THERMAL PERFORMANCE EVALUATION OF AN INNOVATIVE DOUBLE GLAZING WINDOW

Luigi De Giorgi, Carlo Cima, Emilio Cafaro
Dipartimento di Energetica, Politecnico di Torino, Torino, Italy

Volfango Bertola
School of Engineering, University of Edinburgh, Edinburgh, United Kingdom

ABSTRACT

The paper presents the results of the numerical simulations of the conjugate heat transfer process in an innovative double glazing window, represented as a vertical cavity filled with air and equipped with internal transversal. Numerical simulations were performed by a commercial CFD code (Fluent v6.3) varying both the Rayleigh number and the aspect ratio of the cavity. The heat transfer effects of the air flow inside the cavities were estimated both at the onset of convective flows and at working conditions of real systems. The work is aimed to calculate local and global Nusselt numbers for different configurations of the air cavity, which are needed to apply the standard heat loss estimation method to such modified double glazing windows. The thermal performances of the systems were also characterised in terms of an efficiency parameter.

INTRODUCTION

The growing importance of a rational use of energy sources stimulates both fundamental and applied studies on energy dissipations in the built environment, which are often referred to as *thermal design of buildings*. In particular, research is focused on the interaction between the various energy systems and the surrounding environment, in order to predict the rate of heat loss and to develop strategies to minimise them. A typical example is the creation of cavities in the walls so that the loss of heat is reduced.

Among the components of the building envelope, windows require a particularly careful design because they concentrate much of the heat dissipation in the external environment. Energy efficient windows should minimize heat losses as well as air leaks. This is achieved in practice combining different solutions, such as multi-layer glazing, low thermal conductivity gas fills, tinted glass cavities, low-emissive coatings, edge spacers, etc. An optimum window design and glazing stratification can considerably reduce energy consumption for air-conditioning (10%-50%) in most climates. In commercial, industrial and public buildings, an optimum window design has the potential to reduce lighting and heating, ventilation and air-conditioning (HVAC) costs by (10%-40%).

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 opaque components (walls, roofs, floors). One of the factors affecting the intensity of the heat flux through a double glazing 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. The same phenomenon occurs inside

enclosures in building walls or hollow bricks. Convection enhances the heat flux through the window, reducing thermal insulation.
Natural convection inside a square cavity with two vertical isothermal walls and two horizontal adiabatic walls is a classical problem in heat transfer. 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.
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, $\mathrm{Pr} = c_P\mu/k$, and the control parameter of the flow, the Rayleigh number, $Ra = g\beta\Delta T L^3/\alpha\nu$. 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, i.e. thermal insulation reduces.
To characterise the convective heat transfer intensity one can use the Nusselt number, $Nu = hL/k$, 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 bound for the Nusselt number values is $Nu = 1$, corresponding to thermal conduction.

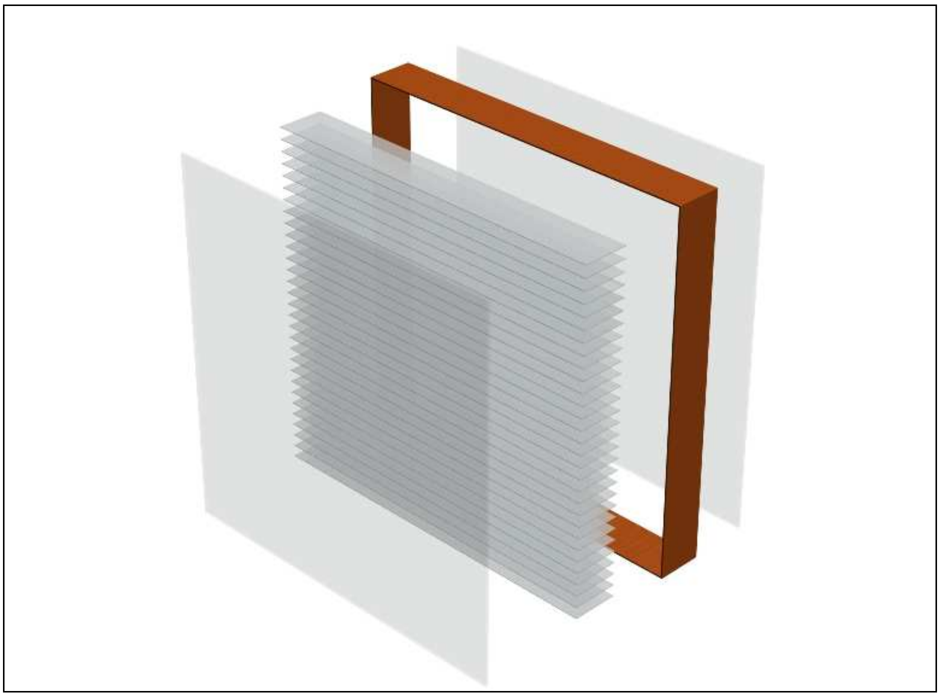


Figure 1. Structure of the double glazing window.

The aim of the present work is to investigate the fluid dynamics inside the cavity of double glazing windows, in order to quantify the heat transfer reduction achieved through an innovative system of fins, an example of which is shown in Figure 1. The concept of convective system efficiency is introduced to quantify the fraction of heat power converted into convection kinetic energy. The efficiency of a double glazing window, a function of the fluid layer depth and the Nusselt number, is used to rank energy efficient window configurations based on thermodynamic principles.

MODEL FORMULATION

The complexity of the window problem is such that no analytical solutions are available, and one must rely on numerical simulations. In particular, the present work focuses on three-dimensional numerical simulations for the temperature and velocity fields inside three different cavities with different side-wall temperatures:

- The first geometry is a standard double glazing window with height and length of 496 mm and gap width of 64 mm, henceforth referred to as "reference cavity";
- The second geometry is obtained from the first one by addition of an array of 30 equally-spaced horizontal fins, at a distance of 16 mm from each other;
- The third geometry is obtained from the first by means of fins that create a labyrinth pattern inside the cavity.

Flow models were solved using the commercial software Fluent (v. 6.2.16), assuming 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 (124x124x16). 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%. Figures 2-5 show the grids used for the three cavities considered.

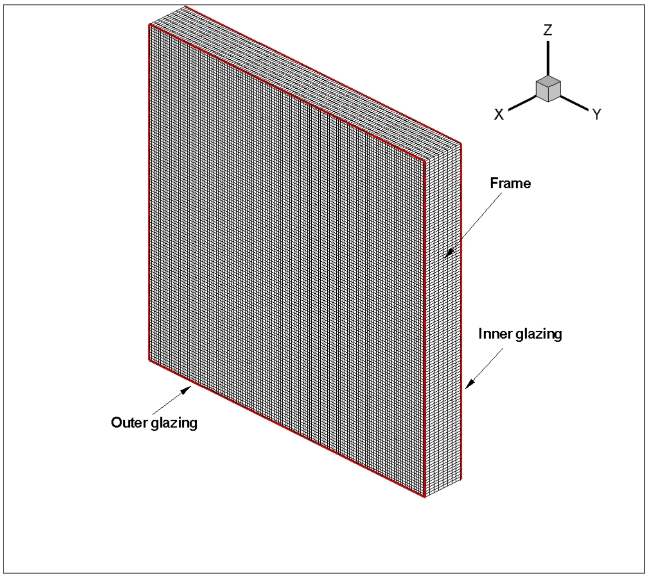


Figure 2. Mesh for the reference cavity.

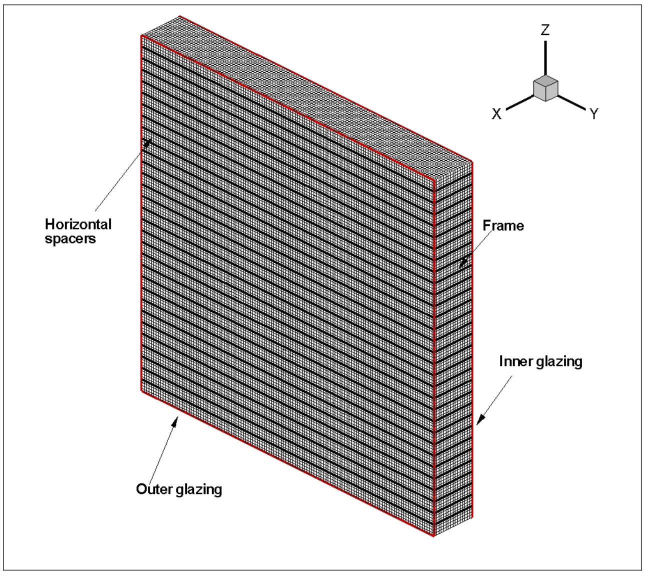


Figure 3. Mesh for the cavity with horizontal fins.

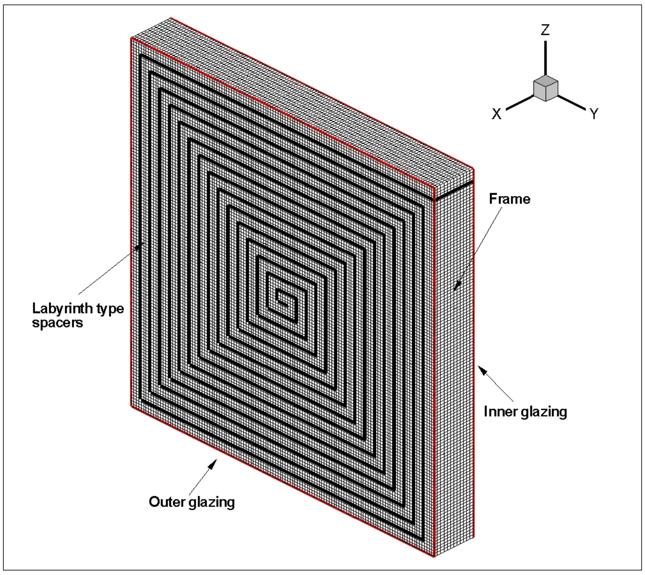
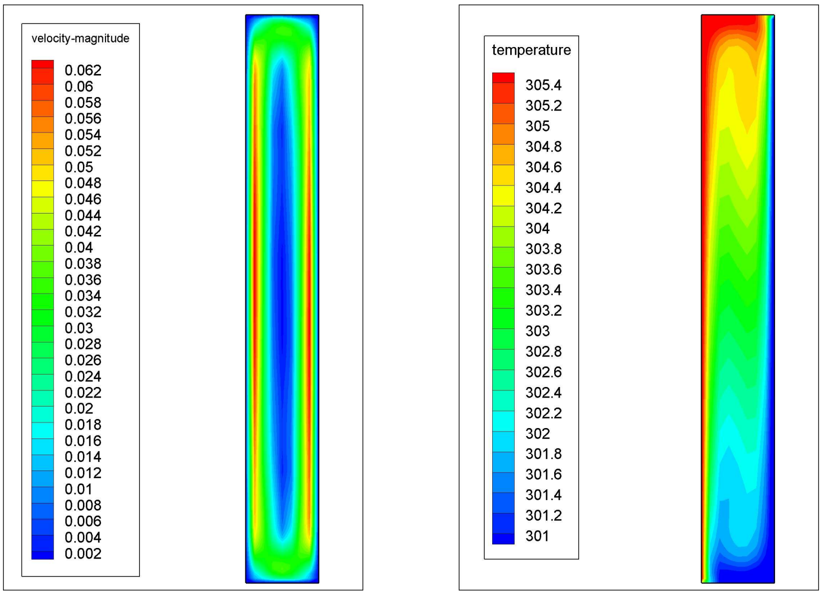


Figure 4. Mesh for the labyrinth cavity.

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 attain convergence. 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.

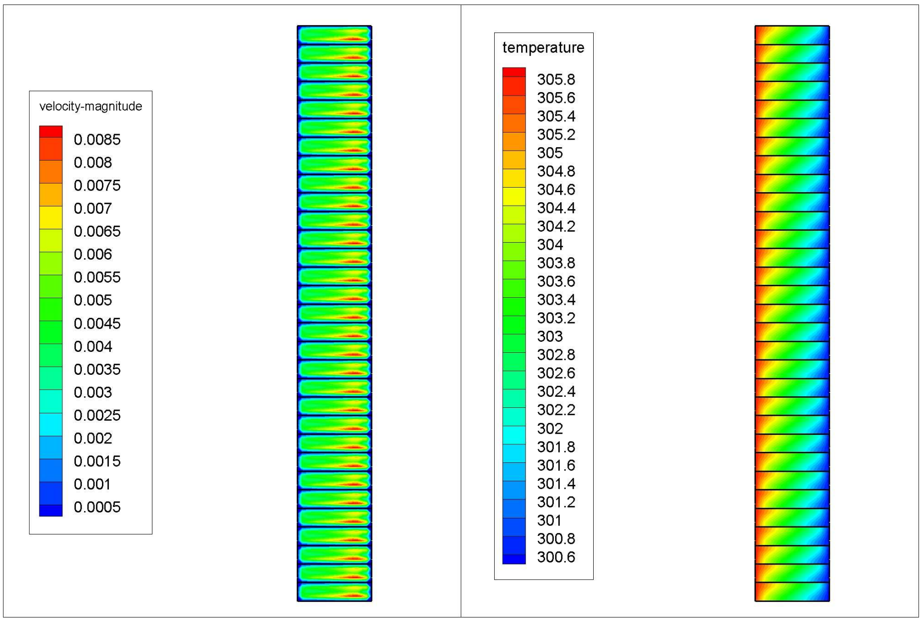
RESULTS

Figures 5-7 show the velocity and temperature fields obtained for the three geometries considered, with a value of the Rayleigh number $Ra = 128000$. In particular, Figures 5 and 6 present values on the mid-plane of the cavity orthogonal to glazing, while Figure 7 those on the mid-plane parallel to glazing for the labyrinth-type window.



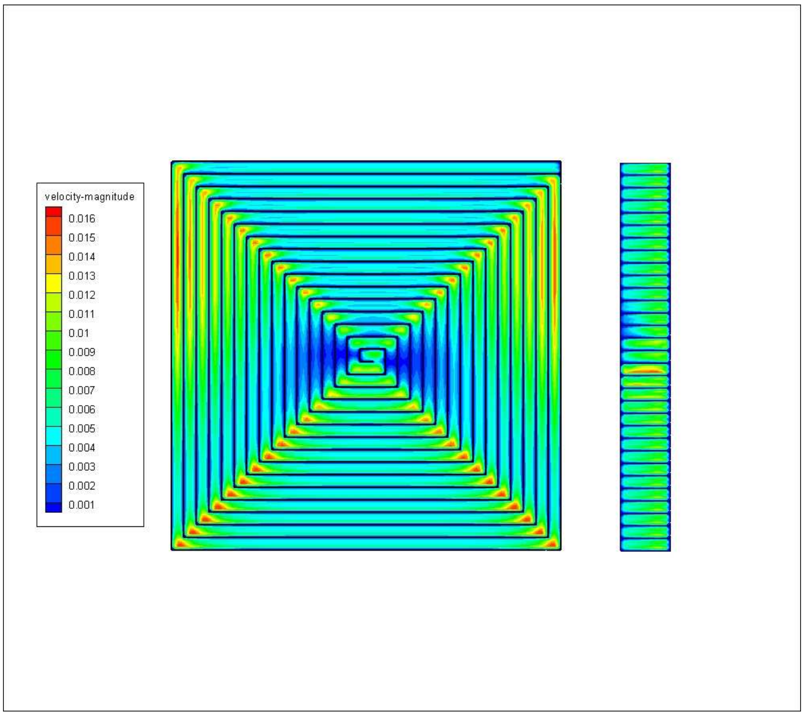
(a) (b)

Figure 5. Velocity field, m/s (a) and temperature field, K (b) in the reference cavity (Ra = 128000).

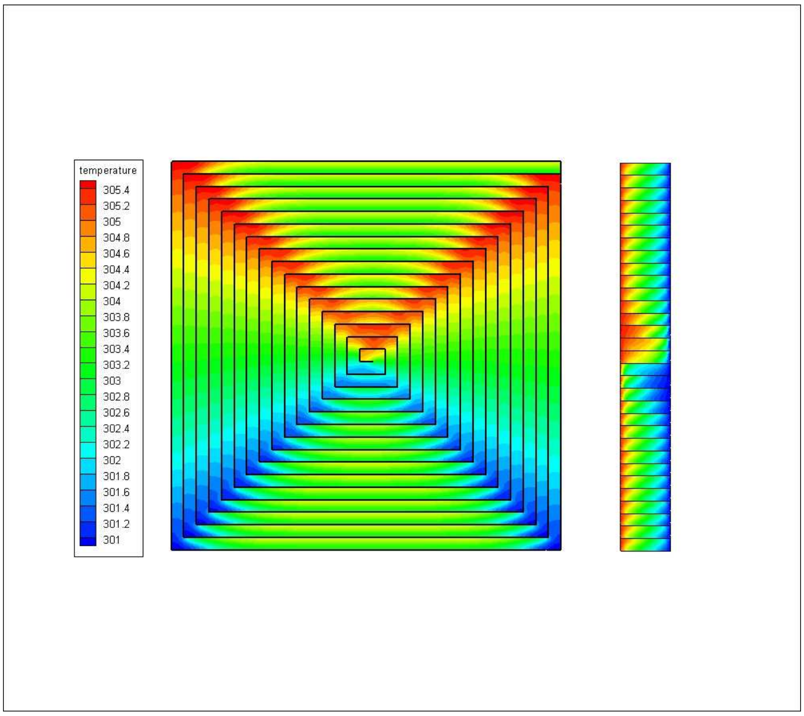


(a) (b)

Figure 6. Velocity field, m/s (a) and temperature field, K (b) in the cavity with horizontal fins (Ra = 128000).



(a)



(b)

Figure 7. Velocity field, m/s (a) and temperature field, K (b) in the labyrinth-type cavity (Ra = 128000).

These figures show how, for a same temperature difference between the internal and the external surface of the window (i.e., for the same Rayleigh number), velocities in the reference cavity are one order of magnitude larger than in the other two cavities, equipped with a system of fins. This means that the convective heat transfer mechanism in the finned cavities is reduced in comparison with the reference cavity without fins.

EVALUATION OF THERMAL PERFORMANCE

To characterize the thermal performance of windows, one can define a local Nusselt number as:

$$Nu = \frac{h(z)x}{k(T)} \tag{1}$$

with:

$$h(z) = \frac{\dot{q}(z)}{T_h - T_c} = \frac{1}{T_h - T_c} \cdot k(T) \cdot \frac{T_h - T(x,z)}{x} \tag{2}$$

where $\dot{q}(z)$ is the wall heat flux calculated at the hot face in the viscous boundary layer ($x=2\times10^{-2}$ m). An alternative is to use an average heat transfer coefficient defined as

$$K_m = \frac{1}{L}\int_0^L h(z)dz \tag{3}$$

Figure 8 shows the average heat transfer coefficient for the three geometries considered, as a function of the Rayleigh number. The presence of fins delays the onset of convection, so that the heat transfer coefficient is smaller. Horizontal fins appear to be more efficient than the labyrinth geometry, and allow a reduction of the heat transfer coefficient of about 50%.

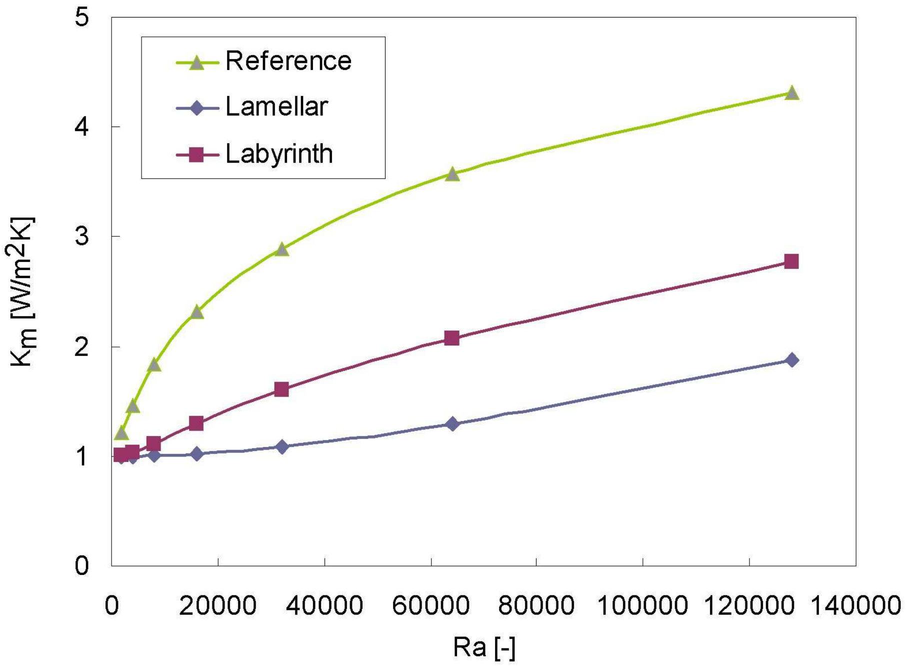


Figure 8. Global heat transfer coefficient for the three window geometries.

The influence of the internal structure on the thermal performances of a double glazing window can be described more synthetically by the following dimensionless parameter:

$$\xi = \frac{K_m(\text{modified cavity})}{K_m(\text{reference cavity})} \tag{4}$$

The performances of windows in terms of this non-dimensional heat transfer coefficient (i.e., normailsed with respect to that of the reference cavity) are shown in Figure 9.

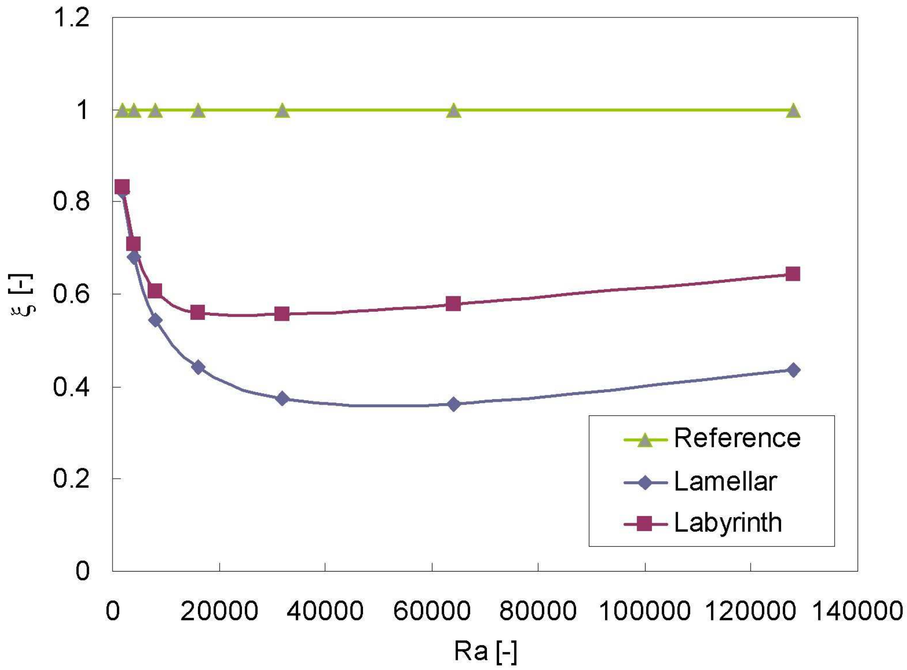


Figure 9. Dimensionless heat transfer coefficient of windows with different internal structure.