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A numerical analysis of the air ventilation management and assessment of the behavior of double skin facades

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ABSTRACT

In the case of ventilated double skin facades, good management of shading devices and rational use of the ventilation channel are the two most effective ways to reduce the penetrating undesirable load inside interior spaces, especially during warm periods. This paper examines the effect of solar radiation, incidence angle and slat angle on the thermal properties, as well as, the solar transmission into the interior environment for a double skin facade equipped with a venetian blind. In addition, the ventilation efficiency was examined as a function of material emissivity, inlet air flow rate and inlet air temperature. To complete this operation the CFD code, FLUENT 6.3, was used with a realizable k–ε turbulence model. In order to solve the radiative transfer equation and to quantify the solar and thermal radiation, the discrete ordinates (DO) radiation method was implemented using a two-band spectral model. It was concluded that, the solar transmission is influenced by the solar radiation, the incidence angle, the slat angle and the material emissivity. The results showed that, when the slat angle exceeds 60°, the heat flux transmitted reach minimum values. The results indicated also, that the dynamic insulation efficiency, ε_d is independent of the ventilation strategy when $\theta > 75°$, and its assessment is important, when the incidence angle is 0° and the slat angle is 85°. Thus, the ventilation channel is necessary when the solar radiation incident on the exterior glazing is maximal and the slat prevents that the solar radiation penetrates into the interior environment.

1. Introduction

The improvement of the thermal comfort, the visual comfort and the buildings ventilation equipped with high glazing surfaces and located in the hot regions, generates significant energy savings. That encourages the domain specialists, to search the ways to deal with this problem, by using several technical and systems, such as: the double skin facade (DSF) and the shading devices. The DSF is a special type of envelope, where a second skin, usually a transparent glazing, is placed in the front of a regular building facade. The air space in between, called the channel, can be rather important (up to 0.8–1.0 m) [1]. In the channel, the solar shading device such as the venetian blinds is often used to improve the DSF performance. As the goal is always, conserved energy and ensure the thermal comfort in the indoor space, several constraints affect the DSF behavior, must be analyzed and managed well, such as: the shading device performances and the ventilation channel. However, the presence of a shading device renders the process of the heat transfer and the airflow, complex. The shading device is an important component of the DSF. The shading device provides protection from direct sun radiation and overheating in summer, thus reducing the cooling loads for the building. Several parameters have been examined in order to assess the shading device performances. The slat angle effect and the distance between the shading device and the glazing were investigated by Gratia et al. [2], Mauricio [3] and Jiru et al. [4]. Other important studies, such as, Pfrommer et al. [5], Rosenfeld et al. [6], Yahoda et al. [7] and Chaiyapinunt et al. [8], were interested in the definition of the solar-optical properties of a shading device, such as: the solar absorption and the solar transmission. These quantities help to assess the DSF thermal performances, especially when we use, the thermal–solar separation technique. Concerning the ventilated channel and its thermal behavior, there are three different operating modes for the ventilated channel: natural, forced or mixed. The natural ventilation is driven by two mechanisms: the difference in the wind pressure or the buoyancy effect produced by the temperature difference between the air channel and the exterior environment. The mechanical ventilation is only used when the natural ventilation

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Nomenclature

A	facade area (m^2)
C_p	specific heat capacity (J/kg K)
D_h	hydraulic diameter (m)
$\vec{g}$	gravitational constant (m/s^2)
h	heat transfer coefficient (W/m^2 K)
I_λ	radiation intensity for wavelength λ (W/m^2 sr)
$I_{b\lambda}$	intensity of black body radiation (W/m^2)
k	thermal conductivity (W/m K)
$\dot{m}_v$	air mass flow rate (kg/s)
p	pressure (Pa)
Pr	Prandtl number
Q	generic heat flux (W)
Re	Reynolds number
R_{sg}	solar radiation incident (W/m^2)
S_h	radiation source term (J)
T	temperature (K)
Y^+	non-dimensional wall coordinate

Greek symbols

α	absoptivity
α_s	solar altitude (°)
α_λ	spectral absorption coefficient (1/m)
ρ	density (kg/m^3)
θ	incidence angle (°)
λ	wavelength (m)
ε_d	dynamic insulation efficiency (%)
ε	emissivity
γ	wall–solar azimuth (°)
μ	viscosity (kg/m s)
μ_t	turbulent viscosity (kg/m s)
Ψ	slat angle (°)

Subscripts

amb	ambient
eff	effective
exh	exhaust
ext	exterior
in	inlet
inc	entering the outer surface of the facade
int	interior
r	removed
ref	reference

driving forces, become insufficient to achieve the desired performances. According to the ventilation type and the system design, the airflow can be oriented upwards or downwards. The experimental results show that, the use of the DSF can reduce the energy consumption until 15%, while using a natural ventilation and until 30% in the winter while using a passive solar heating, Xu et al. [9]. For optimization and study the DSF behavior, numerical and experimental models have been used. Network models, Tanimoto et al. [10], the lumped and the analytical models, Park et al. [11], the dimensional analysis, Balocco et al. [12], the airflow network models coupled with the energy simulation, Gratia et al. [13] and the zonal models, Jiru et al. [14]. However, for mechanically ventilated facades, an experimental study, well detailed by using the computational fluid dynamics (CFD) was led by Manz et al. [15] and for naturally ventilated facades [16].

The study of Safer et al. [17] is concerned for a three-dimensional simulation with a CFD tool for a DSF equipped with venetian blinds. Ji et al. [18] investigated the coupled heat transfers by convection, conduction and radiation in a DSF. Recently Darco et al. [19], proposed a methodology for modeling the solar irradiation with a CFD tool. The authors deducts that the slat angle variation minimizes the solar transmittance into the interior environment by 85%. In terms of energy savings and comfort conditions, several studies have been conducted, such as the works of Corgnati et al. [20], Perino et al. [21], Perino et al. [22] and Serra et al. [23]. In the absence of the experimental tests, the aim of this work is to evaluate and improve the DSF behavior in term of a specific index, in this work, it is the dynamic insulation efficiency, thus the quantification of the flux penetrating inside the local with a CFD tool and taking into account several parameters that influence significantly the DFS behavior, such as: the incidence angle, the slat angle, the material emissivity and the mass flow rate.

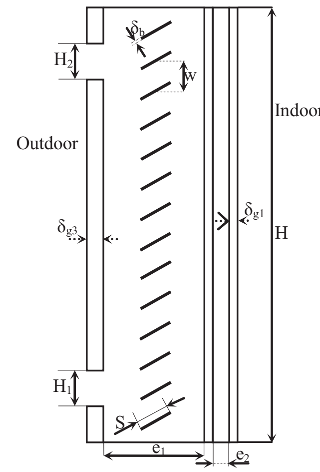

Fig. 1. Schematic of double skin facade.

2. Case description

In this work, Safer's test cell dimensions were selected [17]. We use the notation of Fig. 1, the DSF geometrical dimensions, are summarized in Table 1.

In the Safer study, the inlet and the outlet air, respectively situated at the bottom and the top of the outer facade. The shading device is a venetian blind and has been installed in the channel middle, between the exterior glazing and the interior glazing. In the present work, the weather data used by Safer et al. [17] were adopted.

2.1. Material properties

The air channel and the double glazing air were considered as transparent media, the glass as semi transparent media and the venetian blind was considered as opaque media. The blind material is aluminum. The refractive index (n) and the absorption coefficients (α) (the extinction coefficient) are important when considering radiation in a semi-transparent media. Note that at first, the blind emissivity was fixed at 0.10 and then it takes the values of 0.1 at 0.9 with a step of 0.1. The glazing absorption coefficient is given according to two wavelength bands (0.001–2.7 μm and 2.7–100 μm). The characteristic parameters of the DSF are given in Table 2.

3. Modeling and simulation

In the present study, the CFD code, Fluent 6.3, was used to simulate 2D, coupled convective and radiative heat transfer and fluid flow in the DSF. The flow was modeled as steady-state and two dimensional. It is assumed that the cavity air between the interior