PERFORMANCE EVALUATION OF ADVANCED INTEGRATED FAÇADES IN LABORATORY FACILITIES

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ABSTRACT

A wide experimental campaign on transparent advanced integrated façades with a mechanically, naturally and hybrid ventilated air gap has been carried out both at the Department of Energetics at Politecnico di Torino and at Laboratório Nacional de Engenharia Civil (LNEC) in Lisbon. Measurements were performed by means of:

- the TWINS (Testing Window INnovative Systems) test facility, at Politecnico di Torino
- the reversible flow type DSF test cell, at LNEC.

At Politecnico di Torino a mechanically ventilated climate façade and a hybrid ventilated DSF with an outdoor air curtain ventilation scheme have been investigated. At LNEC a naturally ventilated DSF with different ventilation schemes (outdoor air curtain, indoor air curtain, exhaust air, supply air or, as a limit, a buffer configuration) has been tested. The energy efficiency and thermal comfort implications of these different types of advanced integrated façade have been evaluated. The improvement of performance by varying configurations and operative conditions has also been investigated.

1. INTRODUCTION

The promising ability of innovative responsive building elements (RBE) to maintain a balance between optimum interior conditions and environmental performance, by changing their physical behaviour reacting to changes in boundary conditions and to occupant interaction, highly stimulated research on this kind of building elements.

Advanced Integrated Façades (AIF) are one type of RBE where, besides glazing and shading devices typical of a conventional transparent façade, a key role is played by the presence of a ventilated air gap with a flowing air which could come from inside or outside in a forced, natural or hybrid mode.

RBEs, due to their complexity and dynamic behavior, need different approaches for assessing their performance. In fact it is no more possible to use "static" evaluation parameters like U-value for walls. This poses new challenges for the experimental and numerical analysis of AIF.

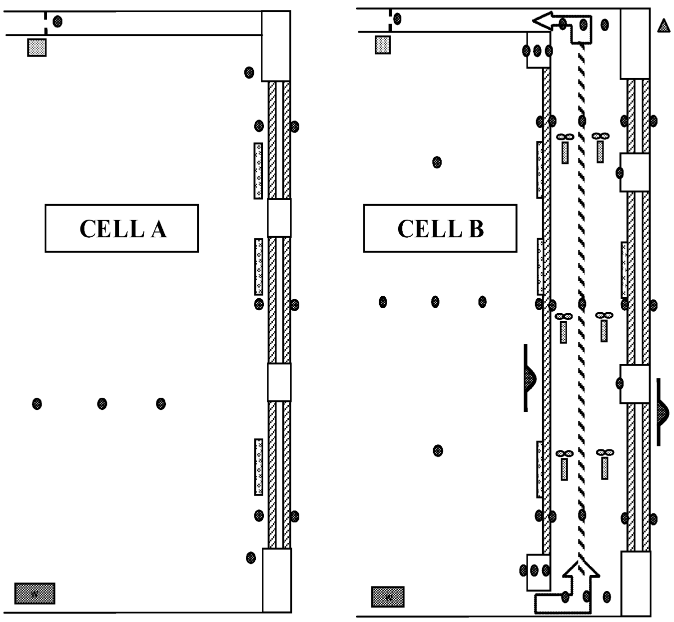
In order to tackle these problems, the TEBE research group of the Department of Energetics at Politecnico di Torino, and the Laboratório Nacional de Engenharia Civil (LNEC) in Lisbon have designed and built two experimental test facilities. New performance indexes have also been proposed and used. In this paper some results of the experimental campaigns carried out by both the research groups are summarized, analyzed and compared.

2. METHODS

2.1 The TWINS facility at Politecnico di Torino

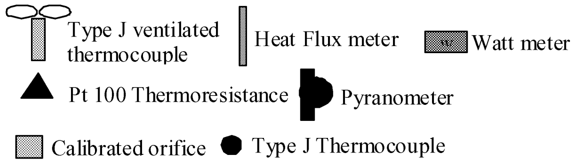
TWINS consists of two identical test cells, one used as a reference (test cell A) and left unchanged during the monitoring campaign, the other adopting different solutions of active façades (test cell B). The use of a reference test cell allows comparisons between various configurations and analysis of the influence of some façade components (such as shading devices, width of the air gap, internal or external glazing, and air flow rate), even with different boundary conditions.

Test cells A and B are fully exposed to the solar radiation as the façades are facing south. The indoor air temperature of both cells is controlled by means of a full air system and kept at a set-point of about 20°C in winter, 26°C in summer and 23°C during mid season.



a) b)

Figure 1- Scheme a of the TWINS test facility sensors.



a) b)

Figure 2 – pictures of: a) Climate façade, b) Hybvent DSF.

Two different AIF were investigated: a mechanically ventilated climate façade and a hybrid ventilated DSF with an outdoor air curtain ventilation scheme (Figure 2b - microfans are powered by PV modules). The measured quantities are: air, glass and frame temperatures, incident and transmitted irradiance, heat fluxes, mechanically driven air flow rate, pressure difference. The reference façade was monitored by means of 18 sensors connected to a datalogger, the measurement apparatus for the tested AIFs consisted of 52 and 41 sensor for the climate and the hybrid ventilated façade respectively. For both the façades the experimental campaign lasted one whole solar year. In Figure 1a scheme of sensors for the reference and the tested façade is shown. In Figure 2 the two studied AIFs are shown.

2.2 The DSF test facility at LNEC

Double skin facades (DSF) may show different layouts, flow path or type of ventilation (natural, mechanical or hybrid). In order to evaluate the thermal behavior of such a façade LNEC (39º N) assembled a south facing test facility allowing changing among some of the possible configurations.

Being a reversible flow type of DSF it means that it is possible to test configurations such as (according to the classification established within the IEA ANNEX 44 - Marques da Silva and Gosselin, 2006): Outdoor Air Curtain (OAC), Indoor Air Curtain (IAC), Exhaust Air (EA), or Supply Air (SA). It is also possible to use any kind of ventilation type, the layout being established as a box window (BW) or, as a limit, as a Buffer (Bf) configuration.

The glazed façade has size of 2.5 m height and 3.5m length, the gap depth being of 0.20 m. The outer pane has a simple annealed 5 mm glass (U=5,7 W/m^2/K; Tv=87%; Te=75%; Ae=18%; g=0,80) and the inner one is a low emissive (U=1,4 W/m^2/K; Tv=69%; Te=36%, Ae=34%+3%; g=0,41) double glass (6-16-5). The shading device is a grey roller blind. The gap has eight sets of louvers, 0.22 5m high and 1.63 m long each, four in the outer pane and four in the inner one, the blades position being adjustable between fully closed and fully open (blades perpendicular to the façade plane).

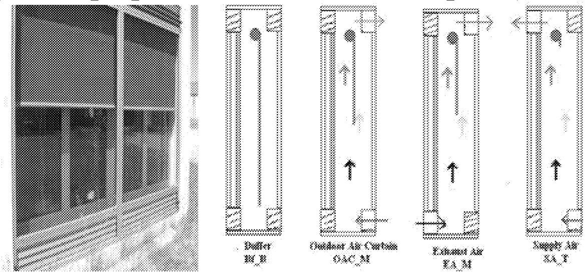


Figure 3 – The AIF at LNEC and the tested configurations.

The monitoring campaigns were carried out between July 2007 and January 2008 having in mind the evaluation of the thermal behavior of the different tested configurations and also the changes of temperature within the DSF gap. Two positions of the shading device were also tested: midway between glazed panes and closer to the inner pane. Environmental parameters were also measured: outdoor and indoor temperature (with Gemini stand alone loggers); wind velocity and direction (NRG with Ammonit logger); and solar radiation on horizontal and vertical (indoor and outdoor) planes (with pyranometers). Measurements were recorded as 10 minutes averages from 30 seconds readings and (apart the referred two) recorded by a Datataker logger.

Measurements considered in this paper refer to the following DSF configurations (Figure 3): Bf; OAC; EA; and SA. The letter after the configuration (**_X) refers to the roller blind position – Bottom, Medium, Top -, and the “i” refers to the shading inner position.

2.3 Performance parameters

The performance of the façade in terms of energy savings has been analyzed considering:

- the ability to pre-heat the ventilation air during the winter season;
- the ability to remove part of the solar load during the summer season;
- the normalized daily energies through the façade.

The thermal comfort performance has been evaluated considering the normalized surface temperature of inner glass.

Pre-heating efficiency

The pre-heating efficiency represents the ratio between the enthalpy flux related to the air flowing in the gap and the enthalpy flux required to heat the ventilation air. It is a parameter representative of the performances of the façade in winter and mid season conditions (heating period).

Dynamic insulation efficiency

The dynamic insulation represents the amount of total thermal load acting on the external surface of the façade that is removed by the ventilation air, it is a

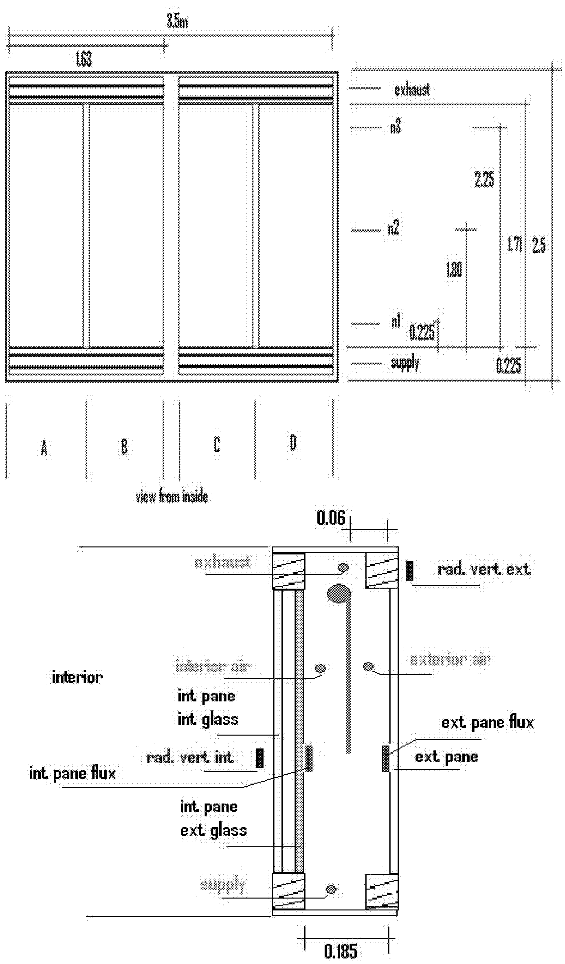


Figure 4 – Scheme for measuring levels and test facility sensors

parameter representative of the performance of the façade for summer and mid season (cooling period).

Normalized heat fluxes and daily energy through the façade

The effect of different configurations and operative conditions in reducing the thermal fluxes and thus the energies entering (or exiting) the indoor environment has been evaluated defining normalized fluxes and normalized energies (Table 1). The subscript A refers to the reference façade, and the subscript B refers to the AIF façade.

Daily energy is calculated as the integral over the time of heat fluxes measured from 8:00 am to 8:00 pm.

$$E_{X,i,d} = \int_{8am}^{8pm} \dot{q}_{X,i}(\tau)d\tau \quad (1)$$

The normalized energies represent the

Performance parameter	Pre-heating efficiency	Dynamic insulation efficiency	Normalized heat fluxes	Normalized daily energy through the façade	Normalized surface temperature of inner glass
Equation	$\eta = \frac{T_{exh} - T_{supply}}{T_{amb} - T_o}$	$\varepsilon = \frac{\dot{Q}_R}{\dot{Q}_{IN}}$	$\phi = \frac{\dot{q}_{t,i,B} - \dot{q}_{t,i,A}}{\dot{q}_{t,i,A}}$	$E_X = \frac{E_{X,B} - E_{X,A}}{E_{X,A}}$	$\vartheta_{gi} = \frac{t_{gi,B} - t_{gi,A}}{t_{gi,A}}$

Table 1 – Adopted performance parameters.

increase (or decrease) in percentage of the energies exchanged through the climate façade with respect to the reference façade. Energies exiting the indoor environment are reported with a positive sign.

Normalized surface temperature of inner glass

It represents the increase (or decrease) in percentage of the internal surface temperature of the AIF with respect to the internal surface temperature of the reference façade. In terms of thermal comfort the AIF shows a better performance, with respect to the reference one, if $\vartheta_{gi} > 0$ during winter and midseason and if $\vartheta_{gi} < 0$ during summer.

3. RESULTS

3.1 Experimental results at Politecnico di Torino

In Figure 5 the pre-heating efficiency of the climate façade for different configurations is shown. The best performance can be observed at low air flow rate and with the venetian blind: at 28 m^3/h a heating effect ($\eta > 0$) is present for about 50% of time and for about 27% of time there's a full compensation of the ventilation losses ($\eta \geq 1$). These values proportionally decrease with an increase in the air flow rate. The venetian blind gives always a better performance than the roller screen. In Figure 6 the dynamic insulation of both the tested AIFs is plotted. The Hybrid ventilated façade always shows a higher capability to remove the entering heat flux with respect of the climate façade, the roller screen is more effective in both the façades. The analysis of normalized total heat fluxes shows (Figure) that in summer conditions the performance of both the façades improves with a higher ventilation rate. The hybrid ventilated one always allows a higher reduction in the entering fluxes during the whole day. The roller screen allows a better

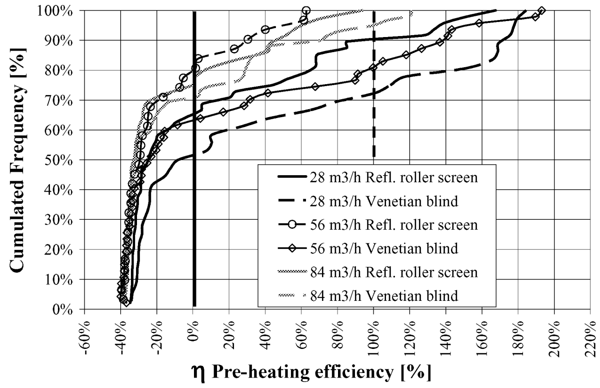


Figure 5 – Pre-heating efficiency for the climate façade.

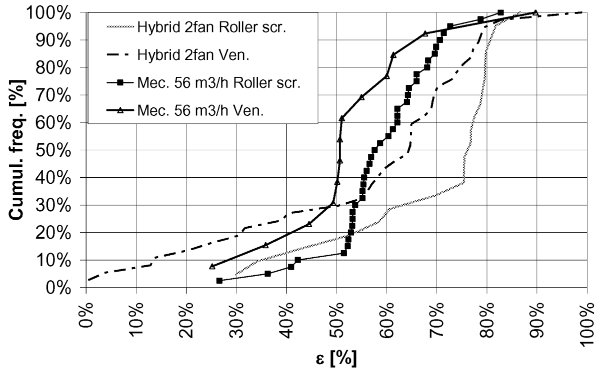


Figure 6 – Dyn. ins. efficiency of the two AIF.

performance. During the day the climate façade performance improves, whereas the performance of the hybrid ventilated one lowers passing from the morning to the afternoon. Furthermore, the hybrid ventilated façade shows, in the summer period, a reduction of the entering daily energy, with respect to the reference façade, between 59% and 75%; the climate façade gives a reduction between 38% and 46%. In both cases a higher air flow rate and the use of a roller screen allows a better behavior in summer conditions.

In Figure 9 is clearly shown that with both the façades a better thermal comfort, with respect to the reference one, is achieved. In summer ϑ_{gi} is always negative. It is clear the influence on the thermal performance of the low-e inner double glass of the hybrid ventilated façade.

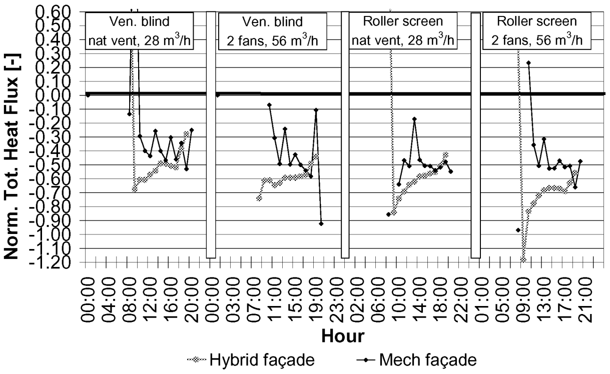


Figure 7 – Normalized total heat flux for the two AIFs.

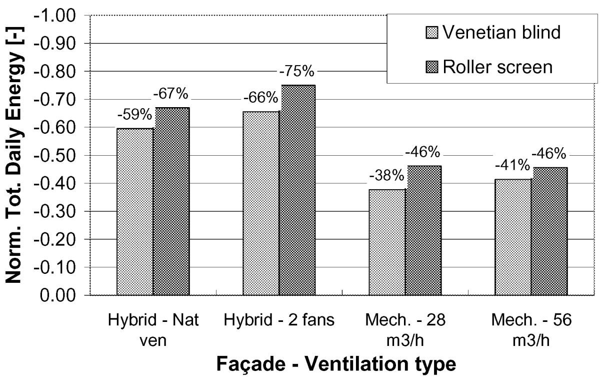


Figure 8 – Normalized total daily en. for the two AIFs.

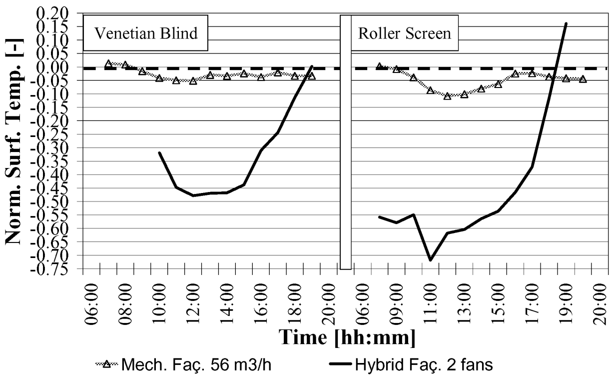


Figure 9 – Normalized surface temp. of inner glass.

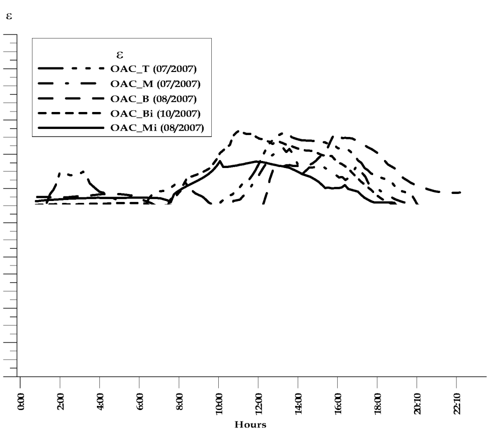


Figure 10 – Dyn. ins. eff. for the OAC configurations.

The climate façade has a inner glass temperature 11% lower than the reference one at the best, whereas for the hybrid façade the maximum reduction is of about 70%. For both the AIFs the reflecting roller screen configuration gives a lower temperature and allows then better comfort conditions.

3.2 Experimental results at LNEC

The tests performed at LNEC's facility had different goals than the ones performed at the Politecnico di Torino, as the main idea was to evaluate the thermal performance of a large set of DSF configurations. Anyway it was considered useful try to present results using the same indicator for both test sets. A major difference lies on the ventilation scheme, being fully natural at LNEC it prevents the mass flow control and needs estimated values for each case. The flow velocity between two openings can be evaluated by,

$$U = \frac{1}{\sqrt{\zeta}}\sqrt{\frac{2}{\rho}\Delta P} \quad [m/s] \qquad (2)$$

where ζ is the head loss coefficient ($C_d=1/\sqrt{\zeta}$), ρ is the air density and ΔP the pressure difference between openings evaluated, for thermally created ΔP by (Marques da Silva, 2004), $\Delta P^T \approx 0{,}042\, H_{12}\, \Delta T \quad [Pa]$ (3)

H_{12} being the openings height difference and the temperature difference between inside and outside in the range $23K<\Delta T= T_I- T_E <8K$.

A value of ~900 m^3/h with no shading (assumed $C_d=0.55$) was estimated for a sunny day and also measured with tracer gas equipment. Anyway flow measurements need further work as well as proper evaluation of the system (louvers and gap) heat losses. The measuring period for each configuration lasts for a few days and a representative one was chosen to be plotted. For the sake of brevity, it is not possible to present the full results, as described above, but they are plotted as daily trends. Concerning the dynamic insulation efficiency, the OAC and the EA configurations have been tested. The daily trends show a higher efficiency during sunshine hours. The OAC configurations (Figure 10) show a more stable behavior than the EA configurations.

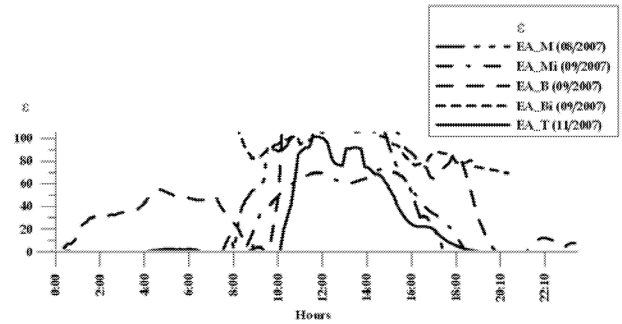


Figure 11 – Dyn. ins. eff. for the EA configurations.

These last ones (Figure 11) provide, on the other hand, a higher heat flux removal ability: the insulation efficiency peaks for EA are mostly close to 100%, the highest peaks for OAC configurations are never higher than 85%.

4. DISCUSSION AND CONCLUSIONS

Due to the differences in AIF configurations and in ventilation schemes, it was not possible to present the results in a common way for the two test facilities. Moreover, also the measuring periods were quite different. Anyway the same indicators were used and it is possible, to a certain extent, compare at least the capability of these parameters in characterizing the AIF behavior. As far as the ability to remove part of the solar load is concerned, Politecnico di Torino results show that it is improved at higher air flow rates and using the reflecting roller screen. LNEC results show that the OAC configuration have a less efficient but more stable behavior than the EA configurations.

Politecnico di Torino results show, furthermore, an increase in the energy exchanges through the façade for the PV assisted ventilated configuration. In relation to the inner glass surface temperature (and, then, to the thermal comfort issues), the adoption of the roller screen and, above all, of the low-e inner glass in the hybrid ventilated façade, seems to minimize the risk of local radiative discomfort.

For naturally ventilated AIF a better understanding of the influence of the wind on both the gap temperatures and mass flow is clearly needed.

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