Chapter 3

The Impact of Utilizing Phase Change Material As Insulation Material on Building Energy Performance and Fuel Costs

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Abstract

In this study, the impact of wielding phase changing material behalf standard insulation material on building thermal performance and fuel cost was evaluated. In this context, two materials with different thermal conductivity coefficients were applied to the outer shell of the building and the results were compared. From these materials, the thermal conductivity coefficients for the classical insulation material and the phase changing material are respectively; 0.035 W/mK and 0.2 W/mK. The EES program was used in the numerical calculations carried out to review the contribution of the phase changing material applied to the structural crust the building energy performance and fuel cost. The action of the phase changing material used on the building energy productivity has been analyzed for the provinces of Antalya and Ankara, which are located in the first and third degree climate zones in Turkey. In the continuation of this paper, the impact of phase change material, which is preferred for insulation in buildings, on fuel performance was investigated. For this purpose, the analyzes were carried out for the provinces of Istanbul and Erzurum in Turkey. The total fuel cost changes for the reference building used in the study were determined and the amount of energy savings that could be achieved in a year were determined. As a result,

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it has been determined that the utilize phase change materials as insulation material in the structure reduces building fuel costs and raises energy savings for all climate zones.

1. Introduction

Increasing energy demand has caused pollution and climate change problems by quickly dispose of fossil fuels (Thirugnanasambandam et al. 2010, Wang et al. 2020). One of the main reasons for this situation is that industrialization and fossil fuel utilize have geratly increased CO_2 production and therefore greenhouse gas emissions. Due to the increasing CO_2 production, the effect of global warming has accelerated, causing risks such as melting glaciers and acid rain in many parts of the world. For these reasons, minimizing CO_2 production is of great importance. Reducing fossil fuel consumption is among the basic methods in the studies aimed at reducing this situation. Because most of the CO_2 emissions are fossil fuels. Therefore, in recent years, minimizing fossil fuel consumption in order to reduce CO_2 emissions and energy consumption is among the popular work topics (Yang et al. 2022). The main condition for economic development and prosperity is the availability of energy (Nair et al. 2022). Recent studies show that buildings state for approximately forty percent of the world's energy wielding. For this reason, buildings are as responsible for the increase in greenhouse emissions and global warming as other consumption sectors (Esbati et al. 2019, Aridi et al. 2021). In order to respond to the increasing energy request, renewable energy systems have emerged. So that, both contributing to the prevention of the consume of naturel sources and contained and alternative energy systems have been advanced. However, there are some limitations such as the applications related to renewable energy systems not having high efficiency in every region and not being effective in every periods. Therefore, energy storage systems have emerged to provide energy efficiency and energy savings (Al-Yasiri and Szabo 2021, Yehya and Naji 2015). Energy storage systems provide the advantage of storing excess energy at once and using it when needed. In this way, a balance is created between energy demand and demand and an economic recovery is achieved (Pavlov and Olesen 2011). Phase changing materials are giant importance so thermal energy applications because of their advanced power stowage capabilities, longevity and flexible operating temperatures (Nair et al. 2022). For this reason, the preference of phase changing material at structures to provide isolation has been among the current issues and many studies have been carried out on this subject.

Rahim et al. 2022 examined the change in terms of economy and conveniences caused by the utilization of phase changing materials in structures located in hot climate regions. They explorationed research on the activity of phase changing materials to increase thermal suitability in different weather conditions for buildings with different wall properties. First, they developed a simulation model. Afterwards, the results were confirmed by an experimental study performed outdoors. Within the scope of the study, six different materials with phase change feature were examined for the summer season. The melting temperature of these mentioned materials varies between 21°C and 31°C. As a result of the analysis, it was determined that the utilizing phase changing material in moderate climate conditions provides thermal convenience and is the right choice.

Feng et al. 2022 underlined that phase changing materials with thermal energy holding feature are gaining importance in building efficiency studies day by day. In the study, they aimed to advance a shape that can accurately modelling hysterical behavior with the choice of phase changing materials in the structure outer crust. The suitability of the two phase design during a complete phase transition was determined by comparing the computational and empirical results. In addition, models were performed on purpose examine the activity of the region referring average weather temperature and heating/cooling loads. As a result, it was observed that there was less than 1% difference in the one hour heating/cooling load, and significant improvements were observed in the region average air temperature as well as the heating/cooling loads in the phase change interval.

Imafidan and Ting observed the change in energy depletion of a structure with different thicknesses of phase changing materials on its walls. In the study, honeycomb phase changing material was placed on the walls of a renovated structure in Canada. By giving information about the climatic conditions of the study area and giving the information that -14°C air temperatures are effective in winter months, the different thicknesses of the phase change material layer and its effectiveness were investigated. As a result, it has been determined that the application of 1 cm thickness phase changing material to the building wall provides the optimum activity for the summer months, where the outdoor temperature varies between 15 - 26.5 °C. Finally, it has been observed that there is no improvement in the efficiency when the phase changing material thickness is exceeded 1 cm and the thermal capacity is exceeded 20 $kJkg^{-1}K^{-1}$.

Lie et al. 2022 stated that 60% of the energy missings from sutructures are due to warming and ventilation systems. It was further emphasized that this would further increase global warming. It has been underlined that phase change materials are of great importance on purpose overcome the mentioned trouble. Scope of work, the coupling technology of bio-based phase change materials was examined and some important conclusions were drawn by comprehensively scanning the existing literature and some problems that need to be investigated further were brought to the agenda.

Khan et al. 2022 researched the impact of phase change material applications to minimize energy losses from residential buildings. In the content of the study, energy performances for sutructures in five big towns where distinct climatic conditions are dominant in the Pakistan region are numerically discussed. First of all, fifteen different phase change materials were evaluated for a one-room house. As a result, 40 mm thick phase change material with a melting heat of 24 °C was the most ideal choice. Afterwards, phase change material application was integrated into multi storey residential areas. The monthly average energy savings were 44.9%, 35%, 32%, 35% and 49.6% for single-storey houses, respectively. Energy savings of at least 12% and maximum 21.4% were provided in two storey residences. In addition, the payback periods and economic feasibility of using phase change materials in sutructures were examined. Consequently all these researches, it was determined that three of the five houses examined were economically suitable so the utilize of phase change materials, and two were not.

Studies on the practise of phase changing materials to enhance energy savings in concrete structures have recently gained acceleration. Drissi et al. 2020 investigated the thermal performance on concrete platte containing phase changing material aggregates planned for utilizing buildings. The concrete panel in the study stores solar energy. Within the scope of the study, research was realised for space warming and refrigeration applications in order to prevent phase changing materials leakage, which reduces efficiency. They observed the effect of developing new clusters of phase changing materials with core-shell structure to store the energy provided by solar radiation in building walls. The obtained consequences demonstrated that the leakage of phase changing material was significantly prevented and the thermal productivity of concrete panel enhanced. As a suggestion, it is stated that the results will be more effective if another phase change material with the suitable phase change temperature is used.

Nematchoua et al. 2020 examined an office building in respect to thermal comfort and chilling power requirement. For this, they discussed phase changing material applications in thermoinsulation and exterior shadowing.

As a result, it has been observed that the prefered of phase change material in insulation reduces chilling energy consumption by 12% and increases the comfort rate by 3% in three climate zones.

Hasan et al. 2018 experimentally examined the insulation made using phase changing material in their study. Within the scope of the study, two separate rooms were constructed using standard and phase changing materials. Paraffin with a melting temperature of 44 °C was preferred as the phase change material. The results were analyzed separately for two separate rooms and for all wall directions considered. As a result, it has been determined that electricity consumption is saved by reducing the heating load with the insulating material with phase changing material added.

In the present study, phase change material is preferred instead of insulation material for a concrete structure. For the sample building used as a reference, energy performance analyzes were carried out in the first and third degree climatic regions. Also, the influence of using phase changing material in the structure crust for insulation purposes on fuel performance was investigated. Natural gas and coal cost analysis actualized for the provinces located in the second and fourth degree day regions of a reference building.

2. Materials and Methods

2.1. The Building

The dimensions of the building, which is taken as a reference within the scope of the study, are as follows: 15.98 m long, 8.21 m wide and 12.32 m high. The aforecited building has been analyzed by comparing the fuel performances for the provinces of Istanbul and Erzurum. Among these provinces, Istanbul is in the second degree climate zone, while Erzurum is in the fourth degree climate zone. In addition, the climatic conditions of the fourth region have heavy continental climate conditions, while the second region is more temperate.

Energy performance analyzes of the structure were carried out for the provinces of Antalya and Ankara. Antalya province is in the first degree climate zone and has temperate climatic conditions. Ankara province is located in the third degree climate zone and continental climate conditions prevail in the region.

2.2. Phase Changing Material

Phase changing material variances phase by taking a certain amount of heat. The heat that causes a substance to change phase is called latent heat.

But when the process is reversed, if the substance is pure, the heat taken earlier is released isothermally. Basic conditions for substances to be used as phase changes materials include stability in the phase change and little change in the volume of the substance. Phase changing materials are widely used in several building materials to decrease the heating and refrigeration charge of structures, to prevent overheating of electronic devices, in the textile industry and in areas such as food transport (Çevik 2012). Pesent working, the use of RT-9HC phase changing material was preferred for insulation purposes. The thermophysical properties of the material with a coefficient of thermal conductivity 0.2 W/mK are shown in Table 1. In the calculations made within the scope of the analysis, it is assumed that the thermophysical properties specified in the table do not change depending on the temperature and that all the energy storaged all day will be used all night. While making these calculations, monthly sunshine durations are taken as a basis for each region separately.

Table 1. Thermophysical properties of RT-9HC material (Bilgin, 2017)

RT-9HC	
Thermal conductivity k (W/mK)	0.2 (solid-liquid)
Density ρ (kg/m^3)	880 (solid) 770 (liquid)
Specific heat c_p (J/kgK)	2000 (solid-liquid)
Melting temperature Tm (°C)	-9
Heat of melting L_H (kj/kg)	250

2.3. Calculation Methods

In response to the need to minimize the losses arising from the building envelope, thermal insulation applications have emerged. In this way, besides providing thermal comfort, it is possible to save energy. Studies in this field are of great importance on purpose increase energy productivity and ensure sustainability (Ustaoglu et al. 2020). In this study, the processes to perform the energy performance analysis were made using the Engineering Equations Solver (EES) program. Within the context of analysis, the provinces of Antalya and Ankara, which are located in the first and third degree climate zones, were discussed. The change in annual energy performance was observed with the use of phase changing material rather than heat insulation material. For the polyurethane and phase changing material used in the analysis, the thickness was changed in the range of 0-0.1 m and included in the calculations.

The general equations used in the study are Eqs. 1-2-5 (Çengel and Ghajor 2015), Eqs. 3-4 (TS 2008) as shown below. The amount of heat energy transfer:

$$\dot{Q} = \frac{\Delta T}{R} = \frac{T_{in} - T_{amb}}{\frac{1}{h_{in}As} + \sum_{i=1}^{i=n} \frac{d_i}{k_i As} + \frac{1}{h_{out}As}} \tag{1}$$

Where T_{in} stands for indoor temperature while T_{amb} stands for ambient temperature. *d* represents the thickness of the components (m) and *k* is the thermal conductivity (W/mK). h_{in} is the convective heat transfer coefficient for the case of inner side and h_{out} is the convective heat transfer coefficient for exterior of the analyzed structural component. R is the thermal resistance (m^2K/W) and can be defined as:

$$R = \frac{1}{h_{in}} + \frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \cdots + \frac{1}{h_{out}} \tag{2}$$

Where d_1, d_2 and d_3 are refers to thickness of the building components (m). h_{in} is the convective heat transfer coefficient for the case of inner side, h_{out} is the convective heat transfer coefficient for exterior surfaces (W/m^2K) and *k* is the thermal conductivity coefficient (W/m^2K).

$$H = H_T + H_V \tag{3}$$

The expression *H* shown in Equation 3 represents the total specific heat loss (W/K). H_T represents the heat loss due to conduction and convection (W/K). H_V is the heat loss through ventilation (W/K) and can be calculated as follows:

$$H_V = \rho c V' \tag{4}$$

where ρ is intension of air (kg/m^3), c is specific heat of the air (J/kgK) and V' is volumetric air change (m^3/h).

In order to find the annual heating energy need, all months are added and calculated as follows:

$$\dot{Q}_{annual} = \sum_{i=1}^{i=12} \dot{Q}_{i,m} \quad (5)$$

where $\dot{Q}_{i,m}$ is indicates the heat requirement for each month.

Total heat requirement can be calculated as follows:

$$P = \frac{\dot{Q}_{an}}{NPV} c \quad (6)$$

P is the fuel cost ($) and c is the unit price of fuel ($/m3, $/tonne or $/kWh). The amount of annual fuel excise (N.m3, kg or kWh) can be calculated as the ratio of annual heat requirement to the net calorific value of the fuel.

3. Results and Discussions

The consequences of the analysis made within the scope of the study are included in this chapter. A one year energy performance review for the first and third degree climate zone was calculated in the Engineering Equations Solver (EES) program. The result graphs below were created in the light of these data.

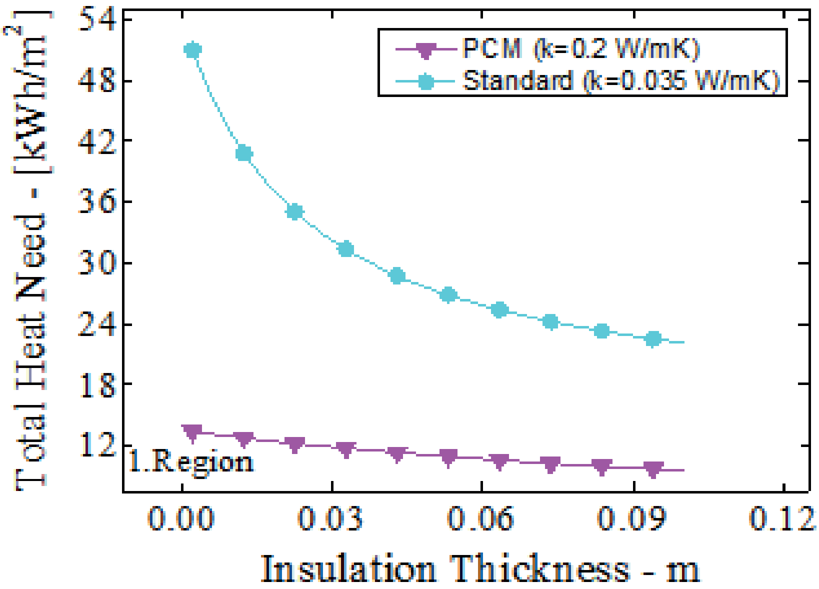

Figure 1. Variation in total heat need for region 1 based on change in the insulation thickness

Figure 1 shows the alteration in a year sum heat requirement of Antalya city depending on the utilize of phase changing materials for insulation purposes. When phase change material is used instead of insulation material in the building, an annual decrease of 74.92% was observed in the total heat requirement. Figure 2 demonstrates the variance of the yearly total heat requirement for Ankara. It is understood from the graph that there is an 82% decrease in the total heat requirement when phase changing material is used to provide insulation in the building. One of the main reasons for the higher savings in the 3rd region is the greater need for heat in the region due to the continental climate. These calculations assume that the phase change material stores the energy during the insolation period and uses the energy stored during the night.

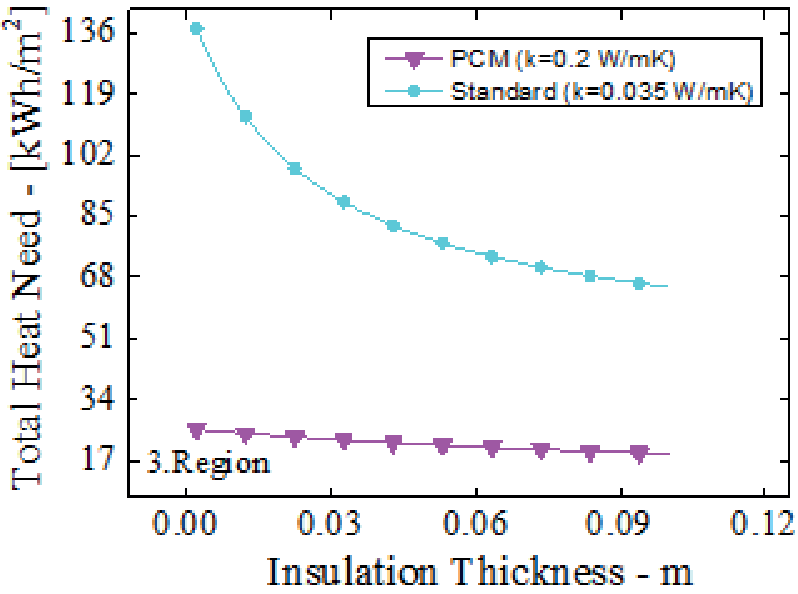

Figure 2. Variation in total heat need for region 3 based on change in insulation thickness

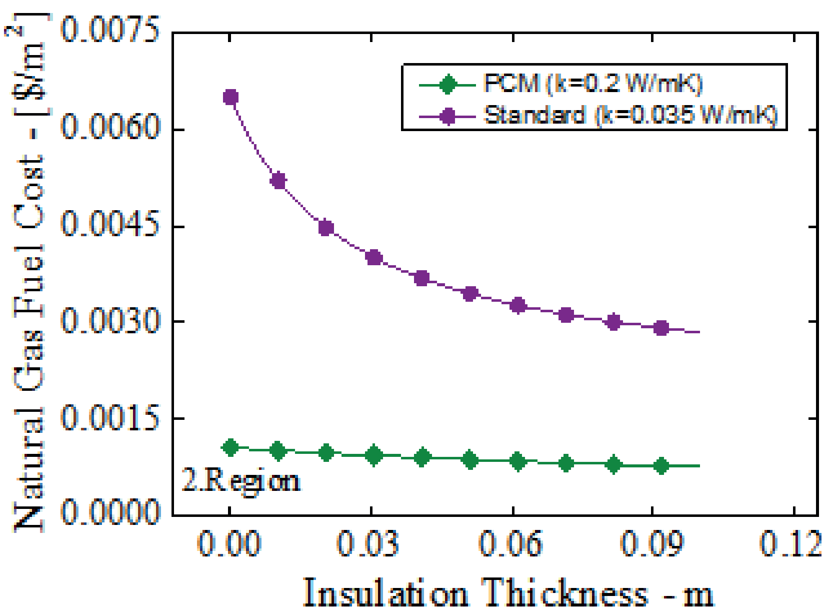

Figure 3. Variation in natural gas fuel cost for region 2 based on change in insulation thickness

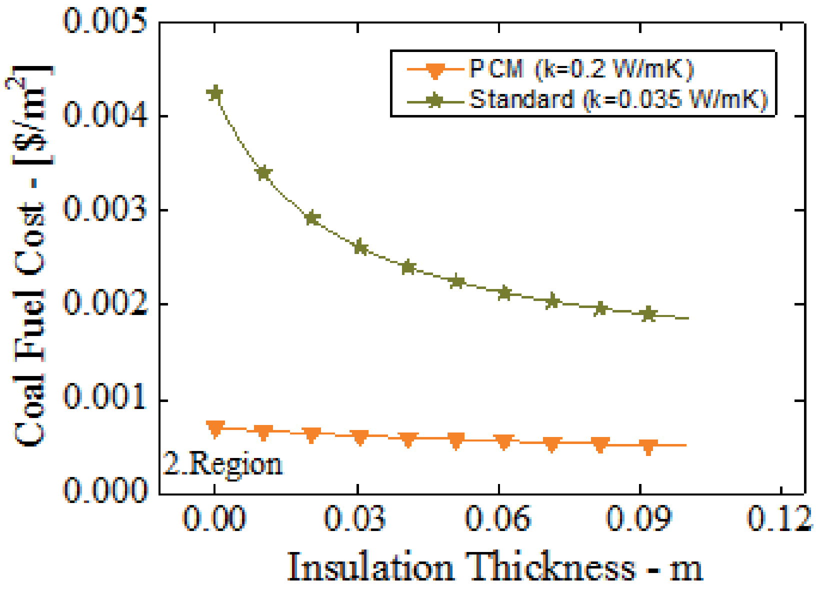

Figure 4. Variation in coal fuel cost for region 2 based on change in insulation thickness

Figure 3 and Figure 4, one year natural gas fuel cost and coal fuel cost of Istanbul province are shown, respectively. As can be seen from the graphics, an 83.5% reduction in annual fuel costs was observed when phase change material was used as insulation material instead of standard insulation material in the building. While making these calculations, it is assumed that the phase change material stores the energy during the sunshine period and uses the energy it has stored during the night.

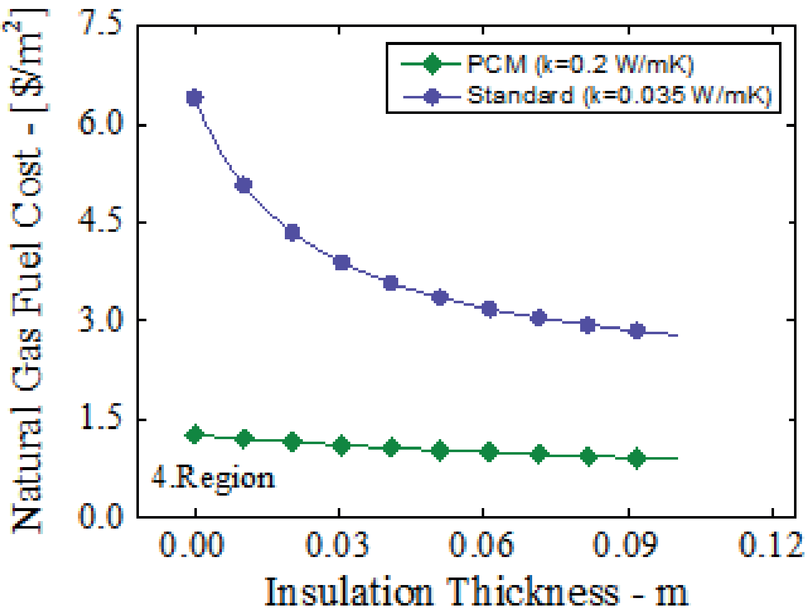

Figure 5. Variation in natural gas fuel cost for region 4 based on change in insulation thickness

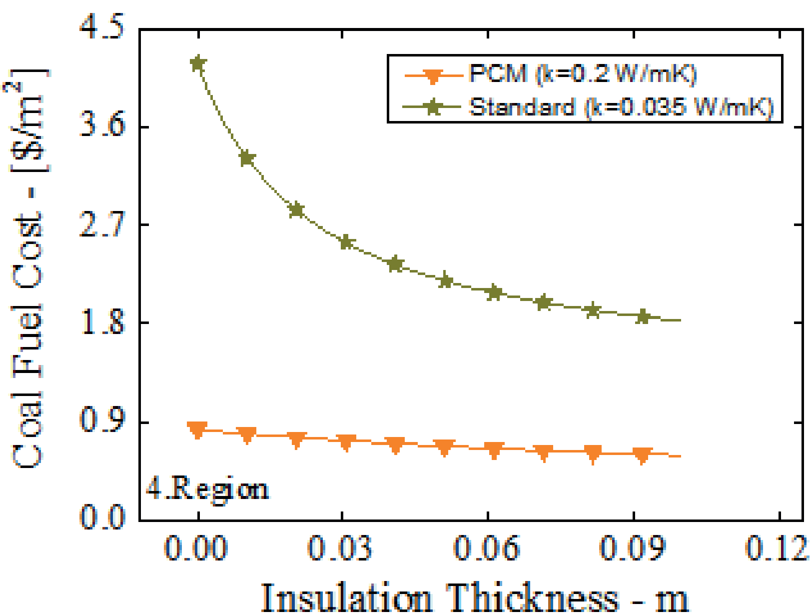

Figure 6. Variation in coal fuel cost for region 4 based on change in insulation thickness

Figure 5 represents the annual change in natural gas fuel cost in Erzurum, and Figure 6 represents the change in annual coal fuel cost. It is clearly seen that it is more economical in all insulation thicknesses when phase change material is preferred instead of standard insulation material in the building. In addition, while there was an 80.14% reduction in the one-year natural gas fuel cost, there was a 80.13% reduction in the one-year coal fuel cost. Since Erzurum is a region with a heavy continental climate, these savings are very important.

4. Conclusions

With the increase in the standard of living, urbanization has also accelerated. Therefore, the need for energy has increased day by day. Nearly 40% of the sum energy depletion originates from the construction sector. Most of the energy losses in the building sectors are due to heating and cooling applications. For this reason, it is aimed to reduce energy depletion by providing the thermal suitability condition. The utilizing phase changing materials in structures is an emerging technology to provide both thermal suitability and energy savings (Suresh et al. 2022). In this scientific study, the cruciality of insulation applications, which are widely used in the building sector, was highlighted and the variation of the total heat requirement for the provinces of Antalya, Ankara has been examined. Also, fuel cost analyzes were made for the provinces of Istanbul and Erzurum. The base consequences of the study can be sum up as follows:

- Preventing heat losses from buildings not only reduces energy consumption and costs, but also provides environmental benefits by reducing greenhouse emissions.
- Providing heat insulation techniques in buildings is not only important in continental climatic regions, but also in warm climatic regions where the walls are exposed to high solar radiation values.
- Studies on thermal insulation materials that are harmless to the environment and have higher performance have gained momentum in recent years. In this context, many studies are carried out on the technique of thermal insulation with phase change materials.
- Phase changing materials, which are frequently mentioned in studies on energy efficiency in the literature, have been preferred in buildings in order to save energy by making use of their storage properties.
- The phase changing material proposed for insulation purposes in the study was applied in the reference building placed in the primary and

third degree day regions. Consequently, the total heat requirement has been greatly reduced and thus energy efficiency has been achieved.

- In this paper, the phase change material, which is preferred for insulation purposes, applied instead of insulation material for a sample building in the second and fourth degree day regions. Consequently, essential findings have been reached with regard to both providing thermal comfort and energy saving.
- Present study, it has been observed that if phase change material is used instead of standard insulation material, it is inevitable to save energy both in terms of thermal insulation and fuel costs.
- Obviously seen in the analysis consequences that the utilizing phase change materials provides significant conservation in both natural gas and coal fuel costs for both regions is clearly seen in the results of the analysis.
- It is clearly seen in the analysis results that the utilize of phase changing material provides significant conservations in annual heat requirement for both regions.
- Finally, commercially common phase change materials such as paraffin are mostly included in the literature. Instead, it will be very helpful to examine the thermal performance of distinct phase changing materials such as salt hydrates and to analyze them for building applications.

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