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# Numerical analysis and parametric study of the thermal behavior in multiple-skin façades

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ABSTRACT

The general aim of this research is contributed to the energy performance assessment of single storey multiple-skin façade. To cover this aim; multiple skin façade are studied by means of experiments and numerical simulation. In this research a numerical model for multiple-skin façades with mechanical and natural ventilation has been developed. The numerical model is two-dimensional and based on a cell centered volume method (CVM). As an improvement, radiation and convection are treated separately and by this means an innovative method is applied to calculate the view factors and heat transfer coefficients between surfaces and each cavity. Then the developed numerical model is validated using measurements from the vliet test building. However, there is no multiple-skin façade application in Tehran. Thus the model is used to assess the influence of different multiple-skin façade parameters in Tehran's climate conditions to show its effect on heat losses if this technology would be applied. As a consequence of the diversity of results, designer should be aware that multiple-skin façades do not necessarily improve the energy efficiency of their designs.



## 1. Introduction

In previous research papers it is appointed that how multiple-skin façades work to improve the building's energy efficiency. Much of the literature deals with specific topics such as the modeling of the convective heat transfer in cavities or the optical properties of glass layers. Most researchers provide models to simulate specific multiple-skin façade topologies but only few models are available about naturally ventilated multiple-skin facades. Todorovic and Maric [1] use a single zone heat balance representing the entire cavity. van Paassen and van der Voorden [2] were developed a network model in which the airflow is mainly based on the stack effect. The model has a limited ability to take into account airflow due to wind through joints distributed over the height of the cavity. Airflow from the cavity toward the building is not considered and no comparison with measurements is given, and extracted results from CFD calculations became available [3,4]. They are mainly illustrative and wind effects are not taken into account. Most multiple-skin façade models have been developed for mechanically ventilated types and there late existing models can be arranged in order of complex and detailed numerical models. Analytical solutions have been developed by Saelens [5], and Ghadamian [6]. Saelens is informed analytical expressions for an airflow window including a shading device with ventilation on either side of the cavity that assume an exponential vertical temperature gradient.

In this research, a numerical model for multiple-skin facades with mechanical as well as natural ventilation is developed, so in the next sections we present the model and the different types of heat fluxes which are involved and devoted to the convective heat transfer and deals with long and short wave radiation. The numerical simulation program needs a sufficient level of complexity to achieve reliable energy simulations, however, this complexity must also be controlled to allow reasonable computation times. The field experiments are applied to become acquainted with the complex physical phenomena that occur in multiple-skin façades. This research assists the reports on the measurements carried out at the vliet test building. It should be mentioned; in this research a numerical model is developed in which the methodology for solving and analyzing the model has been contributed from before references. The numerical model has been investigated for a building which is located in Tehran's geographical condition. So all of the graphs and

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**Nomenclature**

*Symbols and abbreviations*

| | |
|---|---|
| $A$ | area |
| $A$ | aspect ratio |
| AFW | air flow window |
| $c_a$ | specific heat capacity of air (J/kg K) |
| DSF | double-skin façade |
| DT | dimensionless temperature |
| $F$ | fraction of airflow (%) |
| $F_{i,j}$ | view factor |
| $F_H$ | horizon brightening |
| $F_R$ | anisotropy index |
| $F_T$ | temperature factor |
| $g$ | gravitational acceleration (m/s$^2$) |
| $g$ | solar transmittance |
| $G_a$ | airflow rate (m$^3$/h) |
| $g_a$ | airflow rate (kg/s) |
| $H$ | height (m) |
| $h$ | heat transfer coefficient (W/m$^2$ K) |
| $I$ | solar radiation (W/m$^2$) |
| $K_T$ | hourly clearness index |
| $L$ | depth (m) |
| $p$ | pressure (Pa) |
| $q$ | heat flow rate density (W/m$^2$) |
| $Q$ | heat flow rate (W), (W/m) |
| $q_0$ | radiosity (W/m$^2$) |
| $T$ | absolute temperature (K) |
| $T_m$ | cross-section averaged mean temperature (K) |
| $T_\infty$ | free stream temperature (K) |
| $u$ | local longitudinal velocity (m/s) |
| UWT | uniform wall temperature |
| UHF | uniform heat flux |
| $V$ | velocity (m/s) |
| $x, y, z$ | Cartesian coordinates |

*Dimensionless numbers*

| | |
|---|---|
| Gr | Grashof number |
| Nu | Nusselt number |
| Pr | Prandtl number |
| Ra | Rayleigh number |
| Re | Reynolds number |

*Greek*

| | |
|---|---|
| $\alpha$ | absorption coefficient |
| $\delta_{i,j}$ | Kronker delta |
| $\varepsilon$ | emissivity |
| $\lambda$ | thermal conductivity (W/m K) |
| $\mu$ | dynamic viscosity (s Pa) |
| $\theta$ | angle of incidence (°) |
| $\theta$ | Temperature (°C) |
| $\rho$ | reflection coefficient |
| $\rho_a$ | air density (kg/m$^3$) |
| $\sigma$ | Stefan–Boltzmann constant (W/m$^2$ K$^4$) |
| $\tau$ | transmission coefficient |

*Subscripts*

| | |
|---|---|
| a | air |
| ae | exterior cavity air |
| ai | interior cavity air |
| avg | average |
| b | direct solar radiation |
| dp | dew point |
| h | horizontal |
| c | convection |
| d | diffuse solar radiation |
| e | exterior |
| f | fluid |
| g | enthalpy |
| i | interior |
| k | position |
| lw | long wave |
| for | force |
| nat | natural |
| r | radiation |
| r | reflected solar radiation |
| s | short wave |
| s | sky |
| sur | surrounding |
| t | on a tilted surface |
| T | transmission |
| tr | transition |
| w | wall |
| W | wind |

resulted which are concluded for this model are referenced based on city of Tehran's metrological situation.

## 2. Development of the numerical model

### 2.1. Model geometry

Actually, this work is focused on the evaluation of both multiple-skin façades. The construction details are summarized in Fig. 1. It should be considered that the airflow window (Fig. 1a) is ventilated with interior air by means of adjustable fan and the thermal break is suited at the exterior pane. The double-skin façade (Fig. 1b) is ventilated with exterior air; therefore, the thermal break is suited at the top of the cavity. In order to vary the airflow rate, two pair of adjustable grids is built in at the bottom and the interior pane.

### 2.2. Model description

The numerical model is two dimensional and based on a cell centered control volume method (CVM). The section of the multiple-skin façade is divided into a number of vertical layers, however, the number of vertical layer depends on the construction and the fact whether the roller blind is raised or lowered. The vertical layers in turn are divided N parts along the height; which represent the control volume model for mechanically air flow window with lowered roller blind and raised roller blind, respectively. For each volume the heat balance is developed in MATLAB open software code and regarding that the obtained thermal system is then solved to cover the purposes.

### 2.3. Model assumptions

The main assumptions of present model are as follows:

- The cavity layers are only vertically subdivided and temperature of the cavity control volume is presented by a bulk temperature.
- It is assumed that enthalpy flow only occurs in the vertical direction and the air flow in both cavities has the same direction. This assumption would make some limitations for model applications in multiple-skin facades with roller blinds and prohibits the simulation of rotational flow.