Introduction to Phase Change Material in Concrete for Thermal Comfort

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1. Introduction:

1.1 RESEARCH MOTIVATION:

The continuous increase in world population alongside the rapid growth in energy consumption rate, led to growing concerns regarding the energy crises ahead. Stated in the assessment report of the intergovernmental panel on climate change (IPCC, 2012) predictions of unchanged energy consumption mix by 2030, rating fossil fuel as the primary energy source fulfilling 80% of global demand. In order to reduce greenhouse gas (GHG) emission, efforts have been put extensively to substitute fossil fuel with renewable energy sources. Currently energy demand worldwide is met with fossil fuel while hydro power and nuclear power contribute by a small rate, meanwhile renewables have a less significant role in the energy balance. Thus changing the energy source becomes the challenge, however the change to choosing different primary energy source such as renewables over oil or coal is a long term plan and due to the current state of the available technologies of extracting them, furthermore increasing the efficiency of producing the energy, must be accompanied by increasing the efficiency of means of consuming it.

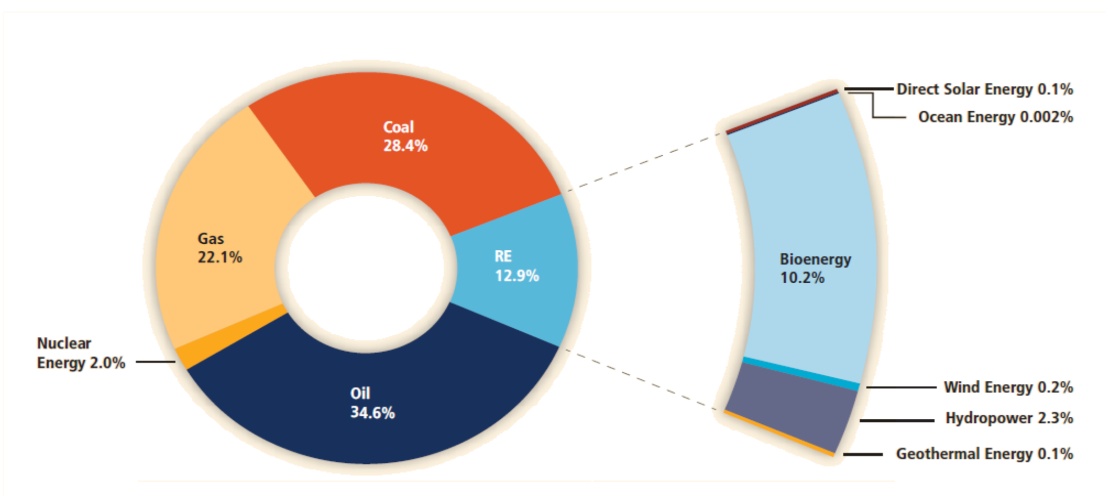

Figure 1: primary energy consumption worldwide (IPCC, 2012)

Built environment is considered one of the most energy consumers, particularly electricity which has been rated as the fastest growing fuel consumer, solely participating in global demand growth by 58% (BP, 2012). Given the fact that energy availability is in parallel with economic stability and technological progress, predicting future demand, considering the constant increase and possible climate change is essential to ensure a sustainable progress of any nation (Dincer and Rosen, 2011). Therefore future buildings mAs statednsider improving their energy efficiency exploring the choices of location, orientation, design, materials as well as various possible parameters that might contribute in energy saving.

Buildings consume energy as a function of its construction materials (Hall and Allinson, 2010), therefore choosing building materials based on the physical characteristics and appropriateness can reduce amount of material to be used, energy input of construction, energy use in operation time and reducing the impact of high embodied energy in the building over a long term of operation, which in return results in higher resource efficiency rate while increasing chances of using better quality materials. The building envelope system dominantly affects the inner comfort level of the building due to its main function as a shelter from outdoor conditions. Simultaneously it acts as the mean of transporting energy between inside and outside, since this incident is not preferable in case of extreme differences between human comfort level acquired inside and the outside conditions, controlling the energy transfer has become the major issue of study in the recent researches as a result of the impact on the energy consumption in buildings to maintain desirable comfort levels. In this area thermal energy storage (TES) have a significant impact on improving the building overall energy efficiency (Mehling and Cabeza, 2008). Thermal energy storages have the ability to retain and release heat resulting a change in their internal energy; this can be in form of sensible heat, latent heat or both (Sharma et al., 2009). Effective use of this property of materials results in improving the thermal conditions in building in addition to more efficient energy use (Wu, 2010). Thus TES will not individually act but rather enhance a designed system to be more effective, energy conservative and cost efficient (Mehling and Cabeza, 2008).

1.2. ENERGY TREND IN HOT CLIMATES:

In hot climates, a large portion of energy is consumed by space cooling, especially in residential sector. In *Energy Outlook 2030* by (BP, 2012)reported; in hot climates like Middle East, where main energy source is fossil fuel, energy demand is expected to grow in a rate of 3% p.a for 2010-2030, due to the rapid increase in energy use per capita in the area. Furthermore the noticeable rise in living standards has affected changing occupants' behaviour regarding acceptable range of thermal comfort, resulting in further energy consumption for space conditioning (Candido et al., 2010). Despite the new global building Trent of using glass and light weight structure, in hot climates, traditional buildings have utilized heavy weight structures like thick brick walls to maintain minimum inside temperature. In the same manner, concrete has behydropower its structural feasibility and thermal performance. While in many areas with a moderate climate utilizing concrete TES for capturing solar energy in winter and reducing or eliminating cooling load in summer will be effective. But for locations with higher average temperature, night time ventilation may not be desirable, thus controlling temperature swing during the day has been managed by active cooling systems rather than depending solely on passive TES systems. Consequently further enhancing the thermal properties of a widely used structural material as concrete will participate actively in reducing the energy consumption in hot climates. in this paper an investigation will be presented in utilizing PCM for enhancing the thermal performance of concrete structures to minimize the temperature swing during the day in hot climates, aiming in providing a better solution for a building envelope that can cut a portion of buildings' need for active cooling, subsequently reducing the annual energy consumption.

2. Thermal energy storage:

A substance in its stable physical conditions possesses energy that can be identified as internal energy. In absolute stabilized settings, the energy remains constant abided by energy conservation law. When the surrounding circumstances change it exchanges energy, in the form of heat, with outside of its physical frame to maintain larger scale energy balance. Once the substance is subjected to heat, on a molecular scale, the reaction of the matter can be transferring the absorbed heat into kinetic energy resulting in increasing the temperature of the body or potential energy resulting in a change of the binding in the particles of the substance's system. In this case the internal energy of the substance is the sum of kinetic and potential energy (Atkins and De Paula, 2006).

Different materials have different reaction while subjected to similar changes; this has been identified as thermal capacity of the material. Thermal capacity is the measurement of thermal energy that a system can retain to change the temperature by a certain amount. The molecules bonds experience variations. Stored potential energy is dependent on the freedom of these molecules in their bonds not only the substance temperature (Reif, 1965). In such manner the enthalpy of the system increases when the energy transfer from the surrounding environment results in vibrating the molecules bonds.

As a case of study in this paper, thermal energy storage systems is described as; sensible heat storage in which energy retained by the system results in increasing the substance temperature, or latent heat storage when energy transfer process changes the physical form of the substance (Hasnain, 1998). In order to have the system functioning as thermal energy storage, the process needs to be reversible, to allow retrieving the energy later, on the other hand its reversibility time affects the uses in building applications.

Recently, in building applications, thermal energy storage has been considered an important energy conservation technology to be integrated in the building system. Its applications in building technology for active and passive cooling systems have proven effective nevertheless valuable from an economic perspective, especially when annual and capital energy consumption is compared with those systems supplying energy to same load and capacity. Meanwhile equally valuable environmental impacts are considered in terms of reducing energy use, subsequently (GHG) emissions. In which when a TES system is in function, less equipment size is required to deliver load compared to convictional systems, meanwhile the system potentially can passively maintain functional, eliminating the need for active cooling or heating load (Paksoy, 2007).

The envelope system of a building composes a shelter for the inner environment from the outside conditions, yet this system does not operate as a function of the ambient temperature, solar radiation or any other outside factors only. But rather its own thermal property plays a main part in indicating whether it will provide reliable thermal energy storage. More accurately the ability of the envelope to store heat or transfer the outside temperature fluctuation is determined by the construction structure and its material (Hindrichs and Daniels, 2007).

Generally all thermal energy storage systems are similar in function, they absorb energy in the form of heat, retain when in equilibrium state with surrounding environment and release energy when reverse circumstances apply, to make the use of energy stored when needed. Meanwhile application of the heat and cold storage differs depending on the storage capacity size and the method. As a result choosing the proper energy storage to be integrated in the building application is considered the key factor in designing a successful building system (Paksoy, 2007).

2.1. SENSIBLE HEAT STORAGE:

The most common and practiced thermal energy storage is sensible heat storage, the heat absorbed by the material as a storage medium causes an increase in the substance temperature. The amount of the energy absorbed is strictly dependant on the specific heat capacity of the material, the temperature change in time and the size of the storage medium. More specifically the stored heat ΔQ ratio to the temperature change ΔTin the material is the heat capacity of the system, which can be expressed as:

$$C_S = \rho\, V_c \Delta T \qquad 1$$

A substance to serve as an efficient heat storage medium has to have a high specific heat capacity, high emissivity, a moderate conductivity and moderate density (Mehling and Cabeza, 2008). Subsequently for the TES system to function, a substantial amount of the substance must be integrated. In building applications solid materials such as concrete, brick or stone are often used as heat storage. Other solid materials as wood cannot conduct heat to be stored in materials interior, while steel has a high heat conductance resulting in reducing the energy storage time to minutes instead of hours.

Material	density kg/m³	Specific heat capacity KJ/kg.K	Emissivity	Absorptivity	thermal conductivity W/m.K
concret HW	2000	840	0.65-0.80	0.85-0.95	1.3
brick	1550	800	0.36-0.62	0.85-0.95	0.84
stone	2880	840	0.5-0.9	0.9	2.9
wood	90	2810	-	0.80-0.95	0.05
steel	7800	480	0.2	0.07-0.09	45

Table 1: specification of some building materials (CIBSE, 2006)

Alternatively concrete has been successfully utilized as a heat storage medium for its convenient physical properties, due to its high thermal capacity and moderate conductance, heat energy can be transferred into the material through the surface and be stored for an adequate period of time. Furthermore discharging time span for concrete is closely equal to the charging period considering equal time steps for changing the surrounding environment. Another positive aspect of using concrete as a thermal storage medium is the common dimensions between structural and thermal storage concrete wall, at the same time concrete as a structural building material has been widely used before its thermal properties in energy conserving strategies been utilized. This subsequently helped establishing solid grounds for coupling concrete in thermal energy storage systems (Haglund and Rathmann, 1998).

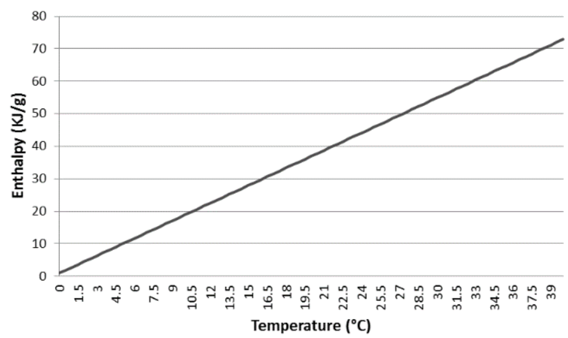

Figure 2: Sensible heat storage in concrete

2.2 LATENT HEAT STORAGE:

Latent heat storage is based on phase transformation of the storage substance due to absorbing energy, heat absorption is associated with a phase change from solid-liquid or liquid-gas. Phase change materials absorb heat in the same order as conventional sensible heat storage materials until their temperature reaches the transition phase level, the amount of heat absorbed in this stage is called heat of fusion. The heat capacity of the material rapidly increases, as the absorbed heat causes vibration on the molecular level resulting in changing the substance physical state, thus the absorbed energy will no longer results in increasing the material's temperature. After complete phase transition for the potential available substance, the temperature of the material starts to rise accordingly (Dincer and Rosen, 2011).

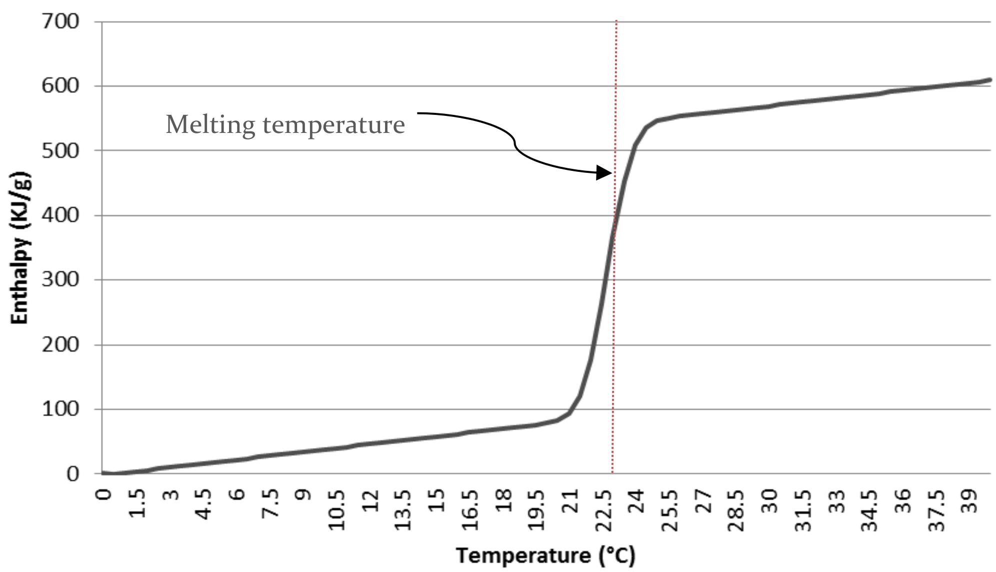

Figure 3: Latent heat storage in PCM

Therefore adding phase change materials to the TES system expands the thermal storage capacity comparing to ones with conventional building materials by 5-14 times (Sharma et al., 2009). In this manner the thermal storage capacity of resultant material can be interpreted as follow:

$$C_{effe} = C_s + C_l \qquad 2$$

$$C_l = A_L e^{-0.5\left(\frac{T-T_m}{B}\right)^2} \qquad 3$$

where A_l is latent enthalpy and B is melting width factor (Tetlow, 2008)

Phase transition is associated with volume changes; in solid-solid phase change the difference in volume is insignificant, since the change is form one crystalline state to another, they do not acquire a large heat of fusion, therefore their latent thermal capacity is limited. In the solid-liquid phase transitions a small volume change occurs, the amount heat of fusion in this change is considerably large and stored in the material. Furthermore the reverse transition results in discharging the heat stored at the same point of melting. On the contrast liquid-gas transition despite its large heat of fusion is associated with a large volume change, which makes it unpractical in building applications.

In general latent heat storages are more attractive than sensible heat storage, due to their large capacity of storage with smaller volume and their effectiveness in passive designs due to less temperature swing in the zones with TES constructions.

Material	Type	Density kg/m³	Heat of fusion KJ/kg	Melting point °C	Thermal conductivity W/m.K
water	Inorganic	998	333	0	0.612
Polyglycol E400	Organic	1125	99.6	8	0.187
Paraffin C18	Organic	0.774	224	28	0.148
$CaCl_2.6H_2O$	Inorganic	1562	171-192	29	0.54
66.6% urea + 33:4% NH_4Br	eutectics	1440	161	76	0.331

Table 2: LHS of some materials (Zalba et al., 2003)

2.3 PHASE CHANGE MATERIALS AS TES

Although early studies in capturing solar energy in building application as TES started as early as world war II (Hasnain, 1998, Farid and Sherrif, 2010), but only in the last decades researches has been conducted in utilizing PCM as thermal energy storage (Lane, 1983, Mehling and Cabeza, 2008, Farid and Sherrif, 2010, Zhao and Zhang, 2011). Employing PCM in building application is becoming progressively more important, given that the major reason of integrating PCM with building constructions refers to its economical implementations. In extreme hot/cold climates, due to temperature fluctuation between day and night, majorities of energy load is consumed in domestic air conditioning. This has affected the energy balance during the day, furthermore resulting in pricing difference between daytime peak load and overnight off-peak load. In order to attempt to restore balance in energy consumption during the day, temperature fluctuation inside the building must be kept at minimum levels. At the same time peak loads to be shifted to off-peak prices periods. Researches has shown the success of using PCM in building construction for this purpose, in which achieved by passively collecting, storing and evenly distributing heat energy in the thermal zone (Khudhair and Farid, 2004, Tyagi and Buddhi, 2007, Voelker et al., 2008).

In general, PCM applications in building is concentrated in to two main areas; integrating it with heating and cooling systems for designing a more efficient active air conditioning system or coupling PCM in building construction to enhance the designed TES system (Paksoy, 2007). In this paper more close investigation in the later area is presented.

3. Phase change materials:

Phase change materials are latent heat storages, energy is stored when the substance with a high heat of storage undertake a transformation in its physical form. This phase transformation can be from solid-solid, solid-liquid or liquid-gas. In the endothermic process, heat is absorbed resulting in breaking the molecular bonds, thus the substance reaches a higher enthalpy state. For different types of PCM, this process takes place in different temperatures, yet every PCM has a certain melting enthalpy around a specific temperature. Alternatively for the exothermic process, absorbed heat will be reverted and pre-heat absorption state will be reserved. In this manner the ratio of energy storage capacity to the substance's volume in Latent TES is much higher than in sensible TES (Atkins and De Paula, 2006).

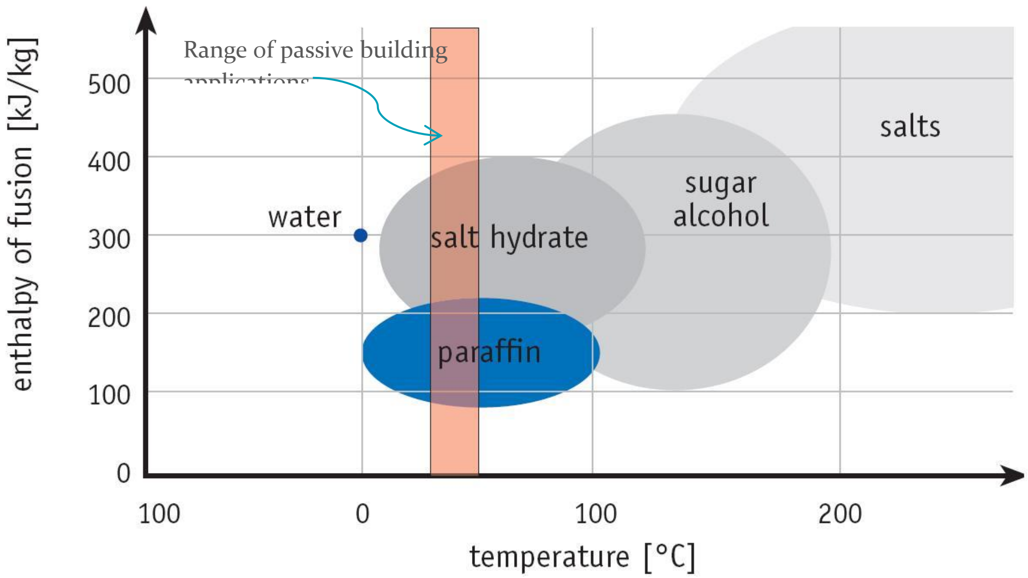

Figure 4: Types of PCM according to temperature application from TROX® Technik

3.1. CHARACTERISTICS AND REQUIREMENT:

Variety of materials can be classified as PCMs, while not all PCMs can be employed in building applications. In general a large melting enthalpy and an appropriate melting temperature are the basic requirements of a PCM considering implementations for a defined location. Furthermore certain characteristics are required from the material to serve as TES; thermodynamically, kinetics, chemicals and economical. Although the importance of these requirements varies with PCM application in the building component, most of the applicable PCMs must share the following characteristics(Paksoy, 2007, Haglund and Rathmann, 1998):

- Thermodynamically it is important for the PCM to acquire a large phase change enthalpy, a suitable fixed phase change temperature, good thermal conductivity and most importantly the reversibility and repetitively of the whole process ensuring cycle stability.

- Kinetic requirements for PCM are: minimum volume change during phase cycling, no sub cooling and a sufficient crystallization rate in each cycle.

- Chemical requirements can be pointes as follow: chemical stability of the substance during the phase change process, resistance to chemical reactions, noncorrosive to other construction materials, non-toxic, non-flammable and non-explosive.

- PCM cost and its availability are of the most important characteristics, as they have a significant impact on utilizing PCM widely in building applications.

3.2. CLASSIFICATION

The melting temperature and the absorbed heat of fusion for PCM depends on the type of molecular bonds, thus the chemical compositions of PCMs differ,

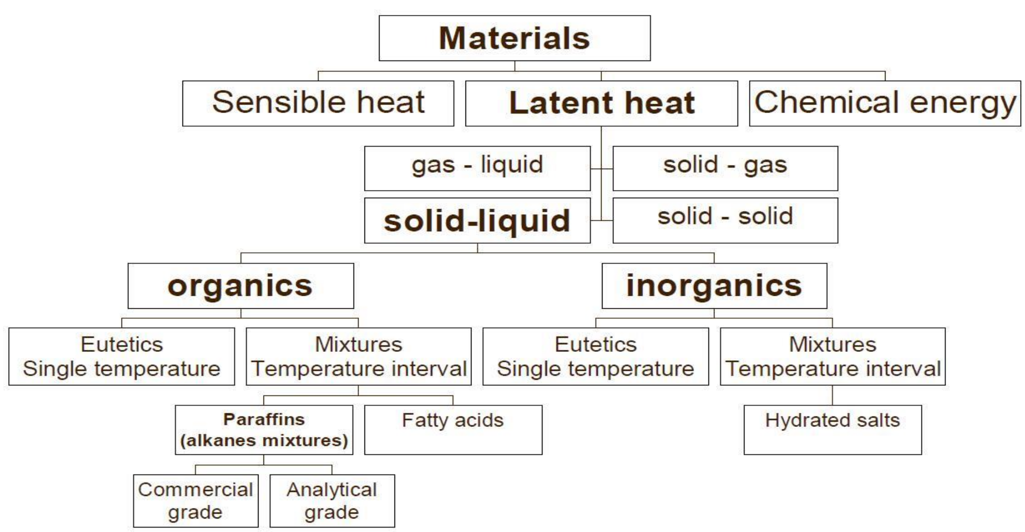

Figure 5:Heat storage classification in materials (Abhat, 1983)

according to this PCMs can be classified in different categories. Clear classification of PCM materials has been given in (Abhat, 1983), in general phase change materials are divided into three groups; organic, inorganic and eutectics, in which are divided into sub groups each within a range of melting temperature and melting enthalpy (Baetens et al., 2010).

3.2.1 Organic materials

Organic PCMs are paraffin, fatty acids and sugar alcohols, their characteristics and range of melting temperature makes them useful in certain building applications. Specifically paraffin waxes, they have a reasonable thermal storage (120-210 kJ/kg) with a melting temperature ranging between as low as 20 ^{0}C and high as 70C, while they show less chemical stability when subjected to higher temperatures (Baetens et al., 2010). Their density is close to 103kg/m3 much less than other inorganic PCMs like water and salt hydrate, thus their melting enthalpy is considerably less. Alternatively they are more stable chemically than inorganic PCMs, phase separation is rare since all the substance melt correspondently, super-cooling does not stand a problem, meanwhile the substance undergo a volume change during phase cycling and experience a low thermal conductivity (Hasnain, 1998). Although organic materials in general come with higher initial cost, but due to their compatibility with various building materials, they pose very competitive long term economic value with inorganic and eutectics materials.

3.2.2 Inorganic materials

Investigating PCM for heat storage started with inorganic materials such as salt hydrate, due to high water content, they have been more economically available. Furthermore they have a high latent heat of fusion and come in a wide range of melting temperature. Although comparing to organic materials they have a higher rate of enthalpy to mass due to their water content, this makes them more vulnerable to corrosion when in contact with metals. Thus integrating it with building construction becomes challenging when metallic containers are used to enhance thermal conductivity, while inorganic PCM require containers and cannot be incorporated in porous building materials.

Among inorganic PCMs, salt hydrates are by far the most examined and applied into TES system applications due to their many advantages. The high heat of fusion ratio to mass and less volume change make them very suitable for encapsulation, as less volume is required to achieve higher storage capacity. Segregation and phase separation in salt hydrates stand a problem during the phase cycling, additionally corrosion in metal containers as the rest of inorganic materials needs to be considered (Mehling and Cabeza, 2008).

3.2.3 Eutectics materials

These are composite materials, can be a mix of organic, inorganic or both together. The composite of the mix have a simultaneous melting process, thus phase separation is unlikely to occur. In the exothermic process they form a composite crystals preventing sinking of any composite due to difference in density (Mehling and Cabeza, 2008). In general eutectic PCM composites have a large heat of fusion in a wide range of melting temperature, the mix is prepared to result in minimum melting temperature with a sharp edge. While the mixing procedure requires many steps, this can be both money and time consuming.

3.3 PCM INCORPORATION WITH BUILDING MATERIALS:

PCMs as storage medium provides a higher capacity due to its heat of fusion, therefore by integrating it with conventional building materials, less volumetric rate is required to achieve the target energy storage capacity (Khudhair and Farid, 2004). Furthermore by absorbing heat for the melting enthalpy the peak load of cooling is shifted to later in time, pass the complete melting of the PCM substance. Thus it has a direct effect on shifting the peak-load to off-peak electricity tariff hours (Sharma et al., 2009). For PCM materials to be used in building applications certain procedures must be undertaken. Most of PCM require containers to prevent leakage or chemical reaction with the building materials, additionally to enhance their thermal conductivity. In choosing effective method of integrating PCM with the building construction, basic physical and chemical characteristics of different materials must be considered. Containers must be compatible with the PCM type, avoiding chances of corrosion and considering probable volume change during phase cycling (Mehling and Cabeza, 2008). Integrating PCM with building material has been classified as; macro encapsulation, micro encapsulation and molten bath for the construction material.

3.3.1 Macro encapsulated element

The most common use of PCM has been in macro encapsulation, usually larger than 1cm in diameter. The main purpose is to protect the PCM from leakage or change of composition due to contact with other materials, also it helps with handling in production and applications (Mehling and Cabeza, 2007). Plastic containers are commonly used to encapsulate inorganic materials such as salt hydrate, as the later have tendency to react with metal containers. Meanwhile organic materials like paraffin are mostly encapsulated in plastic containers, given that some organic materials soften the plastic, additionally metal containers enhance the thermal conductivity of the unit.

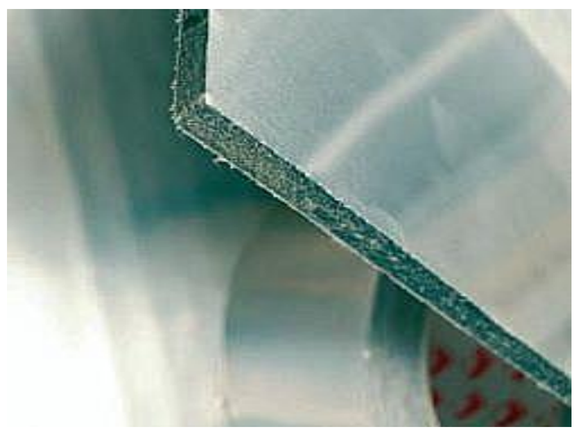

Figure 6: DuPont™ Energain® board

Many researches and experiments has been conducted on integrating macro encapsulated PCMs with building constructions, among those are; the work of

(Alawadhi and Alqallaf, 2011) when used different geometrical shapes for containers in a concrete slab to evaluate the difference in between their performance, while (Pasupathy et al., 2008a) have performed a large scale experiment, supported by numerical calculation and simulation analysis to investigate the performance of roof construction consisted of concrete slab, PCM layer and finished with brick mixture. (Alawadhi, 2008) has investigated the possibility of filling brick cavities with PCM and the effects on temperature swing in hot climates where brick is a common building material. Prefabricated sandwich panel walls with a layer of PCM integrated has been examined in (Carbonari et al., 2006) a full scale experiment to validate a finite element numerical algorithm in predicting PCM behaviours. Results from all previously mentioned tests prove an enhanced thermal behaviour for the building construction, less fluctuating internal temperature and a noticeable shift in peak loads.

3.3.2 Microencapsulation within the mix

Encapsulating PCM in smaller than 1cm diameter is classified as microencapsulation, which is technically feasible and currently applied on a commercial scale on water repelling materials such as paraffin (Mehling and Cabeza, 2007). Among the various PCMs, paraffin wax is commercially available, due to its suitable range of

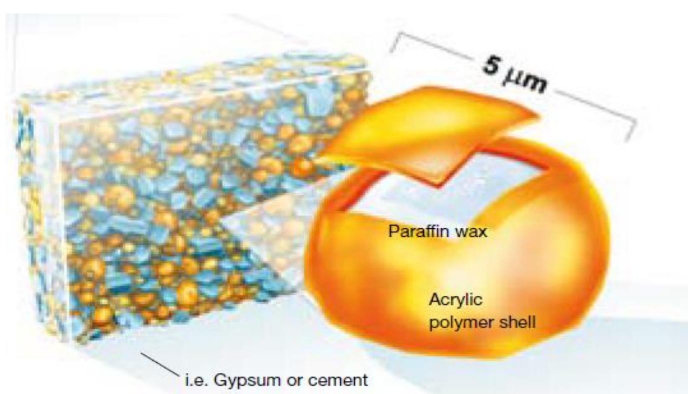

Figure 7:micro encapsulated paraffin wax micronal®PCM (BASF, 2012)

melting temperature for building applications. The widely used available commercial product is micronal®PCM from BASF, also other products such as RUBITHERM®SP by Rubitherm Technologies GmbH and MPCM by Microtek are available. Encapsulation can take a mechanical process such as coating in rolling cylinder or chemical as complex coacervation with gelatine (Mehling and Cabeza, 2008). Besides containing the liquid form of the PCM micro encapsulation provides a better thermal conductivity due to large ratio of surface area to volume. Furthermore the dry powder of encapsulated PCM can be easily integrated in various conventional building materials, either to build a thermal mass storage in light weight construction materials such as gypsum plaster board, or adding extra heat capacity for conventional TES materials such as concrete.

Limitations in macro encapsulations and accompanied problems in its applications such as leakage possibilities, poor heat coefficient in solid state and the possibility of changing the primary material's physical properties, have made researches investigate integrating microencapsulated PCM in building materials (Zhao and Zhang, 2011). Studies have been presented inspecting the subject as a state of art (Hawlader et al., 2003, Tyagi et al., 2011). While others conducted more experimental studies, (Cabeza et al., 2007) presents a case study on real size concrete cubicles validating the hypotheses of enhanced thermal performance, comparing between a conventional concrete structure and a PCM integrated one. While in (Voelker et al., 2008) light weight construction has been investigated using a gypsum wall board containing microencapsulated PCM plastered with gypsum. The experiment has considered two full scale identical rooms, results demonstrated less temperature swing up to 4K. Furthermore in the same paper a mathematical model based on energy balance equation has been developed based on validating the results from the experiment measurements that can be used in approximating resultant conditions in PCM applications.

3.3.3 Pure molten bath

Although this procedure has been experimented less than the two previous ones, results from some conducted researches suggest the possibility of its further implementation in building construction. In this case a porous building element such as gypsum wallboard is submerged in PCM in a dispersion state, commonly containing 46% solid substance. The PCM particles settle in the cavities of the building element (Farid and Sherrif, 2010). While other researches (Zhang et al., 2004, Bentz and Turpin, 2007) has investigated the use of porous aggregate as a primary building component, the aggregate has been subjected to a molten PCM bath, eventually added to a concrete mix. While this procedure is less promising commercially due to possibilities of leakage and unavailability of enough supporting studied in the area to prove its effectiveness.

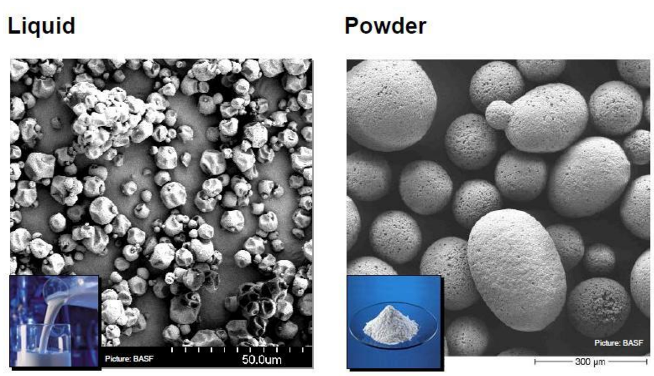

Figure 8: Pure microencapsulated PCM (BASF, 2012)

3.4. PHASE CHANGING PROBLEMS AND POTENTIAL SOLUTIONS

Different types of PCM suffer from different phase changing problems during cycling, in such almost no PCM can fulfil all physical, chemical, kinetic or economical requirements at once. Thus identifying and finding solutions for these problems are significant in correct implementation of PCM in building applications.

- Phase separation: this occurs when the PCM is chemically consists of two components, such as salt hydrates. Generally in pure components like water, the melting temperature is sharp, thus all the substance melt at the same temperature forming a homogenous liquid. Alternatively when retrieving to the solid state, all the substance crystallize congruently at the same melting temperature and melting enthalpy. Salt hydrates are a mix of water and salt, in low temperatures as -4C, the water starts to solidify around the edges of the container leaving the remaining solution having a higher salt content than the basic one. Thus the liquid with higher density sinks in the container due to gravity forming layers. Solution for this problem is by adding additional materials to the mix in such way the resultant component will have a higher viscosity preventing face separation (Mehling and Cabeza, 2008)

- Supercooling: some times in the exothermic process the material does not start to crystallize in the melting temperature, but only does when the temperature reaches below the melting point by several degrees. This phenomena does not pose a problem while the substance is melting, the effect shows in reverse process, as the latent heat stored may not be released. Since the phase cycling is incomplete and the material stays in a liquid stays, the material will act as sensible heat storage only. Solution for this problem is adding an additional component to the mix called nucleator, these materials ideally have the same crystalline form of the PCM with higher melting temperature. The PCM starts to form around the additive particles which are providing a structure to the crystallization to build on. The problem here is having same crystallize form means having the same melting temperature, thus improvement is limited to a few degrees.

- Low thermal conductivity: in order to absorb and release heat from and to the atmosphere, materials depend on the outside layer. While the thermal conductivity of PCM is considerably low (paraffin C18 has a thermal conductivity ranging 0.14- 0.35 W/m.K), unless the stored heat is transferred through the outside surface to be released, the phase cycling will not be completed. Solving this problem has been achieved by encapsulating the material in a metallic shell to improve the thermal conductivity of the surface, micro encapsulation or thin layers of macro encapsulated units in such the surface area to volume size ratio is high. (Mehling and Cabeza, 2007)

3.5. PHASE CHANGE MATERIALS AND CONCRETE

Concrete has been utilized in building industry widely, due to its low primary cost, availability, durability and its structural feasibility, as a storage medium concrete characterize with a high storage capacity, appropriate physical properties and suitable structural proportions close to TES system requirements. Considering the extensive use of concrete, and its applications in passive TES systems, enhancing thermal properties of concrete will have a direct impact on reducing energy loads. In many areas with a moderate climate utilizing concrete TES for capturing solar energy in winter and reducing or eliminating cooling load in summer has proven effective. While for locations with higher average temperature night time ventilation may not be desirable, thus the effect on managing cooling load will be by shifting the peak load to later hours in the day, where off-peak prices are operational (Bentz and Turpin, 2007).

Enhancing the thermal capacity of concrete is achieved by integrating the concrete structure or concrete mix with PCM, thus an additional thermal capacity in the form of latent energy storage will be added. Researches have been proving the effectiveness of adding PCM to the concrete TES system. Among those researches are (Bentz and Turpin, 2007, Cabeza et al., 2007, Hunger et al., 2009). Apart from the thermal performance, adding microencapsulated PCM to concrete mix has other physical effects, such as reducing hydration temperature during mixing, reducing thermal conductivity and more importantly reduction in compressive strength (Hunger et al., 2009). Given that concrete is mainly used for its strength and durability, compromising this will eliminate the potential of utilizing the product despite the enhanced thermal performance. Therefore controlling the amount of

PCM integrated with the concrete mix, and constraining it with maximum allowed amount without affecting the required compressive strength is considered the key factor in its successful implementations. For this purpose (Hunger et al., 2009)

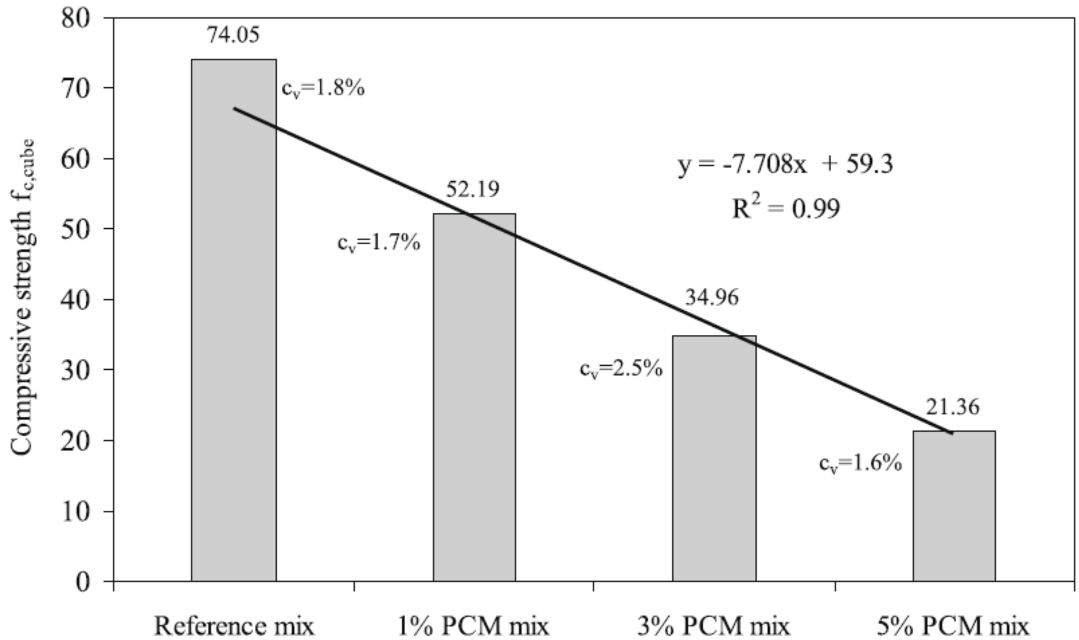

Figure 9: compressive strength of the PCM mixes after 28 days tested in (Hunger et al., 2009)

presents a good amount of information regarding possible successful mixing ratio, the study suggest a mix of concrete with 3% use of PCM will ensure acceptable compressive strength of 35N/mm².

Adding microencapsulated PCM in concrete mix requires careful handling; further researches and experiments need to be conducted to ensure safe long life implementation of it, additionally the main properties of the product such as compressive strength, thermal capacity and durability must be equivalent or superior to basic concrete (Bentz and Turpin, 2007). Alternatively, different approaches can be investigated, such as avoiding the use of the concrete mix for load bearing purposes, or adding macro encapsulated PCM to the concrete construction to enhance the building envelope's thermal performance.

Conclusion:

Potentials of utilizing PCM in building constructions and its promising effects on reducing energy demand has been graded high in the literature about the science. Wide range of application in passive strategies, and the potential of concrete to host PCMs have been major drives for undertaking this study, this and the need of boosting the building fabric role in decreasing summer cooling energy load in hot climates.

Results conducted from studies indicated improvement in the building thermal response consequently reducing the summer cooling load when PCM with melting temperature of 26°C has been integrated in the concrete mix. Results imply a linear relationship between increasing the PCM ratio in the concrete mix and annual energy reduction. However no significant shift of daily peak energy load to off-peak hours of the day has been observed due to heavy thermal inertia of the building fabric.

During the course of the year, particularly in summer, the concrete stores energy more than releasing it, resulting in accumulated heat stored within it. This been the consequence of constant high temperature in the insulated thermal zone, preventing the PCM to solidify and release the heat in a daily cycle. Thus the wall specific heat capacity is reduced or kept to its sensible potential in the higher zone temperature. Solution for this situation is opening a window of opportunity for the energy to escape outside the sealed thermal zone. In this matter controlled natural ventilation has been found beneficial, results indicated a potential of reducing cooling energy consumption up to 70% compared with a conventional typical thermal zone. While attempts for reducing the volume of energy storage medium to the zone volume resulted only in increasing the cooling load.