state, which can slow down the heat transfer process in the energy storage or release processes. Paraffins are flammable materials that use non-flammable containers to solve this problem. Compared to salt hydrates, commercial paraffins do not have explicit melting or freezing points due to their impurity and the fact that they are a mixture of materials, reducing energy storage systems' efficiency.

C.3. Fatty acids:

With the chemical formula CH2) 2n -COOH) CH3 is very similar to paraffins, but their price is about three times the price of paraffins. The enthalpy of their phase change corresponds to that of paraffins, and as with them, the temperature of their phase change increases with increasing molecular length. Similar to paraffins, they have low degrees of sub-cooling and low thermal conductivity. These materials have a gradual corrosion property. They are composed of one component, do not have phase separation, remain stable during the cycle, and have a clear phase change temperature.

C.4. Sugar alcohols:

They are a type of hydrogen carbohydrate given with the chemical formula HO-CH2- [CH- (OH)] n-CH2-OH. This group of materials has been researched relatively recently, and therefore reliable information about them is limited. The phase change temperature of this group of materials is in the range of 90 to 120 °C, and their enthalpy of phase change is generally high. These materials also have a high volumetric phase change enthalpy due to their high density. Unlike other organic materials, their degree of sub-cooling is a certain amount. They are generally safe materials to the extent that some of them, such as Xylitol, are used as artificial sweeteners to replace sugar [10].

C.5. Minerals:

Apart from water, which is the most well-known PCM, salt hydrates are the main group of minerals. Ingredients of salt hydrates include salt and water that are mixed together in a crystalline lattice during freezing. These materials are sometimes used alone and sometimes as part of eutectic compounds. Their phase change temperature is in the range of 15 to 117 °. Due to its low price and high availability, it has been considered commercially. Two examples of available and inexpensive salt hydrates are CaCl2-6H2O and Na2SO4-10H2O. One of the advantages of these materials that increase the efficiency of heat storage systems is having a clear and definite phase change temperature. Also, having high thermal conductivity values compared to other PCMs increases the rate of energy storage or release. Another property is the high phase change enthalpy, which leads to smaller energy storage units. These materials also undergo less volume change than other PCMs during the melting or freezing process. One of the disadvantages of these materials is the formation of hydrate or other dihydrate salts in them. In addition to the problems caused by phase decomposition, it also reduces the volume available for heat storage. This problem can be decreased to some extent by using gels or concentrating mixtures. Another disadvantage is the corrosion of salt hydrates in front of storage containers, which must be checked for compatibility with these materials before use [10].

C.6. Eutectics:

Eutectic compounds combine two or more components that melt or freeze homogeneously. Homogeneous means that there is a similar homogeneous compound at every point before and after the phase change, and the temperature and enthalpy of the phase change are the same. As a result, eutectic compounds usually do not undergo phase separation. These compounds have a clear phase change temperature, but they have a high tendency to corrosion. Research on these compounds is in the early stages, and there is limited information about their thermophysical properties. However, three main subgroups are known: organic-organic, inorganic-organic, and inorganic-inorganic compounds [10].

C.7. Miscellaneous materials:

PCMs that are not classified in one of the main groups are considered as miscellaneous, the most important of which are clathrates. These materials have a crystalline structure that is formed by the placement of molecules of one type in the crystal lattice of another type. If the crystal lattice is water, the resulting compound is called hydrated clathrates. The phase change temperature range of clathrates is usually limited to 0 to 30 °C. Their advantage is the high phase change enthalpy, and their disadvantage is the low thermal conductivity [10].

D. Research Background

Alvadi has thermally analyzed a building brick containing PCMs in hot weather conditions. The use of brick as a PCM is to reduce the heat transfer current from the outside space, which is done by absorbing heat gain in the brick during the day before reaching the inner space. In order to measure the effects of different components in the brick design, aside from study on the number and type of PCMs used and their position inside the brick has been done in this research. The results show that if three cylinders of PCMs are placed in the centerline of the bricks, the heat flow into the room can be decreased by 17.55%. Increasing the quantity of PCMs also reduces the heat gain through bricks [15]. Experimental results obtained for repeated summer days by Kuznik et al. (2008) show that the inside temperature fluctuates between 18.9 and 36.6 °C in the case without PCMs, while temperature fluctuations in the case with PCMs range from 19.8 to 32.8 °C. These results show that walls with PCMs can reduce temperature fluctuations by up to 4.7 ° [16]. Ramakrishnan et al. (2017) studied the effect of PCMs on reducing thermal stress due to heatwaves in Melbourne. They used numerical methods and PCMs for their study. The studied building is shown in Fig 1. The results showed that the use of PCMs can significantly reduce thermal stresses and thus improve the health and comfort of residents. Also, they showed that in the choice of PCM, the phase change temperature and its amount play a significant role in its performance [17].

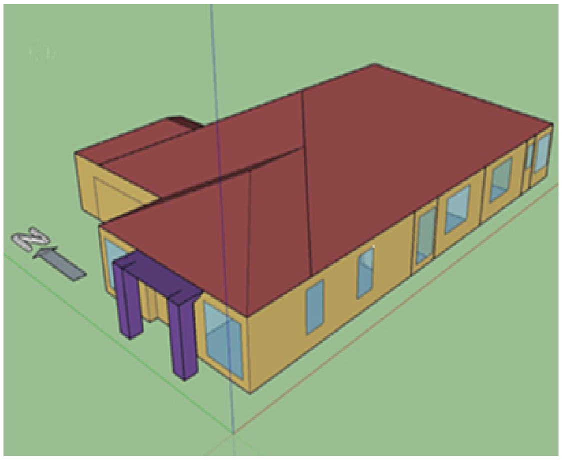

Fig. 1. Studied building

For the first time, Panayiotou et al. (2016) studied the performance of PCMs in a residential building in the Mediterranean. They used TRNSYS software for their study. They considered three modes for the placement of PCMs, as shown in Figs 2 to 4. They looked at different scenarios. In the first scenario, there is neither insulation nor PCM in the building. In the second scenario, there is PCM but no insulation. In the third scenario, insulation is used, but there is no PCM. In the fourth scenario, both insulation and PCMs are considered. The results showed that when only PCMs are used, energy consumption is decreased by about 25% compared to the base state (i.e., a state without insulation and without PCMs). On the other hand, if phase change and insulation materials are used simultaneously, the reduction of energy consumption will reach 66.2% [18]. Mi et al. (2016) examined the energy and economic performance of PCMs in five Chinese cities. They simulated a three-story office building (Fig 5) in Energy Plus software. The placement of the PCM in the wall is shown in Fig 6. Then, for economic analysis, they calculated the static and dynamic return on capital. The results showed that the performance of PCMs is more favorable in Zhengzhou and Shenyang cities with cold weather and in Changsha city with hot summers and cold winters. Economic analysis showed that the three cities of Zhengzhou, Shenyang, and Changsha are favorable for investing in PCMs, while the two cities of Kunming and Hong Kong are not economically viable [19].

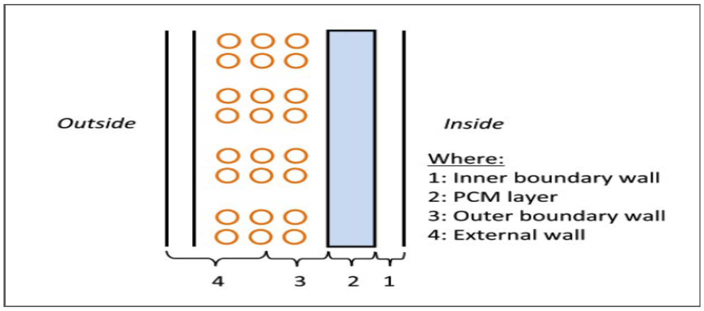

Fig. 2. First arrangement for PCMs

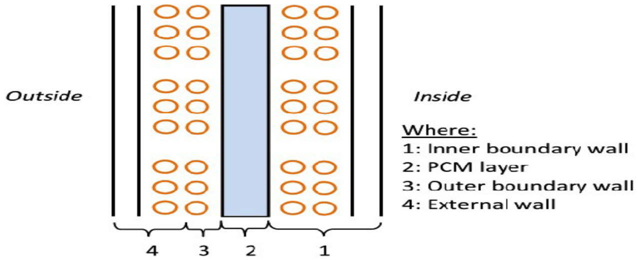

Fig. 3. Second arrangement for PCMs

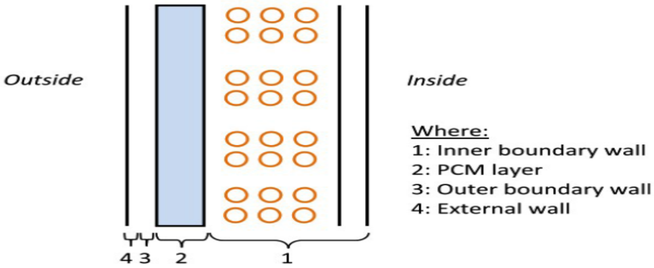

Fig. 4. Third arrangement for PCMs

Kenisarin and Mahkamov (2016) reviewed studies on the use of PCMs in buildings. In their study, they examined the different types of PCMs, such as paraffin and fatty acids. A comparison of 15 buildings in which PCMs were used showed that PCMs reduce temperature fluctuations, demand response, and energy consumption in the building [20].

Nghana and Tariku (2016) practically studied the effect of PCMs

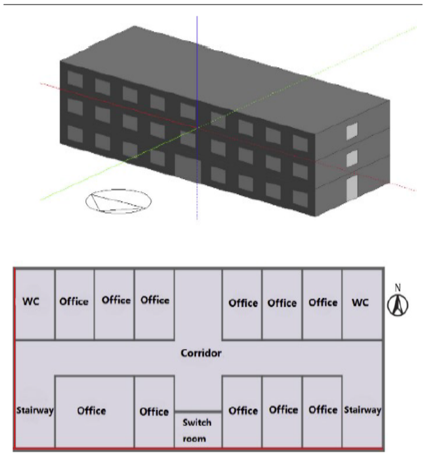

Fig. 5. Studied building

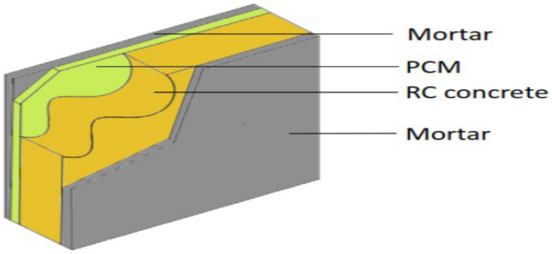

Fig. 6. Placement way of the PCM

on energy performance and building comfort conditions in different climatic conditions. They practically studied two adjacent buildings that were exposed to exactly the same internal and external conditions. Then, they used Energy Plus software for numerical analysis. As shown in Figs 7 and 8, the results showed that PCMs could reduce temperature fluctuations by up to 1.4 °C. In addition, the results showed that PCMs could reduce the heating load by 57% in winter [21].

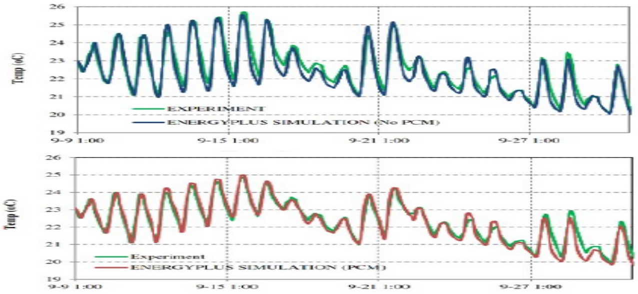

Fig. 7. Comparison of inside air temperature with and without PCMs

Lee et al. (2015) performed the numerical analysis of PCMs on the roof of a residential building. They studied the thermal performance of different roofs containing PCMs in the cold regions of Northeast China. In addition, they examined parameters such as solar radiation intensity, heat capacity, phase change temperature and PCM thickness, and roof slope, which affect roof performance. The roof structure is shown in Fig 8, in which the top layer is aluminum plates and has a protective role. The second layer is made of cement and prevents the penetration of water. The third layer is the layer containing PCMs. In the fourth layer, concrete is used. The results showed that the use of PCMs on the roof has a significant effect on delaying the peak temperature, and compared to common buildings, the peak temperature time is delayed by about 3 hours. The thickness of the PCM and the slope of the roof are also factors influencing the thermal behavior of the roof [22].

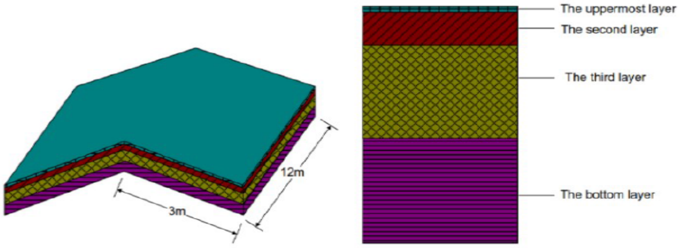

Fig. 8. Placement way of the PCM on the roof

Jin et al. (2016) studied the placement of a layer of thin PCM in the internal walls to increase the thermal mass and reduce the heat flux. As shown in Fig 9, they considered three modes for arranging the PCM and compared them with the state without PCMs. The results showed that the optimal position of the PCM varies depending on the thermal properties of the PCM and the weather conditions. The optimal position of the PCM is close to the outer layer of the wall if the layer thickness, heat capacity, and melting temperature are high, whereas if the inner surface temperature of the wall is high, it is close to the inner layer [23].

Lei et al. (2016) used PCMs to reduce the cooling load on buildings in Singapore's tropics. They modeled a ventilated cubic sample with dimensions of 3x3x2.8 *m* in Energy Plus software. The walls, floor, and ceiling were made of ordinary brick with a thickness of 150 *mm*. The outside temperature of the floor and ceiling was considered to be 25 °C, and the other walls were exposed to the outside air. Three types of PCMs with a thickness of 10 *mm* are included in the vertical walls, and the temperature-enthalpy diagram and specific heat capacity are shown in Fig 10. The main purpose of their study was to examine the efficiency of PCMs and determine the parameters affecting them. The results showed that PCMs

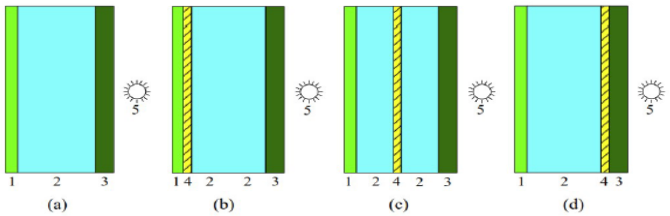

Fig. 9. Placement way of the PCM in the internal wall (yellow indicates the PCM)

could reduce heat receipts during the year, which indicates the optimal performance of PCMs compared to other climatic logic that PCMs only work well in certain seasons. The PCM placed on the outer layer performs better, and with increasing thickness, the heat receipts decrease, while the thin PCM has higher efficiency and is more economical [24].

Darkwa et al. (2006) made significant efforts to evaluate the performance of two integrated gypsum systems of PCMs in construction applications by simulation and experimental methods. These two systems are a prefabricated gypsum wall with PCMs coating and a prefabricated gypsum wall with layers of PCMs that are randomly mixed inside the wall. Also, for a broader material evaluation, the PCMs used in the walls are classified into three temperature ranges, large, medium, and small, according to the temperature range in which the phase change takes place. The results show that the wall with coated PCM has better thermal performance than the wall with mixed PCM. This type of wall with a smaller phase change temperature range is more effective in correcting the night temperature in inactive solar buildings so that the minimum room temperature at this stage is more about 17% compared to the case where the wall is mixed with PCMs [25].

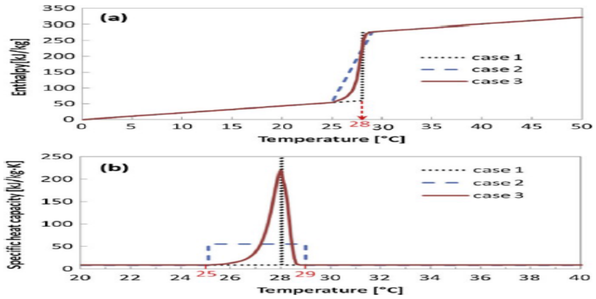

Fig. 10. Temperature-enthalpy diagram and specific heat capacity of the studied PCMs

3. MODELING

A. Model building specifications:

The building studied in this research is a five-story building including parking on the ground floor and four residential floors with a type architectural plan, and each floor has seven heating zones. The total area of the building is 750 m^2, and the area of each floor is 150 m^2. The doors of the rooms were 2.2 m high and 0.8 m wide. All north view windows are with dimensions 1.7 m (height) in 0.9 m (width) and south view windows with dimensions 1.5 m (height) in 1.6 m (width) and 0.7 m (Height) in 1.6 m (width). The main staircase facing the main door is intended for connecting the floors. The floor-to-floor height of the floors is 3 m, and the floor-to-ceiling height of the rooms is 2.65 m. In the case of using common materials, the thickness of the external and internal walls of the building are 22.5 and 22 cm, respectively. In the case of using materials including PCMs, the thickness is 26.2 and 29.4 cm, respectively.Figs 11 to 13 show the north, south, type floor plan, and parking plan of the studied building. The characteristics of the layers forming the external and internal walls, floors, soil-connected floors, and roofs of the studied building with common materials are given in Table 1. In the simulation model with materials including PCMs, the

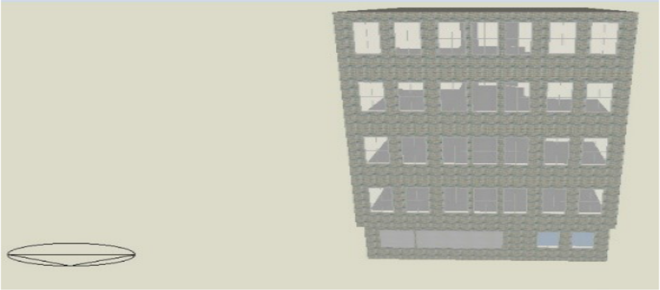

Fig. 11. North view of the building

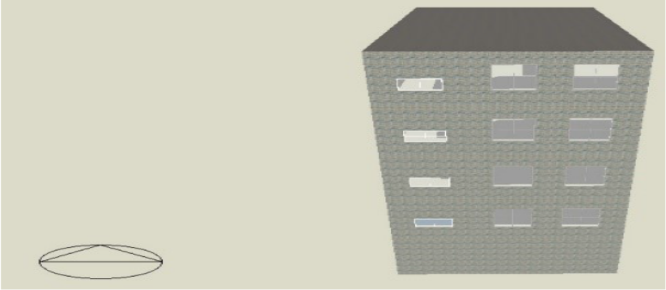

Fig. 12. South view of the building

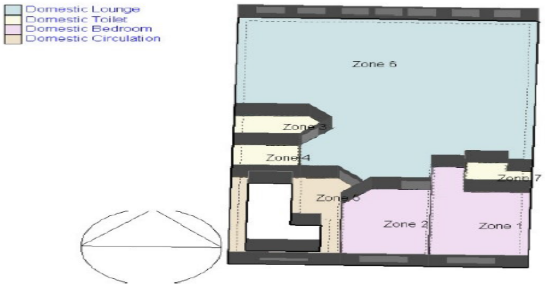

Fig. 13. Type floor plan of the studied building and relevant heating zones

characteristics of the layers forming the external and internal walls of the building with materials including PCMs are given in Table 2.

B. Specifications of PCMs

As mentioned earlier in the classification of PCMs, paraffins are the most widely used organic materials in PCMs due to their high latent heat, spontaneous nuclear bonding behavior, safety, and commercial abundance. However, the high flammability of these materials limits their use in buildings. For this reason, in this research, non-paraffin organic materials called Bio-based PCM (PCMs with biological nature), which are considered as a group of fatty acids, have been used, which have good properties of paraffins and have less flammability. These materials are of natural and renewable origin and are obtained from less used raw materials such as soybean oil, coconut oil, palm oil, and beef tallow; because these materials are fully hydrogenated, they are expected to remain stable over thousands of phase change cycles without the risk of oxidation. These materials, similar to paraffin PCMs, have the ability to absorb, store and release large amounts of latent heat, as well as the ability to encapsulate. They can also be made in such a way that their melting point varies between -22.7 °C to 78.33 °C, which makes them suitable for use in different fields and different climatic conditions. However, PCMs with a biological nature similar to all common organic PCMs have low thermal conductivity, limiting their energy storage use.

Therefore, using PCMs with biological nature filled with materials with high thermal conductivity is a good strategy to improve their thermal properties and wide application. The PCMs selected in this study, brand BioPCM^{T}M, is from the group of PCMs PCMs with biological nature and are products of the Australian Phase Change Energy Solutions Company. PCM can be ordered with one of four phase change temperatures of 21 °C, 23 °C, 25 °C, and 27 °C and is available in different heat storage capacities. In this study, to examine the effect of melting point temperature of PCMs used in building components layers on reducing the energy consumption of the building and also providing thermal comfort, four types of BioPCM with the same heat storage capacity (91 $\frac{Btu}{ft^2}$) and different melting point temperatures (21 °C, 23 °C, 25 °C and 27 °C) have been used. Therefore, the PCMs type 1 used in this project is BioPCM®$\frac{M91}{Q21}$, the second type: BioPCM®$\frac{M91}{Q23}$, the third type: BioPCM®$\frac{M91}{Q25}$ and the fourth type: BioPCM®$\frac{M91}{Q27}$. As mentioned earlier, in the method of finite difference algorithm, conduction for all nodes in a layer with PCM, an enthalpy-temperature function must be formed. Therefore, temperature and enthalpy values for the four types of PCMs used in the project are given according to Table 3 as input data of Energy Plus software.

4. SIMULATION RESULTS

A. Simulation results of a studied residential building in the base model:

After running the software and annual energy simulation, the results according to Table 4 for the studied residential building in Tehran are obtained in the base model.

B. Simulation of the studied residential building with PCMs type1:

In this case, after using PCMs type 1 (BioPCM®$\frac{M91}{Q21}$) in the external and internal walls of the building and its temperature characteristics according to Table 3, with software running and annual energy simulation, the results according to Table 5 are obtained for residential building in Tehran.

By comparing the data and diagrams obtained in this case with the base, the values of energy consumption reduction are obtained in Table 6.

C. Simulation of the studied residential building with PCMs type2:

In this case, after using PCMs type 2 (BioPCM®$\frac{M91}{Q23}$) in the external and internal walls of the building according to Table 4, with software running and annual energy simulation, the results according to Table 7 are obtained for residential building in Tehran.

By comparing the data and diagrams obtained in this case with the base, the values of energy consumption reduction are obtained in Table 8.

D. Simulation of the studied residential building with PCMs type3:

In this case, after using PCMs type 3 (BioPCM®$\frac{M91}{Q25}$) in the external and internal walls of the building according to Table 5, with software running and annual energy simulation, the results according to Table 9 are obtained for residential building in Tehran.

By comparing the data and diagrams obtained in this case with the base, the values of energy consumption reduction are obtained in Table 10.

E. Simulation of the studied residential building with PCMs type4:

In this case, after using PCMs type 4 (BioPCM®$\frac{M91}{Q27}$) in the external and internal walls of the building according to Table 6, with software running and annual energy simulation, the results according to Table 11 are obtained for residential building in Tehran.

By comparing the data and diagrams obtained in this case with the base, the values of energy consumption reduction are obtained in Table 12.

F. Software output diagrams

After simulating the project energy in the various cases mentioned by Energy Plus software, in this section, for better comparative comparison, the output diagrams obtained from Microsoft Excel software and the output data of Energy Plus software, total annual energy consumption, total annual electricity consumption, and total annual gas energy consumption are provided in the Figs. 14 to 16, respectively.

Table 1. Layers of studied building components with common materials [26]

Building components	Layers (outside to inside)	Thermal conductivity (w/m-k)	Thickness (cm)	Specific Heat (j/kg-k)	Density (Kg/m3)
External wall	Marble	3.5	2	1000	2800
	Cement mortar	1	3	920	1600
	AAC block	0.11	15	896	2800
	Plaster and soil	1.1	2.5	960	1500
	White chalk	0.57	1	1090	1300
Internal wall	White chalk	0.57	1	1090	1300
	Plaster and soil	1.1	2.5	960	1500
	AAC block	0.11	15	896	2800
	Plaster and soil	1.1	2.5	960	1500
	White chalk	0.57	1	1090	1300
Floors	Parquet	0.14	0.8	1350	550
	Elastomer insulation	0.32	0.5	1400	50
	Sheet foam	0.1	0.2	1470	38
	Cement mortar	1	3	920	1600
	Pumice (lightweight concrete)	0.52	4	1000	1200
	Ceiling concrete	1.5	20	1000	2200
	Plaster and soil	1.1	2.5	960	1500
	White chalk	0.57	1	1090	1300
Top floor ceiling	Waterproofing	0.017	2	1000	2250
	Cement mortar	1	3	920	1600
	Pumice (lightweight concrete)	0.52	4	1000	1200
	Elastomer insulation	0.32	0.5	1400	50
	Concrete	1.5	20	1000	2200
	Plaster and soil	1.1	2.5	960	1500
	White chalk	0.57	1	1090	1300
Ground floor	Marble	3.5	3	1000	2800
	Cement mortar	1	3	920	1600
	Pumice (lightweight concrete)	0.52	10	1000	1200
	Concrete	1.5	75	1000	2200

Table 2. . Layers of studied building walls with materials including PCMs \cite{r26}

Building components	Layers (outside to inside)	Thermal conductivity (w/m-k)	Thickness (cm)	Specific Heat (j/kg-k)	Density (Kg/m3)
External wall	Marble	3.5	2	1000	2800
	Cement mortar	1	3	920	1600
	AAC block	0.11	15	896	2800
	Plaster and soil	1.1	2.5	960	1500
	Pcm	0.2	3.71	1970	235
	White chalk	0.57	1	1090	1300
Internal wall	White chalk	0.57	1	1090	1300
	Pcm	0.2	3.71	1970	235
	Plaster and soil	1.1	2.5	960	1500
	AAC block	0.11	15	896	2800
	Plaster and soil	1.1	2.5	960	1500
	Pcm	0.2	3.71	1970	235
	White chalk	0.57	1	1090	1300

Table 3. Temperature and enthalpy values of PCMs \cite{r26}

Temperature and enthalpy values BioPCM® M91/Q27		Temperature and enthalpy values BioPCM® M91/Q25		Temperature and enthalpy values BioPCM® M91/Q23		Temperature and enthalpy values BioPCM® M91/Q21	
Temperature °(C)	enthalpy (J/kg)	Temperature °(C)	enthalpy (J/kg)	Temperature °(C)	enthalpy (J/kg)	Temperature °(C)	enthalpy (J/kg)
1	-20	1	-20	1	-20	1	-20
5	0	8	0	12	0	12	0
16458	10	19290	10	23058	10	25058	10
23562	15	27240	15	32580	15	34799	15
32561	20	36990	20	41280	20	38970	20
43078	25	42867	23	55230	21.5	55119	21
57014	26	56221	24	81820	22	80820	21.5
84146	26.5	83245	24.5	128509	22.5	128509	22
134578	27	133649	25	201879	23	201879	22.5
202864	27.5	201879	25.5	236860	24	225581	23
237015	28	236860	26	245462	25	231773	24
251278	30	247994	28	249194	27	233328	25
255234	32	254449	32	254503	30	240711	30
258320	35	257761	35	258813	35	246859	35
267324	45	266724	45	267178	45	254741	45
322093	100	322285	100	300420	100	289545	100

Table 4. Annual energy consumption of the studied building in the base model

Total annual energy consumption of the building (kwh)	71162.46
Total annual electricity consumption (kwh)	35672.16
Total annual gas consumption (kwh)	35490.29

Table 5. Annual energy consumption of the studied building with the materials of PCMs type 1

Total annual energy consumption of the building (kwh)	68658.51
Total annual electricity consumption (kwh)	34984.95
Total annual gas consumption (kwh)	33673.56

Table 6. Comparison of building energy consumption in base mode and studied building with materials of PCMs type 1

Report type	Building simulation in base mode	Simulation with materials including PCM type 1	The rate of decrease (increase) of energy	
Total annual energy consumption of the building (kwh)	71162.46	68658.51	kwh	2503.95
			%	3.52
Total annual electricity consumption (kwh)	35672.16	34984.95	kwh	687.21
			%	1.93
Total annual gas consumption (kwh)	35490.29	33673.56	kwh	1816.73
			%	5.12

Table 7. Annual energy consumption of the studied building with the materials of PCMs type 2

Total annual energy consumption of the building (kwh)	68404.02
Total annual electricity consumption (kwh)	34695.51
Total annual gas consumption (kwh)	33708.51

Table 8. Comparison of building energy consumption in base mode and studied building with materials of PCMs type 2

Report type	Building simulation in base mode	Simulation with materials including PCM type 2	The rate of decrease (increase) of energy	
Total annual energy consumption of the building (kwh)	71162.46	68404.02	kwh	2758.44
			%	3.88
Total annual electricity consumption (kwh)	35672.16	34695.51	kwh	976.65
			%	2.74
Total annual gas consumption (kwh)	35490.29	33708.51	kwh	1781.78
			%	5.02

Table 9. Annual energy consumption of the studied building with the materials of PCMs type 3

Total annual energy consumption of the building (kwh)	68334.22
Total annual electricity consumption (kwh)	34458.53
Total annual gas consumption (kwh)	33875.69

Table 10. Comparison of building energy consumption in base mode and studied building with materials of PCMs type 3

Report type	Building simulation in base mode	Simulation with materials including PCM type 3	The rate of decrease (increase) of energy	
Total annual energy consumption of the building (kwh)	71162.46	68334.22	kwh	2828.24
			%	3.97
Total annual electricity consumption (kwh)	35672.16	34458.53	kwh	1213.63
			%	3.40
Total annual gas consumption (kwh)	35490.29	33875.69	kwh	1614.60
			%	4.55

Table 11. Annual energy consumption of the studied building with the materials of PCMs type 4

Total annual energy consumption of the building (kwh)	68354.11
Total annual electricity consumption (kwh)	34276.55
Total annual gas consumption (kwh)	34077.56

Table 12. Comparison of building energy consumption in base mode and studied building with materials of PCMs type 4

Report type	Building simulation in base mode	Simulation with materials including PCM type 4	The rate of decrease (increase) of energy	
Total annual energy consumption of the building (kwh)	71162.46	68354.11	kwh	2808.35
			%	3.95
Total annual electricity consumption (kwh)	35672.16	34276.55	kwh	1395.61
			%	3.91
Total annual gas consumption (kwh)	35490.29	34077.56	kwh	1412.73
			%	3.98

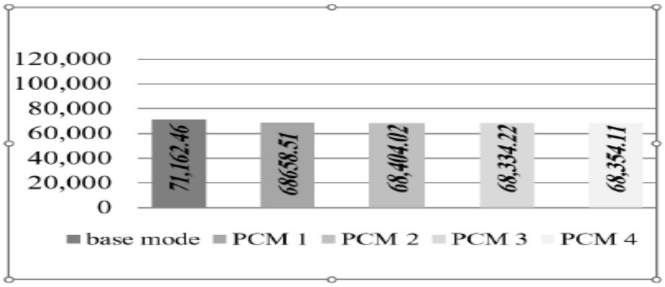

Fig. 14. Total annual energy consumption (kwh) for the studied building in 4 comparative modes

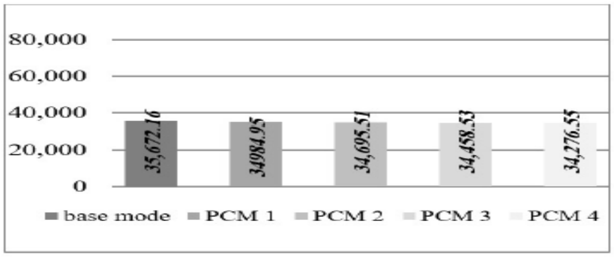

Fig. 15. Total annual electrical energy consumption (kwh) for the studied building in 4 comparative modes

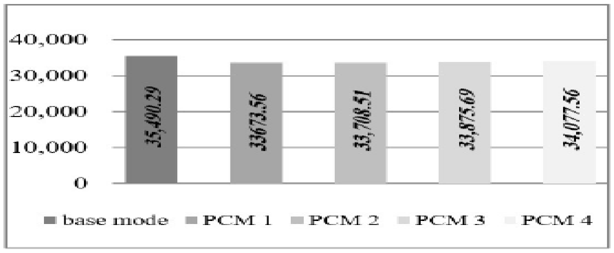

Fig. 16. Total annual gas consumption (kwh) for the studied building in 4 comparative modes

5. CONCLUSION

The simulation results show a significant reduction in heat transfer using PCMs in the building shell so that using PCMs type 1 in the studied building, a reduction of 3.52%, which includes 1.93% electrical energy savings and 5.92% savings in natural gas consumption. Also, the use of PCMs type II shows a decrease of 3.88%, which includes 2.74% saving in electricity consumption and 5.02% saving in natural gas consumption. PCMs type 3 decreased by 3.97%, which includes 3.40% saving in electricity consumption and 4.55% saving in natural gas consumption. PCMs type IV decreased by 3.95%, which includes 3.91% saving in electricity 3.98% savings in natural gas consumption.

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