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Influence of natural ventilation due to buoyancy and heat transfer in the energy efficiency of a double skin facade building

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ABSTRACT

In recent years, the interest in double skin facades has increased because of esthetic reasons and for its use as passive system to save energy. Some authors have investigated their behavior related to thermal performance and energy efficiency compared to single skin facades but only considering the air cavity. The aim of this work is to identify a more efficient double glazed facade configuration that improves energy efficiency and indoor comfort conditions in buildings studying natural ventilation due to buoyancy-driven flow and heat transfer including solar radiation compared to a single skin facade. A simplified model was simulated using a computational fluid dynamics software to investigate the effects due to different cavity widths in winter and summer conditions with opened and closed vents and considering solar radiation or not. The main results obtained were that in winter closed vents is always efficient and ventilating is never beneficial. In summer closed vents is efficient in the absence of solar radiation and in its presence opened vents is favorable. Results showed the optimum air cavity width, and it was concluded that these double skin facades reduce the heating and cooling demands of a building, being more efficient compared to single skin facades.

Introduction

This study is the continuation of a previous work in which the state of the art in relation to the legislation, research and technology of envelope systems in architecture, taking into account natural ventilation and sealing to the penetration of wind driven rain, was analyzed (Sanchez and Rolando, 2014).

Double skin facades consist of two panes separated by an air cavity through which air flows in between. Generally, the outer pane is entirely made out of glass, while the inner pane may be partially opaque; but in this study, the two panes are made out of glass. This type of facade may incorporate vents to ventilate the air cavity when they are opened.

In recent years, the study and the interest in this type of envelopes have increased. They are often used in commercial buildings for esthetic reasons. The advantage of double skin facades is that they admit a high degree of daylight because of its large glazed area, but as a result, heat losses in winter and large increase in heat gains in summer can be achieved due to the solar energy transmittance to the interior and with the possible overheating of the building.

Double skin facades could be used as a passive system to improve thermal comfort conditions and building energy efficiency. These envelopes can be used as an efficient alternative for reducing the energy use in buildings.

The driving forces in the naturally ventilated double skin facades are thermal buoyancy, pressure differences due to wind or combined wind and buoyancy driven flow. In this paper, only buoyancy-driven flow is studied.

Natural convection due to buoyancy in closed rectangular cavities with differentially heated vertical walls has been studied experimentally as well as analytically and numerically extensively over the years (Korpela et al., 1973; Lartigue et al., 2000). The transition from laminar to turbulent flow, the flow characteristics, the physical phenomena that take place inside the cavity and the variables involved in the process were studied. Heat transfer in buoyancy-dominated flows is of fundamental importance in several architectural applications such as fenestration glazing cavities, cavities of ventilated facades and solar chimneys, among others.

In recent years, the behavior of the double skin facade has been investigated related to the thermal performance and energy efficiency of buildings compared to the single glazed facade system. Some authors utilized a CFD program to analyze the impacts of several parameters in double skin facades, such as orientation, wind and solar protection, depth of the cavity, glazing type, openings size, climatic conditions and solar radiation level, among others (Balocco, 2002; Faggembauu et al., 2003; Hien et al., 2005; Saelens et al., 2003; Zerefos, 2007; Gratia and De Herde, 2007). Other authors carried out full scale experiments to quantify the thermal performances and energy transmittance

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Nomenclature

A	aspect ratio (dimensionless)
C_p	specific heat ($\mathrm{Jkg^{-1}\,K^{-1}}$)
g	gravitational acceleration ($\mathrm{m/s^2}$)
H	cavity height (m)
h	average heat transfer coefficient ($\mathrm{Wm^{-2}\,K^{-1}}$)
h_e	external heat transfer coefficient ($\mathrm{Wm^{-2}\,K^{-1}}$)
h_i	internal heat transfer coefficient ($\mathrm{Wm^{-2}\,K^{-1}}$)
h_v	air inlet and air outlet height (m)
L	cavity width (m)
t_p	glass pane thickness (m)
Nu	Nusselt number (dimensionless)
Pr	Prandtl number (dimensionless)
Q	heat flux ($\mathrm{W/m^2}$)
Q_r	heat generation rate ($\mathrm{W/m^3}$)
Q_s	solar irradiance ($\mathrm{W/m^2}$)
q_e	secondary heat transfer factor towards the outside (dimensionless)
q_i	secondary heat transfer factor towards the inside (dimensionless)
$\mathrm{Ra_L}$	Rayleigh number (dimensionless)
S_λ	relative spectral distribution of the solar radiation (dimensionless)
T	average temperature in the enclosure (K)
T^+	average dimensionless temperature in the enclosure (dimensionless)
T^*	dimensionless temperature in the air cavity (dimensionless)
T_c	temperature of the cold pane (K)
T_h	temperature of the hot pane (K)
T_{ref}	reference temperature (K)
x	cavity horizontal distance (m)
X^*	cavity horizontal distance (dimensionless)
y	cavity vertical position (m)
Y^*	cavity vertical position (dimensionless)
α	thermal diffusivity ($\mathrm{m^2/s}$)
α_e	solar direct absorptance (dimensionless)
α_{e1}	solar direct absorptance of the outer pane (dimensionless)
α_{e2}	solar direct absorptance of the second pane (dimensionless)
$\alpha_1(\lambda)$	spectral direct absorptance of the outer pane measured in the direction of the incident radiation (dimensionless)
$\alpha'_1(\lambda)$	spectral direct absorptance of the outer pane measured in the opposite direction to the incident radiation (dimensionless)
$\alpha_2(\lambda)$	spectral direct absorptance of the inner pane measured in the direction of the incident radiation (dimensionless)
β	thermal expansion coefficient of air ($\mathrm{K^{-1}}$)
γ	total solar energy transmittance (solar factor) (dimensionless)
η	energy efficiency index
K	thermal conductivity ($\mathrm{Wm^{-1}\,K^{-1}}$)
Λ	thermal conductance ($\mathrm{Wm^{-2}\,K^{-1}}$)
λ	wavelength (m)
$\Delta\lambda$	wavelength interval (m)
ν	kinematic viscosity ($\mathrm{m^2/s}$)
ρ	density ($\mathrm{kg/m^3}$)
ρ_e	solar direct reflectance (dimensionless)
$\rho_1(\lambda)$	spectral reflectance of the outer pane measured in the direction of incident radiation (dimensionless)
$\rho'_1(\lambda)$	spectral reflectance of the outer pane measured in the opposite direction of incident radiation (dimensionless)
$\rho_2(\lambda)$	spectral reflectance of the inner pane measured in the direction of incident radiation (dimensionless)
τ_e	solar direct transmittance (dimensionless)
$\tau_1(\lambda)$	spectral transmittance of the outer pane (dimensionless)
$\tau_2(\lambda)$	spectral transmittance of the inner pane (dimensionless)

of single and double skin facades (Eicker et al., 2008; Kim et al., 2009). It was concluded that if double skin facades are designed carefully, they would exhibit a significantly better passive behavior than conventional glazed facades, and also would reduce energy consumption.

The goal of this paper is to study natural ventilation due to buoyancy and heat transfer in a double skin facade compared to a conventional glass facade. Other works only study the phenomena that take place in the air cavity, and many of them do not vary either the model geometry or the boundary conditions or take into account the solar radiation.

A CFD model, that includes conduction, convection and radiation is used to study the double skin facades behavior globally. The goal is to find the optimum air cavity width so as to reduce heating and cooling demands in the building, improving building energy efficiency.

The novelty is that a more extensive investigation is performed where the model is analyzed more broadly: outside environment, air cavity and inside the enclosure; varying the geometry: cavity width with closed and opened cavity vents; and under different conditions: winter and summer conditions with and without solar radiation. In all situations, the phenomena that take place from the point of view of heat transfer, temperature distribution, flow regimes and airflow characteristics, are studied and analyzed.

The aim is to achieve or identify a more efficient facade configuration that improves building energy efficiency to improve indoor comfort conditions.

Geometry

A simplified double skin facade model was used for the study. A 2D simulation was carried out and the flow was assumed steady state.

The basic geometry used in CFD simulations is illustrated in Figs. 1 and 2. It is an enclosure with a double skin facade facing south, composed by an inner facade, an air cavity and an outer facade.

The enclosure dimensions are 3 m high (H) and 6 m wide ($2H$). The air cavity extends the whole height of the model. There is an air inlet (h_v) near the bottom and an air outlet near the top of the section, both 6 cm high. The air cavity is completely closed off from the enclosure's interior. Different facade configurations are studied, therefore the air cavity width (L) varies.

In order to study the various facade configurations under different conditions, the computational domain of the CFD simulation had to be extended to include part of the outside environment. In the study, the dimensions for the domain were 21 m wide and 10 m high.

Eight different cases were simulated with 29 facade configurations studied, which is a total of 116 cases. Winter and summer conditions were simulated, with closed and opened cavity vents and considering solar radiation or not. Every possible situation was considered, and several facade configurations were studied from the single skin facade to the double skin varying the cavity width with aspect ratios (A) from 6 to 600, where $A = H/L$, being H the cavity height and L the cavity width.

Simulation software

ANSYS Fluent® (14.0 version) was used to simulate the airflow and heat transfer. This commercial software has been previously validated in literature (Fuliotto et al., 2010). The air properties were assumed to be constant. The airflow inside the cavity was considered steady state and the pressure-based solver was used.