Full scale experimental evaluation of ventilation strategies of a double-skin façade

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ABSTRACT

A double-skin façade is installed in a laboratory full scale test cell. The double-skin façade has a 20 cm wide air cavity with Venetian sun-shading blinds and is provided with mechanical ventilation. The experiments are performed in fully controlled conditions. The results are including temperature measurements in several locations in the façade and test cell. Two main scenarios (summer and winter situation) are investigated. Under these scenarios different ventilation configurations with various operation strategies are implemented. These experimental results enable us to carry out the validation of a DSF model developed simultaneously. This implemented model in MATLAB®/Simulink® and is using the SIMBAD HVAC library.

1. INTRODUCTION

Double-skin façades (DSF) are highly technological building components which are deployed to use maximum of sun in winter (avoiding the glare) and to minimize transmitted radiation during the hot season in order to avoid space overheating. Used in new architectural projects, DSF are designed to fulfil several envelope functions, such as thermal and acoustic insulation, optimization of natural lighting and improvement of ventilation system.

In addition to the envelope itself (façade), DSF have a second glazed layer (with a non-structural role) placed at a certain distance from the inner layer (Streicher, 2005). These two sheets of glass act as an insulation between the outside and inside enabling the air to circulate between the two façade's skins. The distance between glass layers varies from few centimetres to over one meter. The zone positioned between these two layers is named buffer zone or "cavity" and generally is ventilated. It must reduce overheating during hot periods and must contribute to energy savings.

2. EXPERIMENTAL SET-UP

2.1 Minibat test cell

The study of the thermal characteristics of a system connected to a building requires reliable and detailed experimental data. The consistency of such measurements is acquired only through controllable experimental facilities.

Although numerous papers describe different configurations of DSF, experimental results under controlled climatic environment are rarely given. Measurements are very often carried out under real weather conditions where there is a little or no control of the key environmental factors (Pasquay, 2004), (Stec and Van Paassen, 2005), (Corgnati et al., 2007). All these experiments treat different façade configurations. Results of measurements are used generally for validation and enhancement of the developed models. Usually, these results are employed as well to improve DSF performance at the design stage.

The experimental facility, called Minibat, used in this study is formed by two identical test cells (rooms), each one with the dimensions of L × W × H = 3.1 m x 3.1 m x 2.5 m (Figure 1). Five walls of each cell (Table 1 and Table 2) are in contact with a thermal buffer zone with controlled temperature.

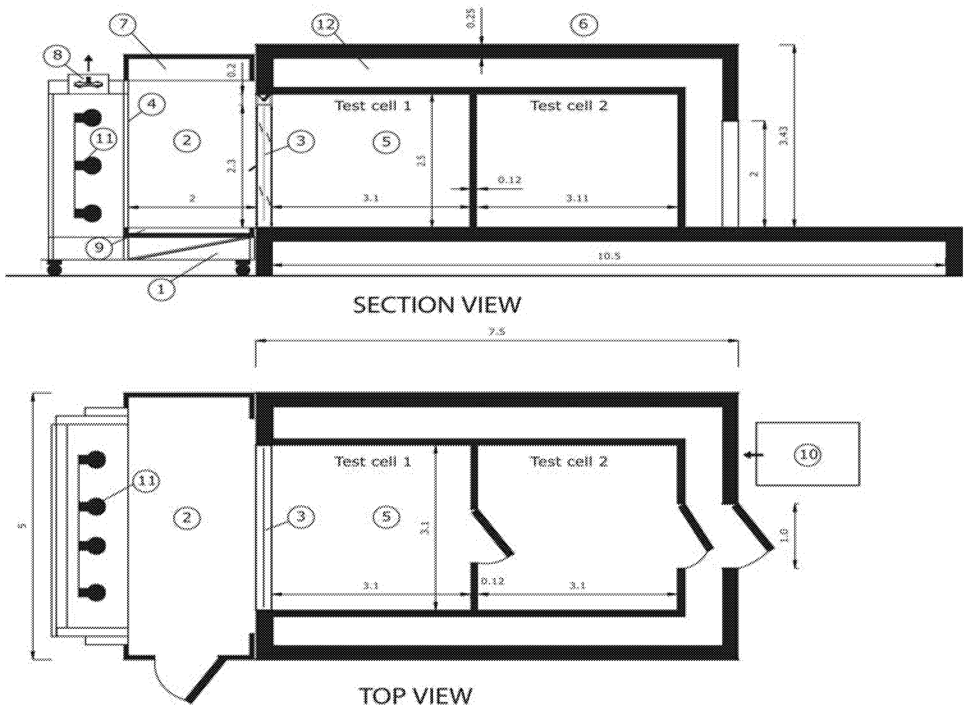

Figure 1. Test cell facility scheme: 1) cooling unit; 2) weather generator; 3) double-skin façade; 4) protection glass of the solar simulator; 5) test cell; 6) concrete; 7) air blowing plenum; 8) solar simulator's heat removal ventilators; 9) air extraction plenum; 10) HVAC unit of the buffer zone; 11) solar simulator; 12) controlled buffer zone.

The sixth boundary of the test cell 1, where the DSF was installed, is in contact with a weather generator. This unit is capable simulating outdoor conditions in terms of temperature (between 1°C and 40°C) and solar radiation.

Table 1. Thermophysical properties of the envelope

Material	λ	Capacity	ρ
	W/m^2°C	J/kg°C	kg/m^3
Plasterboard	0.35	1620	817
Agglomerated wood	0.136	1640	544
Plywood	0.11	1600	417
Polystyrene	0.04	1380	25
Mineral wool	0.06	1000	72
Siporex concrete	0.16	1000	368

The solar simulator installed in the Minibat test cell provides a source of artificial solar radiation to the test façade surface. In this way, the thermal behaviour of the façade, as if bounded by outdoor environment, can be effectively evaluated. Throughout our tests, the lamps of the solar simulator are providing the same irradiation during both scenarios. Thus, during all the tests, the solar simulator is maintained constant.

Table 2. Wall composition (from inside)

Wall	Material	Thickness
		mm
Floor	Cellular concrete	200
Vertical wall	Plasterboard	10
	Polystyrene	50
	Plasterboard	10
	Agglomerated wood	50
Ceiling	Plasterboard	10
	Plywood	8
	Mineral wool	55
	Wood	25

The metrology installed on the experimental facility includes two systems, one for the test cell with all the auxiliary equipment and the other for the façade. Both measurement systems include a set of thermocouples (type K and T) and Pt100 sensors, one inline flowmeter and one stand alone pyranometer for the solar radiation.

2.2 Double-skin façade

A single storey double-skin façade type was selected for investigation (Loncour et al. 2004). In this respect, a full sized double-skin façade incorporating a sun-shading blind was realized and installed in the test cell.

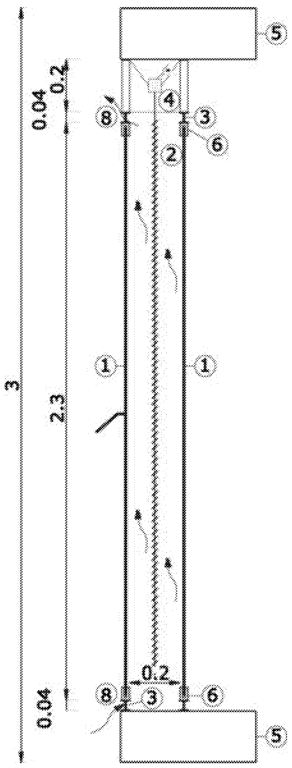

Figure 2. DSF section view: 1) 6 mm glass layer; 2) motorized solar protection (blade width W=0.025 m); 3) metallic support; 4) solar protection action box; 5) structural concrete beam; 6) aluminium frame; 7) pane opening articulation; 8) ventilation openings.

The double-skin façade, presented in Figure 2 is realized of two aluminium frames. The internal is composed of one fixed part (W × H = 2.8 m x 2.3 m) while the external one is divided into two parts that can be separately opened.

The glass area is W × H = 2 × 1.3 × 1.93 m for the external pane and W × H = 2.8 × 1.93 m for the internal. The DSF includes four openings for ventilation (W × H = 2.6 m x 0.04 m). They cover the whole width of the façade, at the top and bottom of each of the two panels. Thus, various configurations of the ventilation of the double-skin can be tested by simple obstruction of these openings.

The sun-shading devices installed for these experiments are Venetian type blinds placed in the middle of the channel.

To represent precisely a mechanically ventilated façade and ensure accurate airflow control a special system is attached to the lower opening. It is composed of a ventilator which blows the air into a convergent diffuser by the intermediate of a duct. A differential pressure flowmeter is installed inside this duct to accurately measure the airflow blown by the ventilator into the DSF.

The DSF is instrumented using thermocouples, distributed on all the elements of the façade. For a better contact with the glass surface, type T thermocouples with flattened joint are used here. The thermocouples are shielded to the solar simulator radiation using a high reflective paint (Labsphere Spectraflect).

3. DOUBLE-SKIN FAÇADE MODELLING

The simulation 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 (Figure 3).

The energy balance is written in every node of each vertical band. Long and short wave radiation, convection and conduction heat exchanges and heat flow due to the mass transfer in the cavity of the façade are represented (Figure 3). It should be mentioned that the model was established based on CFD simulations and PIV measurements, presented in (Safer et al. 2005a, 2005b). Elements such as solar protection angle, ventilation flow inside the channel, sun angles, thermal characteristics of skins and outdoor conditions are included.

The connection of the DSF model to MATLAB®/Simulink® and SIMBAD zone model is made according to three actions. For each time step: (i) the average temperature of

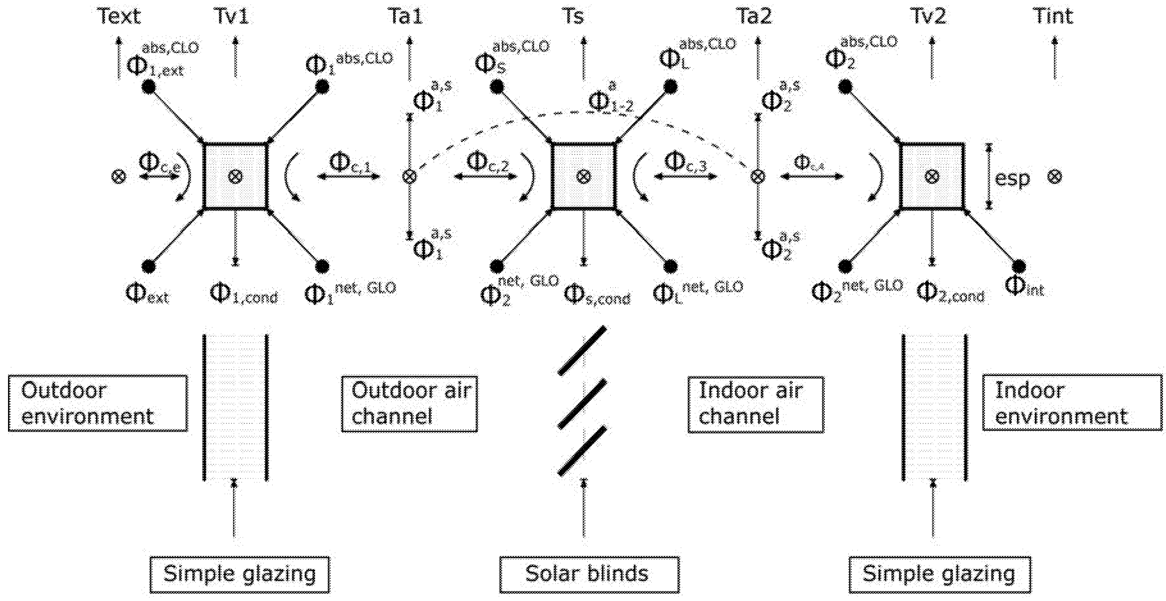

Figure 3. DSF global model

the DSF inner glazing is introduced in the zone module that calculates the walls surface temperature; (ii) the solar radiation transmitted through the DSF is introduced as well in the zone model; (iii) the calculated zone temperature is used in the DSF model for calculations of convective heat flow between the façade and the indoor air (Safer et al. 2006).

The auxiliary models such zone model, weather data, etc., are provided by the SIMBAD HVAC library. SIMBAD library is a HVAC toolbox for the MATLAB®/Simulink® environment. The toolbox provides HVAC models and related utilities to perform dynamic simulation of HVAC plants.

4. RESULTS

4.1 Radiation validation

For validation of the radiative submodel the tests are including solar radiation measurements on the tested façade. By these measurements the radiative fluxes on the façade's glass panes can be evaluated. Thus, entire transparent surface of the DSF was scrutinised.

In the model, the DSF is subjected to a uniform solar flux. The projectors radiation is supposed arriving homogeneously on the external glazing of the DSF. The DSF is considered south oriented (solar azimuth angle is zero). Based on the angle of the lamps, equivalent sun height and incidence angles are then evaluated. The limited distance compared to the distance to the sun in a real situation, can make complicated the estimation of the solar angles needed as input for the model.

Globally, direct measured value of the flux focussed on the façade is approximately 300 W/m². This value was found averaging 24 points of radiation measure on the exterior glass pane (in contact with the weather generator and

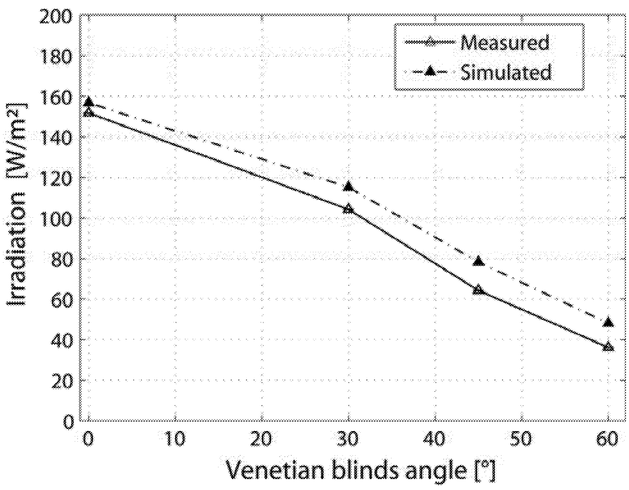

Figure 4. Average irradiation passing the internal glass pane to the test cell

solar simulator). The indoor irradiation was measured function of different angles of the sun-shading blinds. Measured values were compared with simulated data provided by the DSF model. Figure 4 shows the average irradiation measured and simulated on the DSF glass pane giving inside the test cell. For each change of blinds angle, the average irradiation is decreasing by approximately 50% comparing to the previous angle (for example, between horizontal blinds and 30 degrees blinds).

For completely closed blinds (90°), since the theoretical transmittance is equal to 0, the first consequence can be that no radiation will enter inside test cell. Thus, with multiple reflections and solar radiation leakage regions of the façade, the average radiation passing towards the test cell is around 20 W/m^2.

4.2 Summer scenario temperatures validation

The summer scenario is characterized by the weather generator air temperature setpoint fixed at 32°C (a hot summer day) and the second is the buffer zone temperature setpoint fixed at 26°C (the test cell is supposed to be in contact with a air-conditioned zone). The zone in contact with the DSF is not air conditioned. This strategy was imposed for all configurations. Thus, the air temperature inside is not influenced by these systems.

Several configurations with different airflow (200, 400 and 600 m^3/h) combined with different orientation of the shading device (0° and 45°) are scrutinised. During this configuration the air is taken from the weather generator and passed to the façade to be then blown again to the weather generator. This strategy is considered being an outdoor to outdoor ventilation following air movement in the façade.

Figure 5 shows the measured and simulated temperature profiles in different location of the DSF. For each layer of the DSF and the test cell, the temperatures are measured in different location. Thus, a temperature measuring error is eliminated. For example, the external glazing temperature was scrutinised in 6 points. For convenience, these values are averaged and only one value is presented in Figure 5.

Figure 5 presents the temperature profiles for two blinds angles of the DSF shading device. The complete open blinds are considered when the blinds are parallel to floor (0°). For this blinds inclination the major part of the solar radiation is penetrating to the test cell. Thus, the temperature inside the test cell is superior to the following tested blinds inclination (45° angle, the blinds are inclined facing the sun). Between the measured and simulated values, a maximum temperature difference of 1°C is observed in the DSF layer. This difference is reduced instead for the test cell air temperature. For the important airflows (400 and 600 m^3/h) the difference between measured and simulated values is insignificant. Referring to airflow, the imposed values are representing a maximum of 193 m^3/h m of DSF (in the literature, usual airflow in the DSF is between 0 and 200 m^3/h m). As well, Figure 5 presents 45° blinds angle temperature profile. For this situation, the major part of the solar radiation is absorbed or reflected by the blinds.

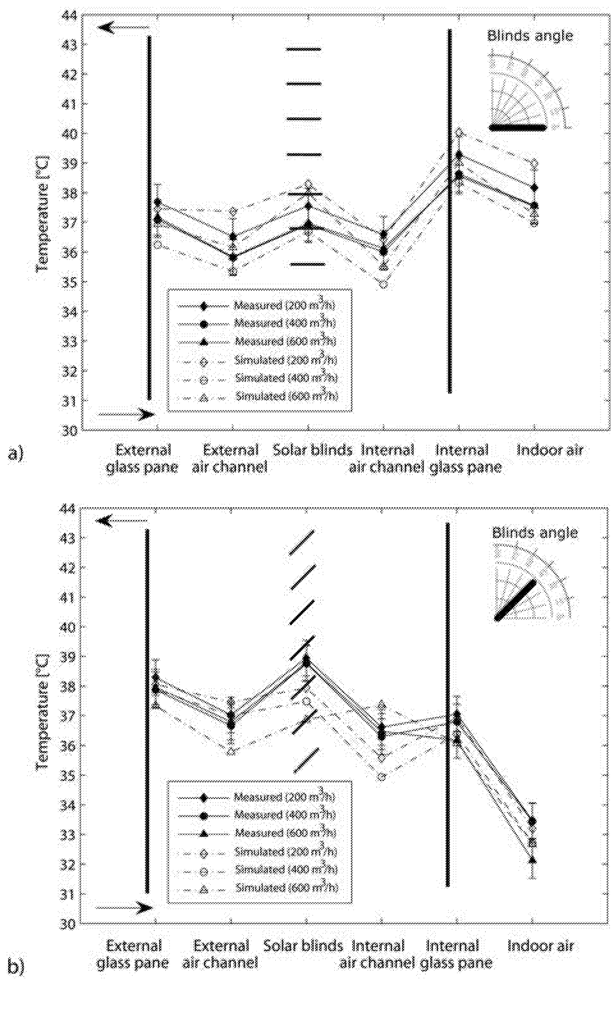

Figure 5. DSF temperatures (summer scenario).
a) open blinds (0°); b) blinds at 45°

Regarding the blinds temperatures, an angle of 45° is intercepting more radiation (up to 60% more, Figure 4) comparing to opened blinds. Thus their temperatures are increased. For the test cell air temperature, more intercepting the solar, more the temperature is decreased. During the scenario with 45° angle, the temperature inside the test cell is situated approximately at the same level as the weather generator temperature (32°C).

4.3 Winter scenario temperatures validation

4.3.1 Outdoor to outdoor ventilation strategy

As for the summer, the winter scenario is characterized by the weather generator temperature and the thermal buffer zone setpoint (3°C, respectively 19°C). This thermal buffer zone setpoint is considered a winter heating setpoint of a virtual adjacent zone to the test cell.

Several assumptions were made for the winter scenario. Since our DSF configuration takes into account exterior to exterior ventilation (with external air temperature at 3°C) the reason to test different configurations with important airflow is not suitable for the winter scenario. Thus, ventilation strategies are limited to 200 m^3/h airflow.

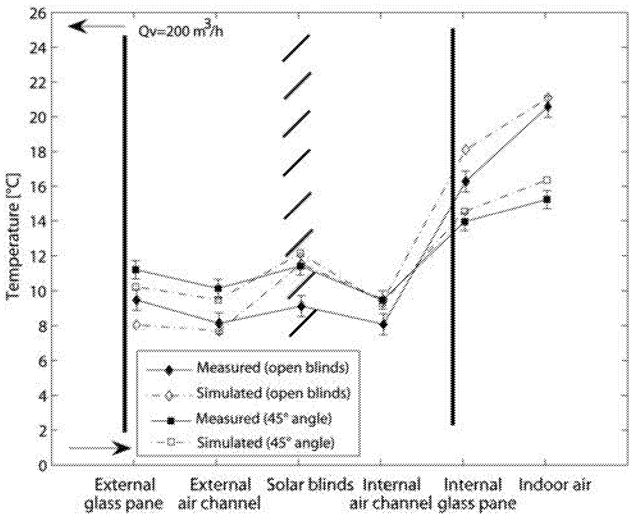

Figure 6. DSF temperatures (winter scenario).

Figure 6 shows the DSF temperature profile with an outdoor to outdoor ventilation strategy. For the winter situation, due to green house effect, the façade is acting as a buffer zone between the test cell and the weather generator. Thus, test cell temperature is superior to the weather generator and thermal buffer zone temperatures. Accordingly to figure 6, for the winter situation, completely opened blinds strategy is better. In this way the room has more solar gains and thus, air temperature inside is increased.

4.3.2 Outdoor to indoor ventilation strategy

An interesting situation during the winter for a DSF building is to blow inside the test cell, the outdoor air passed through the façade. Particularly for air, temperatures at the top of the façade are increased due to the green house effect. Thus, this air can be introduced inside a heat exchanger or directly the room and can serve for the ventilation.

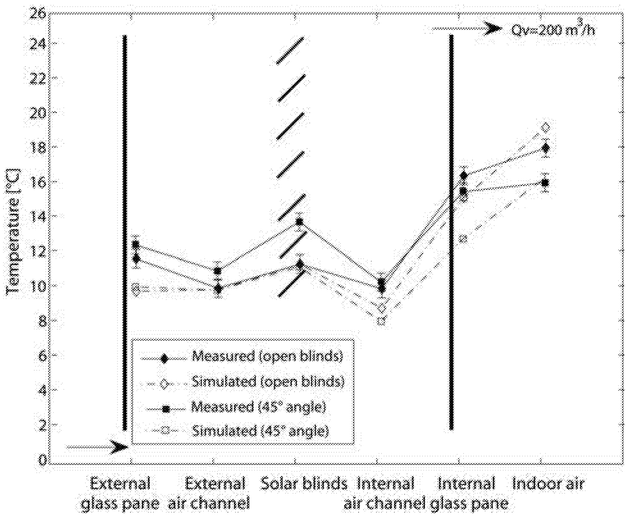

Figure 7. DSF temperatures (winter scenario, cross ventilation).

Figure 7 presents the DSF temperature profile and the test cell temperatures for an outdoor to indoor ventilation strategy. This means that the air is taken from the weather generator, passed through the DSF and then blow to the test cell.

Table 3. Vertical temperature profile (winter scenario).

β	External air channel		Blinds		Internal air channel	
	Bottom	Top	Bottom	Top	Bottom	Top
[°]	[°C]		[°C]		[°C]	
0	5.3	11.8	6.0	12.2	4.1	12.1
45	8.0	16.1	8.9	16.6	6.9	14.6

In this case, the air temperature inside the test cell is influence by the temperature of the airflow. Comparing this DSF ventilation strategy with the outdoor to outdoor strategy presented in Figure 6,

Even with an important airflow for the test cell the significant glazed surface can increase the air temperature in the DSF. Thus, at the entering of the test cell in the upper part (+2.1m), the air temperature is approximately doubled compared to the bottom value (registered near the entering of the DSF at +0.2m). These measured temperatures in the DSF are presented in Table 3.

5. CONCLUSIONS

These experimental campaigns in controlled conditions enable us to evaluate precisely the thermal behaviour of a room provided with a double-skin façade, comparing to real building monitoring. As well, these experimental results enable us to carry out the validation of a developed DSF model. Under these aspects, strategies with internal loads, occupation or natural ventilation of the DSF, not taken into account in this campaign, can be solved by computer simulation.

The different configurations confronted in this paper are showing that the airflow impact is less important compared to the shading influence (summer scenario for example). Small temperature difference is obtained varying the airflow in the façade. Instead, varying the blinds angle and thus diminishing the solar radiation, a more consequent temperature decrease is achieved. Under these scenarios and configurations, the role of the sun-shading is more significant than the airflow value. For the winter scenario, good results are obtained with the two strategies. In particular, the outdoor to indoor ventilation is to be mentioned. Thus, the DSF can be employed as a “heat exchanger”, preheating the air before being introduced in the room. This approach should be studied further.

For the perspectives, a more complete analysis is to be considered, focussing not only to the thermal aspects but also to the visual characteristics (artificial and natural lighting). Future work will focus on the visual aspects correlated with thermal characteristics to an optimal control of this façades.

NOMENCLATURE

L	Length [m]
W	Width [m]
H	Height [m]
β	Blinds angles [°]
$Text$	Outdoor air temperature [°C]
$Tv1$	External glazing temperature [°C]
$Ta1$	External air cavity temperature [°C]
Ts	Blinds temperature [°C]
$Ta2$	Internal air cavity temperature [°C]
$Tv2$	Internal glazing temperature [°C]
Φ	Flux [W]
CLO	Short ware radiation
GLO	Long wave radiation
abs	Absorbed flux
Φ_c	Convective flux [W]
Φ_{cond}	Conductive flux [W]
Q_v	Airflow [m^3/h]

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