RC Networks Approach for Hybrid Envelops in Positive Energy Building

X. Faure[1], F. Joussellin[2], P. Pierson[3], D. Quenard[1]

[1] Centre Scientifique et Technique du Bâtiment (CSTB), Saint Martin d'Hères, FRANCE
[2] Laboratoire des Ecoulements Géophysiques et Industries (LEGI), Université Joseph Fourier, Grenoble, FRANCE
[3] Laboratoire d'étude des Transferts en Hydrologie et Environnement (LTHE), Université Joseph Fourier, Grenoble, FRANCE

ABSTRACT

This work lies within the concept of positive energy buildings. The aim is to develop an active management of local free energy (solar, air and earth) inside the envelops by convection heat transfer and by the use of phase change materials (PCMs) in order to store or release heat when needed. A 1D RC network simulation tool has been developed for different standard fronts including a solar air collector and a double skin façade (south frontage), leading to the thermal simulation of a room with different configurations, with or without PCMs integration and for ventilated envelops. The first results for summer conditions are very encouraging. The management of the air flow inside envelops helps the indoor temperature to be maintained at a reasonable level. An experimental cell is being held at CSTB outdoor site, it will allow us to calibrate the model.

KEYWORDS

Network simulation, convection, building envelop, PCMs.

NOMENCLATURE

C_p	Specific heat, $J.kg^{-1}.K^{-1}$	h	Convective heat transfer coefficient, $W.m^{-2}.K^{-1}$
x	Elementary length, m	T	Temperature, K
L	Cavity thickness, m		
l	Frontage width, m	*Greek Symbols*	
H	Frontage high, m	ρ	density, $kg.m^{-3}$
k	Thermal conductivity, $W.m^{-1}.K^{-1}$	γ	Air temperature stratification parameter in cavities (-)
q_m	Mass flow, kg/s		

INTRODUCTION

Many studies have focused on the building envelop to reduce loses in winter while making the ambience comfortable in summer. Al-Homoud, 2005, among others, has established an overview of what to be considered regarding envelops insulation. Houses like Minergie in Switzerland or PassivHaus in Germany have reached such level of insulation that traditional heating systems are oversized for the energy demand [Hastings, 2004]. One of the ways to develop more efficient buildings consists in developing adaptive envelops, which can collect, store or release heat, depending on the circumstances. Therefore, envelops get hybrid, used for protection, insulation, solar heat collection and storage, heat transfer from one front to another one. Studies on Trombe walls [Zalewski, 1996], Barra-Constantini systems [Imessad, 2002], hollow walls [Bansal, 1999], solar chimney [Bansal, 1993] and double skin facades [Saelens, 2002] show a significant gain in term of energy consumption, for both winter and summer conditions and for many climate. Entirely closed loop

systems have also been studied for building envelops [Hastings,2000], but generally based on natural convection only. Moreover a lack of experimental data has been identified in literature till now. Integration of Phase Change Materials (PCMs) in building for its variable thermal mass gives quite interesting results in term of damping temperatures peaks.
Integration of PCMs in the building envelops using natural convection thermal exchanges with its environment, has already been studied [Ahmad, 2006; Athienitis, 1997]. Coupling PCMs with forced convection to enhance thermal exchange and therefore the use of latent heat has also been the scope of studies from the HVAC system point of view [Halawa, 2005]. Kuroki, 2002, has shown that depending on the position of PCMs coupled or not to the HVAC system in an apartment, the effect was either peak-cut effect or more seasonal storage. The idea of the present work is a coupling of forced convection and latent heat integrated in the envelop to enhance the thermal comfort. Peak-cut effects or longer storage are used by either being in closed or open loop configuration.

The work presented here concerns the numerical part. A room (20m² with 2.5m ceiling high) with ventilated envelops (5cm cavity width) has been modeled with an RC network approach in TRNSys software (see figure 1). After a short description of the model (global and PCM's modeling), different configurations are presented for summer conditions and for a mid-France Climate (lat. 45.2°N).

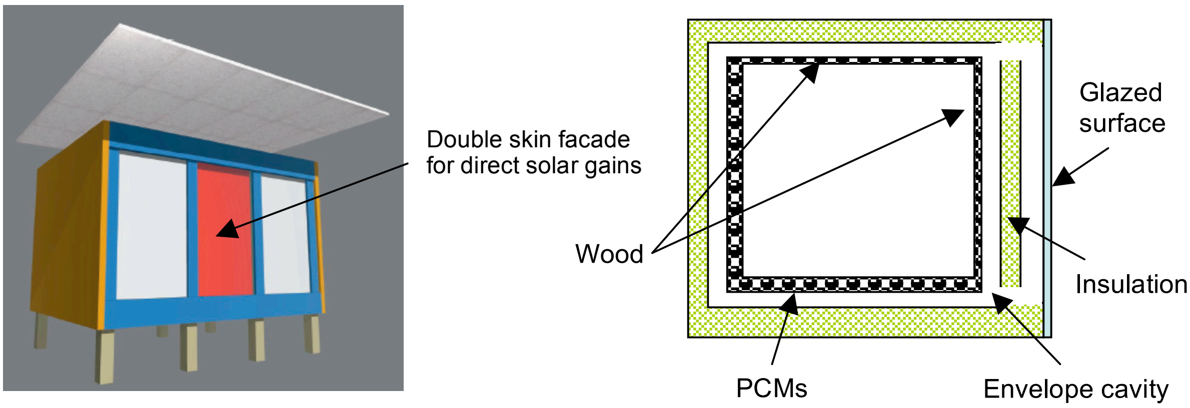

Figure 1: Perspective drawing of the modelled cell (on the left) and transverse section of the modelled cell (on the right)

An experimental cell (with the same dimensions as the modeled one) is being held in CSTB outdoor site and measurements will begin in September 2006.

MODELING DESCRIPTION

1D models (supposing homogeneous surface temperatures) have shown their accuracy for global thermal studies (room temperatures fluctuations). The study of local phenomenon in fluid dynamics and thermal exchanges should need CFD (Computational Fluid Dynamics) approach and therefore high computational capacities for such geometry (46m^3). The aim, here, is to study the entire system in order to get the evolution of internal temperature (global approach).

Heat Transfer Modeling

Eqn.1 describes the energy balance in the cavity of the ventilated envelop (figure 2), with the hypothesis of an established flow without transversal temperature gradient.

$$\rho_f C_{pf} L \frac{\partial T_f}{\partial t} + \frac{\dot{q}_m(t) C_{pf}}{\gamma l} \frac{\partial T_f}{\partial y} = h_{c1}(T_{p1} - T_f) + h_{c2}(T_{p2} - T_f) \qquad (1)$$

Considering unidirectional conduction mode in the solid part, the energy balance for plain layers can be expressed by Eqn.2:

$$\rho_i C_{pi} x_i \frac{\partial T_i}{\partial t} = k_i \frac{\partial T_i}{\partial x_i} \qquad (2)$$

The convection heat transfer coefficients h_{c1} and h_{c2} are calculated from correlation given in the literature for forced convection [Zalewski, 1996]. The mass flow q_m is imposed depending on outdoor/indoor conditions and on inlet temperature (second gradient in Eqn1).
Four nodes are defined in plain layers and one central node for cavities. The room is described by one central node which depends on convection/conduction exchanges with wall surfaces.
The shape factors, necessary to estimate radiation exchanges between inner surfaces, are defined in proportion to the layer surface and with an additional term to respect the complementarities and the reciprocities principles.

Direct solar gains through the double skin façade (in the center of the south frontage, figure 1) are calculated for each inner surface, as function of the sun position and are introduced as surface heat sources in the model.

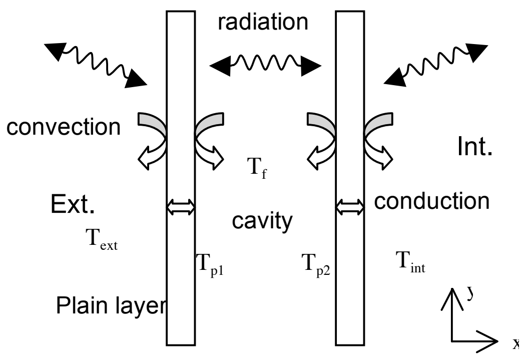

Figure 2 : Schematic ventilated envelop

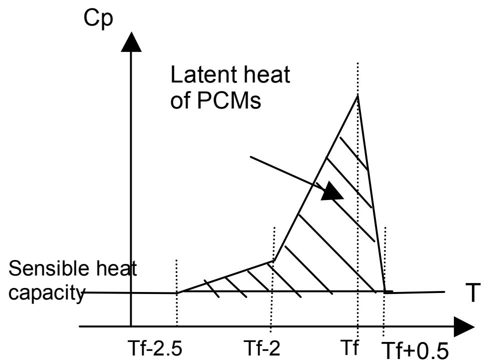

Figure 3: Specific heat evolution with temperature for PCMs

Global approach to study ventilated envelops has been extensively used. One can find similar modeling approach in [Bansal, 1993, Imessad, 2002, Zalewski, 1996, Saelens, 2002] among others. The choice of adapted correlations for convective heat transfer coefficients, considering geometry, flow regime and environment is difficult. Khalifa, 2001, following a overview and a comparison of many correlations for convective heat transfer, found differences up to a factor 2 for vertical surfaces and up to a factor 4 for horizontal ones.

PCMs Modeling

Modeling PCMs behavior requires variable thermal characteristics. Most of the models in the literature use constant density and thermal conductivity in both phases (liquid and solid) and consider the latent heat through a specific heat change [Ahmad, 2006] or as a heat source [Athienitis, 1997]. These kinds of modeling have shown their accuracy for global approach. Figure 3 shows the specific heat change used in this work, it correspond to the one used by Kondo, 2000.

Cases Studied

Simulations have been done for the system described above (fig.1). The external layer is insulated with Vacuum Insulation Panel (VIP) and the internal one is a panel of Oriented Stream Board (OSB) with or without PCMs. Table 1 presents the thermal characteristics of the materials used. No shading systems are used.

TABLE1
Characteristics of the materials used in the simulation

	Density ($kg.m^{-3}$)		Specific heat ($J.kg^{-1}.K^{-1}$)	Thermal conductivity ($W.m^{-1}.K^{-1}$)		Latent Heat ($kJ.kg^{-1}.K^{-1}$)	Thickness (m)
	Sol.	Liq.		Sol.	Liq.		
25°C-PCM	789	763	2600	0.193	0.15	200	0.025
VIP	110		900	0.01		/	0.02
OSB	650		1700	0.13		/	0.01

In order to identify the influence of latent heat, all the considered configurations are defined with the same sensible heat (thermal mass). 30% of the floor and of the north internal layer surfaces are made of PCMs. The melting point is first fixed at a very high level ensuring that the thermal mass is only due to the sensible heat of the solid phase and then fixed at the real value (25°C) to integrate latent heat phenomena.

Open/Closed loop influence

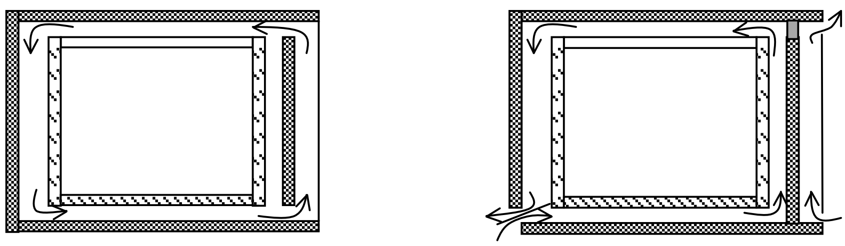

Figure 4: Closed loop (on the left) and open loop (on the right) systems of ventilated envelop.

The open/closed loop system is defined with a buffer zone from 20 to 24°C. It means that if the system is in an open loop configuration, it will switch to the closed one if the internal temperature goes below 20°C., if it is in a closed loop configuration, the target temperature is above 24°C. Fluid speed is fixed at 0.5m/s for closed loop scenario. For the open one, the fluid speed is fixed at 1m/s and 2m/s the interior system and the solar collector respectively (cf.Fig.4).

Figure 5 presents, for two periods, the variations of the external (T_{ext}) and internal temperatures for two configurations: with (T_{int1}) and without (T_{int2}) ventilated envelop (where the thermal mass is only due to sensible heat).

For the same direct gains, the open/closed loop configuration offers the possibility of damping temperature variations and therefore to have internal temperatures below the non-ventilated envelop ones up to 5°C. Inflection points can be seen on the curve when temperature goes below 20°C or above 24°C, corresponding to the two temperatures switching mode.

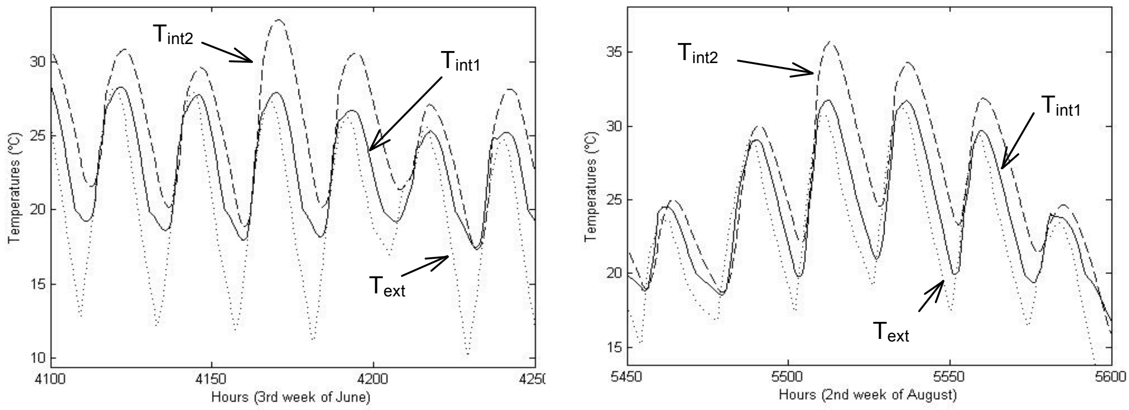

Figure 5: External temperature (T_{ext}) and internal temperatures fluctuations for two configurations (T_{int1} and T_{int2}) for a week in June (right graph) and a week in August (left graph).

Latent heat influence

Considering the same geometry, climate and characteristics of materials, figure 6 presents the influence of latent heat on the curves presented in figure 5.

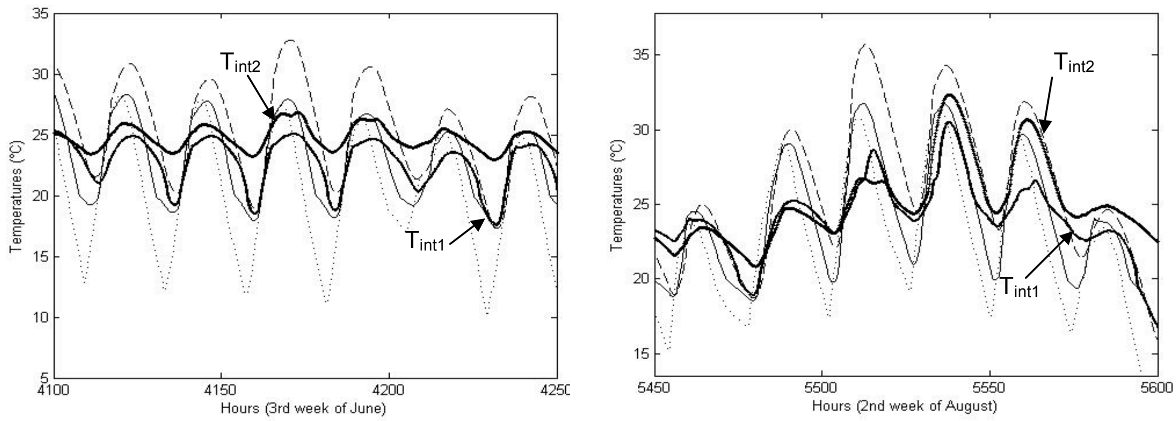

Figure 6: Same curves as presented in figure 5 with over plotted latent heat effect on the two configurations: with (T_{int1}) and without (T_{int2}) ventilated envelops.

Latent heat effect is equivalent to very high thermal mass in the range of fusion. For these particular days, the coupling of convection effect with PCMs gives a more extensive use of latent heat: it helps the PCMs to crystallize during night time and therefore to be more efficient during day time.

Simulations have been done for the 3 months summer period (2500hours, from the end of May to the beginning of September with the Meteonorm climate data files). For the four configurations presented, Table 2 summarises, the number of hours for which the internal temperature goes above 4 target temperatures. It can be seen as the number of hours for which the cooling systems needs to work. One can see the

major difference between the four configurations and the coupled effect of open/closed loop system with PCMs.
Considering the same conditions (geometry, thermal mass, climatic conditions and direct solar gain), the open/closed loop system (config.3) requires more than 40% less energy demand for cooling (above 25.5°C) than the usual one (config.1). Integration of PCMs within the envelop gives high reduction on the energy demand: config.2 and config.4 requires up to 70% and 80% less energy than respectively config.1 and config.3

TABLE 2
Number of hours above 4 target temperatures

	Target Temperatures			
Configuration	**24**	**24.5**	**25**	**25.5**
1 - Non ventilated envelops without PCMs	855	766	656	584
2 - Non ventilated envelops with PCMs	687	421	272	176
3 - Ventilated envelop without PCMs	657	512	406	337
4 - Ventilated envelops with PCMs	457	248	131	68

The coupling between ventilated envelops and PCMs gives very promising results. Reductions in energy demand for cooling goes up to 60% comparing to PCMs passive integration reference (config.2). The config.4 will be realized in the test cell being held.

CONCLUSION

An RC network simulation tool has been developed to study the coupling of forced convection in an open/closed loop configuration around the building and PCMs.
The first results are very encouraging. The coupling of forced convection and PCMs in the building envelop gives effective use of latent heat. In the future, management strategies will be studied in detail in order to improve the coupling.
An experimental cell is being held in CSTB near Grenoble. Accurate measurements will able us to calibrate the model.

REFERENCES

Ahmad M. (2006), Thermal testing and numerical simulation of a prototype cell using light wallboards coupling vacuum isolation panels and phase change material. *Energy and Buildings, 38,* 2006, 673-681

Al-Homoud M.S. (2005), Performance characteristics and practical applications of common building thermal insulation materials. *Building & Environment*, 40, 351-364.

Athienitis A.K. (1997), Investigation of the thermal performance of a passive solar test-room with wall latent heat storage. *Building and Environment*, Vol 32, p405-410.

Bansal N.K. Shail (1999), Characteristic parameters of a hypocaust construction, *Building & Environment*, 34, 305-318

Bansal N.K. *(*1993), Solar Chimney for Enhanced Stack Ventilation, *Building & Environment*, 28 (1993), 373-377

Halawa E., F.Bruno, W.Saman, (2005), Numerical analysis of a PCM thermal storage system with varying wall temperature, *Energy Conversion & Management*, vol46 , 2592-2604

Hastings R. and Morck O. (2000), Solar Air Systems - A Design Handbook Edited by James and James, December 2000.

Hastings S.R. (2004), Breaking the « heating barrier » Learning from the first houses without conventional heating. *Energy & Buildings*, 36, 373-380.

Imessad K. (2004), Performances of the Barra-Constantini passive heating system under Algerian climate conditions, *Renewable Energy*, vol29, p357-367

Khalifa A.J.N. (2001), Natural convective heat transfer coefficient – a review I. isolated vertical and horizontal surfaces, *Energy Conversion & Management*, 42, 491-504

Kondo T. (2000), Research on thermal storage of PCM wallboard, *Workshop for International Energy Agency*, Annex 10, Japan, 2000.

Kuroki T., M.Higuchi, M.Nakamuri, (2002), Application of phase change material to passive cooling of apartment house, IEA*, ECES IA Annex 17, 3rd workshop*,, Tokyo, Japan

Saelens D. (2002), Energy performance assessment of single storey multiple skin façades. PhD, Katholieke Univ. Leuven.

Zalewski L. (1996), Etude thermique expérimentale et simulation numérique d'un mur solaire composite, optimisation des performances énergétiques, Thèse de doctorat, Université d'Artois.