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Experimental evaluation of a climate façade: Energy efficiency and thermal comfort performance

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ABSTRACT

The results of an extensive experimental campaign on a climate façade with a mechanically ventilated air gap, carried out at the Department of Energetics at the Politecnico di Torino, are presented. Measurements were performed utilizing the TWINS (Testing Window Innovative Systems) test facility, which consists of two outdoor cells, one used for reference purposes, and the other which adopts different active façade configurations. The energy efficiency of the façade and the thermal comfort implications have been evaluated considering the ability to pre-heat the ventilation air in the winter season, and the ability to remove part of the solar load during the summer season; the normalized daily energy passing through the façade and the normalized surface temperature of the inner glass were analysed. The improvement in performance obtained by varying the configuration and operative conditions (changing the air flow rate, the shading device and the internal glazing) has been investigated.

1. Introduction

In recent years, highly glazed façades have been frequently adopted in the commercial building envelopes. In order to fulfil the requirements concerning energy efficiency and indoor environmental quality, which cannot be obtained with conventional glazing, great efforts have been made by researchers, designers and manufacturers to develop better solutions [1,2].

Active integrated façades (i.e. climate façades, double skin façades, supply air windows, ...[1]) have resulted to be a highly successful glazed façade technology, both for designers and from the market point of view. Its potential lies on both the possibility of obtaining dynamic behaviour by creating a naturally or mechanically ventilated air gap between two glazed layers and the possibility of locating a solar shading device outside the inner skin, but protected from the external environment by the outer skin [3–5].

Nevertheless, it is not easy to rationally explain the reasons for the commercial success of active integrated façades over the last few years: many designers have opted for a ventilated façade claiming that this technology is sustainable, enhances indoor comfort conditions and reduces energy consumption, but none of these issues has been so far clearly proved [6].

A substantial lack of data concerning its actual functioning has been observed, due to the very complex behaviour of ventilated multiple skin façades; they have components which interact with the control strategies of an HVAC system and actively react to the changes in the boundary conditions.

More knowledge about this technology is therefore necessary and this can be obtained through measurement campaigns. It is rather a hard task to obtain experimental data on active integrated façades, due to the difficulties involved in performing laboratory tests, where the boundary conditions can be completely controlled and, consequently, all the parameters of influence can be analysed.

Field measurements are an alternative solution. These can give good results, though problems related to the management of the monitoring systems, the accuracy and the reliability of the data and the boundary condition variability emerge. Furthermore, it is also very important to extend the analysis period to cover different boundary conditions on a statistical basis.

Outdoor test cells can be a compromise between laboratory measurements, such as hot box tests, and field measurements. These cells allow the indoor boundary conditions to be controlled and different façade configurations to be evaluated; they are not as expensive as hot boxes are and do not suffer from normal problems that occur during field measurements due to the presence of occupants [7].

For this reason, an experimental test facility (TWINS—Testing Window Innovative System) has been designed and built at the Department of Energetics at the Politecnico di Torino. TWINS has been working since 2004 and two kinds of active integrated

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[1] A complete classification of different active integrated façades can be found in [3].

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Nomenclature

E	daily energy (W h)
I_{in}	irradiance entering the indoor environment (W/m^2)
I_{cl}	clothing insulation (m^2 K/W)
M	metabolic rate (W/m^2)
$\dot{q}$	heat flux (W)
$\dot{Q}_{IN}$	total thermal load entering the façade through the exterior surface (W)
$\dot{Q}_R$	thermal load removed by the air that flows in the façade gap (W)
T_{amb}	temperature of the air inside the test cell (°C)
T_{exh}	temperature of the air extracted from the façade (°C)
T_o	temperature of the outdoor air (°C)
t_{gi}	surface temperature of the inner glass (°C)
R.H.	relative humidity
v_{air}	air velocity (m/s)

Greek symbols

ε	dynamic insulation efficiency
η	pre-heating efficiency
ϕ	normalized heat flux
ϑ_{gi}	normalized surface temperature of the inner glass
Σ	normalized daily energy
τ	time (s)

Subscripts

lw	long-wave heat flux or energy
t	total heat flux or energy
A	cell A
B	cell B

façades, a climate façade, with a mechanically ventilated air gap, and a double skin façade, with a natural/hybrid ventilated air gap, have been tested so far.

The monitoring activity concerning the climate façade is presented in this paper. The main aim of the study was to evaluate the overall performance of the façade, in terms of energy efficiency and thermal comfort, and improvements in its performance by varying its configurations and operative conditions e.g. the air flow rate, the shading device and the glazing.

2. The experimental test rig and the analysed active façade

The experimental activity has been carried out by means of the TWINS (Testing Window Innovative System) test facility, at the Department of Energetics at the Politecnico di Torino.

TWINS (Fig. 1) is a measurement facility that has the purpose of evaluating active transparent/opaque façade performances and, more in general, of testing responsive building envelope elements integrated with HVAC systems [3].

The experimental test rig consists of two identical test cells. One cell is used for reference purposes (test cell A) and the façade is left unchanged during the whole measurement campaign.

The other cell is designed to host different configurations and types of active façades (test cell B). The use of a reference test cell allows comparisons to be made between various configurations and sensitivity analyses to be developed, varying different façade features (such as shading devices, width of the air gap, internal or external glazing, and air flow rate), even though the boundary conditions are not exactly the same during the various tests.

The internal sizes of the test cells were chosen accordingly to the IEA-SHC TASK 27 specifications [8] and they correspond to the typical dimensions of façade modules used in office buildings. The TWINS test cells were therefore 1.6 m wide, 3.6 m long and 2.5 m high. The walls, floor and ceiling of the test cells are made up of 48 mm thick sandwich panels, in double painted sheet-steel with expanded polyurethane, with a *U*-value of 0.43 W/(m^2 K).

The test cells are located on the roof of the laboratory in order to be exposed to solar radiation without any shade. They are mounted on wheels in order to be easily rotated to change the façade orientation.

The indoor air temperature of both cells is controlled, with a tolerance of ±1 °C, by means of a full air system that maintains the same thermal environment in both enclosures. The temperature set-point is fixed at 20 °C in winter, 23 °C during the mid seasons and 26 °C in summer.

Since the experimental activity was aimed at analyzing and characterizing the façade component behaviour, the finishing and arrangement of the indoor environment of the two test cells was not designed and built to be representative of any particular configuration, but it was only optimized so that the air from the AHU is distributed as uniformly as possible (in order not to negatively influence the response of the sensors located on the internal facing surface of the façade).

The ventilation system is completely independent of the air conditioning system, which is devoted to control the indoor air temperature. The desired air changes can be adjusted accordingly to the experimental needs. The air flow is generated by means of external centrifugal fans driven by inverters and connected to the cell by PVC ducts (external diameter 11 cm). The ventilation air enters the cells through three holes in the wall opposite the façade. In the reference test cell (A), the air is then exhausted through grilled duct located near the façade. Different configurations may be set up in test cell (B).

During the experimental activity connected to the present study, the active façade was used as the ventilation system exhaust (EA configuration, according to [3]). The air was exhausted through a slot located in the lower part of the façade and then, after flowing from the bottom to the top along the air gap, it was extracted through PVC pipes that run along the false ceiling in the test cell and, finally, conveyed to the outdoor environment.[2]

The analysed active integrated façade (test cell B, Fig. 2a and b), which can be classified as a climate façade, was designed in order to allow the various components and the working parameters to be changed. The external skin is divided into three transparent panes, all made of clear double glass (8/15/6 mm) and separately modifiable. The air gap is mechanically ventilated, and it can be enlarged from 14.8 cm to 30 cm; during the measurements, 14.8 cm was adopted. The internal skin consists of a single clear glass (6 mm) that can be easily replaced with other types of glazing and can be opened in order to make the gap accessible. The shading device is located in the air gap. Two different types of shading devices were tested during the measurement campaign: a venetian blind with micro-perforated aluminium lamellas and a PVC reflective roller screen.

[2] In real applications the air, before being discharged to the outdoor environment, is usually run through a heat recovery system—at least during the heating season. In the present case, this was not done since the aim of the test was just to examine the system performance. To this aim, the potential energy recovery was, nevertheless, continuously measured through a proper experimental set-up, as it will be illustrated in the following section.