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# Full-scale study of a building equipped with phase change material wallboards and a multi-layer rack latent heat thermal energy store system

Julien Borderon<sup>1</sup>, Joseph Virgone<sup>2</sup>, Richard Cantin<sup>1</sup> and Frédéric Kuznik<sup>2</sup>

<sup>1</sup>ENTPE, University of Lyon, LASH, Building and Civil Engineering Department (DGCB), France

<sup>2</sup>CETHIL, UMR 5008, Université Lyon 1, France

*Corresponding email: julien.borderon@entpe.fr*

## SUMMARY

An office building in Lyon, France has been studied. Phase Change Material (PCM) has been installed as wallboard and as latent heat thermal energy storage system coupled with the ventilation system. The main purpose of this study is to determine if the PCM system can guarantee the summer comfort of the occupants without energy-consuming cooling devices. Sensors have been set up and the collected data are monitored to study the thermal behavior of the building and the PCM. Numerical simulations complete the work to study the building behavior without PCM and to compare. The temperature charts in each office show that the comfort of the workers is acceptable in winter and in summer. Numerical results show a difference of temperature in offices due to the PCM in the partitions and in the ceilings. The temperature in the crawl space is included between 13 and 20°C all over the year, so the precooling or preheating system for the ventilation air is efficient.

## INTRODUCTION

Nowadays, thermal energy storage systems are one way for reducing dependency on fossil fuels and then contributing to a more efficient environmentally benign energy use [1]. As demand in thermal comfort of buildings had risen increasingly, the energy consumption of buildings has increased by 30% the last 30 years. Housing and tertiary buildings are responsible for the consumption of approximately 46% of all energies and approximately 23% of the total CO<sub>2</sub> emissions [2].

The use of Phase Change Materials (PCM) for building has been a subject of considerable interest in the last decade, for a review see Tyagi and Buddhi, [3]. An interesting feature is that they can store latent heat energy, as well as sensible energy. As the temperature increases, the material changes phase from a solid to a liquid. As this physical reaction is endothermic, the PCM absorbs heat. Similarly, when the temperature decreases, the material changes phase from a liquid to a solid. As this reaction is exothermic, the PCM releases heat.

Koschenz and Lehmann developed a ceiling panel with PCM for application in lightweight and retrofitted buildings; they used aluminium fins to enhance the conduction through large PCM panel [4]. Lazaro had experimented two real-scale prototypes of vertical PCM-air heat exchangers for free-cooling applications in buildings with macro-encapsulated PCM [5].

In the framework of a French research program, an office building, named VTAP has been built in 2006 with particular attention to the comfort of the occupants and to the control of the energy consumptions. One particularity of this 3-floors building is high thermal load during

workdays. PCM have been installed as wallboard and as latent heat thermal energy storage system coupled with the building ventilation system. The main purpose is to guarantee the summer comfort without energy consuming cooling devices.

First, the building and the PCM, object of the present study, are described; the second part presents the method. Then the next part deals with the main collected results of our experimentations and simulations. And the last part is the discussion about these results and perspectives.

## DESCRIPTION OF THE BUILDING EQUIPPED WITH PCM

### Presentation of the building

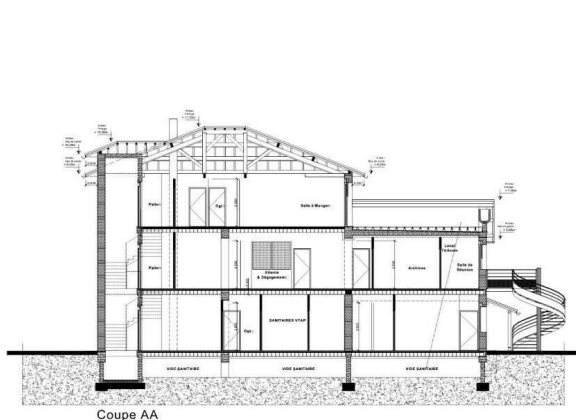


Figure 1 : slice view of the VTAP building

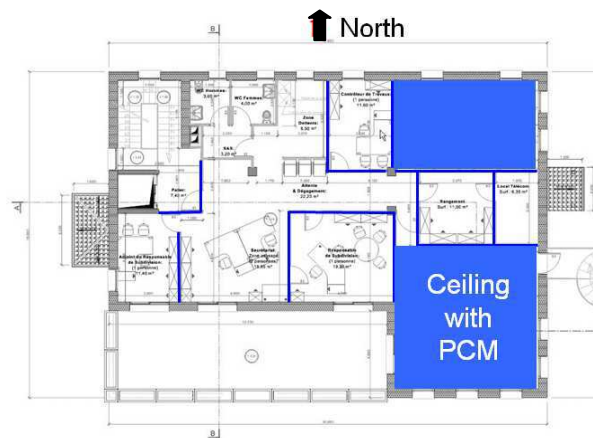


Figure 2 : Position of the PCM in the first floor, the PCM is in color.

The urban services of the city of Lyon are installed in the studied building. This building is located in Venissieux in the suburbs of Lyon. It's composed of three levels (figure 1).

- The crawl space, with a surface of 275 m<sup>2</sup> is used to preheat the air insufflated in winter or to refresh it in summer. 10 PCM racks are located in the crawl space. (figure 3) Each of them contains 10 PCM sheets, 1.2 m large, 2 m long and 0.005 m thick. The distance between each PCM layers is 0.1 m.
- The ground floor, 270 m<sup>2</sup>, is composed of lavatory, showers, changing rooms, and refectory for the occupants. It also contains the boiler room.
- The first floor, 200 m<sup>2</sup>, is intended to the administrative staffs. It contains offices and an assembly room. In the internal walls and in the ceiling of two rooms of this floor two PCM layers of 5 mm have been installed just behind a thin plaster layer (13 mm), see figure 2.
- The second floor of 150 m<sup>2</sup> consists also of offices even if at the construction it has been designed for two dwellings.



Figure 3 : Instrumented multi-layer rack in the crawl space.

### Properties of the Phase Change Material

Common PCMs include paraffins, which are used in this study. The selected one is constituted of 60% of micro-encapsulated PCM. The final form of the material (figure 4) is sheets of 5mm thickness which density is  $900 \text{ kg/m}^3$ . A sheet of aluminium covers them. [6]

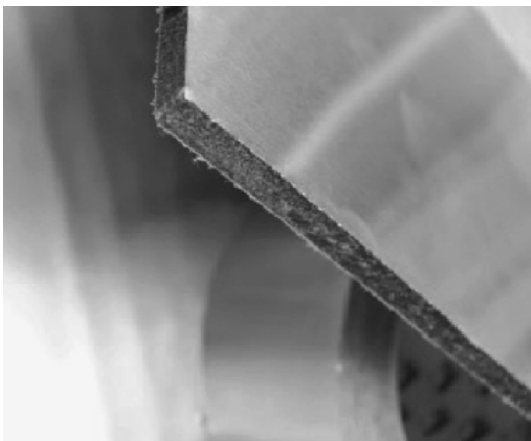


Figure 4 : Micro-encapsulated and aluminium covered PCM

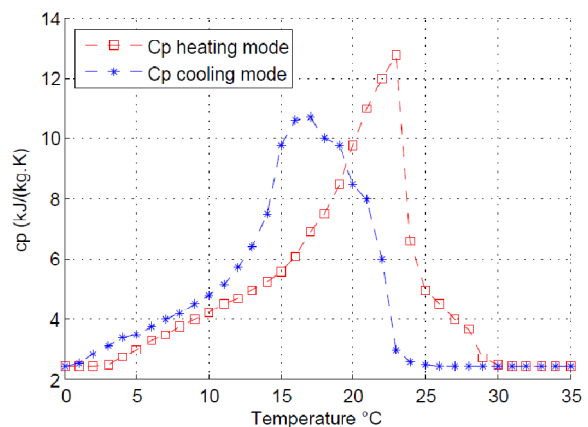


Figure 5 : Specific heat of the PCM

The PCM heat capacity was measured using a differential scanning calorimeter and the thermal conductivity was measured using a guarded hot-plate apparatus in a previous project IMPCBAT [7]. The transition from liquid to solid takes place over a temperature span, so the specific heat varies with the temperature. The measurements show a hysteresis phenomenon, see figure 5. The thermal conductivity is about  $0.23 \text{ W/(m.K)}$  under the melting temperature and decreases, over the melting temperature to about  $0.17 \text{ W/(m.K)}$ .

### Specific ventilation modes for the first floor

The first floor contains offices and then presents the highest thermal loads. Thus, it has been planned to make the hygienic new air pass through the crawl space and filters in order to refresh or to preheat it according to the period of the year. An over-ventilation is needed in summer period to decrease the temperatures of air and structure in the office and to regenerate the PCM in the crawl space. This will limit temperature increase by using the high inertia of

the structure. The principal ventilation strategies are winter mode, (in figure 6 a), summer mode during occupancy (in figure 6 b) and summer mode at night in (figure 6 c).

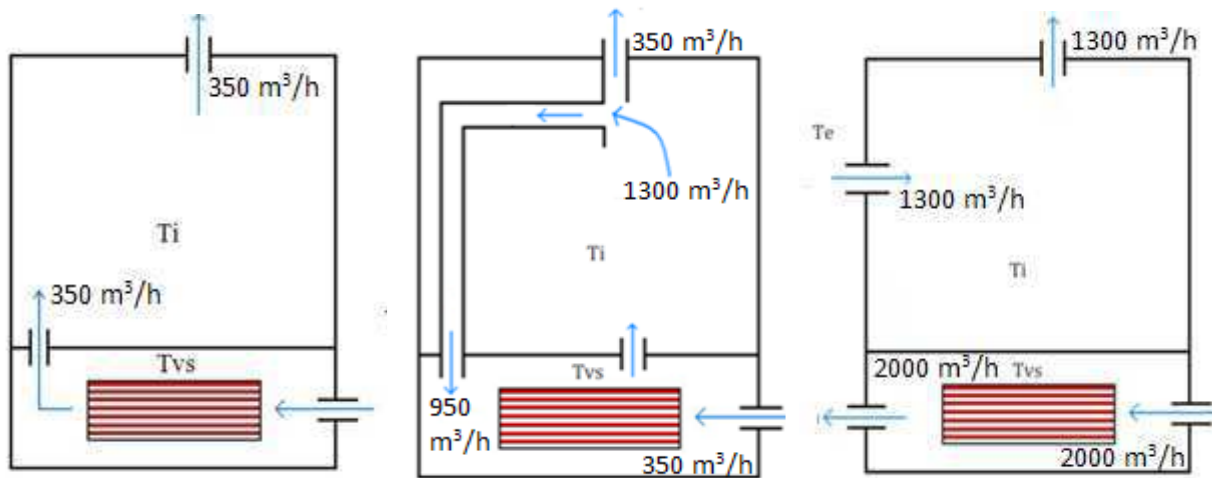


Figure 6 a : Winter (normal) ventilation mode

Figure 6 b : Summer mode during occupancy

Figure 6 c : Summer mode at night : over-ventilation

## METHODS

### Instrumentation of the building

Since September 5<sup>th</sup> 2008, the building is monitored. 68 sensors have been used to follow the behavior of the system. Air temperatures, surface temperature and climatic data like relative humidity, exterior air temperature and solar radiation have been measured. For the temperature measurement, PT 1000 probes have been used. In the crawl space, 4 probes measure the air temperature: the one of the fouled air from the first floor, the one of the air in the two air vents to outside and the one in the air vent to the first floor. The air temperature of all the offices of the first floors and the surface temperature on all the PCM layers are also monitored. On figure 3, the PT 1000 probes in a PCM rack are visible. For each layer, the air temperature and the surface temperatures have been measured.

### Simulation with numerical models

As the only data collected are related to the building thermal behavior with PCM. Numerical simulations have been required to study the building behavior without PCM. In [8], Lepers et al. analyze the advantage of using the crawl space for the ventilation system. A TRNSYS model of the building has been built with the type 56: multizone building [9]. The model contains five zones for the first floor. The table 1 summarizes the assumptions concerning the internal gains. For more details on the geometry and on the materials see [8], Lepers et al. presents all the details about the TRNSYS model of this building. The PCM has been modeled with a home made type. The heat transfer in a PCM sheet is supposed to be unidirectional. The phase change process is modeled using the equivalent heat capacity method. The problem is discretized using a finite-difference method. In order to ensure the stability of the solution, the time step is 60s and the mesh size 0,0005m [6]. With these values, the relative error due to the discretization is less than 1%.

Table 1: Thermal zoning of the building and main hypothesis on internal heat loads

Zone name	Floor	Surface (m <sup>2</sup> )	Volume (m <sup>3</sup> )	Occupants 150 W	Lighting (W/m <sup>2</sup> )	Other gains (W)
Crawl space	-1	276.5	470			
Stairs	0, 1, 2	-	243		7	
Dressing room and offices	0	192	564	8	15	350
Refectory	0	43	126	24	15	
Secretariat	1	92	270	5	10	750
Controller Office	1	11.6	34	1	15	120
Foreman Office	1	19.3	57	1	15	120
Spervisors Office	1	27.1	80	2	15	250
Assembly room	1	44.4	131	20	15	120
2 <sup>nd</sup> floor offices	2	103.5	259	5	15	620
Attic	-	125.5	185			

The program Codyba has been used to simulate the impact of PCM wallboard in offices of the first floor. This software includes PCM in his library to add layers in walls or ceilings. The thermal loads in table 1 have been used and each office has been modeled separately.

## RESULTS

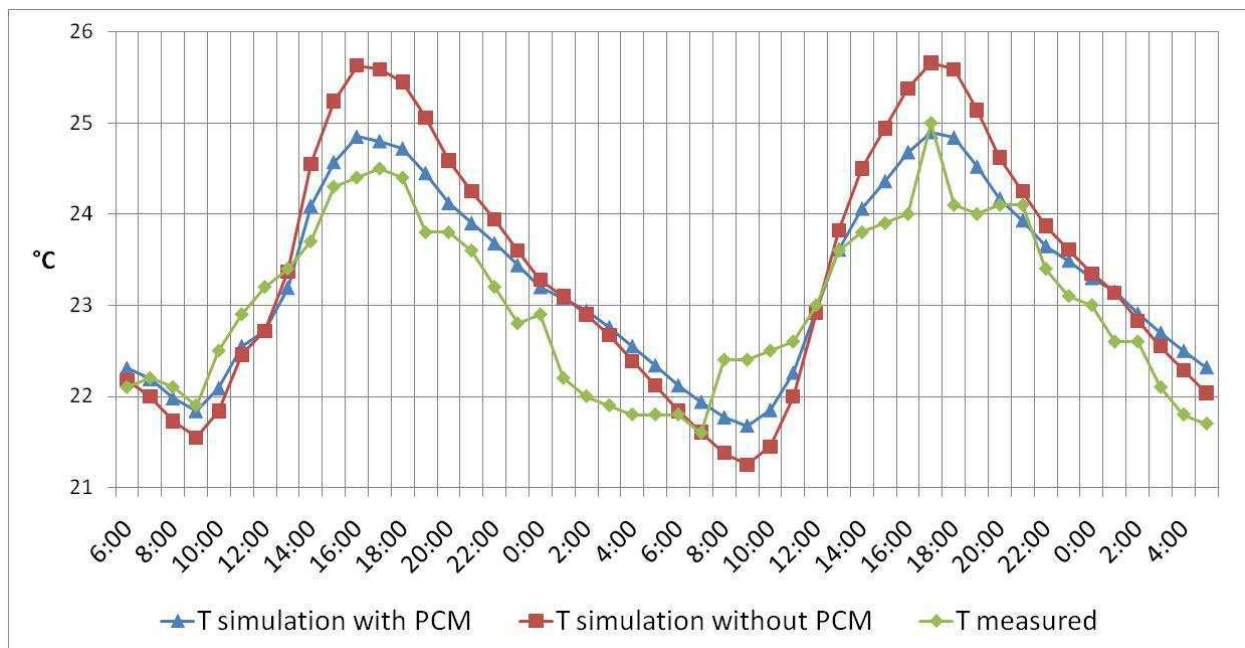


Figure 8: Air temperature in the supervisors office, simulated with PCM, without PCM and measured.

The temperatures on the offices of the first floor have been modeled with Codyba in the real configuration with PCM layers in the internal walls and in the ceiling for the assembly room and the supervisors office. The results show an impact of for PCM, specially in the case where they are also in the ceiling. The amplitude of the daily variation of temperature is higher without PCM. This difference of inertia leads to difference of approximately 1°C between the two simulations. The figure 8 represents the results for the supervisors office for

two days, October 13<sup>th</sup> and 14<sup>th</sup> 2008. These days were normal week days with exterior temperature as high as 25 °C in the afternoon.

The temperatures in the crawl space in 2009 were between 12.7 and 19°C. The function associated with this space is well-adapted. In the cold seasons, with air temperature around 13°C, the fresh air from outside is preheated in the crawl space. In the hot season, with air temperature between 18 and 19°C, the outside air is precooled in the crawl space before being blown in the offices. The figure 9 shows the measured air temperature in the crawl space all over last years.

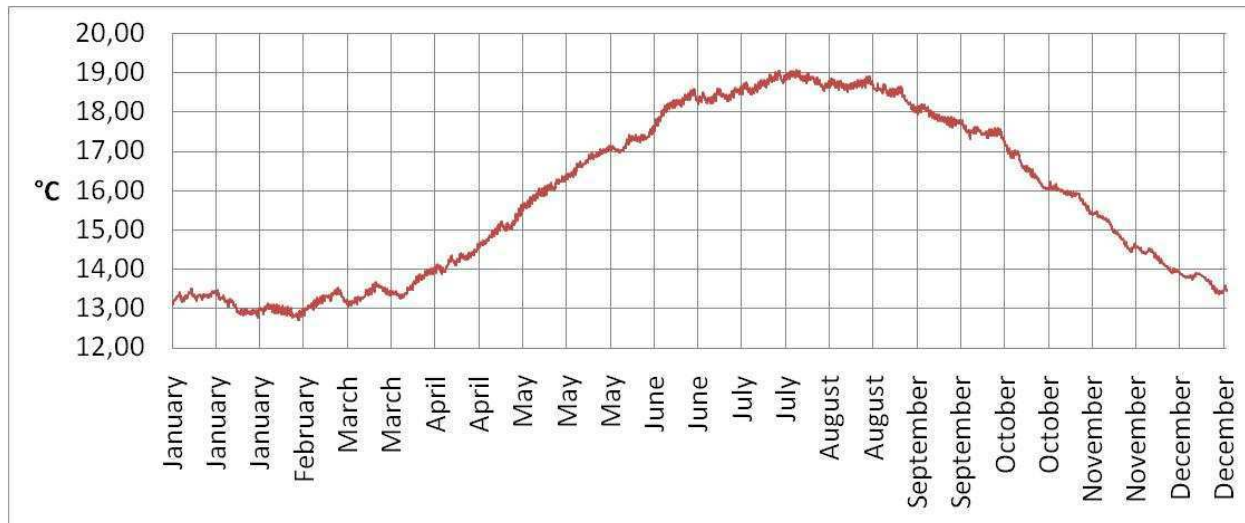


Figure 9: Air temperature in the crawl space in 2009

The TRNSYS simulations have been used to show the impact of the PCM racks in the crawl space. The maximal temperatures statistics for a year have been calculated. On the figure 10, Nh corresponds to the number of hours when the air temperature in the secretariat exceeds a fixed temperature. Because of the racks system, the air temperature in the secretariat, controller and supervisors offices does not exceed much 30°C. The foreman office is the less comfortable one: the air temperature is higher than 31°C 82 hours per year. With the help of the PCM, the temperature in this office never exceeds 31°C.

Globally, a difference of about 100 hours can be observed between the building without racks system and the building with the thermal energy storage system, when the air temperature exceeds 25°C.

In August 2009, it has been measured that the temperature in the secretariat has been higher than 30°C during 54 hours.

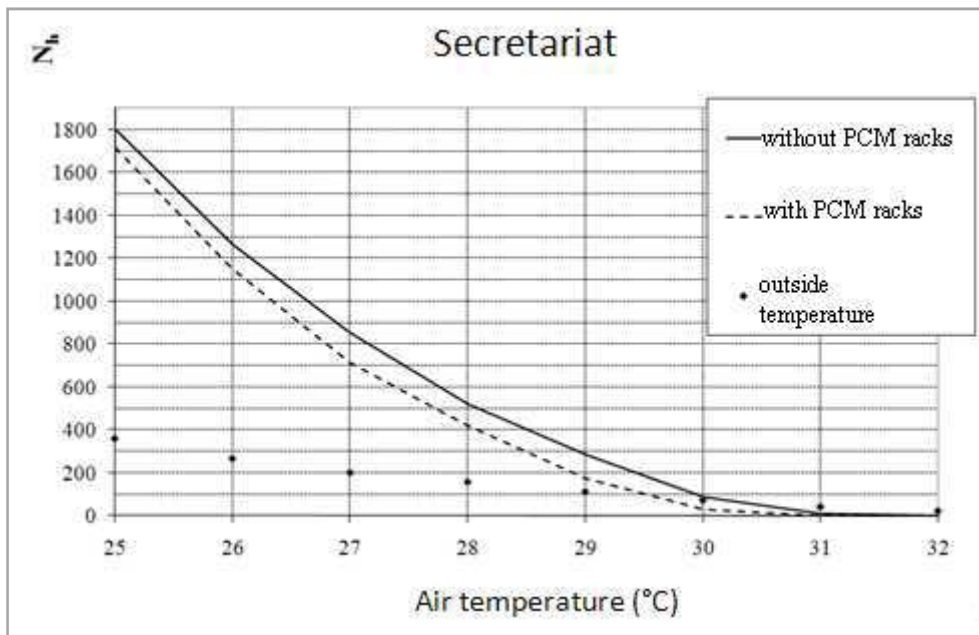


Figure 10: Air temperature statistics for the secretariat

## CONCLUSIONS

A building with latent heat thermal energy storage has been monitored. An original thermal energy storage system composed of a multi-layer PCM racks has also been modeled. The PCM racks, installed in the crawl space, allow to enhance the basement thermal inertia. The racks and the PCM in the internal walls and in the ceiling contribute to enhance the thermal comfort of the workers. This work shows that to obtain the better efficiency with PCM, they have to be included in the building's design and management, especially for the ventilation scenario.

The results show that the thermal comfort in the building isn't perfect for the summer. The temperature is still higher than 30°C during the warmest days. The behavior of the building could be enhanced to increase the thermal comfort in summer. The perspectives of this work are to study a better ventilation strategy and a better configuration for the PCM racks in the crawl space. The air flux in the crawl space have to be forced through the PCM racks to enhance the heat exchanges.

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