Preliminary Evaluation on Air Flow in Atrium of Building in Hot and Humid Climate

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***Abstract*— Atrium is one of the passive design strategies that is known to have certain effects to the indoor environment of a building. These effects can be beneficial or detrimental, depending on the atrium design in response to the climate where it is located. One of the important criteria for designing a building in hot and humid climate is the ventilation aspect. Hence, this study was executed to investigate the air flow in an atrium of a building in hot and humid climate. The investigations were executed using numerical simulation method, which was validated by field measurement. The software used for the numerical simulation was Computational Fluid Dynamic (CFD) which was ANSYS CFX v14.5. The findings indicated that the existence of more air flow paths such as the access corridors that connect the atrium with the outdoor will able to enhance the air velocity inside the atrium. However, further investigations need to be executed in order to improve the air flow inside the atrium. The results and findings from this study will benefit the people in building industry as they provide initial idea on the design strategy of atrium that is appropriate for hot and humid climate.**

***Keywords*— Atrium; air flow; hot and humid climate**

I. INTRODUCTION

Atrium is a top-lit internal space that is surrounded by several storeys [1], and it is widely applied all over the world. It is always incorporated in large buildings such as shopping malls, office headquarters and hotels. This is due to many benefits provided by atrium, whether environmental or social benefits. Atrium is normally located at the front part of a building, and it becomes as a welcoming or introductory space that usually portrays the image of the building. Due to its significant role, atrium also becomes an area for socializing, gathering, and conducting activities such as exhibition and performance. Besides social benefits, atrium also contributes to the controlling of indoor environment of a building. The energy performance of atrium has already been investigated since 1980s. Besides energy performance, among the parameters that are always examined in the previous studies of atrium are shading configuration, roof aperture, type of glazing, ventilation strategies, envelope properties, characteristics of adjacent spaces, geometry and orientation [2]. All these parameters affect the indoor environmental quality of an atrium such as the lighting, ventilation, air temperature and air quality.

The application of atrium in Malaysian buildings is also becoming popular due to the benefits mentioned above. However, some of the atriums have been design to imitate those that are applied in cold and temperate climates. This is because some building projects regard atrium for spatial and aesthetic functions, and neglect its environmental effects, especially the thermal effect [3]. The ventilation mode usually applied in atrium which is fully air-conditioning has made the roof of the atrium to have no aperture. This condition is worsened with most of the roof areas are finished with glazed materials. This condition has increased the cooling load, thus escalating the energy usage of the building.

In an air-conditioned atrium of Malaysian building, the indoor air temperature and relative humidity for thermal comfort are between the range of 20.8 °C to 28.6 °C and 40 % to 80 %, respectively [4]. However, for a naturally ventilated atrium, the maximum range can be slightly higher. This depends on the activity level and the presence of air movement, which is generally between 0.5 m/s to 1 m/s [4]. This is also in agreement with the study of thermal comfort in naturally ventilated atrium conducted by Yusoff [5]. The study indicated that the presence of air velocity between 0.9 m/s to 1.3 m/s had improved the thermal comfort condition inside the atrium. Although people felt slightly warm during the afternoon hours, they were still satisfied with the indoor thermal condition.

Due to the concern for wrong atrium strategy applied in the hot and humid climate of Malaysia, this study intends to compare the air flow inside the atrium with various numbers of access corridors. These corridors act as air flow paths that connect the atrium with the outdoor environment. The access corridors are able to create venturi effect, as they provide constricted areas for the air flow. In venturi effect, there is a reduction in the fluid pressure and an increase in the fluid velocity when the fluid passes through a constricted area [6]. In this study, the wind that hits the building facade will be channeled into the access corridors. The air velocity of the wind increases as it has to flow into a smaller area compared to the previous area. Therefore, it is expected that there is velocity increase of the air that flows into the atrium.

It is significant to understand the air flow inside the atrium as in a naturally ventilated building, the wind and buoyancy driven ventilations are able to remove the heat that is accumulated at the top of the atrium [3]. However, for this preliminary evaluation, the investigations are focusing on the wind driven ventilation only. The findings from this study is hoped to provide knowledge that can benefit many people in designing an atrium, especially for hot and humid climate. Though this study does not provide a total solution to the right atrium strategy for hot and humid climate, at least it is hoped to give initial idea on the air flow inside the atrium.

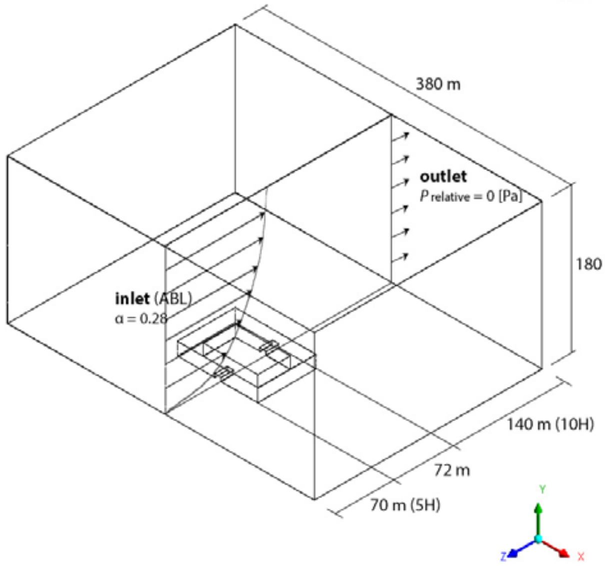
II. Research Methodology

The CFD software used for the numerical simulation is ANSYS CFX v14.5. The validation of the numerical simulation procedures was already executed and presented by the authors in Muhsin et al. [7]. The field measurement was conducted at a Malaysian affordable multistorey housing located in Bandar Baru Bangi, Selangor. The validation results indicated that the percentages of deviation between the numerical simulation and field measurement were in between 9.2 % to 12.83 %. The results showed good agreement between the numerical simulation and field measurement as the percentages of deviation were less than 20%, which was an acceptable percentage by the previous studies [7]. For this simulation, the similar procedures were applied. The difference was just in the building's height, where in Muhsin et al. [7], the building was seven storeys height, while in this study, the building's height was limited to four storeys only. In addition, the simulation also had limitation where no adjacent building was included. Nevertheless, the building was considered to be in a suburban area by applying the exponent value of the atmospheric boundary layer (ABL) wind profile for a suburban condition. This is similar to the condition applied in Muhsin et al. [7].

For the preliminary evaluation, the study focused on the wind driven ventilation only, without considering the buoyancy effect. The turbulence model used for this investigation was the standard k-epsilon (k-ε), which was widely used in the previous studies also [7]. The simulation also employed steady-state airflow, and the ABL wind profile was set to have an exponent value of 0.28 (α = 0.28), which was the value for suburban condition. This value was selected by referring to the location of building in the field measurement that was within the suburban area. The power law equation used for the ABL is as follows:

$$\frac{y}{y_{ref}} = \left(\frac{z}{z_{ref}}\right)^{a} \quad (1)$$

Where y is the wind speed (m/s) measured at the height, Z (meter). Meanwhile, for the wind speed y_{ref}, it was set to be 1 m/s, at the height, Z_{ref} of 10 meter. For this preliminary evaluation, the wind was set up to be from two directions only, which was at 0° and 45° wind angle. The windward and the leeward distances were set based on the building height (H), in which the windward distance was five times of the height (5H), while the leeward distance was ten times of the height (10H), as shown in Fig. 1(a). The building surfaces and ground surfaces were set to be no slip wall condition. The meshing used in this simulation was tetrahedron meshes, as shown in Fig. 1(b), while the maximum number of iteration was set up to be 1000.



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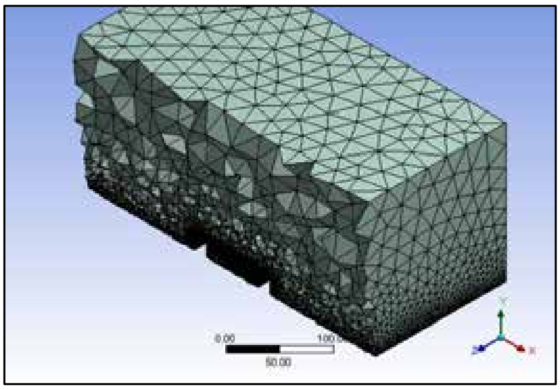

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Fig. 1. (a) The boundary condition set up for the simulation, and (b) the tetrahedron meshes

The investigated atrium was rectangular shape, with the dimensions of 68 m length, 40 m width and 14 m height (Fig. 2). The size of the atrium was referred to the previous atrium that was investigated by the author in Yusoff [5]. The atrium was surrounded by other spaces, and was accessed by corridors that also functioned as air flow paths. The dimensions of the access corridors were 16 m length, 8 m width and 4 m height (Fig. 2). The investigations were executed for two conditions of atrium, which were i) atrium with two access corridors, and ii) atrium with four access corridors. All the corridors had similar dimensions and volumes.

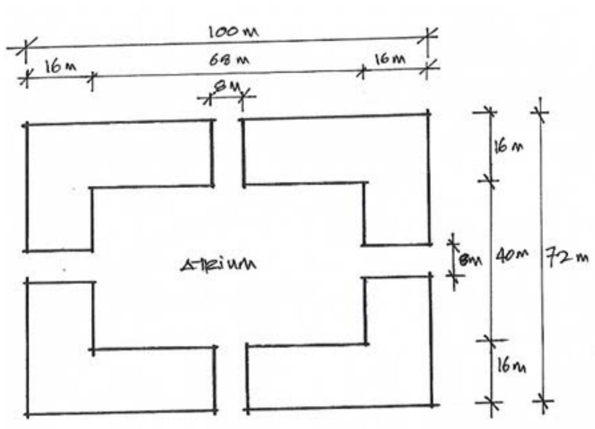
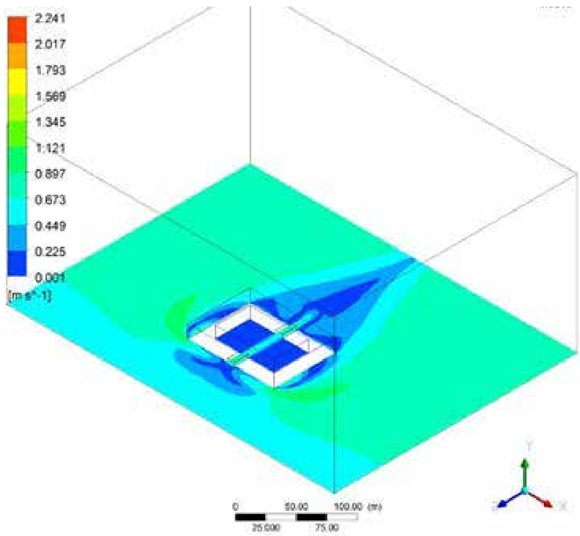


Fig. 2. The dimensions of the atrium and access corridors

III. Results and Discussion

Fig. 3 and 4 indicate the air velocity contours for atrium with two and four access corridors, for 0° and 45° wind angles, respectively. The air velocity contours were plotted at the height of 1 meter from the ground level. This height was selected as it is the height of human scale. From the Fig. 3, it can be seen that higher air velocity was concentrated at the centre of the atrium for both; the atrium with two, and four access corridors. This is due to the venturi effect created inside the corridor. However, the other areas of both atriums suffered low air velocity, which was less than 0.2 m/s.



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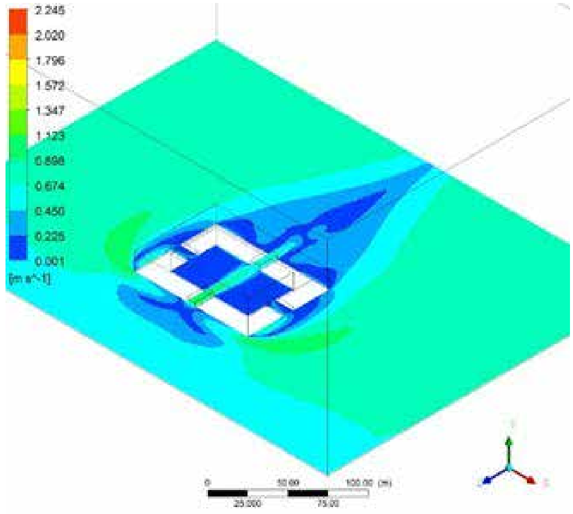

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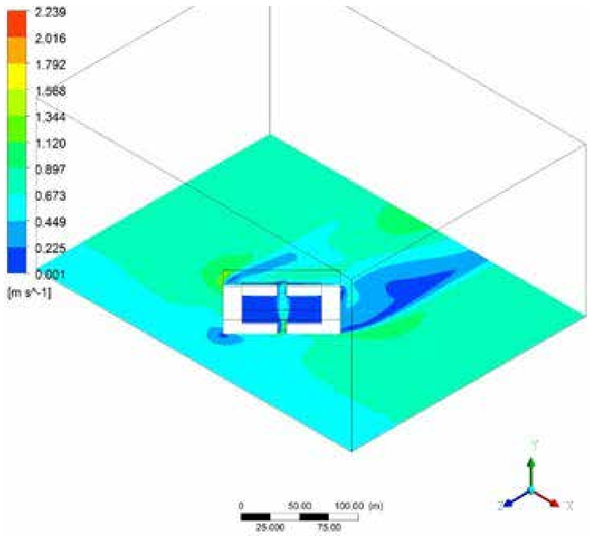
Fig. 3. 0° wind angle, (a) atrium with two access corridors, (b) atrium with four access corridors

For the atrium with four access corridors (Fig. 3b), the side facades experienced negative pressure which resulted in low air velocity that flowed in via the side corridors. However, for 45° wind angle, the atrium with four access corridors had more areas with air velocity of more than 0.4 m/s compared to the atrium with two access corridors (Fig. 4).



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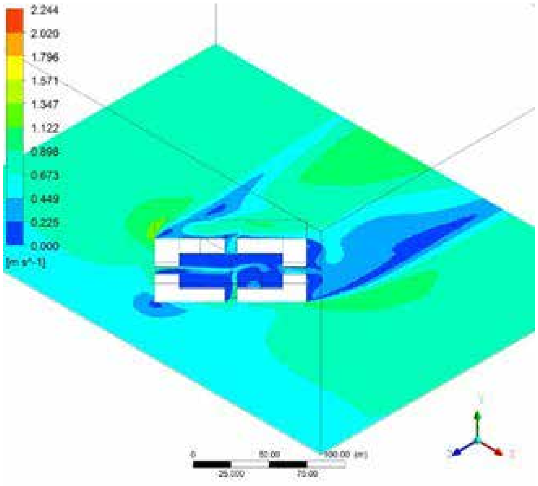

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Fig. 4. 45° wind angle, (a) atrium with two access corridors, (b) atrium with four access corridors

The comparison of average air velocity measured at the height of 1 meter, and at the centre point of the atrium indicated that for 0° wind angle, the atrium with four access corridors experienced higher air velocity compared to the atrium with two access corridors, as shown in TABLE I. However, in contrary, it was found that for the wind angle of 45°, the air velocity (at 1 meter height, and at the centre of atrium) in the atrium with two access corridors was higher than the atrium with four access corridors (TABLE I).

TABLE I. THE AIR VELOCITY MEASURED AT 1 METER HEIGHT FROM THE GROUND LEVEL, AND AT THE CENTRE OF THE ATRIUM

Wind Angle	**Air Velocity (m/s)**	
	Atrium with two access corridors	***Atrium with four access corridors***
0° wind angle	0.683 m/s	0.844 m/s
45° wind angle	0.635 m/s	0.487 m/s

Nevertheless, the average air velocity of the whole area measured at 1 meter height was found to be higher inside the atrium with four corridors compared to the atrium with two corridors, as shown in TABLE II. However, it seems that there was not much differences between the average air velocity inside the atrium with two and four access corridors, for both wind angles. Moreover, referring to Fig. 3 and 4, it seems that there were many areas that suffered low air velocity which was less than 0.2 m/s for both atriums, and both wind angles. The higher air velocity only occurred along the air flow path between the inlet and outlet.

TABLE II. THE AVERAGE AIR VELOCITY OF THE WHOLE AREA MEASURED AT THE HEIGHT OF 1 METER HEIGHT FROM THE GROUND LEVEL

Wind Angle	**Air Velocity (m/s)**	
	Atrium with two access corridors	***Atrium with four access corridors***
0° wind angle	0.673 m/s	0.675 m/s
45° wind angle	0.685 m/s	0.695 m/s

IV. CONCLUSION

The findings from the investigation of air flow inside atriums with two and four access corridors indicate that the increase number of access corridors that connect the inside and outside, and function as air flow path, will provide higher air velocity inside the atrium. However, the findings also demonstrate that higher air velocity is just concentrated at the area where the corridors are located, and along the air flow paths between the inlet and outlet. This is due to the venturi effect created inside the corridors. Meanwhile, the areas inside the atrium that are far from the corridors and air flow path between the inlet and outlet suffer low air velocity. In addition, the average air velocity for the whole area of 1 m height also show insignificant differences between both atriums, and both wind angles. Therefore, it is recommended in future to extend the investigations by examining the potential locations of inlets and outlets (the access corridors), as well as modifying the atrium such as introducing openings at the top level, and taking into consideration the buoyancy effect.

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