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The difference in the effect of phase change materials on the heating and cooling needs of office spaces on the ceiling, floor, interior, and exterior walls in Tehran

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Abstract
Introduction: Given the criticality of energy consumption and the reduction of fossil fuel resources, and the fact that the energy consumption of buildings for heating and cooling includes a significant amount of fuel consumption, one of the ways to deal with this situation is to maintain and prevent energy waste. According to research, one of the newest and most effective technologies in this regard is the use of phase change materials, or PCMs, which can be used in various components and parts of the building.
Research Method: Using energy simulation software in buildings is one of the most reliable methods of finding out the effect of phase change materials in a building. In the present research, an attempt has been made to identify the best phase change material with the best thickness and location in the ceiling, floor, exterior and interior walls, and the most effective of them, using Design Builder software, which is based on the Energy Plus engine.
Results and Discussion: In this study, after simulating the desired building in Design Builder, the wall components were simulated. Then, the phase change material was placed in different layers of the interior and exterior walls, ceiling, and floor to determine the best location for it. Then, the different melting points of the phase change material were examined in the best location. Finally, the effect of the thickness of these materials on the cooling and heating of the building was examined, and the highest effect among them was determined.
Conclusion: According to the results of the simulations in the cases with and without phase change materials, it can be concluded that these materials have a positive effect on reducing energy consumption in cooling and heating the building.
Keywords: Phase change materials (PCM), Design Builder, Energy consumption, Thermal comfort

1-INTRODUCTION

The strong economic and population growth in the past 3 decades has led to a rapid increase in global energy consumption and the production of large amounts of greenhouse gases. Fossil fuels are the main sources of carbon dioxide and account for approximately 65% of the total amount of greenhouse gases. Today, global efforts to reduce greenhouse gases are being made based on research and development of innovative technologies to have a positive impact on reducing these gases. Buildings and the construction sector, as one of the main factors of greenhouse gas production, lead to an increase in the production and consumption of greenhouse gases through energy consumption, and reducing energy demand in buildings, which focuses on research and development of innovative technologies, leads to a decrease in fossil fuel consumption (IPCC, 2013). In recent years, the demand for thermal comfort in buildings has increased dramatically, which has caused a significant increase in global energy consumption. For example, in industrialized countries, building heating and cooling systems (residential and commercial energy consumption) account for between 20 and 40 percent of total energy consumption. Windows also lose between 30 and 50 percent of building energy. Natural gas consumption in American homes is 63 percent for building heating, and the remaining 37 percent is for water heating, cooking, and miscellaneous uses. In the European Union, buildings account for 40 percent of energy consumption, and two-thirds of this energy consumption is related to heating, ventilation, and air conditioning systems. Therefore, reducing the

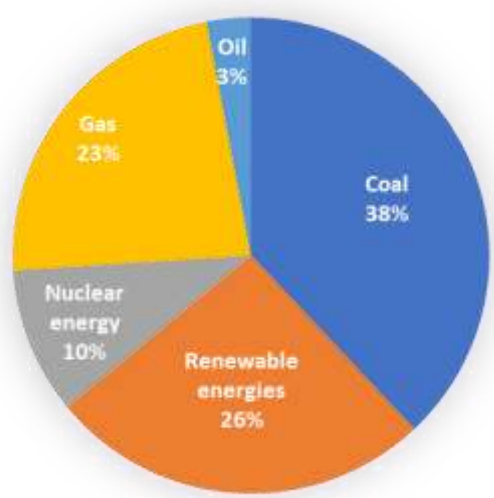

Fig.1- Consumption of fuel and energy in the world by year 2020 (image information from the International Energy Agency)

energy demand of buildings is very important for energy savings. (NREL, 2023)

One way to save energy in a building is to use a thermal energy storage system. This method can reduce the time and quantity gap between energy supply and demand, thereby increasing the efficiency of energy systems. By designing highly efficient and climate-appropriate structures, the solar thermal energy that is available during the day can be used to heat cold nights and prevent the building's interior from overheating during the day. Thermal energy storage occurs in three ways: sensible, latent, and thermochemical (Romdhane et al., 2020).

Latent heat storage is based on the enthalpy of solids and liquids. This advantage is based on a very narrow or constant range of temperature change during energy storage/release. In most cases, the solid-to-liquid phase change process is used due to its low volumetric expansion, where fusion is used to store heat and freezing is used to release heat. Figure (2) shows a diagram of this phase change in exothermic and endothermic states for cooling and heating. (Lajimi & Boukadida, 2020)

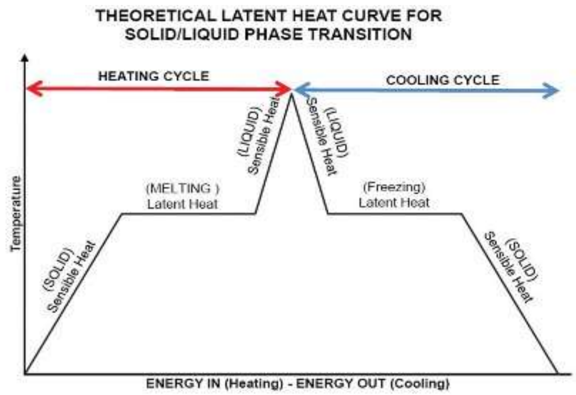

Fig.2- Solid/liquid phase change diagram (Lajimi, & Boukadida, 2020)

One of the future technologies for thermal energy storage is phase change materials (PCMs), which are chemically stable, recyclable, non-reactive, and have a long lifespan. In addition, they are materials with a high heat of fusion that can be used to store or extract heat without a significant change in temperature (Romdhane et al., 2020).

1-1 A review of the research background:

In recent years, due to the high ability of these materials to reduce building energy consumption, there has been a lot of research on the use of these materials, how to use and combine them with other materials, as well as newer ingredients in the future, and various other studies on these materials. The table below attempts to address a number of them by their use in floors, window glass, window frames, and exterior walls:

Place of use in the building	Abstract	Year of publication
Floor	Investigating the benefits of PCM underfloor heating with PCM wallboard for space heating in winter (Devaux & Farid, 2017).	2017
Floor	Proposing a PCM underfloor heating system using a network construction method (Baek & Park, 2017).	2017
Floor	Analysis of thermal performance and energy saving potential of PCM radiant floor heating system based on wet construction method and hot water. (Baek & Kim, 2019)	2019
Floor	Attempt to enhance a radiant floor with a checkerboard pattern of two PCMs for heating and cooling. (Cesari et al., 2024)	2024
Floor	Analysis of an electric underfloor heating system integrated with coconut oil-PCM panels (Faraj et al., 2019).	2020
Window frame	Determining the thermal coefficients of window frames. Simulating various windows with aluminum, vinyl, and wood frames. (Onatayo et al., 2024)	2024
Window frame	Presenting a flow-dependent temperature change model for a thermoelectric window frame (Zeng et al., 2024).	2023

Window frame	Original research on improving the energy efficiency of various window frames and shutter boxes through thermal analysis. Study on six different types of window frames (PVC, wood and wood-aluminum) and four different models of shutter boxes (all with a structure made of expanded polystyrene) (Cardinale et al., 2015).	2015
Window glass	Numerical simulation of flow inside a double-glazed window using computational fluid dynamics (Khatib et al., 2023).	2023
Window glass	Investigation of the heat transfer characteristics of a double-ceramic window system using nano-dispersed phase change materials (NDPCM) (Kaushik et al., 2022).	2022
Window glass	In a 2021 study on the effect of phase change materials in windows, Wang Xiang and Meng designed smart windows with the ability to change color and size in response to temperature changes to save energy in buildings. (Wang et al., 2021)	2021
Window glass	Investigating the performance of smart glass panel technologies, specifically phase change materials, alongside silent and active techniques (Arasteh et al., 2023).	2024
Window glass	Performance evaluation of double-glazed windows containing hybrid phase change materials reinforced with nanoparticles (Yang et al., 2023).	2023
External wall	Discussion on the use of PCM phase change materials to enhance TES thermal energy storage in residential building walls (Arsentev & Rymarov, 2023.(	2023
External wall	Assessing energy consumption in different areas of an educational center, comparing the effects of PCM and polyurethane insulation on cooling energy savings and CO_2 emissions, and studying the effect of different PCM thicknesses (Boliyta et al., 2022).	2022
External wall	Focusing on minimizing the impact of weather conditions and energy consumption in buildings through the use of phase change materials applied to building envelopes (Kose Manioğlu &, 2019).	2019
External wall	Investigating the effect of PCM position on the thermal behavior of a multilayer wall of a building in the summer season, where PCM was used to model the wall (Lajimi & Boukadida, 2021).	2022
External wall	Discussion of laboratory studies on the design of PCM thermal storage and its applications at low temperatures in sunrooms. In this study, PCM layers were placed on the inner surface of a test chamber wall and tested under different indoor and outdoor conditions (Guiero et al., 2017).	2017
External wall	A research paper on investigating the effects of using	2023

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different phase change materials integrated into building exterior walls on thermal energy performance and energy savings (Terhan & Ilgar, 2023).

Tab.1- A list of studies conducted in the field of using phase change materials in buildings

Now, this proposed research project wants to investigate these materials in the exterior and interior walls, as well as the roof and floor of an office building in Tehran, to measure the change in the heating and cooling requirements of this environment with the presence of these materials according to the climate of this city using DesignBuilder software, and then determine which is the most effective location. DesignBuilder is an energy simulation and building design software developed by DesignBuilderSoftware Ltd. This software allows architectural engineers, mechanical engineers, and HVAC system designers to examine and improve the energy and environmental performance of buildings, and is also able to simulate the effect of phase change materials on different building components.

2-RESEARCH METHOD:

First, the building in question was simulated. In order to better compare the area of the interior wall with the exterior walls, the same size was designed. Then, different zones were identified. Next, the time of operation and entry and exit of each section were determined. Then, the materials of the walls, floor and ceiling were determined, and the placement of phase change materials in each layer began. After the best layer was determined, the placement of phase change materials with different melting points began. After the most suitable melting point was determined in terms of the effect on cooling and heating, the different thicknesses of this phase change material in the best layer found were examined and its effect on the cooling and heating of the building was determined, and then it was determined which one has a higher effect on reducing energy consumption.

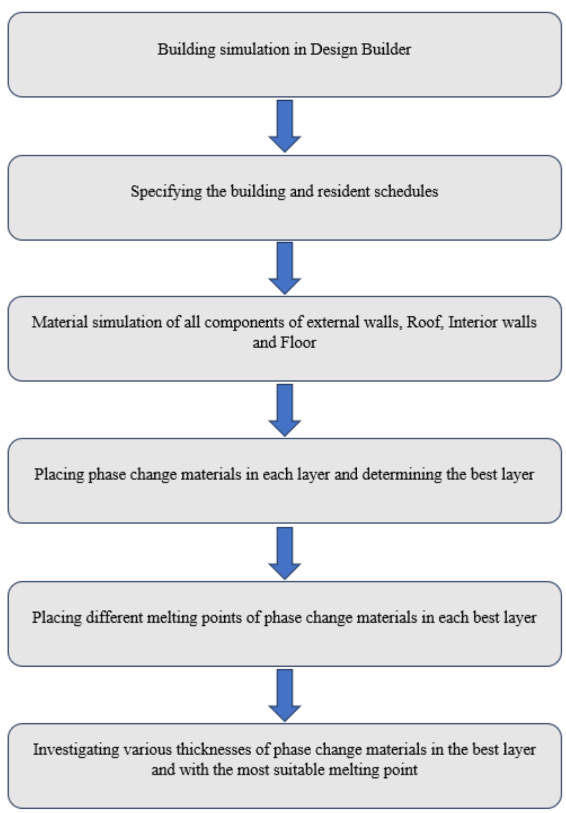

Fig.3- The overall research process

4-RESULTS AND DISCUSSION:

In this study, using the method of theoretical studies on phase changers and simulation, energy modeling and building structure, and methods for predicting weather conditions, the performance of the building in heating and cooling using the phase changer system was studied. Past studies have tried to investigate the use of different phase change materials for different applications in buildings. In this proposed research plan, two methods of library and simulation have been used. With the help of the library method, initial studies in this field have been conducted. In this step, previous works and research and the relevant theoretical foundations for analyzing the performance of thermal mass and phase change materials have been studied. One of the most important factors in choosing a phase change material is the availability of information and its presence in the insulation and construction industries market.

Supplier company name	Country	Phase change material form	Type of phase change material
Infinite R	United States	Bulk	Inorganic-organic
PureTemp	United States	Bulk	Inorganic-organic
Rubitherm GmbH	Germany	Bulk	Inorganic-organic
PlusICE	England	Bulk	Inorganic-organic
Micronal	Germany	Bulk macro encapsulated	Organic - grout
savENRG™	United States	Bulk macro encapsulated	Inorganic-organic
Climator	Sweden	Bulk	Inorganic
Energy PCM	India	Bulk	Hydrated salt
PCM Products Ltd	England	Bulk macro encapsulated	Zero eutectic - salt hydrate

Tab.2- Information of some companies producing phase change materials

Finally, the phase change materials from InfiniteR were used (Table 3), which are identical in all respects, including conductivity, weight, specific heat, and latent heat, except for the melting point. All of the following information has been published by the manufacturer after laboratory research and review (Infinite R, Energy Sheet).

PHYSICAL PROPERTIES	TEST METHOD	VALUES (ENGLISH)	VALUES (METRIC)
M-Value	ASTM	100 BTU per sq. ft	315 W per sq. Meter
Melt Point	DSC	70.0º Fahrenheit	21º Celsius
Specific Heat	DSC	1.35 BTU/lb	~3.14 kj/kg
Latent Heat	DSC	~86 btu/lb	~200 j/g
Thermal Conductivity	DSC	~0.16 W/ft/K Liquid ~0.33 W/ft/K Solid	~0.54 W/m/K Liquid ~1.09 W/m/K Solid
Dimensions	Ruler	24.5" x 48"	622mm X 1219mm
Total Unit Thickness	Micrometer	.25"	6mm
Weight	Scale	1.1 lbs per sq. ft.	5.38 kg per sq. Meter
Permeability	ASTM E96	0.08 (grains/hr*ft²*in Hg)	4.60 ng / N's

Tab.3- Infinite R phase change material information published in the catalog of this material

InfiniteR products are used to improve the energy efficiency of entire buildings in retail, commercial, medical and industrial applications. The company enables the safe transportation of sensitive food and pharmaceutical products and provides advanced thermal storage capabilities for industrial and commercial processes, among other applications. Based on the company's research, studies and results, InfiniteR is one of the leading companies in the field of phase change materials, which is why its products were selected for this study. These phase change materials can be simulated using DesignBuilder. DesignBuilder is an energy audit software with full building and climate simulation capabilities, advanced on the Energy Plus Engine.

Fig.4- An image of Infinite R PCM from her company's website

Table 3, which is a catalog published by Infinite R, contains the melting points published for phase change materials 18, 21, 23, 25 and 29. In fact, except for the melting point, the rest of the information and details of the catalogs are the same. The apparent heat temperature of these materials is 3.14 kJ/kg and the latent heat temperature is 200 j/g, but the thermal conductivity in the liquid and solid states of these materials is different, which is 0.54 w/m/k and 1.09 w/m/k, respectively. It should be noted that these phase change materials are produced and marketed in six thicknesses: 6, 12, 18, 24, 30 and 36 mm.
In the next step, the complete simulation of the exterior walls, windows, interior walls, ceiling, and floor was carried out in the Design Builder software. In the next step, by determining the use of the building, the level of activity during the day, week, and year, determining the level of activity of the heating and cooling systems that use fossil fuel and electrical energy, respectively, the amount of heat from electrical and thermal devices, the types and energy of lighting devices, and the level of natural and artificial ventilation, the simulation of the interior of the building was carried out, as well as determining the amount, time, and type of activity of each section. Then, by determining the longitude and latitude of Tehran and extracting Tehran's weather information from TMYIRAN, an effort was made to fully simulate the existing state of the building and obtain its temperature and comfort information. Now, we will examine the exterior wall, ceiling, interior wall, and floor separately:
1-External wall:

Type of materials	Conductivity (W/m-k)	Thickness(cm)	Specific heat (J/kg-k)
Brickwork outer	0.8400	10	800

Tab.4- Simulated materials along with their thickness and conductivity

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XPS Extruded Polystyrene - CO2 Blowing	0.0340	7.95	1400
Concrete block	0.5100	10	1000
Gypsum plastering	0.400	1.3	1000

Fig.5 External wall detail from Design Builder

After drawing all the wall details in Design Builder, a default phase change material was taken. Our default phase change material had a melting point of 18 degrees and a base thickness of 6 mm. In order to better understand and choose the best location for it in the current wall detail, placing and simulating each of these possibilities in Design Builder was done to check the effect on the amount of heating and cooling in constant conditions.

Placement layer	Cooling kWh	Cooling percentage	Heating kWh	Heating percentage
Without PCM	17012.25	-	945.02	-
First layer	16955.44	2.62	970.45	-0.33
Second layer	16871.36	14.46	1104.88	-0.83
Third layer	16769.67	24.44	1250.79	-1.44

Tab.6- The effect of the location of the phase change material on the outer wall of heating and cooling

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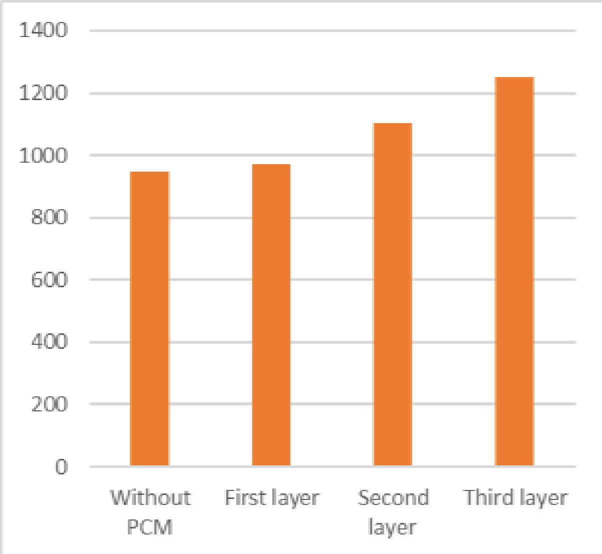

Fig.6- The effect of the location of the phase change material in heating

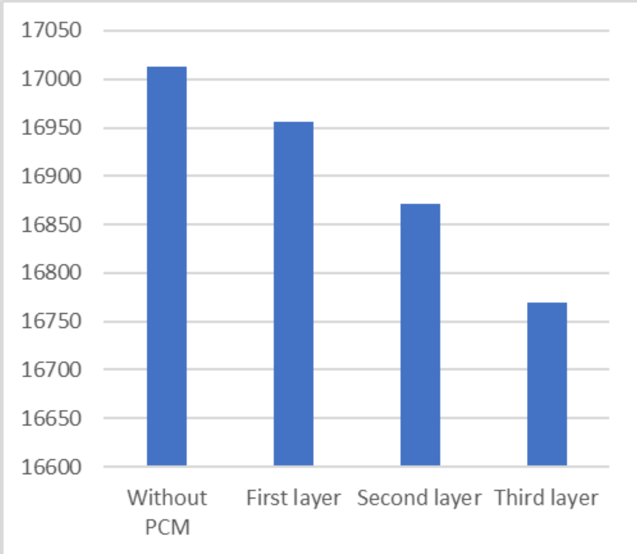

Fig.7- The effect of the location of the phase change material in cooling

According to the simulation results of phase change materials in wall layers, which are given in Table 6 and the graphs in Figures 6 and 7 and were performed in 4 simulation modes, we find that as we move from the outside to the last layer (the finishing layer), the effect of phase change materials on reducing cooling increases, and the opposite result is observed for heating. In the case without phase change material and in the case with phase change material in the last layer, we see a decrease of about 1.44% in cooling and an increase of about 24% in heating.
Now that we know the best location in the wall, we started simulating phase change materials with different melting temperatures: 18, 21, 23, 25, and 29 degrees. The types of phase change materials manufactured and marketed by InfiniteR are:

PCM Melting Point	Cooling kWh	Cooling %	Heating kWh	Heating %
Without PCM	17012.25	-	945.02	-
PCM18	16769.67	-1.44	1250.79	24.44
PCM21	16508.56	-3.05	854.38	-10.60
PCM23	16422.45	-3.59	675	-40.00
PCM25	16597.95	-2.49	696.32	-35.71
PCM29	17175.61	0.95	886.3	-6.62

Tab.7- The degree of influence of the melting point of the PCM in heating and cooling

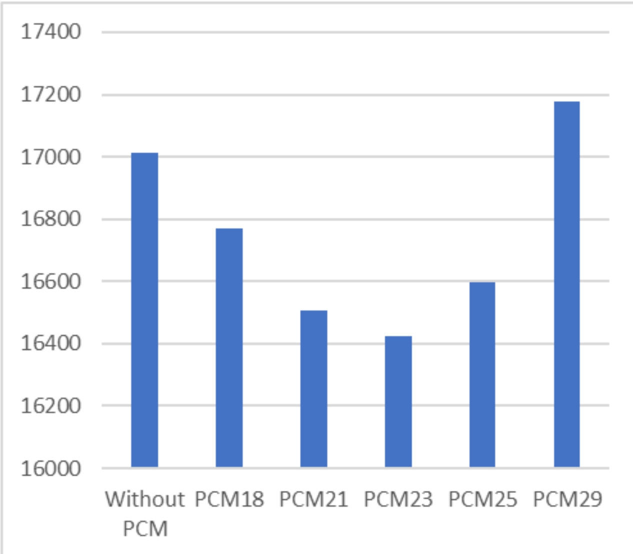

Fig.9- The effect of the location of the phase change material in heating

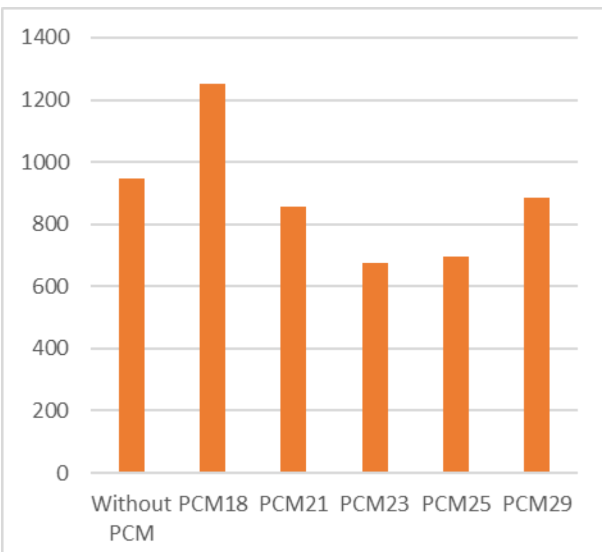

Fig.8- The effect of the location of the phase change material in heating

According to the numbers obtained from the simulation of various phase change materials with different melting points in Table 7 and the graphs in Figures 8 and 9, which were examined in 5 other cases, it can be concluded that PCM23 has the best effect in cooling and heating compared to the case without phase change materials. In cooling, we see a downward trend from the case without phase change materials to PCM23, and then in the next two phase change materials, this trend is upward, so that in PCM29, more energy is consumed than in the case without phase change materials. In the case of using PCM23, we see a reduction in energy consumption of about 3.59% in cooling and about 40% in heating, which indicates the greater effect of these materials in reducing heating.

Now that we have the best possible phase change material in terms of placement and melting temperature, we began to investigate different thicknesses. As mentioned earlier, 6, 12, 18, 24, 30, and 36 mm are the thicknesses produced and available for these materials. Each of these was investigated separately at the best melting temperature and best placement. The table and chart below show the simulation results with Design Builder:

Thickness	Cooling kWh	Cooling %	Heating kWh	Heating %
6mm	16422.45	-3.59	675	-40.00
12mm	16329.82	-4.17	575.97	-64.07
18mm	16207.22	-4.96	543.67	-73.82
24mm	16001.57	-6.31	531.69	-77.73
30mm	15705.74	-8.31	528.34	-78.86
36mm	15548.88	-9.41	522.48	-80.87

Tab.8- The effect of the thickness of the PCM on heating and cooling

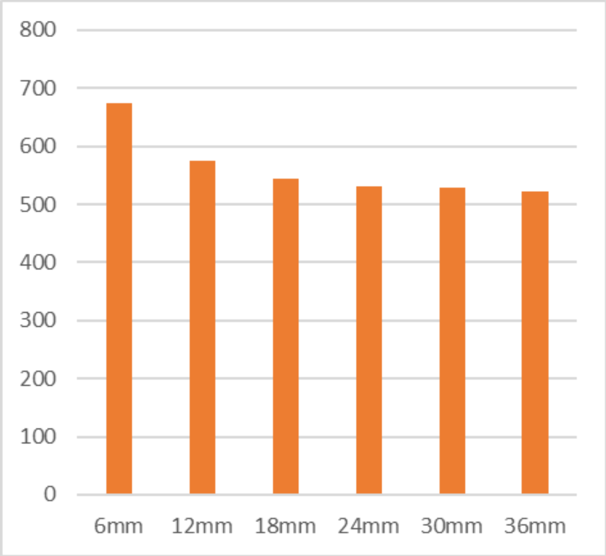

Fig.10- The effect of the location of the phase change material in heating

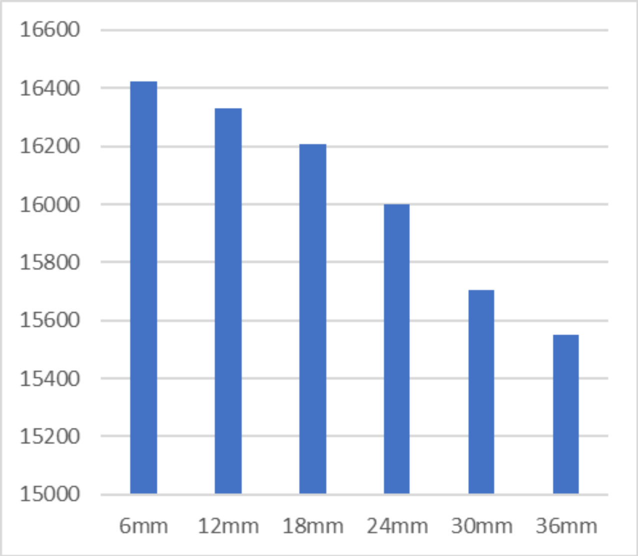

Fig.11- The effect of the location of the phase change material in cooling

By examining the numbers obtained from the simulation in Table 8, it was shown that increasing the thickness of the phase change materials, both in cooling and heating, has a very positive effect on reducing the heating and cooling consumption of the building, so that there is a difference of about 40 percent in heating and about 6 percent in cooling between the 6-mm and 36-mm cases.

2-Roof:

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Type of materials	Conductivity (W/m-k)	Thickness(cm)	Specific heat (J/kg-k)
Asphalt	0.700	1	1000
Glass Wool (Roll)	0.040	14.45	840
Air Layer	-	20	-
Gypsum Board	0.250	1.3	896

Fig.12 Roof detail from Design Builder

After drawing all the details of the roof in Design Builder, a default phase change material was used, like the exterior wall. Our default phase change material had a melting point of 18 degrees and a base thickness of 6 mm.

Placement layer	Cooling kWh	Cooling percentage	Heating kWh	Heating percentage
Without PCM	17012.25	-	945.02	-
First layer	16938.01	-3.21	915.57	-0.43
Second layer	16595.35	12.40	1078.91	-2.51
Third layer	16568.42	28.30	1318.13	-2.67

Tab.10- The effect of the location of the phase change material on roof of heating and cooling

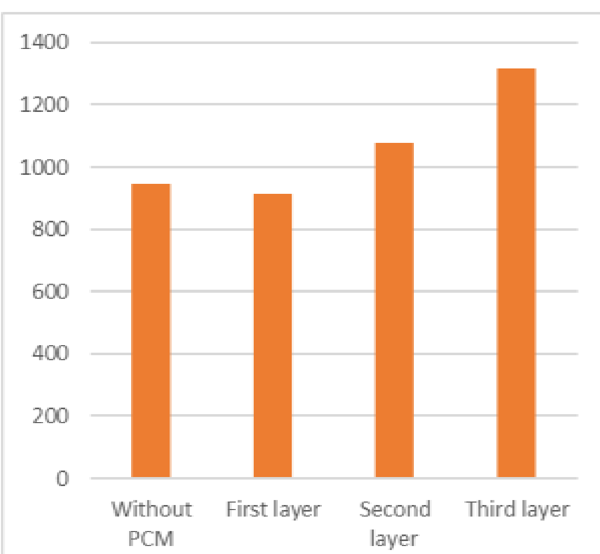

Fig.13- The effect of the location of the phase change material in heating

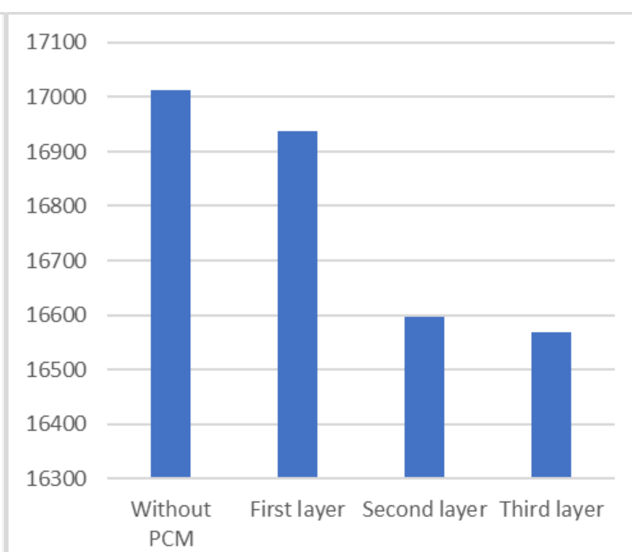

Fig.14- The effect of the location of the phase change material in cooling

According to the simulation results of phase change materials in the wall layers, which are given in Table 6 and the graphs in Figures 13 and 14, in cooling, we follow a downward trend from the layer without phase change material to the last layer, but in heating, only the first layer is effective, so that the next two layers consume more energy than the state with phase change material.
Now that we know the best location on the roof, we can start simulating phase change materials with different melting temperatures, and simulate various melting points of phase change materials in this layer.

PCM Melting Point	Cooling kWh	Cooling %	Heating kWh	Heating %
Without PCM	17012.25	-	945.02	-
PCM18	16938.01	-0.43	915.57	-3.21
PCM21	16942.15	-0.41	916.92	-3.06
PCM23	16958.68	-0.31	918	-2.94
PCM25	16979.41	-0.19	917.94	-2.95
PCM29	17015.34	0.018	918.25	-2.91

Tab.11- The degree of influence of the melting point of the PCM in heating and cooling

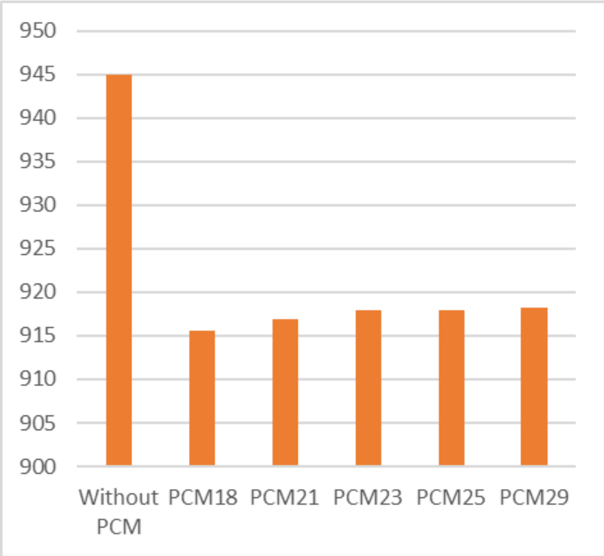

Fig.15- The effect of the location of the phase change material in heating

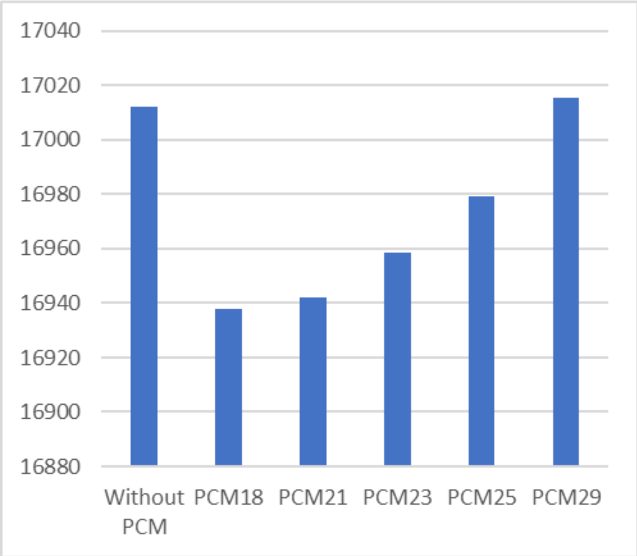

Fig.16- The effect of the location of the phase change material in cooling

According to the numbers obtained from the simulation of various phase change materials with different melting points in Table 11 and the graphs in Figures 15 and 16, which were examined in 5 states of the melting point of phase change materials, it can be concluded that PCM18 has the best effect compared to the state without phase change materials in relation to cooling and heating. So that in both the cooling and heating states, the greatest effect is in the same phase change material and then it follows an upward trend, in which the slope of this rise is high in cooling and less in heating, the percentage of effect in heating was about 3.21 and in heating was about 0.43.

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Thickness	Cooling kWh	Cooling %	Heating kWh	Heating %
6mm	16938.01	-0.43	915.57	-3.21
12mm	16878.72	-0.79	858.94	-10.02
18mm	16837.07	-1.04	798.77	-18.30
24mm	16809.21	-1.20	757.52	-24.75
30mm	16787.78	-1.20	735.96	-28.40
36mm	16775.55	-1.33	725.35	-30.28

Tab.12- The effect of the thickness of the PCM on heating and cooling

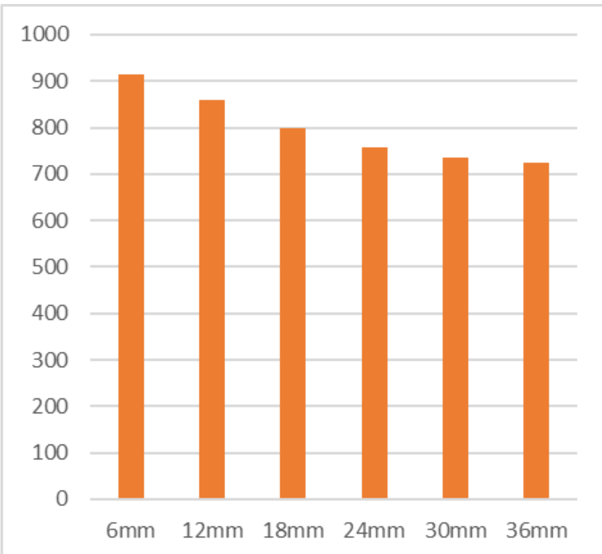

Fig.17- The effect of the location of the phase change material in heating

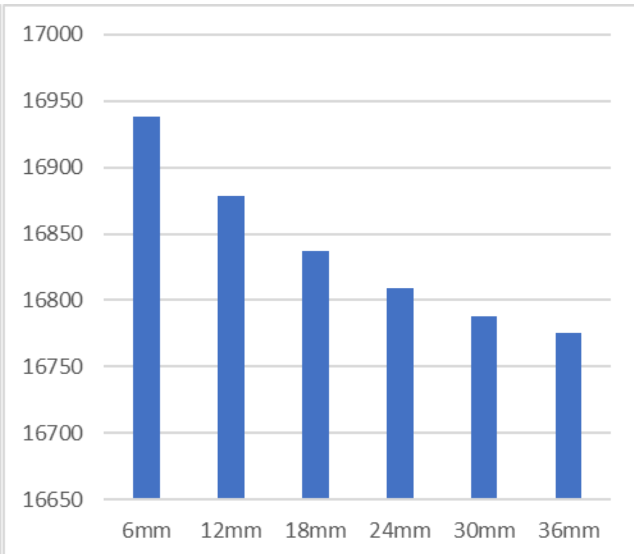

Fig.18- The effect of the location of the phase change material in cooling

By examining the numbers obtained from the simulation in Table 12 and the graphs in Figures 17 and 18, it was shown that increasing the thickness of the phase change materials, both in cooling and heating, has a very positive effect on reducing the heating and cooling consumption of the building, in such a way that there is a difference of about 27% in heating and about 1% in cooling between the 6 and 36 mm states. We also saw a difference of about 30% in heating and 1.33% in cooling compared to the state without phase change material.
3- Interior wall:

Tab.13- Simulated materials along with their thickness and conductivity

Type of materials	Conductivity (W/m-k)	Thickness(cm)	Specific heat (J/kg-k)
Gypsum board	0.250	2.5	1000
Air layer	-	10	-
Gypsum board	0.250	2.5	1000

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Fig.19 Interior Wall detail from Design Builder

After drawing all the details of the interior wall in Design Builder, a default phase change material was taken as in the previous sections. The default phase change material from Infinite R had a melting point of 18 degrees and a base thickness of 6 mm.

Placement layer	Cooling kWh	Cooling percentage	Heating kWh	Heating percentage
Without PCM	17012.25	-	945.02	-
First layer	16576.74	-2.62	1672.69	43.50
Second layer	16589.39	-2.54	1699.87	44.40

Tab.14- The effect of the location of the phase change material on inner wall of heating and cooling

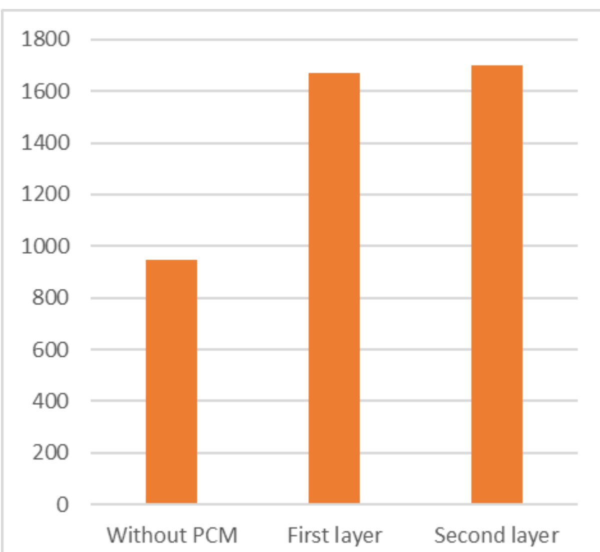

Fig.20- The effect of the location of the phase change material in heating

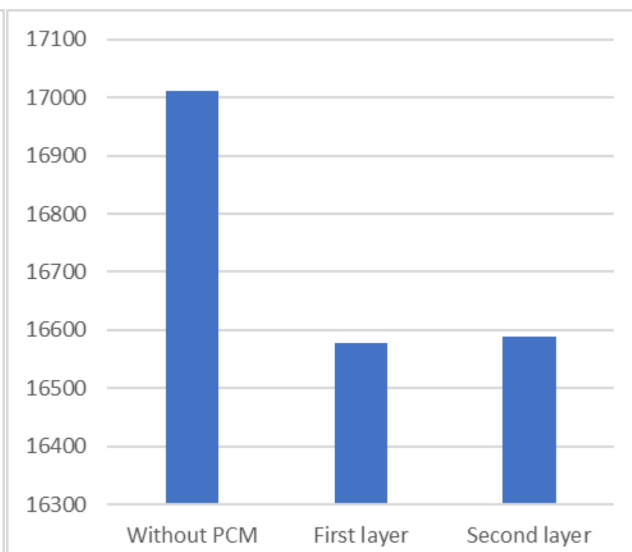

Fig.21- The effect of the location of the phase change material in cooling

According to the simulation results of phase change materials in the wall layers, which are given in Table 14 and the graphs in Figures 20 and 21, we see a positive effect in cooling in the first and second layers, and

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this effect is slightly greater in the first layer, so that we have a consumption reduction of about 2.6% in the first layer and about 2.5% in the second layer. On the other hand, in heating, however, phase change materials show an opposite effect in reducing consumption, so that we see an increase of 43% in the first layer and 44% in the second layer.
Now, knowing the best location on the inner wall, we begin to simulate phase change materials with different melting temperatures, and simulate various melting points of phase change materials in this layer.

PCM Melting Point	Cooling kWh	Cooling %	Heating kWh	Heating %
Without PCM	17012.25	-	945.02	-
PCM18	16576.74	-2.62	1672.69	43.50
PCM21	15994.41	-6.36	926.91	-1.95
PCM23	15646.79	-8.72	517.3	-82.6
PCM25	15780.49	-7.80	335.21	-181.91
PCM29	17724.99	4.02	761.24	-24.14

Tab.15- The degree of influence of the melting point of the PCM in heating and cooling

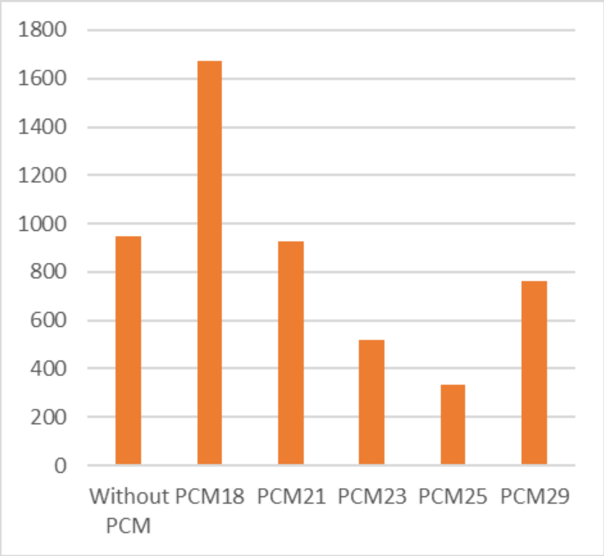

Fig.22- The effect of the location of the phase change material in heating

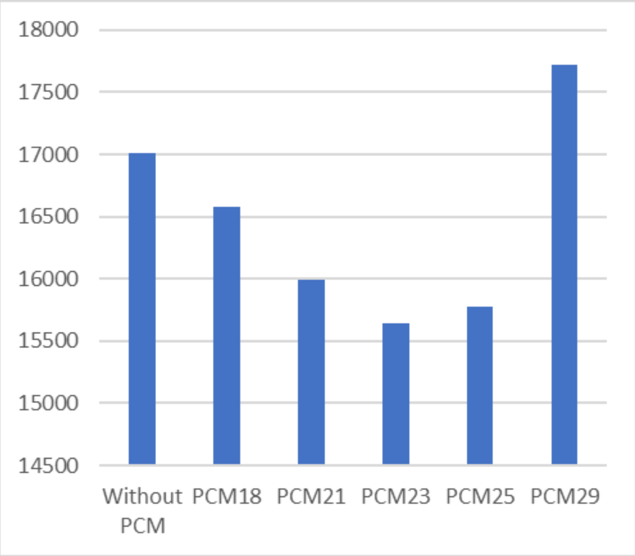

Fig.23- The effect of the location of the phase change material in cooling

According to the numbers obtained from the simulation of various phase change materials with different melting points in Table 15 and the graphs in Figures 22 and 23, which were examined in 5 cases of the various melting points of phase change materials, it can be concluded that PCM25 has the best effect in relation to cooling and heating compared to the case without phase change materials. In heating with PCM18, we first encounter an increase in energy consumption, but then in the next phase change materials we encounter a decrease in consumption, so that in PCM25, which has the best performance, we have a 181% reduction in consumption. On the other hand, in cooling, we encounter a decrease in consumption from the beginning, except for PCM29, which has the opposite performance in this regard. Now we will examine the types of PCM25 thicknesses.

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Thickness	Cooling kWh	Cooling %	Heating kWh	Heating %
6mm	15780.49	-7.80	335.21	-181.91
12mm	15798.03	-7.68	282.98	-233.95
18mm	15744.49	-8.05	238.98	-295.43
24mm	15669.16	-8.57	222.7	-324.34
30mm	15619.43	-8.91	209.08	-351.98
36mm	15561.01	-9.32	198.98	-374.93

Tab.16- The effect of the thickness of the PCM on heating and cooling

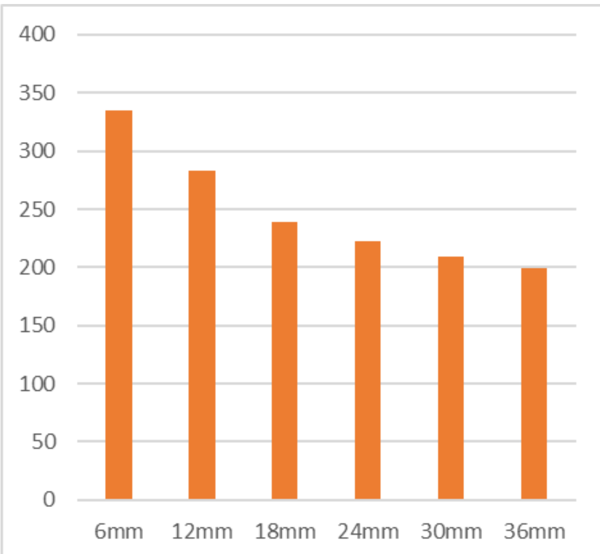

Fig.24- The effect of the location of the phase change material in heating

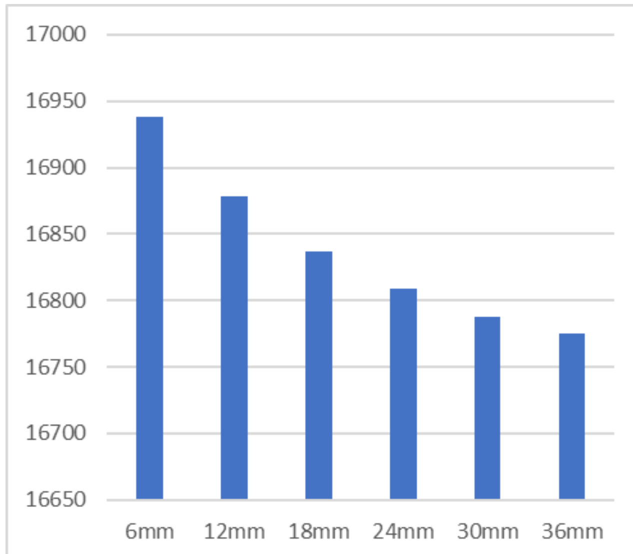

Fig.25- The effect of the location of the phase change material in cooling

By examining the numbers obtained from the simulation in Table 16 and the graphs in Figures 24 and 25, it was shown that increasing the thickness of phase change materials, both in cooling and heating, has a very positive effect on reducing the heating and cooling consumption of the building. With these materials, we see a difference of about 374% in heating and 9.3% in cooling compared to the state without phase change materials.

4-Floor:

Type of materials	Conductivity (W/m-k)	Thickness(cm)	Specific heat (J/kg-k)
Urea Formaldehyde Foam	0.400	13.27	14000
Concrete	1.130	10	1000
Floor Layer	0.410	7	840
Wooden Flooring	0.140	3	1200

Tab.17- Simulated materials along with their thickness and conductivity

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Fig.26 Roof detail from Design Builder

After drawing all the floor details in Design Builder, a default phase change material was taken, as in the previous --sections. The default phase change material from Infinite R had a melting point of 18 degrees and a base thickness of 6 mm.

Placement layer	Cooling kWh	Cooling percentage	Heating kWh	Heating percentage
Without PCM	17012.25	-	945.02	-
First layer	17034.26	0.129	979.86	3.55
Second layer	16999.86	-0.072	1007.59	6.20
Third layer	16953.91	-0.34	1076.79	12.23

Tab.18- The effect of the location of the phase change material on floor of heating and cooling

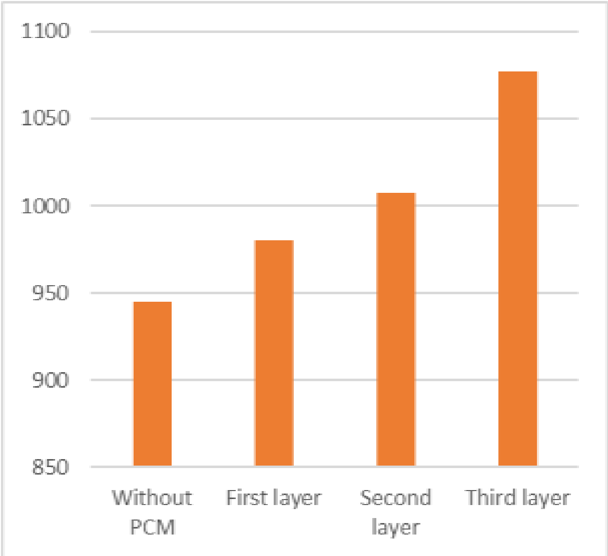

Fig.27- The effect of the location of the phase change material in heating

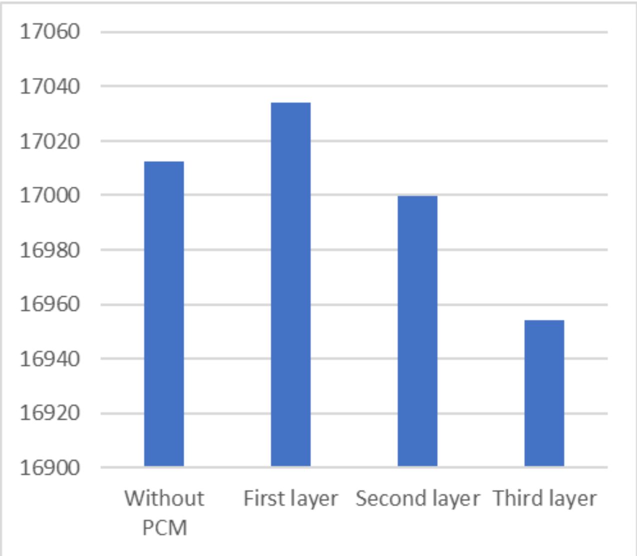

Fig.28- The effect of the location of the phase change material in cooling

Now, knowing the most appropriate location relative to the others in the floor, we begin to simulate phase change materials with different melting temperatures, and simulate various melting degrees of phase change materials in this layer.

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PCM Melting Point	Cooling kWh	Cooling %	Heating kWh	Heating %
Without PCM	17012.25	-	945.02	-
PCM18	17034.26	0.12	979.86	3.55
PCM21	16943.22	-0.40	957.76	1.33
PCM23	16905.89	-0.62	894.34	-5.66
PCM25	16875.65	-0.80	915.7	-3.20
PCM29	16969.02	-0.25	932.94	-1.29

Tab.19- The degree of influence of the melting point of the PCM in heating and cooling

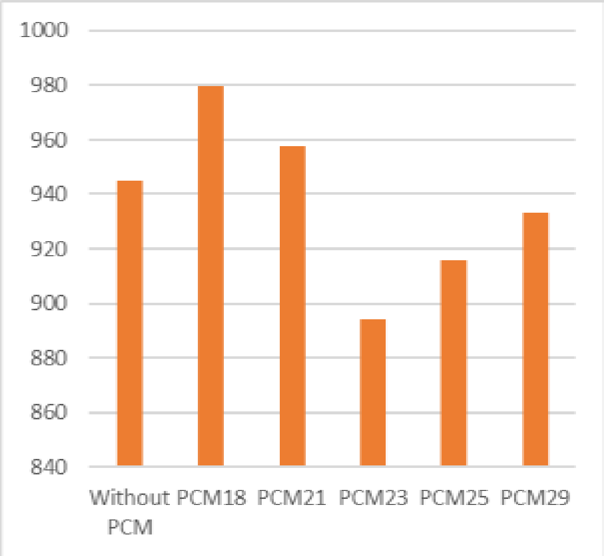

Fig. 29- The effect of the location of the phase change material in heating

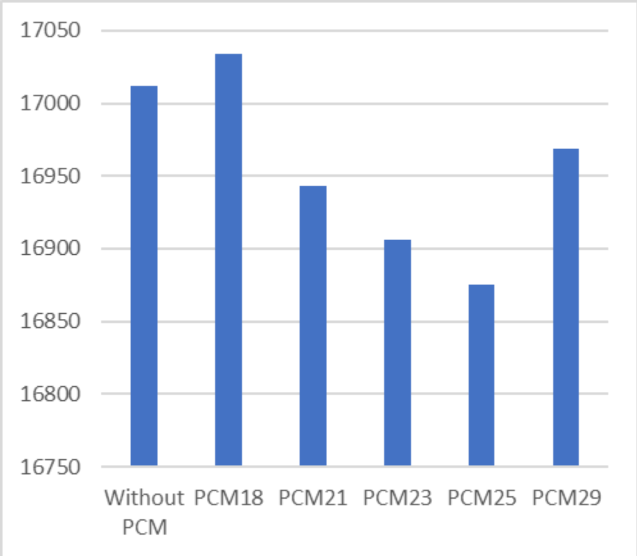

Fig.30- The effect of the location of the phase change material in cooling

According to the numbers obtained from the simulation of various phase change materials with different melting points in Table 19 and the graphs in Figures 29 and 30, which were examined in 5 cases of the various melting points of phase change materials, it can be concluded that PCM23 has the best effect in relation to cooling and heating compared to the case without phase change materials. In heating with PCM18, we first encounter an increase in energy consumption, but then in the next phase change materials we encounter a decrease in consumption, so that in PCM23, which has the best performance, we have a 5.6% reduction in consumption. On the other hand, in cooling, we first encounter an increase in consumption and then the graph takes a downward trend. Now let's examine the types of PCM23 thicknesses.

Thickness	Cooling kWh	Cooling %	Heating kWh	Heating %
6mm	16905.89	-0.62	894.34	-5.66
12mm	16844.41	-0.99	870.07	-8.61
18mm	16801.37	-1.25	860.63	-9.80
24mm	16773.17	-1.42	853.84	-10.67
30mm	16743.23	-1.60	851.25	-11.015
36mm	16709.16	-1.813	848.95	-11.31

Tab.20- The effect of the thickness of the PCM on heating and cooling

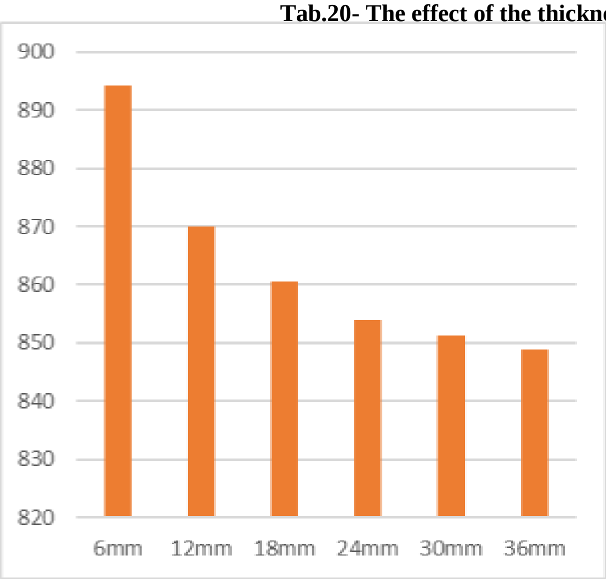

Fig.31- The effect of the location of the phase change material in heating

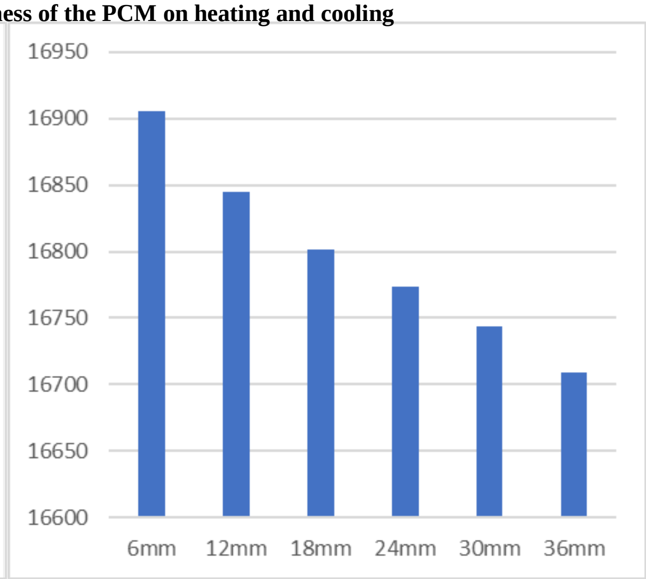

Fig.32- The effect of the location of the phase change material in cooling

By examining the numbers obtained from the simulation in Table 20 and the graphs in Figures 31 and 32, it was shown that increasing the thickness of the phase change materials, both in cooling and heating, has a very positive effect on reducing the heating and cooling consumption of the building. With these materials, we see a difference of about 11.3% in heating and 1.8% in cooling compared to the state without phase change materials.

4-Conclusion:

In this study, the energy consumption of the Hamedan School of Architecture building was simulated using Design Builder software based on Energy Plus in order to investigate the effect of phase change materials as insulation on the external wall of this building in Tehran. For this purpose, in the simulation of the building section in Design Builder, an attempt was made to determine the daily, weekly and monthly schedule of the building. Then, the details of the external wall, roof, internal wall and floor of the building were simulated, and then, by adding phase change materials to each layer of these building components, it was determined which is the best layer for placing these materials for each. Then, in the most appropriate layer, the different melting points available on the market, which are 18, 21, 23, 25 and 29, were simulated and it was determined which is the best type of phase change material for each section that has a good effect on both cooling and heating. In the final stage, considering the best layer and the best melting point, the best thickness was determined. We found that as the thickness of the phase change material layer increases, the effect of these materials increases. With a 36 mm heating and cooling layer, we had a suitable reduction in energy compared to the case without using these materials.

Part of the building	Cooling kWh	Cooling %	Heating kWh	Heating %
No pcm	17012.25	-	945.02	-
External wall	15548.88	-9.41	522.48	-80.87
Roof	16775.55	-1.33	725.35	-30.28
Interior wall	15561.01	-9.32	198.98	-374.93
Floor	16709.16	-1.813	848.95	-11.31

Tab.21- The highest impact rate of each component

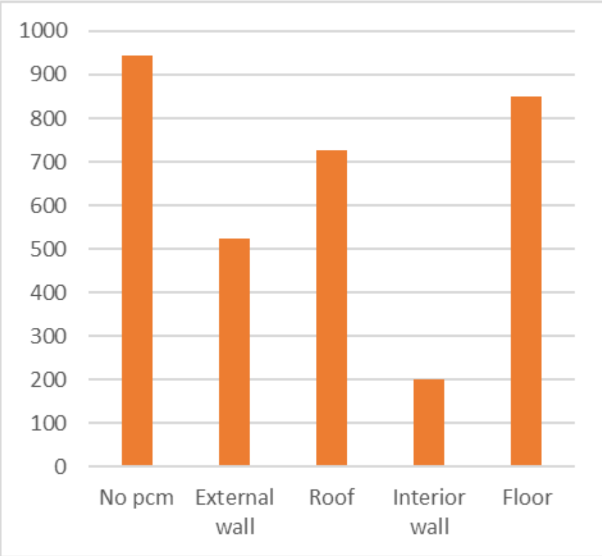

Fig.33- The effect of the location of the phase change material in heating

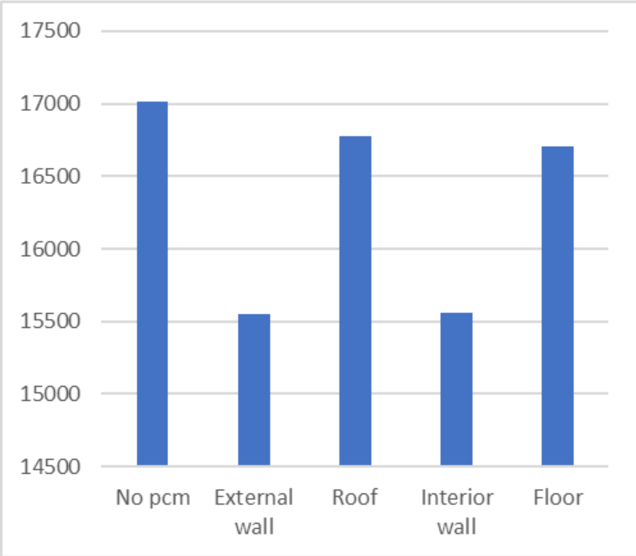

Fig.34- The effect of the location of the phase change material in cooling

As is clear from the results of Table 21 and the figures in Figures 33 and 34, the highest effect on heating is in the inner wall, outer wall, ceiling and then the floor. The effect of the outer wall was very significant in this case, but in cooling, the outer wall, inner wall, floor and finally the ceiling had the highest effect. So it can be concluded that by insulating and using phase change materials in the inner and outer walls, the highest energy consumption reduction can be achieved in an economic sense.

Also, based on the results obtained in which this part of the building was simulated in 55 different cases, and taking into account the current energy needs and crisis, it can be said that because these materials are harmless to nature and have a long lifespan, and because they have a low risk of decay and deterioration due to their structure; by using these materials extensively in the energy consumption of buildings, which account for a relatively high percentage of energy consumption, appropriate results can be achieved in saving fuel and energy consumption.

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