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Energy management in residential building using phase change materials

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ABSTRACT

This study aimed to calculate the heat losses from the building through walls, windows, and waste energy in boiler flue gases, where the problem of this study is to reduce the heat loss through the building using phase change materials and to extract the waste energy from boiler flue gas and store it in phase change materials as a thermal mass storage. The study revealed a group of results among which by adding a new layer from phase change material to the wall, it behaves as a thermal insulation due to low thermal conductivity and contributed to reduce heat loss through walls by (72%). In the south side of the building phase change material work as a thermal energy storage and contributed to reduce heat load by (43%) of the total heat load. The study found that the paraffin wax is suitable for use in building applications because of its physical properties and relatively low cost, and there are a significant amount of energy wasted in boiler flue gases, which can be recovery to use as a heating source

1 Introduction

Phase change materials applications in building are divided into two main categories which are passive and active system. For the passive system it must achieves the function of collecting, storing and releasing heat, basically three ways to use PCM in building applications which are:

1- PCM in building wall

2- PCM in building component such as celling and floor.

3- PCM building interior instead of envelop.

The research aimed to take advantage of waste energy in boiler flue gasses, by extracting it and store the heat in PCMs that located in the building wall. PCM in the wall will works in two ways the first on as a thermal insulation due to low thermal conductivity and the second as a thermal storage mass. Boiler will operate for three hours during this period the heat will extract from the flue gasses by heat exchanger and stored in the PCM located in the south side of the building wall. After shout down the boiler PCM start to release the heat stored on it. An insulation is added on the outside face of the PCM to ensure all heat will transfer inside the building.

1.1 Phase Change Materials

Phase change materials (PCMs) are substances that change their physical characteristics due to absorbing or releasing heat, when PCM absorbing heat from the environmental. It melts, when the temperature decreases such

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material is releasing heat in the form of latent heat causing the material to freeze. Therefor phase change materials are considered as an effective thermal energy storage by utilizing the heat produced in phase change (liquid – solid and solid – liquid).

Phase change materials are used for many applications. One major sector is in building. It can be integrated with wall, ceiling boards and under floor heating system to increase the thermal storage capacity, increasing the internal comfort conditions of building and reducing the use of heating and cooling system. PCM are considering a useful in providing thermal insulation properties. Another sector that is interest in using phase change material is solar water heating.

1.1.1 The Mechanism of PCMs in Thermal Energy Storage

As shown in Figure (1), in sensible heat storage, heat will be stored or released due to change in temperature of the storage media, whereas in the latent heat storage the heat is released or stored as heat of fusion/solidification during phase change processes of the storage media. Phase change materials (PCM) transitioning between solid and liquid phase near room temperature have been used to enhance the thermal storage capacity of building materials. They store thermal energy in the form of latent heat when subjected to temperatures in excess of their melting point. Reversibly, PCM can release the thermal energy previously stored when the system temperature drops below their melting point [1].

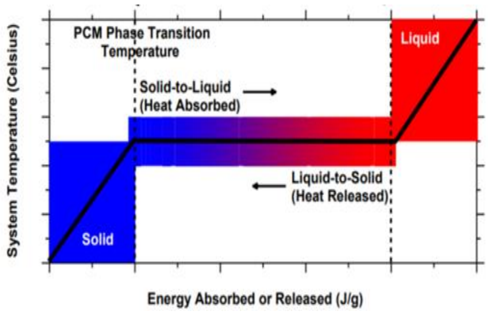

Figure 1. Mechanism of PCMs in thermal energy storage [1].

1.1.2 Types of Phase Change Materials

Phase change materials are classified in three categories: organic, inorganic, and eutectics as shown in the figure (2) [2].

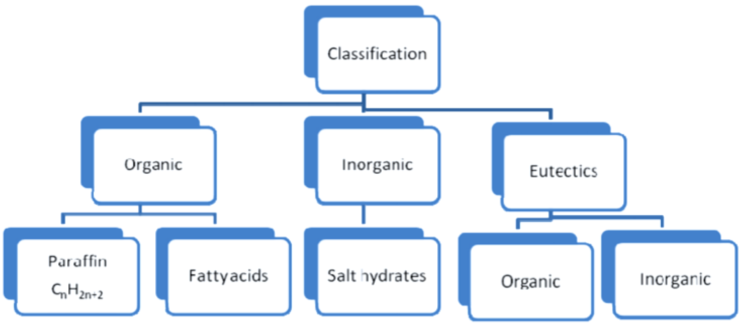

Figure 2. Type of PCMs [3].

. a- Organic PCMs are biological materials that consist of paraffin and fatty acids compound, and they have relatively low melting temperature.

b- Inorganic PCMs consist of salts or metal and they have relatively higher temperature.

c- Eutectics PCMs consist of two or more of organic compound, inorganic compound or a combination of them. They have lower melting temperature than the substance in the mixture.

1.1.3 Review of Previous Studies

Barreca and Praticò (2019) [4] conducted their study aimed to propose a control temperature system based on applying PCMs on the buildings envelope. To evaluate the effect of using a PCM, a case study was conducted on an olive mill building located in Scido (a small town in the province of Reggio Calabria in southern Italy), for purpose of improving the energy savings for temperature control. The intervention on the EVOO storage room to enhance the energy savings for temperature control depended on insulating partitions and installing a false ceiling to limit the air volume, with a sandwich of two layers; one of phase change material (PCM), and the other of rigid polyurethane foam with a 4 cm thick metal cladding. A Design Builder software was used for conducting a thermal analysis simulation to calculate the electric energy spent during a year to control air temperature in arrange of (8 to 22 °C). The results showed that the rate of energy consumption was 3590. 67 kWh/year for existing building corresponding to 2539.52 kWh/year for building with PCM, also a thermal indoor air stabilization in the storage room in the storage room. This condition obviously led to avoidance of a thermal fluctuation to the EVOO and it is the best storage condition. [4]

Frigione, et al. (2017) [5], conducted their study aimed to outline the advantages of PCMs in terms of their thermal efficiency in building materials, especially in passive building systems. The first part of the study introduced the main characteristics of PCMs, with description of the different ways of introducing them in building materials, whereas the second part reviewed recently published PCM experiments, focusing on some examples of PCMs introduced in concrete or mortars. Through the literature survey, the current study reviewed the utilized materials, and their supporters, procedures of preparation (methods used for incorporating PCMs in building materials), the performed tests to analyze the final product. The study, through its review of the PCM literature, concluded that PCMs are considered efficient materials improving thermal comfort in building, the selection of PCM to be constructed in a specific material or a definite application must depend on its properties (chemical, functional, thermos-physical, economic, environmental, etc.), micro-encapsulation is the most used method in incorporating PCMs in building materials, mortars and concretes are suitable construction materials for incorporating PCMs because of their presence in building constructions, and the most popular PCMs in building materials are PCM that has organic nature with a range of melting point between (20-40 ◦C).

Jin, at el. (2014) [6] conducted their study to find out the effects of PCM location on the building walls thermal performance. The effects of the state of salt hydrate PCM on performance of its phase change were tested using differential scanning calorimeter tests and the cooling experiments. The three phase change states are: fully melted state, partially melted state, and the not melted state. The results showed that the state of PCM had high effects on the PCM performance and super-cooling degree. In the three states, when the PCM was in the fully-melted state before cooling, its super-cooling degree was large, when the PCM was in the partially -melted state before cooling, it had the ability to release quickly the latent heat. Because the ranges of temperature of PCM during the thermal cycles were different when the PCM was located in different locations of the wall, the PCM location had significant effects on its state, and thus on the PCM performance and the improvement of building walls thermal performance.

The study applied by Evola and Marletta (2014) [7], the study discussed the effectiveness of PCM wallboards for improvement of thermal comfort in summer in lightweight buildings. Two types of PCM were used in the study investigation in different climate conditions. The study built its methodology depending on the results confirmed by some previous studies that is using wallboards composed of micro-encapsulated paraffinic PCMs is considered an effective and promising solution for the refurbishment of energy in lightweight buildings, and the ability of a PCM to enhance thermal comfort in summer in buildings is highly concerned to the probability to exploit its latent heat capacity. Therefore, to achieve the study aim, a parameter called PCM storage efficiency was introduced and computed. The study results confirmed that the main factors affecting storage efficiency of PCM are: the location of the PCM wallboards in the room, the temperature melting value for the determined PCM, and the rate of nighttime ventilation. Also, the results confirmed that PCMs must be convenientially related to the local climate in in existing buildings.

1.1.4 Paraffin Wax

The natural paraffin was known in the 1850s when scientists figured out how to separate wax materials from oil [8]. Paraffin Wax is a pure mixture of saturated hydrogenated coal and steel that form chemical alkanes, which have a high molecular weight, and a wide range of phase change temperature. They are expressed in chemical formula ($C_nH_{2n} + 2$), and are prepared from petroleum oil and shale oil [9]. They are straight chain saturated hydrocarbons with melting temperature ranging from 23 to 67°C. The chemical structure of paraffin is shown in the Figure 3.

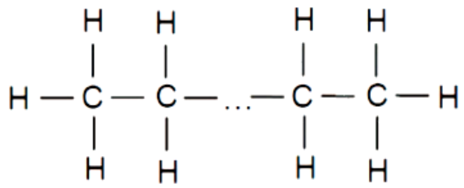

Figure 3. Chemical structure of paraffin [10].

The researcher believe that not all type of phase change materials are suitable for used as a thermal storage, it's depend on thermal, chemical and physical properties of the material that make it the best selection. This research is using paraffin wax (RT24) for thermal energy storage (TES), in the south side of the building, because of Features that makes it suitable for latent heat storage, they have a large heat of fusion per unit weight, non-corrosive, non-toxic, chemically stable. On melting, they have a low volume change and a low vapour pressure, and a melting temperature in the desired operating temperature range. The building of this research in located in al-karal city in Jordan, figure below shows the building plan.

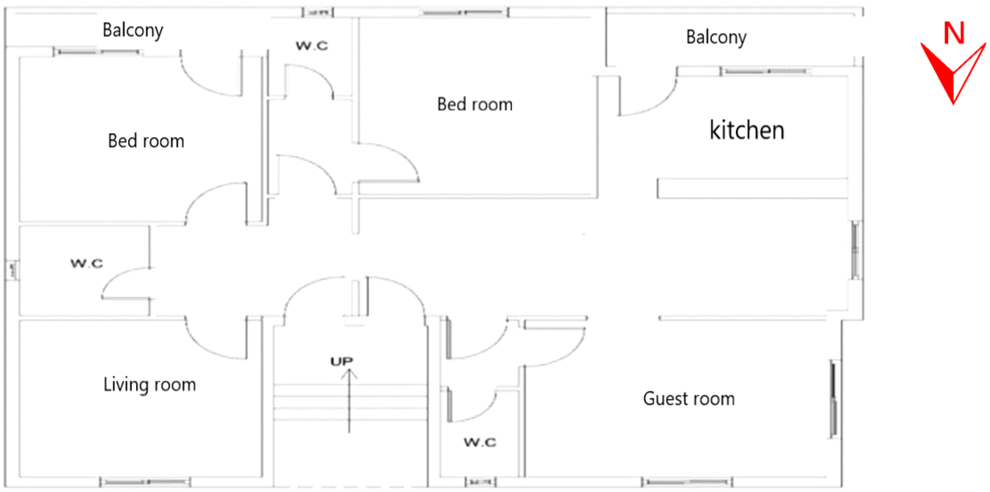

Figure 4. Floor Plane

The building of this research consists of two bed rooms, living room, guest room, two bathrooms and kitchen.

The table below shows the important parameters related to the building in this study.

Table 1. Building Specification

Component	Area (m^2)
Wall	144.54
Windows	18.25
Door	8.36
Celling	151
Floor	151

1.1.5 Boiler and Flue Gas Heat Recovery System

Boiler is a closed vessel that combust fuel with air in order to convert the chemical energy in a useful form of energy (heat), which used to heat water for various heat applications [11].

Fire tube boiler: or known as "fire in tube boiler " it contains long steel tubes through which the hot gasses from a furnace pass and around the water , and this type is the one used in this study, as shown in figure (5) below.

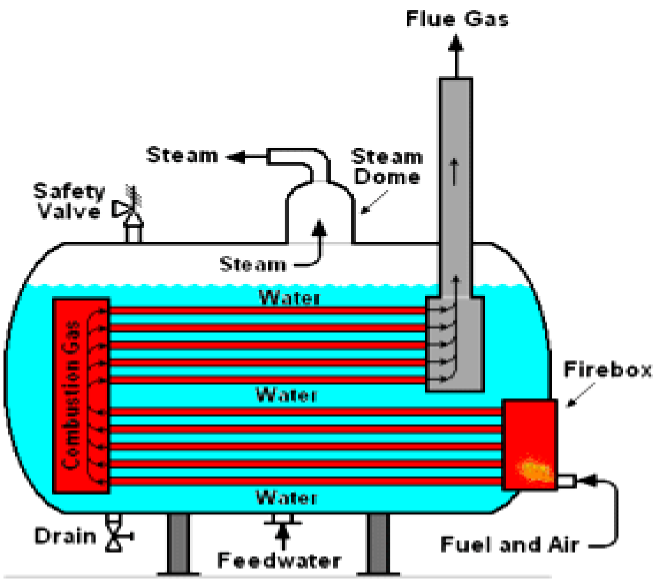

Figure 5. Fire tube boiler [11]

This research is taking advantage of the heat loss in flue gases by using flue gases heat recovery system to extract amount of heat that can be used to heat up phase change material in the wall using a zig zag pipeline through the phase change materials.

The Percentage heat loss due to dry flue gas (L1) is equal to [11]:

$$L1 = \frac{\dot{m} * cp * (Tf - Ta)}{Gcv\ of\ fuel} * 100\% \quad (1)$$

Where,

L1 is the percentage heat loss due to dry flue gas, ṁ is mass of dry flue gas (Kg), cp is specific heat of flue gas (Kcal/Kg °C), Tf is flue gas temperature (°C), Ta is ambient temperature (°C), Gcv is gross calorific value of fuel (KJ/Kg).

Table 2. Parameters for Boiler [12]

Data	Value
Flue Gas	
O2 In Flue Gas	8.3%
Co2 In Flue Gas	11.4%
Flue Gas Temperature	190 ^{0}C
Fuel Analysis	
Carbon	86%
Oxygen	1.3%
Nitrogen	0.7%
Hydrogen	10%
Sulphur	1.4%
Moisture	0.6%
Gcv For Fuel	10000 Kcal/Kg
Atmospheric Air	
Ambient Temperature	8 ^{0}C
Humidity In Air	0.01977 Kg/Kg Dry Air

L 1 is calculated using parameters in the table as following

$$L1 = \frac{28.5 * 0.24 * (190 - 8)}{10000} * 100\% \quad = 12.45\%$$

So the amount of heat in flue gasses is equal to (1.25 KW). The heat exchanger effectiveness is equal to (70%) this will lead to extract (875) W of heat from flue gas.

2 Methodology of the research

This research is using ansys software for comparing the heat losses through the walls with/without using (PCMs), and to shows the amount of heat that can be extracted from the boiler flue gasses and stored in the phase change materials along the south side of the building.so the feasibility of using (PCMs) as thermal energy storage can be determined.

3 Ansys Software Results

The plane wall of the building integrated with phase change materials, each layer has a thickness of (0.1 m), wall is divided to small sufficient number of volume element ($\Delta x = 0.05m$), with assumption of steady state one-dimensional heat transfer through the wall thickness with heat generation in the phase change materials layer, The source of heat generation is from the heat recovery from the boiler flue gas. The figure below shows the wall of building.

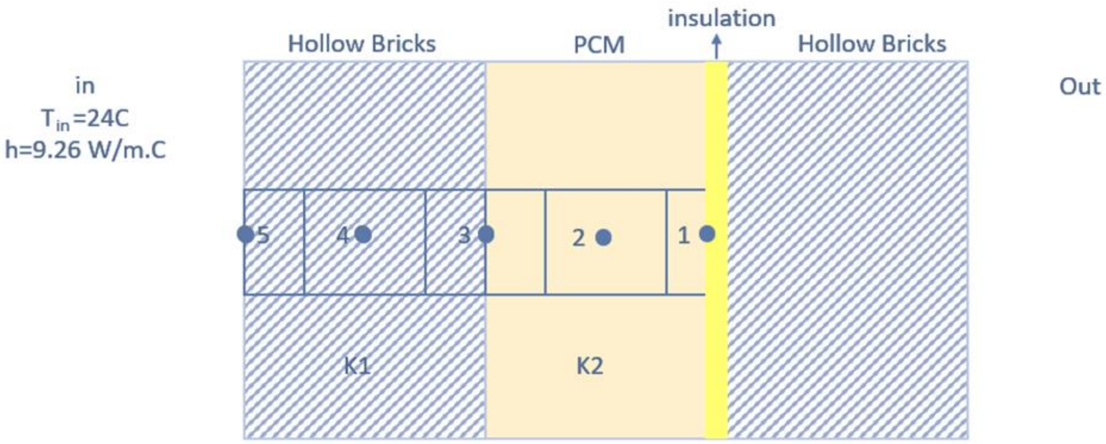

Figure 6. Plan Wall of the Building

3.1 Ansys Software Results without Using PCM in the Building Walls

By using the Ansys software figures (7) and (8) below show the heat transfer through the wall and temperatures distribution between walls layers:

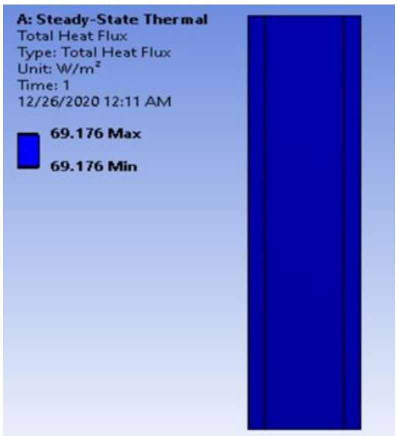

Figure 7. Heat flux through Wall

In figure (4.1) it ca be noted that the amount of heat flux through the wall without use phase change material is equal to (q = 69.176 W/m2), therefor the heat losses is equal to:

$$Q = q/A \qquad (2)$$

Where;

q: is the heat flux (W/m2)
A: is the wall area (m2)
Q = 69.176 * 144.54 = 9998.69 W

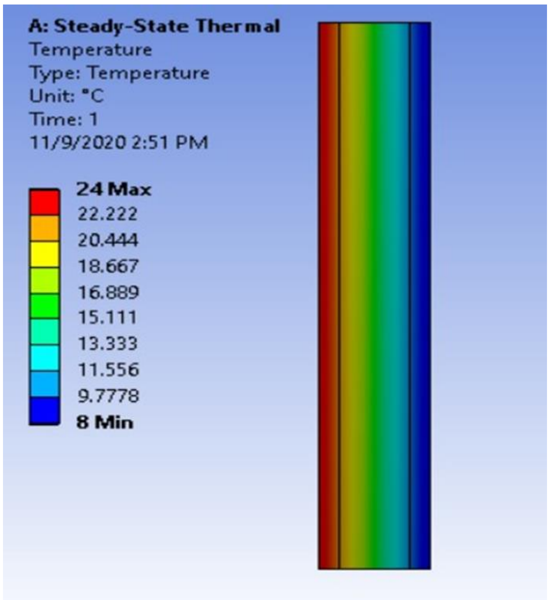

Figure 8. Temperature Distribution through the Wall

The figure above shows the maximum temperature inside the wall where its decrease through the outside layers. Temperature difference is the reason of heat transfer.

3.2 Ansys Results with Using PCM in Building Walls

Figure (9) and (10) show the heat flux and temperature distribution through the wall integrated with phase change material using Ansys software

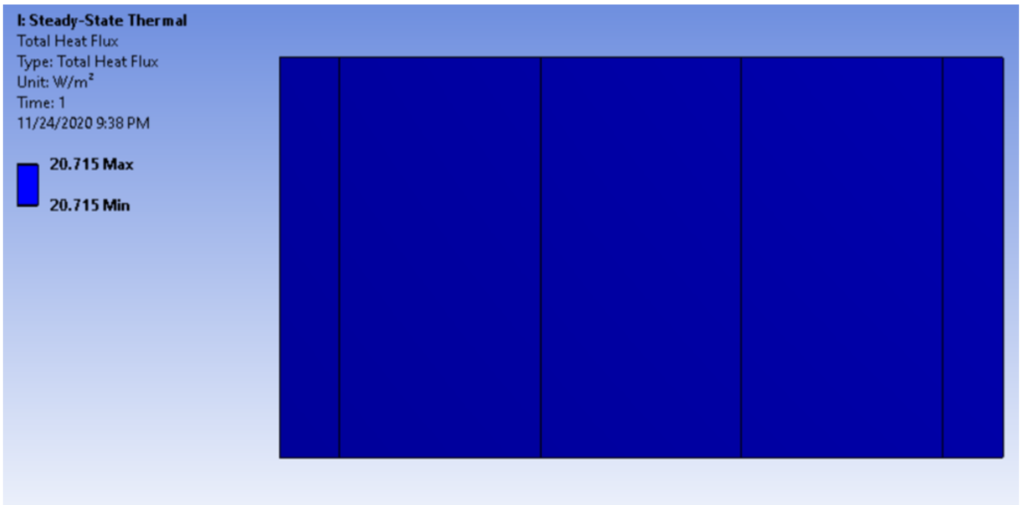

Figure 9. Heat Flux through Wall Using PCM

The total heat flux is (20.715 W/m2) which equal to (2994.15 W), phase change material behaves as a thermal insulation and help to reduce the heat transfer through the wall by (7667.12 W) with percentage equal to (72%), that indicate that phase change material has a good thermal insulation properties.

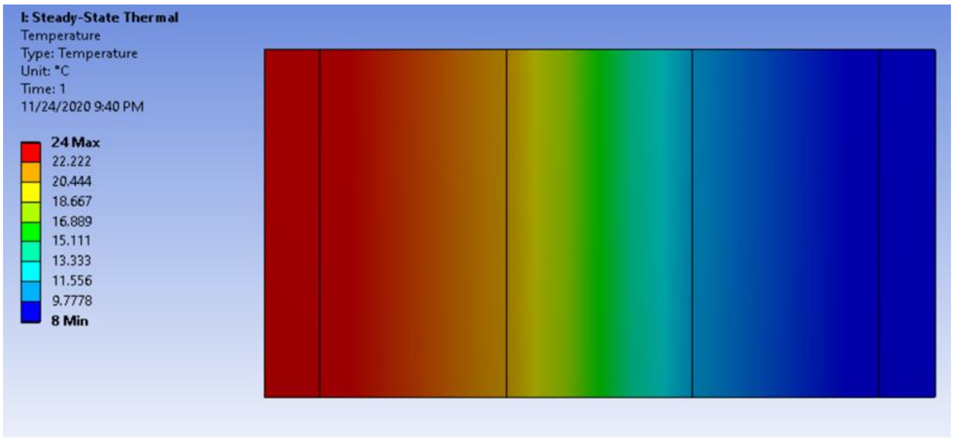

Figure 10. Temperature Distribution through Wall Integrated PCM

3.3 Charging Mode of PCM in the Building Wall

The table below shows the value of temperature at each nodes of the wall during charging mode where the heat is continuing to be added to the PCM from the heat exchanger located on the boiler flue gases.

Table 3. Temperatures Distribution for Each Surface Element by Using Ansys.

Time step (min)	T1 C̊	T2 C̊	T3 C̊	T4 C̊	T5 C̊	Q conv. (W)
15	25.845	25.687	24.401	24.167	24.39	151.67
30	28.44	27.908	25.034	24.437	24.51	198.34
45	32.355	31.237	26.002	24.833	24.62	241.13
60	37.581	35.636	27.318	25.383	24.72	280.02
75	43.545	40.564	28.882	26.089	24.81	315.02
90	49.845	45.754	30.611	26.905	24.90	350.02
105	56.55	51.293	32.502	27.813	24.99	385.03
120	63.536	57.06	34.518	28.798	25.07	416.14
135	70.687	62.962	36.624	29.841	25.14	443.036
150	77.909	68.921	38.788	30.926	25.21	470.59
165	85.129	74.88	40.98	32.013	25.23	478.37
180	92.289	80.787	43.161	33.08	25.25	490.03
Total						4220.27

The results of table (3) show the temperatures for each volume element during three hours when the boiler powered on, during this time phase change material is absorbed heat that came from the heat exchanger causing raised its temperature, we note from the table (3) that phase change material temperature is increased from (25.84 C̊) in the first (15 min) to (92.28 C̊) at the end of (180 min), and the total heat enter to the building by convection is equal to (4220.27 W). Figure (11) shows the temperature distribution using Ansys software during charging mode.

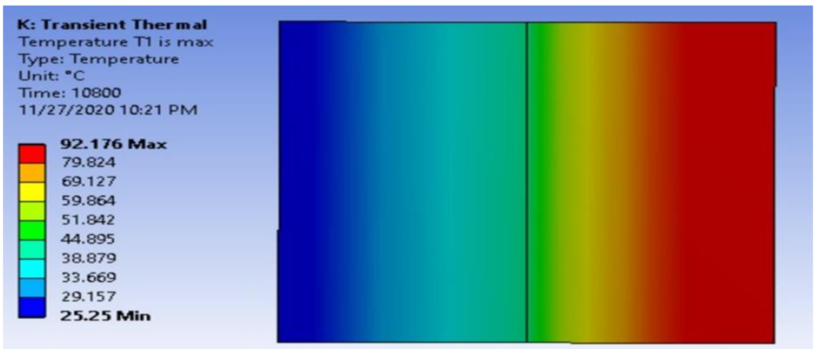

Figure 11. Temperature Distribution inside the Wall after 3 Hours

3.4 discharge mode of PCM in building wall

Table 4 shows the temperature distributions during the discharge mode using Ansys software.

Table 4. Temperature Distributions for Each Volume Elements by Using Ansys

Time step (min)	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C	Q conv. W
15	90.194	77.99	43.459	33.929	25	388.92
30	80.739	69.885	42.076	33.911	24.94	365.5848
45	72.562	63.533	40.547	33.377	24.88	342.2496
60	65.766	58.257	38.968	32.651	24.82	318.9144
75	60.096	53.788	37.426	31.865	24.77	299.4684
90	55.296	49.948	35.969	31.084	24.72	280.0224
105	51.218	46.648	34.628	30.342	24.68	264.4656
120	47.726	43.796	33.413	29.654	24.63	245.0196
135	44.719	41.324	32.322	29.028	24.6	233.352
150	42.119	39.175	31.352	28.466	24.56	217.7952
165	39.868	37.308	30.493	27.962	24.52	202.2384
180	37.909	35.679	29.732	27.514	24.49	190.5708
195	36.201	34.255	29.062	27.118	24.46	178.9032
210	34.711	33.011	28.471	26.767	24.43	167.2356
225	33.409	31.923	27.951	26.456	24.4	155.568
240	32.271	30.971	27.493	26.182	24.38	147.7896
255	31.275	30.137	27.091	25.941	24.36	140.0112
270	30.403	29.406	26.737	25.728	24.33	128.3436
285	29.64	28.766	26.425	25.538	24.31	120.5652
300	28.97	28.204	26.15	25.371	24.29	112.7868
315	28.383	27.711	25.908	25.223	24.27	105.0084
330	27.868	27.278	25.695	25.091	24.25	97.23
345	27.415	26.897	25.505	24.971	24.21	81.6732
360	27.018	26.562	25.332	24.844	24.09	35.0028
375	26.667	26.263	25.166	24.72	24.06	23.3352
390	26.356	25.996	25.013	24.615	24.03	11.6676
405	26.078	25.756	24.878	24.523	24	0
Total						4853.722

Table (4) shows the results of temperature value when the boiler is shutting down, the heat is flow inside the building from the energy stored in phase change material during working hours of the boiler.as shown in figure (12) below.

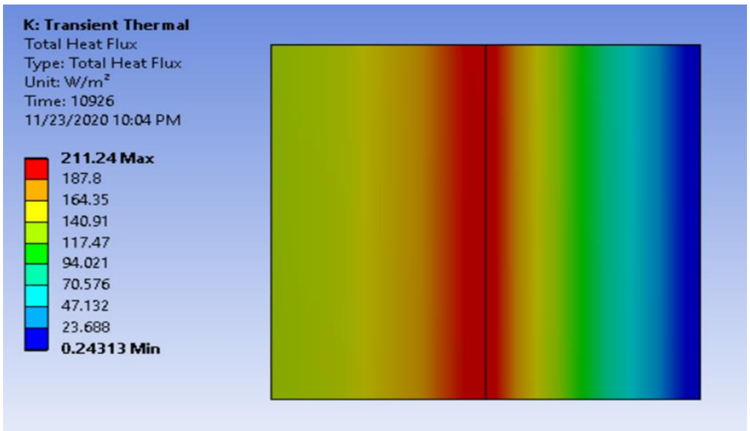

Figure 12. Heat Flux inside the Wall after Turn off The Boiler

Figure (12) shows that the maximum heat flux after turn off the boiler is occurred at the interface between the phase change material and the hollow brick on the negative x directions (-x axis), while lower heat flux into positive x direction where the thermal insulation is located. The total heat comes from stored energy is equal to (4853.722 W) and it takes (405 minutes) to discharge all the heat from phase change material.

4 Conclusion

Based on this study, the following results is obtained:

1- By adding a new layer from phase change material to the wall, it behave as a thermal insulation due to low thermal conductivity, and contributed to reduce heating load by (7.66712KW), which represent (72%) of the total heat loss through the wall.

2- In the south side of the building phase change material work as a thermal energy storage, and contributed by (9.07 KW) entered the building by convection heat transfer, which represent (43%) of the total heating load of the building.

3- The heat stored in phase change material is continuo to adding heat by convection to the building after turned off the boiler for (405 min). which means to reduce the operating hours needed for the boiler and reduced harmful gases and fuel consumed.

4- The study found that the paraffin wax is suitable for use in building applications because of its physical properties and relatively low cost.

References

[1] Wel Zhenhua, Phase Change Materials and Clinkering-Free Cementation for Sustainable Building Materials, PhD Thesis, University of California, Los Angeles, 2017.
[2] Weaver Ryan, Heat Transfer Enhancement of Phase Change Materials for Thermal Energy Storage Systems, Ms thesis, University of Missouri-Kansas City, 2019.
[3] Zeyad Amin Al-Absi, at el., Phase Change Materials (PCMs) and Their Optimum Position in Building Walls. 12(1293) (2020) 3.
[4] Barreca, F. and Praticò, P. (2019). "Environmental Indoor Thermal Control of Extra Virgin Olive Oil Storage Room with Phase Change Materials"
[5] Frigione, M., Lettieri, M., and Sarcinella, A. (2017)."Phase Change Materials for Energy Effciency in Buildings and Their Use in Mortars"
[6] Jin, X., Zhang, S., Xu, X., and Zhang, X. (2014)."Effects of PCM State on its Phase Change Performance and the Thermal Performance of Building Walls". Building and Environment, 81, 334-339
[7] Evola, G., and Marletta, L. (2014)."The Effectiveness of PCM Wallboards for theEnergy Refurbishment of Lightweight Buildings".
[8] Rathgeber, C., Miró, L., Cabeza, L., Hiebler, S., Measurement of enthalpy curves of phase change materials via DSC and T-History: When are both methods needed to estimate the behaviour of the bulk material in applications. Thermochimica Acta, 596 , (2014), 79–88.
[9] Yeon, J. H., and Kim, K. K. , Potential applications of phase change materials to mitigate freeze-thaw deteriorations in concrete pavement. Construction and Building Materials, 177, 202 (2018) 20.
[10] Rashid, Y., Ziauddin, M., Mathew, B., and Alnaimat, F. , The potential of phase change materials in mitigating cooling load of buildings in UAE. International Journal of Low-Carbon Technologies, 14, (2019) 568–575.
[11] Ahmad Mahmoudi Lahijani., A Review of Indirect Method for Measuring Thermal Efficiency in Fir Tube Steam Boiler. (2018).
[12] Bureau of energy efficiency, Energy Efficiency in Thermal Utilities. (2015).