International Journal of Information Science & Technology – iJIST, ISSN : 2550-5114
Vol. 7 - No. 2 - December 2023

Integration and Validation of the Phase Change Materials on Thermal Comfort and Energy Efficiency of Buildings Envelope

[1] ***NOUHAILA BENACHIR,*** [2] ***FARIDA BENDRIAA,*** [3]***TAOUFIQ MOUHIB***
Hassan I First University of Settat, Ecole Nationale des Sciences Appliquées, LISA Laboratory, Berrechid 26100, Morocco

Corresponding **author :Benachir Nouhaila**
Benachir.nouha@gmail.com / n.benbachir@uhp.ac.ma/

Abstract: **The envelope of buildings has remained for a long time a passive means of limiting heat loss or heat gain on the one hand, to ensure a certain air conditioning by its thermal inertia. The increase in peak electricity demand in recent years has stressed the importance of peak electricity demand shifting technologies. The overall objective of the project is to improve the living conditions of the local population. The specific objective is to set up a pilot unit using local building materials, with low environmental impact, provided with organic phase change materials also the main objective here is to model, quantify and optimize the impact of the presence of PCMs in a thermal zone subjected to the climatic conditions of Morocco with the ultimate goal of developing low energy buildings and crated the comfort zone. First, a complete numerical model of the thermal behavior of a zone will be developed using the Trnsys, with the possibility of including phase change materials. The achievement of this objective will allow to have available a customized code, fully scalable, able to calculate all the thermal variables of interest in a building interacting with the environment. Such a complex wall technology integrating PCMs must be properly taken into account in order to simulate the energetic behavior of buildings and to evaluate their impact in several domains (environmental, thermal behavior of buildings). Once the thermal characterization of the building has been performed. (PCMs) have a potential to improve the building envelope by increasing the thermal mass as well as contribute to a signify cant peak shift in whole building power demand. Therefore, special attention is given to properly capture the thermal behavior of PCMs in advanced building energy modeling software. Design of effective PCM thermal storage systems requires accurate energy modeling. There are analytical and numerical models developed during last few decades for this purpose, many have not been fully validated. Based on the current status of literature, the study identifies the limitations and drawbacks of existing methods. A parametric study is conducted to identify the optimum PCM thermo-physical properties, The results show that the Mechanical solar ventilation with the phase change materials (PCM+MSV) reduces the operating temperature of the house significantly and relative humidity and maintain the demand energy from HVAC system. Indeed, the Mechanical solar ventilation has decreased its average operating temperature by about 2.7°C-3°C and created the fresh and comfort space.**

Keywords: Comfort, TRNSYS, Phase change material, Thermal energy storage, Building envelope.

I)INTRODUCTION

For several decades, low-income citizens in Moroccan cities have been suffering from thermal inequality, energy poverty and thermal comfort constraints. They are resistant to indoor temperatures of less than 16°C and more than 32°C, which causing heat stress. The most vulnerable to climate change are the people who live in the densest environments and whose resources are the most limited. The lifting of all subsidies by 2025 in Morocco will exacerbate the energy disparity. Reducing energy expenditure is a major challenge in Morocco. This mobilisation is justified primarily by the costs associated with energy consumption. In fact, 10% of Morocco's gross domestic expenditure in 2014. Such consumption also has disastrous long-term environmental consequences: greenhouse gas emissions, depletion of natural resources, and so on resources, etc. Among the sources of energy consumption, Heating, Ventilation and Air Conditioning (HVAC) systems account for around 50% of total expenditure in buildings. This considerable proportion Can be explained in part by the wide variations in temperature recorded in Morocco, which make it essential to provide air conditioning or heating virtually at all times.

The development of green buildings therefore inevitably involves optimizing the use of HVAC SYSTEMS. With this in mind, there is a clear difference between the use of HVAC systems during the day and at night. This is because during the day, the solar irradiation incident on the façade of a building, coupled with the various internal gains (occupancy density, lighting, etc.) result in a high demand for air conditioning. Conversely, at night, internal and solar gains are non-existent solar gains are non-existent and the outside temperature is lower: heating is often required. With this in mind, storing the excess loads emitted during the day and re-emit them at night, when heating is required, is an ideal solution for increasing energy efficiency. This is because less heat would then have to be supplied and extracted by the HVAC system. Most of the materials used in buildings have either a relatively low thermal mass or a high structural mass., such as concrete. The addition of thermal inertia is therefore necessary, but is accompanied by disadvantages and restrictions in terms of structural design, aesthetics and ecology. But there is a type of material that combining high thermal inertia with excellent specific properties, which is taking an increasingly prominent place in the design of new buildings integrate the Phase change materials (PCMs). The high thermal inertia of these materials comes from their ability to change phase at a temperature that can be adjusted by the user. In fact, the absorbed during the melting of the PCM is stored in the material, then released at the desired moment when the PCM solidifies. when the PCM solidifies through an exothermic process. Depending on the properties of the thermal zone in which the material is located, it is therefore possible to integrate PCMs and optimise their parameters with the aim of advantageously dephasing the peaks of consumption peaks and, by the same token, significantly reduce the use of the

HVAC system. Consequently, the integration of

in the envelopes of new buildings or buildings undergoing renovation would help to reduce the energy bill in the Moroccan building sector. For a long time, the envelope of traditional buildings was a passive means of limiting heat loss and heat gain, and of providing a certain amount of cooling due to its thermal inertia.

on the one hand, to limit heat loss or heat gain and, on the other, to provide a degree of air conditioning thanks to its thermal inertia. The thermal energy stored in the walls during hot periods is released during cold periods. In today's buildings, particularly in the commercial sector, efforts are being made to reduce the thickness of the walls to cut costs, while at the same time standards to limit heat loss. However, such structures do not provide sufficient thermal inertia to absorb fluctuations in outside temperature. One way of reducing a building's energy requirements of a building is to design an energy-efficient envelope that limits heat loss and recovers as much passive heat as possible and passive solar gain as much as possible. To achieve these objectives, there are a number of basic principles, the most important of which are insulation, thermal inertia and the use of solar gain. As far as thermal inertia is concerned, the use of PCMs in the walls themselves allows latent heat storage to be substituted for sensible heat storage, latent heat, which requires much less volume and mass for the same amount of thermal energy.

One of the key objectives of research into low-energy buildings is to find a way of managing the time differences between energy sources and energy consumption. The main objective here is to model, quantify and optimise the impact of the presence of PCMs in a thermal zone climatic conditions in Morocco, with the ultimate aim of developing low-energy buildings.

This result will be delivered in the form of energy efficiency gains by reducing energy consumption in heating and air-conditioning systems, ventilation and in the form of a reduction in the energy consumption of buildings equipements, and in the form of improved thermal comfort. The use of bio-sourced materials will provide a sustainable gain that respect the environment. The economic spin-offs will be significant for low- and medium-income citizens, and through the creation of new jobs and businesses associated with this sector. In terms of research, the project will make it possible to assess the potential of phase-change materials. It will provide scientific data on the merits of integrating these materials and their impact on the thermal comfort of buildings. The impact on the stability of daily temperature fluctuation inside the building is a win-win scenario for energy efficiency in buildings and for the environment.

The results will provide a better understanding of the adaptability of phase change materials to Mediterranean climatic zones. They will also shed light on the influence of climatic conditions on the stability of PCMs. This study will serve as a framework for the design of composite walls incorporating PCMs for passive buildings in various climates. These phase change materials are often used to store energy to overcome times of mismatch between thermal supply and demand in a building, such as storing solar thermal energy for space heating in the evening. The lifting of all energy subsidies by 2025 in Morocco will exacerbate the energy disparity. Reducing energy costs is a major challenge in Morocco. This mobilization is justified primarily by the costs associated with energy consumption. Indeed, 10% of Moroccan gross domestic expenditure in 2014 was dedicated to energy expenditure. In addition, such consumption has disastrous environmental consequences in the long term: greenhouse gas emissions, depletion of natural resources, etc. Among the sources of energy consumption, heating and air conditioning systems represent about 50% of the total expenditure in buildings. This considerable proportion can be explained in part by the great temperature variations recorded in Morocco, which make the contribution of air-conditioning or heating indispensable almost at all times. The development of the green buildings passes thus inevitably by an optimization of the use of the systems Heating and air conditioning. In this perspective, a clear difference between the use of systems during the day and during the night has been observed. In fact, during the day, the solar irradiation incident on the facade of a building coupled with the various internal gains (occupancy density, lighting, etc.) density, lighting, etc.), cause a high demand for air conditioning. Conversely, during the night, the internal and solar gains are solar gains are non-existent and the outside temperature is lower: heating is often required. From this point of view, storing the excess loads emitted during the day and re-emitting them during the night when heating is required is an ideal solution for increasing energy efficiency. Indeed, less heat Most materials used in buildings have either a relatively low thermal mass or a high structural mass, which means that they can be used in a variety of ways. or a high structural mass, such as concrete. The provision of thermal inertia is therefore necessary, but is accompanied by disadvantages and restrictions in terms of structural design, aesthetics and ecology. However, there is a type of high thermal inertia and excellent specific properties, which is becoming more and more important in the design of new phase change materials (PCMs). The high thermal inertia of these materials stems from their ability to change phase at a user-adjustable temperature. Depending on the properties of the thermal zone where we are, it is therefore possible to integrate PCMs and to optimize their parameters in order to favorably dephase the energy consumption peaks and energy consumption and, by the same token, significantly reduce the use of the heating and air conditioning system. Consequently, the integration of PCM in the envelopes of new buildings or in renovation would contribute to reduce the energy bill in the building sector in building sector in Morocco. The envelope of traditional buildings has remained for a long time a passive means to limit heat loss or heat input and to ensure a certain air conditioning by its thermal inertia. Indeed, the thermal energy stored in the walls during the hot periods is restored during the cold periods. One of the key objectives of the research on low energy buildings is to find a way to manage the time differences between energy sources and energy consumption. The main objective here is to model, quantify and optimize the impact of the presence of PCMs in a thermal zone conditions of Morocco with the ultimate goal of developing low energy consumption buildings. energy consumption. First, a complete numerical model of the thermal behavior of a zone will be developed using the simulation tool Trnsys, with the possibility of including phase change materials. The achievement of this objective will allow to have at disposal a customized code, fully scalable, able to calculate all the thermal variables of interest in a building in interaction of interest in a building in interaction with the environment. Such a complex wall technology integrating PCM must be properly taken into account in order to simulate the energy behavior of buildings and to evaluate their impact in several domains (environmental, thermal behavior of buildings, etc.) Once the thermal characterization of the building has been completed, the second specific objective will be to process all of the data obtained in order to measure the impact of the presence of CAMs from several perspectives. On the one hand, the average temperature will be examined after integration of the PCMs in a zone. The simulation of a PCM is supported by type 204. The simulations are performed for different indoor convective heat transfer coefficients (h-value) [1], where the h-value increases from 0.5 to 10 W / m².K. The simulation[10], results show that the heating energy demand increases when the h-value increases, but the cooling load decreases slightly. Bontemps and al[3], showed the new PCM module was validated with experimental. The results showed that, during the summer, there is a reduction of 2°C in indoor temperature for the room with PCM walls compared to the room without PCM walls. It was also shown that, in winter, the thermal discharge for the wall with PCM in the interior temperature drops to -9°C. Xu et Zhang [2] further investigated the effect of various parameters such as, melting temperature, the heat of fusion and thermal conductivity of PCM on the thermal performance of the building. They found that the heat of fusion and thermal conductivity of PCM should be greater than 120 kJ / kg and 0.5 W /(mK) a large number of numerical studies, which have been recently performed in different countries, helped in better understanding of the physics behind the PCM-enhanced building products and their potential energy performance. For decades, different types of PCM-enhanced building boards and plasters have been the most popular objects of computer simulations. Earliest numerical studies started during the late 1970and had been continued till the1990s. They were mainly focused on gypsum wallboards impregnated with paraffin (Solomon 1979[4]; Tomlinson and Heberle 1990[5]; Kedl 1990[6]; Stovall and Tomlinson 1995[7];Kissock et al. 1998[8]). A combined experimental–numerical work was performed by Athienitis and al. (1997) [9], who conducted extensive field testing followed by one-dimensional numerical analysis of a full-scale outdoor test hut with PCM-enhanced gypsum board installed as an inside wall sheathing. In more recent projects, PCM wallboards and plasters containing microencapsulated PCMs (Hawlander and al.2002[10]; Darkwa and Callaghan (2005) [11], Schossig and al. 2005[12]; Kendrick and Walliman2007[13]) have been studied. In addition, the thermal performance of shape-stabilized PCM board products has been analyzed using numerical methods (Kuznik and al. 2007[14]; Virgonet and al.2009[15]; Constantinescu and al.2013[16]). Due to flammability concerns about paraffinic PCMs, a number of numerical models have been utilized recently to analyze the thermal performance of boards and insulation products thermally enhanced with bio-based alternatives kinds to paraffin(Rozanna and al.2005[17]; Riza 2007[18]; Kośny and al. 2009c; [19] Dhanusiya and Rajakumar 2013[20]).

PCMs can store energy in two forms, latent heat and sensible heat. The magnitude and the rate of latent heat absorbed and released depends on material properties [20].

Therefore, the advantage of using PCMs lies in the amount of latent heat a small amount of PCM can store under different storage techniques compared to that in a sensible heat storage material of the same volume. For an instance, a 25 mm thick PCM layer can hold same amount of energy as a 420 mm concrete wall as long as the PCM layer changes phase [21]. Therefore, PCMs can shift peak timeperiods based on the latent heat capacity, and other physical parameters related to the applicationof PCMs.

different thermo-physical characteristics while they co-exist within the enclosure. Enclosure/encapsulation is how the PCM is packed in the particular application. During the phase transition of the PCMs, the liquid state and the solid state are separated by a moving interface. Considering the basic physics, the energy and mass balances should be satisfied in either side of this moving boundary which makes it difficult to model. Either side of this moving boundary is also called two phase/ “mushy” region. The enthalpy change which occurs across this region is quite complex and dependent upon the material properties of the PCMs such as the latent heat, expansion coefficient, melting range and rate of heat transfer [21].

Latent heat of the PCMs defines the heat storage capability of the PCMs. When compared with other building envelope materials like stone, wood, brick and gypsum, PCMs present more attractive thermal storage characteristics. To indicate the importance of the latent heat, Zhang et al. [24] discuss how in order to keep the indoor air in the comfort range for a longer period without heating or cooling load, the heat of fusion of a PCM should be high enough to keep the inner surface of the wall at the melting temperature. This refers to having high latent heat next to the inner surface of the wall so the PCM are not fully melted nor frozen. Furthermore, the latent heat capacity of the material determines the weight/volume fraction of the PCMs required for the optimum performance of the building envelope.

Melting temperature of the PCM is another important property. Melting temperature is usually selected to fall within the comfort range of the occupants and are researched in the existingstandards [36]. The exact value of the optimum melting temperature required depends on the building, climate, and the application [35]. Furthermore, a study of a PCM wall in a passive solar house indicates that heat storage occurs with a melting temperature of 1-3 ˚C above the average room temperature [37]. This section discusses these attractive characteristics of PCM in detail.

-

Figure 1 shows the temperature-enthalpy curve of a Bio based PCM comprising of fatty acids, fatty alcohols, esters, emulsifiers, and thickening/ gelling agents. PCMs used in building applications are usually not pure substances and therefore indicate a melting temperature range. The red shaded area shows the melting temperature range of the material approximated by the author using the starting point and the end point of the melting. This temperature interval is also referred to as the "mushy" region of melting.

1a shows microencapsulated PCMs embedded in drywall. This drywall is available in 1.2m x 1.2 m (4ft x 4ft) PCM panels. Figure 2-1b shows the shape stabilized PCMs in thin aluminum foil.

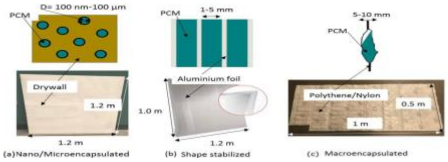
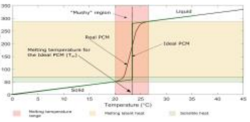


Figure 1 Different PCM encapsulation types: (a) microencapsulated PCMs embedded in drywall, (b) Shape-stabilized PCMs: thin PCM layers enclosed between aluminum foil sheets, and (c) Macroencapsulated PCMs: PCMs enclosed in pouches. Figure shows the dimensions of the single PCM included unit and the commercially available dimensions.



Thermal characteristics and properties of PCMs

Figure 2.Enthalpy variation across the mushy region and deviation observed in PCMs used in building applications (Real PCM) in contrast to an ideal PCM. Graph shows the melting temperature range, melting latent heat, and melting sensible heat of the PCM.

The total enthalpy difference during the phase change comprises of the sensible heat and the latent heat. The sensible heat calculation for each phase is defined in the equation 2-1. $T_{m,low}$ is low bound of the melting temperature range and then $T_{m,high}$ is the higher bound of the melting temperature range. $q = c_{s,PCM}\Delta T, T \leq T_{m,low}$ $q = c_{l,PCM}\Delta T, £T \geq T_{m,high}$.

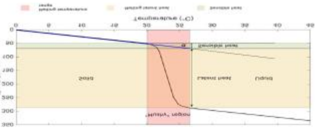


Figure 2.1 shows the sensible heat and latent heat contributions to the enthalpy change during the melting process for the Bio-based PCM in Figure 2-2. The cream color shared enthalpy difference is the melting latent heat and green color shaded enthalpy difference is the sensible heat. Phase separation of the material Phase separation of the material takes place within this "mushy" region of phase change. This phenomenon usually occurs when there is more than one constituent in the substance, whichis common practice in commercial PCMs. Kosny [21] discusses how the melting/solidifying temperature of each component might also be influenced by the composition of each constituent of the mixture.

Subcooling/supercooling effect and Hysteresis

Hysteresis PCMs are categorized as real hysteresis and apparent hysteresis. Real hysteresis occurs due to material properties and apparent hysteresis is independent of the material properties.The most common form of real hysteresis is Subcooling. Many PCMs do not freeze at the melting temperature and start crystallization only after a temperature below the nominal melting temperature. Solidification/ freezing of the PCM happens where the solid phase grows with the liquid layer at the interface. As the temperature decreases this interface should occur at a certain point. At the initiation, there is no or only a small solid particle. This solid particle is also called the nucleus. At the surface of the nucleus there occurs an instance where energy released by crystallization at the surface is lesser than that of surface energy gained. This energy flow barrier exists until the nucleus grow satisfactorily.

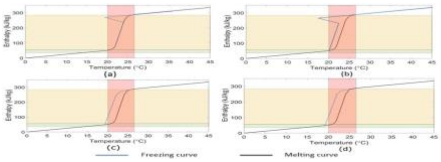


Figure 3. Enhanced view of different PCM enthalpy curve combinations showing hysteresis (a)
Subcooling effect and freezing temperature curve comes back and overlay on the melting curve,

(a) subcooling causing separate curves for melting and freezing (c) hysteresis due to slow latent heat release, (d) apparent hysteresis due to non-isothermal conditions in measurements (Enthalpydata available at [53] and the curve concept inspired by [54]).

(b)

(c) If this nucleation is delayed to occur with the temperature decreases below the melting point the Subcooling occurs. Real hysteresis can occur as a result of slow latent heat release. Mehling and Cabeza [26] discusses the reason for the slow heat release being slow formation of the crystal lattice or diffusion processes are necessary to homogenize the sample. The temperature of the sample then drops below the cooling heating temperature. This is not observed in the melting process since the kinetics process occurs much faster [52]. These conditions can separate melting and freezing curveand is shown in Figure 3-4c.Apparent hysteresis occurs due to non-isothermal conditions at measurement for the characterization. This can be caused by the heating rates used in the characterization in melting if high heating rates. If the heating rates are high thermal equilibrium of the specimen could not be reached and the melting curve could be pushed further right in the graph and fro freezing curve it could be pushed to further left. This could cause curves shown in Figure 3-4d. Careful calibration of the instrumentation can minimize the effects of the apparent hysteresis which occurs due to theinstrumentation in methods of characterization.

The magnitude of the separation of the curves candepend on the heating rates used, sample size used in the tests, and the data acquisition steps used. All four curves in Figure 3-4 shows effects of hysteresis while only Figure 3-4a and Figure 3-4b showing Subcooling effect.

II)METHODOLOGY: MODELING PCMS IN BUILDING ENVELOPE

The overall objective of the project is to improve the living conditions of the local population, through welfare and the fight against poverty and social inequalities.

The specific objective is to set up a pilot unit using local building materials, with low environmental impact, provided with with organic phase change materials in order to study the improvement of the energy efficiency of residential and tertiary buildings.

The valorization of local materials represents a priority for this project. Clay bricks are the basic matrix in which organic PCMs developed from bio based materials will be incorporated from biosourced materials. One of the tracks considered is the use of PCMs in the form of fatty acids extracted from the transformation of the olive into oil, allowing the valorization and the treatment of these wastes and therefore the protection of the environment.The research work will bring innovation, through the combination of local materials and bio sourced PCM, and will allow the companies of the building materials to develop by making evolve their products. Indeed, the analysis of the environmental performance and economic feasibility of these materials is an important new field of scientific research. The benefits, the energy consumption and the environmental indicator for all stages of the life cycle of the PCM must be evaluated in detail to configure an appropriate energy balance perspective of the material life cycle. Our research strategy aims to examine in detail the topic of PCM use as thermal energy storage materials for the building sector. The aim will therefore be to verify the feasibility and technical performance of PCM as a new way to stabilize the air temperature inside buildings. The study includes a modelling and numerical simulation and an experimental part.

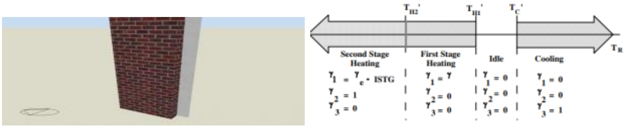


Fig.4. The multi-zone building of Trnsys.

Mathematical Description:

hback > 30 kJ / (h m² K) => 1 W 30 ≥ hback >0.005 => 1/α = 0.13 m² K / W 0.005 ≥ hback => 1/α = 0 m² K / W hfront => 1/α = 0.13 m² K / W If the ntypes 27 and 46 are used in short term calculations, large errors in the energy balances of the building may occur due to the neglect of internal energy changes within massive walls. hk is the enthalpy of the layer k. For non-phase change building materials, partial derivative of enthalpy is given **by** $\partial hk / \partial t = Ck * (\partial T / \partial t)$ With the heat capacity Ck that remains constant. For the PCM material, the following formulation is $\partial hPCM / \partial t = (\partial hPCM / \partial T) * (\partial T / \partial t) = CPCM(T)(\partial T / \partial t)$

With cpcm (T) the analytical expression of the effective heat capacity.The heat flux φ (phi) is the amount of energy or heat passing through 1m2 of wall during one second when there is a temperature difference between its 2 sides. It is expressed in W/m2

$\varphi = \frac{\lambda \Delta T}{e}$ **With λ the thermal conductivity; ΔT the temperature difference and e the thickness of the wall.**

The amount of heat escaping from a simple wall decreases: when the thermal conductivity decreases, when the temperature difference between the 2 faces of the wall decreases and when the thickness of the wall increases.

Presentation the energy balance :This Balance shows the detailed energy balance of a surface. BAL_ENERGY_Surf = − DQwalldt − QCOMI + QCOMO + QT_RGain_i + QT_Rgain_o − QT_AL [kJ/hr].

BAL_ENERGY_Surf energy balance for a surface should be always 0. DQwalldt: change of internal energy of surface.

QCOMI :combined heat flux to inside (going into zone+; going into wall -).

QCOMO :combined heat flux to outside (going to outside-; going into wall +).

QT_RGain_i :Total radiative gains for inner surface node (including solar gains, rad. internal gains wallgains and rad. In each layer k composing the wall, the heat equation is:

$$\rho k (\partial hk / \partial t) = -(\partial / \partial x (\lambda k * (\partial T / \partial x))$$

The detailed results were generated directly from the DesignBuilder software used for the Dynamic Thermal Simulation recognized a house (occupied by 4 people) is located in (CASABLANCA NOUASSEUR). Its total area is 110 m2 and it rises on: a basement, a first floor and the main facade is oriented to the south. Heating and cooling systems control internal temperatures to meet the setpoint temperatures specified on the Activity tab. These setpoint temperatures can be interpreted as air, operative or some other radiant fraction and DesignBuilder provides corresponding options to allow HVAC systems to be controlled by: • 1-Air temperature - control the zone mean air temperatures to the heating and cooling setpoint temperatures specified on the Activity tab. • 2-Operative temperature - control the room temperature using 0.5 radiant fraction. This equation works because the temperature of the air in the zone can safely be assumed to be the zone cooling set point and so there is fixed difference in temperature between zone air and supply air. Calculating the design supply cooling airflow rate in this way does not work for operative temperature control because the air temperatures in the space are often much lower than the zone cooling setpoint temperature and sometimes in zones having very high radiant temperatures, the air temperature in the zone approaches the supply air temperature. In other words the difference in temperature between zone air and supply air in the simulated system becomes very low and therefore very large airflow rates are required to meet cooling loads. So in order to account for this DesignBuilder assumes a Delta T of 1K in the above calculation when operative temperature control is in use When the regular wall with pcm on if **γo = 1 If γι = 1 and ΔtL > (th-tl), γo = 0 γi γi = 0 and Δth ≤ (th - tl), γo = 1**

The heating and air conditioning (on/off) Temperature $th1' = th1 + (\gamma 1 \cdot \Delta Tdb) - (\gamma set \cdot \Delta Tset$ $2\ heat\ source\ thl2' = th2 + \gamma 2 \cdot (\Delta Tdb - (\gamma set \cdot \Delta Tset))$.

Conditioning source $tc' = tc - (\gamma 3 \cdot \Delta Tdb)$. And ySet [any] Setpoint for the controlled variable.

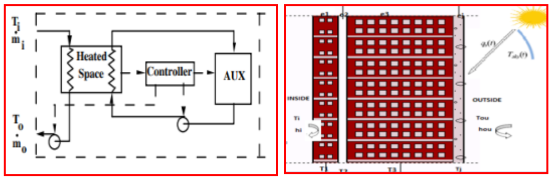


Fig.5. Mode 1 (parallel auxiliary).

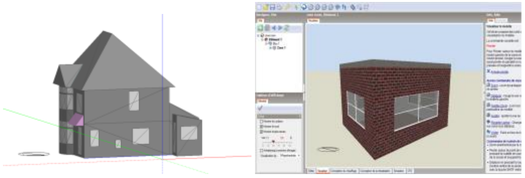


Fig.6. 3D outlook zone

$$\rho \frac{c_i^n \Delta x}{\Delta t}\left(T_i^{n+1} - T_i^n\right) = T_{i-1}^{n+1}\left(\frac{1}{\frac{\Delta x}{2\lambda_{i-1}^n} + \frac{\Delta x}{2\lambda_i^n}}\right) + T_i^{n+1}\left(\frac{1}{\frac{\Delta x}{2\lambda_{i-1}^n} + \frac{\Delta x}{2\lambda_i^n}} - \frac{1}{\frac{\Delta x}{2\lambda_i^n} + \frac{\Delta x}{2\lambda_{i+1}^n}}\right) + T_{i+1}^{n+1}\left(\frac{1}{\frac{\Delta x}{2\lambda_i^n} + \frac{\Delta x}{2\lambda_{i+1}^n}}\right)$$

Thermal inertia in TRNSYS

Type 56 assumes by default that a thermal zone contains only air, which is not always true. Internal walls and furniture usually have a thermal inertia to consider. This assumption taken by default by TRNSYS leads to consider that the thermal capacity of a thermal zone within the building is automatically set to a default value of 1.2 multiplied by the volume of the zone in question (TRNSYS). This value is taken into consideration since the approximate value of the heat capacity of air under standard conditions is 1kJ.kg-1.K-1 and the approximate value of the density of air is 1.2 kg.m-3. To avoid this default assumption, the thermal inertia of the internal walls for each of the thermal zones was calculated using the equation while for that of the furniture, the value of 20 kJ.K-1.m-² was taken into consideration according to the Thermal Regulation (RT 2012) $In = \rho . Cp$.

Table N°1°. Thermophysical properties of materils Source (TRNSYS °)

Materials	Tickness (cm)	Density	Resistance (mk/w)	**Heat capacity** J/kg·K	Heat conductivity W/(m·K)
Brick layer	25	1800	0.337	1000	0.88
Air gap	4	1000	0.278	1200	0.09
Brick layer	7	1800	0.07	1000	0.88
PCM layer	5	850	0.106	2200	0.47

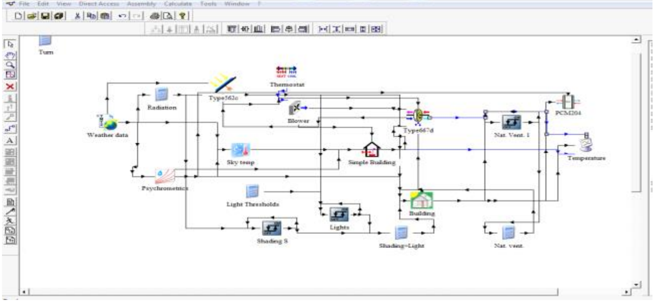
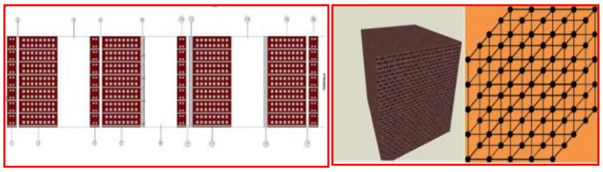


Figure 7.TRNSYS interface of building energy modeling.

Figure 8. Different scales of building energy modeling



Considered in the current study are at building scale, envelope scale. The PCM modeling algorithm incorporates PCM characteristicsin the envelope modeling algorithm.

III)Results and discussion

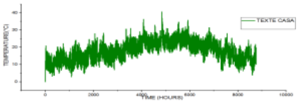


Fig.9. The external temperature in CASABLANCA.

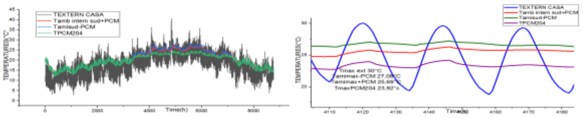


Fig10.Annual evolution of the external and internal temperature without and with pcm.

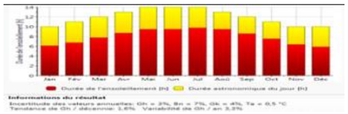


Fig.11. The external and internal temperature without and withpcm in summer.

The high thermal inertia of these materials stems from their ability to change phase at a user-adjustable temperature. This is because the large amount of latent energy absorbed when the PCM melts is stored in the material and then released when the PCM solidifies using an exothermic process. Depending on the properties of the thermal zone in question, it is therefore possible to integrate PCMs and optimise their parameters with the aim of advantageously dephasing energy consumption peaks and, by the same token, significantly reducing the use of the CVA system. Consequently, integrating these PCMs into the envelopes of new buildings or those undergoing renovation would help to reduce the energy bill in Morocco's construction sector.

Figure 12 show the minimum and maximum magnitude of the internal ambient temperature without phase change materials and with phase change materials and external temperature. The building envelope with phase change materials debilitate the temperature of 3.19 °C in comparison to the building without pcm. The pcm phase change materials can attenuate the internal temperature to 11.4% of thermal debilitate reduction. The employment of phase changematerial increases the internal temperature of the building envelope.So the internal temperature in the building envelope has inferior to than the ambient temperature extern, which is close by the restrict of thermal comfort space

.

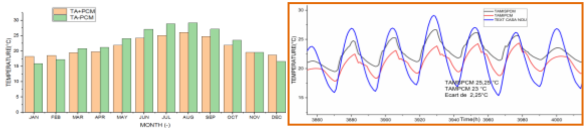


Fig.12. Comparison of the air temperature without and with PCM.

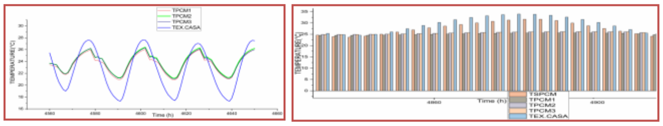


Fig.13. The internal temperature with pcm1.2.3.

Figs. 13. shows the comparison about the internal wall ambient temperature during charging and discharging withotand with pcm 1.2.3 in summer, the results obtained in the indoor wall temperature of PCM 1 25.7°C and PCM2 26.4°C,PCM 3, 26.68°C and without PCM is 28.08 °C and a maximum peak temperature of 2.4 °C.

The Simulations compare the ambient temperature for three wall scenarios with different locations of the MCP layer, the internal, the middle and the external. The internal ambient temperature with MCP1 is 25.8°C and MCP2 26.3°C, MCP3 26.62°C, on the other hand wall 1 is the greatest control of internal thermal comfort and humidity, great hours for phase change temperature and energy saving, wall 1 effectively behaved as a heat store during the summer. In conclusion, the PCM placed in the inner part of the envelope prevents the best heat flow from the inside (all the heat is stored in the PCM layer for the melting process latent heat with a high capacity and thermal inertia.

The effect of PCM density:

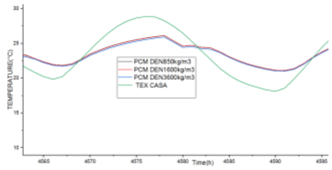
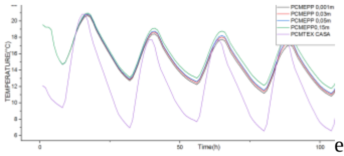


Fig. 14 Presentation of the pcm density in sum



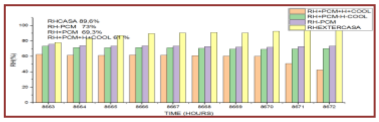
er.

Fig.15.Evolution of pcm thickness parameter

Figure 14present the density of pcm in summer; so when the density parameter is increased,the internal ambient temperature with pcm decreases if the temperature increases, the molecules of the fluid move apart and the density decrease if the temperature decreases, the opposite occurs. So the pcm can storage more energy and the integration the pcm into the building envelope can storage more the energy and minimize the heating and cooling consumption.

Fig.15.Present the growth up of pcm parameter thickness wall in winter,when we growth up the thickness of the wall with PCM the internal ambient temperature also graduate so this condition is good in winter, not in summer so we take the optimum thickness of PCM between 0.01 m and 0.05m.

Relative humidity (RH): The results conveyed that the building with phase air gap and phasechange materials not only had the reaction on the heat flow transfer and temperature and exchange transfer convection,conduction and radiative transfer in the wall, but also had reaction on the ratio relative humidity and moisture transfer in the wall. The apex relative ratio humidity and the moisture flux of the wall with phase change materials were both small. Compared with external relative ratio humidity and the relativeratio humidity of the wall without phase change materials. The reduction of the relative humidity of the pcm wall is 28.6 % with the external relative ratio humidity and the relative humidity percentage range of the wall without pcm was 13 %. Although the apex diminution of the relative humidity was small, it is concluded that the risk of crystallization, condensation and infiltration of the wall could be diminish.



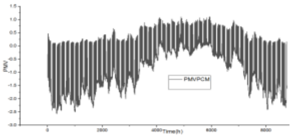


Fig. 16. Evolution of the external RH and internal relative humidity with and without PCM.

Fig.17. The "PMV" index simulated during one year with PCM

Thermal comfort:

The "PMV" index)gives the average vote of the individuals surveyed which indicates opinions on their average thermal sensations according to the ASHRAE scale1 which varies from (-3) to (+3) where each number expresses a thermal sensation.

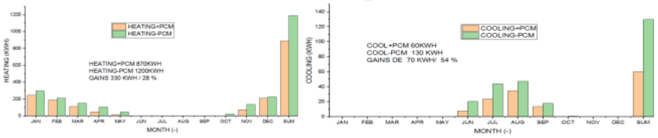


Fig. 18. Annal consumption of heating and cooling equipement.

Figure18 summarize the annual heating and air conditioning loads.The total thermal and electrical energy cnsumption for heating and air conditioning equipments shows that the building with PCM minimize the energy for the tow loads compared to a building without PCM, the energy need for the PCM wall is 1125KJ and without PCM 1348KJ difference of 226 KJ. SO the building envelope with phase changematerials maintain the thermal and electrical energy consumption17%. The energy consumption with pcm in August was 33 Kwh and without pcm51 Kwh. The some results convey that the presence of the phase change material in the building envelope maintain the annual consumption and demand for heating and cooling and achieved energy savings by diminishing the cold period retaining the heat solar charging during the phase change can storage the solar energy and heat transfer and minimize the period of air conditioning maximally avoiding overheating due to solar gains and internal gains and control the heat flux and thermal comfort in the interior wall for the building envelope. The annual needs for consumption air conditioning and heating are according to the NOUSSEUR climate zone 1 (AGADIR), these annual needs are 25 kWh/m²/year for residential buildings [RTCM, 2014]. The results clearly convey that the charge needs are about 13.31 kWh/m²/year. These percentage needs represent 48.76% of the needs set by the MOROCCAN regulation (RTCM.2014.).

Convective heat flow:

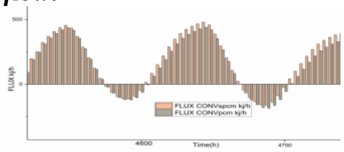


Fig. 19. Evolution of convective heat flow without and with PCM in summer.

The comparison of the convective solar heat flow asserts that the phase change materials has a effect influence on the reduction ofenergy solar heat gains transmitted in the interior of the building envelope, which directly affects the heat transfer convection conduction and radiative transfers, the air temperature variations and the thermal comfort and the relative humidity of the building as well as its improving the energy performance.

The improvement of the wall through the reduction of the thermal transmission also influences in a positive way the internal ambient temperature, the creation of thermal comfort inside the building and present the best inertia for the all wall the building envelope.

Fig. 20 shows the results of the growth of the internal surface temperature without and with pcm phasechange materials in summer and the outside surface temperature without and with phase change materials. The internal surface temperature of phase change materials is 23°C and without pcm 25.3 ° C, within a fluctuation range of 2.06 °C. The outside surface temperature of phase change materials is 29°C and without PCM 34.42 °C within a fluctuation range of 5.36 °C.so the phase change materials acts the control for the external and intern surface temperature and thermal and electrical energy and thermal and fresh comfort zone.

Fig. 20. Growth rate of the external and internal surface temperature with and without phase change materials.

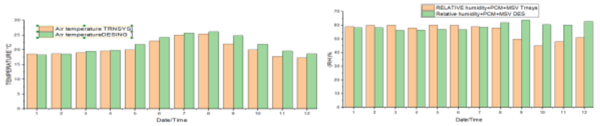


Fig. 21 Growh rate the internal ambient air temperature with PCM in energy plus and TRNSYS.

Figure 21 present the growth rate of the ambient temperature and relative ratio humidity of the two software TRNSYS and Energy plus. The results of the simulation similar in the regalement RTCM ;so it is according to a comfort interval (19°C to 26°C).The difference of the ambient internal air temperature is 2.6°C and 17 % the difference about relative ratio humidity.So the difference between TRNSYS and Energy plus conclude that TRNSYS is it, expert software for dynamic temperature and thermal ans electrical energy simulation.

- EnergyPlus: Tool developed by Department of Energythat has a finite difference algorithm (CondFD) method coupled with an enthalpy temperature function to simulate PCM that has been verified and validated
- -

V)CONCLUSION

The application the composite phase change materials (PCM) into the building envelope results in an increase in the electrical and thermal energy storage capacity, providing an effective and reliable means of improving the energy efficiency of buildings. It is concluded that composites incorporatingphase change materials are capable of diminish the thermal and electrical energy costs, about air conditioning and heating demands of the building. Also we can contribute to diminish the CO2 emissions associated withair conditioning and heating equipment. The thermal and electrical energy performance of a building located in (CASABLANCA NOUASSEUR) were addressed. First, a dynamic thermal simulation of the building using TRNSYS TYPE 204 software was according and its results were successfully validated against the experimental results obtained from the monitoring. In this study, the effects of the location of the incorporating the phase change materials on the thermal and electrical performance of the multi-layer wall3D is studied numerically under the climatic conditions of (CASABLANCA NOUASSEUR). The simulation also convey that the use of phase change materials in brick walls diminish overheating in the summer period, losing the ambient indoor air temperature by 3.4°C in summer, require the annual percentage about the electrical and internal energy for heating and air conditioning by 31%. These percentage needs represent 48.76% of the needs set by the MOROCCAN regulation (RTCM.2014.). So the total results convey that the presence of the phase change material in the building envelope maintain the annual consumption and demand for heating and cooling and achieved energy savings by diminishing the cold period retaining the heat solar charging during the phase change can storage the solar energy and heat transfer and minimize the period of air conditioning maximally avoiding overheating due to solar gains and internal gains and control the heat flux and thermal comfort in the interior wall.In summer, a high thermal capacity prevents the indoor air temperature from rising, minimizes the cooling load or eliminates it altogether and minimizes the investment costs of the necessary cooling equipment. It is concluded that the efficiency of the PCM can be improved if the building can be properly ventilated so for that in the next article we will deal with the integration of mechanic solar ventilation with the phase change material to increase the thermal and electrical energy and created the comfort and fresh zone and attenuate the performance energy to achieve a positive building+

Competing interests : "The authors declare that they have no competing interests"

References

[1] R. Marshall, Natural convection effects in rectangular enclosures containing phase change material, in: F. Kreith, R. Boehm, J.Mitchell, R. Bannerot (Eds.), Thermal heat transfer in solar energy systems, ASME, 1978, pp. 61–69.

[2] Xu, X., Zhang, Y., Lin, K., Di, H., & Yang, R. (2005). Modeling and

simulation on the thermal performance of shape-stabilized phase change material floor used in passive solar buildings. Energy and Buildings, 37(10), 1084–1091.

[3] Maha. Ahmad, A. Bontemps, H. Salle, D. Quenard, Thermal testing and numeric simulation of a prototype cell using light wallboards coupling vacuum isolation panels and phase change material, Energy and Buildings 38 (6) (2006) 673–681

[4]Solomon AD (1979) An easily computable solution to a two-phase stefan problem. Sol Energy 23 (525–528).

H. Schranzhofer, P. Puschnig, A. Heinz, and W. Streicher Institute of Thermal Engineering, University of Technology Graz. Inffeldgasse 25/B, A-8010 Graz, AuVALIDATION D'UN MODÈLE DE SIMULATION TRNSYS POUR L'ÉNERGIE PCM.

[5] Tomlinson JJ, Heberle D (1990) Analysis of wallboard containing a phase change material. In: Proceeding of the 25th Intersociety Energy Conversion Engineering Conference, vol 4, Reno NV, USA.

[6] Kedl RJ (1990) Conventional wallboard with latent heat storage for passive solar applications. 25th Intersociety energy conversion engineering conference Reno, NV, 12–17.

[7] Stovall TK, Tomlinson JJ (1995) What are the potential benefits of including latent storage in common wallboard? J Sol Energy Eng 117.

[8] Kissock KJ, Hannig JM, Thomas IW (1998) Testing and simulation of phase change wallboard for thermal storage in buildings. In: Morehouse, Hogan (eds). Proceedings of 1998 international solar energy conference, June 14–17, Albuquerque, N. M. USA, American Society of Mechanical Engineers, New York.

[9] Athienitis AK, Liu C, Hawes D, Banu D, Feldman D (1997) Investigation of the thermal performance of a passive solar test-room with wall latent heat storage. Build Environ 32 (5):405–410.

[10] Hawlander M, Uddin M, Zhu H (2002) Encapsulated phase change materials for thermal energy storage: experiments and simulation. Int J Energy Res 26(2):159–171.

[11] Darkwa K, O'Callaghan PW (2005) Simulation of phase change drywalls in a passive solar building. Appl Therm Eng 26:853–858.

[12] Schossig P, Henning HM, Gschwander S, Haussmann T (2005) Micro-encapsulated phase-change materials integrated into construction materials. Sol Energy Mater Sol Cells 89(2–3):297–306.

[13] Kendrick C, Walliman N (2007) Removing unwanted heat in lightweight buildings using phase change materials in building components: simulation modelling for PCM plasterboard. Archit Sci Rev 50(3):265–273.

[14] Kuznik F, Virgone J, Noel J (2007) Optimization of a phase change material wallboard for building use.
Appl Therm Eng 28:1291–1298.

[15] Virgone J, Noël J, Reisdorf R (2009) Numerical study of the influence of the thickness and melting point on the effectiveness of phase change materials: application to the renovation of a low inertia school. In: Proceedings of the 11th international IBPSA conference. Glasgow, Scotland, 27–30 July 2009.

[16] Constantinescu M, Anghel EA, Buixaderas E, Pavel PM, Popa VT (2013) Shape-stabilized nano composite elements based on phase change materials (PCM)-Epoxy for hauses with low energy consumption. In: Proceedings of the 2nd international conference on sustainable energy storage in buildings, Trinity College, Dublin, Ireland, June 19–21, 2013.

[17] Rozanna D, Salmiah A, Chuah TG, Medyan R, Thomas Choong SY, Sa'Ari M (2005) A study on thermal characteristics of phase change material (PCM) in gypsum board for building application. J Oil Palm Res 17:41–46.

[18] Riza M (2007) Thermal characteristics of eutectic mixture of capric-lauric acids as phase change material (PCM) in gypsum board. Jurnal Teknologi Proses, Media Publikasi Karya Ilmiah Teknik Kimia 6(1):31–38. ISSN 1412-7814.

[19] Kośny J, Yarbrough DW, Riazzi T, Leuthold D, Smith JB, Bianchi M (2009c) Development and testing of ignition resistant microencapsulated phase change material. In: Proceedings of the Effstock 2009—the 11th international conference on thermal energy storage, Stockholm, Sweden, 14–17 June 2009.

[20] Kośny, J., Short history of PCM applications in building envelopes, in PCM-Enhanced Building Components. 2015, Springer. p. 21-59.

[21] Al-Saadi, S.N. and Z.Q. Zhai, Modeling phase change materials embedded in building enclosure: A review. Renewable & Sustainable Energy Reviews, 2013. 21: p. 659-673.

[22] Wijesuriya, S., M. Brandt, and P.C. Tabares-Velasco, Parametric analysis of a residential building with phase change material (PCM)-enhanced drywall, precooling, and variable electric rates in a hot and dry climate. Applied Energy, 2018. 222: p. 497-514. [23] Cao, S., State of the art thermal energy storage solutions for high performance buildings.

[24] Biswas, K., et al., Combined experimental and numerical evaluation of a prototype nano- PCM enhanced wallboard. Applied energy, 2014. 131: p. 517-529.

[25] Ibanez, M., et al., An approach to the simulation of PCMs in building applications using TRNSYS. Applied Thermal Engineering, 2005. 25(11-12): p. 1796-1807.

[26] Mehling, H. and L.F. Cabeza, Heat and cold storage with PCM. 2008: Springer.

[27] l-Saadi, S.N. and Z.Q. Zhai, A new validated TRNSYS module for simulating latent heat storage walls. Energy and Buildings, 2015. 109: p. 274-290.

[28] Al-Saadi, S.N. and Z. Zhai, Systematic evaluation of mathematical methods and numerical schemes for modeling PCM-enhanced building enclosure. Energy and Buildings, 2015. 92: p. 374-388.

[29] Tyagi, V., et al., Thermal performance assessment of encapsulated PCM based thermal management system to reduce peak energy demand in buildings. Energy and Buildings, 2016. 117: p. 44-52.

[30] Jeon, J., et al., High thermal performance composite PCMs loading xGnP for application to building using radiant floor heating system. Solar Energy Materials and Solar Cells, 2012. 101: p. 51-56.

[31] Jeong, S.-G., et al., Improvement of the thermal properties of Bio-based PCM using exfoliated graphite nanoplatelets. Solar Energy Materials and Solar Cells, 2013. 117: p. 87-92.

[32] Peippo, K., P. Kauranen, and P. Lund, A multicomponent PCM wall optimized for passive solar heating. Energy and buildings, 1991. 17(4): p. 259-270.

[33] Borreguero, A.M., et al., Improvement of the thermal behaviour of gypsum blocks by the incorporation of microcapsules containing PCMS obtained by suspension polymerization with an optimal core/coating mass ratio. Applied Thermal Engineering, 2010. 30(10): p. 1164-1169.

[34] Tyagi, V., et al., Development of phase change materials based microencapsulated technology for buildings: a review. Renewable and sustainable energy reviews, 2011. 15(2): p. 1373-1391.

[35] Zhang, Y.P., et al., Application of latent heat thermal energy storage in buildings: State- of-the-art and outlook. Building and Environment, 2007. 42(6): p. 2197-2209.

[36] Zhang, Y., et al., Preparation, thermal performance and application of shape-stabilized PCM in energy efficient buildings. Energy and Buildings, 2006. 38(10): p. 1262-1269.

[37] Kuznik, F., et al., A review on phase change materials integrated in building walls.

[38] Zalba, B., et al., Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. Applied thermal engineering, 2003. 23(3): p. 251-283.

[39] Zhou, D., C.-Y. Zhao, and Y. Tian, Review on thermal energy storage with phase chage materials (PCMs) in building applications. Applied energy, 2012. 92: p. 593-605.

[40] Su, J.-C. and P.-S. Liu, A novel solid–solid phase change heat storage material with polyurethane block copolymer structure. Energy Conversion and Management, 2006. 47(18-19): p. 3185-3191.

Mehling, H. and L.F. Cabeza, Heat and cold storage with PCM. 2008: Springer.

[41] Salunkhe, P.B. and P.S. Shembekar, A review on effect of phase change material encapsulation on the thermal performance of a system. Renewable and Sustainable Energy Reviews, 2012. 16(8): p. 5603-5616.

[42] Qiu, X., et al., Microencapsulated n-octadecane with different methylmethacrylate-based copolymer shells as phase change materials for thermal energy storage. Energy, 2012. 46(1): p. 188-199.

[43] Karkri, M., et al., Thermal properties of phase-change materials based on high-density polyethylene filled with micro-encapsulated paraffin wax for thermal energy storage. Energy and Buildings, 2015. 88: p. 144-152.

[44] Kheradmand, M., et al., Assessing the feasibility of impregnating phase change materials in lightweight aggregate for development of thermal energy storage systems. Construction and Building Materials, 2015. 89: p. 48-59.

[45] Konuklu, Y., et al., Review on using microencapsulated phase change materials (PCM) in building applications. Energy and Buildings, 2015. 106: p. 134-155.

[46] Figueiredo, A., et al., Mechanical and thermal characterization of concrete with incorporation of microencapsulated PCM for applications in thermally activated slabs. Construction and Building Materials, 2016. 112: p. 639-647.

[47] Wiser, R.H. and M. Bolinger, 2017 Wind Technologies Market Report. 2018: United States.

[48] Wei, J., et al., Study on a PCM heat storage system for rapid heat supply. Applied thermal engineering, 2005. 25(17-18): p. 2903-2920.

[49] Zukowski, M., Experimental study of short term thermal energy storage unit based on enclosed phase change material in polyethylene film bag. Energy Conversion and Management, 2007. 48(1): p. 166-173.

[50] Solé, A., et al., Corrosion of metals and salt hydrates used for thermochemical energy storage. Renewable Energy, 2015. 75: p. 519-523.

[51] Formato, R.M., The Advantages & Challenges of Phase Change Materials (PCMs) In Thermal Packaging, in White papers and presentations on PCMs and thermal energy storage. 2013, Cold Chain Technology. p. 1-8.

[52] Li, X., et al., Advanced nanocomposite phase change material based on calcium chloride hexahydrate with aluminum oxide nanoparticles for thermal energy storage. Energy & Fuels, 2017. 31(6): p. 6560-6567.

[53] Mandilaras, I., D. Kontogeorgos, and M. Founti, A hybrid methodology for the determination of the effective heat capacity of PCM enhanced building components. Renewable Energy, 2015. 76: p. 790-804.

[54] Solutions, P.C. ENRG Blanket Specifications. 2019 [cited 2019; Available from: phaschange.com/products/enrg-blanket

[55]Soares, N.M.L., Thermal energy storage with phase change materials (PCMs) for the improvement of the energy performance of buildings. 2016.

[56]Ogoh, W. and D. Groulx. Stefan's Problem: Validation of a One-Dimensional Solid-Liquid PhaseChange Heat Transfer Process. in Comsol Conference 2010. 2010.

[57] Benachir Nouhaila Journal of Pharmaceutical Negative Results ¦ Volume 13 ¦ Special Issue 1 ¦ 2022: Role of solar mechanical ventilation and phase-change materials on thermal comfort and electrical energy of building envelope.

[58] Benachir Nouhaila Benachir, J Nucl Ene Sci Power Generat Technol 2022, 11:9 August 29, 2022, manuscript no. JNPGT-22-73579; Publisher's Date of Assignment: August 31, 2022, pre QC no. JNPGT-22-73579 (PQ); Date of Revision: September 14, 2022, QC no. JNPGT-22-73579; Revision date: September 21, 2022, manuscript no. JNPGT-22-73579 (R); Publication date: September 28, 2022, DOI: 10. 4172/2325-9809.1000292 Nuclear Journal Énergy Science & Pooù Genrestion Ttechnologie.

[59] Benachir Nouhaila NGSJ : Volume 10, Issue 6, June 2022 ISSN 2320-9186942 GSJ© 2022.

[60] Benachir Nouhaila Maghrebian Journal of Pure and Applied Science e-ISSN : 2458-715X Copyright © 2023, Université Mohammed Premier Oujda Maroc.Maghr. J. Pure & Applied Sci, 2022, Vol. 8, Issue 2, Page 63- 81 https://revues.imist.ma/index.php/mjpas. Received November 24, 2022, revised December 12, 2022, accepted December 30, 2022. Benachir et al, Maghr. J. Pure & Appl Sci, 2022, Vol. 8, Issue 2, Page 1-19. CREATING AN ENERGY-EFFICIENT BUILDING ENVELOPE BASED ON PHASE-CHANGE MATERIALS ([23] Benachir Nouhaila Benachir, Evolution the Energy in the Building Envelope Using Phase Change Materials. Benachir, Nouhaila and Mouhib, Taoufiq and Bendriaa, Farida, Evolution the Energy in the Building Envelope Using Phase Change Materials. Available at SSRN: https://ssrn.com/abstract=4489421 or http://dx.doi.org/10.2139/ssrn.4489421.

[60] Benachir Nouhaila 2022 Paper ID APEN-MIT-2022_8017 Applied Energy Symposium: Effect of solar ventilation on thermal improvement and energy efficiency of buildings using phase change materials. https://doi.org/10.46855/energy-proceedings-10079.

[61] Benachir Nouhaila Benachir, The Energy Performance of the Building Envelope Using Phase Change Materials.Benachir,Nouhaila and Taoufiq, Mouhib and Farida, Bendriaa, The Energy Performance of the Building Envelope Using Phase Change Materials (July 7, 2023). Available at SSRN: https://ssrn.com/abstract=4503411 or http://dx.doi.org/10.2139/ssrn.4503411

[62] Benachir Nouhaila Benachir, B. Nouhaila. / International Uni-Scientific Research Journal Vol.3 (2022) 126-172. Powering Wireless IoT devices in a Smart Greenhouse. © 2022 IUSRJ. OpenAccess https://doi.org/10.59271/s44768.022.2010.19.