International Journal of Civil Engineering (IJCE)
ISSN: 2278-9987
Vol.1, Issue 1 Aug 2012 102-109

A GREEN APPROACH FOR THE INTEGRATION OF PHASE-CHANGE MATERIALS IN BUILDING ENVELOPES IN HOT ARID COUNTRIES

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ABSTRACT

There has always been a great gap between the use of natural materials to create buildings with improved environmental performance and the mainstream construction market which is always on the side of using artificial conventional materials. Until recent scientific research has succeeded to introduce and test materials which can act like natural clay and stone in the sense of thermal capacity and conductivity and yet practical enough to be used in the conventional manner of building. These materials were called the phase-change materials (PCMs).

However, the previous studies for PCMs have regularly marginalized the link between natural PCMs and the natural setting and diagnosis of the area of interest. Thus, this work aims at presenting an overview of the key researches in the field of use of PCMs in buildings and presenting a green approach for their uses in building envelopes with specific implementation on the case of hot arid countries. This is achieved by analyzing key works of choice and implementation of PCMs in buildings from a green perspective to use of their findings and re-adjust them for application in hot arid countries. Consequently, this paper proves that the use of certain green techniques combined with natural PCMs available in the immediate context can be very beneficial in the sense of reaching buildings with acceptable environmental and thermal performance. The research outcomes imply developing certain green building techniques and materials new to hot arid countries. However, the research findings are applicable only where the bioclimatic diagnosis of the area of the designated case and its natural resources coincide with those expressed in this work. This research is limited by the to-date advancements in PCM manufacturing technologies. It represents a new approach, yet a series in the chain of efforts for the integration of PCMs in building envelopes.

KEYWORDS: Phase-Change Materials (Pcms), Green Architecture, Building Envelope, Heat Transfer, Archtiecture in Hot Arid Countries.

INTRODUCTION

Thermal storage can either take the form of sensible heat storage -where energy is stored by raising the temperature of a storage medium, for instance water or rock- or latent heat storage where energy is stored by altering the physical state of the storage medium, which can be solid-solid, liquid-gas or solid-liquid. (Gates,2000).

During their transformation of phase (solid-liquid), there are certain materials that make it possible to absorb or release a great quantity of latent heat. These materials absorb energy during the phase of liquefaction and release it in the environment while returning in an initial state, which supports the storage of thermal energy. These materials are called the Phase-change Materials (PCMs).

Many PCMs are liquefied and solidified in a wide range of temperature, which allows their employment in several applications. This property can be of great utility in the reduction of the consumption of energy in the buildings, through providing adequate time lag and heat storage/insulation. However, the incorporation of PCMs in particular applications calls upon specific analyses to be able to optimize their performances. The non-linear nature of the problem requires the recourse to the numerical analysis for obtaining the suitable solutions for thermal behavior of the systems.

This work reviews some scientific efforts that has been done to identify the most appropriate ways of choice and application of PCMs, and the possibility of exploiting their heat storage/insulation properties for use in building envelopes in hot arid climates, based on their specific bioclimatic diagnoses.

OVERVIEW ON PHASE-CHANGE MATERIALS (PCMs)

Definition of PCMs

A Phase-change Material (PCM) is a substance with a high heat of fusion which, when melting and solidifying at certain temperatures (termed phase change) is capable of storing or releasing large amounts of energy (McDonald, 2008). This property is found in a wide range of materials, but their capacity to absorb/release/store thermal energy varies greatly.

Knowing that water content has an important role in the process of heat transfer; many of the PCMs are hydrated salts, or paraffins that can isolate water. Thus, the control of the process of evaporation is a key factor regarding the thermal storage capacity of the PCM.

Types of PCMs

Several researches were made for a big variety of PCMs that allowed the classification of these materials according to their chemical nature in three families: organic, inorganic and eutectic. The following diagram (Fig.1) summarizes the classifications of PCMs.

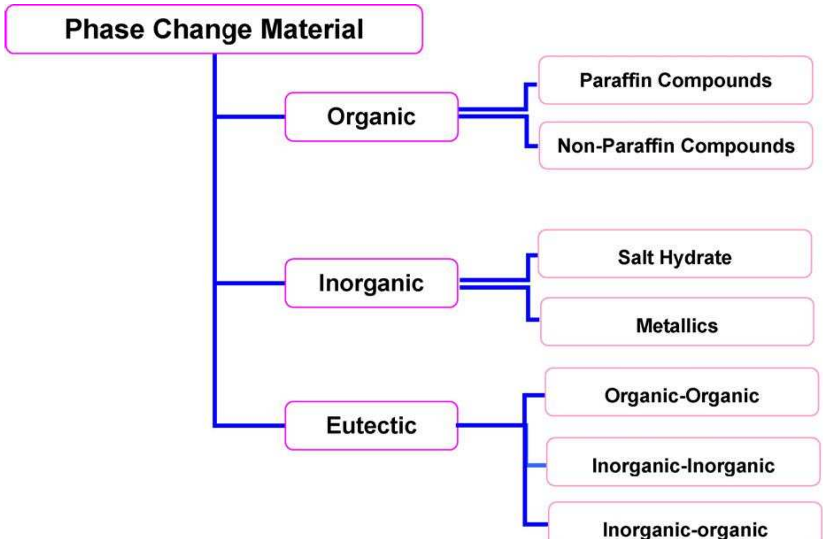


Fig. 1 Chemical Classification of PCMs (Source: Sharma et al., 2009)

Table 1: Examples of PCMs and their transition points/ranges and heat of fusion. (Source: Yinping Zhang et al., 2006)

PCM	Transition point/range (°C)	Heat of fusion (kJ/kg)
$CaCl_2 \cdot 6H_2O$	24–29	192
$Na_2S_2O_3 \cdot 5H_2O$	40	210
$CaCl_2 \cdot 6H_2O$ + Nucleator + $MgCl_2 \cdot 6H_2O$ (2:1)	23	—
Hexadecane	18	236
	18	205
Heptadecane	22	214
Octadecane	28	244
Black paraffin	25–30	150
Emerest2325 (butyl stearate + butyl palmitate 49/48)	17–21	138–140
Emerest2326 (butyl stearate + butyl Palmitate 50/48)	18–22	140
Butyl stearate	19	140
1-dodecanol	26	200
Capric-lauric 45/55	21	143
Capric-lauric 82/18	19.1–20.4	147
Capric-lauric 61.5/38.5	19.1	132
Capric-myrstic 73.5/26.5	21.4	152
Capric-palmitate 75.2/24.8	22.1	153
Capric-stearate 86.6/13.4	26.8	160
Peg1000 + Peg600	23–26	150.5
Propyl palmitate	19	186
RT25	25	147

PCMs used in latent heat thermal storage systems must reveal some thermodynamic, kinetic and chemical properties. Those properties depend on the previous application. Moreover, the economic factor of their employment has to be considered.

As shown in Table1, Calcium Chloride Hexahydrate has a transition range between 24-29ºC which is near to the human comfort range, while having a relatively high heat of fusion of 192 kJ/kg. Black paraffin, on the other hand, shares a similar transition range of 25-30ºC but has a heat of fusion as low as 150 kJ/kg.

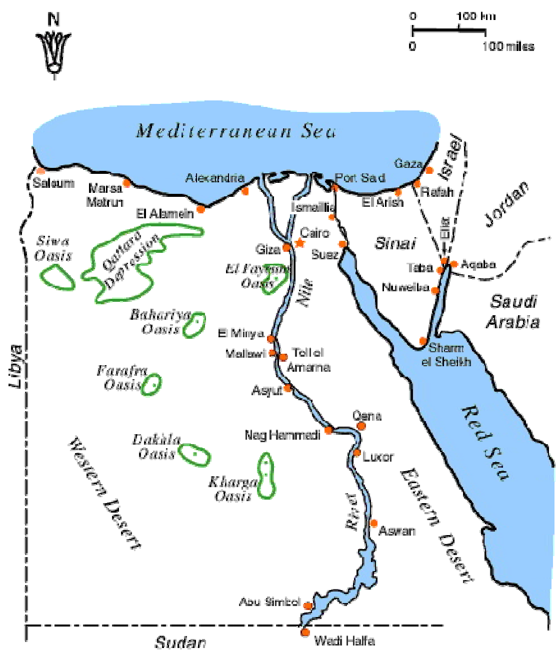


Fig. 2: The Western Desert and its 7 Oases (Source: magellan.com)

BIOCLIMATIC DIAGNOSIS FOR HOT ARID REGIONS, CASE STUDY: BAHARIYA OASIS,EGYPT

Location

The Egyptian Western Desert, also called the Libyan Desert, makes up two-thirds of the area of Egypt with an area of 680,650 square km. It is the eastern-most part of the great North African Sahara. It is one of the driest and hottest areas on earth. It is mainly composed of a vast arid desert with very few kinds of plants and animals, while 7 oases do exist around sources of water like wells or small natural ponds.

Climate

Sahara has one of the harshest climates in the world. The prevailing north-easterly wind often causes the sand to form sand storms and dust devils. Half of the Sahara receives less than 20 mm (0.79 in) of rain per year, and the rest receives up to 10 cm (3.9 in) per year. The rainfall happens very rarely, but when it does it is usually torrential when it occurs after long dry periods, which can last for years. (Tiempo Climate Newswatch: 2010).

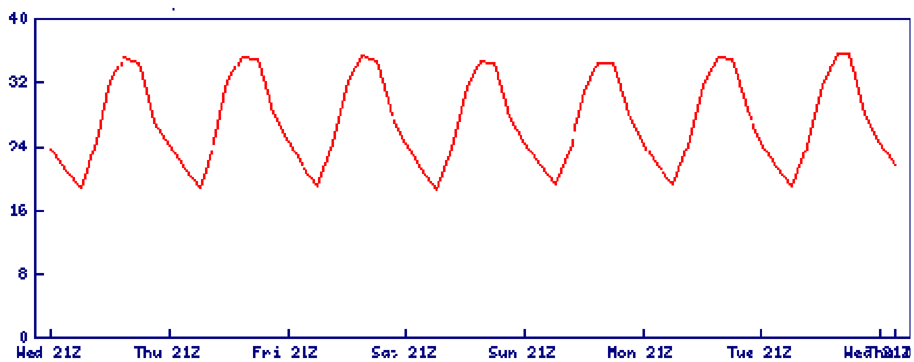


Fig. 3: Temperature (ºC) at Bahareya Oasis from Jun 30 to Jul 8. (Source: fallingrain.com)

Particularly, temperature in the Western desert can reach as low as 4ºC at night during winter and as high as 40ºC during day in summer. It also varies greatly during the same day, either in summer or winter. As shown in Fig.3, the daily range can go up to 16ºC during the beginning of July (Faggal, 2003). Knowing that the thermal comfort for the average male adult ranges from 23ºC to 27ºC, it is clear that the change of temperature is too steep to reach indoor thermal comfort with conventional architectural methods.

Bioclimatic diagnosis

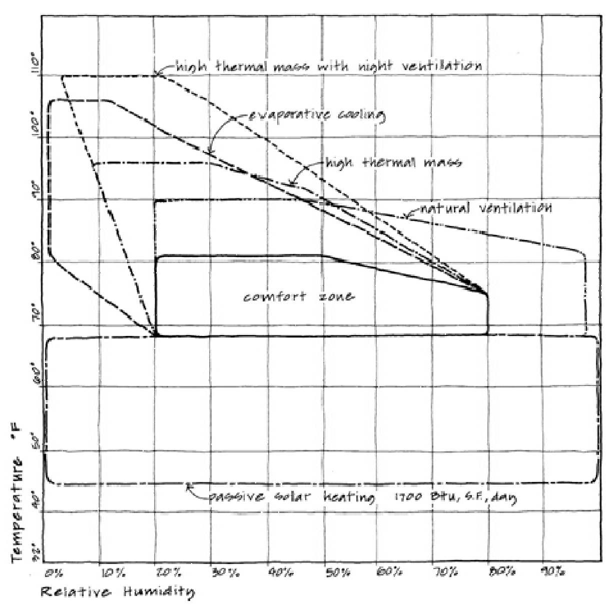


Fig. 4: Victor Olgyay’s biochlimatic chart with design strategies. (Source: oikos.com)

According to Khaled S. Faggal, the bioclimatic diagnosis based on Victor Olgyay's chart and Martin Evans schedules showed that 10 months a year lie in the hot region during day, while 7 months a year lie in the cold region at night. It is also notable that 5 months of the year show overheated conditions during day and underheated conditions at night.

Table 2: Thermal comfort during day and night year-round in Bahariya Oasis. C=Comfortable, H=Hot, L=Cold. (Source: Faggal, 2003)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day	C	H	H	H	H	H	H	H	H	H	H	C
Night	L	L	L	L	C	C	H	H	C	L	L	L

INTEGRATION OF PCMs IN BUILDING ENVELOPES

There are numerous applications for PCMs in the constructed environment, going from the impregnation of the wood and the plasterboards of PCMs up to the use of the heat accumulators with PCMs in big scale. During the last years, there was an increased interest for PCM potential use in the construction presented as a long-sustainable concept design to improve the thermal and energetic performance.

Choice of the Environmentally Appropriate PCM

The first step for the integration of PCMs within a specific building envelope would be the choice of the most appropriate type to use. In hot arid countries, especially in sensitive ecosystems like deserts, it is advisable not to introduce PCMs that are not found in the original context of the ecosystem. Hence, the use of organic PCMs should be minimized compared to the exploitation of hydrated salts found in the surrounding environment. The western desert, especially the Bahariya Oasis area is famous for richness in calcified salts.

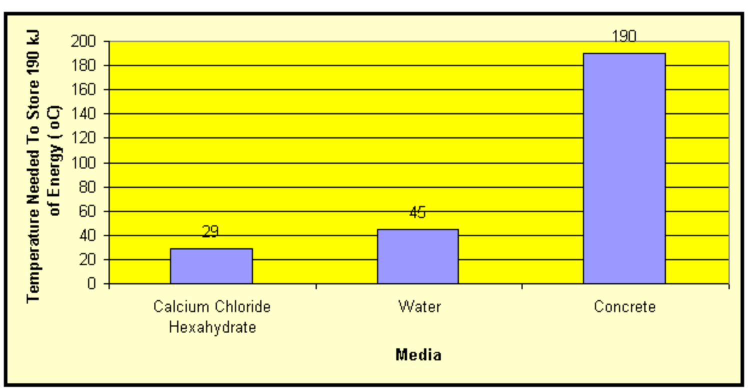


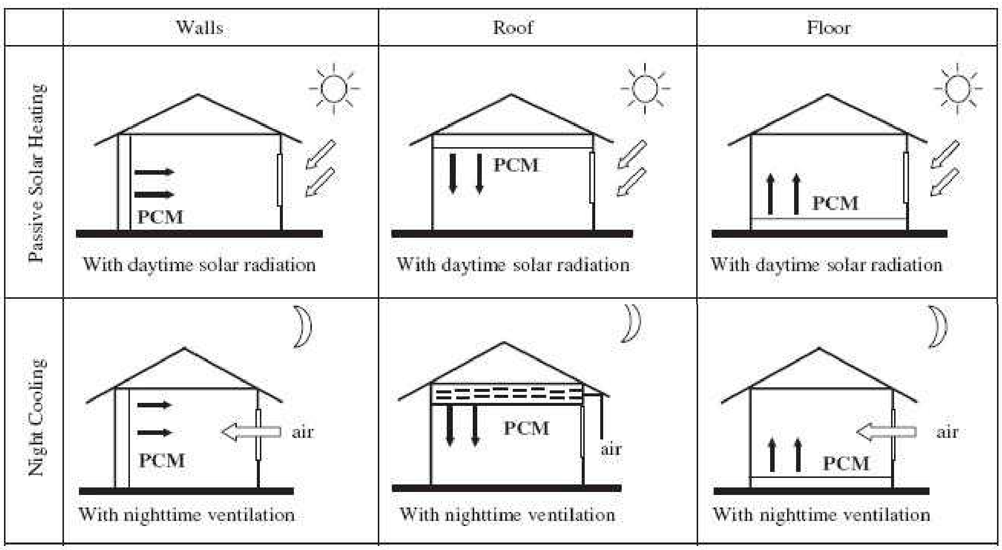
Fig. 5: Calcium Chloride Hexahydrate as a Competitive Thermal Storage Material as it Needs Relatively Low Temperature to Store a Given Amount of Thermal Energy. (Source: Gates, 2006)

Integration Methods for Hot Arid Regions

There are different ways to integrate the chosen PCM within building envelopes. One of the recently formulated systems of integration is the PCM shutter system. In this system, shutters containing the chosen PCM are placed outside of window areas. During daytime they are opened to the outside the exterior side is exposed to solar radiation, heat is absorbed and PCM melts. At night we close the shutters, slide the windows and heat from the PCM radiates into the rooms (Mehling et al., 2008). This is an effective way of narrowing the gap between the high temperature during day and the low one at night in arid deserts, and bringing them both within the human thermal comfort range.

Table 3: Suggested Alternatives for PCM Integration Methods, within Walls, Roofs or Floors.

(Source: Marco, 2005)



However, the appropriate way of integration of the chosen PCM should be also discussed with local builders and craftsmen, in order to make use of their long knowledge of local material behavior and properties.

CONCLUSIONS

It is noticeable that many of the PCMs are natural and can be found in their original contexts without extensive efforts. The use of natural PCMs like hydrated salts has been practiced vernacularly and systematically through ages without prior scientific research. However, with continuous and deepened research, natural PCMs have been identified and studied in a way that can be combined with common local knowledge of certain regions to produce building envelopes with high thermal performance according to the specific bioclimatic diagnosis of the region and its recommendations.

In the case of hot arid regions, like the western desert in Egypt, PCMs can play an effective role in flattening the sin-curve which represents the difference in temperature throughout the day, by storing thermal energy during day and releasing them at night. The release of heat energy can be directed inwards in winter as a method of providing warmth, or outwards in summer as a method of preventing heat penetration.

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