EXPERIMENTAL ANALYSIS OF AIR FLOW PROFILES IN A DOUBLE SKIN FAÇADE IN A MARITIME CLIMATE

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ABSTRACT

Glazed Double Skin Facades (DSF) offer the potential to improve the performance of all-glass building skins, common to commercial office buildings in which full facade glazing has almost become the standard. Single skin glazing results in increased heating and cooling costs over opaque walls, due to lower thermal resistance of glass, and the increased impact of solar gain through it. However, the performance benefit of DSF technology continues to be questioned and its operation poorly understood, particularly the nature of airflow through the cavity.

This paper deals specifically with the experimental analysis of the air flow characteristics in an automated double skin façade. The benefit of the DSF as a thermal buffer, and to limit overheating is evaluated through analysis of an extensive set of parameters including air and surface temperatures at each level in the DSF, airflow readings in the cavity and at the inlet and outlet, solar and wind data, and analytically derived pressure differentials. The temperature and air-flow are monitored in the cavity of a DSF using wireless sensors and hot wire anemometers respectively. Automated louvre operation and building set-points are monitored via the BMS.

Thermal stratification and air flow variation during changing weather conditions are shown to effect the performance of the DSF considerably and hence the energy performance of the building. The relative pressure effects due to buoyancy and wind are analysed and quantified.

This research aims to developed and validate models of DSFs in the maritime climate, using multi-season data from experimental monitoring. This extensive experimental study provides data for training and validation of models.

Keywords: double skin façade, air flow, energy efficiency, building skins

INTRODUCTION

Since the middle of the twentieth century glass has become the most common material choice for commercial building envelopes, particularly for office buildings. While glass cladding systems have become both affordable and constructionally efficient, their environmental performance continues to present problems. In comparison to insulated, but opaque skins, glass gives rise to high levels of heat loss and increased risk of overheating in buildings. Glazed Double Skin Facades (DSF) offer the potential to improve the performance of all glass building skins. However, a poorly designed DSF can further increase the risk of overheating in buildings [1].

The DSF generally consists of two glazed skins with an air cavity, of varying width (~0.15m-1.5m), between them. Using two separated layers of glass over multiple stories of the building façade allows for air to rise up the cavity through buoyancy. Ventilating the cavity at top and bottom allows for the removal of heated air through the cavity rather than heating the internal building air - particularly worthwhile during summer season. Similar to single skin facades the risk of overheating is a consistent disadvantage of DSF. Other disadvantages include increased construction costs and a reduction in rentable office space.

Even though DSF technology and construction is now well resolved and commonplace, the performance benefit of DSFs continues to be questioned [2]. Their impact is reported in the literature to vary between possible energy savings of over 50% [3], and possible increases in building energy load [4]. Because DSFs are designed to suit the conditions and needs of a specific site, consistency of performance is varied. Also climatic conditions, orientation, construction and geometry are varied and hence comparison difficult and identification of a defining set of indices and thresholds complicated.

Although there has been extensive literature published on the performance of DSFs over the last decade there remains a paucity of experimental studies focused on analysis of real, installed DSFs. The literature has instead focused on CFD modelling based studies. Prolonged monitoring studies of DSF performance, and analysis of operational data during changing climate conditions are necessary to progress the understanding of complex DSF operation during different climatic conditions.

Temperature and airflows in the cavity are a result of many simultaneous thermal, optical, and free/forced convective turbulent fluid flow processes [5]. Solar radiant energy entering through the glass is absorbed by interior objects and surfaces, which then retransmit the energy as thermal radiation mainly in the far infra-red band (above 5 µm). Louvers and shades within the cavity are proposed to impact the air flow in the cavity due to the emittance of thermal radiation from their surfaces. To simply the problem key indices for evaluation of the thermal performance of DSFs are required and Pappas and Zhai (2008) outline a set including; i) airflow rate through cavity openings, ii) average cavity air temperature, iii) peak cavity air temperature and (iv) convective heat transfer through interior glazing.

The first of these, the airflow rate through openings into the cavity, is documented by only a few authors [6]. They generally report low airflow speeds. The standard equation for airflow through openings is generally represented as a function of the applied pressure difference across the opening and its length, cross sectional area and internal geometry.

$$q_v = C(\Delta p)^n \tag{1}$$

where, q_v is the volumetric flow rate through the opening (m^3/s) C is the flow coefficient ($m^3/s/Pa^n$) and n is the flow exponent [7]. The flow coefficient C may be replaced by the product of I_c and k_l, where I_c is the total length of opening (m) and k_l is the flow coefficient per unit length of opening ($L/s.m.Pa^n$). Similarly airflow through openings is also represented in terms of temperature; $q_v = C\Delta T^n$ where, Pappas and Zhai (2008) describe C and n as coefficients that describe the cavity size and geometry of the DSF [6].

The use of average air cavity temperatures to approximate the temperature in the DSF cavity in modelling studies misrepresents the real operation of DSF. Thermal stratification has been well established in previous research [8]. Although not often reported experimentally this seems to be a common occurrence in DSF cavities. Hot air stratifying in the upper stories has a differential and detrimental impact on comfort conditions and operating conditions in the adjoining building spaces. They provide correlations for cavity airflow rate, air temperature stratification, and interior convection coefficient.

Peak temperatures are often 10-15°C higher than average temperature over a 3 story range and can reach values of >35-40°C in the top levels of the cavity, with outdoor air temperatures of 15°C [8].

The convective heat transfer through the interior glazing is only of concern in the case of a DSF ventilated to the interior. This study is focused on a sealed cavity.

METHOD

Case Study DSF

The interior façade is the thermal barrier, with lower thermal, and solar, transmittance. The external glazing is single pane glazing with higher solar transmittance.

The airflow through the cavity is naturally, rather than mechanically driven, due to buoyancy and effects of wind pressure. However, the louvers at top and bottom of the façade are mechanically activated in response to excessive wind speeds (>7m/s) and high cavity temperatures (>24°C). The DSF is automated and works in closed (T_{cav} <24°C) and open (T_{cav} >24°C) modes during the winter period. Temperatures reach peak values of >35-40°C in the middle of the cavity. Airflow in the cavity is generally low (<1m/s) with peak variations during periods of high solar radiation.

Monitoring Study of DSF

A monitoring study was undertaken over a 4-month winter period. Data was gathered at weekly to fortnightly intervals. Temperatures at all levels were extensively monitored with multiple wireless temperature sensors. Two anemometers are used to monitor airflow at different locations in the DSF during different 2-weekly periods – the maximum extend of life of the remote battery, with additional power from attached PV panel.

Figure 1: Equipment installed in the DSF to power anemometers to monitor air flow in DSF.

RESULTS

The following are the key results from the monitoring study of airflow within the DSF during the winter season of 2014/15. Shown are airflows at different levels in the façade and differential airflows during days of high and low levels of direct solar radiation. Airflow at mid and upper levels of the DSF cavity are shown in Figure 2. Days of high solar radiation exhibit higher air velocities than days of low solar radiation.

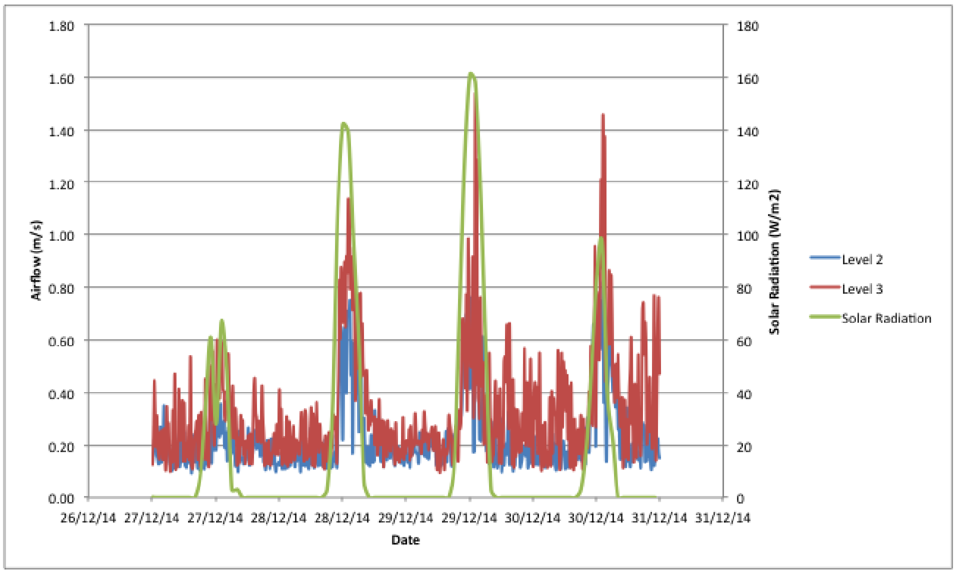

Figure 2: Airflow in mid (Level 2) and top (Level 3) levels of the 3-story DSF during a 4 day period.

The air velocity through the cavity due to buoyancy is low through the monitoring period, with values of < 0.6 m/s common.

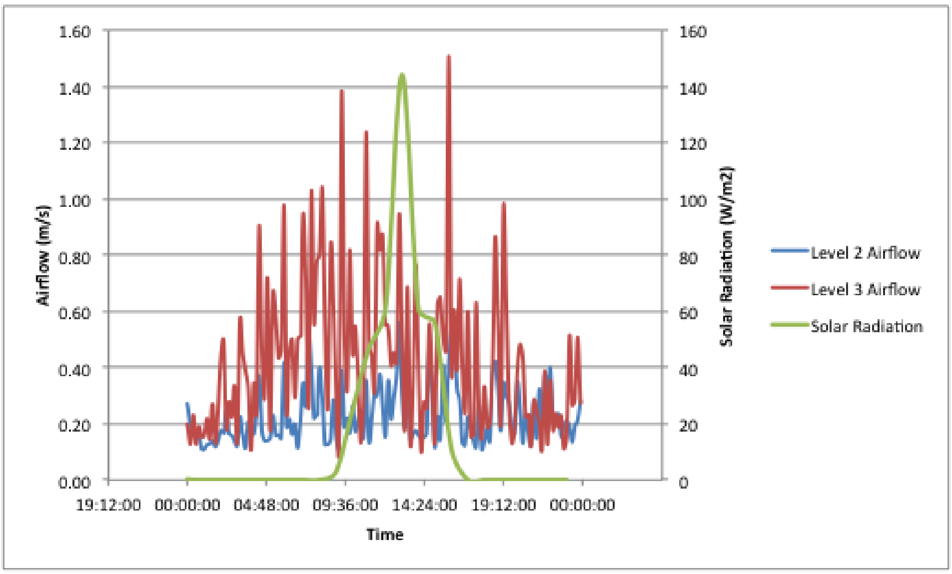

Figure 3: Airflow in mid (Level 2) and upper (Level 3) levels of the DSF on a day of average solar radiation.

Direct and diffuse airflow

The relative impact of diffuse and direct solar radiation, on the airflow characteristics in the DSF cavity, is plotted in Figure 4. During periods of strong direct solar radiation airflow in the mid and top cavity regions are seen to increase from 0.15 m/s to 0.4 m/s and 0.2 m/s to 0.54 m/s respectively.

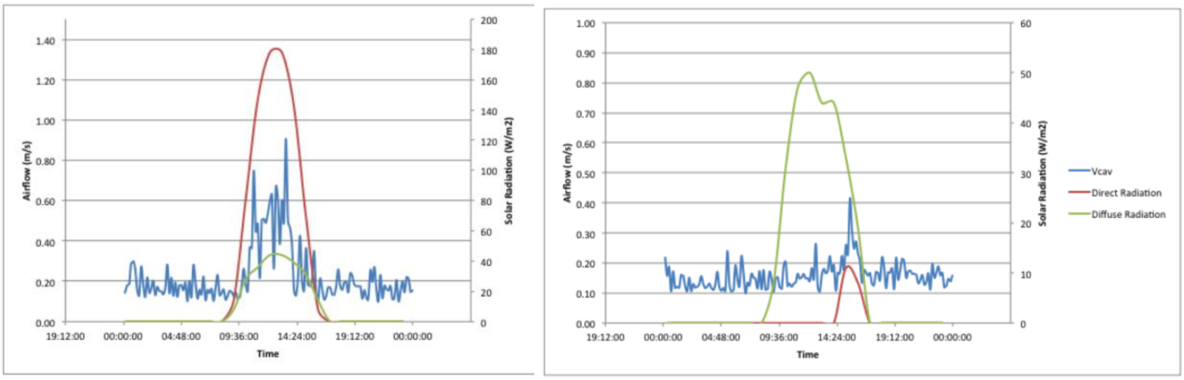

Figure 4: Evidence of the impact of direct and diffuse solar radiation on airflow.

Significant increases in airflow above the consistent night-time flow are observed when direct solar radiation predominates (Figure 4 (right)). On the day shown when diffuse radiation predominates (Figure 4 (left)) peaks in airflow are seen to correlate with late afternoon peaks in solar radiation.

DISCUSSION

Buoyancy drives airflow in the cavity and hence dominates DSF operation in the winter period monitored. Some airflow ingress is constant through designed gaps in louvers, but air velocity increases in the cavity are observed when solar radiation heating of the exterior glazed layer and hence, cavity air temperature.

Airflow velocity in the cavity is generally low (<1m/s) in agreement with those values reported in experimental and modelling studies [6]. During cloudy conditions, with predominantly diffuse solar radiation velocities of <0.2 m/s are commonplace. Airflow increases rapidly in response to direct solar radiation.

The airflow increase results from wind driven air being drawn into the cavity by the negative pressures set up due to the hot air rising in the cavity. Similarly at the outlet, the air is drawn out as a negative pressure zone is created on the backside of the façade. Given the orientation of the façade, slightly offset from the perpendicular to the prevailing wind direction, the impact of the wind needs also be considered.

Wind induced effects could be seen to augment operation at the inlet and outlet. Although the louvers remain ‘closed’ throughout the winter period monitored, gaps exist between the louvers and air can gust through these gaps. Hence prevailing southwesterly wind impacting the facade enhances the drive of air into the cavity, through the gaps in the louvers and out at the outlets. The cavity temperature remains below 24°C during the majority of the monitoring period hence the louvers do not activate for durations that would be viewed to affect the DSF operation significantly.

Given its Northern European geographical location Ireland has extensive cloud cover for long durations of the year. Hence its ratio of direct to diffuse solar radiation is much lower than many continental European cities.

This study is limited to winter season monitoring. Extended monitoring is required to develop an understanding of the contrasting airflows during summer months, when ambient temperatures and solar radiation can be expected to be significantly higher.

CONCLUSION

Based on the results of this study DSFs are observed as beneficial to building performance in Irish winter conditions. Although air movement is observed, flow velocities are generally low and warmed air is thereby retained in the cavity, at higher temperatures relative to the outdoor, to enable the DSF act as a buffer from lower temperatures outside.

Increased levels of airflow are observed in proximity to the inlet and outlet vents, although they remain predominantly ‘closed’ for the winter season. Airflow is highly responsive to direct solar radiation. A significant increase in airflow is observed in sunny, clear sky conditions even when the louvers remain ‘closed’.

Inefficient operation of new and retrofit non-domestic buildings remains all too common in this age of climate change concern [9]. The DSF can provide a solution to glass buildings.

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