Evaluation of a multi-layer rack latent heat thermal energy storage system coupled with a building ventilation system

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ABSTRACT

A numerical simulation is used to evaluate the efficiency of a multi-layer rack composed of phase change material (PCM) sheets each. The building, object of this study, is actually under construction in Lyon and will be monitored. 10 of these racks are installed in the crawl space of the building. A fan is forcing fresh air to pass through the crawl space and then through the multi-layer racks. Then, this air is used in the building ventilation system, depending on its temperature. The software TRNSYS is used to simulate the behaviour of the building equipped with racks. The numerical results show that the racks system allows enhancing the thermal comfort of the workers inside the building during the summer.

1. INTRODUCTION

Nowadays, thermal energy storage systems are essential for reducing dependency on fossil fuels and then contributing to a more efficient environmentally benign energy use (Dincer and Rosen (2002)). As demand in thermal comfort of buildings rises increasingly, the energy consumption is correspondingly increasing. For example, in France, 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 19% of the total CO_2 emissions (French Ministry of Ecology and Sustainable Development (2004)).

Thermal energy storage can be accomplished either by using sensible heat storage or latent heat storage. Sensible heat storage has been used for centuries by builders to store/release passively thermal energy, but a much larger volume of material is required to store the same amount of energy in comparison to latent heat storage. During the summer days, the fresh air coming from outside is hot. Then the phase of the PCM is changing from solid to liquid. The chemical reaction being endothermic, the PCM absorbs heat and the air entering the building ventilation system is cooled. Similarly, during the summer nights, the material changes phase from liquid to solid. The reaction being exothermic, the PCM releases heat.

The object of this article is to evaluate a multi-layer racks composed of PCM plates as an energy storage system. 10 of these racks are placed in a crawl space situated under an office building. The storage system is coupled with the building ventilation system to enhance the summer thermal comfort. Numerical simulations are held using the software TRNSYS allowing to simulate the racks thermal energy storage system linked with the building ventilation system.

First, the VTAP building, object of the present study, is described. The building structure and the main hypothesis that have been made for its thermal modelling (occupancy, thermal loads…) are also presented. The second part deals with the numerical model used for the thermal simulation. Finally, we give the main results of our simulations that show the real effectiveness of the considered system.

2. DESCRIPTION OF THE VTAP BUILDING

2.1 Presentation of the building

In the framework of a large research program called PREBAT (France), a new building, called VTAP (see Figure 1) will be monitored in order to evaluate its thermal behaviour. This building of the "Grand Lyon" is a new one located at Vénissieux (Rhône), near Lyon. It is composed of three levels. The distribution of the activities within the building is:

► the crawl space, with a surface of 275 m², is used to preheat the air insufflated in winter or to refresh it in summer. The PCM racks are located in the crawl space.

► the ground floor, 270 m², is intended for the agents of the subdivision. It is composed of dressing room, refectory, toilets and showers. It also contains the boiler room.

► the first floor, 220 m², is intended to the administrative staffs. It contains offices and an assembly room. This floor is the object of the specific ventilation and is the subject of the study.

► the second floor of 150 m² consists of two dwellings.

Figure 1: East view of the VTAP building

During the design phase, a specific attention was related to the control of the energy consumptions, the thermal comfort during winter and summer.

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

Zone name	Floor	Surface (m²)	Volume (m³)	Occupants 150 W (50 % sensible, 50 % latent)	Lighting (W/m²)	Other gains[1] (W)
Crawl space	-1	276.5	470			
Stairs	0, 1, 2	-	243		7	
Dressing Room and Offices	0	192.0	564	8	15	350
Refectory	0	43.0	126	24	15	
Secretariat	1	92.0	270	5	10	750
Controller Office	1	11.6	34	1	15	120
Foreman Office	1	19.3	57	1	15	120
Supervisors Office	1	27.1	80	2	15	250
Assembly Room	1	44.4	131	20	15	120
Studio	2	23.8	60	1	15	500
Dwelling	2	79.7	199	4	10	1000
Attic	-	125.5	185			

[1] Computers, copying machine, slot machine, electrical goods…

2.2 PCM racks

10 PCM multi-layer racks are installed in the crawl space. Each rack is composed of 10 PCM sheets of 1.30mx2.70m length and width (see Figure 2). The space between two sheets is 10cm.

The PCM tested is ENERGAIN® product from Dupont de Nemours. It is constituted of 60% of micro-encapsulated PCM. The final form of the PCM material is flexible sheets of 5mm thickness which density is 1019kg/m^3. They are covered by a sheet of aluminum.

The thermal properties of the composite PCM can be found in Kuznik et al. (2008)(b). The melting temperature of this material is about 22°C; the latent heat during the phase change is about 72J/g.

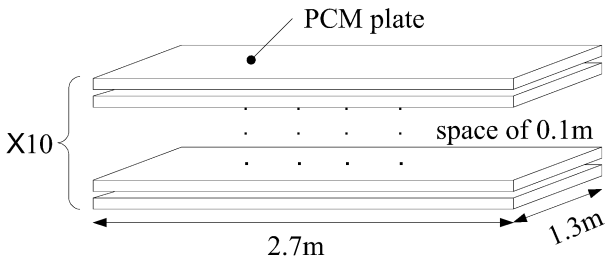


Figure 2: PCM multi-layer rack system

2.3 Thermal zoning of the building

For this study, the building has been decomposed in 12 zones whose surfaces, volumes and localizations are given within the Table 1. Thermal zoning makes it possible to merge into volumes having similar uses and profiles of internal and external heat loads.

The Figure 3 shows the thermal zoning of the office floor (first floor).

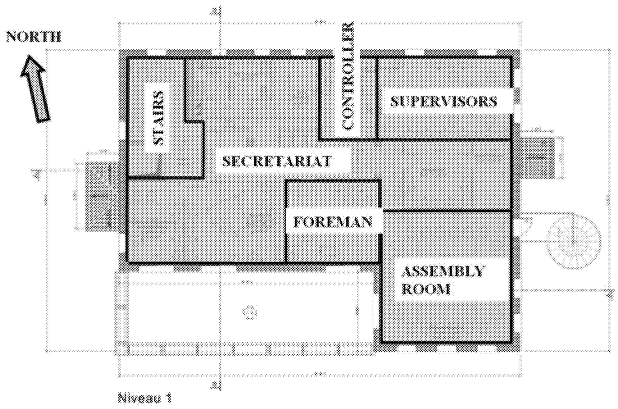


Figure 3 : Thermal zoning of the first floor

2.4 Characteristics of walls and windows

The various walls used have the following characteristics (given interior towards outside in Table 2):

Table 2 : Characteristics of walls

Wall name	Layers	U (W/m²/°K)
Exterior wall	1. Plaster: 1.3 cm 2. Clay brick: 37.5 3. Exterior rendering: 1cm	0.34
Partitions (Ground floor)	1. Clay brick: 7 cm	2.28
Partitions (1st and 2nd floor)	1. Plaster: 1.3 cm 2. Air layer: 7 cm 3. Plaste: 1.3 cm	0.71
Crawl space ground	1. Ground: 60 cm	0.57[1]
Crawl space wall	1. Concrete: 20 cm 2. Ground: 40 cm	0.56[1]
Slab between crawl space and ground floor	1. Expanded polystyrene: 10 cm 2. Concrete: 20 cm 3. Cement: 5cm	0.34
Slab between floors	1. Concrete: 20 cm 2 Cement: 5cm	0.37
Dwellings' ceiling	1. Plaster: 1.3 cm 2. Hemp wool: 18 cm	0.23

[1] : Ground coupling as been taken into account by considering that the evolution of the ground temperature was one year period sine curve between 10 and 20 °C with a maximum in September.

Different windows are used depending on the orientation. South and west windows are made with solar control glass, with reinforced thermal insulation. These one are interesting for summer comfort but are not sufficient. Windows frames are constituted by aluminium with thermal bridge rupture. Detailed characteristics are given in Table 3.

Table 3 : Characteristics of windows

Orientation	U-value (Frame + glazing)	g-value (Frame + glazing)	g-value with blind
North, East	1.4	0.64	0.25
South, West	1.4	0.30	0.15

2.5 Internal loads and occupancy

Internal loads are given in Table 1. The building is occupied from 7 a.m. to 7 p.m, the temperature setting is 21 °C (17 °C during nights and week end for offices). For the assembly room, it is considered in occupancy during 2 hours per day by 20 persons and the dressing room is supposed to be occupied 2 hours per day by 30 persons.

2.6 Specific ventilation of the first floor

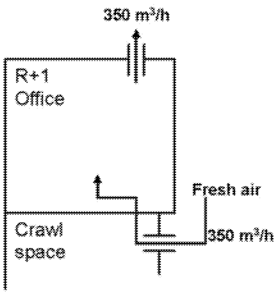
In order to guarantee a minimum level of comfort during summer, it was decided to use specific ventilation for the first floor. The first floor contains the majority of offices and then presents the highest thermal loads. Thus, it is planned to make the hygienic new air pass through the crawl space and filters, in order to refresh or to preheat it according to the period of the year. In the same way, an over-ventilation is envisaged in summer period to decrease the temperatures of air and structure sufficiently in the office. This will limit temperature increase by using the high inertia of the structure.

The principal modes of ventilation considered are:

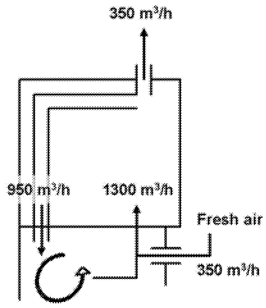
♦ winter mode: The hygienic fresh air passes through the crawl space which temperature is higher than outside air temperature. Then the air is preheated before being heated in air handling unit.

♦ summer mode: There are several operating modes in summer or in mid-season.

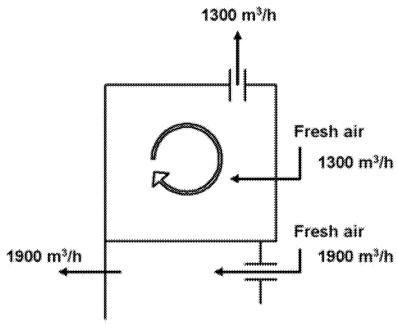
- During occupancy, if the internal temperature is lower than 23°C, rooms are ventilated with airflow rate of 350 m3/h (0.6 ACH). Fresh air passes through the crawl space before being insufflated inside offices. Waste air is extracted in roofing via the air handling unit.



Normal mode



Summer mode over-ventilation



Night over-ventilation

Figure 4 : Specific ventilation modes of the first floor

- During occupancy, if the internal temperature becomes greater than 23°C, workplaces of the first floor are ventilated with a higher airflow. The airflow is about 4 times greater than the base one (1300m3/h or 2.3 ACH). If the internal temperature is lower than outside then a part of the ventilation air is thrown out in the crawl space, if not all wasted air is extracted in roofing.

- If the building is empty, then the crawl space is over-ventilated in order to refresh it. The airflow is about 4 ACH: this "night ventilation" allows to evacuate the thermal load of the crawl space, so it will be able to absorb the heat generated in offices during work-time. Offices are over-ventilated with airflow of 1300 m3/h (2.7 ACH).

3. NUMERICAL MODEL

3.1 Simulation tool

The building is modeled using the well known dynamic simulation software TRNSYS 16 (Klein et al. (2005)). Within TRNSYS every component is described by a specific routine, called "type", that can be either a standard or a user-written one. Types are then linked together. The standard Type 56 Multizone Building Model is used for the VTAP building.

Specific "equations" are used to take into account the management of the ventilation and the artificial lighting of the different rooms (see Figure 5).

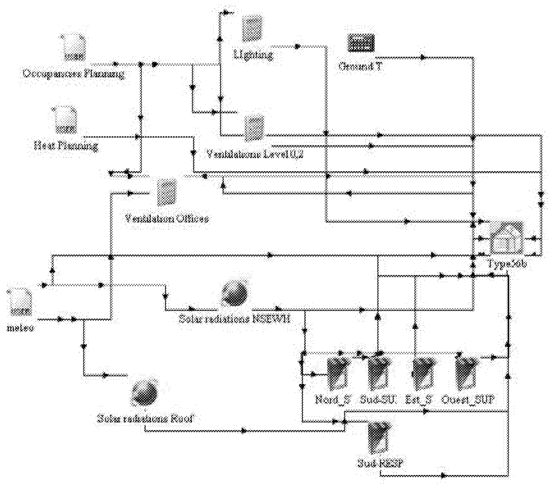


Figure 5 : TRNSYS modeling of the VTAP building with systems

3.2 PCM rack modeling

A PCM rack is composed of 10 PCM sheets of 5mm thickness and 1.30mx2.70m length and width.

A home-made "type", named type 230, is

used to simulate the PCM racks. 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 (Kuznik et al. (2008)(a)). With these values, the relative error due to the discretization is less than 1%.

4. RESULTS

For all the simulations carried out, yearly weather data of Lyon are used.

4.1 Air temperature statistics

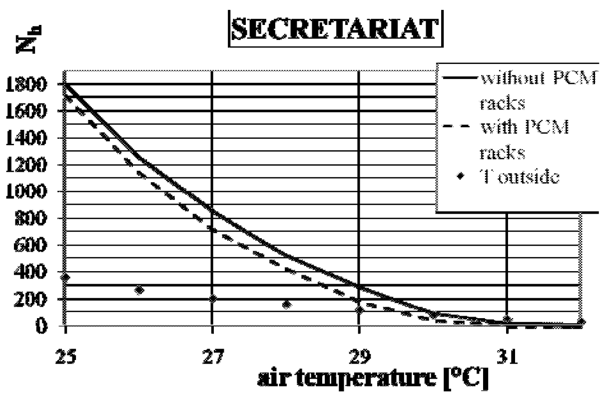


Figure 6 : Air temperature statistics for the secretariat

The following figures, Figure 6 to Figure 9, show the maximal temperatures statistics for a year: Nh corresponds to the number of hours when the air temperature in the zone of interest exceeds a fixed temperature.

The figures show clearly the benefits of the multi-layer rack system for thermal energy storage. 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.

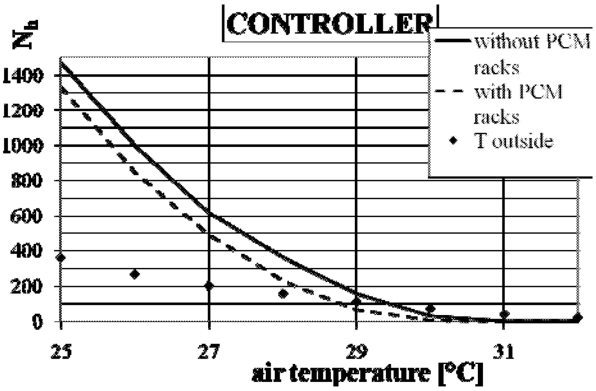


Figure 7: Air temperature statistics for the controller's office

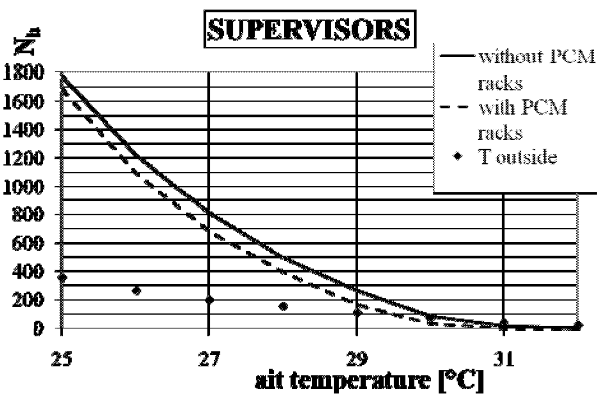


Figure 8: Air temperature statistics for the supervisors' office

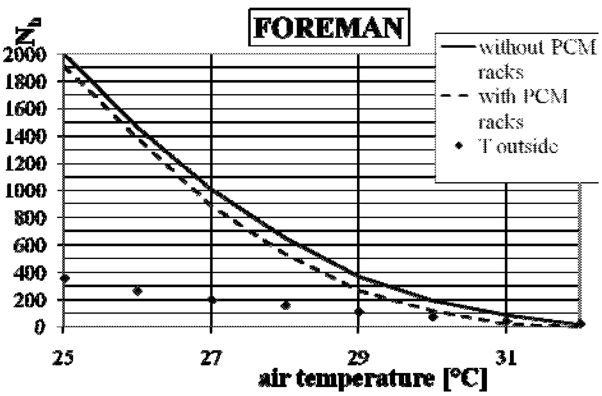


Figure 9: Air temperature statistics for the foreman's office

4.2 Air temperature evolution

The Figure 10 shows the air temperature evolution for the 10th of august which is a very hot summer day. The coupling between the air ventilation system and the crawl space allows to refresh the air entering the offices. The effect of the PCM racks system is to enhance the crawl space thermal inertia. Then, the air temperature in the foreman office is reduced by a maximum of 1.5°C.

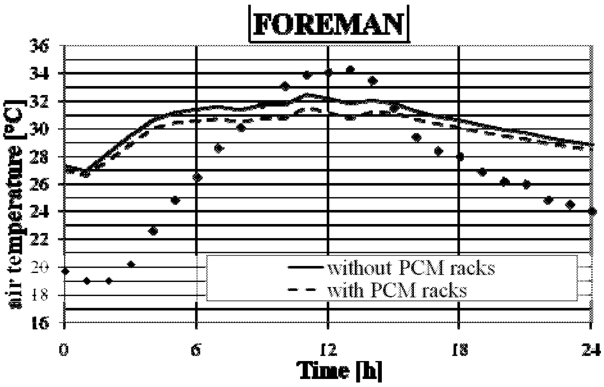


Figure 10: Air temperature evolution in the foreman office – 10th of august

5. CONCLUSIONS

A whole building with air ventilation system has been modeled using the software TRNSYS. An original thermal energy storage system composed of a multi-layer PCM racks has also been modeled. The thermal simulation of the coupling between the storage system and the building is the main purpose of this study.

The PCM racks, installed in the crawl space, allow to enhance the basement thermal inertia. The air ventilation system using the crawl space, the temperature of the air blown in the offices is lower in the case of the building with racks system.

The main conclusion is that the racks allow enhancing the thermal comfort of the workers. The latent heat storage system can store overheating during the day, the night ventilation allowing releasing this energy. For example, during one of the hottest day of august, the PCM racks allow to reduce the air temperature in the foreman office by a maximum of 1.5°C.

The future monitoring of the building will permit to confirm the effectiveness of the ventilation by measuring temperatures inside offices, inside the crawl space and in the racks.

ACKNOWLEDGEMENT

This work has been supported in the framework of the ANR/PREBAT IMCPBAT French project. The Energain® is a trade mark from E.I DuPont de Nemours and Company.

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