ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Numerical Investigation of a Prototype Phase Change Material Construction Elements

Hyder M. Abdul Hussein
Faculty of Engineering, University of Kufa, Al Najaf, Iraq,
Muna Hameed Alturaihi
Mechanical Engineering Department, Faculty of Engineering, University of Kufa,
Sanaa TurkiMousa AL-Musawi
University of Baghdad, Department of Reconstruction and Projects
LaithJaaferHabeeb
Training and Workshop Center, University of Technology, Baghdad, Iraq,

Abstract
With the development of modern architecture in buildings, the introduction of thermal engineering has become very widespread, as studies are focused on increasing the utilization of the natural thermal source.Which is the sun, as renewable energy sources have become widely used and benefited from.But solar radiation can be used only from daylight hours, as it is necessary to put it enables us to use the sun's heat in the night hours.So, phase-changing materials are used that help retain heat by converting its phase from solid to liquid.Where it is solid during daylight hours and after gaining sunlight, it turns into a liquid phase and when the sun sets, it expels that heat in order to return to the solid phase. Where in this research paper, the placement of phase-changing materials inside the wall to maintain room Temp.s during the night was studied. The results show that the greater the thickness of the concrete material, the greater the storage of heat-phase-changing materials after sunset.Therefore, the greater the thickness of the gypsum material, the greater the storage of the gypsum material for heat transmitted from the materials of variable length.And that the best case simulated as results are concrete thickness of 100 mm and thickness of gypsum 15 mm.
Keywords:Phase change material, construction elements, concrete material, gypsum material.

1. Introduction

Phase change materials (PCMs) are used to stabilize Temp.s and store heat. PCMs have higher energy density and fairly insignificant Temp.variations. The incorporation of PCMs into wall layers such as plasters or gypsum boards improves the building's thermal mass [1].In the United States, space heating and air conditioning accounted for 48% of residential end-use energy consumption. Through the use of phase change materials (PCMs), it is possible to enhance the energy efficiency of buildings by reducing the heating and cooling loads produced by the envelope [2]. The thermal performance of integrated phase change materials (PCM) in building walls has been investigated. PCMs must be incorporated into the walls in thin longitudinal layers. The thermal performance of south and west facing walls with and without PCMTS was evaluated using two identical test dwellings [3]. A PCM dimension incorporates phase change material as a heat storage medium (PCM). Solar transmittance of the TGU fell by nearly 100% in the summer compared to the winter. There were no overheating issues with the PCM walls over the summer [4]. An optimization study was conducted on an office wall that had a layer of phase change material (PCM) and was subjected to intermittent cooling. Regardless of the thickness of the PCM layer, the optimal phase transition Temp.was 25 °C. PCM installed near the outside did not save energy and may have increased consumption [5]. Thermal performance testing equipment was built, and an experimental model was created in which solar light irradiated the

PCM layer during the day and disappeared at night. The findings indicate that by enhancing the absorptivity of the wall, PCM layers may increase surface Temp.and heat flow during the heat storage process [6]. Thermal energy storage using phase change materials (PCMs) is gaining popularity as a means of conserving energy. This study examines the effect of PCM on the rate of heat transmission through a building wall. Moving the PCM closer to the heat source results in a cold-water bath with a negligible Temp.rise [7]. A novel PCM material has been developed to improve the thermal performance of light weight building interior partition walls. Numerical modeling was used to investigate energy storage. Five millimeters of PCM wallboard increases the amount of energy that may be provided and destocked throughout the experiment by a factor of two [8]. A brick wall integrating phase change materials (PCM) is compared to a solid brick wall in terms of thermal sensitivity. PCM is used for thermal insulation, Temp.hysteresis, and thermal comfort during occupation. As the quantity of PCM increases, the volatility of the inner wall surface Temp.is greatly smoothed down [9]. Along with the observable energy capacity of conventional building materials, phase change materials (PCMs) may store latent thermal energy. Solar energy is harnessed via the introduction of PCMs into building envelope solutions, resulting in a reduction in total energy consumption related with the usage of air conditioning systems. [10]. PCMs melt around 16 hours per day in Room C, which is approximately 2.3 hours longer than in Room B. In general, the RC-PCM-wall offers a great deal of promise for reducing fossil fuel use during the summer season. The phase change process of the PCM is examined for its effect on the attenuation and time delay of Temp.fluctuations in interior spaces [11]. The melting and freezing of a PCM thermal storage unit (TSU) with variable wall Temp.is investigated numerically. The model utilized takes into consideration both Temp.variations along the direction of air flow and sensible heat. The article addresses the typical melting and freezing properties of PCM slabs in an air stream [12]. The evaluation of a novel translucent super-insulated latent heat storage wall that incorporates transparent insulation and phase change materials. In polar and subarctic conditions, the application of the TIM-PCM wall has a high economic value, and the investment looks to be attractive. Due to low energy prices and high discount rates, it is economically impractical to use the wall in Dras (continental climate) [13]. Because the fuel efficiency of a conventional PCM wall is poor during the summer, PCM that stores heat during the day acts as a supplementary heat source, returning heat to the room at night. In a hot region, the pipe-encapsulated PCM's internal surface cumulative heat transfer may be decreased by 74.5 percent when compared to a normal wall. It has considerable potential for energy-saving applications in buildings [14]. According to the researchers, a pipe-encapsulated PCM wall system with self-activated heat removal through a nighttime sky radiation cooler is a feasible way for insulating and cooling buildings with natural energy. According to the experts, this system is capable of resisting or removing 55.6 percent -82.8 percent of heat from the external environment during the day and 54.7 percent -81.0 percent of heat during the night. When compared to a conventional wall, the suggested technology has the potential to reduce accumulated heat entering the interior environment by 32.4 and 55.5 percent, respectively [15]. The integrated PCM Trombe wall may raise the Temp. of the inside air by 0.82°F (1.88°C) in the low heat input mode and by 3.27°H (3.75°F) in the high heat output mode. It has a melting point of 21.33 °F and a latent heat of 133.4 KJ/kg, respectively, and a volume expansion rate of 7.94 percent. Even if the absorber surface is heated equally, two-dimensional heat transmission in the height and thickness directions of the PCM wall results in significant Temp.differences in these two dimensions. The irregular-shaped liquid/solid interface occurs [16]. This study discusses the thermal performance of several kinds of systems, including PCM Trombe walls, PCM wallboards, and PCM shutters, as well as air-based heating systems. All of these methods offer significant promise for heating and cooling buildings through phase change materials, as well as for lowering the energy consumption of buildings [17]. Phase change materials (PCMs) are an effective technique to lower a building's energy usage. Although PCM wallboards used in buildings have been extensively investigated and improved in several studies, more thermal performance study is required. The energy consumption of the building utilizing a PCM with a greater phase change range was found to be 103 kJ less in June and 72 kJ more in December [18]. We show an exterior wall solution for solar space heating and daylighting. The technology allows solar radiation to be transmitted optically selectively. Visible light is mostly transmitted, but infrared radiation is primarily absorbed and transformed to heat, producing phase change in particular.A mean energy flow of 13 W/m^2 (system efficiency of 0.27) was determined through a south facing TIM–PCM wall in a Swiss lowland environment [19].

2. Originality

Through the exploration of research packages that are concerned with the study of phase-changing materials, we did not notice the researchers' interest in using these materials and taking advantage of their thermal ability to change the phase in the wall and modern structure and the development of comfort technology in construction, where the benefit of using phase-changing materials in the wall and the correct dimensions were studied. Which helps to keep the nappy at room Temp.during the winter time.

3. Methodology

The shape of a section of the wall, which is in the form of a hexagon, where the wall is like a beehive, is designed because the beehive is characterized by the diaper on the existing wax. The section of the wall was divided into three regions, an area containing concrete, which is the outer area, and then the phase-changing materials, which are in the middle of wax. Paraffin and then gypsum, This is the wall's inside surface, where a study was conducted on the effect of the dimensions of the outer and inner wall surrounding the phase-changing materials, where Lc represents the length of the concrete and variable outer wall (60mm, 80mm, 100mm), Lg represents the length of the inner wall consisting of gypsum (5mm,10mm,15mm),Where the shape was completely designed with the SOLIDWORKS program as in Figure (1).

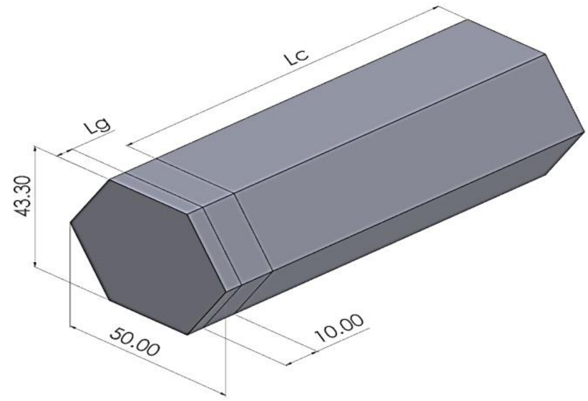
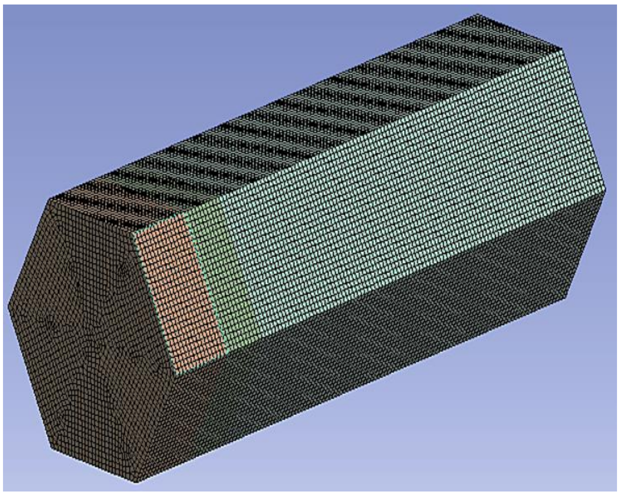


Figure (1):Domain dimensions

The simulation process was carried out by ANSYS CFD program, which requires obtaining an accurate mesh to obtain good and satisfactory results, as many types of mesh were made to obtain stability at Temp.s as shown in Figure (2).



Figure(2): mesh domain

Table (1): mesh depends

Case	Nodes	Elements	T(K)
1	64590	51207	309.5
2	120756	105298	315.2
3	163458	152457	317.7
4	227493	213180	317.8

Where stability or reliability in Temp.s was obtained for one of the cases studied on element 213180as the best reliable mesh.

Paraffin wax, which is one of the types of phase-changing materials, was used to melt it and convert its phase at low Temp.s, and the building materials used in the study have physical properties that are in line with the current construction reality.

Table (2): Material properties

Material properties	Paraffin wax	Gypsum	Concrete
Melting Temp.	45 ºC	....	....
Fusion's latent heat	190 kJ/kg	....	....
Density of solids	930 kg/m^3	784 kg/m^3	2300 kg/m^3
Liquid density	830 kg/m^3	....	....
Thermal conductivity	0.21 W/m.C	0.24 W/m.K	1.8 W/m.K
Specific heat of solids	2.1 kJ/kg.C	0.95 kJ/kg.K	0.8 kJ/kg.K
Specific heat of liquid	1.98 kJ/kg.C	....	....

Where the outer surface of the system was used and solar radiation was shed on it after setting the conditions of the situation from the latitude and longitude of Iraq and using the month of November to obtain the effect of radiation in this place and time used.As for the inner surface of the case, a convective heat transfer of 8.3W/m²K and an internal Temp.of 300 K was used.

4. Governing equations

The mass production rate during the non-equilibrium condensation on process is defined in classical nucleation on theory as the sum of the mass increase due to nucleation on (the creation on of critically sized droplets) and the growth/demise of these droplets.Therefore, Γ is written as:

$$\Gamma = \frac{4}{3}\pi\, \rho_l\, I r_* 3 + 4\pi\, \rho_l\, \eta \bar{r}^2 \frac{\partial r}{\partial t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

Where $\bar{r}$ is the droplet's average radius, and r_* is the Kelvin-Helmholtz critical droplet radius, the value beyond which the droplet expands and below which it dissipates.

$$r_* = \frac{2\sigma}{\rho_l\, R\, T\, \ln S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2$$

where is the liquid surface tension at Temp.T_{pl} is the condensed liquid density (also at temperature T), and S is the super saturation ratio, defined as the ratio of the vapor pressure to the equilibrium saturation pressure:

$$S = \frac{P}{P_{sat}(T)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 3$$

Typically, the growth process is fairly fast. As a result, When the state path exceeds the saturated-vapor line, the process departs from equilibrium, resulting in a super saturation ratio S greater than one. Condensation is a two-step process that involves mass transfer from vapor to droplets and heat transfer from droplets to vapor through latent heat.

$$\frac{\partial r}{\partial t} = \frac{P}{h_{lv}\,\rho_l\sqrt{2\pi RT}}\frac{\gamma+1}{2\gamma}C_{pv}(T_0 - T) \dots\dots\dots\dots\dots\dots 4$$

where T_0 is the droplet Temp.,h_{lv} is the specific enthalpy of evaporation at pressure P,C_{pv} is the vapor isobaric specific heat capacity, γ is the ratio of specific heat capacities, and R is the specific gas constant for gaseous mixture of air and vapor. Hill's droplet growth formula (Equation 4) is shown to predict reasonably well the Wilson Point pressure rise for nozzle flows. However, it tends to underestimate average droplet size distribution. To improve the average droplet size, Young's droplet growth. This formula is tunable with two modeling parameters, α and β:

$$\frac{\partial r}{\partial t} = \frac{k_v\,\Delta T\left(1 - \frac{r_*}{r}\right)}{\rho_l h_{lv}\,\bar{r}\left(\frac{1}{1+2\beta\,Kn} + 3.78(1-v)\frac{Kn}{Pr}\right)} \dots\dots\dots\dots\dots 5$$

Where

$$v = \frac{RT_s}{h_{lv}}\left(\alpha - 0.5 - \frac{2-q_c}{2q_c}\left(\frac{\gamma+1}{2\gamma}\right)\left(\frac{C_{pv}T_s}{h_{lv}}\right)\right) \dots\dots\dots\dots\dots 6$$

And ΔT is the vapor sub cooling:

$$\Delta T = T_s - T \dots\dots\dots\dots\dots\dots\dots\dots\dots 7$$

withT_S being the saturation Temp.at pressure P.

Other variables are as follows:

$Kn = \bar{l}/2r$is the Knudsen number, $\bar{l} = 1.5\,\mu_v\sqrt{R\,T/p}$ is the mean free path of a vapor molecule, μ_v is the vapor dynamic viscosity, k_v is the vapor thermal conductivity, $Pr = \mu_v\,c_{pv}/k_v$ is the vapor Prandtl number, q_c is the evaporation coefficient, α is a modeling parameter with default value 9. It is the growth coefficient that relates the condensation coefficient with the evaporation coefficient. $\beta$is a modeling parameter with default 1. It is a coefficient that adjusts the distance from the droplet at which continuum processes, as opposed to free-molecular processes, occur, with typical values between 0 and 2.Both formulas for the droplet growth are available in Fluent, with Young's formula beingthedefault.In the absence of contaminants or foreign particles, the traditional homogeneous nucleation theory explains the creation of a liquid phase in the form of droplets from a supersaturated phase. The steady-state classical homogeneous nucleation rate, adjusted for non-isothermal influences, is given by:

$$I = \frac{q_c}{(1+\theta)}\left(\frac{\rho_v^2}{\rho_l}\right)\sqrt{\frac{2\sigma}{M_m^3\,\pi}}\,e^{-\left(\frac{4\pi\,r_T^2\,\sigma}{3k_B\,T}\right)} \dots\dots\dots\dots\dots\dots 8$$

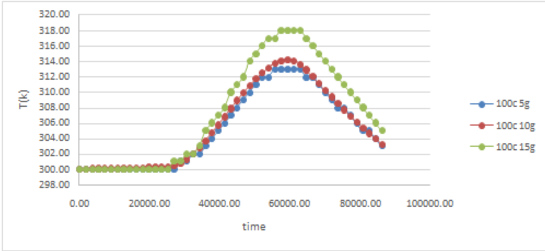
where$q_c$is the coefficient of evaporation, $k_B$is known as Boltzmann's constant, $M_m$is the mass of a single molecule, $\sigma$is the surface tension of a liquid, and ρ_l is the liquid density at Temp.T. A factor that is not isothermal, θ, is given by:

$$\theta = \frac{2(\gamma-1)}{(\gamma+1)}\left(\frac{h_{lv}}{R\,T}\right)\left(\frac{h_{lv}}{R\,T} - 0.5\right) \dots\dots\dots\dots\dots\dots\dots 9$$

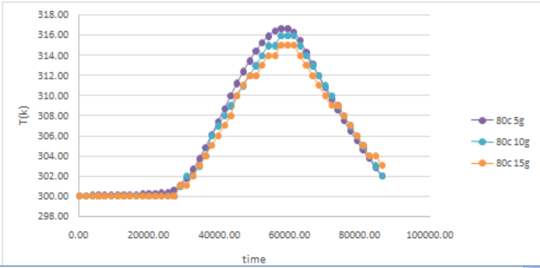
where$h_{lv}$is the evaporation's specific enthalpy at pressure$p$ and $\gamma$is the reciprocal of the ratio of specific heat capacities.

5. Results and discussion

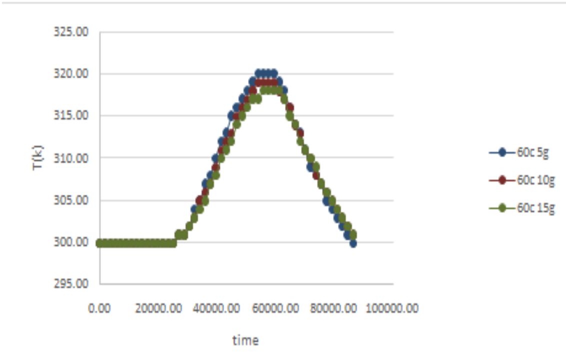
The simulations were carried out under natural weather conditions in November, using a total time of 24 hours, and the time step was 1800 seconds. The simulation results were taken every half hour using the different dimensions of concrete and gypsum.



(a)



(b)



(c)

Figure (4): Temp.s over time on the inner surface

Through the previous figure, where the change in the Temp. of the inner surface during the time was according to the different lengths of gypsum and concrete, where we note that the increase in the length of the gypsum material affects the Temp.s due to maintaining Temp.s through the PCM, where the length-changing materials work to feed the gypsum material during the times when As for the difference in the lengths of the concrete material, the time required to feed the PCM material increases after a decrease in the incident solar radiation due to sunset.

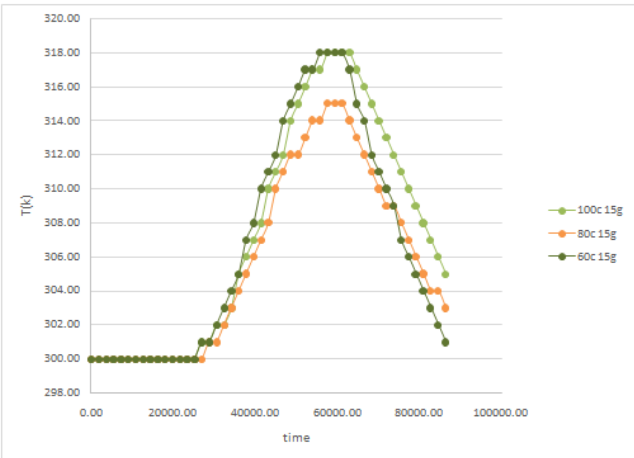


Figure (5): Temp.s over time on the inner surface

Figure (5) gives the final concept of understanding the situation, as the largest length of the concrete wave helps to perpetuate the feeding of the PCM material after sunset and maintain it on the heat until the next day.

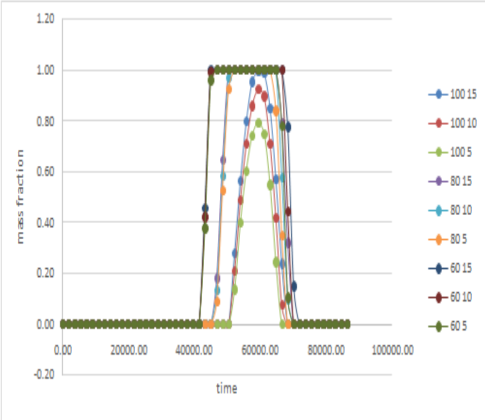
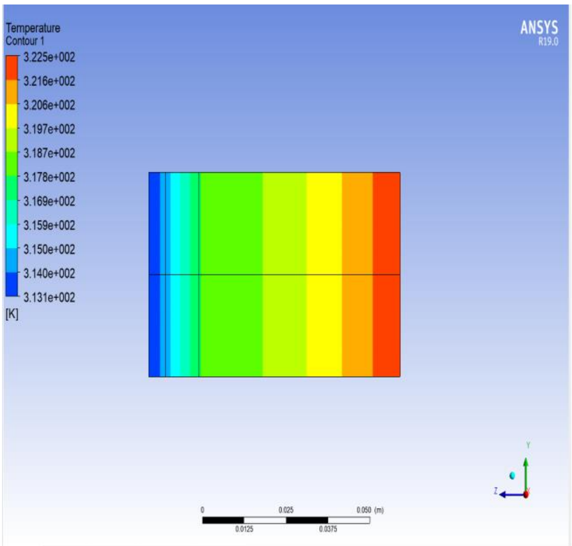
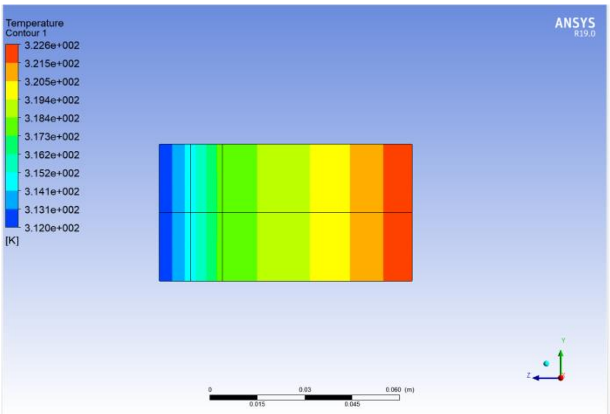


Figure (6): Mass fraction over time on the inner surface

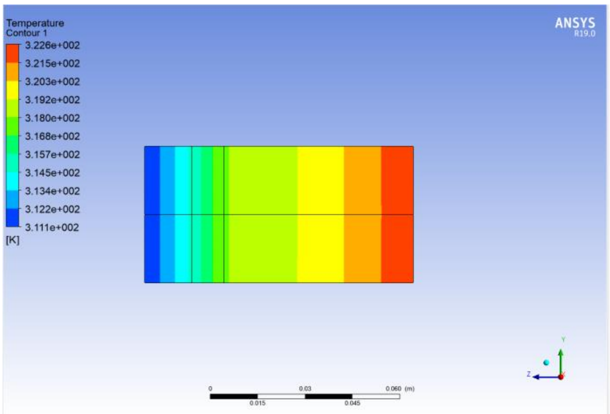
The process of phase transformation in phase-changing materials requires an increase in Temp.s and through the previous figure we note that the best time for PCM is in the melting state, the length of concrete is 60 mm and gypsum is 5 mm, due to the large heat transfer within the materials, and this does not mean that it represents the best case, because rapid loss of Temp., figure (6).



(a)



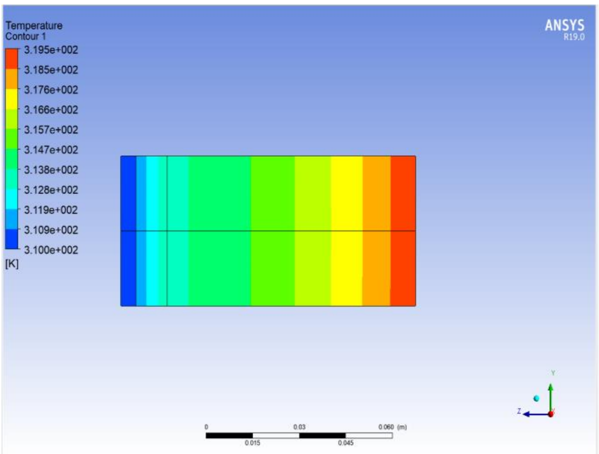
(b)



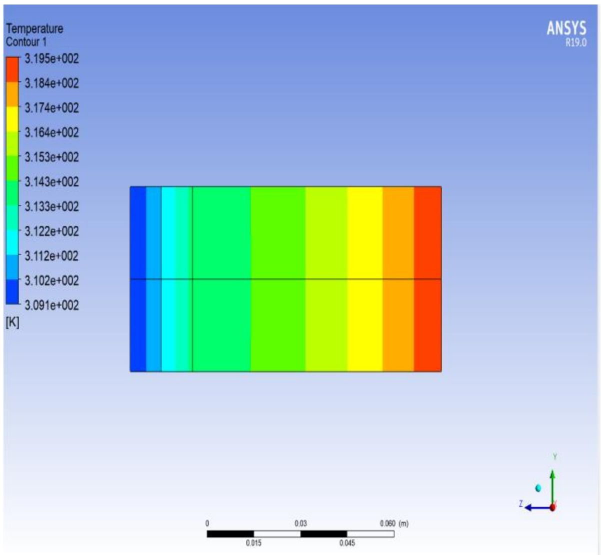
(c)

Figure (7): Distribution of Temp.s inside the materials at 12 o'clock for thickness concrete 60mm. (a)thickness gypsum 5mm, (b)thickness gypsum 10mm, (c)thickness gypsum 15mm.

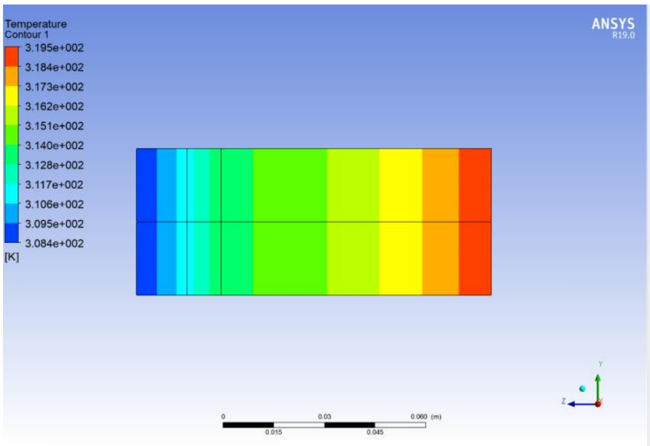
The Increased thickness of the internal gypsum greatly affects the process of heat transfer to the interior and the existing phase-changing materials. We note through the previous figures in the thickness of concrete 60 mm at the thickness of gypsum 5 mm that the Temp.reached is a maximum of 322 K and a minimum of 313 K and that the state whose thickness is 10mm has a maximum Temp.of 322K and a minimum of 312K. Also, the thickest thickness of 15mm has reached 322K and the minimum is 311K. It was found through the results that the large thickness kept the Temp.for a longer time and entered it into the room.



(a)



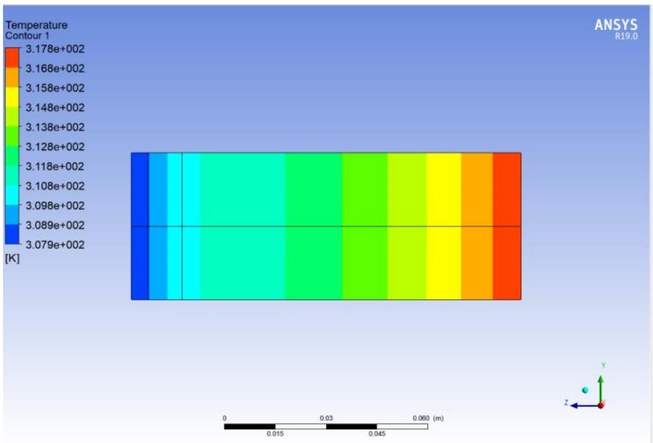
(b)



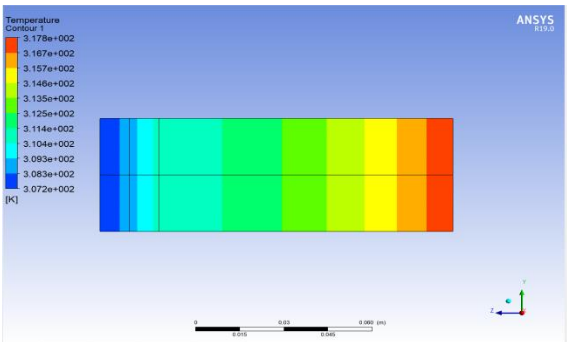
(c)

Figure (8): Distribution of Temp.inside the materials at 12 o'clock for thickness concrete 80mm. (a)thickness gypsum 5 mm, (b)thickness gypsum 10mm, (c)thickness gypsum 15mm.

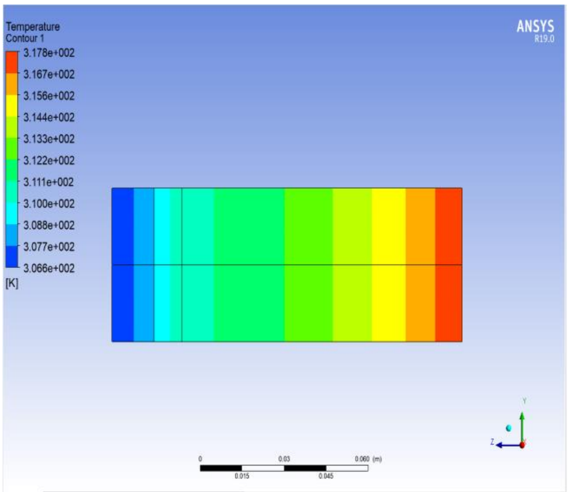
The Increased thickness of the internal gypsum greatly affects the process of heat transfer to the interior & the existing phase-changing materials. We note through the previous figures in the thickness of concrete 80 mm at the thickness of gypsum 5 mm that the Temp.reached is a maximum of 319K& a minimum of 310K and that the state whose thickness is 10mm has a maximum Temp.of 319K and a minimum of 309K. Also, the thickest thickness of 15mm has reached 319K and the minimum is 308K. It was found through the results that the large thickness kept the Temp.for a longer time and entered it into the room.



(a)



(b)



(c)

Figure (9): Distribution of Temp.s inside the materials at 12 o'clock for thickness concrete 100mm. (a)thickness gypsum 5mm, (b)thickness gypsum 10mm, (c)thickness gypsum 15mm.

The increase in the thickness of the internal gypsum greatly affects the process of heat transfer to the interior and the existing phase-changing materials. We note through the previous figures in the thickness of concrete 100 mm at the thickness of gypsum 5 mm that the Temp.reached is a maximum of 317 K and a minimum of 308K and that the state whose thickness is 10mm has a maximum Temp.of 317K and a minimum of 307K. Also, the thickest thickness of 15mm has reached 317K and the minimum is 306K. It was found through the results that the large thickness kept the Temp.for a longer time and entered it into the room.

6. Conclusions

One of the benefits of variable length materials is that they maintain Temp.s

1. They can be used after the absence of sunlight.
2. A study was conducted to put paraffin wax inside the wall space between concrete and gypsum.
3. Changing the longest of them and knowing the best of the longer ones that help in maintaining high Temp.s during times that are not the sun is present.
4. It turns out that the best length we can benefit from is from harnessing the heat of the sun when the thickness of the concrete for the outer wall is 100 mm and the thickness of gypsum in the inner wall is 15 mm to get the best result.
5. The Temp.remains high until the next day.

References

1. H. Schranzhofer, P. Puschnig, A. Heinz, and W. Streicher, VALIDATION of a TRNSYS SIMULATION MODEL for PCM ENERGY STORAGES and PCM WALL CONSTRUCTION ELEMENTS.
2. Kaushik Biswas, JueLu,ParvizSoroushian, SomShrestha.“Combined Experimental and Numerical Evaluation of a Prototype Nano-PCM Enhanced Wallboard.” Applied Energy, vol. 131, Oct. 2014, pp. 517–529, 10.1016/j.apenergy.2014.02.047. Accessed 7 Nov. 2021.
3. Kyoung Ok Lee, Mario A. Medina, Erik Raith, Xiaoqin Sun. “Assessing the Integration of a Thin Phase Change Material (PCM) Layer in a Residential Building Wall for Heat Transfer Reduction and Management.” Applied Energy, vol. 137, Jan. 2015, pp. 699–706, 10.1016/j.apenergy.2014.09.003. Accessed 7 Nov. 2021.
4. Kara, Yusuf Ali, and AslihanKurnuç. “Performance of Coupled Novel Triple Glass Unit and Pcm Wall.” Applied Thermal Engineering, vol. 35, Mar. 2012, pp. 243–246, 10.1016/j.applthermaleng.2011.10.033. Accessed 7 Nov. 2021.
5. EkremTunçbilek, Müslüm Arıcı1, Michal Krajčík, SandroNižetić, HasanKarabay. “Thermal Performance Based Optimization of an Office Wall Containing PCM under Intermittent Cooling Operation.” Applied Thermal Engineering, vol. 179, Oct. 2020, p. 115750, 10.1016/j.applthermaleng.2020.115750. Accessed 7 Nov. 2021.

6. JingchaoXie, Wei Wang, Pengfei Sang, Jiaping Liu. “Experimental and Numerical Study of Thermal Performance of the PCM Wall with Solar Radiation.” Construction and Building Materials, vol. 177, July 2018, pp. 443–456, 10.1016/j.conbuildmat.2018.05.123. Accessed 7 Nov. 2021.
7. Rafid Jahangir Khan, Md. Zubayer Hossain Bhuiyan and Dewan HasanAhmed. “Investigation of Heat Transfer of a Building Wall in the Presence of Phase Change Material (PCM).” Energy and Built Environment, vol. 1, no. 2, Apr. 2020, pp. 199–206, 10.1016/j.enbenv.2020.01.002. Accessed 7 Nov. 2021.
8. Fre´de´ricKuznik, Joseph Virgone, Jean-Jacques Roux. “Energetic Efficiency of Room Wall Containing PCM Wallboard: A Full-Scale Experimental Investigation.” Energy and Buildings, vol. 40, no. 2, Jan. 2008, pp. 148–156, 10.1016/j.enbuild.2007.01.022. Accessed 7 Nov. 2021.
9. Chengbin Zhang, Yongping Chen, Liangyu Wu, Mingheng Shi. “Thermal Response of Brick Wall Filled with Phase Change Materials (PCM) under Fluctuating Outdoor Temp.s.” Energy and Buildings, vol. 43, no. 12, Dec. 2011, pp. 3514–3520, 10.1016/j.enbuild.2011.09.028. Accessed 7 Nov. 2021.
10. Tiago Silva, Romeu Vicente, Nelson Soares, Victor Ferreira. “Experimental Testing and Numerical Modelling of Masonry Wall Solution with PCM Incorporation: A Passive Construction Solution.” Energy and Buildings, vol. 49, June 2012, pp. 235–245, 10.1016/j.enbuild.2012.02.010. Accessed 7 Nov. 2021.
11. Wei He, Cairui Yu, Jichun Yang, Bendong Yu, Zhongting Hu, DongmeiShen, Xianghu,Liu,Minghui Qin, Hongbing Chen. “Experimental Study on the Performance of a Novel RC-PCM-Wall.” Energy and Buildings, vol. 199, Sept. 2019, pp. 297–310, 10.1016/j.enbuild.2019.07.001. Accessed 7 Nov. 2021.
12. E. Halawa, F. Bruno, W. Saman. “Numerical Analysis of a PCM Thermal Storage System with Varying Wall Temp..” Energy Conversion and Management, vol. 46, no. 15-16, Sept. 2005, pp. 2592–2604, 10.1016/j.enconman.2004.11.003. Accessed 7 Nov. 2021.
13. Farah Souayfane, Pascal Henry Biwole,Farouk Fardoun. “Energy Performance and Economic Analysis of a TIM-PCM Wall under Different Climates.” Energy, vol. 169, Feb. 2019, pp. 1274–1291, 10.1016/j.energy.2018.12.116. Accessed 7 Nov. 2021.
14. Tian Yan, JiajiaGao, Xinhua Xu, Tao Xu, Ziye Ling, JinghuaYua. “Dynamic Simplified PCM Models for the Pipe-Encapsulated PCM Wall System for Self-Activated Heat Removal.” International Journal of Thermal Sciences, vol. 144, Oct. 2019, pp. 27–41, 10.1016/j.ijthermalsci.2019.05.015. Accessed 7 Nov. 2021.
15. Tian Yan, Zhongwei Sun, JiajiaGao, Xinhua Xu, Jinghua Yu, Wenjie Gang. “Simulation Study of a Pipe-Encapsulated PCM Wall System with Self-Activated Heat Removal by Nocturnal Sky Radiation.” Renewable Energy, vol. 146, Feb. 2020, pp. 1451–1464, 10.1016/j.renene.2019.07.060. Accessed 7 Nov. 2021.
16. Duan, Shuangping. “Experimental Study on Thermal Performance of an Integrated PCM Trombe Wall.” Renewable Energy, vol. 163, Jan. 2021, pp. 1932–1941, 10.1016/j.renene.2020.10.081. Accessed 7 Nov. 2021.
17. Tyagi, Vineet Veer, and D. Buddhi. “PCM Thermal Storage in Buildings: A State of Art.” Renewable and Sustainable Energy Reviews, vol. 11, no. 6, Aug. 2007, pp. 1146–1166, 10.1016/j.rser.2005.10.002. Accessed 7 Nov. 2021.
18. JingchaoXie, Wei Wang, Jiaping Liu, Song Pan. “Thermal Performance Analysis of PCM Wallboards for Building Application Based on Numerical Simulation.” Solar Energy, vol. 162, Mar. 2018, pp. 533–540, 10.1016/j.solener.2018.01.069. Accessed 7 Nov. 2021.
19. Manz, H. “TIM–PCM External Wall System for Solar Space Heating and Daylighting.” Solar Energy, vol. 61, no. 6, Dec. 1997, pp. 369–379, 10.1016/s0038-092x (97)00086-8. Accessed 7 Nov. 2021.