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Double skin façade: Modelling technique and influence of venetian blinds on the airflow and heat transfer

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HIGHLIGHTS

- CFD investigations on modelling strategy, blind proximity and inclination of a DSF with venetian blind have been conducted.
- Significant computational saving is possible considering a simple domain.
- The proposed methodology establishes how solar irradiation can be modelled with CFD.
- Variation of blind tilt angle can minimise incoming solar energy to indoor space by about 85%.
- Optimum blind position in terms of energy saving is about one third from the external façade.

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ABSTRACT

The demand to reduce building cooling load and annual energy consumption can be optimised with the use of Double Skin Facade (DSF). Computational Fluid Dynamics (CFD) methods are frequently used for the analysis of heat transfer through DSF. However, considerable uncertainty exists regarding few key parameters, such as modelling strategies and the solar heat transmitted to the indoor space as a function of the blind tilt angles and positioning within the façade channel. In this paper we have investigated four modelling strategies and the influence of blind tilt angle and their proximity to the façade walls. The DSF system used in this investigation is equipped with venetian blinds and facades that absorb and reflect the incident solar radiation and transfer the direct solar heat gain into the building. A finite volume discretization method with the SIMPLE solution algorithm of the velocity-pressure coupling involving the low-turbulence $k-\varepsilon$ model is used. A ray-traced solar model is coupled with long wave radiation model to solve the complete solar and radiation fields along with convection and conduction fields.

On the modelling strategies, three dimensional domains were cast over three computational zones; external zone with solar radiation entering the outer skin of glass; buoyancy-driven air cavity zone with convection and transmitted solar radiation; and an internal zone. Also investigated is the thermal behaviour of the DSF due to the blind tilt angles (30°, 45°, 60°, and 75°) and its position from the facade walls (104 mm, 195 mm, 287 mm and 379 mm). Validations of the results are based on experimental data from the literature and the predicted trends compared very well with the experimental measurements. The heat gain due to direct solar radiation and convection through the facades to the internal space are presented. Comparative analysis of the four modelling strategies shows little variation of the results. The implication is a reduction in complexity and cost of modelling, since the additional effort requires in the CFD modelling is not justified by a significant improvement of the results. The variations of the blinds tilt angles as well as its proximity to façade walls significantly influences the convective flow within the façade cavity and the heat gains to the indoor space.

1. Introduction

The potential to reduce building cooling load and annual energy consumption is widely recognized in the use of devices to control solar gain. Double-skin facades (DSF) are getting more and more attention and are widely used in commercial buildings. In hot

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Nomenclature

RANS	Reynolds-average Navier–Stokes
DSF	double skin façade
DO	discrete ordinate radiation model
I	radiation intensity
V	air velocity, m/s
a	absorption coefficient
β	thermal expansion coefficient, 1/K
ρ	density, kg/m^3
σ	Boltzmann constant = 5.67×10^{-8} Wm^{-2} K^{-4}
T	temperature, K
ΔT	temperature difference, K
τ	transmittance of the glaze
θ	blind tilt angle, degree
$ø$	attenuation energy function
S_g	extinction coefficient
L_g	thickness of glaze
T_g	temperature of glaze, K
T_{amb}	outdoor ambient temperature
α	absorptivity
δ	blind proximity from façade

Subscripts

rad	radiation
in	inlet condition
out	Outlet condition
v	visible radiation
IR	infrared radiation
D	diffuse hemispherical radiation

summer and cold winter regions, a naturally ventilated external DSF with solar shading device such as venetian blinds are often used to enhance DSF energy performance [1–3].

In order to save air-conditioning energy and to guarantee indoor thermal comfort, the performance of shading, ventilation and heat transfer in naturally ventilated DSF buildings should be analysed and optimized. Although the concept is not new, its complexity and adaptability to different climatic conditions increase the need for further careful analysis. The accuracy of numerical modelling of the flow and heat transfer predictions in the facade will lead to less uncertainty in the design and construction by better adapting to the performance requirements of the designer. The aim of this study is to perform detailed numerical investigations on the heat transfer and flow inside a DSF system, and, in particular, to explore the influences of location and inclination of the venetian blinds on the heat transfer to the indoor space. Also reported is the influence of numerical modelling strategies which involves the coupling of different fluid zones and comparing the results, which aim to limit the cost and effect in the numerical modelling of DSF. This paper considered various parametric studies on DSF airflow and heat transfer.

To achieve the above aims, a systematic three-dimensional numerical investigation of turbulence natural convection flow and heat transfer in a DSF containing isolated venetian blinds has been conducted. A parametric study was conducted to quantify the influence of several factors of the airflow and heat transfer by the DSF. Firstly, a detailed numerical study was conducted to analyse different CFD modelling strategies involving the coupling of different fluid zones and comparing the results. Secondly, comparative numerical analyses of the influence of venetian blind inclination and proximity on the heat transfer to the indoor space have been reported. The quantified data and analyses will serve as an outline and guidance to assist designers of such facades, and will further enhanced the understanding of the thermal behaviour of such ventilated double skin facades.

2. DSF with blind

The recent trend in the research community for the numerical modelling of flow and heat transfer in double skin facades is focused on facades with interaction of obstacles with the flow and heat transfer within the cavity. These obstacles are in the form of venetian blinds for solar shielding and building construction elements. Mei et al. [4], Safer et al. [5] and Ye et al. [6] conducted 2D numerical simulation to investigate the coupled convective and radiative heat transfer through the DSF with venetian blinds inside the facade cavity. They investigated the influence of the blind angle in the range of 0–80° on the airflow and heat transfer within the cavity and their modelling results were validated with the measurement from a section of facade tested within a solar simulator, and with predictions from a component based nodal model. Agreement between experiment and numerical results was generally good and any discrepancies were caused by the implication of the CFD model resulting in less turbulence mixing within the facade cavity. Their results have shown that the presence of the venetian blinds has led to 35 percent enhancement in natural ventilation flow and 75 percent reduction in heat loads for the internal environment and also the changes of the convective heat transfer coefficient on the glazing surfaces was caused by the venetian blinds with different angles.

Pasut and Carli [2] investigated the performance of the two most commonly used turbulence models (k–ε and k–ω) for simulating the naturally ventilated DSF and results validated against available experimental data. Safer et al. [5] conducted a comprehensive numerical modelling of radiative and convective heat transfer of a compact double-skin facade equipped with venetian blind and concluded that the convective heat transfer coefficients found were weak and only little influenced by slat tilt angles, but its effects on radiative heat transfer was very important, since it regulated the solar radiation transmitted to the inside. Fuliotto et al. [7] used a decoupling method to evaluate thermal performances and analysed fluid phenomena in a DSF. Solar radiation effects were evaluated with an analytical model, while complex flow and thermal effect were simulated using CFD. There is good agreement between the numerical results and experimental data collected on a full scale test room with a ventilated DSF. Mei et al. [8] investigated the effects of external conditions, solar irradiation and exterior air temperature on double skin facade with differing internal characteristics. The effect of blind blade angle on cavity temperatures and airflow were also reported.

Teshome et al. [9], investigated the airflow and heat transfer for a DSF system equipped with a venetian blind using the RNG turbulence model for a three-level combination of slat tilt angle and blind position. The prediction was validated using experimental data collected for a mechanically ventilated DSF equipped with venetian blinds. The predicted trends in glass and blind surface temperatures of the CFD model are compared well with the experimental measurements. Their results show that the presence of venetian blinds influences the surface heat transfer coefficients and the temperature and the air distribution in the DSF system. Also, the changes in