ADVANCED FAÇADES AND HVAC SYSTEMS: PRELIMINARY RESULTS OF FULL-SCALE MONITORING

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ABSTRACT

Double skin façades may help combine a high degree of transparency with high thermal and solar performance. Advanced façades serve as filters and may be responsive to changes in environmental conditions and occupant requirements. Since the strategies for heating and cooling depend closely on the façade characteristics, an integrated design approach is instrumental. The paper introduces two examples of innovative advanced façade technology. Twelve full-scale test rooms are currently used for monitoring of different configurations of façades and environmental systems. The paper gives a brief description of the facilities and preliminary results are discussed. Indicative measurements of the solar heat gain coefficients have been carried out for ventilated double skin façades. Energy consumption is assessed by means of transient simulation program TRNSYS. Comfort parameters are estimated in terms of predicted mean vote with different façades and plant configurations. Finally, daylighting measurement have been carried out in order to demonstrate the advantages of double skin façades in terms of visual comfort and energy efficiency, in comparison with traditional façades.

KEYWORDS

Double skin facades, building envelope, daylighting, thermal comfort, energy performance.

BACKGROUND

The demand for sustainable building designs with both daylighting and thermal comfort has lead to novel solutions in terms of façade and HVAC technology. Although these systems are conceived on the basis of fundamental building physics, the general design process is changing and there is a pronounced need for both design tools and guidelines. As a world leader in the curtain walling industry, Permasteelisa is developing advanced façade systems and joining the efforts to provide adequate façade characterization for the design process.

INNOVATIVE, ADVANCED FAÇADE TECHNOLOGY

It is a great challenge to design sustainable buildings and realize transparency without compromising occupant comfort and energy consumption, at an overall cost equal to that of a similar building with conventional technology. Innovative technology adds value in terms of comfort/productivity and image, but on a speculative market first costs are the key driver. High performance building envelopes may, however, allow for plant downsizing, yielding savings on equipment and increasing net-lettable area. All of these aspects must be carefully analysed during the feasibility studies and schematic design phases of a given project.
**Façade Systems**

In order to introduce the adopted terminology, four fundamentally different façade categories are briefly described: *Conventional (fully glazed) façade*: this base case incorporates insulating glazing units and either external or internal shading devices. Coated glass is used to modify thermal and solar glazing performance. *Naturally ventilated façade*: the glazing configuration is composed of an external single layer of glass and an internal insulating glazing unit. The cavity between the two skins is naturally ventilated with outdoor air through openings in the external skin. The cavity can be continuous over one or more floors. *Active Wall* (Figure 1): the glazing system is composed of an external insulating glazing unit and an internal single layer of glass. The cavity between the two skins is ventilated with return room air, which is extracted from the room at the base of the glazing and returned to the air-handling unit at the top. *Interactive Wall* (Figure 1): as per the naturally ventilated wall, the glazing configuration is composed of an external single layer of glass and an internal insulating glazing unit. The cavity between the two skins is ventilated with outdoor air, which is introduced at the base of the glazing and returned to the outside at the top by means of temperature-regulated micro-fans located in the façade itself.

![Figure 1: Schematic of Active Wall (right) and Interactive Wall (left).](image)

**HVAC system interaction**

The performance of the building envelope has a fundamental impact on HVAC options in terms of required capacity and, consequently, the type of applications meeting the requirements. The interaction is even more direct when the façade is ventilated with indoor air (Active Wall), acting as a duct in the ventilation system. In this context conventional façade characterization is no longer readily applicable, since the overall energy performance depends on the combined façade/ventilation scheme and varies with environmental conditions. When developing a design, the façade engineer estimates a series of parameters to allow for analysis of various scenarios by the mechanical engineer, taking the enthalpy changes of the ventilation air into account as required. The field is relatively new and simulation tools for whole building analysis are lacking behind, just as demonstration of energy code compliance is no longer straightforward.

**FULL-SCALE TEST FACILITIES**

In recognition of the lack of data for comparison of different design solutions, measurements are carried out in 14 full-scale test rooms at Permastelisa’s headquarters in Italy (Figure 2). 12 rooms are operative, whilst another 2 are in progress. A series of advanced façade
solutions in conjunction with innovative environmental systems are continuously monitored in terms of energy consumption and indoor environment. The measurements provide a direct comparison between different solutions exposed to identical climatic conditions and yield a basis for validation of both simplified and detailed engineering tools. The building envelope configurations comprise double skin façades (naturally and mechanically ventilated), demonstrating stand-alone systems as well as integration between façade and environmental systems, which comprise variations of radiant systems as well as displacement ventilation. For comparison, innovative solutions are installed side-by-side with conventional systems adopting high performance glazing and fancoil cooling/heating (Kragh, 2001).

![Figure 2: View of the test room facility and two of the test rooms (centre: room 03 / naturally ventilated façade incorporating perimeter HVAC and PV-louvers, right: room 09 / Interactive Wall and dynamic beams).](image)

**Data Acquisition / Control System**

The test rooms constitute a complex combination of solutions in terms of HVAC. The different rooms are generally maintained at identical set point temperatures, although differences will occur depending on HVAC capacity and outdoor environmental conditions. Data acquisition and control is based on a commercially available Building Management System, which is customized to accommodate the experimental requirements.

Every minute the system stores the following parameters: 9 room ambient temperature (3 heights, 3 distances from façade), façade temperatures (3 heights on the different layers and cavities of façade), room ambient humidity, transmitted solar radiation through façade, outlet/inlet airflow rate and temperature, outlet/inlet water flow rate and temperature. A meteorological station records outdoor climatic data. Moreover, mobile instrumentation is available for short duration studies of thermal and visual comfort and acoustic insulation.

**PRELIMINARY RESULTS**

Whereas the test rooms are continuously controlled and monitored, the present papers deals with preliminary results in order to primarily communicate the potential of the test facilities. The long-term main objective is to study the complex relationship between occupant comfort and energy consumption. The present paper is focusing on four of the rooms as follows.
Figure 3: Internal views of three test rooms 07, 08 and 14.

- **Room 07**, reference room, brick wall with high performance glazed punch windows, internal Venetian blinds (white), fancoils (Figure 3).
- **Room 08**, Active Wall with silver coloured Venetian blinds in the ventilated façade cavity, dynamic beams and a radiant ceiling panel along the façade (Figure 3).
- **Room 09**, Interactive Wall with silver coloured Venetian blinds in the ventilated façade cavity, dynamic beams (Figure 2).
- **Room 14**, reference room, fully glazed curtain wall with high performance glazing, internal roller blinds (white), fancoils (Figure 3).

**Solar Heat Gain Coefficient**

When dealing with transparent building envelopes one of the main characteristics is the solar heat gain coefficient (g-value), assessed in conjunction with the light transmittance. Double skin configurations usually comprise shading devices in the ventilated cavity, allowing for efficient control of solar gains, glare, and light transmission. Modelling of complex glazing systems can be carried out be means of the WIS software tool (TNO, 1996), which features cavity ventilation as well as a variable shading model. At Permasteelisa, the performance estimation procedure is validated by test room measurements.

The solar heat gain coefficient is estimated on the basis of measurements of internal surface temperatures and transmitted radiation, assuming an indoor film coefficient of 3W/m·K for convection and 5W/m·K for radiation. During July 2001, measurements were taken at 11am when the solar irradiance on the façade was highest. With silver coloured Venetian blinds (45° slat angle), the Active Wall was found to have a solar heat gain coefficient of 0.21±0.03 (WIS prediction: 0.23), whereas that of the Interactive Wall was found to be 0.14±0.03 (WIS prediction: 0.15). Both systems are fitted with clear glass with one low-e coating, resulting in a light transmittance of 0.70 (no blinds).

**Energy and Comfort**

In order to estimate and compare energy consumption related to the comfort studies, the test rooms have been modelled employing the transient simulation tool TRNSYS (SEL, 1996). In this regard it is noted that one of the main future focus areas is the way the advanced facades are described in such building energy models. The results presented in this paper are based on a simplified characterization in terms of ‘static’ U-value, g-value and light transmittance. The
specific case is based on measured environmental conditions – the outdoor conditions are input as a weather data file, whereas the measured room temperature (averaged over nine positions) is defined as a set point. A longer period of time has been simulated, but the performance is discussed for a certain, critical situation with high solar loads.

Case study: May 17th 2002, 11am, outdoor temperature 28°C, solar irradiance on vertical 700W/m². The predicted (peak) cooling power is reported in Table 1. The comfort has been assessed in terms of the PMV/PPD indices according to EN ISO 7730 (1995) on the basis of measured ambient and façade surface temperatures. The standard states limits for comfort as follows: -0.5 < PMV < +0.5, PPD < 10%. In Table 1 the comfort conditions at 1m from the façade is compared with peak cooling loads in the test rooms.

<table>
<thead>
<tr>
<th>May 17th 11am</th>
<th>PMV (-)</th>
<th>PPD (%)</th>
<th>Cooling power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 07, reference room, brick wall, punch windows, fancoils</td>
<td>-0.42</td>
<td>8.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Room 08, Active Wall, dynamic beams (radiant, convective)</td>
<td>+0.30</td>
<td>7.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Room 09, Interactive Wall, dynamic beams (radiant, convective)</td>
<td>+0.13</td>
<td>5.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Room 14, reference room, fully glazed curtain wall, fancoils</td>
<td>+0.53</td>
<td>10.8</td>
<td>3.1</td>
</tr>
</tbody>
</table>

**Daylighting**

The daylight penetration has been measured in a test room with a fully glazed façade (clear glass) and the reference room with punch windows.

Case study: May 17th 2002 at 11am (daylight saving time). Room 09 (Interactive Wall with silver coloured Venetian blinds, room depth 8.0m) and room 07 (brick wall with punch windows and internal, white Venetian blinds, room depth 4.5m). The blind configuration was varied (no blinds, slat angles 0°, 45° and closed blinds). With the blind slats at 45°, 500lux was recorded in a distance of 2.5m from the façade with punch windows and up to 5.0m from the fully glazed Interactive Wall, in spite of lower blind reflectance. The measured daylight penetration is shown in Figure 4. At the time of the measurements, the solar altitude was approximately 50° and the horizontal shadow angle approximately -10° (defined as the difference between surface azimuth and solar azimuth).

A glare analysis was carried out by means of the Radiance software (LBNL, 1998), analyzing the fully glazed façade with silver coloured blinds (slat angle 45°), applying a CIE standard clear sky model. During May 17th, the daylight glare index (DGI, relates source luminance to background luminance) varies within a range from 11 to 15, which is acceptable compared with the usual limit of 21 (UNI 10840, 2000). At 11am, the DGI is found to be 13 (Figure 5).

**FINDINGS**

Development of advanced façade and HVAC technologies enables architects to design sustainable buildings with daylighting and high levels of thermal comfort. Design tools and standardisation is lacking behind and the whole design process needs to adapt to the explicit interaction between façade and environmental systems. Preliminary results show that mechanically ventilated double skin facades improve daylighting without compromising
thermal comfort close to the façade. The double skin systems in conjunction with soft cooling result in significant energy savings compared with a fully (high performance) glazed curtain wall with internal shading and fancoils.

Figure 4: Daylight penetration, punch windows (left), fully glazed façade (right).

Façade view with light sources

Luminance distribution [cd/m²]

Figure 5: Glare assessment, May 17th at 11am.

ACKNOWLEDGEMENTS

The work of A. Franceschet, A. Simonella and R. Pelizzaro at Permasteelisa, is greatly acknowledged.

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