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Measuring and estimating airflow in naturally ventilated double skin facades

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ABSTRACT

An accurate assessment of the airflow in naturally ventilated double skin facades (DSF) is crucial for a correct design and performance evaluation. Measuring and predicting DSF airflow is not a straightforward task, given the stochastic nature of the wind, which can assist or oppose the buoyancy force. The present paper resumes the results of airflow measurements inside a naturally ventilated double skin facade using a tracer gas technique. The tests were performed on an outdoor air curtain (OAC) DSF test cell with a movable slat venetian blind. Measurements with no active shading and at night were also performed. Outdoor and test cell air gap temperatures were continuously measured and wind pressure coefficients were determined from wind tunnel tests. Experimental results were then compared to those obtained by a simple model taking into account both thermal and wind effects on the facade. From this comparison discharge coefficients were estimated, which can be used for characterizing the DSF behaviour.

1. Introduction

The building sector accounts for a large percentage of the total energy use in most developed countries (directives 2002/91/EC [1] and 2010/31/EU [2] estimate that buildings are responsible for more than 40% of the energy use in European Union). As a result, the adoption of new environmentally friendly and energy efficient building solutions is highly recommended. A building envelope solution that is touted as providing reduction in energy consumption and increasing sound protection, daylighting and natural ventilation conditions is the double skin facade (DSF). But the success of this solution is mainly driven by its aesthetics, transparency and high-tech image. Double skin facades are characterized by having two panes, mostly glazed, separated by an air gap through which the air flows. Usually a shading device is placed inside the air gap. DSF different layouts, characteristics, drawbacks and favourable aspects may be found in Refs. [3,4,5]. One important drawback of this kind of facade is the cooling energy demand of the building during summer to overcome the common overheating problems and that can exceed the heating energy savings in winter. Only a well-ventilated DSF and a proper shading device can overcome this problem. Therefore, an accurate assessment of the DSF airflow is crucial for the design and performance of the system.

The ventilation of the air gap can be natural or mechanical. Whereas in mechanically ventilated DSF the airflow of the cavity is known, in naturally ventilated DSF determining the airflow rate is a key and challenging issue. The airflow is dependent on wind conditions and facade's thermal behaviour and simultaneously influences the gap temperature distribution. This fact constitutes the main problem of uncertainty in flow value estimates, as reported in Ref. [6]. Gap airflow is responsible for heat removal, but also depends on the removed heat and on the wind action on the inlet and outlet louvers.

In this study a set of tracer gas measurements was performed in order to establish the airflow dependence on the actions referred to above. Those tests were carried out at a naturally ventilated DSF test cell with a movable slat venetian blind. Different tracer gas injection and sampling positions were used for the ventilation rate estimation. Although there are several DSF typologies, only an one storey outdoor air curtain (OAC) case, where outdoor air is introduced into the cavity and then rejected towards outside, will be analysed in this paper. Measurements with no active shading and at night were also performed. A simple model, that takes into account

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Nomenclature

A	area [m^2]
$\overline{C}$	time averaged tracer gas concentration in the space [mg/m^3]
C_d	discharge coefficient [-]
c_i	sampling position (i = 1,2,3) [-]
$C(t)$	tracer gas concentration at time t [mg/m^3]
C_p	wind pressure coefficient [-]
D_g	dosing rate [mg/s]
d_i	emission position (i = 1,2,3) [-]
g	gravitational acceleration [m/s^2]
G_{est}	estimated airflow rate [m^3/h]
G_{pot}	maximum potential airflow rate [m^3/h]
$G_{trc\ gas}$	measured airflow rate [m^3/h]
H	height between upper and lower louvers [m]
I_v	incident solar radiation on vertical surface [W/m^2]
n_c	number of sampling positions [-]
n_d	number of emission positions [-]
P_i	local surface wind induced pressure [Pa]
P_{st}	upstream static pressure [Pa]
t	time [s]
T	temperature [K or °C]
$\overline{T}$	average temperature [K or °C]
U	air velocity in the cavity [m/s]
U_∞	wind velocity [m/s]
V	volume [m^3]
Greek letters	
Δ	difference
θ	slat angle [°]
ρ	air density [kg/m^3]
$\sigma_{C_{d_\theta}}$	standard deviation of the discharge coefficient [-]
ψ	relative contribution of stack effect to the natural airflow in the DSF cavity [-]
Subscripts	
0	reference
c	sampling position
d	emission position
e	outdoor
gap	air gap
lower	lower louver
sh	shading device
θ	slat angle
T	temperature
tot	total
upper	upper louver
W	wind

both thermal and wind effects, was used to predict the maximum potential airflow rate. By comparing the measured airflow with the maximum potential values, an overall gap discharge coefficient was estimated for each slat angle position.

2. Test cell and equipment

The test cell was assembled at LNEC (National Laboratory of Civil Engineering) premises for a measuring campaign under the framework of IEA-ECBCS Annex 44 [7]. The main goal was to assess the thermal behaviour of a DSF operating in a Mediterranean climate using several ventilation modes (air supply, air exhaust, inside air curtain, outside air curtain and buffer), and different shading devices (roller blind and venetian blinds) in different positions and with different slat angles.

The DSF was built into the SSE test cell face (160° clockwise from North), measures 3.5 m width and 2.5 m height, with glazing area of 3.2 × 2.05 m^2, and has a 0.2 m gap depth (Fig. 1). The outside pane consists of a 5 mm thickness single clear glass and the inside pane is composed of a clear low-ε double glazing (6 mm cavity facing low-ε glass +16 mm air +5 mm room facing clear glass). Both panes have top and bottom louvers as inlet and outlet openings for the air flow circulation. These consist of a total of eight aluminium dampers built in the facade's frame (Fig. 1). Each of the eight vents has 1.63 × 0.225 m^2 and three equally distanced parallel and horizontally pivoted blades allowing changing from fully open to fully closed position. The open and closed dampers' positions determine the airflow path within the facade gap, i.e., the ventilation mode. The OAC mode means that external pane louvers are open and internal pane louvers are closed.

The shading device is a manually controlled venetian blind system with varying slat angles, θ (0°, 45° and 90° were used).

The measurement equipment used in the test cell includes temperature and irradiation sensors. For temperature measurement T type thermocouples were used in the glazing and shading surfaces and in the air gap at three levels (n_1, n_2 and n_3 – Fig. 1) – in front of and behind the shading – and close to the louvers. From time to time, anemometers (AirFlow TA5) were also used to assess local air velocities in the DSF cavity. The incident solar radiation on the DSF was measured with a Kipp & Zonen CMP3 pyranometer.

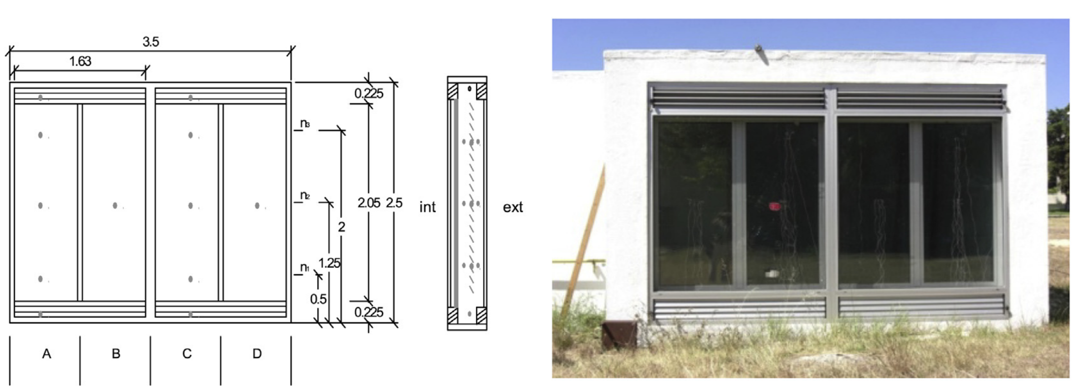

Fig. 1. Test cell dimensions (in meters), temperature sensors' positions (●) and the DSF test cell.