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Performance enhancement of double skin facades in hot and dry climates using wind parameters

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ABSTRACT

This research aims to demonstrate a model of Double Skin Facade (DSF) that functions efficiently in hot and dry climates. Knowing that DSF performs well in winter at hot and dry climates as thermal mass is needed. However, this method during summer evinces overheating between the two skin layers. This paper introduces some modifications in order to improve the functioning of DSF when overheating occurs in the cavity between the two skin layers. Overheating in DSF can be prevented by using properties of wind pressure. Considering the condition of the wind flow, different geometric forms in the upper part of DSF as well as its lower portion of window opening are evaluated. The numerical method and Computational Fluid Dynamics (CFD) simulations are used in order to evaluate the hypotheses of this study. The obtained results of this research suggest that dividing the cavity space into smaller parts makes no significant changes. Designing an additional channel in the northern part of the models, directly impacts the functionality of DSF, which can be concluded to be very efficient. Finally, by increasing airflow velocity within the cavity, it is possible to decrease the problems of using DSF in hot and dry climates.

1. Introduction

Glazing facades have recently been the center of attention [1,2], and its popularity is increasing due to creating a desired facade transparency along with improved acoustical quality and reduction of energy consumption [3]. If they are designed properly it can significantly diminish energy consumption of HVAC systems in buildings by obtaining solar energy during winter and controlling overheating in summer [4]. It all can be reasoned and justified by energy consumption perspective and the increased tendency towards new approaches such as passive solar systems [5]. As an appropriate alternative, the DSF is composed of an external layer (usually glass) and a centric space as well as an internal layer [6–9]. In addition to providing necessary transparency, the DSF can save the absorbed solar radiation by an external glass facade in winter and provide the appropriate ventilation during summer. As a result, it improves the thermal comfort while reducing cooling and heating loads [5]. However, this technology performs better in countries with moderate and cold climates [10–12]. As the temperature increases during the summer, especially in hot and dry climates, the cavity between the facade skins experiences a severe increase in temperature due to the greenhouse effect, and subsequently creates an uncomfortable condition for the occupants [13].

Recently, the technology of the double skin facade is being utilized in new buildings in regions that are very hot during the summer and cold in the winter. This also can be related to the recent growth of economic development [14]. As a result, the tendency towards implementing these facades is increasing and this can be witnessed in Iran, where vast majority of the country is located in hot and dry climates [5]. Although the double skin facades works well in winter of hot and dry climates, this application may cause overheating between the skins layers during the summer. In order to solve the issue of cavity temperature, the appropriate dimensions of windows, suitable situation and position of shading devices as well as the optimized space of the cavity are suggested [15–19]. However the wind parameter, as an effective factor for overheating ventilation in the cavity, is less emphasized. There is a potential for using natural ventilation through the local wind power in Iranian hot and dry climates. This paper studies the direct effect of wind distribution on the air flow inside the cavity by implementing some changes on the upper part of the DSF and changing the position of windows. By dividing the cavity space into

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smaller parts as well as adding a channel upon the arrival of wind flow, functionality of different DSF layouts is compared.

1.1. Function of the double skin facades

As an important architectural element, the double skin facades are widely used in office buildings. These facades are composed of two layers, one exterior and the other interior, which are of different glass materials that are separated by a cavity. The exterior layer protects the structure and significantly minimizes noise pollution.

This advantage allows users of this technology to enjoy opening their windows without facing the problems of mono-skin facades which are the effects of wind pressure and speed, direct sunlight, and environmental pollution. The possibility of installing shading devices inside a cavity between two skins is another feature of the DSF. The shading devices protect the rooms from direct light of the sun while they decrease the cooling load in summer. The DSF functions as a heat exchanger in cold weather, meaning that the radiant energy is retained between the two layers and its temperature equals that of the building. This reduces the heat exchange between outer and inner space. The method of ventilation inside the DSF can be natural, mechanical, or a combination of both. Natural ventilation is produced by the buoyancy resulting from the difference in temperature (which causes pressure difference inside the cavity) between inside and outside of the cavity. Also, factors including pressure, velocity, and direction of the wind, building orientation, and dimensions of the openings are effective in creating appropriate natural ventilation in a building [14,20].

Considering the aforementioned points, the advantages of DSF are as follows [21]: suitable insulator of noise, thermal insulator in winter and summer, night ventilation (night ventilation can be used for cooling the thermal mass of structure and decreasing mechanical load in regions with high temperature difference between day and night as well as dominant wind during the summer), saving energy and reducing environmental damages, suitable protection of shading devices, deduction of wind pressure, transparent designing, natural ventilation and reduction of heat transfer.

However, the system has its own particular drawbacks, including: Increasing the primary cost of building, conflagration crisis (if there are no modifications in designing, the DSF can intensify the fire due to the high suction), the issue of increasing temperature in summer (due to lack of suitable ventilation and shading devices can convert this facade into a thermal furnace), increasing air velocity and interfering the system as well as increasing the total weight of the structure [21].

This study focuses to investigate both the behavior of airflow and reduction of temperature within the cavity of DSF during the summer.

2. Method

In order to examine and evaluate the DSF behavior while proving the hypothesis of this project, meticulous studies are conducted to forecast the created conditions. Solutions that include both analytical and experimental, laboratory measurements and computer simulation are among common methods used for this particular matter. However, since analytical and experimental solutions are not highly accurate and due to high cost of laboratory measurements, computer simulation is used. Instead, the high credibility of numerical model and Computational Fluid Dynamics (CFD) simulation are considered as an appropriate method in order to meet the objectives of this study. The necessity of using CFD simulation is well emphasized as one of the most powerful techniques in the design phase of a DSF [1]. Fluent and Gambit software (Geometry and Mesh Building Intelligent Toolkit), the commercial Toolkits of CFD are used for the design and analysis of the models and the hypothesis respectively.

3. Simulation procedure

Three different basic models are precisely analyzed for purpose of studying the effects of DSF upper part and the location of its windows. This analysis includes 16 different states based on the change in wind direction and positions of the windows (Fig. 1). At a constant speed of 3 m/s models are analyzed once the DSF is on leeward and also when the DSF is on windward at angles of 0 and 180° respectively (the dominant wind velocity in Isfahan from 1955 to 2005 during warm months is about 3 m/s) (Table 1). The wind flow in DSF is investigated and analyzed based on the urban and buildings structure and orientation in Iran which is predominantly north–south. However due to the complexity of wind flow model, the direct wind flow is considered whereas the turbulence is omitted. After designing the models using Gambit software, their networking is made by organized networks. The boundary conditions of the models are defined based on Fig. 2; although these conditions can be altered by "Fluent software" in the next stages of the analysis. The boundary condition of the windows is considered to determine the correct function of the windows in states of high and low pressure.

In the second stage, the models are utilized in "Fluent software" (Fluent 6.3.26), the solution condition is described in Table 2 and as followings:

Solver: Pressure based.
Space: 3D.
Formulation: Implicit.
Time: Steady.
Operating pressure: 101325P.
Pressure–velocity coupling: SIMPLE.

Energy equation is inactive at this stage, since the study of air flow speed and pressure is sufficient and the air is described as the concerned fluid (not as an ideal gas). With the entrance speed of 3 m/s, the flow fluid is non-density. Depending on the chosen viscose model for conditions of the flow, turbulent model of K-epsilon [22,23], is used. The flow is dominated by continuity equations, momentum, K and epsilon while the tolerance for solving them is considered to be 1e−06. These equations become convergent after a repetition range of 1000–1500.

Validity of the data is determined by wall Y plus criterion. It is necessary to evaluate the sensitivity of the network near the wall which is done by Y plus, since turbulent flows are highly influenced by the walls. Using K–epsilon modeling, the network arrangement near the walls should be such that Y plus < 5 or Y plus > 30. The black dots represent the amount of Y plus along the vertical axis of the northern wall of the DSF volume, as Fig. 2 demonstrates. In the mentioned region, according to the model validity and the problem data none of the DSF levels are located between $5 <$ Y plus < 30.

Velocity vectors, dynamic pressures and the difference in pressure created around and inside of the model are used to analyze the model as well as to study the dynamic pressure and velocity of the air flow, as shown in Fig. 3, the selected lines (a, b, c) are used.

4. Results and discussions

The main categories of the results and analysis are classified as follows for precision in providing detailed results and analysis.