Simulation of PCM storage in flat plate water heater structure in buildings under different weather conditions

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Abstract:

Nowadays, the use of phase change materials is very important to reduce energy consumption in buildings and industry structures. The use of phase change materials in the structure of buildings will be widely used in the near future. Because the presence of these materials in the building structure, such as the use in water heater cultures, will reduce the consumption of fossil energy.Phase change materials (PCM) store thermal energy in the latent heat method. These materials have a high thermal storage density and with small temperature changes, they provide an important role in saving energy and thermal insulation in the building. Materials naturally delay the transfer of heat to the building by several hours due to the reduction of indoor air temperature fluctuations and the room air temperature remaining close to the desired room temperature for a longer period of time. In order to recover heat or cold, the storage method is used. In general, there are two types of thermal energy storage systems during physical processes:1- Storage of sensible thermal energy ,2- Latent thermal energy storage. In this article, we investigated the use of phase change materials in the solar collector installed in the building. In this article, Ansys Fluent software is used for simulation. The amount of solar radiation in Iran is estimated between 1800 and 2200 kilowatt hours per square meter per year, which is higher than the world average.

Keywords: Renewable energy, Phase Change Materials, Ansys Fluent, buildings, structure

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Introduction

Phase change materials will reduce energy consumption in the structure of buildings.Today, the use of renewable energy is developing at a remarkable rate. Researchers around the world believe that energy should be extracted from oil and supplied through renewable energy sources such as hydropower, wind, and solar. On the other hand, the challenge that researchers face is storing energy in the right shape. This leads to the storage of surplus energy and makes the system more economical by reducing energy waste and capital costs [1] Various methods for storing renewable energy can be named, among which the storage of latent thermal energy is more important due to the ability to create high-density energy storage and energy storage properties at a constant temperature. The materials that conserve energy in this way are called phase change materials.

Phase change materials in building structure

Buildings account for 40% of total global energy consumption, which is responsible for 38% of greenhouse gas emissions. Increasing the energy efficiency of buildings is very important to reduce global warming.

1- Methods of storing thermal energy

Thermal energy storage, commonly called heat and cold storage, refers to the storage of heat or cold for use at another time. In order to recover heat or cold, the storage method is used. There are generally two types of thermal energy storage systems during physical processes:

1. Sensible thermal energy storage
2. Storage of latent thermal energy

The choice of each of these methods depends on the storage period required (eg daily, seasonal and the like) [1]

1-1 Sensible thermal energy storage

The most common method of storing thermal energy is to store it as tangible heat, in which heat is transferred to a storage environment, which leads to an increase in temperature. A sensor can measure this increase in temperature and therefore the stored heat is called sensible heat. In fact, in the storage of tangible thermal energy, energy is stored by changes in the temperature of intermediate storage such as water, air, oil, brick, sand, or soil. The amount of energy stored by sensible heating devices is proportional to the difference between the initial and final storage temperature, the mass of the interface storage used, and its heat capacity. [1]

1-2 Storage of latent thermal energy

The thermal energy that occurs when a substance changes state from one phase to another is called latent heat. The latent heat change is usually much greater than the perceived heat change at a given temperature, depending on the specific heat. Choosing the right material, solid-liquid phase change or melting and freezing can save a lot of energy. The melting process usually takes place with a change of less than 10% in the volume of the material. If the chamber contains a larger volume - usually liquid - the pressure will not change much, resulting in the process of melting and freezing the storage material at a constant temperature. During the melting process, when heat is transferred to the phase change material, the material maintains its temperature at the melting temperature, which is called the phase change temperature. Latent heat storage systems store energy by phase change materials, which will be discussed below [1].

In general, the term latent heat describes the heat of change of solid-solid, solid-liquid, and liquid-gas phases. However, the terms latent heat storage and phase change materials are usually used for the first and second cases and not for the liquid-gas phase change. In a liquid-gas phase change, the phase change temperature strongly depends on the boundary conditions and therefore the phase change is not only used to store energy. This is usually related to the pressure and temperature changes between the charging and discharging processes. In fact, in the liquid-gas phase change mode, because a large volume or pressure is required to store gas, and the latent liquid-gas heat is less than the liquid-solid transformation, and in the solid-solid state change, it is very slow and energy Not much heat is transferred, so latent heat and phase change materials usually refer to the solid-liquid phase change, which stores energy during the process of changing state from solid to liquid. These materials actually store latent heat and use chemical bonds to store and release thermal energy [1]. Phase modifiers are organic or inorganic compounds that can secretly absorb and store large 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). These materials absorb heat from the environment or return it to the environment as the phase changes from solid to liquid or from liquid to solid. The phase change material can retain heat energy without any change, even after thousands of phase change cycles.[2] . These are heat storage materials that have a higher thermal energy storage density than perceptible heat storage materials and can absorb or release large amounts of energy at a constant temperature. Materials used to store energy from phase change need to have high latent heat and have good or low thermal conductivity depending on their application. The design and application of latent heat storage depend on the physical and chemical factors of the phase change materials used [1].

1-3 Performance of phase change materials:

Materials in nature exist in three phases: liquid, solid and gas. If a substance changes state from one phase to another, it absorbs or releases a quantity of heat called latent heat. For example, a solid, after heating and reaching its melting point, absorbs a large amount of energy (called latent melting heat) and changes its state from solid to liquid. Phase change materials have the property of changing their state in a certain temperature range, in the sense that during the change process, they maintain their temperature for the duration of the change state. In fact, the working method of these materials for storing thermal energy is that during the process of heating the environment, they are heated in parallel with the environment until they reach their melting temperature (phase change).[3] After reaching this temperature, despite the fact that the ambient temperature continues to increase, the temperature of these materials and of course the surrounding environment, because it is changing phase, remains constant and resists increasing temperature. In fact, during this period, which usually lasts several hours, the phasing agent absorbs large amounts of ambient heat, but does not use it to increase its temperature, but to absorb this heat from its phase change. It solidifies into a liquid and keeps its temperature and its environment constant during the phase change process.

1-4 Selection of phase change materials:

Phase change materials are available in different groups of materials, the specificity of each of which determines their application to specific processes. In this section, after an overview of the properties of phase change materials, the most common of these materials and the existing categories for them are introduced. Finally, some indicators that can be decisive in the selection of phase change materials for the desired processes are introduced [4].

1-4-1 Properties and properties of phase change materials

The phase change material to be used in heat storage systems must have a number of desirable physical, thermal, chemical and kinetic properties as follows [5], [6]:

Thermal properties

• Appropriate phase change temperature

The melting point of different phase change materials covers a wide temperature range from 30 to 90 ° C. By mixing different materials with different weight ratios, a wide range of melting temperatures from 64 to 117 ° C can be achieved. Meanwhile, phase change materials in the temperature range of

20 to 32 degrees have a better capacity for use in the building and thermal comfort.[7]

• Latent heat of high phase change

To select the phase change material for a particular application, the operating temperature of the cooling and heating must correspond to the phase change temperature of the selected material. High latent heat is especially considered on the basis of volume to reduce the physical size of the heat storage device, which makes these systems applicable in industrial and commercial centers that face limited dimensions. High latent heat based on mass reduces the amount of material used to store heat.

• High conductivity

The high thermal conductivity also causes the temperature gradient for the charge and discharge process (storage and release) to be small and the heat storage or release to be done at a high growth rate.

- Physical properties
- Optimal phase balance
- High density
- Low volume change
- Low steam pressure
- Renewable phase change
- Low viscosity of liquid phase

Fuzzy stability during the phase change process helps to store heat and high density in order to reduce the volume of the heat storage container. Also, small volume changes during the thawing and freezing process and low steam pressure at the operating temperature of the system reduce problems related to the storage of phase change material and simple design of containers containing them (avoiding additional costs or avoiding the risk of bursting due to pressure. When encapsulating the phase change material), reversible phase change is also necessary to continue using the phase change material. One of the problems of renewable phase change is phase separation.

Phase separation occurs when phases of different compositions are separated macroscopically. The presence of homogeneous melting property also causes the phase change material to melt completely and during the phase change, the liquid and solid phases formed are homogeneous.[9]

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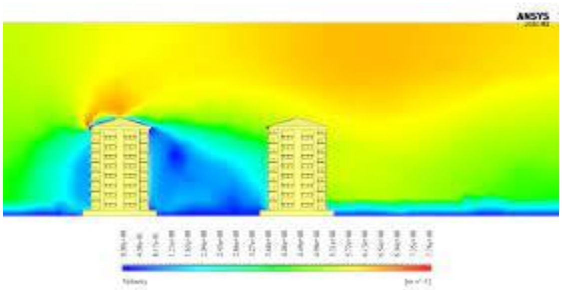


Fig 1 . Building simulation with Ansys Fluent

Use of phase change materials in the building

PCMs have been particularly exploited extensively in buildings to realize the management of interior temperature against external weather and temperature variations. This proves to be an environmentally much greener approach as lesser electrical energy will be consumed to heat up the building interior with radiators in the cold winter, or to cool down the building interior with air-conditioning in the hot summer.

Fig 2 . Use of phase change materials in the building

Synthetic properties

• Appropriate nucleation rate to prevent overcooling

Cooling is the effect in which the temperature drops significantly below the melting point until the material begins to freeze and release heat . If we do not reach this temperature, the phase change material does not freeze and stores only tangible heat [6]. Preventing overcooling causes the melting and freezing temperatures to match. Sub-cooling of more than a few degrees prevents proper heat extraction from the amount of heat stored, and even 5 to 10 ° C sub-cooling can completely prevent the use of stored heat.[10]

• High crystal growth rate required to achieve optimal heat recovery and optimization of storage systems.

Chemical properties

- Long-term chemical stability

This feature increases the useful life of phase change materials. Assuming that the useful life of materials and structures containing these materials is 30 years, the thermal properties must be constant during this period and be able to perform 1100 daily cycles of melting and freezing.

- No structure change during several cycles of melting and freezing
- Compatibility with system structural materials
- Non-toxicity and corrosion
- No risk of ignition and explosion
- Lack of radioactivity

Economic properties

- Availability
- The price is right

Environmental features

- Recyclability
- Low pollution

In general, no substance has all the desirable properties mentioned. Therefore, according to the specific application, the optimal and desirable phase change materials should be selected.

1-4-2 Classification of phase change materials

So far, different people have come up with different categories for phase change materials. This classification can be based on the structure of the phase change material or on the temperature of the phase change. In any case, phase change materials are generally divided into materials with organic, inorganic compounds, and eutectic compounds.

The following figure shows an example of the classification of phase change materials [5].

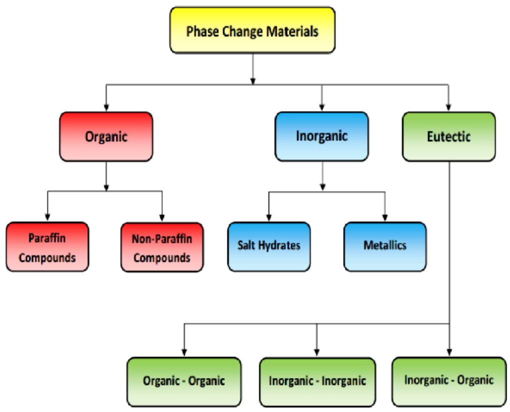


Fig 3: Classification of phase change materials [44]

Nowadays, the use of phase change materials is very important to reduce energy consumption in buildings and industry structures.

1-4-2-1 Organic phase change material

Organic phase change materials are divided into two categories: paraffinic materials and non-paraffinic materials. Organic phase change materials are known for their ability to sequential melting and freezing cycles without phase separation and without reducing the latent heat of the corresponding melt. Paraffins are petroleum products and mainly contain heavy hydrocarbons from a family of organic substances called alkanes and have the general formula $C_n H_{2n+2}$ (saturated hydrocarbons). Four series of primary alkanes, from methane (CH_4) to butane (C_4H_{10}), are gaseous at room temperature and atmospheric pressure. Components between C_5H_{12} to $C_{17}H_{36}$ are liquid, and components with more than 17 carbon at room temperature are solid waxes. Paraffins and fine waxes are considered as important products in the refinery and according to the published statistics of the refining industry, the demand for these products is constantly increasing. As a result, paraffin hydrocarbons can be introduced as other main products of the installation refinery to other by-products. Paraffin waxes are one of the most common organic materials for storing thermal energy for commercial applications. Straight or straight-chain paraffins have a higher melting point than branched hydrocarbons. Their chemical properties are obtained by considering their related structural states so that straight-chain hydrocarbons are normal and hydrocarbons are more stable with symmetrical branches. Due to the effect of how atoms are placed in space, there are differences between alkanes with the number of even atoms and alkanes with the number of atoms. Paraffins with an even number of atoms have more use than paraffins with an odd number of carbon atoms because they are more available and economical. They also have higher latent melting temperatures. Melting points and melting points of alkanes increase with increasing molecular mass and the number of carbon atoms.

Organic materials have insulating properties comparable to the best insulating materials and are even better than insulations such as wool. Since paraffins have a low thermal conductivity, the use of metal fillers is recommended. Aluminum is a hexagonal arrangement of materials that can improve system performance. Paraffins were among the first materials to be introduced as a phase change material. They are generally safe, harmless, predictable, safe, and non-corrosive; But on the other hand, they are flammable and their low thermal conductivity limits their performance. There are numerous non-paraffinic organic materials for use as phase change materials. This category of materials includes a variety of different organic materials with very diverse properties. Each material has its own design parameters, while paraffinic materials exhibit similar properties. These materials are flammable and should not be exposed to very high temperatures, fire or strong oxidants. Exposure to high temperatures can cause vapors to decompose to moderate to high toxicity. Therefore, in using these materials, the relevant safety warnings should be heeded [5].

1-4-2-2 Inorganic phase change

These phase change materials are divided into two categories: salt hydrates and metals. These materials are noticeably supercooled. And their melting temperature does not decrease with multiple melting-freezing cycles. In terms of abundance, inorganic phase change materials are more than organic materials.Hydrates Salts are water and salts that combine into a crystalline matrix when the substance freezes. These materials are one of the cheapest ways to store thermal energy and their main disadvantages are the phenomenon of supercooling and phase separation [8] A major difference between metals and other phase-shifting materials is their high thermal conductivity and low Prandtl numbers of about 0.001 to 0.1. Corrosion is important in the use of some of these materials. Gallium, for example, is a highly reactive metal that affects the structure of common metals such as aluminum. The use of inhibitors can reduce the problems of corrosion with some substances [5]

1-4-2-3 Eutectic phase change materials

Eutectics consist of two or more components, each of which is mutually melted and frozen to form a mixture of crystalline components during the crystallization process. The eutectic is usually melted and frozen without phase separation, and during the melting process, all components are liquefied simultaneously without the possibility of phase separation. Pleasures can be a combination of organic-organic materials, inorganic-inorganic materials, and organic-inorganic materials [5]. Molten salt flavors consist of two or more inorganic salts that make up the eutectic components. Basically, there is a possibility of many phase change materials in this category. But there is currently relatively little data on these phase change materials.[10] Due to lack of data or poor performance, there are few eutectic phase change materials tested, and much research is needed on the thermophysical properties of these compounds. Some of the substances that fall into this category are nitrates; Nitrates may seem desirable because they have a lower melting point than their corresponding halides, but heating nitrates is generally not recommended. Nitrates may be shocked by fire or heat or explode during spontaneous reactions [11].

1-5 Phase change process

Phase change can take the following forms: solid-solid, solid-liquid, solid-gas, liquid-gas, and vice versa. In solid-solid conversion, heat is stored when the crystalline state of matter changes. In solid-solid phase change, no liquid or gas is produced and no encapsulation is required, but despite all these advantages, few of these solid-solid phase change materials are known. Solid-liquid conversion has less latent heat than liquid-gas but is associated with less volume change (about 10% or less), so they are more cost-effective for use in thermal energy storage systems. Therefore, all latent energy storage systems must have at least the following three components [12]:

1) Suitable phase change material whose melting is in the desired range.
2) Suitable heat exchanger surface
3) Retaining compartment compatible with phase change material

The temperature of the phasing material remains almost constant during the thawing and freezing process. High heat transfer without a noticeable change in temperature makes phasing material a significant source of heat storage in practical processes.In 1981, a useful classification for thermal energy storage materials was presented, as shown below [13]

1-6 Methods of using phase change materials

Phase change materials can be used in three forms of raw material, micro, and macro. However, since the use of these materials in raw form can have disadvantages depending on the type of phase change material and also due to the flowability of phase change materials in the liquid phase, containers that are in the liquid phase will be needed. It acts as a container containing these materials, so these materials are usually used in packages of two types, micro, and macro in different industries. To prepare both micro and macro, phase change materials are embedded in chambers and encapsulated. Thus, the main difference between the two methods of microcapsules and microcapsules is the size of the containers used. In the microcapsule method, the materials are embedded in tiny spheres with a diameter between 1 and 30 micrometers. In the microcapsule method, materials are embedded in larger containers in the form of envelopes or containers of different materials. Most of these containers are made of plastic bags as well as hard panels made of high-density polyethylene.

1-7 Application of phase change materials

Phase change materials have various application potentials in different industries. These abilities can be classified into two main groups:

1) Thermal control (thermal inertia)
2) Storage of thermal energy

Phase-changing materials also have special applications for small-scale cooling and heating [14]. Phase change materials have the ability to change phase (for example, from solid to liquid) over a relatively constant temperature range, and the process of phase change in such materials is usually accompanied by the exchange of large volumes of energy, called the latent heat of phase change. The exchange of this high volume of heat is in harmony with nature and automatically and intelligently, in accordance with changes in ambient temperature.[15]

1-7-1 Application in construction

The use of modifiers in the construction industry can have two different purposes: 1. Using natural heat as solar energy for heating or cold at night for cooling. 2- Using handmade heating and cooling sources. In either case, heat storage or capital will be required to create a structure between use and consideration of time and power [15]. The use of phase change materials, if the role of recycling and consumption is doubled, finds important aspects in energy management, and the use of these materials, for example, in the east and west walls is about 29% and in the north and south walls of a house. . It will have about 19% energy recovery.

The purpose of the above is to use phase change in the building for two main reasons:

- Utilizing the natural heat of the sun for cooling and heating
- Utilization of heat stored by cooling and heating systems

To change the phase using the research method for the above materials, there are three general :

- Phase change material in the wall of the building
- Phase change materials in the ceiling and floor
- Phase change material in cold and heat storage tanks

Other methods of using phase change materials in the building include PCM shutters, PCM walls facing the sun, underfloor heating systems, and PCM ceiling boards. They are used as part of the heating and cooling system by placing phase change materials in the false ceiling. Also, using a wall equipped with phase change materials can help reduce the load on the air conditioning system. The use of phase change materials in the walls, in addition to making them lighter, saves energy. These materials are usually made of hydrocarbons or hydrated salts, which are used in combination with ferrous additives to increase thermal conductivity .Radiant heating from the floor is better compared to displacement due to more favorable heating and less space occupied. By using phase change materials in floor materials and assuming electric heating, electrical energy consumption can be reduced. In this method, at night when electricity consumption is lower, by turning on the electrical system, the material of the phase change material melts. And stores heat inside and is returned to the environment during the day when the heat flow is cut off, which in addition to the above-mentioned savings in electricity consumption, electricity production by power plants is balanced.

The main policy of climatic design of the building is to deal with severe temperature fluctuations of the surrounding environment in different seasons. The basic building in terms of climate should have the ability to prevent the penetration of summer heat inside and the exit of heat from outside to outside in winter. In this way, by reducing the internal temperature fluctuations, relative comfort can be provided to the occupants of the building. The phase change material can intelligently and without the use of mechanical equipment by adapting to ambient temperature fluctuations, reduce the intensity of these fluctuations, and thus create a more balanced air temperature for the indoor space. If such a technique is used, the operation of mechanical cooling and heating equipment can be significantly reduced during peak hours.[16]

1-7-2 Use of phase change material in solar systems

One of the capacities of detergent materials is to store solar energy in buildings that have the ability to store solar energy using solar panels. If degrading materials are used in such systems, a large amount of solar energy can be stored during the day and the same energy can be used for heating during the night.

Contagious materials in these systems are usually stored in thin chambers stacked with the arrangement of the plates, and then the heat transfer fluid moves through these plates and in indirect contact with these materials. The method used in these systems is that the energy collected by the collectors during the day heats the heat transfer fluid (usually water). The heated water then transfers its heat to the plates containing the phasing agent, and the substance receives this heat in the form of latent heat and spends it changing its phase from solid to liquid. During the night, cold water replaces hot water in the system. Due to the decrease in temperature, the phase change material undergoes its phase transfer process in reverse (from liquid to solid) and therefore returns the volume of heat received during the day to cold water and causes the water to heat up [17] [18]. Then the resulting hot water is used to heat the building. To increase the efficiency of such systems, techniques are needed to maximize the heat transfer process between the phase change material and the heat transfer fluid, and most studies have been done in this field.

1-7-3 Phase change materials and energy storage

With the expansion of industries and cities and with the continuing increase in greenhouse gas emissions, the planet is getting warmer by the minute. Global warming is causing ice to melt in the North and South Poles and causing environmental catastrophes. On the other hand, scientists believe that due to the demand for more welfare, the development of industries and cities can not be stopped. So in the last few years, researchers have been looking for different ways to store heat loss energy in appropriate forms for reuse.Energy storage not only reduces the gap between energy supply and demand but also increases the performance and reliability of energy-producing systems and plays a very important role in energy storage.[19] This system saves money by collecting energy waste. For example, thermal energy storage devices can improve the performance of power plants by reducing their load levels and higher efficiency, leading to lower storage costs and costs. According to the chart below, which is related to the final energy consumption in different economic sectors (million barrels equivalent of crude oil) and in Iran in 2006, the importance of paying attention to heat loss recovery in different sectors shows.One of the most popular thermal energy storage techniques recently is the storage of thermal energy by phase change materials.[20] Phase change materials are materials that store energy using latent heat. Thermal energy transfer occurs when matter changes state from solid to liquid or liquid to solid. This change of state is called phase change. The phase change material absorbs and releases heat at an almost constant temperature.[21] These materials store approximately 5 to 14 times more heat per unit volume than other materials such as water. Phase change materials are widely used due to their desirable leading properties [22]

A) Thermal properties:

- Appropriate phase change temperature
- Latent heat of high phase change
- Good heat transfer

B) Physical properties:

- High density
- Small volume change during phase change

C) Chemical properties:

- Long-term chemical stability
- Compatibility with system components
- Non-toxic
- Nonflammable

D) Economic:

- Abundance and availability
- The price is right

2-1 Research history

What is certain is that phase change materials have been widely used in various systems to store energy.[23] In the following, some studies have been done in the field of using phase change materials in converters, etc. to increase the thermal performance of energy storage equipment, which includes experimental, numerical, etc. research.

Abdolmaleki et al. [24] in 2013 in a general study to study the research conducted in the field of heat recovery from diesel engines and heat loss recovery from compression systems by heat exchangers containing phase change materials. The results of this research indicated that the use of phase change materials has been developed as a new and cost-effective solution for storing thermal energy and heat loss. It was also found that these materials can play a positive role in storing thermal energy and preventing its loss, as well as preventing destructive damage to the environment. He also stated that one of the results of his research is that this stored heat can be used in other places where heat is needed.

In 2009, Nashina and Takahira [25] conducted a study on greenhouses using flowering phase change material. As in some studies using Na_2SO_4.10H2O phase change material with additives that prevent phase decomposition and energy loss, you find that only 40 to 60% of the latent heat sample of this material is released and as a result it is almost adjective. . Its capacity remains unused. And this is while almost half of the PCM usage is not used. Other phase change materials they have studied include polyethylene glycol and $CaCl_2$ .6H_2O. They compare traditional greenhouses with greenhouses that compare the PCM storage system. They found that the efficiency of greenhouses that store energy combined with solar collectors is approximately 59%, and this system maintains it with the temperature inside the greenhouse overnight at 8 ° C while the ambient temperature up to 0.6. - The temperature has dropped.

Covert heat storage in PCM is a method that has been extensively studied in recent decades. This research has been done theoretically and experimentally on PCM heat storage in different geometries. Among them, Saito and Hervis [26] theoretically and experimentally investigated the heating behavior of an energy storage unit hidden in spherical capsules.

Labat et al. [27] experimentally designed a sample heat exchanger containing PCM material to provide kw1 of thermal power over 2 hours (ie, to store kwh2 of energy). They tested the converter in a closed-loop wind tunnel for a constant airflow rate with temperature changes, so that the PCM was allowed to melt and then solidify. They measured temperature and velocity for eight airflow rates and estimated the heat output of the converter. The second purpose of this work is to provide accurate results by validating numerical models. Therefore, the exact geometry of the converter and the data are given in connection with the power measurement. Their results show that the required energy is stored in the heat exchanger, however, due to the use of a constant airflow rate during the thermal power test before 2 hours is less than 1 kw and the use of this simple method to optimize Energy is very useful in the system.

Musafi et al. [28] investigated the latent thermal storage of phase change material (PCM) in several applications, including building air conditioning systems. They developed an approximate analytical model to study the thermal storage of the solidification process in the shell and finned tubes. They performed a comparative study of PCM solidification in cylindrical and rectangular shells with the same volume and surface heat transfer. They found that the PCM solidification rate in cylindrical shell thermal storage was higher than in rectangular shell storage. He also investigated the effects of thermal fluid inlet temperature (HTF) and flow rate on thermal storage performance. Their results showed that the inlet temperature has a greater effect on thermal storage than the flow rate.

Pablo et al. [29] developed numerical and experimental models to simulate the thermal energy storage performance of a real-scale PCM-air heat exchanger. They also evaluated the analysis of heat transfer between air and phasing materials in commercial microcapsules. The model can calculate the enthalpy curve and heat transfer within PCM using effective guidance if necessary. They compared the measurements with the simulations to evaluate the model, with an average thermal power error of less than 12% for the entire cycle.

Three-dimensional numerical simulations of transient heat transfer were investigated by Wang and Yang [30] to investigate cooling using PCM in a multi-blade heat well. Numerical analysis was performed with different numbers of blades (0 blades, 3 blades, 6 blades) as well as different thermal power (w2, w3, and w4). Their study was performed in different conditions (horizontal/vertical/inclined) and based on charging and discharging modes. The results showed that their developed theoretical model was in good agreement with comparing numerical predictions with existing experimental data. They also found that the transient surface temperature was predicted to deviate by 10.2. They also concluded that the temperature of the above operation can be controlled by the presence of phasing materials and a longer melting time using a multipurpose heat well.

Shalabai et al. [31] investigated solar drying systems in which phasing-out materials are used as an energy storage source. They concluded that the use of a solar dryer with PCM reduces heat loss and improves system efficiency.

Guelpa et al. [32] investigated the latent heat storage of the skin and tubes using a design method based on the analysis of entropy production. In this study, using a computational fluid dynamics (CFD) model, they investigated the phase change in phase change materials (PCM) using the enthalpy method. They calculated the local entropy production rate for bladeless and bladed systems. According to the analysis and analysis of entropy production that the freezing time of PCM in the coupled state is reduced, which increases the efficiency of the system.

The effect of natural displacement on the melting zone location has been studied by Lamberg and Siren [33]. In this study, the melting process is performed analytically in a semi-infinite PCM chamber with the presence of a vane inside. This analytical model involves solving the Newman equation, in which it is assumed that heat is transferred only to transmission and that the natural displacement mechanism can be ignored. They also estimated the location of the melting zone to accurately solve their Newman equation.

Lamberg et al. [34] conducted another numerical study of the PCM melting process in a rectangular chamber with and without natural displacement. The results obtained from the numerical study are compared with the laboratory results. The results showed that by ignoring the effect of natural displacement, the time required to reach the maximum temperature is twice that of real-time.

Agen et al. [35] did a similar job on melting paraffin in a vertical tube in the shell arrangement. In this test, the PCM is heated from the inside wall. They observed that the molten PCM expanded radially outward, forming a conical region.

Aginim et al. [36] In laboratory work, the effect of hot fluid inlet temperature changes in a tubular shell exchanger with a longitudinal fin on the heat behavior of the phasing material in the charge and discharge process has been investigated. In this work, 20 kg of Erythritol (with a melting point of approximately 117 ° C) was used as the phase change agent, and hot oil at 130 ° C, 135 ° C and 140 ° C was used as HTF. They found that the maximum amount of recycled energy associated with the inlet temperature was ℃ 80 and the efficiency of this recycling relative to the charged energy was calculated to be 76%.

In numerical and laboratory work, Terp et al. [37] studied the effect of working conditions of geometric parameters on the performance of the tubular shell exchanger in the melting and freezing process. In this experiment, RT30 was used as PCM in the shell space and water was used as HTF. In this experiment, 16 thermocouples were used in radial and longitudinal positions. Their results analyze the amount of energy given and recycled in the charging and discharging process. They found that changes in Reynolds number flow had little effect on the amounts of energy given and recovered from the PCM. The results also showed that with increasing the difference between the inlet temperature and the melting and freezing temperatures, as well as increasing the length to diameter ratio of the converter, the amount of charge and discharge energy increases linearly.

Algafi and Lafdi [38] prepared the property by adding carbon nanofibers with an average diameter of 100 nm and an average length of 20 mm in composite paraffin. Their studies are on heat transfer lines in the freezing process. They found that the thermal conductivity of the composite increases specifically with increasing mass fraction of nanofibers in the composite. Even with a 1% volume fraction of nanofibers, a 23% reduction in freezing has been observed. They also find that structural fiber decreases with the addition of fiber to the PCM, so the output power also increases linearly with increasing mass fraction of carbon fibers. Their results show that by evenly distributing the fibers in the PCM, more performance is achieved.

Obidi et al. experimentally studied the use of a three-tube heat exchanger with internal-external vanes to store thermal energy.

3- Equations governing the numerical simulation of fluid flow in the collector

Navirastox equations provide a complete mathematical model for a fluid. Due to the complexity of these equations in full Navirastox form, it is impossible to solve them analytically, so computer-aided numerical methods are the best option for solving part of these equations. The rapid progress in the field of computer technology in the last few decades has led to the widespread use of computational fluid dynamics in the numerical solution of fluid flow problems. Considering that all the solvers of the simplified Navirastox equations require a lot of processing time and memory, so some simplification in solving these Navirastox equations is necessary to reduce the required computing resources. For example, in external aerodynamic flows with high speed and low angle of attack, non-viscous Euler equations can be used. Or in problems where the thickness of the boundary layer is very small, the non-viscous assumption of the flow is a safe assumption. When the parts related to viscosity are removed in the Navierstox equations, these equations will become Euler's equation, which has a high relative calculation speed (increasing the processing speed and reducing the required memory).

3-1 Continuity equation

The basic principle used in fluid mechanics is the principle of conservation of mass. This principle states that mass is neither produced nor destroyed and is expressed by the equation of continuity.(40)

Fluid mechanics is not defined only by having the continuity equation, but the principle of conservation of momentum or Newton's second law must be stated about it. The magnitude of motion is the product of mass times velocity. Newton's second law states that the forces acting on an object are equal to the net changes in momentum.

3-3- Governing equations for laminar flow

The semi-elliptical Navirastox equations governing the steady, incompressible and two-dimensional flow in quiescent state are as follows

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0 \qquad (1)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + v\frac{\partial^2 u}{\partial y^2} \qquad (2)$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + u\frac{\partial^2 u}{\partial y^2} \qquad (3)$$

3-4- Governing equations for turbulent flow

Considering that the flow investigated in this work is a turbulent flow, it is necessary to check the form of the equations in a turbulent form. In the following, a brief review of the formation of turbulent flow equations will be given, and then the turbulent form of each equation will be introduced.

3-5- Statistical method of examining turbulent flows

In the statistical method, we first define a time average value for the quantity f as follows :

$$\overline{f} = \frac{1}{\Delta t}\int_{t_0}^{t_0+\Delta t} f \, dt \qquad (4)$$

where Δt is chosen so large that for time values greater than T_1 no change in the size of the integral is observed. In other words, f ̅ is independent of the selected time Δt. In this statistical method, flow variables that change randomly are expressed as the sum of time averages with fluctuating values.The only difference between the above momentum equation and the momentum equation with instantaneous quantities is the addition of the last term on the right side of the equation, i.e $\rho\overline{u_i' u_j'}$ We call this term turbulence stress or Reynolds stress. The only difference between the smooth and turbulent flow equations is the presence of this term. In general, this expression does not become a tension physically, but it expresses the effect of the exchange of inertia (momentum).

3-6- Turbulent flow modeling [41]

In the present study, ka-epsilon model is used to simulate the turbulent flow. This model is one of the common turbulence models, although it does not perform well in large reverse pressure gradients. The ka-epsilon model is a two-equation model, in other words, it includes two additional transition equations to calculate the turbulence properties of the flow. [42] These equations can be used to calculate the effects of displacement and diffusion in turbulence energy. The first transition variable is kinetic turbulence energy or K and the second transition variable in this model is turbulence loss or ε. In other words, it can be said that Ka determines the energy in turbulence and epsilon determines the scale of turbulence. The main goal of the ka-epsilon model can be considered to improve the complex length model, so that it can express an algebraic description for the turbulence length scale in highly complex flows. The ka epsilon model has good accuracy and performance for internal and external flows and flows with limited walls with a relatively small pressure gradient. Subsequently, the accuracy of this model decreases for flows with high back pressure.

Reynolds number is used to determine the flow regime inside the pipe. If the Reynolds number is greater than 2300, the flow is turbulent and if it is smaller, the flow is smooth. The Reynolds number is obtained from the following equation :

$$Re = \frac{\rho V D}{\nu}$$

(5)

ρ : fluid density

V: fluid velocity

D: Pipe diameter

v: viscosity

3-7- Modeling the heat flow in the collector [48]

In the present study, DO model is used for radiation modeling. The radiative transfer equation (RTE) for absorption, emission and scattering in position $\vec{r}$ and direction $\vec{s}$ is expressed as follows

$$\frac{dI(\vec{r},\vec{s})}{ds} + (\alpha + \sigma_s) I(\vec{r},\vec{s}) = a n^2 \frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\vec{r},\vec{s}\,')\Phi(\vec{s}\cdot\vec{s}\,')d\Omega' \qquad (6)$$

$\vec{r}$ = position vector

$\vec{s}$= vector direction

$\overrightarrow{s'}$ = direction of scattering vector

s = path length

α = absorption coefficient

n = index of refraction

σ_s = scattering coefficient

σ = Stefan Boltzmann's constant (5.67×10^(-8) W/m^2 - K^4)

I = radiation intensity that depends on position and direction

T = local temperature

Φ = phase function

Ω' = angle

$(\alpha + \sigma_s)$= The thickness is optical or medium turbidity.

The volumetric expansion coefficient b is defined as follows:

(7)

The energy equation solved in this part is as follows:

$$\rho C_P\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \quad (8)$$

3-8- Investigating the geometric dimensions and calculation scope of the solar collector

The following table shows the geometric dimensions of the desired collector. As you can see, the length of the pipe and the entire collector is 800 mm and its diameter is 10 mm. Also, the thickness of the tube and absorber plate is considered to be 1 mm, and the thickness of the thermal insulation and glass cover is also considered to be 3.5 mm. In addition, the length of the distance between the glass plate and the absorbent plate is also equal to 25 mm.

Table 1- Geometrical parameters of the solar collector

Length in mm	**Parameter**
length of the pipe	800
Diameter pipe	10
Pipe thickness	1
The thickness of the absorber plate	1
Thermal insulation thickness	3.5
The thickness of the glass cover	3.5
The distance between the glass cover and the absorbent plate	25

The following table shows the thermophysical characteristics of the materials used in the collector. As can be seen, the highest coefficient of thermal conductivity is related to copper, which forms the wall of the pipe.

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p$$

Table 2 -Thermophysical characteristics of PCM materials

Thermophysical properties	Thermal conductivity coeficient (w/m.k)	Specific Heat (j/kg.k)	density (kg/m3)	Publication coefficient
Air	0.0242	1006	1.22	-
Water	0.6	4182	998.	-
Aluminium	177	875	2770	0.9
Glass	1.7	840	2500	0.9
Copper	401	420	8800	0.9
Insulation	0.039	1	72	-

3-9- Investigating the boundary conditions and computational network of the solar collector

After generating the geometric model of the solar collector, a suitable computing network is generated for it. In the figure below, a cut view of the generated computing network is shown. As it can be seen, due to the fact that the fluid passes through the pipe, it is necessary to create a boundary layer mesh around the pipe wall due to pressure drop changes along the pipe. Organized mesh is also used for other parts of the collector. The generated computing network includes 879,812 elements and 613,480 nodes.

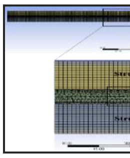


Fig 4 - Representation of the generated computational network [43]

Building energy saving

Building energy saving is essential to overall energy conservation from different sectors. To build a comfortable indoor thermal environment, the energy consumption of air conditioning is increasing rapidly, which has negative impacts on sustainable development. Passive low-energy buildings are developed to solve the problem. Improving thermal performance of building envelope is an effective approach to achieve a stable indoor thermal environment and reduce building energy consumption

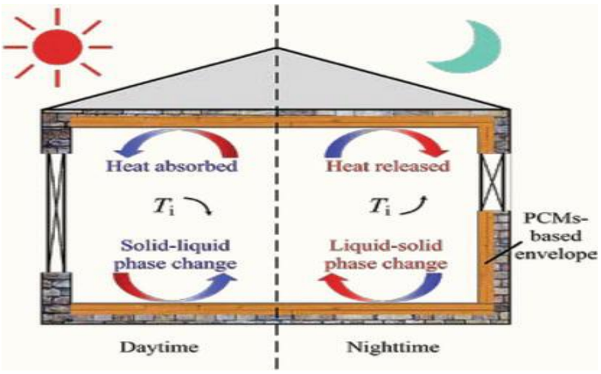


Fig 5 - Building energy saving

One of the criteria for measuring the quality of the generated computing network is the elongation of the cells, the closer it is to zero, the better the quality of the computing network. In the figure below, the graph shows the amount of elongation of the generated computational cells. As it can be seen, most of the produced computing cells have an elongation of less than 0.38, which shows that the produced network is of high quality.

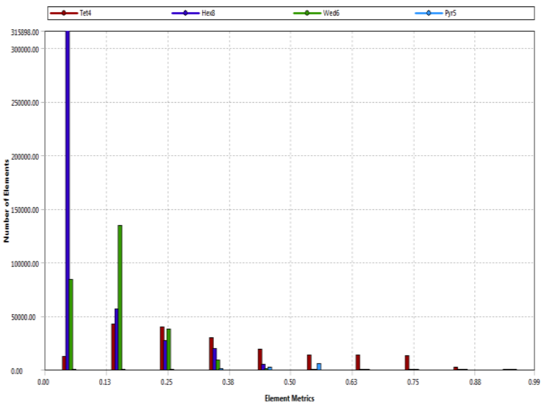


Fig 6 - A graph of the growth rate of computational cells

Examining phase change materials for use in solar collectors

In order to investigate the effect of using phase change materials in the desired solar collector, four types of PCM with different thermophysical characteristics have been selected. The following table shows the thermophysical characteristics of PCM materials.

Table 3- Thermophysical characteristics of PCM materials

Thermophysical properties	PCM-1
Melting/freezing temperature	35.4-36.4
hidden heat	2.4×10^5
Solid state density	910
Density of the liquid state	769
Specific heat of the solid state	1926
Specific heat of the liquid state	2400
Solid thermal conductivity coefficient	0.423
Liquid thermal conductivity coefficient	0.146
viscosity	4.9×10^{-3}
Coefficient of thermal expansion	8.1161×10^{-4}

the boundary conditions of the front, back and bottom walls of the collector are shown. As it can be seen, the boundary condition for the front and back walls as well as under the wall collector is considered without slip. In addition, for the internal walls of the collector, such as the wall around the pipe and the surface of the absorber, the wall boundary condition is considered. the boundary condition for the surface on which the heat flux caused by solar radiation is applied, Wall with the properties of glass, is considered.

The purpose of this article is to introduce phase change materials and their use in buildings for energy storage and optimal consumption. In recent decades, the aforementioned materials and their unique features have been noticed in advanced countries, while in our country, the aspects of its research and application remain unknown. Understanding and using the physical capabilities and properties of these materials can naturally delay the transfer of heat to the building for several hours during peak energy consumption hours. These materials will naturally adapt to environmental temperature fluctuations without the use of mechanical equipment, intelligently, and only through the inherent tendency to phase change, and will reduce energy consumption.

Fig 7- Use of phase change materials in the interior walls of the building

Result discussion

The structure of the phase change material is very important. And the presence of these materials in the structure of buildings reduces the consumption of fossil fuels. The main policy of climate design of the building is to deal with severe temperature fluctuations of the surrounding environment in different seasons. In terms of climate, a basic building should have the ability to prevent summer heat from penetrating inside and the heat from inside to outside in winter.The first chapter examines the independence of the simulation results from the number of computing networks, and then examines the accuracy of the simulation results and compares them, and examines the results of the simulation scenarios.

Checking independence from the computing network In the figure below, the curve of temperature changes of the outlet water in the collector is shown. As it can be seen, with the increase in the number of elements to 890156, the outlet water temperature has not changed. Also, the comparison of water temperature changes in the number of elements 890156 and 879812 shows that the water temperature has not changed much with these two elements. Therefore, the desired collector with the number of 879812 elements can be used in the simulation.

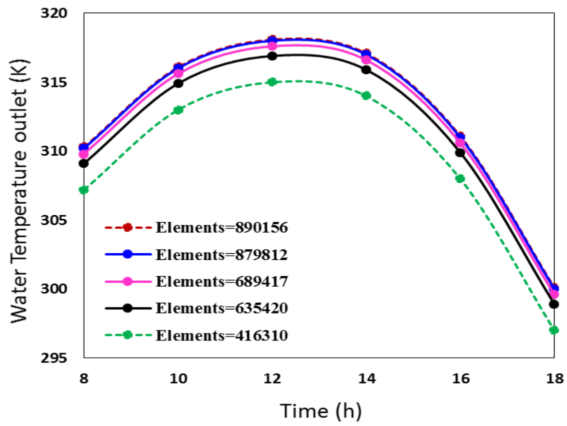


Fig 8 - the curve of changes in outlet water temperature with the number of different elements

Verification of simulation results

In the figure below, the temperature change curve of the water output from the solar collector in the city of Shiraz in the winter season is compared with the present work. The results show that the biggest difference between the present work and the reference results is less than 2%, which is about 5 degrees Celsius. Considering that the simulation error is less than 5%, the simulation results can be accepted.

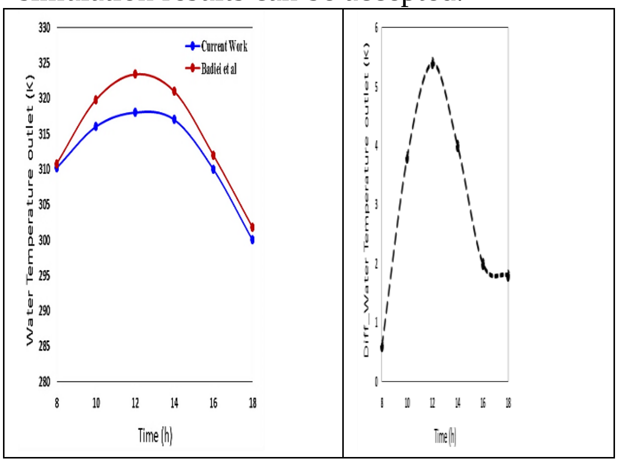
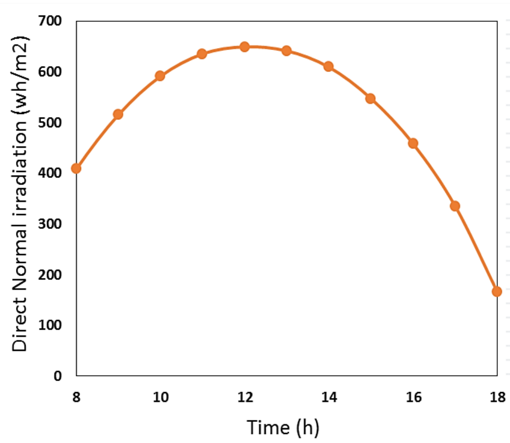


Fig 9 - The curve of changes in outlet water temperature and its difference with the reference results

Examining the results without phase change materials in the stable conditions of Tehran

In the figure below, the curve of the average hourly solar radiation changes for the city of

Tehran with a longitude of 35.689252 degrees and a latitude of 51.3896 degrees from 6 am to 6 pm in July is shown. As it can be seen, the highest intensity of pleasant radiation is at 12 o'clock, which is equal to 649 kilowatt hours per square meter. Also, the total average hourly radiation in July for the city of Tehran is equal to 5947 kilowatt hours per square meter. Now, based on the hourly solar radiation in Tehran and the heat flux applied to the collector every hour, the performance of the collector is checked.



	Jul
0 - 1	
1 - 2	
2 - 3	
3 - 4	
4 - 5	1
5 - 6	107
6 - 7	276
7 - 8	408
8 - 9	515
9 - 10	591
10 - 11	635
11 - 12	649
12 - 13	641
13 - 14	609
14 - 15	547
15 - 16	458
16 - 17	335
17 - 18	166
18 - 19	9
19 - 20	
20 - 21	
21 - 22	
22 - 23	
23 - 24	
Sum	5947

Fig 10 - Curve of changes in solar radiation in July in Tehran

In the figure below, the curve of changes in outlet water temperature along the length of the collector for stable weather conditions is shown. As you can see, the temperature of water with a temperature of 30 degrees gradually increases every hour so that at 12 noon when there is the most solar radiation on the surface of the collector, the water temperature increases to 40 degrees.

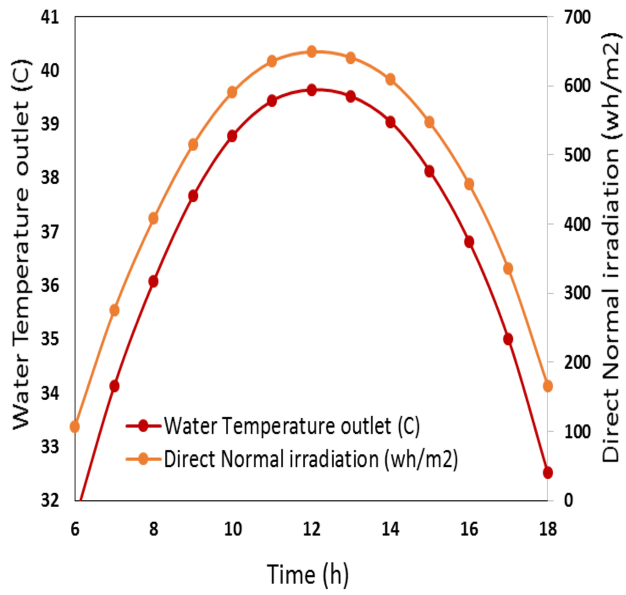


Fig 11. Curves of changes in solar radiation and outlet water temperature in July

Contour curve of temperature distribution on the surface of the collector in stable conditions

Examining the results using phase change materials in the unstable conditions of Tehran city

To investigate the effect of using phase change materials in unstable weather conditions, it is assumed that at 14:00 to 15:00 in the afternoon, 200 watt hours per square meter will reduce the solar radiation on the surface of the collector due to cloudiness. In the figure below, the solar radiation curve is compared in unstable and stable weather conditions. Now, the effect of using phase change materials in solar collector in unstable weather conditions is investigated.

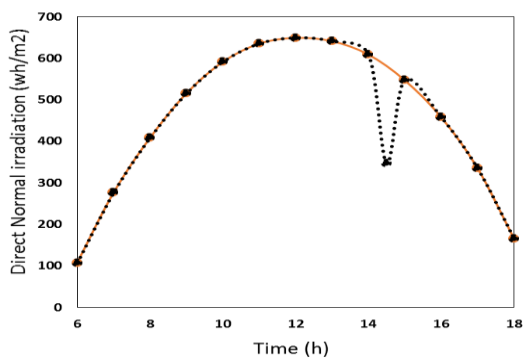


Fig 12. Curve of changes in solar radiation in stable and unstable weather conditions

the curve of temperature changes of the water coming out of the collector is shown. As it can be seen, the use of phase change material in the collector has caused the temperature of the outlet water to decrease. In other words, the heat that should be absorbed by the water is absorbed by the phase change material and causes the temperature of the outgoing water to decrease. The reason for this performance can be the low melting and freezing temperature of the phase changing material, which changes phase with a temperature lower than 40 degrees. Therefore, the phase change material used in the collector has not been able to perform well due to the low melting and freezing point and the area used in the collector.

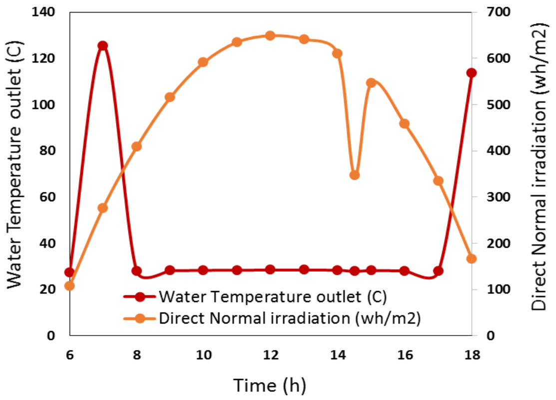


Fig 13. The curve of changes in solar radiation and outlet water temperature in July in unstable atmospheric conditions and the use of phase change material in it

Conclusion

Phase change material has a different structure and can be used in the structure of buildings. The use of phase change materials in buildings and their structures will reduce the consumption of fossil fuels and save energy in the near future. In this article, we used phase change materials to reduce the consumption of fossil fuels so that energy can be used. In this article, Ansys Fluent software is used for simulation. Renewable energy and phase change materials are used to reduce energy consumption in buildings. the aim is to investigate the use of a PCM tank in a flat plate solar collector. So far, many studies have been conducted on the use of phase change materials in a solar water heater, but no study has investigated the effect in atmospheric conditions. In this article, Ansys Fluent software is used for simulation. Different on the performance of solar water heater with PCM tank has not been done. In the results, as an example of heat flux changes during a sunny, cloudy, and partly cloudy day, the purpose of this study is partly cloudy. That is when there is a sudden decrease in the solar flux, which causes a decrease in the received heat flux and the output temperature of the water. In this study, by using PCM, we intend to keep the outlet temperature of water constant by storing thermal energy in clear weather and releasing the thermal energy stored in PCM. The average hourly changes of solar radiation for the city of Tehran with longitude of 35.689252 degrees and latitude of 51.3896 degrees from 6 am to 6 pm in July are shown. As it can be seen, the highest intensity of pleasant radiation is at 12 o'clock, which is equal to 649 kilowatt hours per square meter. Also, the total average hourly radiation in July for the city of Tehran is equal to 5947 kilowatt hours per square meter. Now, based on the hourly solar radiation in Tehran and the heat flux applied to the collector every hour, the performance of the collector is checked. As it can be seen, the temperature distribution on the surface of the collector is such that it shows that the heat transfer at the edges of the collector is less than its center. Also, the comparison of the temperature distribution on the surface of the collector during the day shows that the temperature of the surface of the collector increases with the increase of radiation so that the most heat transfer occurs in the outlet part of the collector. As you can see, the temperature of the water with a temperature of 30 degrees gradually increases every hour so that at 12 noon when there is the most solar radiation on the surface of the collector, the water temperature increases to 40 degrees. As can be seen, at 6 to 7 o'clock, the surface of the collector increases strongly, which causes the phase change of the phase-changing material and increases the heat transfer to the surface of the collector and the middle space of the collector. After changing the collector level, it decreases and reaches the phase with the solution amplitude. It shows that the use of a phase changer in the collector causes the surface of the collector and the space between the collector and the absorber to become hotter and the speed of heat transfer decreases due to the absorption of heat by the phase changer material. Also, the phase change in the phase-changing material at the end of the day is due to the decrease in the intensity of the swing, which has increased the surface of the collector.

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