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USE OF PCM IN GLASS BLOCK WALLS FOR SUMMER THERMAL COMFORT

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Abstract- Summer thermal comfort is often a problem encountered in internal insulation buildings with low inertia. To lessen these problems, Phase Change Materials (PCM) can be used and introduced in walls. Some studies have already been carried out on this subject introducing PCM in concrete wall, in plaster board, in light internal components… conclusive that it is a great solution to improve building inertia. In this paper, experiments on a glass block wall containing PCM are carried out. The experimental setup is described and results are discussed for three MCP. These experimental results are used to assess a one-dimensional model developed in TRNSYS, which is used to study how phase change materials affect model houses thermal performances. Some differences are observed between experimental and numerical results and are explained by several reasons.

Key Word: simulation, experimentation, phase change materials, energy storage

Nomenclature

Cp	Mass heat capacity, $J.kg^{-1}.K^{-1}$	*Greek symbols*	
T	Temperature, °C	*?*	Flux density, $W.m^{-2}$
Tf	Fusion temperature, °C		
E_{Hz}	Horizontal radiation, $W.m^{-2}$	*Indexes and exponents*	
L	Latent heat, $J.kg^{-1}$	ext	Outside
S	Heat-transferring surface, m²	int	Inside

INTRODUCTION

Thermal comfort in residential building is essential as regards an occupant. However, most of the buildings which have been built during the last thirty years in France suffer from overheating in summer, generally compensated by the use of air-conditioning which entails energy over consumption. The current context aims to reduce the energy needs without threaten the thermal comfort level (RT2005). Consequently, it is important to find solutions. Different scientific studies have shown that inertia building control could have an undeniable impact on thermal comfort while limiting the energy resort.

In 1980, a study realised on isotherm partition wall integrated into the building showed that the replacement of storage classical materials by 'chliarolithe' – a phase change material – led to improve the performance of the systems; in other words, led to an increase of energy savings, a comfort improvement by temperatures stabilization, while reducing the material mass necessary, until a factor of six [Bourdeau, 1980].

Later, different researchers worked on the PCM impregnation in plaster boards or other construction materials [Salyer & al., 1985; Shapiro & al., 1987; Babich & al., 1994; Banu & al., 1998, Tyagi and Buddhi; Xu & al., 2005] in order to store or keep out stock the energy coming from solar radiation and internal contributions.

Recently, Cabeza [2006] has studied on the introduction of a microencapsulated PCM in concrete walls; temperature fusion is 26 °C for a latent heat of 110 $kJ.kg^{-1}$. The experimentation which takes place at Lleida in Spain, and consisted of two trial cells, explains that PCM allows a reduction of inside and surface temperatures. Thanks to this experiment, the author explains that the microencapsulation introduction in concrete does not deteriorate mechanical properties of this one.

As regards Lai [2006], he has researched the influence of a PCM when it's integrated in earthenware bricks situated outside on flat roof. Results are also positive. On the one hand, PCM allows to reduce the temperature on the brick surface – inside- by 4,5 °C compared to a no treated brick. But, on the other hand, this study does not deal with the temperature evolution inside the room.

Ahmad [2004, 2006] has worked on inertia of 1 m^3 trial cells. She has characterized intern inertia brought by paraffin, a fatty acid and an hydrated salt, showing again the interest of such a coupling with classical materials of building (outside insulation).

Thus, our study proposed is based on this principle of trial cell. PCM addition is realised in a glass brick division, which is assimilated with a dividing wall for two cells; process which can be extended to partition wall for rooms or offices…

The experimental device and achieved results will be presented in this paper, showing different PCM influence on thermal inertia.

EXPERIMENTAL SET UP

Cells structure

The experimental set up is consisted of two double cells facing south: the reference and the PCM one. Every cell is composed of two juxtaposed cells and separated by their common wall made of glass bricks and filled or not with PCM (figure 1). The separated wall is consisted of a sixteen glass bricks assembling, the whole rigidified by an aluminium frame (figure 2). Every cell of the double one is also composed of a double glazing facing south and of four light weight walls made of a steel sheet metal $75/100^e$, 20 mm of vacuum insulation panel (VIP) and a steel sheet metal $75/100^e$. Three phase change materials are studied: a fatty acid, a paraffin and an hydrated salt whose fusion temperatures announced by manufacturers are respectively 21 °C, 25°C and 27,5 °C.

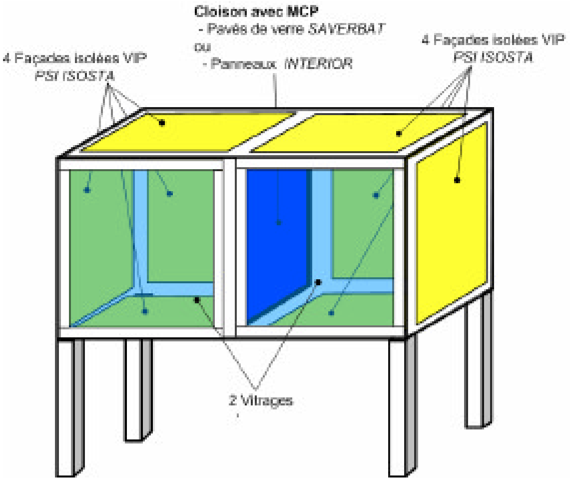

Figure 1: Twin cells separated by a glass bricks wall containing or not PCM

Figure 2: Glass bricks wall containing PCM

Cells instrumentation and measurements

Ten fluxmeters, beforehand calibrated, are set in the middle of every insulation wall and a fluxmeter is put on both sides of the glass block partition wall in the middle. Every fluxmeter presents a temperature sensor. An additional thermocouple is set in the middle of every cell to measure the inside temperature. Cells are located outside; consequently they undergo climatic variations which symbolize boundary conditions for numerical simulation. Weather parameters are recorded thanks on the experimentation site. An autonomous acquisition station set in a tight box with an alimentation choice: battery or mains, allows to acquire flux sensors exits, to digitise, treat them and finally to safeguard the results. In our case, data are directly collected thanks to an interface network between the measurement station and a micro-computer fits out with a specific software of communication (PC208W Datalogger support software).

Experimental results

During the period of measures, three divisions in glass bricks are trailed with the three PCM selected. Figures 3 and 4 present the different temperatures evolution according to time, and the vertical solar radiation part crossing the double glazing. Every period of measures, characterizing a different PCM, shows an inside temperature reducing according to the reference case, reduction between 3°C and 5°C according to the PCM state – completely melt or not. On figure 3, between may 25th and 26th , for close outside conditions, the division temperature which was initially 28 °C reached 35 °C, showing that PCM is entirely liquid May 26th. This day, the temperature variation was 4°C between the reference cell and the cell with PCM.

The PCM influence on inside temperature evolution is difficult to assess because boundary conditions are different. Moreover, experimental results show temperature inside the cells is very high. This phenomenon is due to important solar contributions. So, to characterize PCM influence on cell thermal comfort with more precision, we have to reduce solar contributions and we can possibly overventilate during night but we must especially submit PCM to the same boundary conditions. Numerical modelization can also answer questions and that is the reason why the followed study deals with the development of an one-dimensional model in TRNSYS environment and presents at last a comparison with experimental results.

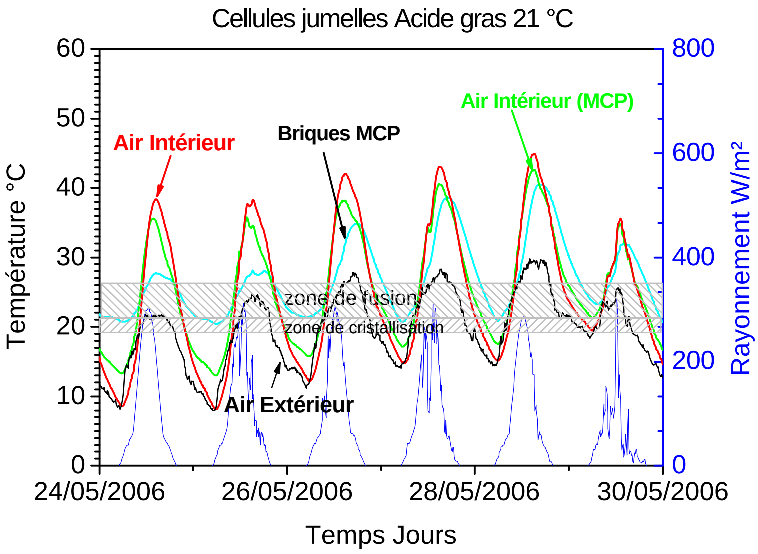

Figure 3: Thermal behaviour comparison between reference cell and the PCM one (fatty acid)

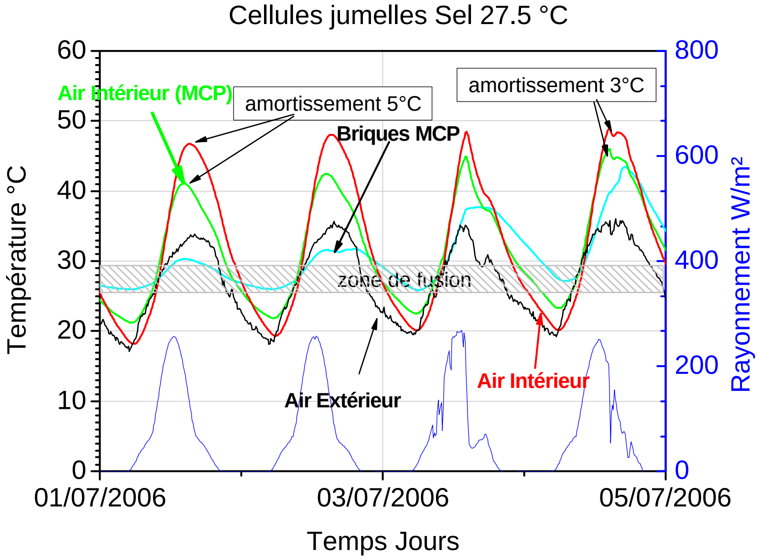

Figure 4: Comparison between two states of salt (partially melt: absorption of 5 °C, entirely melt: absorption of 3 °C)

NUMERICAL SIMULATION

Numerical model description

Studies on simple cells Ahmad [2004] realised were carried out thanks to a 3D model developed by Josikalo [1999]. Although achieved results are close to real phenomena, simulation time is always important (from 2 to 3 hours to symbolise one year). Thus, we have decided to develop an one-dimensional model in TRNSYS environment in order to reduce calculation time. The model assesses thermal behaviour of a wall consisted of 7 layers maximum: 3 externs layers on both sides of a phase change material. The multi-layers wall is modelled by a resistance/capacity approach (figure 5). Every material layer, except PCM one, is modelled by a 3R4C network whereas the capacity number in the PCM layer has to be defined. (100 maximum). Connection between every material layer is taken into account by a predefined contact resistance. Boundary conditions (Fourier conditions) are ambient temperature and radiation one of every wall side. An incident flux can also be chosen on both sides of the wall. As regards PCM change of state modelization, we can think about three possible solutions: Kondo's model [2000] on the approximation of *Cp* graph by straight lines, a square model or *Cp* real characteristics measured.

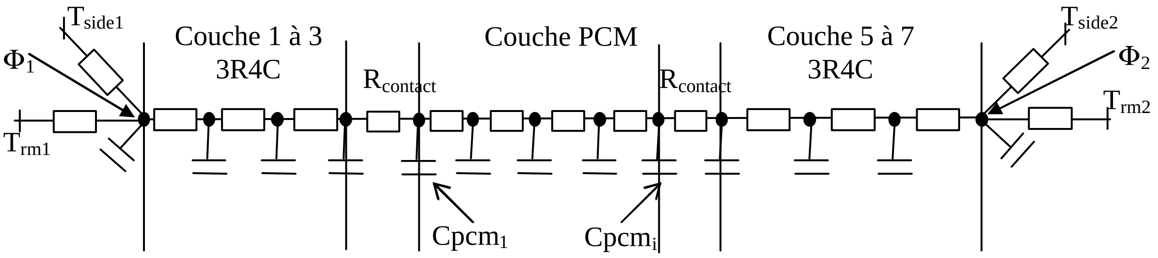

Figure 5: Wall RC network with a phase change material

Kondo's model was developed as part of a study on PCM in plaster plates. Authors have measured thermal conductivity and capacity of materials used in their experimentation and especially for plaster boards containing the phase change material. Three measures have been realised – on solid, diphasic and liquid phase – in order to evaluate sensitive and latent thermal capacity. Authors deduced the specific heat model used with their simulations (figure 6), which depends on temperature and fusion range. Then, specific heat value is calculated thanks to three straight lines defined in the temperatures periods: [*Tf*-4,5 °C; *Tf*-2 °C]; [*Tf*-2 °C; *Tf*]; [*Tf*; *Tf*+0,5 °C].

Finally, this model was two studies main topic, which allow to assess coherence between achieved results. First of all, it was the subject of a Benchmark [IMCPBAT, 2006] assessing a simple wall with PCM or no. This Benchmark explains that a single wall model gives good results. Then, Faure & al. [2006] show the model gets coherent results when we assess by numerical simulation, the phase change material contribution on summer thermal behaviour of a 40 m^3 room. Consequently, the next stage of this analysis consists in comparing results achieved by model with the experimental ones described in the experimental part of this study.

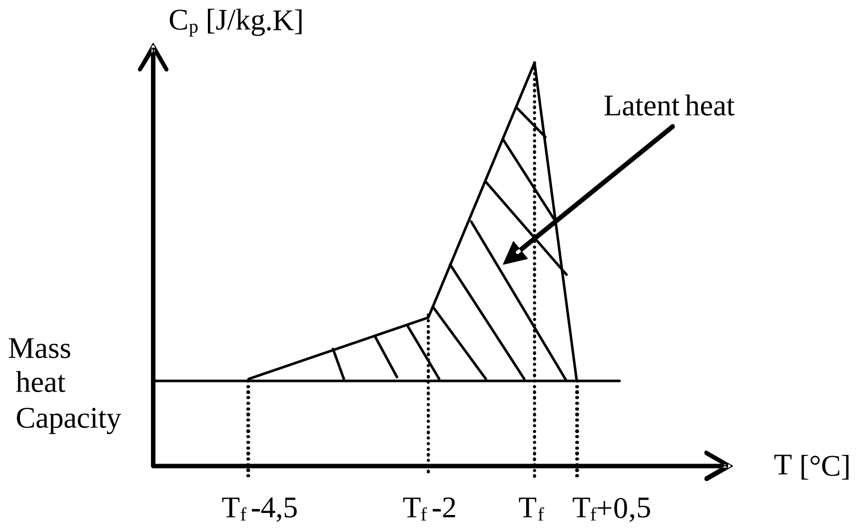

Figure 6: Specific heat evolution depending on temperature according to Kondo & al.

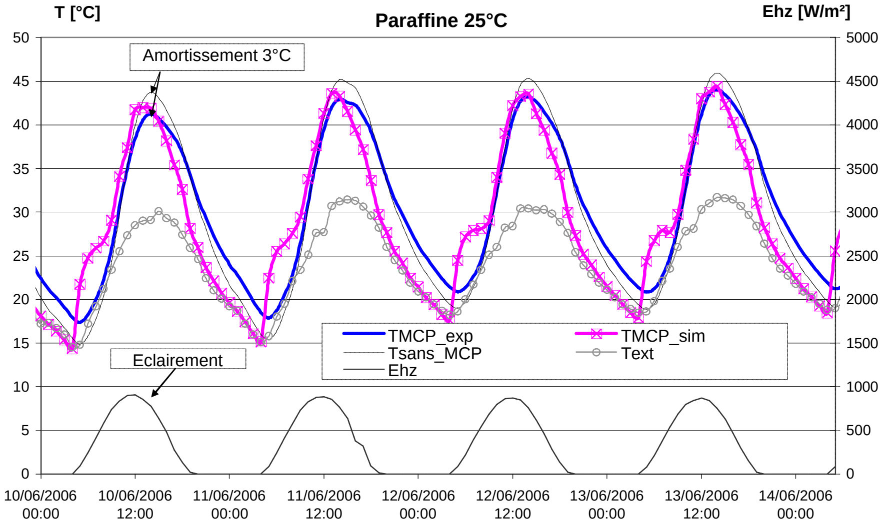

Figure 7: Comparison between inside temperatures with and without PCM for a paraffin

Comparison between numerical and experimental results

The dividing wall model was coupled with the ‘Type 56 building’ available in TRNSYS to simulate the double cell. A first comparison whose results are not described in this paper shows the model is faithful to the double cells behaviour when the dividing wall doesn’t present any PCM. Results showed in figure 7 take into account PCM in glass wall. Boundary conditions used during the simulation are real data measured in-situ – outside temperature (T_{ext}) and horizontal sunning presented on the last picture announced. It’s interesting to notice that inside air temperature with PCM ($T_{PCM\text{-}sim}$) presents the same dynamics as experimental air temperature ($T_{PCM\text{-}exp}$). However, one phase difference can be noticed and entail problems of inertia and phase change phenomenon representation. Several points can explain this issue:
The first one is linked to the simulation which has been realised with Kondo’s model; because PCM experimental values were not available. Fusion temperature and heat latent used are data fixed by manufacturer thanks a canning calorimetric measure at the rate of 3 °C/min.

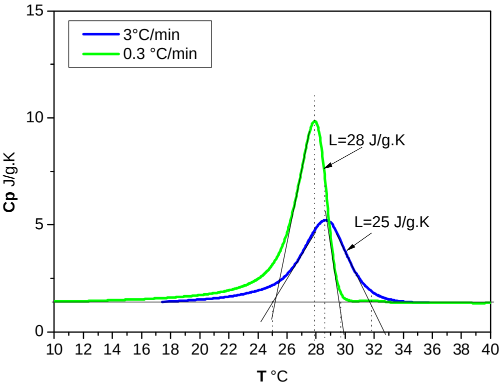

Figure 8: PCM specific heat evolution depending on solicitation speed

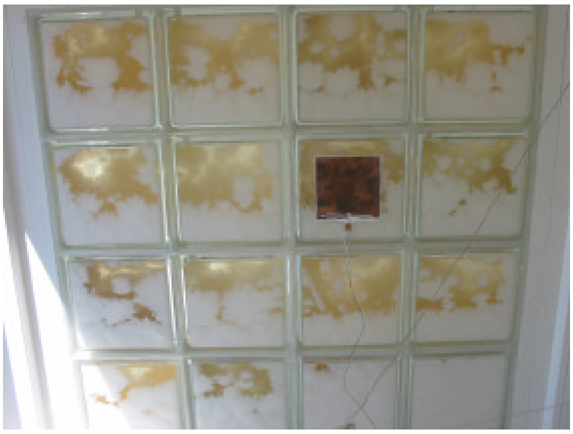

Figure 9: No homogeneous PCM fusion in glass block stones.

But, measures realised thanks to micro differential scaling calorimetry process (figure 8 – cycle close to reality at the rate of 0,3 °C/min) revealed fusion temperature given by the manufacturer is not really the one measured. Moreover, this noting was highlighted by an AIE study [2005]. So, you have to be careful when you decide to measure mass thermal capacity evolution and you must take the closest measures context as possible to real entreaties conditions. Moreover, surfusion problem doesn't appear in the model.

The second point is linked to the fact that experimentally, the fusion front material is not homogeneous. Figure 9 shows phase change material is liquefied in the middle of the brick, on the edges sometimes, explaining that simulation hypothesis on an homogeneous fusion front is not valid in case of glass bricks.

Finally, the solid phase migration towards the bottom of the glass bricks highlights natural convection phenomena which increase heat transport from one side to the other one. With surfusion, observed "smoothing" of the phase change phenomenon is not numerically represented.

CONCLUSION

The experimental aspect of this study allows to highlight several points. First of all, it's important to notice the phase change materials impact on inside temperature damping, reducing the air-conditioning use. Besides, we have shown that our experimental set up should be improved in order to characterize PCM. So, it's important to reduce solar contributions, to ventilate during the night and especially to compare PCM influence with equal boundary conditions. Moreover, an important point was raised concerning the measure of mass thermal capacity. It must be realised in the same conditions as its real load otherwise important differences could appear, especially on the fusion crest segment.

On a numerical point of view, we have developed an one-dimensional model which will take into account, later, the surfusion problem, and the real characteristics measured at a slow rate. In spite of that, the model gives coherent results. Then, it will allow to characterize phase change materials with equal boundary conditions, to assess these materials impact at a building scale, to study their site, the maximum thickness and other criteria…PCM conditioning in glass bricks needs numerical models more precise, which take into account migration phenomena and natural convection.

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