PRELIMINARY EVALUATION OF 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*

1. INTRODUCTION

Atrium can be defined by three characteristics, which are 1) a small court in a Roman House surrounded by a roofed area or roofless opening in the centre; 2) an open court surrounded by a roofed arcade or colonnaded walk, and 3) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, from the definition give, an atrium can be either roofed or roofless. It is slightly different from a courtyard and an air well, where a courtyard is an open area surrounded by walls or buildings (J.S. Curl, 2006), while an air well also has openings, which normally located on top, that allow the air to flow in and out from the building.

Atrium 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.

1.1 Previous Studies Related to Atrium

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 (Wang, Huang, Zhang, Xu, and Yuen, 2017) . All these parameters affect the indoor environmental quality of an atrium such as the lighting, ventilation, air temperature and air quality. Among the previous studies of atrium are Acred and Hunt (2014), Abdullah and Wang (2012), Chu, Sun, Jing, Sun, and Sun (2017), Ghasemi, Noroozi, Kazemzadeh, and Roshan (2015), Huang, Borong, Yao, and Yingxin (2015) and Acosta, Varela, Molina, Navarro and Sendra (2018). The buoyancy induced ventilation in an atrium of a multi-storey building was investigated by Acred and Hunt (2014). In the study, a glazed atrium was connected to multi-storey spaces, and functioned like a solar chimney as there was opening on top that allowed the air to flow out. The study found that the stack pressure that drove the ventilation was lesser at the upper floor spaces. Meanwhile, Abdullah and Wang (2012) investigated the atrium designs in the tropics which were top-lit and side-lit, as well as with and without clerestory windows. The study indicated that the side-lit atrium with clerestory windows provided better thermal comfort than the fully transparent top-lit atrium. Meanwhile, the air distribution and comfort condition of an atrium that was incorporated with radiant floor heating was examined by Chu et al. (2017).

The daylighting in atrium was studied by Ghasemi et al.(2015), Huang et al.(2015) and Acosta et al. (2018). In the study by Ghasemi et al. (2015), it was found that the increase of clerestory windows' height resulted in the escalation of average daylight factor in the atrium and its adjoining spaces. Huang et al. (2015) investigated the daylighting effects on double atriums, while the study by Acosta et al. (2018) provided recommendation on a rapid and precise method for determining daylight factor of a rectangular courtyard or the central space of an atrium.

Besides the worldwide study and application of atrium, this strategy is also becoming popular in Malaysian buildings due to the benefits mentioned above. However, some of the atriums have been designed to imitate those that are applied in cold and temperate climates. This is because some building projects regard atrium for spatial and aesthetic functions only, and neglect its environmental effects, especially the thermal effect (Abdullah and Wang, 2012).

1.2 Issues Related to Atrium in Hot and Humid Climate

An atrium that is fully glazed has the tendency of increasing the energy load due to greater solar heat gain during summer, and heat loss during winter (Yasa, 2015). Hence, for the hot and humid climate countries like Malaysia, the usage of glass in atrium should be balanced between the daylight amount needed and the solar heat gain. In addition, there are two effects provided by atrium, namely the greenhouse effect and the chimney effect. The greenhouse effect provides positive role during winter, and negative role during summer. Meanwhile, the chimney effect is opposite to the greenhouse effect (Chu et al., 2017). For hot and humid climate countries like Malaysia, the chimney effect is more desirable in allowing the hot air to flow out from the building. There are three type of ventilation modes usually applied in atrium, namely natural ventilation, mechanical ventilation, and hybrid ventilation which combines mechanical and natural ventilation modes. The examples of mechanical ventilation mode are the utilization of mechanical fan and air conditioning. For an atrium that is fully ventilated by air-conditioning, there is normally no aperture at the roof level, and sometimes the atrium area is made to be air tight. With most of the roof areas finished using glazed materials, such condition provides an atrium with greenhouse effect instead of chimney effect. As the result, the cooling load increases, 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 (Abdullah and Wang, 2011). 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 (Abdullah and Wang, 2011). This is also in agreement with the study of thermal comfort in naturally ventilated atrium conducted by Yusoff (2017). 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. Meanwhile, the study by Yusoff (2006) had found that lower air velocity was needed to achieve thermal comfort for sedentary activities in hot and humid climate, which was 0.8 m/s. This is also in accordance with Cândido, de Dear and Lamberts (2011) who stated that the presence of air velocity higher than 0.81 m/s was able to enhance thermal comfort for indoor air temperature between 29 °C to 31 °C.

The implementation of natural ventilation in atrium should be promoted as there are many benefits derived from it. Among them are the reduction of energy consumption, and the improvement of users' health via internal air renewal (Sacht and Lukiantchuki, 2017). In a naturally ventilated atrium, normally alternative such as mechanical fan is provided in case the atrium's indoor environment does not achieve thermal comfort (Yusoff, 2017). However, with the correct strategies of natural ventilation, the atrium's indoor environment may achieve thermal comfort, especially with the presence of sufficient air velocity.

Due to the concern for wrong atrium strategy applied in the hot and humid climate of Malaysia, this study intends to examine the air flow inside the atrium with various numbers of access corridors. The access corridors are selected due to the current scenario where they are normally regarded as the pedestrian walkways that connect the atrium with the outdoor, without considering their importance in functioning as air flow paths. 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 (Fox and McDonald, 1998). 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.

In a naturally ventilated atrium, the wind and buoyancy driven ventilations are able to remove the heat that is accumulated at the top of the atrium (Abdullah and Wang, 2012). Nevertheless, the presence of both, the wind and buoyancy driven ventilations will either be beneficial or detrimental to the air flow inside the building, as it depends on many factors such as the positions of inlet and outlet (Yusoff, 2010). However, for this preliminary evaluation, the investigations are focusing on the wind driven ventilation only, where the result analyses, discussion and conclusion are purely based on this wind driven condition. The reason for considering the wind driven ventilation only is because this study is a preliminary investigation conducted with the purpose of deriving an initial idea on how the access corridors affect the air flow inside an atrium. The findings from this study are hoped to provide knowledge that can benefit many people in designing atriums, especially in 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.

2. RESEARCH METHODOLOGY

The research methodology employed in this study was numerical simulation. The CFD software used for the numerical simulation was ANSYS CFX v14.5. This CFD software is able to simulate fluid flow, heat and mass transfer, chemical reactions and other related cases. The results derived from the simulation of this software are relevant in many areas such as conceptual studies of new design, detailed investigation of product development as well as troubleshooting and redesign for betterment. The solvers of this software are based on the disintegrating of a fluid region into a finite set of control volumes. In this set of control volumes, the general conservation equations for mass, energy, momentum and many more are solved.

In ensuring the reliability of the CFD results, the numerical simulation needs to be validated against the experimental data (Ai and Mak, 2018). The validation of the numerical simulation procedures used in this study was already executed and presented by the authors in Muhsin, Yusoff, Mohamed and Sapian (2017). The validation was executed by comparing the numerical simulation results with the field measurement data. The field measurement was conducted at a Malaysian affordable multistorey housing located in Bandar Baru Bangi, Selangor.

The measuring tools utilized were a weather station (P5), two units of air velocity meter (P1 and P4) and two units of thermal comfort meter (P2 and P3). The weather station was placed at the building's rooftop, while the other measuring tools were located in one of the house units and the void area near the selected house unit. The weather station was able to measure the wind direction and wind speed, whilst the other measuring tools were utilized to measure the indoor air velocity. The measurement was executed for 22 days in March 2015 (Muhsin et al., 2017).

Upon deriving data from the field measurement, the similar condition was then developed in the numerical simulation using CFD software ANSYS CFX v14.5. The validation 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 (Muhsin et al., 2017). The validation results of numerical simulation against field measurement as conducted in Muhsin et al. (2017) are demonstrated in Table 1.

Table 1: The validation results of numerical simulation against field measurement (Muhsin et al.(2017)

Label	Measuring tools	Location	Field measurement results (m/s)	Numerical simulation results (m/s)	Difference	Deviation (%)
P1	Air velocity meter	Sliding door	0.95	0.86	0.09	9.47
P2	Thermal comfort meter	Living	0.16	0.18	0.02	12.5
P3	Thermal comfort meter	Entrance door	0.82	0.68	0.14	17
P4	Air velocity meter	Void	0.56	0.62	0.06	10.7
P5	Weather station	Roof top	1.7	1.48	0.22	12.9

**The data was already presented in Muhsin et al. (2017) in graph format. With the permission, the data is represented in table format for this journal.*

For the numerical simulation of this study, the similar procedures in Muhsin et al. (2017) were applied. The differences were just in the building's height, where in Muhsin et al. (2017), the building was seven storeys height, while in this study, the building's height was limited to four storeys only. In addition, the simulation in this study 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 was also similar to the condition applied in Muhsin et al. (2017). The grid sensitivity test had also been conducted and presented in Muhsin et al. (2017). Hence, in the present numerical simulation, the similar grid characteristic was applied.

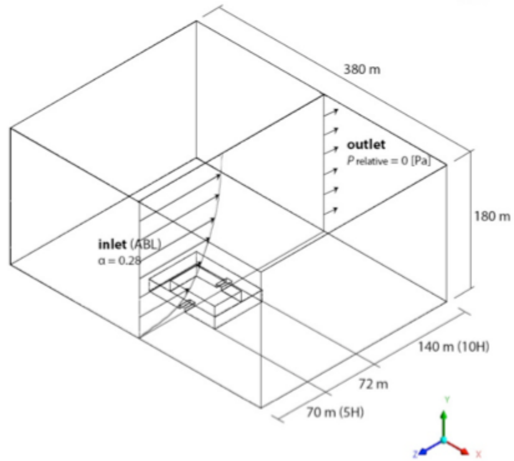
For the preliminary evaluation, the study focused on the wind driven ventilation only, without considering the buoyancy effect. The turbulence model used for this investigation was the standard k-epsilon (k-ε), which was widely used in the previous studies also (Muhsin et al., 2017;Montazeri and Montazeri, 2018). Cheung and Liu (2011) conducted a thorough investigation on the reliability of standard k-ε turbulence model for natural ventilation simulation. The findings of the study indicated positive results for cross ventilation performance. Besides Cheung and Liu (2011), other studies that employed k-ε turbulence model in the natural ventilation simulation were Shirzadi, Naghashzadegan, and Mirzaei (2018), Yang and Jian (2017), Yusoff, Sapian, Salleh, Adam, Hamzah and Mamat (2014), Yusoff, Sapian, Salleh, Adam and Hamzah (2014) and Yusoff, Sapian, Salleh, Adam and Johar (2015).

The numerical simulation in this study 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:

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

Where y is the wind speed (m/s) measur ed at the height of z (meter). Meanwhile, in this study, the wind speed yref was set to be 1 m/s, at the height, Zref of 10 meter. For this preliminary evaluation, the wind was set up to be from two directions only, which were 0° and 45° wind angles. 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 Figure 1(a). These were the minimum leeward and windward distances proposed by Montazeri and Montazeri (2018) and Tominaga et al.(2008) in determining the domain size. The building and ground surfaces were set to be no slip wall condition. The meshing used in this simulation was tetrahedron meshes, as shown in Figure 1(b). The tetrahedron meshes were also utilized by Cheung and Liu (2011) and Farea, Ossen, Alkaff and Kotani (2015) in their natural ventilation investigations. In this study, the maximum number of iteration was set up to be 1000.

(a)



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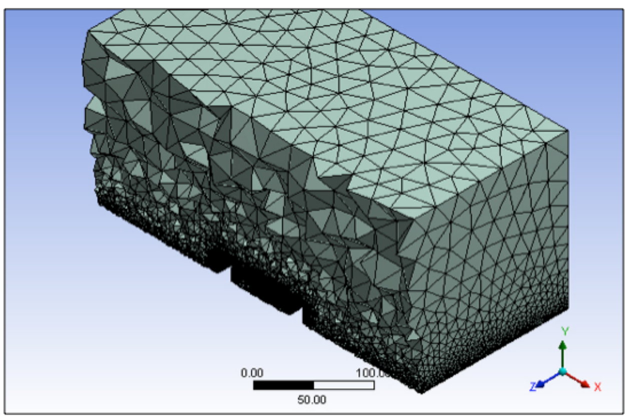
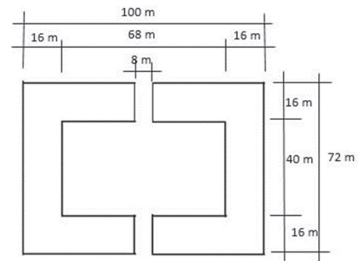


Figure 1: (a) The boundary condition set up for the simulation, and (b) the tetrahedron meshes

The building model constructed in the simulation consists of an atrium that is located in the middle. It is considered an atrium, and not a courtyard or an air well, as the top of the space is covered by a roof. As mentioned before, the investigation in this study focuses on the wind driven ventilation only, without any consideration of thermal factor. Therefore the top of the atrium is only specified as having a flat roof, with no materials specified for the roof. The investigated atrium was rectangular shape, with the dimensions of 68 m length, 40 m width and 14 m height (Figure 2). The size of the atrium was referred to the previous atrium, located in Bangi Gateway Shopping Mall, that was investigated by the author in Yusoff (2017). 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 (Figure 2).



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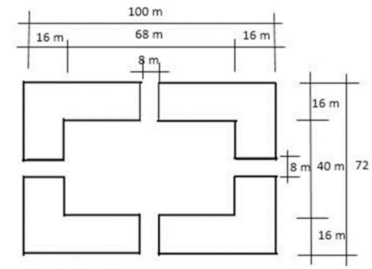

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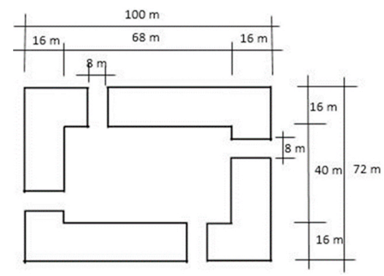
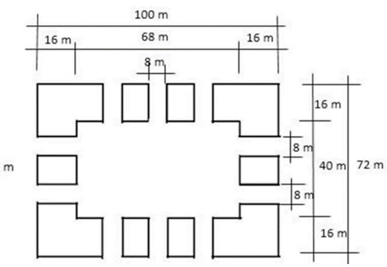


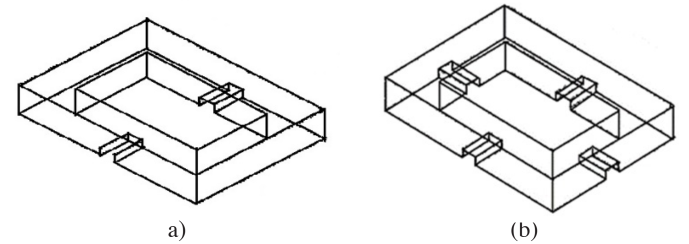
(c)



(d)

Figure 2: The plans that indicate the dimensions of the atriums with (a) two access corridors, (b and c) four access corridors, and (d) ten access corridors

The numerical simulation consisted of three stages. The first stage simulation encompassed the investigations executed for two conditions of atrium, which were the atrium with two access corridors, and the atrium with four access corridors. The access corridors were located opposite to each other (Figures 3(a) and (b)). The second stage simulation involved the atrium with four access corridors only. This was due to the findings derived from the first stage simulation, where the higher amount of corridors resulted in greater air velocity. In the second stage simulation, the access corridors were relocated to be not opposite to each other (Figure 3(c)). Meanwhile, in the third stage simulation, the number of access corridors had been increased to ten numbers (Figure 3(d)). The purpose was to obtain larger distribution of high air velocity inside the atrium. Nevertheless, all the corridors had similar dimensions and volumes in all stages of simulations.



(c) (d)

Figure 3: The axonometric views of the atriums with (a) two access corridors, (b and c) four access corridors, and (d) ten access corridors

3. RESULTS AND DISCUSSION

The results and discussion were presented for all the three stages of numerical simulations. The results and findings from the first stage simulation influenced the next steps conducted in the second stage simulation. Meanwhile, the third stage simulation was executed due to further enhancement needed to the air velocity resulted from the second stage simulation.

3.1 Numerical Simulation Stage 1

Figures 4 and 5, as well as Tables 1 and 2 indicate the results derived from the first stage simulation. The results of air velocity contours for atrium with two and four access corridors, simulated with 0° wind angle were depicted in Figure 4. Meanwhile, the results of air velocity contours for the similar atrium configurations, simulated with 45° wind angle were demonstrated in Figure 5. The air velocity contours were plotted at the height of 1 meter from the ground level. This height was selected as it is within the height of human scale.

(a) (b)

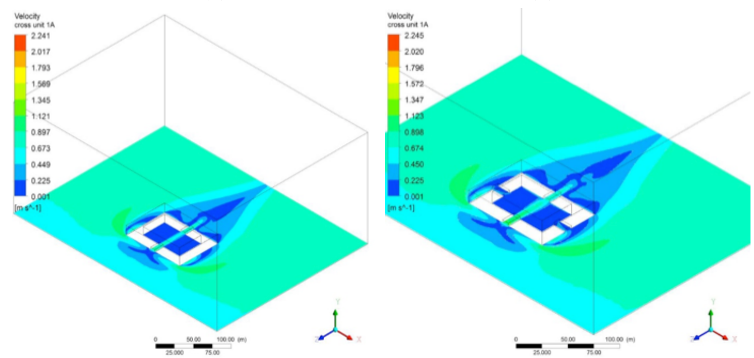


Figure 4: The air velocity contours for (a) atrium with two access corridors, and (b) atrium with four access corridors, at 0° wind angle

From the Figure 4, it can be seen that higher air velocities were concentrated at the centre of the atrium for both; the atrium with two, and four access corridors. This was due to the Venturi effect created inside the corridor. However, the other areas of both atriums suffered low air velocities, which were less than 0.2 m/s. For the atrium with four access corridors (Figure 4b), the side facades experienced negative pressure which resulted in low air velocities that flowed in via the side corridors. However, for 45° wind angle, the atrium with four access corridors had more areas with air velocities of more than 0.4 m/s compared to the atrium with two access corridors (Figure 5).

(a) (b)

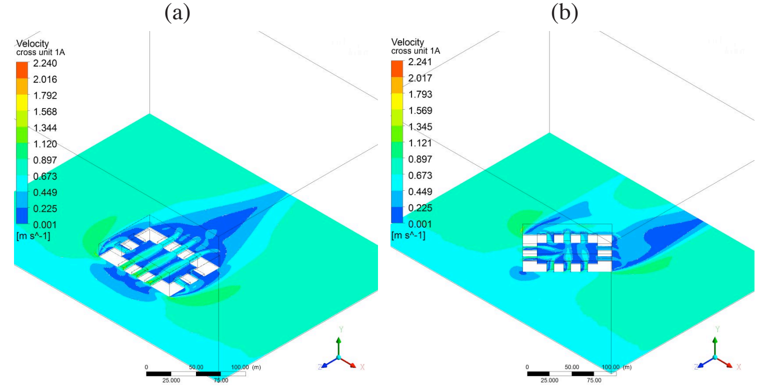


Figure 5: The air velocity contours for (a) atrium with two access corridors, (b) atrium with four access corridors, at 45° wind angle

The comparison of average air velocities 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 average air velocity compared to the atrium with two access corridors, as shown in Table 2. However, in contrary, it was found that for the wind angle of 45°, the average 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 2).

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 3. However, it seems that there were not much differences between the average air velocities inside the atrium with two and four access corridors, for both wind angles. Moreover, referring to Figures 4 and 5, it seems that there were many areas that suffered low air velocities which were less than 0.2 m/s for both atriums, and both wind angles. The higher air velocities only occurred along the air flow paths between the inlets and outlets.

Table 2: The average air velocities 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

Table 3: The average air velocities of the whole atrium area measured at 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

The results from the first stage simulation (Tables 2 and 3) show that in average, the air velocities were higher inside the atrium with four access corridors. However, the differences of air velocities between both atriums were insignificant, as in average, the differences were approximately 0.2 m/s and lower. In addition, the average air velocities inside the atrium with four access corridors were also lower than 0.8 m/s, except at the centre of the atrium for 0° wind angle. Therefore, further numerical simulation was executed in the second stage simulation with the purpose of searching ways to enhance the air velocity and air distribution inside the atrium.

3.2 Numerical Simulation Stage 2

In the second stage simulation, only the atrium with four access corridors was selected. The access corridors were arranged to be not opposite to each other as depicted in Figure 3(c). Nevertheless, the sizes and dimensions of the access corridors and atrium were still similar to the first stage simulation (Fig 2(c)). The results of second stage simulation were shown in Figure 6 and Table 4.

Figure 6 demonstrated the air velocity contours distribution inside the atrium for 0° and 45° wind angles. For 0° wind angle (Figure 6(a)), it can be seen that high air velocities still concentrated within the corridors and the air flow path outside the corridor that faced the wind direction. Outside the mentioned area, the air velocities were very low. The average air velocity measured at the centre of the atrium and 1 m height from the ground level was 0.101 m/s (Table 4). In addition, the air velocities at most of the atrium areas were below 0.2 m/s, which were represented by the dark blue colour. Meanwhile, the average air velocity for the whole atrium area measured at 1 m height from the ground level was 0.543 m/s (Table 4).

For the 45° wind angle (Figure 6(b)), the air velocity contours seemed to be distributed wider inside the atrium, though the average air velocity values were only 0.082 m/s (measured at the centre of atrium and 1 m height from the ground level), and 0.579 m/s (for the who le atrium area measured at 1 m height from the ground level).

(a) (b)

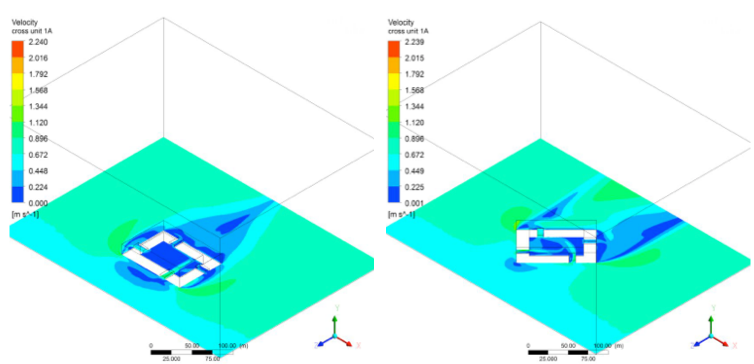


Figure 6: The air velocity contours in atrium with four access corridors that were located not opposite to each other for (a) 0° wind angle, (b) 45° wind angle

Table 4: The average air velocities inside the atrium with four access corridors that were located not opposite to each other

Wind Angle	Air Velocity (m/s)	
	Centre of atrium measured at 1m height from ground level	*Whole atrium area measured at 1 m height from ground level*
0° wind angle	0.101 m/s	0.543 m/s
45° wind angle	0.082 m/s	0.579 m/s

From the second stage simulation, the findings show that such arrangement of access corridors were able to distribute wider air velocities of higher than 0.2 m/s for 45° wind angle. However, the amount of average air velocity for the whole atrium area measured at 1 m height from the ground level was still lower compared to the first stage simulation. Therefore, further simulation was executed, which was the third stage simulation, in searching the strategy to enhance air velocities inside the atrium with access corridors.

3.3 Numerical Simulation Stage 3

In the third stage simulation, the amount of access corridors had been increased, as shown in Figure 3(d). Nevertheless, the sizes and dimensions of the access corridors and atrium were still similar to the first and second stage simulations (Figure2(d)). The results derived for the third stage simulation were shown in Figure 7 and Table 5. Figure 7 indicates the air velocity contours inside the atrium with ten access corridors, for both, 0° and 45° wind angles. It was found that there was greater distribution of air velocities more than 0.45 m/s inside the atriums for both wind angles. The results also indicated that for 0° wind angle, the average air velocity was found to be more than 0.8 m/s at the centre of the atrium. Meanwhile, the average air velocities for the whole atrium area measured at 1 m height from the ground level were found to be more than 0.5 m/s for both wind angles (Table 5). Though the velocities of air inside the atrium with ten access corridors were found to have not much differences with the other atriums, the advantage of this configuration was in term of the air velocity distribution. The findings show that greater amount of access corridors resulted in wider distribution of higher air velocities inside the atrium.

(a) (b)

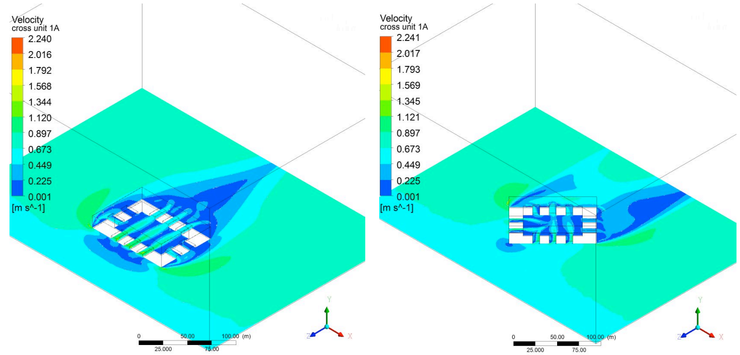


Figure 7: The air velocity contours in atrium with ten access corridors, for (a) 0° wind angle, and (b) 45° wind angle

Table 5: The average air velocities inside the atrium with ten access corridors

Wind Angle	Air Velocity (m/s)	
	Centre of atrium measured at 1m height from ground level	*Whole atrium area measured at 1 m height from ground level*
0° wind angle	0.101 m/s	0.543 m/s
45° wind angle	0.082 m/s	0.579 m/s

From the findings of all simulation stages, it can be summarized that the access corridors create Venturi effect which enhances the velocities of air that flow into the atrium. Based on the power law equation used for the ABL in this simulation, the outdoor wind speed at the height of 1 meter from the ground level was found to be approximately 0.5 m/s.

For 0° wind angle, it was found that the average air velocities for the whole atrium area, measured at 1 m height from the ground level, were more than 0.5 m/s. In addition, the average air velocities at the centre of atriums with four and ten access corridors had achieved more than 0.8 m/s, which was the recommended air velocity to obtain thermal comfort for sedentary activities in hot and humid climate (Yusoff, 2006;Cândido et al., 2011). For 45° wind angle, the average air velocities for the whole atrium areas, measured at 1 m height from the ground level, were also found to be more than 0.5 m/s. Therefore, it is believed that the velocity of air inside the atrium may increase with the increasing of outdoor wind speed.

4. CONCLUSION

The findings from the investigations 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 result in higher air velocities inside the atrium. However, the findings also demonstrate that higher air velocities are just concentrated at the area where the corridors are located, and along the air flow paths between the inlets and outlets. 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 paths between the inlets and outlets suffer low air velocity. Therefore, in ensuring wider distribution of higher air velocities inside the atrium, it is suggested to allocate as many amount of access corridors as possible. The appropriate locations of the access corridors can be decided based on the area or space functions, as well as activities inside the atrium.

The findings from this study is expected to create awareness among the people in built environment such as designers, building owners, developers and many others, to highly consider the importance of appropriate amount and location of air flow paths in the atrium design. This is due to the current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium.

The study in this paper focuses on wind driven ventilation only, without considering buoyancy effect. Therefore, it is recommended in future to extend the investigations by examining the effects of both; the wind and buoyancy driven ventilations, to the air flow inside the atrium. The atrium with openings at the top level creates chimney effect, which is desirable for hot and humid climate.

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