Journal of Engineering and Applied Sciences 3 (6): 516-523, 2008
ISSN: 1816-949X

Impact of Using Wallboard with Phase Change Materials on Electric Consumption in Algeria

[1]A. Hamid, [1]N. Ait Messoudène and [2]E. Palomo
[1]Laboratoire Des Applications Energétiques De L'hydrogène,
Département De Mécanique, Université De Blida, Algérie
[2]Laboratoire Trefle , Esplanade Des Arts et Metiers 33405 Talence Cedex, France

Abstract: The electrical distribution networks overload, caused by a massive use of heating and air-conditioning systems in peak hour, has made load shedding the only means of recourse to protect the network from total collapse. This problem can be attenuated by energy storage produced at off peak hour by incorporating some phase change materials in the envelope of the building. To evaluate the impact of such a material used as wallboard on thermal comfort, a numeric model based on the thermal balances of the building is elaborated and solved using an explicit diagram of finite differences. The use of the model, after validation, for the simulation of a building in extreme conditions alloys the confirmation of the possibility of shifting part of the electrical consumption from peak hour to off peak hour.

Key words: Electric consumption, phase change material, wallboard, latent heat storage

INTRODUCTION

According to the reports of the National Society of Electricity and Gas (SONELGAZ), in Algeria the demand of electricity has been growing at a fast yearly rate of 7%, i.e., close to 36 Terawatt-hour in energy and about 6500 mw in power. In peak hour, it happens that the demand exceeds the offer because of the massive use of heating and air-conditioning systems. The electrical over consumption often forces SONELGAZ to resort to load shedding that can last several h in order to preserve the electrical power network from total failure Table 1. A better management of the electricity production and a significant advantage can be achieved if part of the maximum load could be shifted from peak period consumption to off peak period. This is effectively possible by using thermal storage.

There are three kinds of thermal storage methods: sensitive heat storage, latent heat storage and storage of reversible heat of chemical reaction. In many cases, the storage by latent heat presents some features that make it the best choice:

- The phase change process is nearly an isothermal process.
- Compared to sensitive heat storage, it generally has bigger heat storage intensity.

Table 1: Production and sales of electricity in Algeria

Année	2001	2002	2003	2004
National production (Gwh)	266625	27648	29523	31250
Production (SONALGAZ) (Gwh)	26256	27403	29192	30885
Electricity sales (Gwh)	21901	22977	24936	25910

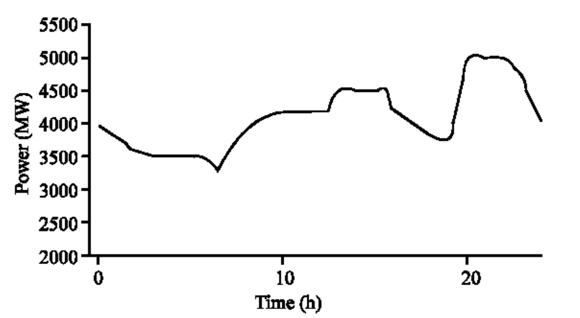

Fig. 1: Daily national electric consumption (SONELGAZ Algeria August 2005)

The building sector is currently considered among the sectors that are the biggest consumer of energy and responsible of the emissions of greenhouse gases. Facing the climatic changes that ensue, it is essential today to become aware of the necessity to rationalize the energy consumption in this sector (Fig. 1). The use of phase change materials in the building envelopes remains the fastest and the cheapest solution that permits the

Corresponding Author: A. Hamid, Laboratoire Des Applications Energétiques De L'hydrogène, Département De Mécanique, Université De Blida, Algérie

decrease in heating and cooling energy consumption while insuring the quality and the comfort of the occupants. The walls, the ceilings and the floors offer large sectors for the passive thermal transfer. Gypsum or plaster wallboard impregnated with phase change materials (PCM) can be installed in the new constructions or in the renovated old buildings.

Several authors have studied solid-liquid phase change materials and the performances that their use as a storage medium offer. Zalba *et al.* (2003) gave a history of the thermal storage using solid-liquid phase change materials focusing more particularly on the different materials used, their latent heats and the different applications.

Khudhair and Farid (2004) presented an overview on the use of PCMs encapsulated in concrete and the gypsum wallboard used in ceilings and floors for energy conservation in buildings.

An experimental and numerical simulation study in a full-scale outdoor test-room has been carried out by Athienitis *et al.* (1997). For the internal lining, they placed gypsum panels with the butyl-stearate (BS) as phase change material. The PCM weight represents about 25% of the weight of the panel. A numerical model has been developed to simulate the thermal behaviour of the room. They showed that the use of PCM gypsum board can reduce the maximum ambient temperature by about 4°C during the day and can reduce the thermal load significantly at night.

Neeper (2000) examined the thermal dynamics of a gypsum wallboard soaked with fatty acids and waxes of paraffin as PCM. The wallboard is submitted to the variation of the daily ambient temperature but is not directly illuminated by the sun. The temperatures of fusion of these PCM are adjusted by adapting the ratio of mixture of the PCM component. He examined 3 parameters of the wallboard with PCM that can influence the amount of energy that can passively be absorbed and released during a daily cycle:

- The temperature of fusion of the PCM.
- The difference between the ambient temperature and the temperature of fusion.
- The wallboard latent heat capacity per unit of area.

The results show that, in most cases, the maximum daily energy storage occurs for a value of the temperature of fusion of the encapsulated phase change material that is close to the ambient temperature of average comfort.

He also optimized the conception of such a type of walls and studied the daily absorbed and released energy by a wall containing PCM that is subject to a daily cycle of ambient temperature of sinusoidal or square shape.

Maha *et al.* (2006a, b) produced and experienced test cells with light wallboards containing PCMs associated to a VIP (vacuum insulation panel). The study of the wall thermal properties and of the behaviour of two test cells isolated by a VIP has been presented. The validity of the concept of MCP and super insulator coupling to produce light envelopes of weak thickness with a good insulation and a significant inertia is proven. The commercial software TRANSYS has been used for the numerical simulation. Darkwa and Callaghan (2006) has analytically and experimentally evaluated two kinds of gypsum PCM mixture compounds: randomly-mixed and laminated. They noticed that the laminated compound presents an 18% improvement in performances over the randomly-mixed compound. Shilei *et al.* (2006) tested a room in the north of China. The room is made of walls containing 18% of PCM composed of an eutectic mixture of capric and lauric acids. They compared the measurements with those of an adjacent room with conventional walls. Scalat *et al.* (1996) carried out tests on the room having walls and partitions with PCM. They compared their results with those obtained on an adjacent identical room with conventional walls. Zhang *et al.* (2006) presented the results of a detailed theoretical investigation and analysis of thermal energy storage and temperature control achieved using passive building construction elements incorporating phase change materials. The predictions detail the effect of using various quantities of different PCM materials with phase change temperatures of 28 and 43°C incorporated into a selection of wall constructions for selected ambient conditions of temperature and insolation. Zhang *et al.* (2006) presented a shape-stabilized change material. It has the following properties: a great apparent specific heat for phase change temperature region, suitable thermal conductivity, keeping shape stabilized in the phase process and any need for containers. The preparation for such a pleasant material was studied and its thermo physical properties were measured. Some applications of such a material in the buildings for energy effectiveness were studied. Some models to analyze the thermal execution of the systems were developed, which were validated with the experiments.

This project enters in the university of Blida mechanical department thermal storage research activities. This research is a contribution to the energy efficiency national programme for the period 2006-2010. Indeed, in the current economical revival context, the demand for energy in Algeria could double between 2000 and 2020 and reach 60-70 million TEP. The specialists have estimated that the cumulated potential of energy saving for this period is 120 million TEP where the building represents the most significant layer for the control of energy.

In this study, we present the diversity of the climate of the different zones that constitute Algeria and give a general idea of its housing park. The second part deals with the modelling and the simulation of a house with phase change material panels. We propose different patterns of heating and air conditioning. This will allow the investigation of the possibilities that the technique of PCM addition offers on the one hand the reduction of the electrical consumption and the displacement of the electrical consumption peak and on the other hand, the possibility of avoiding thus to resort to the load shedding during the peak periods of winter and summer

CLIMATE IN ALGERIA

Considering the diversity of the climatic zones of Algeria, a subdivision of the territory in a certain number of zones more or less homogeneous is necessary. In general, there are 4 zones.

In the Tell, i.e. the coastal zone, the climate is moderate, with pleasant temperatures particularly during the winter, snow being very rare. During the summer, the temperature is, in general, only exceptionally very high, remaining in the average of 31-32°C during the day. But on the whole coast, humidity that can prove to be bothersome.

The High Plateaux climate is a lot rougher. It is cold in the winter and a large quantity of snow may sometimes fall. On the other hand, it is very hot in the summer, with day temperature much higher than that of the Tell zone, but nights are in general much cooler. Besides, it is dry which makes heat more bearable.

In the Atlas Mountain, the climate is typical of the mountain climates. In the winter, the mountain summits are covered with a thick layer of snow, though there are no glaciers or eternal snow there. In summer, the temperature is always very pleasant with very cool nights.

Finally, in the Sahara, extreme temperatures are found. During the winter, the nights are cold and there is frequently frost, with temperatures falling easily to -6-8°C, whereas at high noon, the temperature goes up to around +25°C. The gap between the minimum temperature overnight and the maximum temperature of the day reaches and sometimes goes over 30°C. In summer, these gaps remain important with concrete examples of day temperatures of +54°C in the shade and night temperature of +30°C in the same place.

A frequently enough phenomenon that contributes to raise the temperature in an excessive way is known as" sirocco". It is a violent wind coming from the South. It is particularly hot, dry and charged of extremely small sand particles that penetrate everywhere.

HOUSING SITUATION IN ALGERIA

Algeria, a developing country, is unfortunately since the 80's under the pressure of a housing strong demand. To solve this problem, huge programs to meet this demand are underway. The program 2005-2009 foresees the realization of 1 million houses. Unfortunately the choices of the type of constructions and of the materials don't take into account the climatic specificities of the different regions of the country. The carelessness of these parameters on one hand generates some annoyances and requires excessive expenses of heating and air-conditioning and on the other hand causes an electrical energy over consumption.

HOUSING: CASE STUDY AND MODELLING

The house proposed for modelling is a reference house of a 60 m^2 area and of a 2.9 m height. It is the type of individual houses that are most widespread in Algeria. The walls are composed of a layer of 2.5 cm sealer cement, 20 cm hollow bricks and wallboards of 8 cm thick.

The wallboard used is made of a mixture of gypsum and granules containing phase change material (paraffin) whose fusion temperature is of 26°C. The gypsum is an ideal support as 40% of its volume is air.

The apparent heat capacity of wallboard gypsum/pcm was deduced by DSC measurements (Fig. 2) (Maha *et al.*, 206b).

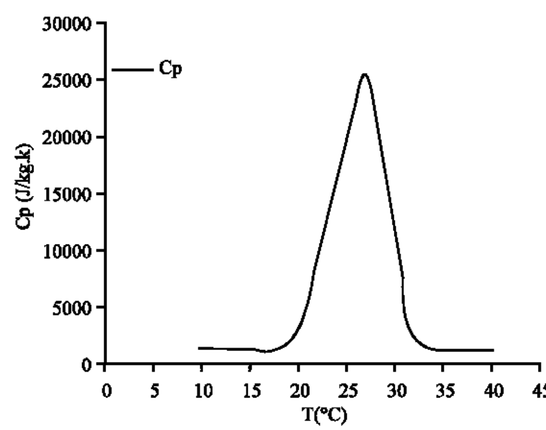

Fig. 2: Specific heat capacity of gypsum/pcm (Maha *et al.*, 2006)

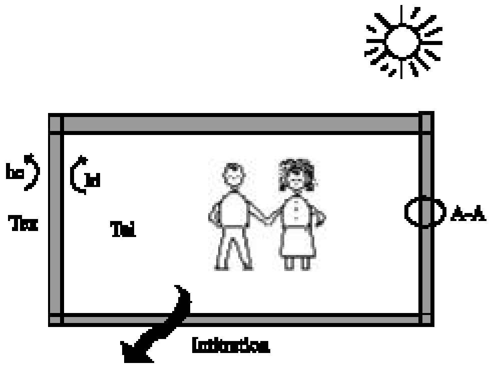

Fig. 3: Different thermal exchanges

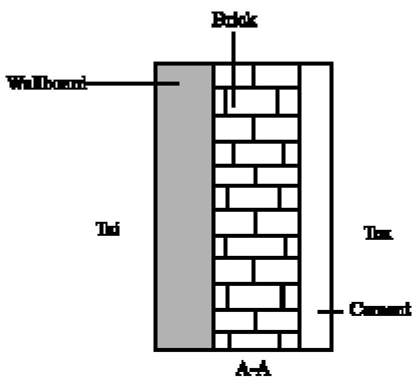

Fig. 4: Wall components

In order to simplify the house modelling and of its thermal behaviour, the following assumptions are made:

- The phase change material and the matrix of plaster are supposed to compose only one body with homogeneous thermo physical properties.
- The transfer of heat through the walls is supposed unidirectional; these are subdivided into three layers at uniform temperatures (1 corresponding to the sealer cement, 2 to the wallboard and 3 to the external brick wall).
- The air temperature of air inside the house is uniform (mono zone).

The thermal balances at the 3 knot level considered in the walls and the interior air can be expressed as follow (Fig. 3-5):

$$\rho_C.e_1.C_{P,C}.\frac{\partial T_C}{\partial t} = \frac{\lambda_C}{e_1}(T_B - T_C) + h_e(T_{ex} - T_C) + Qs_{ex} \quad (1)$$

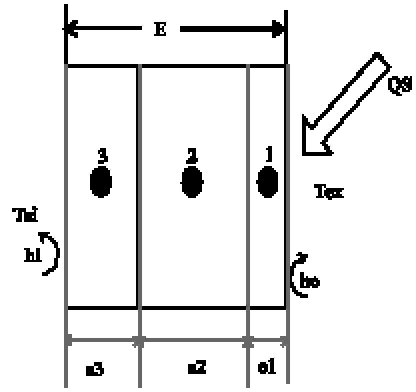

Fig. 5: Different nodes

$$\rho_B.e_2.Cp_B\frac{\partial T_B}{\partial t} = \lambda\frac{\partial^2 T_B}{\partial x^2} \quad (2)$$

$$\rho_W.e_2.Cp_W.\frac{\partial T_W}{\partial t} = \frac{\lambda_W}{e_2}(T_B - T_W) + h_i(T_{ai} - T_W) \quad (3)$$

$$\rho_{ai}.V.Cp_{ai}\frac{\partial T_{ai}}{\partial t} = h_i.A_C(T_W - T_{ai}) + 0.34\, h_{inf}(T_{ex} - T_{ai}) + Q_{APP} + Qs_i \quad (4)$$

With h_{inf} given by the following expression.

$$h_{inf} = 2.V.n_{50}.e_i.\varepsilon_i \quad (5)$$

And where n_{50} is le the hourly rate of air renewal (h^{-1}), e_i wind exposition class and ε_i is a coefficient that takes count of the local height.

RESULTS AND INTERPRETATIONS

The thermal properties of the component of the wall of masonry employed as given entries in simulations are presented in Table 2.

The numerical solution of the system of equations is carried out using the finite differences method with an explicit scheme for the time step.

The model was validated using Darkawa and O' Callaghan (2006). The comparison of our results showed a good agreement.

Thermal simulation: To see the impact of wallboard with materials phase shift has on thermal comfort, we simulated the house under external conditions similar to some areas of the country (Saharian areas and the high lands) for the winter and summer periods.

Table 2: Characteristics thermo physical of the components of the building

	ρ (kg/m^3)	CP (kJ/kg°K)	5th (W/m°K)
Gypsum	900	900	0.34
Gypsum + PCM	900		0.306
Brick	2400	1000	0.79
Cement	977	837	1.75
Air	1.2	1000	0.024

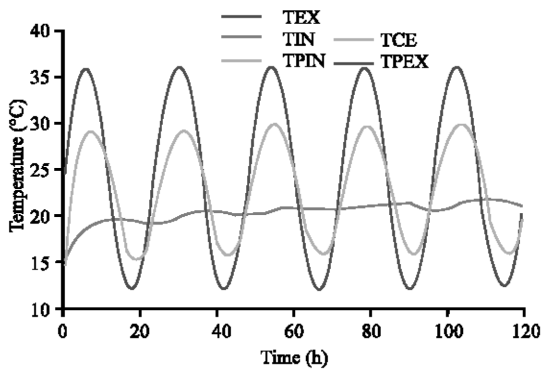

Fig. 6: Temperature profiles of the building with wallboard gypsum PCM during 5 days

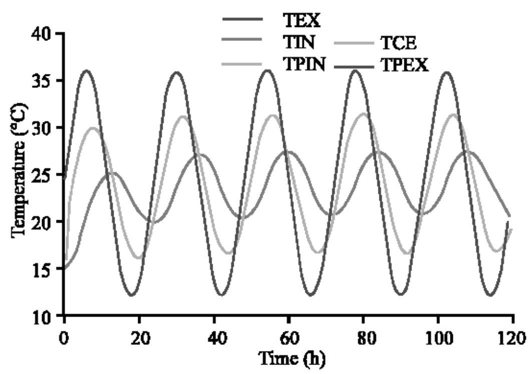

Fig. 7: Temperature profiles of the building With wallboard gypsum during 5 days

Simulation for several days: It was supposed that the outside temperature changes with a uniform sinusoidal model with a temperature maxim ale of 36°C and a minimal temperature of 12°C.

The results obtained for 5 days of simulation are presented on Fig. 6 and 7. We observe that the presence of the granules of PCM in the wallboard allows the attenuation of the amplitude of the oscillation of the interior temperature and that it remains almost constant (20°C). On the other hand, the use of the gypsum wallboard only of the same thickness shows a weak reduction in the amplitudes of the oscillations of the interior air temperature. The phase lag between the peaks of the outside temperatures and the inside temperatures is of 2 h with the maximum value of the indoor temperature is of 25°C.

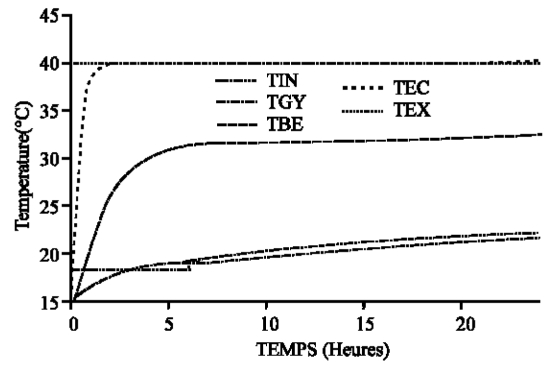

Fig. 8: Variation of indoor, outdoor and different nodes of the wall with wallboard gypsum/PCM

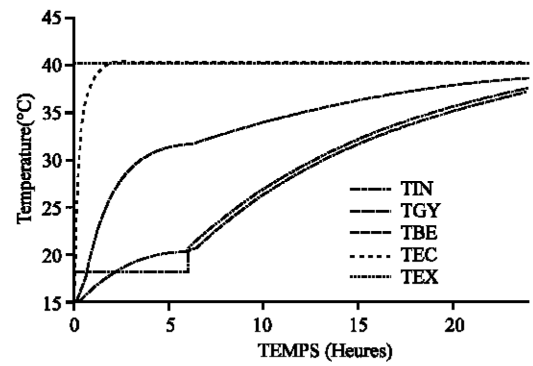

Fig. 9: Variation of indoor, outdoor and different nodes of the wall with wallboard gypsum

Case of air-conditioning: The conditions of simulations are:

- Outside temperature is 40°C during all the period of simulation (24 h).
- The number of people included in simulation is 6 (national average).
- The air-conditioning system operates 6 h during the off-peak h and stops for the remaining time of simulation.
- The solar contributions in the house are neglected.

Simulation is made for 3 types of houses:

- House with Wallboard Gypsum/PCM.
- House with wallboard Gypsum.
- House with a 2 cm thickness of plaster in the place of the wallboard.

On Fig. 8-10, we represent the changes of the temperatures of the various nodes during 24 h of simulation. We note that after the stop of the air-

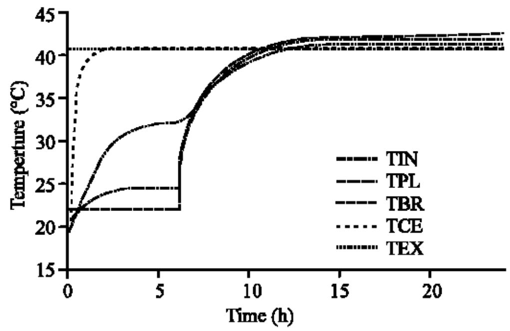

Fig. 10: Variation of indoor, outdoor and different nodes of the wall without wallboard

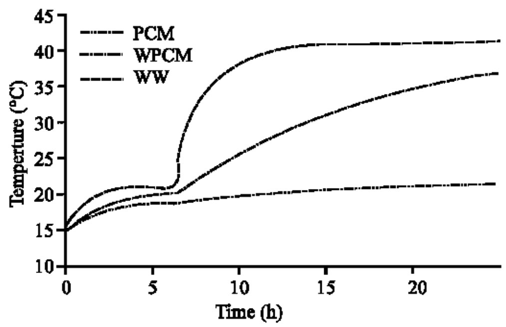

Fig. 11: Comparison of indoor surface temperatures the wall for three cases

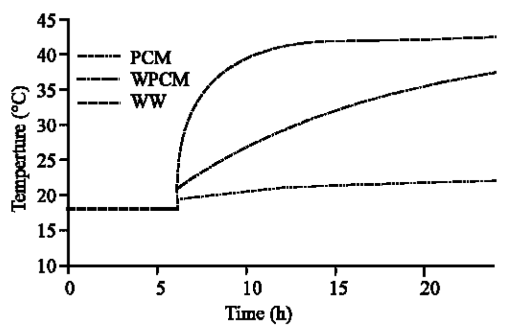

Fig. 12: Comparison of indoor temperatures for three cases

conditioning system, the temperatures of the house without wallboard increase quickly after only a few hours and exceed the outside temperature. This fast increase is due to its thermal inertia, bad heat insulation of the house and the contribution of the humans.

For the house with gypsum wallboard, we notice that the temperatures increase less quickly than in the first case. The presence of the wallboard with gypsum improved the heat insulation appreciably.

For the house with wallboard with gypsum/PCM, we note that, the temperatures of the internal wall and the interior air increase slowly throughout all simulation.

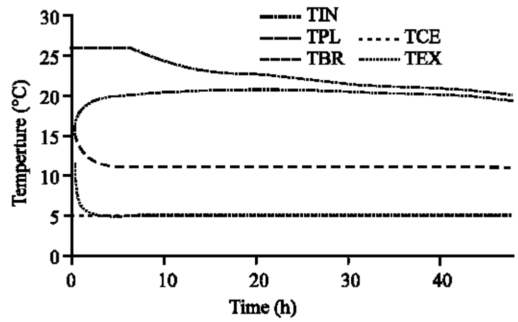

Fig. 13: Variation of indoor, outdoor and different nodes of the wall with wallboard gypsum/PCM

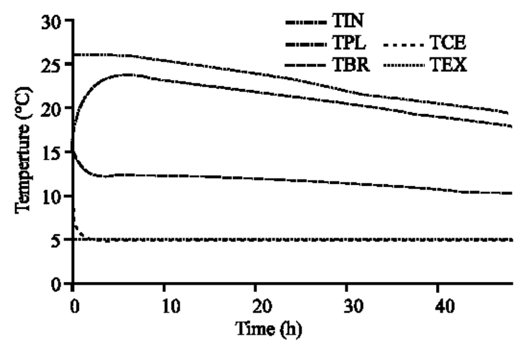

Fig. 14: Variation of indoor, outdoor and different nodes of the wall with wallboard gypsum

The comparison of the temperatures of the internal walls and interior air of Fig. 11 and 12, show that the presence of the PCM increases thermal inertia considerably and improves the heat insulation of the house and the temperature of the interior air remains in the zone of comfort with approximately 23°C.

Cases of heating: In the case of heating, we consider that the outside temperature remains constant within 5°C and that the heating system functions during 6 h before being turned off. The temperature

During the heating is regarded as constant and equals with 26°C. For this case, the humans contributions are neglected. The period of simulation is 48 h.

On Fig. 13-15, we presente the changes of the temperatures for each node for the three cases of wall. After two days of simulations we notice that the temperatures of cement, brick are almost identical for the three walls, on the other hand for the temperature of the wallboard and the interior air temperature. One notes that after the end of heating, the temperature of the air for the wall with pcm decrease according to a parabolic profile. The two others follow a linear decrease (Fig. 16). The

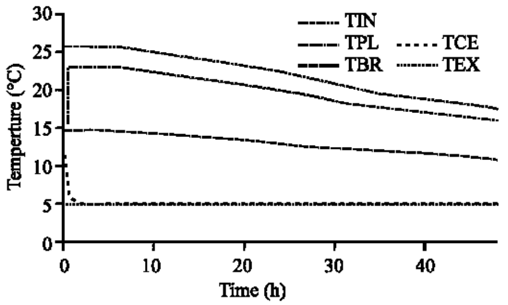

Fig. 15: Variation of indoor, outdoor and different nodes of the wall without wallboard

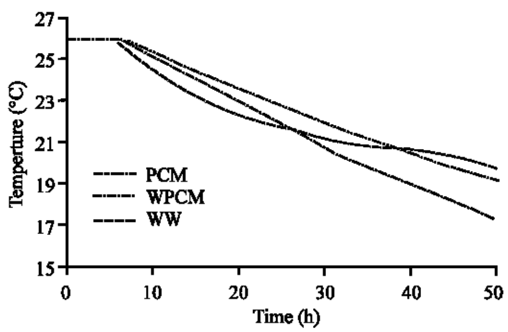

Fig. 16: Comparison of indoor temperatures for three cases

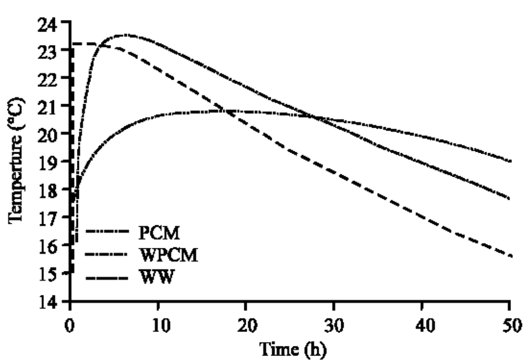

Fig. 17: Comparison of indoor surface temperatures for three cases

comparison of the internal temperatures of walls (Fig. 17) shows that for the wall with pcm, temperature increases slightly and than remains constant for more than 20 h. On the other hand, for the walls with pcm one notices that wall temperature approach that of heating then decreases with a high slope after the end of heating.

CONCLUSION

A mathematical model based on the heat balances was developed to simulate the thermal behaviour of a house and to determine the impact that the inclusion of phase change materials has on the envelope of the building. A series of thermal simulations and comparative analyses of the house under conditions close to several areas of the country showed the advantages of employing the heat latent, low temperature for the passive design of buildings.

A building provided with 8 cm thickness wallboard gypsum/ PCM makes it possible to store the electricity in the form of heat or cold during the off-peak h in the envelope of the building and to maintain the temperature interior under satisfactory conditions of thermal comfort for 18 h.

Nomenclature:

Ac	:	Heat-transferring surface [m^2].
CP	:	Specific heat [kJ/kg°K].
e	:	Thickness of the component of the wall [m].
h	:	Convection coefficient [W/m^2.°K].
h inf	:	Infitration flow rate [m^3/h].
QS	:	Solar radiation [W/m^2].
Q APP	:	Internal contributions [W].
T	:	Temperature [°C].
t	:	Time [s].
V	:	Volume [m^3].
Greek letters		
ρ	:	Density [kg/ m^3].
λ	:	Thermal conductivity [W/m.°K].
Suffix		
ai	:	Interior air.
B	:	Brick.
C	:	Cement.
ex	:	External.
i	:	Internal.
W	:	Wallboard.

REFERENCES

Athienitis, A.K., C. Liu, D. Hawes and D. Feldman,1997. Investigation of thermal performance of passive solar test room with latent heat storage. Building and Environ., 32 (5): 405-410.

Darkwa, K. and P.W. O'Callaghan, 2006. Simulation of phase change drywalls in a passive solar building. Applied Thermal Eng., 26: 853-858.

Khudhair, A.M. and M.M. Farid, 2004. A review on energy conservation in building applications with thermal storage by latent heat using phase change materials. Energy Conv. Manage., 45: 263-275.

Maha, A., A. Bontemps, H. Sallée and D. Quenard, 2006a. Thermal testing and numerical simulation of prototype cell using light wallboard coupling vacuum isolation panels and phase change material. Energy and Bluiding, 38: 673-681.

Maha, A., A. Bontemps, H. Sallée and D. Quenard, 2006b. Experimental investigation and computer simulation of thermal behaviour of wallboards containing a phase change material. Energy and Buildings, 38: 357-366.

Neeper, D.A., 2000. Thermal dynamics of wallboard with latent heat storage. Solar Energy, 68: 393-403.

Shilei, L., Z. Neng and F. Guohui, 2006. Impact of phase change wall room on indoor thermal environment in winter. Energy and Building, 38: 18-24.

Scalat, S., D. Banu, D. Hawes, J. Parish, F. Haghighata and D. Feldman, 1996. Full scale thermal testing of latent heat storage in wallboard. Solar Energy Materials and Solar Cells, 44: 49-61.

Zalba, B., J.M. Marin, L.F. Cabeza and H. Melhing, 2003. Review on thermal energy storage with phase change materials, heat transfer analysis and applications. Applied Thermal Eng., 23: 251-283.

Zhang, Y.P., K.P. Lin, R. Yang, H.F. Di and Y. Jiang. 2006. Preparation, thermal performance and application of shape-stabilized PCM in energy efficient buildings. Energy and Buildings, 38: 1262-1269.