# Application of Phase-Change Materials in Buildings: Case Study Al Khobar City, Saudi Arabia

**Nader A. Nader**

***Abstract*—Phase-Change Materials (PCMs) are substances with a high heat of fusion that melt and solidify at a certain temperature range. They are capable of storing and releasing large amounts of energy and have a high capacity of storing heat. PCMs prevent energy loss during material changes from solid to liquid or liquid to solid. They have several advantages such as its self-nucleating properties, and disadvantages such as having low thermal conductivity [4]. There are different types of PCM with a wide range of applications. This paper studies the potential application of PCMs in building energy conservation materials. The analysis shows that the use of BioPCM material as an insulation layer in building can decrease the cooling load by 20% in comparison to a standard one. In addition, this research reviews the program performance to date through conducting a survey to evaluate the HVAC energy consumption efficiency in Residential and Commercial Buildings in Al Khobar City, Saudi Arabia. Forty Buildings were surveyed in October 2014. The survey results showed that fifty perecent of the buildings don't have insulation and their HVAC systems were more than 10 years old and with lower efficiencies.***

***Index Terms*—Phase-Change Materials, Energy Cosumption, Cooling Load, Insulation Material**

## I. INTRODUCTION

The current electricity peak demand in the Kingdom of Saudi Arabia (KSA) is about 55 Gigawatt (GW) out of which 72% is used for Heat Ventilation and Air conditioning system (HVAC). The peak demand is projected to reach 120 GW by the year 2032. The Saudi Government initiated a massive program to improve HVAC energy consumption efficiency in 2007. The program includes HVAC rating system, comprehensive implementation program for new system, and 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. The respondents' feedback highlighted the need to improve the current HVAC energy conservation program in KSA. Targeting new constructed building only for efficient HVAC system will not improve HVAC 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. Researchers have investigated Phase-Change Materials (PCMs) heavily over the last two decades as energy conservation materials in buildings.

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The tremendous increase in energy prices has motivated researchers to search for new materials that has the capacity to reduce energy demand. PCMs thermophysical properties that include melting point range, heat of fusion, thermal conductivity, and density; have promoted it as a valid option for energy conservation. Additionally, PCMs can freeze with little supercoiling; compatible with construction material; chemically stable; recyclable; and can reduce HVAC load. However, PCMS have a few drawbacks include the requirements of a freezing cycle in order to transfer high heat; and the capacity of its volumetric latent heat storage (LHS) is low making PCMs flammable. Therefore, PCMs need to be stored in a proper container to avoid any of these disadvantages. PCM can be classified under three categories: organic, inorganic and eutectic [15]. Organic PCMs have technical grade paraffin's or paraffin mixtures made of oil that help PCMs obtain reliable phase change points [7]. Paraffin is also available in large temperature ranges, making them accessible, especially because they have a long freeze-melt cycle. PCMs can also be made out of non-paraffin compounds. The benefits for using this organic material in heat storage are that it has the advantage of not being corrosive or undercooled, but still do cause a lower phase change enthalpy, low thermal conductivity and inflammability. In using inorganic PCM materials for heat storage such as hydrated salts and metallic, have a greater phase change enthalpy despite its disadvantages of undercooling, corrosion, phase separation and lack of thermal stability. The third classification of PCM is eutectic which can be organic or inorganic [8]. They have a sharp melting point and their volumetric storage capacity is higher than organic paraffin compounds. However, its thermophysical properties are limited and are still rather new to thermal storage [9]. To increase heat conductivity in PCM without affecting the energy storage, Mehling et al. [5] and Py et al. [6] designed a compound-material made of a graphite matrix to embed the PCM in it. Graphite decreases the sub cooling of PCMs hydrated salts and decreases the volume change of paraffin's. This produces high thermal conductivity where there is 8% of the latent heat of fusion per unit mass of the paraffin [3]. When heat is applied to a substance, the energy transfers in one of two ways. The first is that the substance gains heat [2, 3]. For example, if heat is applied to water, it will rise in temperature to a maximum of 100°C, its boiling point. Likewise, if heat is removed, the temperature of the water will fall, to a minimum of 0°C, or its freezing point. This type of heat transfer, or storage, is called sensible heat as seen in **Figure 1**. The temperature of a substance however, doesn't always rise when heat is added. Boiling water for example, remains at 100°C no matter how much heat is added which is why the water turns



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into vapour [2, 3]. Therefore, any substance that absorbs heat reaches either its melting or evaporation point without getting any hotter. Latent heat is this type of heat storage. Without latent heat, PCMs would not be able to act alone in controlling room temperature because when used in construction they change from solid to liquid at 23-26°C. When PCM melts, they absorb heat from the room to keep the room temperature stable. PCMs only return to its original solid state during ventilation at night. These valuable properties of PCMs shall dramatically reduce cooling and heating energy demand if properly managed and implemented. This paper studies the potential application of PCMs in building energy conservation materials.

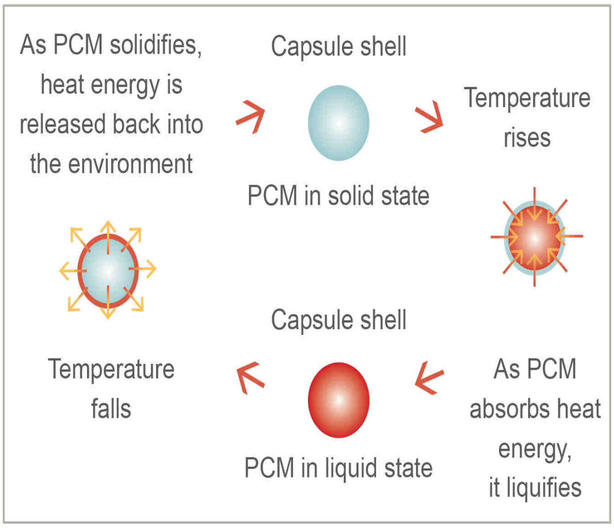


**Fig. 1. PCMs work by solidifying to release heat energy and absorbing heat energy before being liquidities. [20]**

## II. PCMS APPLICATIONS IN BUILDINGS

More than 500 natural and synthetic PCMs are known in addition to water [11]. They differ from each other by their altering phase change temperature ranges and their heat storage capacities. Other properties of PCM for a high efficient cooling system with thermal energy system (TES) include [9]:

- A melting temperature in the desired operating range, in construction this would be 23°C or 26°C.
- A high latent heat of fusion per unit volume. In other words, they can store a large amount of heat per unit of volume, minimizing the area of PCM tiles that are needed.
- High thermal conductivity. The quicker the PCM reacts to changes in temperature, the more effective the phase changes will be.
- Minimal changes in volume. Substances expand or contract when they change state. Because PCMs in construction need to be contained within a cassette, large changes in volume could create 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 freezing/melting cycle.
- Durability over a large number of cycles.
- Non-corrosiveness to construction materials.
- Non-flammable.

PCMS can be for heating and cooling in buildings as seen in **Figure 2**[12]. PCM can be placed in porous construction material such as plasterboard to increase heat [13]. As for cooling, air conditioners with PCM collect and store ambient air during the night. PCMs can also be placed in thermoelectric refrigeration to improve effectiveness of the heat sink such as using a window with a PCM curtain [13, 14]. A PCM curtain fills up the double sheeted gap between the window and the air vent, and upon freezing the PCMs would prevent the temperature of the air from decreasing and this reduces overheating around the window [15]. By altering the state of aggregation of a PCMs in a specific temperature range, applications of PCMs can be placed in apparel, blankets, surgical tools, antibacterial and hygiene applications, insulation, clothing and many more [11].

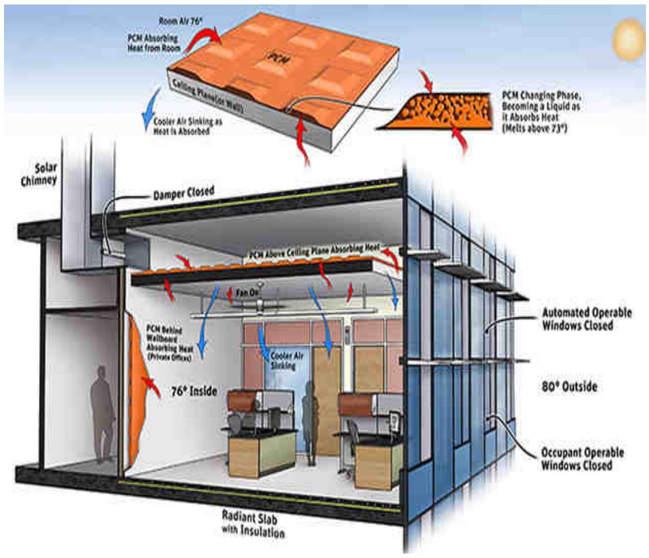


**Fig. 2. All types of PCM applications in a building [19]**

Additionally, PCMs have multiple applications for solar energy storage due to their hydrated salts, alkanes, waxes or paraffin's [10]. Many of which are organized in **Table I** below [17, 18]:

**Table I. PCM-TES applications [4].**

| 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 |

## III. CASE STUDY OF PCMS APPLICATIONS IN BUILDINGS

PCMs can smooth temperature variability's in a building especially when used in air conditioning applications. This can have substantial economic and environmental benefits.



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To evaluate the value of PCMs materials in air conditioning application the cooling load needed for the building shown in **Figure 3** was estimated with the application of PCMs materials and without. The building is located in the Dammam 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.

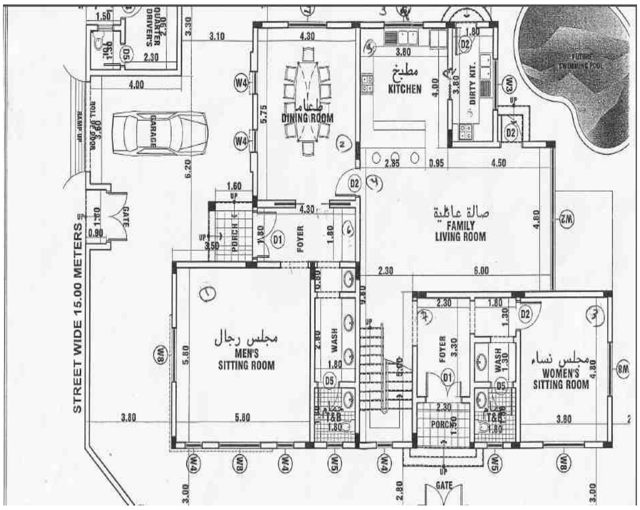


**Fig. 3. Comparing a normal wall with a PCM wall.**

The standard materials for the walls are made 0f 20mm brick wall, 2mm insulation of polyurethane. Whereas the BioPCM properties are given in Table 2 below:

**Table II. 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 |

## IV. Results

The cooling load from a normal wall and the cooling load from a PCM wall were calculated for each room in the building. The analysis shows a total reduction of needed cooling load for the whole building of about 20% when utilizing PCMs in the building. The total cooling load for the building with normal construction materials was estimated to be about 16 tonnes while with PCMs was estimated to be about 13 tonnes. More details are provided for the men sitting room in the building. **Table III** shows the cooling load calculation results for Men sitting room with normal construction materials is presented in **Table III**. While the cooling loads with PCMs material for the same room is presented in **Table IV**.

**Table III. Cooling load for men sitting room estimate for a normal wall.**

| 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 |

| 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 |

## V. Survey Analysis

### 4.1 Building And Hvac System Types:

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

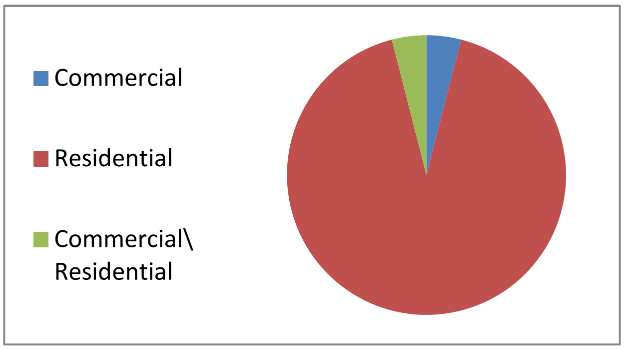


**Fig. 4. Distribution of housing types.**



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

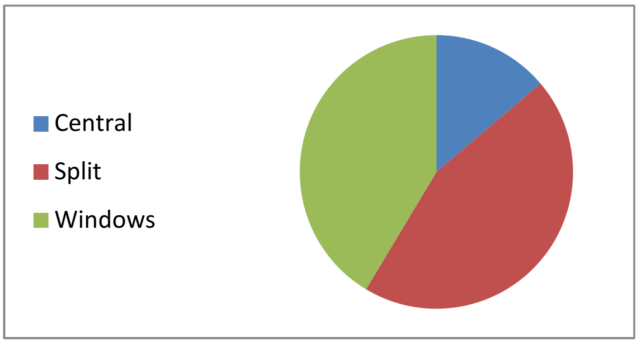


**Fig. 5. Distribution of the type of HVAC systems.**

**Figure 4** shows that 92% of the buildings we surveyed are residential buildings and 4% are the of commercial buildings surveyed. Regarding the number of floors,about 55% of the buildings considered have 1 or 2 level floors and 36% of the targeted houses have only a ground floor and a attic. The left percentage (8%) are buildings with 3 to 5 level stories. Most of Al Khobar's residential houses rnages from 1 to 3 floors. Moreover, the survey included the number of apartments in the buildings. Fifty percent of the buildings have 1 to 3 apartments, whereas 20% have 4 to 6 apartments, and 30% have 6 to 10 apartments. There are 4% of the buildings have more than 10 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 10 years old**.**

### 4.2 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 apartments 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 |

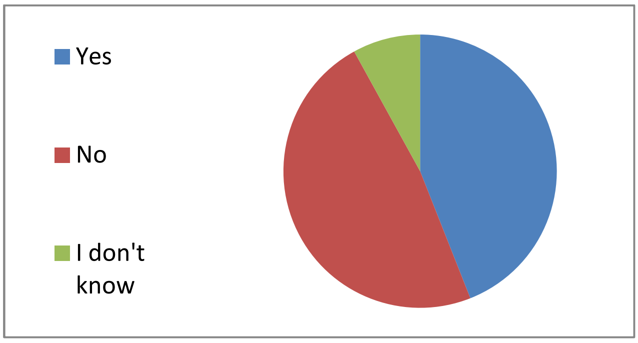


**Fig. 6. Usage of insulation systems.**

## VI. Conclusion

The potential use of PCMs in construction material, heat transfer and other applications are promising given the magnificent it thermophysical properties. PCMs should be incorporated further in global energy management solutions due to the stress for innovations with a low impact on the environment. The results gained from analysis shows a 20% reduction of cooling load when utilizing PCMs materials in comparison to standard construction materials. Accordingly, PCM wall is a promising solution for the problem of depleting fuel resources in the form of latent heat storage materials. PCM should be used in buildings, ceiling tiles, air conditioners, thermal heating and many other applications. Further research is recommended in PCMs application in the construction industry due to its magician properties and potential wide 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 is the key to improve on thermal insulation and thus reducing power consumptions.

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