XXXIII IAHS
World Congress on Housing
Transforming Housing Environments through Design
September 27-30, 2005, Pretoria, South Africa

Development of a technology for inserting a PCM layer in building envelopes

M. Lemma, R. Fioretti

[#]Department of Architecture Construction and Structures
Polytechnic University of Marche, Ancona, Italy
e-mail: m.lemma@univpm.it
rob111078@yahoo.it

M. Imperadori

Department of Building Environment Science and Technologies
Politecnico di Milano, Milano, Italy
atelier2@arcoquattro.it

Key words: PCM, light structures, dry assembled walls, passive cooling, low energy consumption

Abstract

Numerous experimental results now demonstrate that the insertion of Phase Change Materials (PCM) in light, dry assembled buildings represent a valid solution for solving problems related to the overheating which they are subject to when located in climatic contexts characterized by strong solar irradiation.

The present paper illustrates a number of building solutions regarding finishing panels conceived at the Department of Architecture Construction and Structures. Thanks to its flexibility characteristics, it can be adapted, from the aesthetic and technological point of view, to different solutions; in new constructions and in restoring operations as well.

This new technology demonstrated its ability to lower thermal load peaks and, more importantly, it demonstrated its ability to shift the peaks to the hours of the day in which they are useful hence guaranteeing temperature stability within the internal environment.

Furthermore, the technology demonstrated its ability in solving problems regarding the durability of this type of component, in particular, solving problems tied to change phase material's deformable quality apart from problems tied to its potentially corrosive behavior.

The results of experimental tests (both in laboratory and on site) carried out during the campaign held in the summer of 2004 are proposed. The experiments were finalized at verifying the components' ability to reduce incoming thermal flux.

Lastly, the results obtained through laboratory tests regarding the characteristics of different types of PCM (all of which had, as principal heat storage principal, Glauber salt stabilized using additives), in order to obtain the types of composites which are more adequate for guaranteeing durability when subjected to numerous loading and discharging cycles. In addition to the information provided regarding PCM's capacity, the test cycles also furnished information regarding the plastic containers' durability and their compatibility with the PCM.

1 Introduction

The search for technological solutions in the building field has the aim of improving buildings' performance and reducing costs related to their administration. In particular, there is the need to reduce energy consumption and hydrocarbons used for maintaining internal comfort conditions with the aim of obtaining buildings which are always more efficient from the energetic consumption point of view and in terms by reducing their running costs, as well as improving their thermal comfort conditions acting not only on the air-conditioning implants but by reducing the causes which entail a lack of well-being.
The use of PCM (Phase Change Materials) in the construction field aims to be a solution for the control of thermal flows and the exploiting solar energy by using its enormous capacity for accumulating heat around temperatures close to its melting point. In effect, by exploiting their latent fusion heat, and in smaller part, their specific heat, these materials act as heat accumulators; absorbing and discharging heat keeping their temperature unaltered and thus avoiding the overheating of the elements they are contained in. In particular, these experiments evaluated the possibility of introducing PCM within the stratifications of vertical walls exposed to solar radiation in order to control incoming solar flux during the summer season. The advantage given by the use of PCM instead of traditional systems lies in their accumulation ability and in their weight – making their use advantageous as compared to specific heat systems and making them more suitable for use in light building technology.
This experiment evaluated technological solutions which allow the use of PCM within modular elements used in the construction of external walls. The performance of these elements was evaluated and the advantages obtained using these materials was quantified in the tests carried out in the laboratory through the simulation of actual use conditions and by installing such wall panels in experimental buildings.
Meanwhile research activities concerning the durability of the materials used were carried out, demonstrating that the lower of the accumulation capacity of certain PCM due to physical/chemical phenomenon turned out to be one of the principal factors arresting the real possibility of using these materials in the building industry. Among all the PCM available, it was decided to use Glauber salts (decaidrato sodium sulphate), which, because of its characteristics, is among the most suited for use in the building industry.

2 PCM's Durability

The hydrate salt family represents the most promising candidate for use as phase change material (PCM) in the construction field. In fact, a number of them possess the characteristics and basic requirements which a PCM must have for these applications [1].
Among these, the salt identified as the most suited for use as PCM is sodium sulfate decahydrate ($Na_2SO_4 \cdot 10\ H_2O$), in particular because of its high latent heat per weight unit (254 kJ/kg), its melting point (32.4 °C), its cost and availability.
Hydrate salts and Glauber salt - especially at their pure state - present problems relative to performance lose if exposed to melting and solidification cycles.
The principle problem attributed to these salts, but on the other hand to hydrate salts as well, lies in performance loss with repeated thermal cycles, which entails a substantial lowering of their storage and discharge capacity during phase change. This phenomenon cannot be ignored as already after 20 – 40 cycles' latent heat passes from 238 kJ/kg to 63 kJ/kg diminishing over 70% [2].

2.1 Problem analysis

The possibility to use sodium sulfate decahydrate as PCM in the building industry can be realistic if its performance in time can be stabilized in order to control them and keep them unchanged. In order to do so we must first and foremost observe and evaluates all the phenomenon which determine their loss of storage capacity and deterioration in time.
In Glauber salt performance loss is had with repeated melting and solidification cycles for the following reasons:

- Segregation of the mixture;
- Problems related to crystallization.

Performance loss is tied in both cases to the incomplete reformulation of the hydrate salt after melting and solidification, which entails a reduction of the quantity of material storing and discharging latent heat during the phase passage. The segregation of the mixture due to the incongruous state of the mixture for temperatures above the melting one represents the principal problems needing investigation: not facing this problem leads to deterioration of the vast part of the storage capacity for latent fusion heat after a short number of cycles.
This problem emerges when the Glauber salt, formed by 44% of Na_2SO_4 and 56% water, for temperatures above the melting ones, does not become totally liquid, hence sodium sulfate solution, but becomes 85% water solution 238 kJ/kg at 63 kJ/kg diminishing more than 70% [2].
As the density of Na_2SO_4 (2550 kg/m^3) is superior to that of the solution (1350 kg/m^3). The salt will tend to precipitate and deposit on the bottom. In the moment in which the temperature will start falling below the melting point, problems tried to the re-composition of the hydrate salted due to the mixtures' separation will be had, hence an incorrect reinstatement of the hydrate salt. In the delimitation surface between the solution and the deposited salt, hydrate salt will start forming, finding in these points both water and salt molecules, but once this part is solidified a solid layer which avoids the passage of molecules for the re-composition of the hydrate salt will be created. This phenomenon cannot be reversed and it tends to worsen with phase passage increases, losing part of the anhydrous salt in each melting phase by sedimentation. Problems correlated to salt crystallization processes are of various types and interest both the crystallization of anhydrous salt in the liquid mixture and the crystallization of hydrate salts at the moment of solidification.
They are:

- Size of the anhydrous salt crystals;
- Super-Cooling;
- Solidification time;
- Formation of heptahydrate salt.

For temperatures above the melting one, as previously observed, the mixture presents, apart from the solution saturate, anhydrous salt crystals. The size of these crystals greatly influences the PCM's performance loss. After various cycles, the mixture tends to present notable sized crystals (around mm size)[2], which are difficult to return to the hydrate state at the moment of solidification, as they have a lower proportion between exchange surface and volume as compared to small sized crystals. The consequence of this is the lost formation of the same quantity of hydrate salt, hence a reduction of the material storing latent heat. The phenomenon tends to worsen with the cycles, tending to the formation of always bigger crystals, always more difficult to melt and convert into hydrate salts. Their storage capacity during the phase passage attributed to this phenomenon is 25% in only 30 cycles [3].
Furthermore, larger size salts present difficulty in remaining suspended, falling more quickly than smaller sized crystals.
The super-cooling phenomenon happens in the initial phases of solidification of the Glauber salts, causing an overcooling of the material before the phase passage begins. This is caused by a delay in the "nucleation", hence, in the crystallization which tends to delay up until the material falls below the

melting point, but at a lower temperature. Super cooling is a problem when we wish to exploit the heat discharged by the PCM during the solidification phase.
A reduction of the mixtures' storage capacity after only a few cycles, if carried out in a time interval which is too brief, is connected to the kinetic of the decahydrate crystallization and to the dissolution of the anhydrous salt.
When the temperature falls below the melting point, a rapid formation of the vast part of the Glauber salt is had, using the salt which is in the solution. In order to have a total transformation, the anhydrous salt must dissolve with the same speed and in the same quantity as the decahydrate up until all the anhydrous salt is melted. It has been observed that this generally does not happen and anhydrous salt crystals are found in the cooled mixture, which represents a missed discharge of the thermal energy and a reduction of the storage capacity. Leaving the material at rest at a temperature below the melting one for a few days, it can be observed that the material requires the lost properties [2].
The formation of anhydrous salt with a different water content as compared to the decahydrate is a phenomenon which can be observed in Glauber salts, in particular forming sodium sulfate heptahydrate ($Na_2SO_4 \cdot 7H_2O$) salt, hence substance having different characteristics, determining its different behavior, with a melting point and storage and discharge capacity variation [2].

2.2 Stabilizing the properties

Solutions for preventing the formation of phenomenon determining the deterioration of the Glauber salt's performance, in part embracing other types of hydrate salts which can be used as PCM was sought in various studies carried out by different authors.
Segregation, the first problem highlighted, was solved in different ways, all based on increasing the viscosity of the solution. A marked increase in its viscosity prevents displacement, and hence the precipitation and sedimentation of the particles present in the solution, which otherwise would tend to move towards the top or bottom making the mixture non homogeneous and difficult to reform the hydrate salt in the solidification phase.
The solutions' viscosity increase is made possible introducing thickeners which, introduced in variable quantities, offer the possibility of obtaining the desired viscosity level. Besides increasing the viscosity, certain types of thickeners create an actual network which totally prevents the movement of the particles within the solution. [4].
The problems related to crystallization can be solved adding substances to the mixture which correct its undesired behavior.
In order to limit the growth of the salt crystals that form when the material goes beyond the melting point, [3] a small quantity of "crystal habit modifiers" are added to the mixture. These tend to limit the growth of the crystals. As a consequence of the limitation of the salt crystals' size we also have a reduction of the salt precipitating and a quicker complete re-composition process of the hydrate salt.
In order to diminish the super cooling phenomenon it was observed that a nucleation agent must be introduced within the mixture as it favors solidification by setting off the nucleation process. Generally, the "nucleation agent" consists in a salt which has the structure and composition similar to that of the salt we use to store the latent heat. The phenomenon is not completely eliminated but it is markedly reduced to values considered to be more than acceptable.
Apart from reducing the super cooling, the nucleation agent acts to avoid the formation of hydrate salts with salt molecule on water molecule proportions different from the starting one (1:10), such as the formation of heptahydrate (1:7)[2].

3 Technological solutions and performance

Due to their characteristics PCM (Phase Change Material) are materials which stand out as compared to other building materials. They are not found in an only phase, as is normally the case for building materials, but can take on different conformations:

- The solid state for temperatures inferior to their melting one;
- The transition state between the solid and the liquid state at temperatures closer to the melting one;
- The liquid state for temperatures higher than the melting one.

This factor does not consent their direct application on buildings, as they haven't got a proper shape, hence they must to be used only contained in containers. These container can be of different nature and size, but behavior and deterioration in time must be considered, as this could lead to seepage. Hence efficiency loss due to a physical deterioration of the containers or shape loss could create situations leading to initial performance loss, and the loss of the energetic behavior expected and forecast, with a sensible energetic and economic waste. The first phenomenon which leads to performance deterioration of the PCM layer which can be observed even after one only melting and solidification cycle is the container's loss of shape if these are flexible. This deformation is due to the fact that the liquid within the containers tends to deform the containers making them "belly-out" up until they reach a rigid prop. This loss of shape leads to the lowering of the containers and creates a point of discontinuity in the PCM layer. In designing new technological solutions, the compatible nature of the containers with the material container was evaluated: for hydrate salts the possibility of using metal containers was excluded as they are subject to deterioration due to corrosion.

3.1 The prototype

A technological solution that produces results reducing the problems deriving from the PCM's characteristics to a minimum was ideated . It proposes the use of a new type of high density polyethylene container which is not subject to deterioration due to the corrosive quality of hydrate salts. At the same time, these containers are rigid enough to contain the PCM without sensible shape loss. Furthermore, the elastics quality of these materials allows slight shape deformation which occur as a variation of the PCM's volume during the phase change and its' thermal expansion during the temperature shifts. The option of more containers reduces the vertical height of the same and of the PCM, reducing the segregation possibility which is present even if the material is improved with thickeners. The envelope obtained by two aluminum plates allows protecting the containers from direct exposure to atmospheric phenomenon, direct irradiation and possible blows. Furthermore, the envelope already presents supports and a versatile anchorage system for different continuous, linear or point type substructures, fostering quick and simple positioning. The panels can be used either as an internal layer within a wall panel or as an external buffering layer. The prototypes built in the laboratory of the University of Ancona a PCM obtained using stabilized Glauber salts at a 32°C melting point was used.

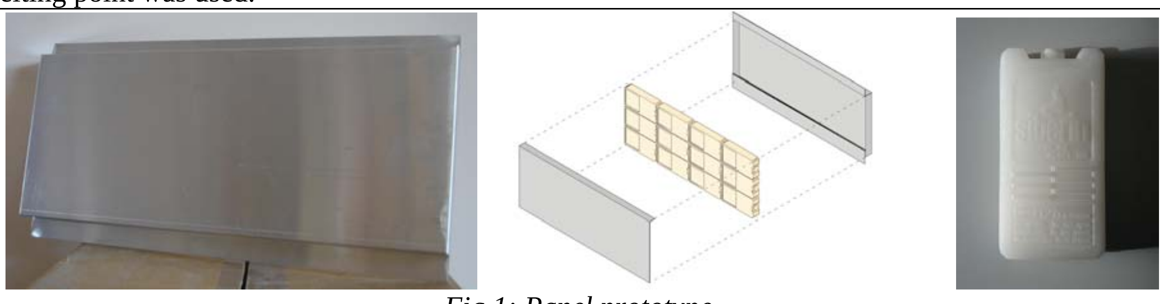

Fig.1: Panel prototype.

3.2 Façade technologies

In this part we describe a solution of façade technologies with inserting PCM layer that can be applied in new building and restoring operation. This stratified wall is made up of the internal and external finishes, an air layer, can be ventilated, one PCM layer and an insulation layer, settled behind the PCM. The PCM layer is in front of the air layer. This solution is chose because is easy to apply in different situation, like layer put outside to old wall and for made a layer in new wall. The PCM panel already described is also the external surface of the wall. The façade is made with a steel sub-structure compound of some vertical L-shaped profiles and steel plate that anchor the façade to the structure of the building. The PCM panel is fixed on the beam through with bolts and the support present in the envelope.

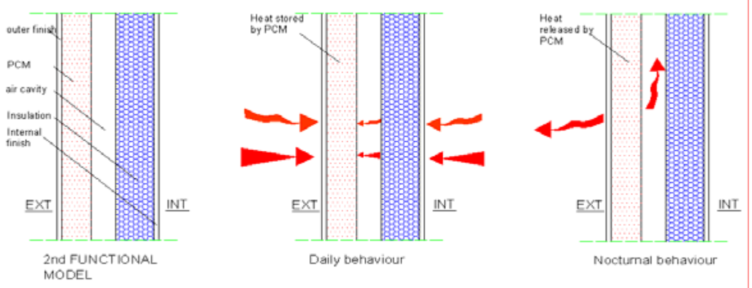

fig.2: Behaviour of the functional model during the day and the night

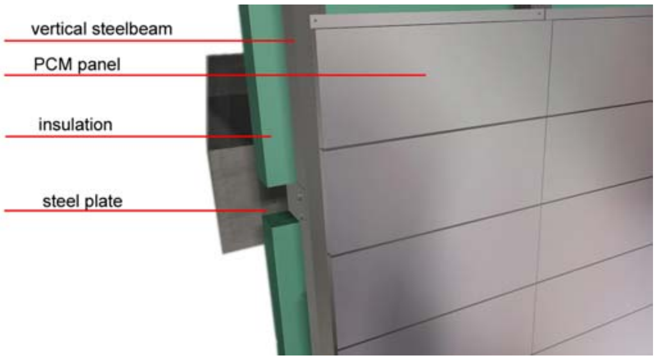

fig.3 Solution of façade with inserting PCM layer

3.3 Technological evaluation

An evaluation of the technological validity and an initial evaluation of the storage capacity withholding the thermal flow and avoiding excessive overheating of the built elements within the PCM was carried out in tests in a ventilated air chamber using a solar irradiation simulator. The simulator is made up of 16 OSRAM Ultra-Vitalux light bulbs which allow the even irradiation of a surface placed at 0,60m with a 1000 W/ m2 with a maximum error of 5%. The panels are assembled on a wooden substructure on 10cm thick polystyrene wall which divides the test chamber in two parts: one simulates an external part and the other an internal one.

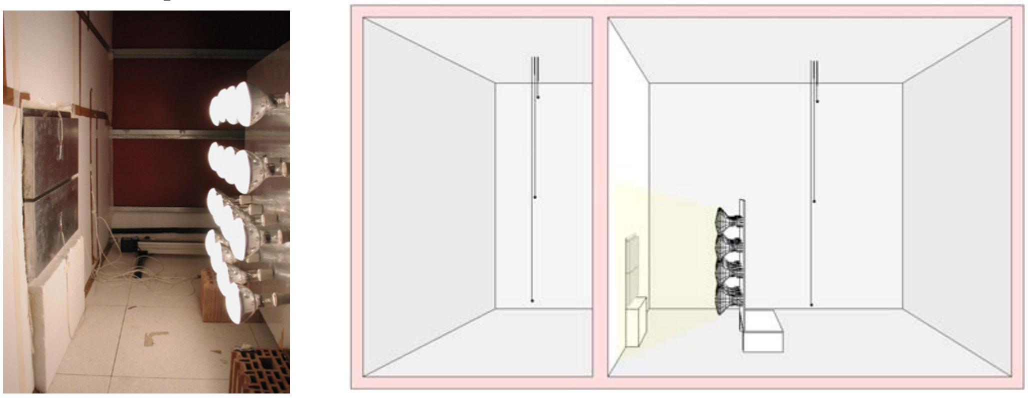

Fig.4: Test chamber set up

Temperatures were recorded using a system made up of a HP AGILENT 34420 A NANOVOLT – MICROOHM METER together with a HP 34970 A DATA ACQUISITION – SWITCH UNIT and an ice point reference KAYE K170. Furthermore, the monitoring system is made up of thermo couples placed in the two environments and a RTD 100 system placed on the front and back of the panels.
From the graphs it is possible to observe the panels' capacity to store energy at a temperature lower than the melting one (32°C), in extreme conditions also (perpendicular irradiation was chosen) for n approximate 6 hour period. The tests were repeated highlighting in each test a similar behavior.

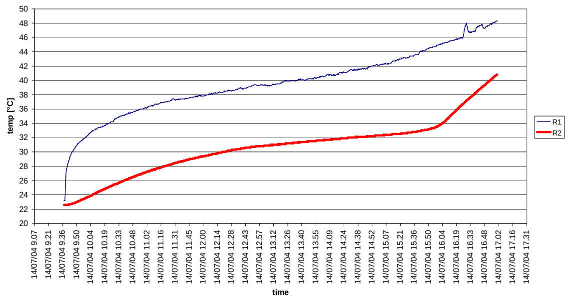

Fig 5: Temperature in the front and back of the panels.

3.4 Energetic evaluation

The energetic evaluation of walls with a PCM layer when undergoing actual actions was carried out in experimental buildings equipped with PCM containing walls at the University of Ancona. They were evaluated for the duration of the summer season in terms of the gains and the performance of this type of wall and comparing these results with those of traditional walls. The experimental buildings consisted in square boxes measuring 3m x 3m built using sandwich panels and further isolated using polystyrene , the south facing walls, on the other hand, were built using different technology box per box in order to evaluate their performance and differences. Three different stratification types were tested in this experiment: one using PCM inserts (melting point 32°C) and a ventilated air chamber, one using PCM inserts (32°C) and the comparison with a similar stratification but without PCM inserts.

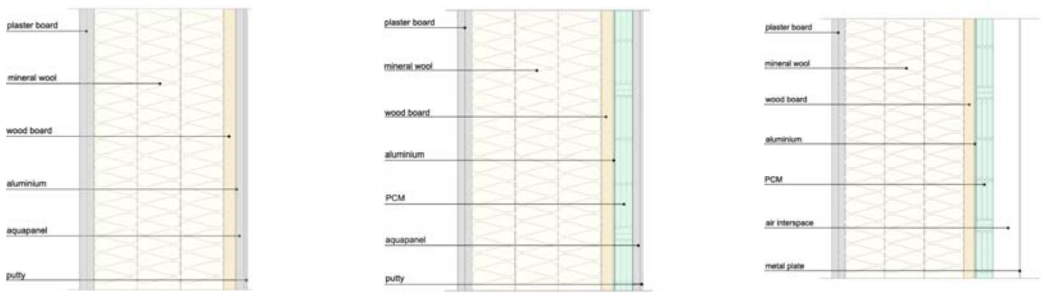

Fig.6: Layering of the 3 south facing walls:(a) without PCM,(b) using PCM insert, (c) using PCM insert and ventilated air chamber.

The temperature monitoring system was carried out using a series of 9 T type thermo couples for monitoring external air temperature and 15 RTD 100 for recording wall temperatures and the temperatures of the single south facing wall layers. The temperature of the single boxes were harvested with a Datataker DT500 with CEM expansions. The temperature within the box was set at 25°C and checked using a control system designed and experimented for these boxes. The climatic conditions were checked using an LSI meteorological switchboard placed on site.
The recordings were carried out for the period between the first of July 2004 and the ninth of September 2004.

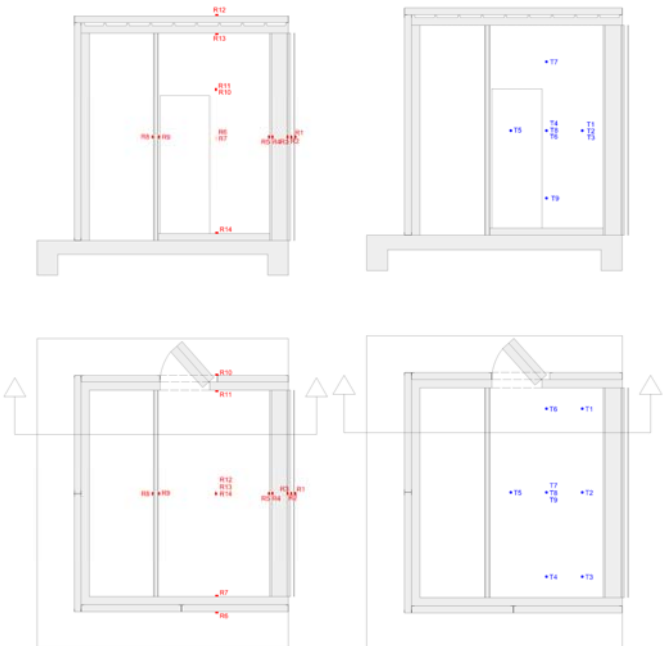

Fig. 7 :Monitoring system (a)thermocouples T, (b) RTD 100.

A statistical method was used in order to evaluate the advantages and performance of the walls equipped with PCM as compared to those without. The results of the samples were compared using a test with a 95% degree significance level after having established that the behavior of the samples was normal using the Jarque-Bera test.
Through the analysis carried out, the effective reduction of the thermal flows entering through the south facing wall was compared with the two different PCM containing wall typologies and with the one without PCM.
It was evaluated that the south facing walls are crossed by a lesser maximum daily thermal flow without PCM, and that the flow difference for this meaningfulness is 2,36 W/m2 (62% reduction) for

the wall with PCM and without ventilation and 2,51 W/m2 (67% reduction) for the wall with PCM and ventilation.
In the same manner the temporal delay of the maximum daily flux which was evaluated in 2,93 hours for the box with PCM and 3,03 hours for the wall with PCM and ventilation, shifting the maximum flux to the cooler hours.

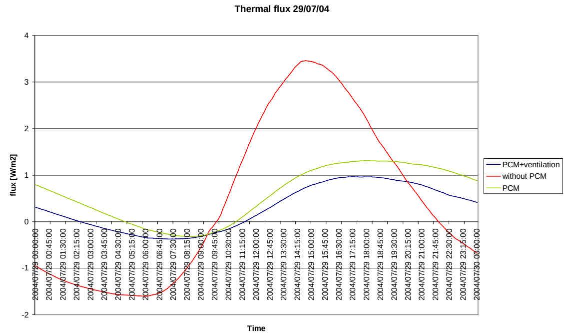

Fig 8: Thermal flows entering through the south facing (29 July 2004)

3.5 Conclusions

These result confirm that the insertion of the PCM layer in the wall is a valid method to reduce the swinging of the thermal flow and the overheating of the building. .
This new technology demonstrated its ability to lower thermal load peaks and, more importantly, it demonstrated its ability to shift the peaks to the hours of the day in which they are useful hence guaranteeing temperature stability within the internal environment. The heat that is release in the night can guaranteed a not excessive overcooling of the building and allows to maintaining the internal thermal comfort .

References:

[1] A.Abhat (1983), Low temperature latent heat thermal energy storage: heat storage Materials, Solar Energy Vol.30, No.4, pp.313-332

[2] S.Marks (1980), An investigation of thermal energy storage capacity of Glauber’s salt with respect to thermal cycling, *Solar Energy Vol.25, pp 255-258*.

[3] S.Marks (1983), The effect of crystal size on the thermal energy storage of thickened Glauber’s salt, *Solar Energy Vol.30, pp.45-48.*

[4] M.Telkes(1952), Nucleation of supersaturated inorganic salt solution. *Ind. Eng. Chem* **44,**1308