

The Use of Phase-Change-Material in Facades

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ABSTRACT: So called “Phase-Change-Material” (PCM) is able to store temperature through change of their physical condition from solid to liquid without heating-up. If outside temperature drops to a certain limit the stored heat will be emitted again. The storing effect of PCM is comparable to implementing thermal mass like concrete or brick walls in building.

In order to enable the effect of phase change a significant difference of maximum daytime and minimum night-time temperature is required. The Chilean climate of the central valley does fit perfectly since the average temperature difference between day- and night-time in Santiago range from 11 (15/4 in July) up to 16 degrees (29/13 in February). The use of PCM in the central part of Chile could be an energy-efficient and economical way of passive cooling of buildings.

If special façade elements with PCM will be developed that do allow a direct connection to the inside and outside climate, the storing capacity of PCM could be highly amplified. The night-cooling effect could enhance the “recharging” of the PCM. A prototype of a PCM-based building concept of the author will be introduced illustrating this possible principle.

Keywords: Phase Change Material, latent heat storage, night cooling, Chile

1. INTRODUCTION

One of the most amazing facts of the central valley climate in Chile – where in the area between Copiapó, Santiago and Temuco nearly 70 % of the total population lives (INE, 2003) – are the large variations between day and night temperature throughout the whole year. These very significant diurnal swings that ranges in the case of Santiago between 16 degrees in summer (February) and 11 degrees in winter (July) on the average temperatures (see Fig. 1) could be used to increase comfort conditions in building especially in summer where overheating becomes a problem.

The following study should demonstrate that trough simple measurements like using the capacity of certain materials to store heat, using the effect of night-cooling, suitable

comfort conditions in summer are achievable without energy-consuming mechanical systems.

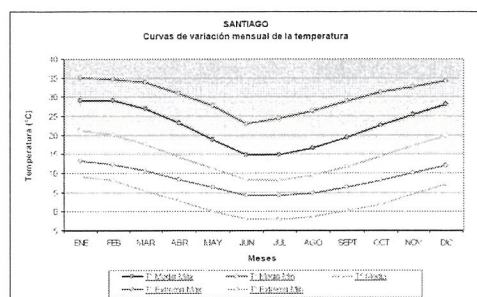


Figure 1: Variations on temperature for Santiago de Chile. The blue and the pink curve are showing average maxima and minima. The red and the yellow curve show the temperature extremes. Source: Bustamante, W; Encinas, F; Ugarte, J. J. (2006)

2. THE PROBLEM OF OVERHEATING

Non-residential buildings like offices, schools, clinics etc. in Mediterranean climates are affected by overheating in summer time through high internal gains of technical equipment, artificial lighting and occupation of people. They tend to need much more cooling than heating. If we consider the fact that cooling a room requires three times the energy of heating we can imagine what potential lies in reducing the demand for air conditioning.

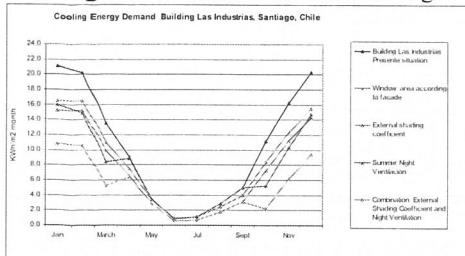


Figure 2: Graph showing the cooling demand of a recent office building in Santiago. Even with combining useful strategies of lowering the overheating-effect (window design, external shading, night ventilation), the building needs to be actively cooled throughout most of the year. Still in June and July, the coldest month, a certain level of active cooling is still necessary. So not the winter-case or heating is crucial regarding the energy consumption of office building in Santiago but the enormous cooling demands caused by internal and external gains. Source: W. Bustamante

But the problem of summer overheating is not only critical for office buildings with their heavy internal gains and their extended glazed surfaces but also increasingly for residential buildings. As people's living standard raises, like for instance in Chile, a growing attention to thermal comfort in housing will further amplify the use of air-conditioning equipment in the private housing sector.

3. THERMAL MASS

One solution to fight the consequences of overheating in summer peak, especially in central Chile with their large variation in day and night temperature, would be to implement thermal mass, i.e. enlarging the

sensible heat storage capacity of the building. Massive building out of masonry or concrete in reasonable wall thickness do allow to store the penetrating external (solar gains, solar radiation) and internal heat loads (equipment, persons) in their surface. This stored sensible heat in the building surface will be discharged within a certain time delay thus allowing modulating the indoor temperature swings. The effect of thermal mass is generating a much more stable and comfortable temperature level for the inside.

Because of seismic conditions (earthquake zone do enforce flexible, light-weight building) and economic reasons (building costs, consumption of floor space), the implementation of high building mass turns out to be problematic, especially in Chile.

4. PHASE CHANGE MATERIAL (PCM)

A way to increase the storage capacity of building without significantly enhancing the total mass is to use Phase-Change-Material (PCM). Main characteristic of this material is the possibility to absorb large amounts of heat when the material changes its phase from solid to liquid. The stored heat will be released when the PCM will solidify again. The effect is similar to water that change from liquid to solid at 0°C. Because the energy is stored as latent energy this takes place without significant increase of the temperature of the PCM itself. Depending on the different properties of the material, PCM's do show a variety of different melting temperatures. Those PCM's that are been used for building purposes change their aggregate state within the human comfort range of 20°C up to 33°C.

Two different classes of PCM's are used for building purposes:

- Inorganic PCM (salt hydrates) that do have advantages in a high latent heat capacity, low price and good availability. Also they are not flammable, an important fact when implementing PCM inside building. On the other hand, certain disadvantages

like high corrosiveness, instability and a tendency towards incomplete re-solidification and sometimes effects of supercooling (non-crystallization even below its freezing point) do occur.

- Organic PCM (waxes, paraffin) instead show some attractive properties in their chemical stability and in their congruent melting behavior. Also they do not show a tendency towards supercooling. Higher price, inflammability and the production of harmful gases when combusting are mayor disadvantages.

Both groups of PCM's will have their advantages and disadvantages. Depending on the parameters of application, organic or inorganic PSM might be taken into favor.

PCM's could be used as pure material (direct incorporation), in form of immersions or in encapsulated shape. There are two forms of encapsulation normally used in building:

- the micro encapsulation, where the PCM (in this case paraffin) is enclosed in microscopic small spherical or rod-shaped units enclosed in a polymeric film
- the macro encapsulation where the raw PCM is filled or packed in tubes, spheres, panels or pouches.

In any case if PCM is implemented in building it could serve directly as heat exchangers in order to improve thermal distribution.

5. NIGHT-COOLING

The principle of thermal distribution via latent thermal storage does only perform efficiently if the thermal storage will be periodically discharged.

In the case of the Chilean climate with its diurnal swings between daytime and night-time temperature, the effect of thermal mass combined with night-time ventilation could be used for reinforcing the discharge of the thermal mass. At the end this could lead to a passive cooling strategy for building that

significantly cools the building without the need of energy-consuming air-conditioning. How this specific system of PCM combined with night-cooling works?

Throughout the day the heat that is been emitted by the occupants, computers and lighting inside and the solar gain through glazing from the outside will be absorbed as sensible or latent heat. Anyway, it is highly recommendable to limit the gained external heat by applying an appropriate external shading system and to minimize the internal gains through energy-efficient equipment.

In the evening, when outside temperature decline and the building starts to cool down, the latent heat will be discharged by night cooling. The easiest way to achieve this is by opening the windows, preferably on opposed sides of the building, creating the effect of cross-ventilation through the building. Automatic vents, even supported by ventilators in windless weather conditions could be a more advanced solution for enhanced night-cooling in office building.

In the following morning, when the PCM has completely re-solidified and expelled all the latent heat, the PCM is able – like a recharged battery – to begin the cycle of absorbing internal heat again.

Actually, the most common way to insert PCM in building is through special gypsum boards that contain microencapsulated paraffin. Besides the effect of cutting the daily temperature peaks by transmitting them to the night-time, this use of PCM in inner walls or floors do not results in lowering the average temperature in the building.

Under normal conditions, because of the poor properties of air for conducting heat, the heat exchange between the PCM-element and the surrounding air is inefficient, that means that air movement on the surfaces of inner walls is rather too little to secure necessary heat exchange rate. Forcing the supply air to flush along the surface of PCM through cross-ventilation and/or mechanical ventilation can help a

little, but the problem of insufficient discharge remains to be critical even then. This could occur when the indoor temperatures are still above a certain grade so that the process of discharge of the PCM could not start (what probably happens in the first hours of the night).

6. PASSIVE COOLING WITH PCM

In order to avoid insufficient discharge of the PCM and to enable passive cooling, a system where PCM is arranged along the façade with direct contact to the inside should be developed. Main advantage of implementing PCM in facades is ensuring much more effective discharge in night-time, since the released heat of the PCM could directly be emitted to the outside without detour through the inside of the building. Also the release of latent heat immediately starts in cold outside temperature. Instead, discharging of PCM inside the building is much more insufficient and sometimes even impossible when temperatures do not fall below freezing point of the PCM (normally at about 22°C) due to insufficient cross-ventilation or simply because there has accumulated too much internal heat in the building.

In a workshop in Island in 2004, sponsored and organized by a chemical company, a producer of stucco-systems and a German trade publication, different architects and engineers were asked to develop new solutions to integrate PCM in building. One group of investigators, formed by members of the architecture firms of Hascher Jehle Architektur and Behnisch & Partner and engineers of Arup, joined together and developed a solution of integrating a PCM-element in the façade that serves as heat exchange device. The so-called "Magic Cube" contains of panels out of PCM. Inside of these panels water tubes were been integrated. The whole system is working like a reverse radiator that collects and stores the heat of the ambient air as latent energy in the PCM.

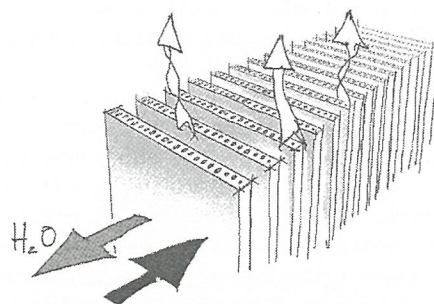


Figure 3: The so-called "Magic Cube". A PCM-collector that collects and store heat from ambient air. The stored heat can then be used in a second water-based system to cool or heat-up a liquid medium. Project-group: Arup/ Behnisch & Partner/ Hascher Jehle, © 2004

The stored heat could be released directly as convective heat using air as medium or via a liquid medium that runs through the ducts of the panels.

The system is being integrated in the façade so to control the in- and outlet of air through different openings. The PCM-collector becomes part of a passive system for cooling.

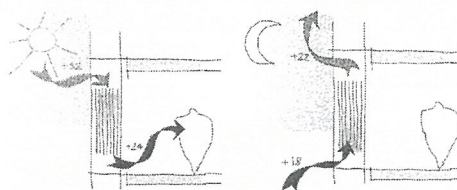


Figure 4: The "Magic Cube" as passive cooling-system. Hot summer-day (left) and summer-night (right) with significant diurnal swings between day and night (in this example 14 degrees difference is suggested). Project-group: Arup/ Behnisch & Partner/ Hascher Jehle, © 2004

Through the opened outer layer of the façade the PCM-collector will operate in hot summer days as a huge thermal storage that will cool down the incoming ambient air. The chilled and heavier air that passed through the PCM-collector will be inserted to the inside through controllable gaps of the inner façade. These gaps of the inside will be closed in night-time in favor of ones in

the outside in order to allow the discharge of the PCM throughout cold night ambient air.

Another similar solution was worked out by the project-group of the architects Kramm + Strigl and Gerber, together with a producer of stucco-systems. Rotatable façade elements with two different sides create the same effect: If the side with the PCM layer is twisted inside, the material absorbs inner heat; spinning the same façade module through 180° to the outside enables the recharge by the cold night air.

In a research study for an office building in Tehran the author developed a technique for passive cooling using PCM filled façade modules.

The façade of this 350 square meter office building is been developed due to the climatic conditions in Iran. In order to react to the overheating problem in Iran it is most important to reduce the solar gain to a minimum by using innovative materials as ETFE-foil and PCM. Through the use of PCM the power requirement for the air conditioning is been reduced as far as possible, allowing comfort conditions without the use of a conventional air conditioning system.

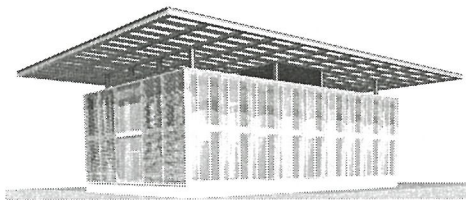


Figure 5: Prototype for an office building in Hashgert (Iran). Design K. Saleh Pascha in collaboration with structural engineer Dipl.-Ing. R. Lippke (TU-Berlin). Part of BMBF-Project: „Young Cities – New Towns in Iran. New Towns as a concept for the sustainable development of Mega-Regions”, funded by the German Federal Ministry of Education and Research.

The two-layer façade consists of an outer ETFE-foil, which will minimize the heating up of the building primarily in the morning and evening hours and an inner, slideable double glazed façade where the cavity is

filled with paraffin PCM. During the day the photovoltaic roof protects the lower part against direct sun exposure.

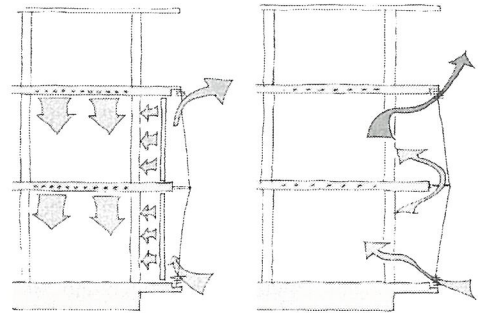


Figure 6: Left: Summer day (+35°) - Sliding PCM-Glass-element as heat absorber, - Ventilation openings should be held opened to evacuate solar gains, - No natural ventilation through double skin, - Additional active cooling through concrete slabs Right: Summer night (+ 20°): - Sliding PCM-element stored in shaft, thus creating single skin façade with high U-value thus supporting cooling down, - Ventilation openings are released allowing night ventilation.

The inner PCM façade absorbs and stores part of the internal heat during the day. The paraffin is opaque when frozen but becomes transparent, in the moment when it is completely melted. The PCM will be then unable to absorb any more latent heat. Through changing his grade of transparency the building “shows” its thermal comfort condition. At night these inner PCM façade elements are moved at the central chimney.

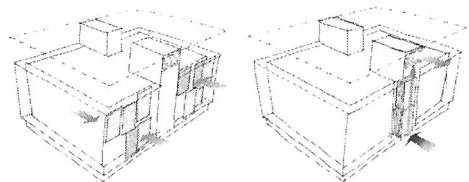


Figure 7: Translucent inner PCM-façade in day- (left) and night-time (right).

The chimney-effect will promote the heat exchange between the PCM-elements and the cool night air and enables thermal convection. Through ventilation vents in the chimney the cooler night air will cool these

inner PCM façade elements until the PCM is completely re-solidified again and has expelled its stored latent and sensible energy. In the morning the recharged PCM modules are again be able to store latent heat from the inside of the building.

7. CONCLUSION

In climates like the central valley in Chile the overheating is a much more serious problem in energy means then heating in wintertime. In order to avoid energy-extensive mechanical cooling, passive strategies for cooling, using the effects of thermal mass and night-ventilation, are the ecological and economical solution. Because of the high temperature differences between day and night, it is possible to cover all cooling demand by storing and releasing the different ambient temperature levels. A possible way to achieve this is by implementing thermal mass into the building. Instead of using “classical” sensible thermal storage materials like concrete or brickwork, Phase Change Material has some special advantages in their thermal distribution property and their cost and space-saving implication. By enabling high thermal storage within very little weight, PCM is particularly suitable for passive cooling and heating strategies in building where the façade is been used as a heat exchanger. New ways of implementing PCM in building facades should be developed that allows to actively charge or discharge the PCM directly through the ambient air. These systems will be much more effective than the “classical” implementation of thermal mass in the building construction since they enable higher temperature differences (and therefore higher efficiency) and direct energy transmission either to the inside of the building or to the outside ambient air. The task for architects and engineers will be to create new adaptable facades that do change their “faces” according to the environmental climate condition.

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