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Short communication

Thermal convection in double glazed windows with structured gap

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A B S T R A C T

Convective heat transfer inside the gap of double glazed windows is studied numerically using a commercial CFD code (Fluent v6.3), for different Rayleigh numbers and aspect ratios. A reference window with empty gap is compared with windows where the gap contains fins arranged in such a way as to reduce heat transfer. The effects of convective air flow inside the cavities were estimated both at the onset of convection and at steady-state in real environmental conditions. The global Nusselt numbers were calculated for different configurations of the fins in the window gap, in order to apply the standard heat loss estimation method to this type of windows.

1. Introduction

Concerns about the rational use of primary energy sources stimulate both fundamental and applied research on energy dissipations in the built environment, which is often referred to as *thermal design of buildings*. In particular, much research is focused on thermal energy losses due to heat transfer between the building envelope and the surrounding environment, in order to predict the rate of heat loss and to develop minimisation strategies. The fluid movement in enclosures used in building walls due to buoyancy forces resulting from a temperature difference between both vertical surfaces is generally laminar and uni-cellular. Multi-cellular flow, always in laminar regime, will develop in the core cavity, which tends to increase local and average heat transfer coefficients.

Among the various components of the building envelope, windows require a careful design because much of the heat dissipation occurs there. Energy efficient windows should minimize heat losses as well as air leaks: this is achieved in practice by a combination of different technical solutions, such as multi-layer glazing, low-thermal conductivity gas fills, painted glass surfaces, low-emission coatings, edge spacers, Venetian blinds, etc. [1–3]. An optimal window design with a suitable glazing layering can considerably reduce the energy consumption of air-conditioning systems (10–50%) in most climates. In commercial, industrial and public buildings, an optimum window design has the potential to reduce the cost of illumination as well as that of heating, ventilation and air-conditioning (HVAC) by 10–40% [4].

However, despite these advanced design solutions, which increase significantly the cost of windows, heat losses through the glazing remain one order of magnitude larger than in other components of the building envelope (walls, roofs, floors). One of the main factors affecting the magnitude of the heat flux through a double glazed window is the phenomenon of free convection within the gap, which depends both on the geometry (characteristic size and aspect ratio) and on the temperature boundary conditions. In particular, convection enhances the heat flux through the window, reducing thermal insulation.

Theoretical and numerical studies refined the problem solution, i.e., the accuracy of heat transfer calculations. These studies showed that the problem solution is a function of three dimensionless parameters: the aspect ratio of the cavity, the Prandtl number, $Pr = c_P\mu/k$, where c_P is the specific heat, μ the dynamic viscosity, and k is the thermal conductivity of the fluid, and the control parameter of the flow, the Rayleigh number, $Ra = g\beta\Delta TL^3/\alpha\nu$, where β is the thermal expansion coefficient, α the thermal diffusivity, ν the kinematic viscosity of the fluid, g the gravity acceleration, L is a characteristic geometric size, and ΔT is the temperature difference driving the convective flow. In particular, for $Ra < 1750$ viscosity prevents the onset of buoyancy-driven convective motions. Within the range $1750 < Ra < 3000$ one can observe the onset of convection, depending on the geometric parameters. For $Ra > 3000$ heat transfer is a growing function of the Rayleigh number, which means a reduction of thermal insulation.

To characterize the convective heat transfer intensity one can use the Nusselt number, $Nu = hL/k$ (where h is the convection heat transfer coefficient), which represents the ratio between the actual thermal power transferred from the wall to the fluid (or vice versa), and the thermal power that would be transferred in case of purely conductive heat transfer mechanism. This implies that the lower

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bound for the Nusselt number values is $Nu = 1$, corresponding to thermal conduction.

Recently, fenestration products with "integrated shades" have become popular, especially in North America. These include various types of shades located between the panes of a double or triple glazed window such as louvered blinds, pleated blinds, and roller blinds [4–7]. The convective heat transfer characteristics of windows with internal Venetian blinds were studied experimentally [8,9]. More recently the thermal performance of a window with a between-panes pleated cloth bind was investigated by means of CFD simulations [10].

The aim of the present work is to study the fluid dynamics inside the cavity of double glazed windows, in order to quantify the heat transfer reduction that can be achieved through a suitable arrangement of transparent fins within the gap, designed with the purpose of reducing or suppressing convective motions. In particular, convection within a reference window with empty gap is compared with convection in two windows, where the gap contains parallel fins and fins arranged to form a spiral, respectively.

The advantages of these windows with respect to many commercially available products is that the thermal performance is improved without a significant reduction of illumination. Moreover, transversal fins block direct solar radiation and may be designed to filter the infrared radiation, hence improving insulation during the hot season.

2. CFD model

The flow field induced by temperature gradients within the selected complex geometries was solved using the commercial software Fluent (v. 6.2.16). In particular, the present work focuses on three-dimensional numerical simulations for the temperature and velocity fields inside three different cavities with different wall temperatures, shown schematically in Fig. 1:

- The first geometry is a standard double-glazed window with empty gap, height and length both equal to 496 mm, and gap width of 64 mm, henceforth referred to as "reference cavity".
- The second geometry is obtained from the first one by placing in the gap an array of 30 equally-spaced horizontal fins, spaced 16 mm from each other.
- The third geometry is obtained by placing in the gap fins arranged to create a spiral labyrinth pattern inside the cavity.

It was assumed that window frames are adiabatic, that air in the gap is a Newtonian, incompressible fluid within the Boussinesq approximation, that the flow is laminar, and that radiative heat transfer is negligible.

Numerical simulations were carried out in a three-dimensional Cartesian mesh consisting of 246,000 cells ($124 \times 124 \times 16$). Previous tests verified that the grid-independency of the solution: in particular, when the mesh is refined further the change of both local values and integral parameters is less than 3%. Fig. 1 shows the grids used for the three cavities under consideration.

Numerical simulations were carried out solving the steady-state problem with the second-order upwind scheme. Convergence was defined imposing a magnitude of residuals of 10^{-7} for continuity and momentum equations, and 10^{-10} for the energy equation. All simulations required less than 200 iterations to converge. Adiabatic boundary conditions were imposed on the window frame and on fins, while temperature boundary conditions were imposed on the internal and external surfaces of the glazing.

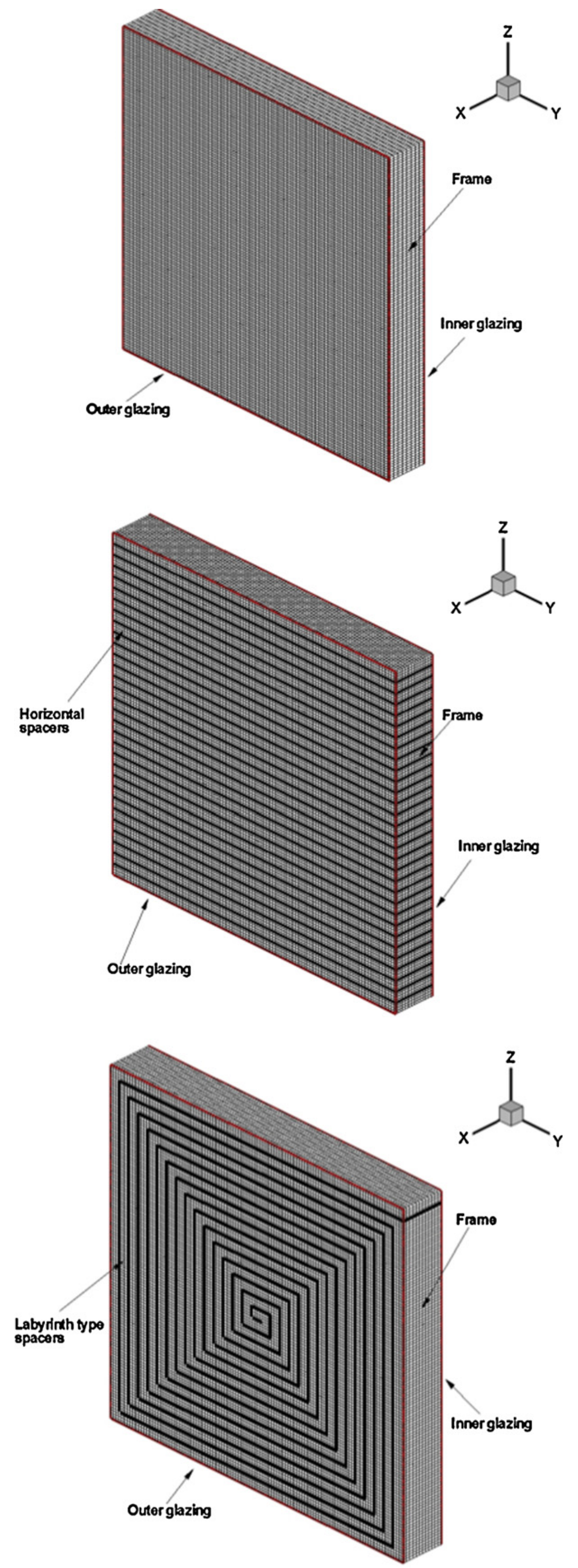

Fig. 1. Fin arrangements within window gaps and computational grids.