CFD analysis on velocity and temperature distribution of airflow inside model building with windcatcher

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Abstract. Windcatchers are ventilation instruments used for obtaining the characteristic of cooling. They have been utilized in the buildings for a long time ago in countries with hot dry atmospheres especially in the Middle East. Natural ventilation is progressively utilized in the modern building to limit the use of non-sustainable supply. This study describes another alternative for adopting clean energy in buildings by applying windcatcher on buildings. This present study analyses between two types of windcatcher (one-sided and two-sided windcatcher) by varying the inlet velocity of airflow. This study aims to investigate wind velocity and temperature distribution in a model building with one outlet opening position using Computational Fluid Dynamics (CFD) simulation. Reynolds-Average Navier Stokes (RANS) approach with the turbulence model of standard k-ε was used to perform the simulation. It is shown that the two-sided windcatcher is more effective than the one-sided windcatcher. Two-sided windcatcher induces a high volume of airflow inside the building compared to the one-sided windcatcher.

1. Introduction
The exhibit of ventilation forte is available to the outside air causing unrestrained air flow in an enclosed space. Ventilation can be either completely regular or completely mechanical. Natural ventilation does not involve any mechanical appliances or devices to make the airflow inside the building. Meanwhile for mechanical ventilation, to make the air circulate inside the building, a mechanical device such as a blower or power drive is needed.

Recently windcatchers have undergone a considerable amount of research in terms of understanding better the effect of airflow through and over windcatchers as well as the ventilation rates by these systems [1]. Windcatcher is one of the methods used for natural ventilation. It can be characterized as an engineering component set on a building which gives natural air to the inside of living spaces and then discharges the stale air through windows or other depletes fragments [1]. It also could capture the wind at a high level and direct it to the building [3]. Windcatchers are generally classified into five groups which are one-sided, two-sided, four, six and eight-sided [4]. Numerous academic studies investigated the cooling performance that is executed by windcatchers. The result shows that windcatcher can play a significant role in creating natural ventilation and adjusting the thermal comfort of interior living spaces [5]-[6]. This present paper investigates the velocity and temperature distributions for both types of windcatcher by the means of CFD simulation.

The parameter that influences the performance of the windcatcher is the direction of the wind, the wind speed and the angle of incidence [2]-[3]. The distance between the windcatcher and opening outlet also is one of the factors for windcatcher performance. If the distance between the windcatcher and opening outlet is short, it will not give better-induced airflow for the windcatcher [1].
2. Methodology
This study performed a simulation on a building with one-sided and two-sided windcatcher by comparing with two different inlet velocities which are 1.8 m/s and 3 m/s. This study aims to evaluate the velocity and temperature distribution inside the building with windcatcher. 3D model of the building was drawn using Computer-Aided Design (CAD), CATIA V5. The simulation of the airflow inside the model building was used Computational Fluid Dynamics (CFD), ANSYS 16.0 and Reynolds-Average Navier Stokes (RANS) approach with a turbulence model of standard k-ε was used. ANSYS FLUENT has been applied to various research works and found to be useful [9]–[12], which is adopted in this study which is to evaluate the airflow inside the building. Previous studies have also proved that these methods are reliable in terms of evaluating the ventilation performance of windcatchers [3].

2.1 Model Geometry and Building Configurations
Two different models were drawn using CATIA. The model building dimension is 6 m x 3 m x 8 m (width x height x length). Meanwhile, the dimension for the windcatcher is 1 m x 1.5 m x 1 m (width x height x length) and the size of the opening is 1 m x 1 m. Figure 1 shows the model building with one outlet opening at the opposite wall.

![Figure 1. Model building with one outlet opening in CATIA drawing.](image)

2.2 Numerical Setup and Model Validation
The turbulence model selected is the standard k-Epsilon; in short, k means the turbulent kinetic energy transported while Epsilon means turbulent dissipative energy. This turbulence model has been used widely for industrial purposes and performs better in low-speed air. Figure 2 shows the result of present study for normalized velocity in x-direction along with distance x, compared to validation from H. Montazeri et al [2].

In this study, the inlet velocity, U_{ref} used is 1.8 m/s and 3 m/s as it is the average wind speed in Malaysia and the temperature has been set to 300 K. The inlet velocity is in the x-direction. The velocity and temperature distribution were analysed in the next section of this paper.

![Figure 2. Model validation with result from H. Montazeri et al [2]](image)
3. Results and Discussions
This section discusses the results obtained from CFD simulation with Reynolds-Average Navier Stokes (RANS) approach to perform the simulation. The result will be discussed in two sections: velocity and temperature distribution of the airflow inside the model building along the distance x, y, and z.

3.1 Velocity distribution in model building along x, y and z direction
Figure 3 (a)–(c) and Figure 4 (a)–(c) show comparisons between velocities inside the model building with one-sided and two-sided windcatchers. Both cases of the study investigated velocity and temperature distribution when the inlet airflow to windcatcher is 1.8 m/s and 3.0 m/s. It shows that the airflow velocity inside the model building fluctuated. It also shows that the two-sided windcatcher is more effective than a one-sided windcatcher. This result has been agreed based on a previous study [13] that shows that the two-sided windcatcher has higher efficiency than any other type, particularly in zero degrees wind incident angle which can induce a high volume of airflow into the room. Hence, this two-sided windcatcher is a typical conventional windcatcher in regions with predominant wind direction [14].

Figure 3(a) shows that the velocity of airflow inside the model building increases along distance x from the wall to the outlet of windcatcher. It is due to the source of the airflow leaves from the windcatcher to the model building. Then it shows that the velocity of airflow gradually reduces until it reaches near the wall with opening, and the velocity increases again due to the position of an opening which allows the airflow to speed up to enter the opening (which has a small area ratio to the wall). While Figure 3 (b) and (c) show quite similar profiles of airflow velocity inside the model building which increases at two streamwise positions: at the outlet of windcatcher and along with the position of opening at the opposite wall. But it also shows in Figure 3 (c) that there is evidence of reverse flow near the top of model building (about distance z is 3 m) and it shows also the airflow normalized velocity becomes almost unity inside the windcatcher. The airflow velocity in the model building can be seen as it increases very much at two significant locations: the outlet of windcatcher and near the outlet opening.

Figure 4 (a)–(c) show similar velocity profile to Figure 3 (a)–(c) except that the airflow velocity inside the model building is higher and will provide more flow rate since the inlet velocity is higher (3 m/s). The velocity reaches zero value from wall to wall (for y-direction) and also from bottom to top plane (for z-direction). But the airflow velocity reaches the maximum value at the outlet opening (for x-direction) for both inlet velocities: 1.8 m/s and 3.0 m/s.
Figure 3. Velocity distribution in model building for inlet airflow 1.8 m/s along (a) distance x (b) distance y (c) distance z.

Figure 4. Velocity distribution in model building for inlet airflow 3.0 m/s along (a) distance x (b) distance y (c) distance z.
3.2 Temperature distribution in model building along x, y and z direction

Figure 5 (a) – (c) and Figure 6 (a) – (c) show comparison between temperature distribution inside the model building with one-sided and two-sided windcatchers. It shows that the temperature distribution inside the model building fluctuated and the profiles show similarity for both cases of velocity inlet to windcatcher (1.8 m/s and 3.0 m/s). It also shows that the temperature distribution inside the model building with two-sided windcatcher is lower than the one-sided windcatcher due to better airflow ventilation. The temperature also reduces in all direction inside the model building, except it, increases again when it reaches near boundaries (walls, top plane, and bottom plane) as the temperature is set to 300 K.

(a) (b) (c)

Figure 5. Temperature distribution along distance x, y and z in model building for inlet airflow 1.8 m/s.

(a) (b) (c)

Figure 6. Temperature distribution along distance x, y and z in model building for inlet airflow 3.0 m/s.
4. Conclusions and Recommendation

In conclusion, the effects of one-sided and two-sided windcatcher to the model building with one opening at the opposite wall were examined in this present study by solving with the use of Reynolds-Average Navier Stokes (RANS) approach with standard k-ε turbulence model. The airflow velocity distributions inside the model building are affected by the velocity of inlet airflow, opening position, and also the type of windcatcher.

Based on the results of this present study, it can be concluded velocity and the temperature inside the simplified model building for both types of windcatchers are similar, except for small variations of normalized velocity at y-components which two-sided windcatcher has decreased at the middle plane of y-direction compared to a one-sided windcatcher. Meanwhile, the two-sided windcatcher gives a higher value of velocity or similar trend of the velocity profile at other location in x, y and z directions.

From the simulation result also can be concluded that a two-sided windcatcher induces a higher volume of airflow inside the building. Thus, it shows that both windcatchers are capable to provide better ventilation and thermal comfort inside the building but a two-sided windcatcher is preferable due to its more incoming airflow. Numerous studies have been done in order to evaluate the performance of windcatchers. For future research, the design of the windcatcher can be improved by adding humidifier or wet cloth or water spray so that it will be more effective. In terms of CFD modeling, researchers should investigate the impact of using other turbulence models to further improve the prediction of the models especially for complex flow inside the windcatcher.

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