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NET-ZERO ENERGY BUILDING – CASE STUDY AL KHOBAR CITY, SAUDI ARABIA

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ABSTRACT
The main goal of the proposed project is to demonstrate that considerable energy conservation can be done in residential building area in the KSA, considering the living conditions of house users. For this purpose, several houses will be tested using sizable Building Integrated PV (BIPV) system. In addition, the energy needs per year for each household will be covered in this study. Moreover, the proposed BIPV system will supply sufficient amount of electrical energy to allow free daily commute for homeowner (max. 60 km a day) with use of the electric car. The results indicate that the use of an insulation layer (BioPCM material) in building structure will decrease significantly the cooling capacity by 20%. The addition of solar hybrid air conditioner system improved the EER by 5.41% and the COP by 12.24 %. Finally, the installation plan for the PV panels in each residential household is in agreement with the official KSA government policy.
Keywords: Net zero energy, Energy consumption, Building integrated PV, Solar energy, PCM, Solar Hybrid air condition.

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Contribution/ Originality

This study is one of the few studies which have investigated the net zero energy building at Alkhobar area. The paper primary contribution is finding the proper energy saving system, hybrid plus PCM. Furthermore, this study documents all the work that has been done previously by same researcher (Nader, 2015;2016).

1. INTRODUCTION

The current electricity peak demand in the Kingdom of Saudi Arabia is nearly 55 Gigawatt out of which 72% is consumed by air conditioning units. The peak demand is anticipated to increase to 120 GW by the year 2032 as the population will be doubled. The Government of Saudi Arabia started a huge program to improve the energy consumption efficiency by A/C units in 2007. The program includes the rating of an existing air conditioning system, comprehensive implementation steps for new system, and instructions as part of the public awareness campaigns. Building landlords and resident's awareness of the values of energy conservation practices including high efficiency HVAC system is low. The existing electricity tariff dose not encourages electricity conservation practices in KSA. All the previous studies and feedback focused on the need to make better the existing HVAC energy conservation program in KSA (Nader, 2015; Nader *et al.*, 2016; Nader *et al.*, n.d). Targeting new constructed building only for energy efficient HVAC system will not improve energy consumption efficiency in the short term. Program amendment that includes financial incentives for building landlords to replace their HVAC systems with an efficient once, re-structuring the electricity tariff system, and intensifying the public awareness program is recommended. Many researchers have studied Phase-Change Materials (PCMs) recently as materials that conserve

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energy in buildings. The increase in energy prices was the motive to researchers to look for new materials that has the capacity to reduce energy demand (Nader, 2015). PCMs are strong alternative for energy conservation because of their thermo physical properties such as melting point range, heat of fusion, thermal conductivity, and density (Nader *et al.*, n.d) Furthermore, PCMs can reduce HVAC load by freezing with little supercoiling, having it compatible with construction material, making it chemically stable, and recyclable. However, PCM have some disadvantages in such way it is flammable. This is due to the stronger requirements of a freezing cycle in order to transfer high heat, and to the lower volumetric capacity of the latent heat storage. Consequently, PCMs should be stored in a well-designed container to avoid any of these drawbacks.

PCM can be classified under the following categories: eutectic, organic, and inorganic (Juarez *et al.*, 2013). Organic PCMs have technical grade such as paraffin's or paraffin mixtures made of oil that help PCMs obtain the best phase change points (Shapiro *et al.*, 1987). Paraffin is also abundant in large temperature scale, making them accessible because of a long freeze-melt cycle. PCMs are also made out of non-paraffin compounds. The use of organic material in heat storage is beneficial for not being corrosive or undercooled, but still has low thermal conductivity, lower phase change enthalpy, and inflammability. Despite of the disadvantages of several conditions such as undercooling, corrosion, phase separation and thermal instability, the inorganic PCM materials (heat storage) have a greater phase change enthalpy, *for example hydrated salts and metallic*. The other PCM classification is eutectic either organic or inorganic (Perez, 2010). Eutectic materials have sharp melting point. The volumetric storage capacity is usually higher than most of the organic paraffin materials. However, there is limitation to their thermophysical properties and more studies need to be done in the area of the thermal storage (Alkan *et al.*, 2009). The effect of heat conductivity changes in PCM without affecting the storage of thermal energy, several researchers designed a compound-material made of a matrix of graphite material to be embedded within the PCM (Py *et al.*, 2001; Marin *et al.*, 2013). Graphite decreases the volume change of paraffin's and decreases the sub cooling of PCMs hydrated salts. As a result, thermal conductivity increase will occur where there is 8% of the latent heat of fusion per paraffin weight unit (Phase-Change Materials, 2013).

When heat is applied to a substance, it gains heat (Chair *et al.*, 2010; Phase-Change Materials, 2013). For example, as heat is applied the temperature of water will rise to a maximum of 100°C (boiling point). Likewise, if heat is removed, the temperature of the water will decrease, to a minimum of 0°C (freezing point). This type of heat transfer, or storage, is called sensible heat as seen in Figure 1. The temperature of a material however, doesn't always increases with the addition of heat. Water boils and remains at 100°C no matter how much heat is added which make the water turns into vapour (Chair *et al.*, 2010; Phase-Change Materials, 2013). This is why for any substance with the addition of heat, it will reach either its melting or evaporation point without getting any hotter. Latent heat is this particle type of heat storage. Upon controlling the room temperature and without the addition of latent heat, PCMs would not be able to act by itself. Moreover, when they are used in construction building, change phase occur from solid to liquid at 23-26°C. As PCM start to melt, they will absorb heat from the room and thus the room temperature will be stable. At night, PCMs will go back to its original solid state during ventilation. These valuable PCMs properties will significantly decrease cooling and heating energy demand if properly implemented and managed. This paper studies the potential application of PCMs in net zero building energy.

2. PCMS APPLICATIONS IN BUILDINGS

Many natural and synthetic PCMs mentioned in the literature are known in addition to water (Mondal, 2008). They are different from each other by changing their temperature ranges of the phase change and their heat storage capacities. Other properties of PCM for a high efficient cooling system with thermal energy system (TES) include (Mondal, 2008):

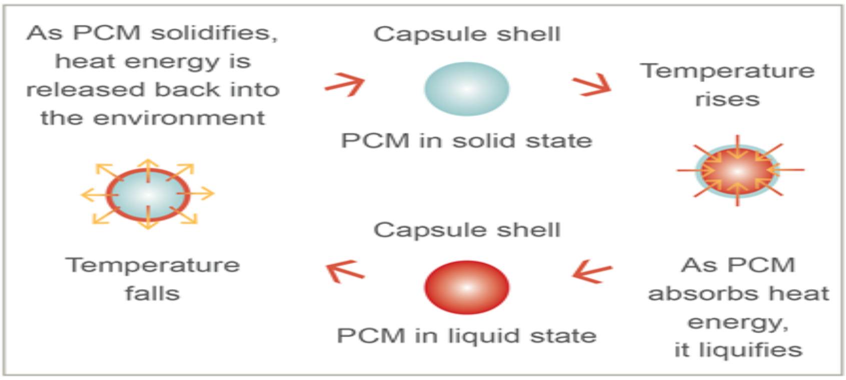

Fig-1. PCMs release heat energy by solidification process and absorb heat energy before liquefaction takes place.
Source: Kosny and Kossecka (2013)

- In construction, many melting temperature range between 23°C and 26°C.
- PCM can store a large amount of heat per volume and thus minimizes their area tiles that are needed.
- Phase change is more effective with the increase in thermal conductivity
- Changes in volume are minimized. Material can expand or contract as the phase is changed. Because of that PCM in construction need to be contained. Significant changes in volume could cause problems.
- Congruent melting. This means that the composition of the liquid is the same as that of the solid, which is important to prevent separation and super cooling.
- A completely reversible cycle for freezing or melting.
- Last longer over a large number of cycles.
- Non-corrosive to construction materials.
- Non-flammable.

Figure 2 shows how PCM can be seen for heating and cooling in buildings (Streicher *et al.*, 2005). PCM is placed in construction with porous material such as plasterboard to increase heat transfer (Zalba *et al.*, 2003). In cooling situations, PCM store ambient air during the night. PCMs are also used in thermoelectric refrigeration for better effectiveness of the heat sink such as using a window unit with a PCM curtain (Zalba *et al.*, 2003; Sharma *et al.*, 2009). A PCM curtain can be placed within the double sheeted gap of the window and the air vent, and once PCMs freeze, it will prevent the temperature decrease of the air and this reduces overheating around the window (Juarez *et al.*, 2013).

Upon changing the state of aggregation of a PCMs in a specified temperature range, applications of PCMs can be placed in apparel, blankets, surgical tools, antibacterial and hygiene applications, insulation, clothing and many more (Mondal, 2008).

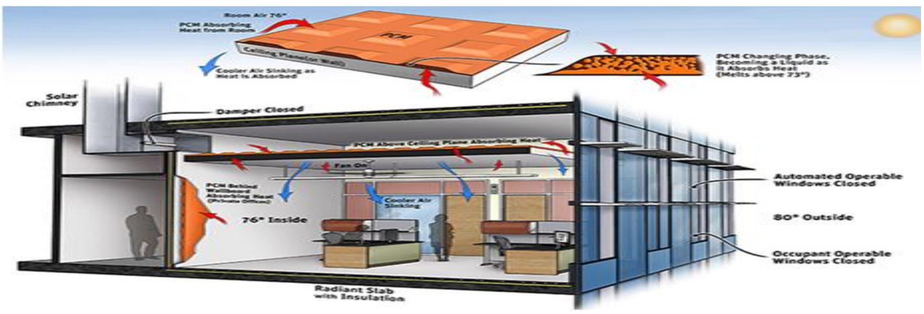

Fig-2. All PCM types applications in a building
Source: Infinite, n.d

Moreover, PCMs have multiple applications in solar energy storage systems and these are due to their hydrated salts, alkanes, waxes or paraffin's (Dincer, 2002). Many of which are provided in **Table 1** below (Rai and Kumar, 2012; Kosny and Kossecka, 2013):

Table-1. PCM-TES applications.

PCM-TES applications
Aplication
Thermal storage of solar energy
Passive storage in bioclimatic building/architecture (HDPE + paraffin)
Cooling: use of off-peak rates and reduction of installed power, ice-bank
Heating and sanitary hot water: using off-peak rate and adapting unloading curves
Safety: temperature maintenance in rooms with computers or electrical appliances
Thermal protection of food: transport, hotel trade, ice-cream, etc.
Food agroindustry, wine, milk products (absorbing peaks in demand), greenhouses
Thermal protection of electronic devices (integrated in the appliance)
Medical applications: transport of blood, operating tables, hot–cold therapies
Cooling of engines (electric and combustion)
Thermal comfort in vehicles
Softening of exothermic temperature peaks in chemical reactions
Spacecraft thermal systems
Solar power plants

Source: Phase-Change Material (2012)

3. CASE STUDY OF PCMS APPLICATIONS IN BUILDINGS

PCMs can control or reduce the variation of temperature in a building with many air conditioning applications use. Thus substantial economic and environmental will be beneficial. For evaluation of the value of PCMs materials in air conditioning application, the cooling load calculation is needed for the building. As shown in Figure 3, cooling load calculation was conducted with the application of PCMs materials. The building is located in the Alkhobar City in the Eastern province of Saudi Arabia where the average outdoor temperature (To) be about 45 °C and indoor temperature (Ti) is about 24 °C.

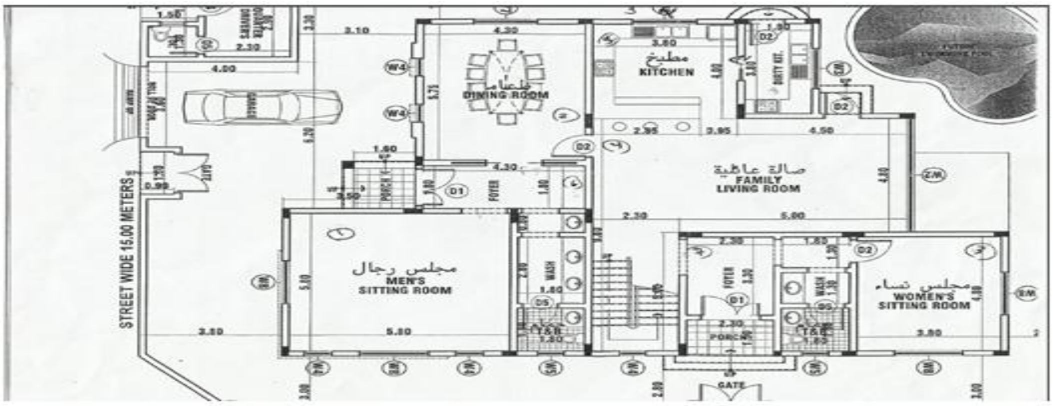

Fig-3. Comparing a normal wall with a PCM wall.

Source: Nader (2015)

The standard materials for the walls are made of 20mm brick wall, and 2mm insulation of polyurethane. The BioPCM properties used in this study are given in Table 2 below:

Table-2. BioPCM properties.

Description	BioPCM	GR27	Water
Melting Point (°C)	29	28	0
Density (kg/m3)	860	710	1000
Specific Heat (kJ kg-1 °C-1)	1.97	1.125	4.179
Latent Heat (kJ/kg)	219	72	334
Viscosity @ 30 °C (cp)	7	--------	0.798
Boiling Point (°C)	418	---------	100
Thermal Conductivity (W m-1 °C-1)	0.2	0.15	0.6

Source: Nader (2015)

4. RESULTS

The cooling loads calculation for the wall with PCM was computed for each space. The results showed that cooling loads for the building were decreased by 20% using PCMs material. In term of capacity, the total cooling loads of the building with normal construction materials was estimated to be about 16 tones whereas the PCMs was estimated to be about 13 tones. Table 3 shows the cooling load calculation results for Men sitting room with normal construction materials is presented in Table 3. While the cooling loads with PCMs material for the same room is presented in Table 4.

Table-3. Cooling load of normal wall (men sitting room).

Location		Area	U	SC	CLF	Tin-To	Q (w)
Wall	N(inner)	17.4	2.36			0	0
	S (inner)	11.46	2.36			0	0
	E (inner)	17.4	2.36			0	0
	W (inner)	14.7	2.36			0	0
	N(outer)	17.4	2.34			21	855.04
	S (outer)	11.46	2.34			21	563.14
	E (outer)	17.4	2.34			21	855.04
	W (outer)	14.7	2.34			21	722.36
Floor		33.64	1.5			0	0.00
Ceiling		33.64	1.5			21	1059.66
Window	S	5.94	2.07	0.57		21	147.18
window	W	2.7	2.07	0.57		21	66.90
Door	N	2	0.26			0	
				Sum of Q(w)			4269.32

Source: Nader (2015)

Table-4. Cooling load, with a PCMs wall (men sitting room)

Location		Area	U	SC	CLF	Tin-To	Q (w)
Wall	N(inner)	17.4	2.36			0	0
	S (inner)	11.46	2.36			0	0
	E (inner)	17.4	2.36			0	0
	W (inner)	14.7	2.36			0	0
	N(outer)	17.4	1.1			21	401.94
	S (outer)	11.46	1.1			21	264.73
	E (outer)	17.4	1.1			21	401.94
	W (outer)	14.7	1.1			21	339.57
Floor		33.64	1.5			0	0.00
Ceiling		33.64	1.5			21	1059.66
Window	S	5.94	2.07	0.57		21	147.18
window	W	2.7	2.07	0.57		21	66.90
Door	N	2	0.26			0	
				Sum of Q(w)			4269.32

Source: Nader (2015)

5. SURVEY ANALYSIS

5.1. Building and HVAC System Types

What is your building type?	Commercial	Residential	Commercial/ Residential
Survey	2	46	2
%	4	92	4

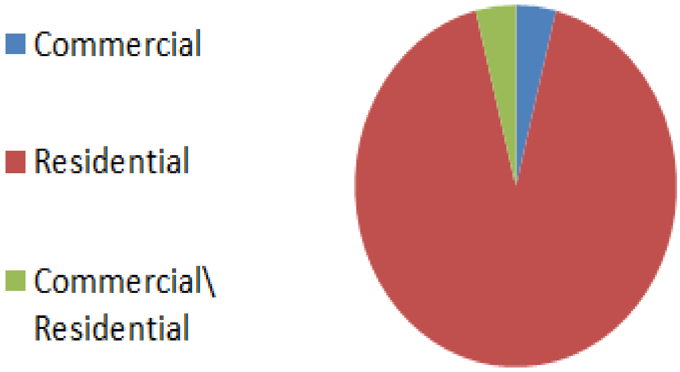

Fig-4. Distribution of housing types.
Source: Nader *et al.* (2016)

Type of AC	Survey review	%
window	21	42
Spilt	22	44
central	7	14

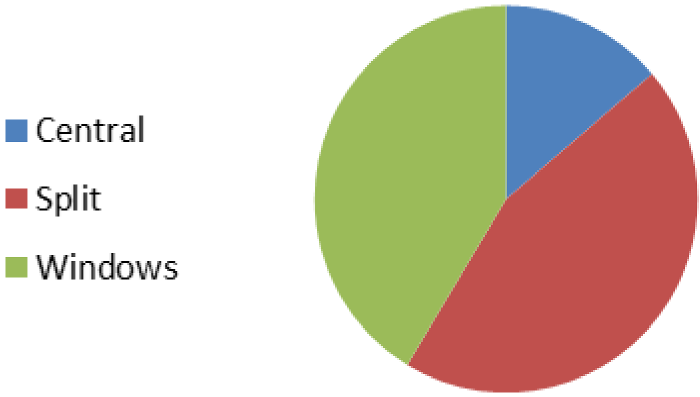

Fig-5. Distribution of the type of HVAC systems.
Source: Nader *et al.* (2016)

Figure 4 shows that 92% of the buildings surveyed are residential buildings and 4% are of commercial ones. Regarding the number of floors, about 55% of the buildings considered have one or two level floors and 36% of the targeted houses have only ground floor and attic. The left percentage (8%) is buildings with three to five level stories. Most of Al Khobar's residential houses rnages from one to three floors. Moreover, the survey included the number of apartments in the buildings. Fifty percent of the buildings have one to three apartments, whereas 20% have four to six apartments, and 30% have six to ten apartments. There are 4% of the buildings have more than ten apartments.

Most of the building air conditioning system have split and window (86%). Buildings with central units are about 14% of the buildings investigated (Figure 5). The age of the building is very important to determine the best HVAC system that suits it. It was found that about 55% of the buildings are more than ten years old.

5.2. Use of Insulation

Since the use of insulation is very important in keeping the house temperature cooled and thus reducing power consumption. From the study it was observed that 48% of the apartment's buildings don't have insulation. About 44% of Al-Khobar city ones use insulation. The other 5% was unknown (Figure 6).

use of insulation	Yes	No	don't know
Survey	22	24	4
%	44	48	8

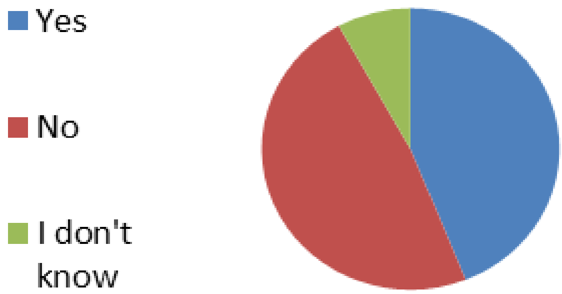

Fig-6. Usage of insulation systems.
Source: Nader *et al.* (2016)

6. SOLAR HYBRID AIR CONDITIONINER

Air condition plays a very high role for power consumption in Saudi Arabia. The increase in population, currently 20 million and the prediction for the year 2030 is double of that (United Nations, n.d). This large increase requires a tremendous power supply which most is consumed by air conditioning units. To reduce the power consumption, the transmitted solar heat and its effect on building structured will be studied. In addition, use of PCM is needed in reducing the power consumption and thus increase the efficiency the air conditioning systems.

The thermal solar collector was installed between the compressor and the condenser (Fig. 7, and 8). The results for the fully system air conditioning with solar collector and the bypass system (no solar), shows that the EER is better with solar by average of 20% than the bypass one.

The study focused on the feasibility assessment of building solar air conditioning system. The researchers found that, EER, COP and consumption of power were improved using the solar Air conditioning system and thus reduction in the consumption of power. The analysis of data and discussion proved that the solar air conditioning system not only increased the efficiency but also reduced the consumption of power.

The results of EER, COP and power consumption will have great effect on implementing the solar air conditioning system within the kingdom of Saudi Arabia.

Fig-7. Solar Thermal Collector
Source: Nader *et al.* (2016)

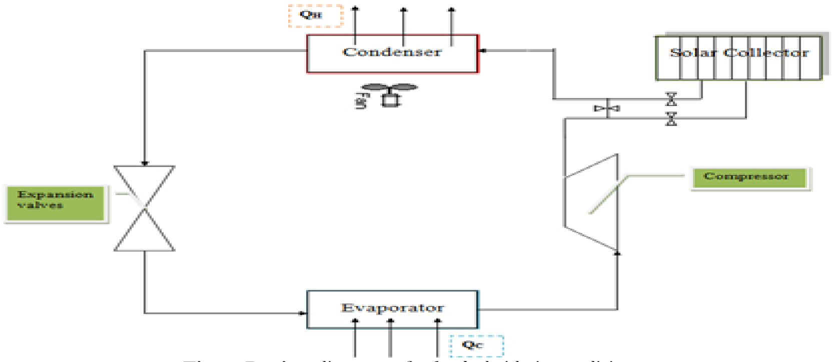

Fig-8. Design diagram of solar hybrid air conditioner

Source: Nader *et al.* (2016)

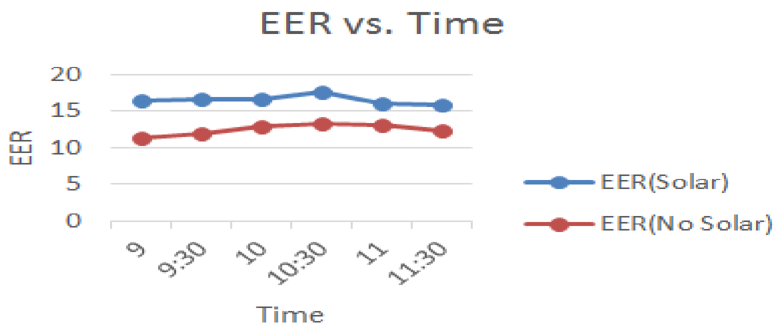

Fig-9. EER vs. Time for A/C

Source: Nader *et al.* (2016)

7. CONCLUSION

The potential use of PCMs in construction material, heat transfer and other applications are promising given the magnificent of its thermo physical properties. PCMs should be considered further in net zero energy management solutions for systems with low impact on the environment. The results analysis shows a 20% reduction of cooling load when utilizing PCMs materials in comparison to conventional ones. Accordingly, PCM wall is the future solution for the problem of running out the fuel resources in the form of latent heat storage materials. PCM should be used in construction, ceiling tiles, air conditioners, thermal heating and many other applications. Moreover, Al-Khobar City is growing at a faster rate, and with air conditioning systems being indispensable and rising in demand daily, there is an urgent need for more of power to operate more AC units. The PCM material and solar hybrid air conditioning is the key to improve on thermal insulation and thus reducing power consumptions.

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REFERENCES

Alkan, C., A. Sari, A. Karaipekli and O. Uzun, 2009. Preparation, characterization and thermal properties of microencapsulated phase change material for thermal energy storage. Solar Energy Materials and Solar Cells, 93(1): 143-147.

Chair, P.P., T. Lee and A. Reddy, 2010. Application of phase change material in buildings: Field data vs. Energy Plus Simulation. Arizona State University. Retrieved from http://repository.asu.edu/attachments/56138/content/Muruganantham_asu_0010N_10151.pdf.

Dincer, R.M.A., 2002. Thermal energy storage. Systems and applications. England: John Wiley & Sons.

Juarez, D., R. Balart, S. Ferrandiz and M.A. Peydro, 2013. Classification of phase change materials and his behaviour in SEBS/PCM blends. Manufaturing Engineering Society International Conference.

Kosny, J. and E. Kossecka, 2013. Understanding a potential for application of phase-change materials (PCMs) in building envelopes. E ASHRAE Transactions, 119: 1-11.

Marin, J.M., B. Zalba, L.F. Cabeza and H. Mehling, 2013. Determination of enthalpy–temperature curves of phase change materials with the temperature-history method: improvement to temperature dependent properties. Measurement Science and Technology, 14(2): 184.

Mondal, S., 2008. Phase changing materials for smart textiles – an overview. Applied Thermal Engineering, 28(11–12): 1536-1550.

Nader, N.A., 2015. Application of phase-change materials in buildings: Case study Al Khobar City, Saudi Arabia. International Journal of Advanced Engineering and Nano Technology, 2(7): 19-23.

Nader, N.A., B. Bandar, J. Mohammad and S. Mohammad, n.d. Application of phase-change materials in buildings. American Journal of Energy Engineering, 3(3): 46-52.

Nader, N.A., A.M. Ibrahim and A.S. Rami, 2016. Hybrid air conditioning, solar, HVAC, energy consumptions. International Journal of Modern Engineering Research, 6(10): 34-32.

Perez, A.D.P., 2010. Situacion y future de los PCM (Phase Change Material). Centro de Desarrollo Tecnologico – Fundacion LEIA.

Phase-Change Material, 2012. Wikipedia. Retrieved from http://en.wikipedia.org/wiki/Phase-change_material.

Phase-Change Materials, 2013. Building. Retrieved from http://www.building.co.uk/business/cpd/cpd-1-2013-phase-change-materials/5050027.article.

Py, X., R. Olives and S. Mauran, 2001. Paraffin/porous-graphite-matrix composite as a high and constant power thermal storage material. International Journal of Heat and Mass Transfer, 44(14): 2727-2737.

Rai, A.K. and A. Kumar, 2012. A review on phase change materials & their applications. International Journal of Advanced Research in Engineering and Technology, 3(2): 214-225.

Shapiro, M., D. Feldman, D. Hawes and D. Banu, 1987. Thermal storage in drywall using organic phase-change material. Passive Sol. J.;(United States), 4(4).

Sharma, A., V.V. Tyagi, C.R. Chen and D. Buddhi, 2009. Review on thermal energy storage with phase change materials and applications. Renewable and Sustainable Energy Reviews, 13(2): 318-345.

Streicher, W., L. Cabeza and A. Heinz, 2005. A report of IEA solar heating and cooling programme - task 32 advanced storage concepts for solar and low energy buildings. Solar Heating & Cooling Programme: 1-33. Ecostock Conference 2005, Printed by Servei de Publicacions Universidad Lleida, Spain. pp: 170.

United Nations, n.d. Department of economic and social affairs, population division. World Population Prospects. Available from https://populationpyramid.net/saudi-arabia/2030/.

Zalba, B., J.M. Marin, L.F. Cabeza and H. Mehling, 2003. Review on thermal energy storage with phase change: Materials, heat transfer analysis and applications. Applied Thermal Engineering, 23(3): 251-283.