DIMENSI − Journal of Architecture and Built Environment, Vol. 41, No. 2, December 2014, 65-72 DOI: 10.9744/dimensi.41.2.65-72
ISSN 0126-219X (print) / ISSN 2338-7858 (online)

NATURAL AIRFLOW PERFORMANCES OF DOUBLE-SKIN FACADE TYPES

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ABSTRACT

DSF (Double-Skin Facade) aplications required on highrise building envelope to increase its thermal performance. The performance DSF with natural airflow, especially external air curtain mode, is affected by airflow around the building, and the design characteristics of the DSF. This paper investigated the performance of some DSF models, namely the multi-storey and box-window type, as well as those modification in utilizing natural airflow, especially with 90° wind direction toward the facade, using CFD techniques. The results showed that the multi-storey type has the best performance with higher average wind speed and equitable airflow distribution in all the facade zones.

Keywords: Double-skin facade; natural airflow; high-rise building.

INTRODUCTION

DSF, consisting of two-layer skin facade which allows airflow in its gap, is one of passive design technologies to improve the building performance, such as thermal performance (Poirazis, 2006). In tropical region, multi-storey buildings receive excessive solar radiation on those building envelope. On the other hand, DSF is used to cool the building envelope, so that the energy consumption for cooling load can be minimized (Hien, Liping, Chandra, Pandey and Xiaolin, 2005). Basically, the DSF performance is strongly influenced by the type of ventilation, namely natural ventilation, mechanical ventilation, or hybrid ventilation (Wong, Prasad and Behnia, 2008). Natural ventilation can utilize the natural wind pressure, as well as stack effect utilize the principal of vertical heat flow to warmer area a room with air inlet and outlet when there is no wind pressure (Szokolay, 2004). Areas that have the high potential of natural wind pressure can optimize its as ventilation source for the DSF.

The types of DSF revealed by Saelens (2002) and Lee at al. (2002), in Poirazis (2006), is divided into multi-storey, corridor, shaft-box and box-window type. Multi-storey type has a wide air gap with an air inlet at lower and air outlet at upper facade without any partition, while the corridor type has horizontal partition, as well as air inlet and outlet at each of floor height of the building. Box-window type has horizontal and vertical partitions that divided the air gap into some boxes with air inlet and outlet at each lower and upper side of the box. While shaft-box type has the same concept with box-window type, with additional vertical shaft ti enhance the airflow. The fourth type of DSF shows the difference in horizontal and vertical position of air gap partitions, as well as the position of the air inlet and outlet, with characteristics that tend to be typical at any height and orientation of the building. On the other hand, the wind speed and airflow pattern will be different at each height and orientation of the building facades, and affect the performance of DSF in these parts (Iyati, Indraprastha and Wonorahardjo, 2013). Meanwhile, according to (Seok, Jo and Kim, 2009) the wind velocity in the air gap of DSF is affected by the width and height of the air gap, as well as the dimensions and position of air inlet and outlet. Then the distance of the inner and outer skin should also be considered to avoid overheating in the air gap, by using the minimum distance about 20 cm (Jager, 2003, in Poirazis, 2006).

This paper aims at investigating the performance of multi-storey and box-window type using natural airflow, especially with 90° wind direction toward the facade by external air curtain mode. Modification of the DSF models to be studied in this paper refer to some variables such as the position of partition in the air gap, the air inlet and outlet positions, and the tilt angle of the outer skin. Then, this paper also examines the effect of the application and modification of the conventional DSF under perpendicular wind direction toward the facade, to determine the effect of application of DSF with typical design. A multi-storey office building in Bandung, Indonesia, serve as a model for the DSF simulation of the experimental studied using CFD techniques. The results are expected to assist the designer in determining the DSF models that utilize the natural ventilation, as well as developing the DSF technology. The application of passive design technologies, such as DSF with natural airflow, are expected to support the sustainable development for better human life.

RESEARCH METHOD

This study used simulation method of Computational Fluid Dynamics techniques (CFD) to investigate the performance of conventional DSF as well as those modification and combination. Computational Fluid Dynamics has proven to be a useful tool for modeling the airflow and heat transfer in a double glass façade, which includes the phenomenon of heat transfer by conduction, convection and radiation (Guardo, Coussirat, Valero, Equsquiza and Alavedra, 2011). The examining of the airflow around the building envelope in high rise building will need complex equipment and take a long time.

In this study, we used a highrise office building in Bandung, Indonesia, for DSF simulation with CFD technique. Bandung is located in hot-humid climate of Indonesia, with average temperature at 23,4 °C, 79,5 % average relative humidity, and average wind speed at 1,37 m/s at 10 m height in the last 3 years. Before performing the DSF models simulations, we compared the field measurements of thermal conditions on the case study with CFD simulation. Measurements have been carried out at three points on four orientations in three storey of the building facade representing lower, middle and upper tower (2^{nd}, 5^{th}, 11^{th} floor) in this 11-story Single-Skin Facade (SSF) building. The results of the thermal measurements on the existing building envelope, the surface temperature of the glass on all four orientations (north, east , south, west), then compared with the results of CFD simulation and showed an average deviation of 1.96% (see Table 1).

Furthermore, each DSF models simulated under perpendicular wind direction toward the front facade (90°). In this CFD simulation, we used 5.10^{-2} to 1.10^{-1}m grid system to simulate the detail of airflow in the gap of DSF. We also used the toggle localized mode in the grid system to produce a more detailed calculation on the air gap. The investigated DSF models refers to conventional DSF that have been widely applied in the field, namely multi-storey and box-window, as well as those modifications and combinations, based on the position and distance of the air gap partitions, the air inlet and outlet positions, as well as the tilt angle of the outer skin. While the inner and outer skin distance serve as a fixed variable, 20 cm, which is the minimum distance of the glass to avoid overheating on the air gap.

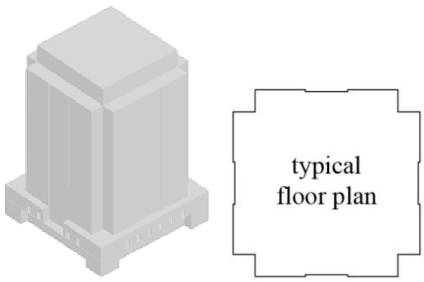

Figure 1. Three dimentional and typical floor plan of the investigated highrise building

Table 1. Comparison of field measurement and CFD simulation

Facade	Time	Outdoor Air Temp. (°C)	2nd Floor			5th Floor			11th Floor		
			Glass Temp. (°C)		Std. Dev.	Glass Temp. (°C)		Std. Dev.	Glass Temp. (°C)		Std. Dev.
			Field Meas.	Cfd		Field Meas.	Cfd		Field Meas.	Cfd	
North	10.00	27,6	29,5	29,5	0	34,67	30,6	2,88	33	31,6	0,99
	14.00	31	28	30,7	1,91	31,8	31,2	0,42	29,67	31,1	1,01
	16.00	29,8	27,5	30	1,77	28	30	1,41	28,5	29,9	0,99
East	10.00	32,3	38	31,1	4,88	39,67	30,7	6,34	41	39,3	1,2
	14.00	30	27,25	32,3	3,57	29,67	30,3	0,45	29,33	30,3	0,69
	16.00	29,6	28	30,5	1,77	26,63	30,5	2,74	27,83	30,1	1,61
South	10.00	27,9	27	29,5	1,77	28,5	29,6	0,78	27,67	31,1	2,43
	14.00	29	27,07	31,5	3,13	28	31,6	2,55	27,33	31,6	3,02
	16.00	29,5	27	30	2,12	27,3	30,1	1,98	27,67	30	1,65
West	10.00	28	27	31,1	2,9	27	31,4	3,11	28,33	30,8	1,75
	14.00	35	38,5	36,9	1,13	33	34,6	1,13	38,5	34,5	2,83
	16.00	30	30	32,2	1,56	28,67	31,3	1,86	31,17	31,4	0,16

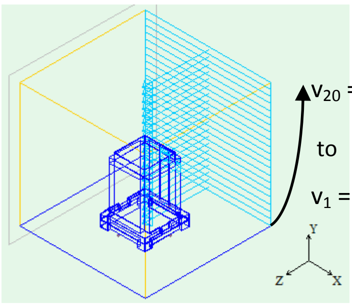

Figure 2. Five meter fixed flow segmentation field based on wind velocity chart for CFD simulation system: 90° toward front facade

Simulation results consisting of wind speed on the air gap and its distribution in each zone of the facade compared to determine the performance of each model DSF studied in utilizing natural airflow.

THE MODELS

The box-window types that we studied are consists of a base type with the outer skin parallel to the inner skin (BW-B), then sloping the outer skin downward and enlarging the air inlet at the lower side (BW-SB), as well as sloping the outer skin upward or enlarging the air outlet at the upper side (BW-ST).

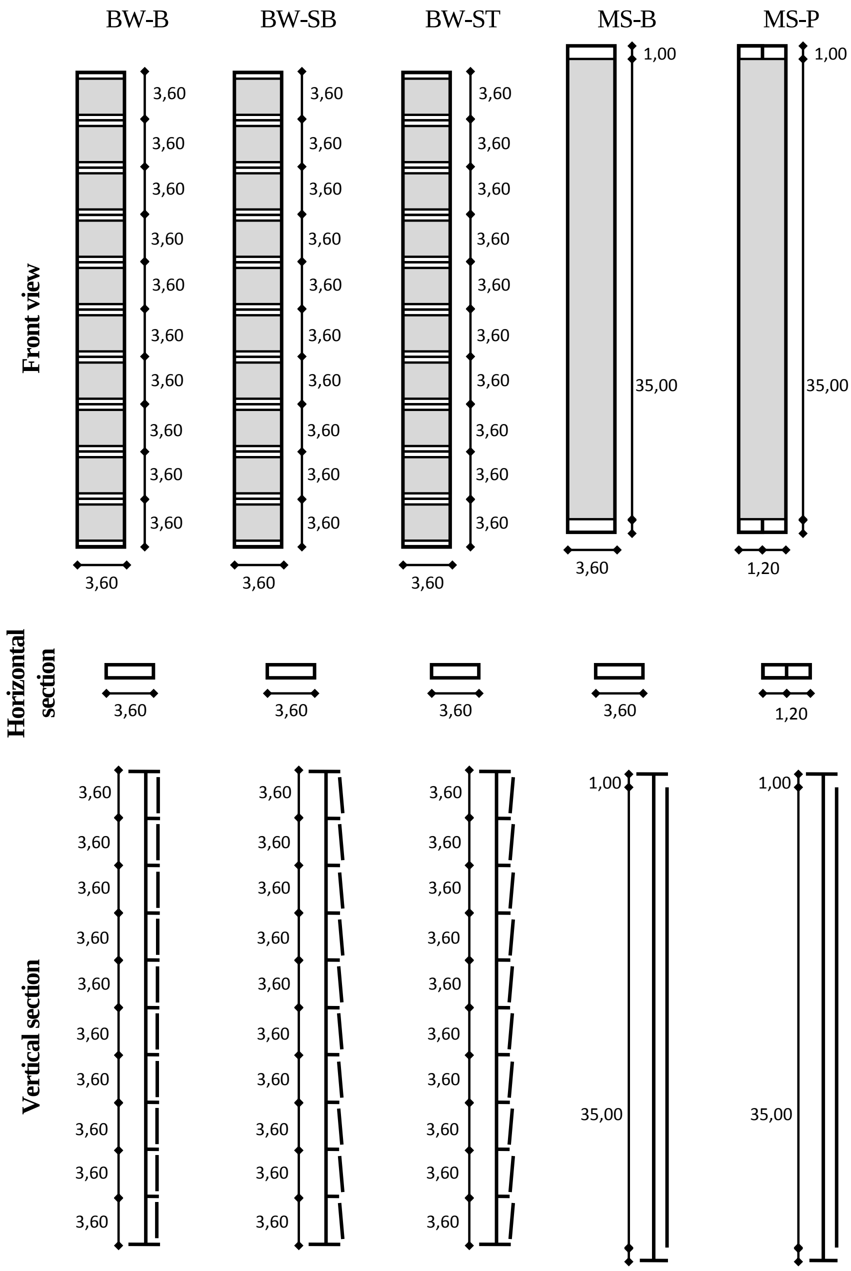

Figure 3. Investigated DSF model: box-window, multi-storey and those modification

We investigated the modification of the outer skin tilt angle and the size of the air inlet and outlet to know those natural airflow performance. Then, multi-storey types consist of basic types (MS-B) as well as the addition of a vertical partition (MS-P) with 50% air gap volume of the basic types (figure 3). We also investigated the additional vertical partition to know those effect in increasing natural airflow in the air gap. While the type of combination and modification of box-window and multi-storey type consists of a multi-storey type with additional air inlet and outlet at each building floor level, with the outer skin parallel to the inner skin (BM-B), then the outer skin tilted downward or enlarged air inlet at the lower side (BM-SB), and the outer skin tilted upward or enlarged at the upper side (BM-ST). All these types have no horizontal partition (figure 4).

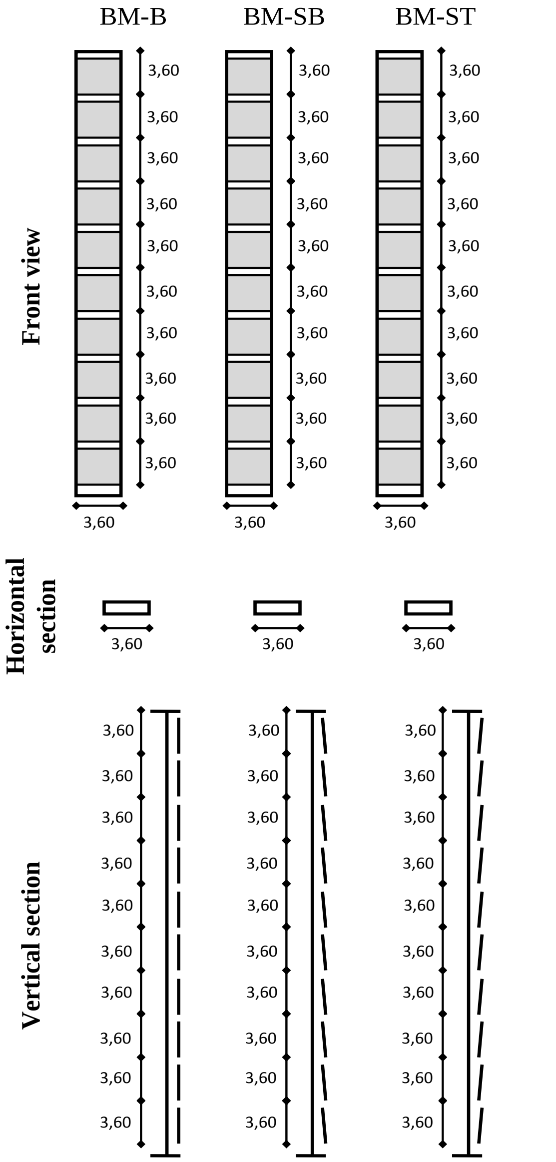

Figure 4. Investigated DSF model: combination and modification of box-window and multi-storey type

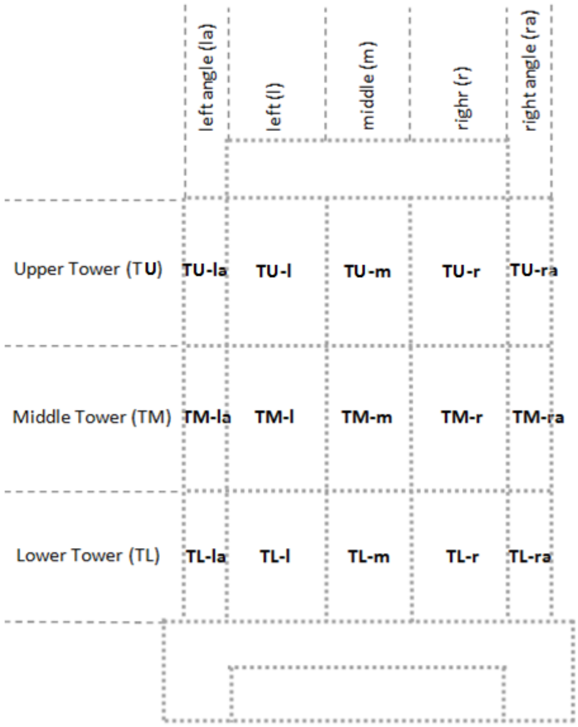

Figure 5. Building zones in CFD simulation

The goal is to know the effect of additional air inlet and outlet at each floor level without the use of horizontal partitions as the box-type window. Eight types of DSF are applied to the front facade of the case study building with perpendicular wind direction toward the front facade.

To calculate the average wind speed across the air gap, we divided the facade into 15 zones accordance with the characteristics of the existing building envelope (figure 5). The 15 zones representing the lower, middle and upper of the tower vertically, and the division is based on the characteristics of the existing facade horizontally. The average wind speed in the whole field of front facade derived from the average wind speed in each zone. Further analysis comparing the average wind speed and airflow distribution at each DSF models have been studied (see Figure 7).

RESULTS & DISCUSSION

The simulation results of BW-B model, BW-SB and BW-ST that use the principle of the box-window type, shows the lowest average wind speed at 0.21, 0.29 and 0.36 m/s (Figure 7). While a fairly uniform distribution indicated by the standard deviation of the average wind speed in each module, 0.10, 0.06 and 0.08. Simulation of MS-B and MS-P models performs the highest average wind speed at 0.56 and 0.6 m/s with a very good airflow distribution, that

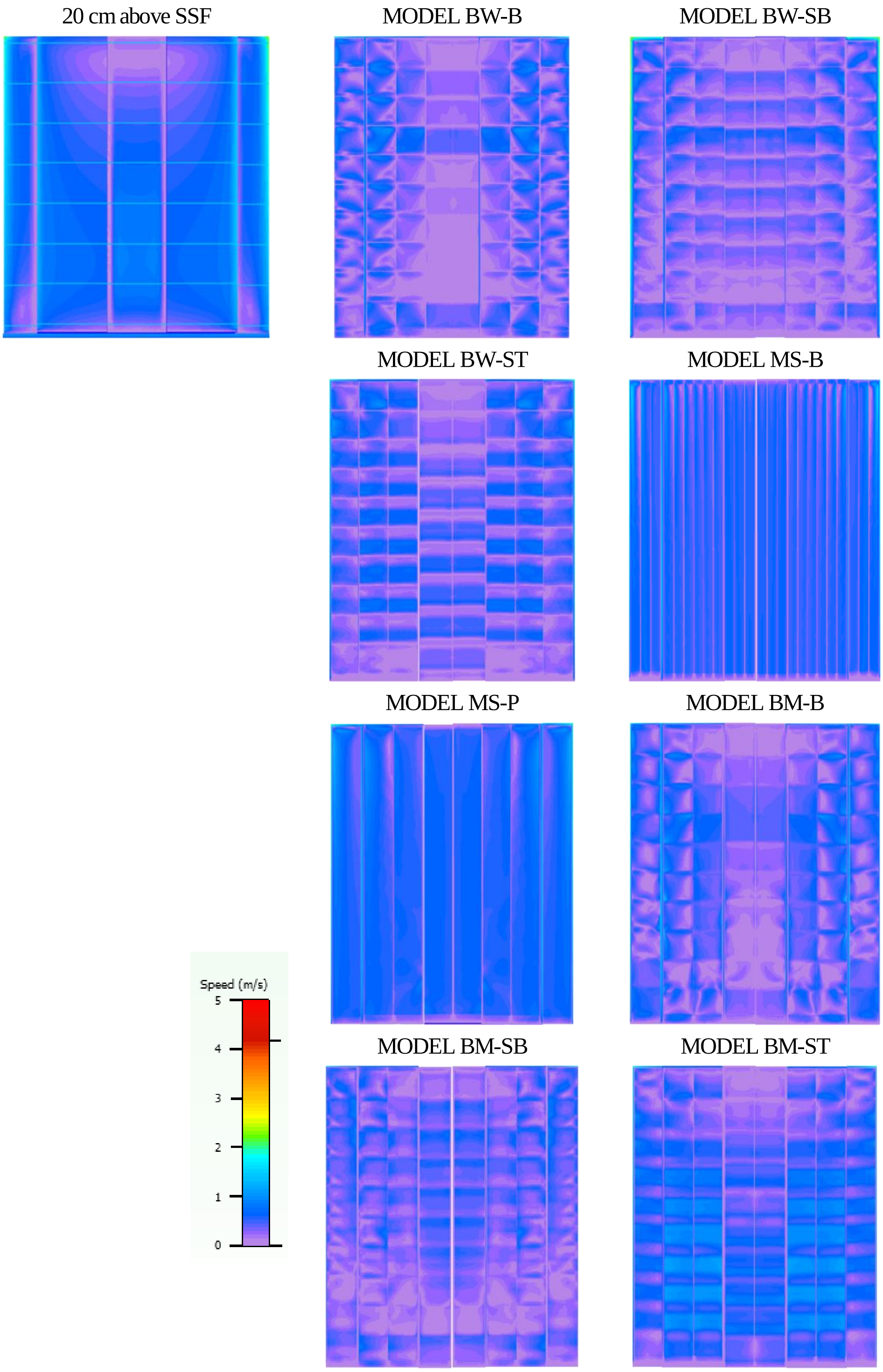

Figure 6. CFD simulation results of airflow performance at 20 cm above Single-Skin Facade (SSF) and in the DSF's air gap

indicated by the small standard deviation, 0.04 and 0.02. While the average wind speed of BM-D, BM-SB and BM-ST model is higher than BW-B, BW-SB and BW-ST model. BM-D and BM-SB shows the lower average wind speed when compared to the MS-B and MS-P model, with 0.38 and 0.34 m/s wind speed, as well as a fairly uniform airflow distribution with a standard deviation respectively at 0.08. While the average wind speed of BM-ST model has not significantly different from the MS-B and MS-P, which is equal to 0.55 m/s, but showed the most uneven airflow distribution with a standard deviation of 0.16. Overall, the multi-storey type of DSF shows the best performance in utilizing the natural airflow, as well as performing good airflow distribution in all zones of the facades (Figure 7).

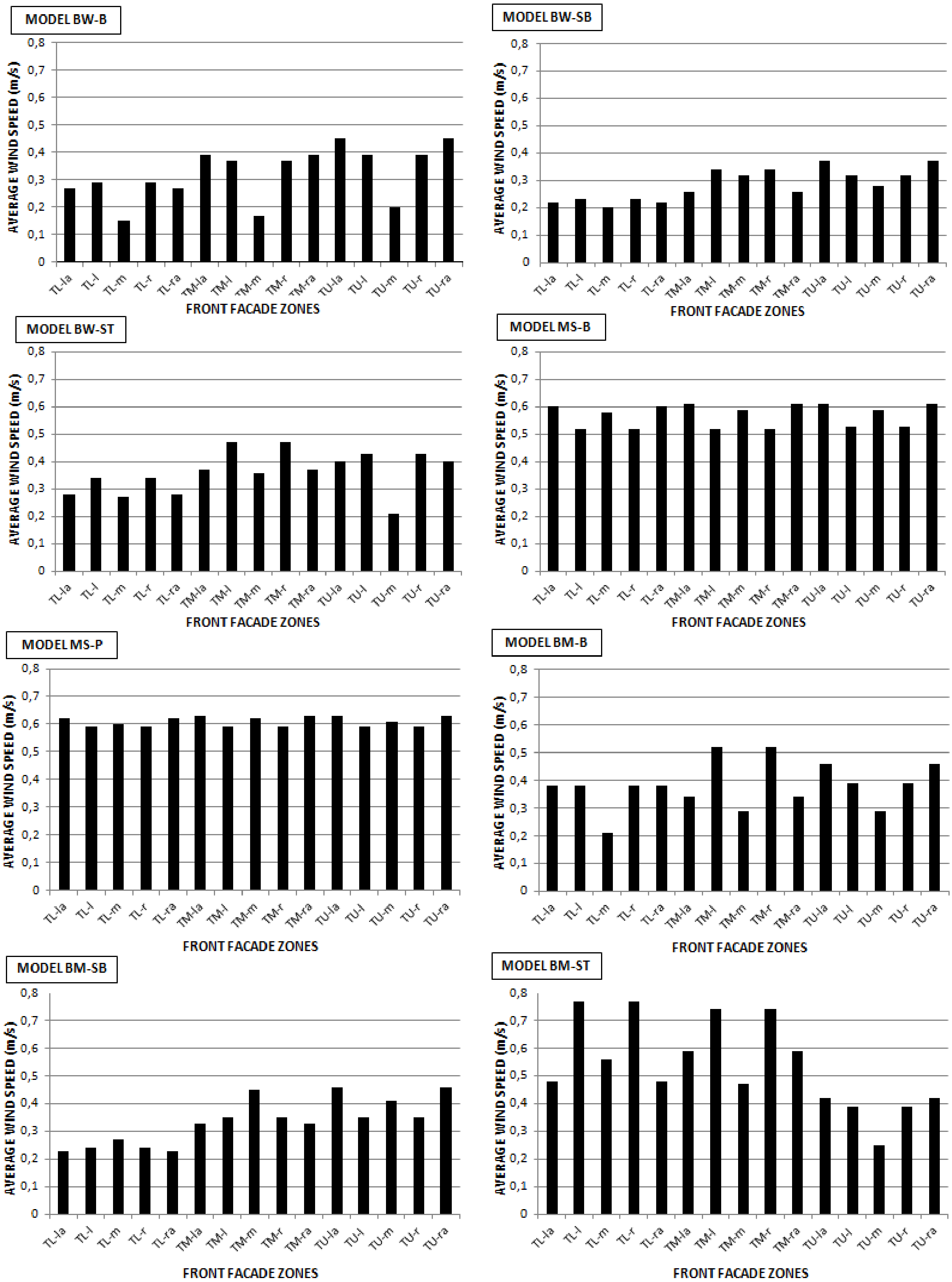

Figure 7. Average wind speed and distribution in air gap

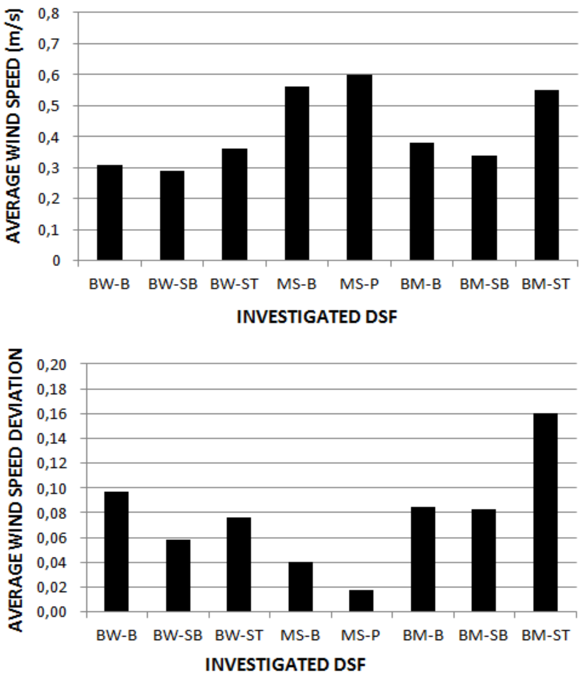

Figure 8. Average wind speed (upper figure) and airflow distribution showed from the average wind speed deviation (lower figure) of investigated DSF models

The addition of a vertical partition as in the model MS-P showed no significant effect in speeding up the airflow in the air gap. While the box-window type shows the lowest average wind speed due to the horizontal partition that hinder the movement of the wind from the lower to the upper side. The results also show the combination of multi-storey and box-window type shows similar performance with box-window type, especially BM-D and BM-SB.

While the BM-ST model indicates the similar performance with the multi-storey type. The use of the inclined of outer skin, with larger inlet at the lower side shows the reduction of wind speed in the air gap. This is indicated by the BW-SB and BM-SB model that has an average wind speed lower than the BW-B and BM-B model. While the use of the inclined of outer skin with a bigger air outlet hole in the upper section shows an increase in wind speed. This is especially shown by the model BW-ST and MS-ST when compared with the parallel inner and outer skin. The results also showed that the addition of air inlet and outlet at each floor level in a multi storey type (model BM-B) reduces the wind speed in the air gap (Figure 8).

The multi-storey type also showed the best performance of the airflow distribution in each zone of the facade, with the smallest standard deviation of average wind speed. On the other hand, inequality airflow. distribution in the air gap will affect the indoor cooling performance. In addition, when compared to the average wind speed at 20 cm from the building envelope surface or without DSF (single skin facade), at 0.86 m/s, the entire DSF models studied actually reduces the average wind speed in the air gap. It is proved that the typical conventional DSF such as box-window type may not necessarily be able to accommodate the differences of natural wind direction and speed that occurs in each zone of the facade. Similarly, the type of multi-storey which has an air inlet at the bottom of the tower and the air outlet at the top of the tower, is not necessarily to catch the wind and pull it out optimally.

Therefore, further research is needed on the DSF models which are able to accommodate the differences in the direction and wind speed of airflow in each zone of the facade, as well as in conditions of wind direction different sources. Thus, DSF with optimal natural ventilation not only when using the stack effect principle, but also optimal when utilizing of wind effect.

CONCLUSION

Based on the investigation of the comparative analysis of CFD simulation results, it was found that multi-storey type (MS-B and MS-P) gives the best generating airflow in the air gap as well as evenly airflow distribution in every zone of the facade. The use of the inclined plane (BM-SB or BM-ST) on the outer skin of the DSF need to consider the dominant airflow on the surface of the building envelope and create big hole as the air outlet.

The results also show that the box-window type is less optimal than in utilizing wind pressure naturally. Overall, all the models studied have reduced the existing wind speed about 30,23% to 66,28%. So that the DSF performance in reducing indoor air temperature as well as reducing energy consumption for cooling load must be considered. Furthermore, the DSF model that can increase natural airflow in its air gap also has to explored.

ACKNOWLEDGMENT

The author wish to thank the Laboratory of Building Technology, School of Architecture, Planning and Policy Development, Bandung Institute of Technology, Indonesia for the supporting data of field measurement and facilities for CFD simulation.

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