AN INVESTIGATION INTO THE EFFECT OF VENTILATED DOUBLE-SKIN FACADE WITH VENETIAN BLINDS: GLOBAL SIMULATION AND ASSESSMENT OF ENERGY PERFORMANCE

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ABSTRACT

Double-skin facade (DSF) is an additional glass skin on the outside wall of the building. In this study a mechanically ventilated and equipped with solar protections (venetian blinds) facade was studied. The airflow inside the facade as well as opening/closing degree of the blinds was controlled in order to increase annual energy performance for both heating and cooling. Numerical simulations for climatic data of Lyon (France) showed good performance of studied DSF compared to a traditional façade.

KEYWORDS

Building simulation, double-skin facade, energy performance, global model.

INTRODUCTION

In the current socio-economic context, the components of a sustainable energy strategy are: control of the energy consumption, diversification of the energy resources and use of clean and effective technologies. New concepts of equipment and solutions must be studied in order to be integrated in the buildings.

The French building sector is a key actor to solve environmental national challenges. The sector is responsible for approximately 25% of the national CO_2 emissions and 43% of the French energy bill. It offers sufficiently strong possibilities of progress to meet the greenhouse gas reduction challenge.

DOUBLE-SKIN FACADE

The building envelope corresponds to the concept of protection, of cover. It is the interface between a space which must satisfy the needs for comfort and protection of its occupants and the outdoor environment. Compared to the past evolutions, the priorities are changing. Improvements find new ways, like for instance insulation and comfort.

In addition, new technologies appear in the building components design, being able to answer several functions but asking for different management techniques.

To optimize the summer comfort and energy saving, the topics related to solar protection are getting more and more important. Indeed it is necessary to use the maximum of the sun in winter (avoiding the glare) and to minimize transmitted radiation during the hot season in order to avoid the space overheating. The double-skin facades (DSF) could allow both characteristics.

In addition to the envelope itself (facade), DSF have a second glazed layer (with a non-structural role) placed at a certain distance from the inner layer (Figure 1). The distance between both layers goes from a few centimeters to over one meter. The zone positioned between these two layers is named buffer zone or “channel” and generally is ventilated. This ventilation can be mechanical, natural or mixed. It must reduce overheating during hot periods and must contribute to energy savings.

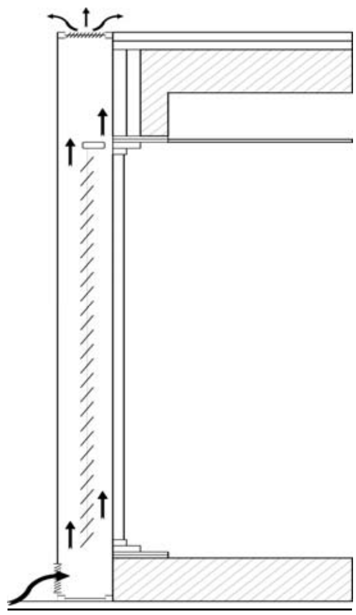

Figure 1 General outline of a double-skin facade

Particularly during the cold time of year, the ventilation of DSF can be connected to the building ventilation system. The external fresh air ensuring the ventilation of the interior spaces can be preheated inside the channel of the DSF before being introduced inside.

There are many classifications of the double-skin facades. The majority of these classifications are based primarily on the geometrical characteristics of these facades.

A general classification of the DSF (Loncour and Deneyer 2004) takes into account for example the operating modes and introduces three independent criteria like the ventilation type, the partitioning of the facade and the cavity ventilation mode.

The principal distinction between a DSF and a multiple glazing unit, integrating or not a solar protection in the cavity, lies in the possibility of controlled ventilation of the DSF.

In a traditional building the effective control of the solar gains via the usual outdoor blinds is in general difficult because of the interaction between the weather and the equipments. The additional external glazing, protecting these blinds from bad weather, thus creating a double-skin facade, makes it possible to solve this difficulty. This double layer envelope also allows to open the internal window and to carry out natural ventilation of the space.

DOUBLE-SKIN FACADE MODELLING

DSF global model

It is necessary to mention that the architectural trend of increasing facades glazed surfaces generates technical difficulties, such as the decrease of the visual comfort (glare), the increase of building cooling demand, etc.

A DSF solution must therefore respect many constraints. Numerical simulations of building energy behavior can help in a correct design and operation of the building. In this work numerical predictions of energy behavior of a DSF on an office building were of interest. The well known building simulation code Trnsys was used here along with a nodal DSF model developed by Safer in (Safer et al. 2006).

Compared to other models in the literature, Safer's model presents the particularity of modelling the heat transfer through a DSF equipped with venetian blinds. Various DSF models are presents in the literature. Saelens et al. (2003) takes into account a naturally and mechanically ventilated multiple skin facade with roller blind in numerous configurations (DSF, airflow window, supply window). Stec and Paassen (2005) study a DSF with venetian blinds instead. Both models use the nodal approach and integrate the models in a simulation environment. Saelens implements the simulation model in the Trnsys environment, while Stec simulation model of the building with the additional components such as double skin facade, HVAC system and control strategies was implemented in Matlab/Simulink.

Our model is represented by a DSF equipped with venetian blinds and external mechanical ventilation. The model is a two-dimensional representation, based on dividing the height of DSF into a number of vertical bands. Each vertical band is divided into 6 nodes characterized by their temperature (Fig. 3).

The energy balance is written in every node of each vertical band. Long and short wave radiation, convection and conduction heat exchanges and the heat flow due to the mass transfer in the channel of the facade are represented. It should be mentioned that the model was established based on the knowledge gained from CFD simulations and PIV measurements, presented in (Safer et al. 2005a, 2005b). Elements such as solar protection angle, ventilation flow inside the channel, sun position, geometry and the outdoor conditions are included.

Integration of the DSF model

The connection of the DSF model to Trnsys building simulation environment (popular type 56) is made according to three actions (Figure 2).

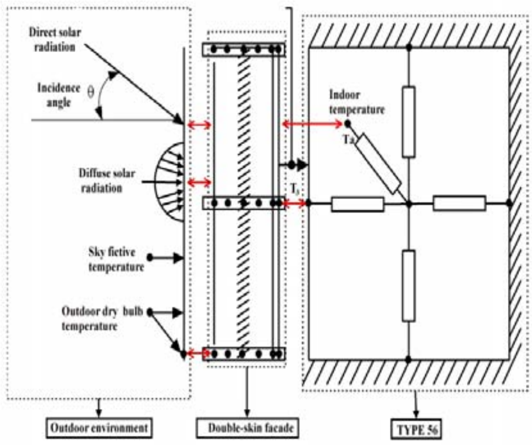

Figure 2 DSF model connections with the Trnsys environment

For each time step: (i) the average temperature of DSF inner glazing is regarded as being the average temperature of building wall equipped with a double-skin facade; (ii) the solar radiation transmitted through the DSF is introduced inside the zone; (iii) and the zone temperature is used in the DSF model for calculations of convective heat flow between the facade and the indoor air (Safer et al. 2006).

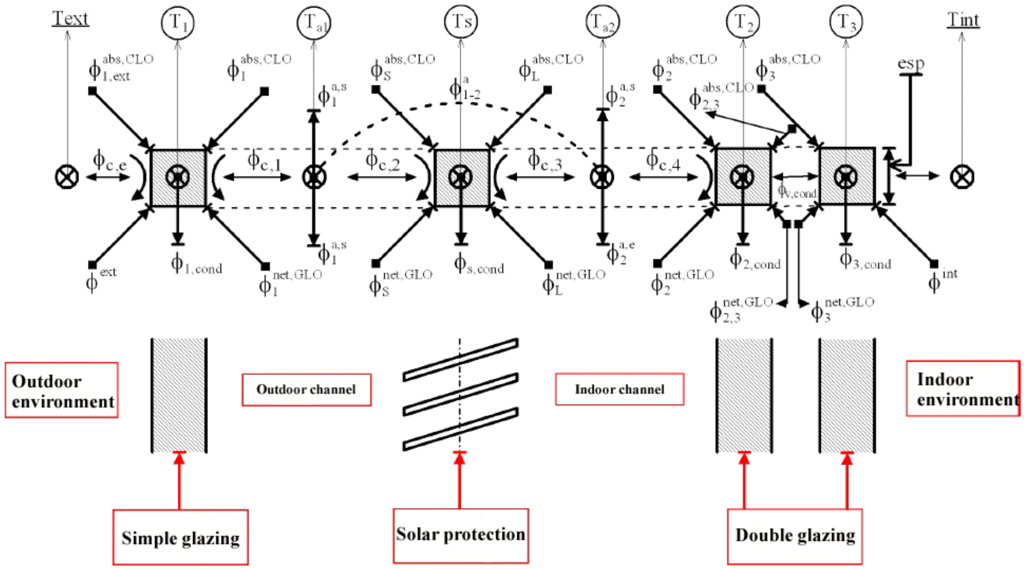

Figure 3 Global outline of the DSF model

Simulated office building

A two-storey small office building of 1000 m² (50 m long by 10 m large structure) was used for this study. The envelope uses high-performance insulation materials (Table 1 and 2), according to the actual French standard. Two types of facades were tested: traditional facade (TF) and double skin façade (DSF). TF has double glazed windows with U=1.4 W/m^{2}K. Each external wall glazing surface is defined by a ratio accordingly to the orientation This ratio is considered only for the TF building, since the DSF takes all the southern wall surface. This ratio is expressed taking into account an optimal link between the thermal and visual comfort and the actual trend in the architectural design (increase of the glazed surfaces). In the light of these facts on the north side face of the building 15% of the wall total surface is considered as glazing, 20% for the west, respectively 30% for south and east orientated wall. On southern and eastern building walls, external controlled solar devices are installed. The control is realized according to the sun radiation received on the envelope and to the indoor temperature. The DSF is a mecanically ventilated active facade with venetian blind inside the channel.

Table 1 Building walls description

LAYER [CM]	EXT. WALL	CEILING	FLOOR
Mineral wool	15	-	-
Concrete	15	30	30
Polyurethane	-	12	-
U [W/m²K]	0.23	0.19	-

Table 2 Walls elements description

LAYER [CM]	λ	ρ	C
	[W/mK]	[kg/m^3]	[J/kgK]
Mineral wool	0.035	55	1030
Concrete	2	2400	1000
Polyurethane	0.024	32	1400

The building is divided into 5 representative zones, two zones of 300 m² for offices use and two conference rooms (80 and 120 m²). A special zone is assigned to the entry space (surface of 200 m²). The building has at the ground floor one zone for offices, a conference room and the entry zone, while what's left of the spaces is at the first floor.

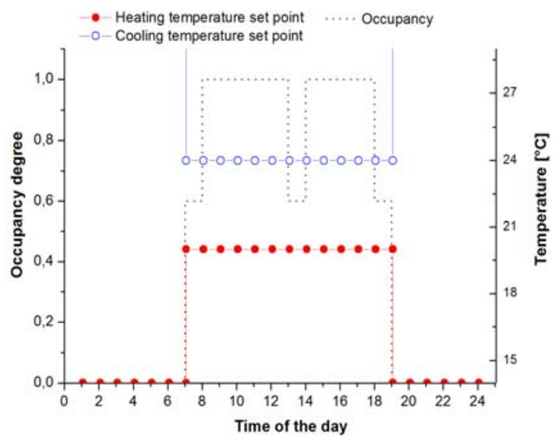

Figure 4 Occupancy levels and temperature settings

The zones are occupied according to a well defined scenario. The occupancy rate is 1 person/12 m² for the offices and 1 person/2 m² for the conference rooms. This rate is distributed during the week time as follows: 60% of the occupation from 7 to 8 hours, from 12 to 14 hours, from 18 to 19 hours, 100% occupation between 8 and 12 hours and 14 and 18 hours during the workdays and 0% in the other situations.

The lighting gain ratio is 10W/m² following the same scenario as occupation except for the entry zone where the lighting operates from 7 to 19 hours. For the offices, the office equipments scenario is given according to the occupation pattern. It is supposed that office equipment is running 100% during occupation (from 8 to 12 hours, 14 to 18 hours) and 50 % between 7 and 8 hours, 12 and 14 hours, 18 and 19 hours). We suppose a unit for every person (120 W for a computer and printer).

The temperature setting for heating is 20°C, during office hours and 14°C during unoccupied time. The space is cooled only during periods of occupation with temperature set at 24°C.

Air infiltration rate of 1.2 m^3/h.m² of vertical walls was used, according to French regulations for office buildings. The building is ventilated with a mechanical exhaust with a rate of 18m^3/h and per person, giving 0.5 vol/h during occupation.

Weather data from Lyon Bron were used in simulations.

Proposal of a control system

As in every controlled environment the occupant must be assisted by a stable, all-year long control system in order to evaluate his choice regarding the indoor status. That's because the occupant is sensitive to his comfort but not able to evaluate the annual energy performance.

According to (Stec and Paassen 2005) the control strategy in a DSF building gives priority to the use of the passive components of the building like windows, blinds, valves in the cavity of the facade. The more these components are used the higher energy savings are.

As a passive glazed double envelope has a much poorer summer behavior than a traditional envelope, a control system for DSF was proposed. Blinds angle from 0 to 90° (totally opened to fully closed) and the airflow that circulates inside the channel (value between 0 and 200 m3/h·m) were controlled. This control was carried out according to the information received from the sensors installed outside and inside (sun radiation on the facade and the indoor air temperature), as shown in Figure 5.

In this study a unique control strategy was used for a two-input/two-output system. The solar beam radiation (Ens) on the facade and the indoor air temperature (T_{int}) were considered as control parameters (inputs) as shown in Figure 6. The angle of solar protections and the airflow inside the channel were used as controlled variables.

Following (Saelens et al. 2003), the lower and the upper limit for solar beam radiation were initialized to 108 kJ/m² and 360 kJ/m² respectively. For the air temperature the lower limit was set to 19°C and the upper to 26°C (Figure 6).

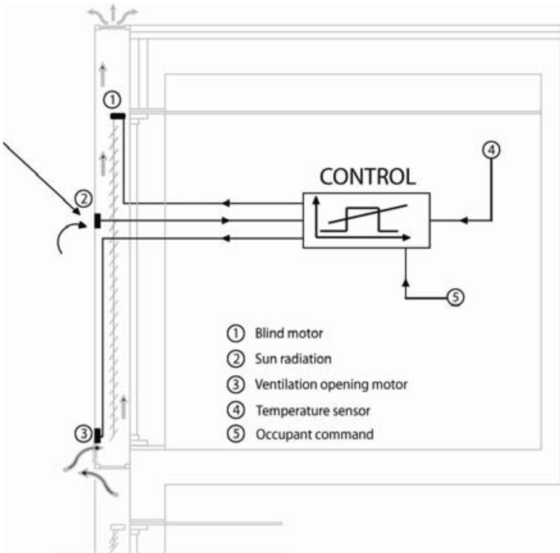

Figure 5 General outline of the DSF control strategy

A secondary condition was imposed in order to synchronize both inputs. It was imposed that there is no change in the status of the controller until both inputs converge. When the output of the controller is equal to 0 the blinds are fully opened and there is no ventilation in the DSF. When the output is equal to 1, the blinds are fully closed and the ventilation flow in DSF is maximum. There is a linear interpolation between both values.

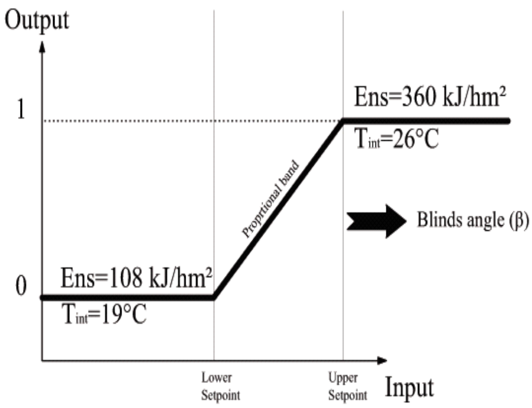

Figure 6 Control strategy for the blinds angle

Same regulation strategy was applied to the solar protections (screens) on the traditional façade. When the output from the controller was equal to 0 the screen was completely opened and when the output was equal to 1 completely closed.

It should be noticed that during occupational time in summer the blinds are never completely closed (indoor air temperature is set at 24°C) in order to improve the daylight inside.

RESULTS

The simulations were run for whole year with hourly time-step. In the following the energy consumption of the entire building and temperature profiles and control system outputs for a south oriented office are presented. In Figure 7 and Figure 8 the annual energy consumption is presented. Due to the thermal performance of the walls (low wall transmission coefficients) and to the solar gains control, yearly consumptions for heating and cooling as low as 44 kWh/m²·year (TF) and of 38.7 kWh/m²·year (DSF) are recorded. Saelens, Roels et al. (2006) found similar and very appropriate results although the geometry, the control strategy and the climate are different. Stec and Paassen (2005) simulates a 20 m² office under the Dutch climate and finds a global energy consumption of 38 kWh/m²·year although the general simulation hypotheses are not the same with the actual study.

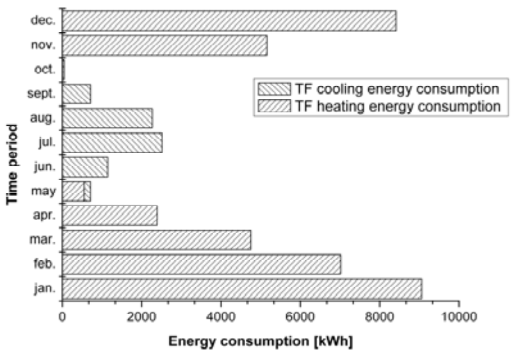

Figure 7 Annualy energy consumption for TF building

If we take into account only the cold season, the glazed double envelope has a better behavior. On the other hand, during the summer season, the consumption for cooling is higher, compared to the reference case. This fact is due to the increased surface of glazing. It should also be noticed that the traditional facade has an exterior screen solar protection that follows the same control as DSF.

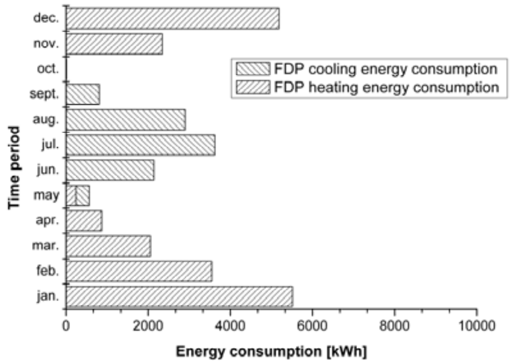

Figure 8 Annualy energy consumption for a DSF building

In Figure 9 and Figure 10 are presented simultaneously the temperature values inside the DSF during the cold and the hot season for a south oriented facade. Two different situations were considered. First represents the control system presented before, with blinds angle varying between 0 and 90° and the airflow between 0.5 and 1.5 m^3/s according to the information received from the controller. The second one has no control system: the blinds angle is preset to 0° and the airflow to 0.5 m^3/h in winter and 1.5 m^3/s in summer.

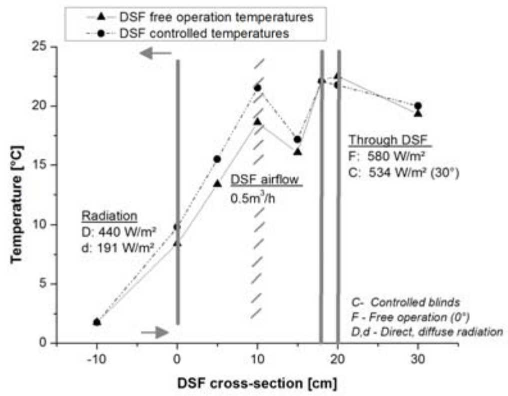

Figure 9 Completely open versus controlled blinds in winter case (15 of January, 2 pm)

During the cold season even with our control system installed blinds remain completely open for a long period of time. This situation was expected because to change the blinds angle, both signals limits (solar radiation and indoor air temperature) should simultaneously be achieved. This fact is act as a benefit for the reason that will allow the office space to increase the solar gains.

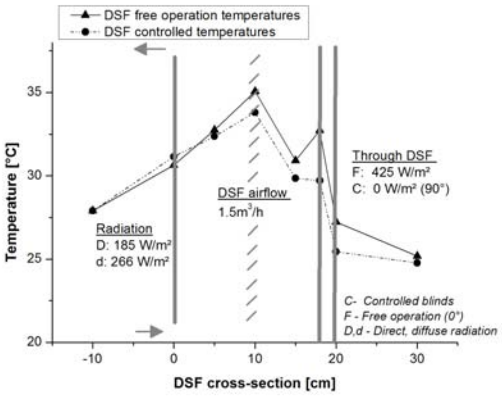

Figure 10 Completely open versus controlled blinds in summer case (21 of July, 2 pm)

In the summer case both upper limits of the control system were exceeded. This means that control system operates rapidly and adjusts the blinds angle and the airflow value, decreasing the inner glazing temperature of approximately 2°C. As the indoor temperature was kept constant by the cooling system, the energy used for cooling is decreasing.

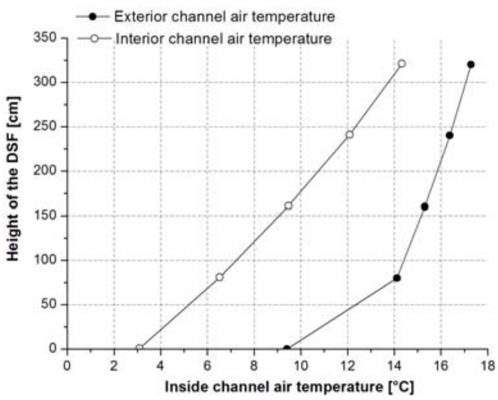

Figure 11 Vertical air channel temperature profile in summer case (blinds at 30°, 15 of January, 2 pm)

In Figure 11 are presented the temperature profiles of the air inside the channel, for a controlled DSF. As the air in the channel is much warmer than the outdoor air, the DSF ventilation can be connected to the general building ventilation system in order to reduce the ventilation energy loss.

For the summer case (Figure 12), the winter strategy does not apply. Here, the exhaust air from the building can transit through the DSF to decrease the temperature in the channel and consequently the inner glazing surface temperature impacting indoor air temperature.

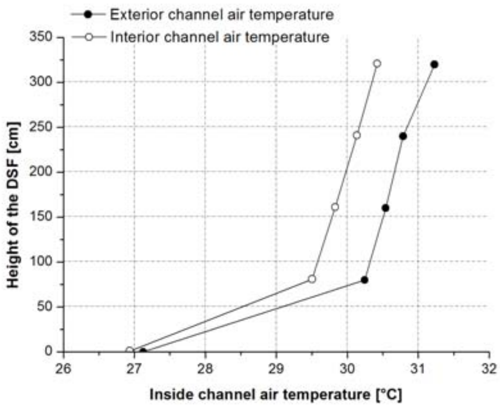

Figure 12 Vertical air channel temperature profile in summer case (blinds at 90°, 21 of July, 2 pm)

CONCLUSION AND PERSPECTIVES

Numerical simulations presented in this study showed that double skin facade is a promising system for energy savings. In spite of significant glazed surface a double-skin facade contributes to the energy saving. However it must be controlled in order to limit overheating problems in summer.

The proposed controller enables correct energy performance, but does not include visual comfort. Moreover the study showed that the benefits can be increased by better integration of the building and DSF ventilation.

Also the numerical model of the DSF used in this study proved to be suitable for building energy simulation. The inputs and outputs of the model are also well adapted for control system studies, as they allow for example varying airflow and venetian blind opening.

As a next step of this project the double-skin facade model will be validated in a full scale test facility. The experiments will be performed in fully controlled conditions (temperature and solar radiation) in order to develop further the DSF model.

NOMENCLATURE

$\Phi_i^{abs,CLO}$ Absorbed heat flux (short wave radiation).

$\Phi_i^{net,GLO}$ Net exchanged heat flux (long wave radiation).

$\Phi_{c,i}$ Convective exchanged heat flux.

$\Phi_{cond,i}$ Conductive exchanged heat flux.

Φ_{ext} Radiative heat flux exchanged with the outdoor.

Φ_{int} Heat flux exchanged with the indoor.

Φ_k^a Heat flux due to mass transfer (air inside the FDP).

T_{ext} Outdoor air temperature.

T_{int} Indoor air temperature.

L, S Solar protection (lower face and respectively upper face).

esp Venetian blinds gap.

λ Layer conductivity [W/mK]

ρ Layer density [kg/m^3].

C Layer capacity [J/kgK].

ACKNOWLEDGMENTS

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REFERENCES

Loncour X. and Deneyer A. 2004. Ventilated double facades. Classification & Illustration of facade concept (Belgium).

Saelens D., Carmeliet J. and Hens H. 2003, Energy Performance Assessment of Multiple Skin Facades, International Journal of HVAC&R Research, vol. 9, nr. 2, pp.167-186.

Saelens D. Roels S. and Hens H. 2006. Strategies to improve the energy performance of multiple-skin façades. Building and Environment (on line).

Safer N., Gavan V., Woloszyn M. and Roux J-J.. 2006. Double-skin facade with venetian blind: global modelling and assessment of energy performance. EPIC Conference, Lyon (France).

Safer N., Woloszyn M., Roux J.J., 2005a. Global modelling of double skin facades equiped with venetian blind model based on CFD approach. CISBAT 2005, Lausanne (Suisse).

Safer N., Woloszyn M., Roux J.J., Kuznik F.. 2005b. Modelling of the double skin facades for building energy simulation: radiative and convective heat transfers. 9th International IBPSA Conference Building Simulation 2005, vol. 2, Montreal (Canada). 1067-1074.

Stec W.J, van Paassen A.H.C., 2005. Symbiosis of the double skin facade with the HVAC system, Energy and Buildings 37 (2005) 461–469.