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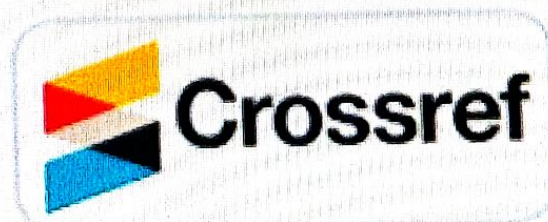
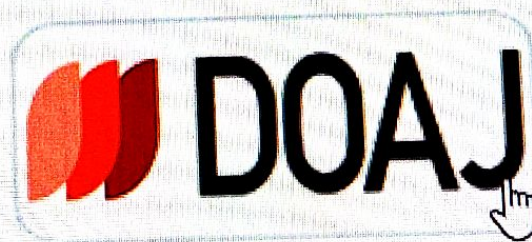
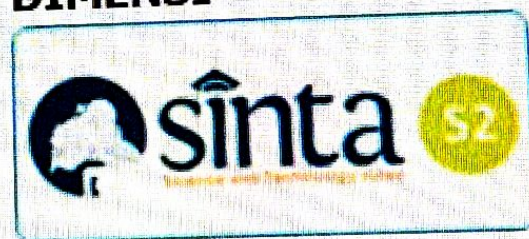
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BALCONY GEOMETRIES PERFORMANCE AS WINDCARRIERS INTO LIVING SPACE ; CASE STUDY: APARNA SIWALANKERTO

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ABSTRACT

In majority, housing flats use natural ventilation to cope with humid tropical climate in Indonesia, which requires airflow to achieve thermal comfort. One of the potential architectural element in delivering air into the living space of vertical buildings is balcony. But in reality, balconies in Indonesian housing flats are only functioning as façades, and have not optimized their potential as windcarriers, which partially cause air discomfort in living space. This study examines the performance of balcony geometries as windcarriers into living space through simulation by Ansys Workbench CFX 2021 on Aparna Siwalankerto as a case study. It was found that balcony with more well-ordered wind receiving planes could carry wind into the living space best, in terms of both speed and distribution, as such in this study was the symmetric pentagonal balcony. Still, between the two aspects, wind distribution determines balconies performance, rather than wind speed.

Keywords: Balcony geometry; CFD; airflow; wind velocity; housing flats.

INTRODUCTION

Indonesian housing flats are residential buildings built for low-income people. Based on their financial abilities, most housing flats use natural ventilation to cool space, which makes the phenomenon of opening windows and doors in Indonesian housing flats natural as residents try to let air flows into their living space. This logic matches with the high temperature and relative humidity of tropical humid climate in Indonesia, which requires wind speed in its natural ventilation (Maarof and Jones, 2009). Furthermore, Feriadi and Wong (2004) also studied natural ventilation in Indonesian housing and stated that residents prefer higher wind speed for comfort.

To optimize airflow entering living space, the influential architectural element is balcony (Ribeiro et al., 2020). Previous researches have stated balcony existence could optimize natural ventilation and indoor comfort, thus decreasing mechanical cooling demands and overall energy consumption of a building. This is relevant to Indonesian housing flats, that rely on outdoor wind speed and indoor wind distribution to achieve thermal comfort.

Unfortunately, this potential has not been studied as much in Indonesia. Balconies only function as facades, and have not optimized their roles as windcarriers, especially in housing flats building. According to previous researches and a survey conducted at case study Aparna Siwalankerto in Surabaya, the average indoor and outdoor temperature is 31°C and average wind speed is 0.2 m/s. Even though residents have opened doors and windows all day, the received wind at balconies could not reach the living space, making


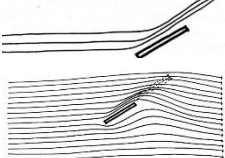
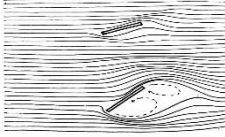
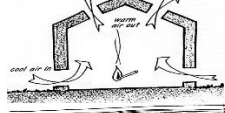


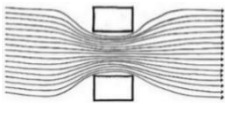
the space stale. Based on issues above, balcony design as an architectural element must be studied further for balconies to optimally function as windcarriers. This study will examine the performance of balcony geometries as windcarriers into living space.

THEORETICAL FOUNDATION

As foundation in analyzing wind movement, Moore (1993) in his book *Environmental control systems: Heating, cooling, lighting*, has identified the principal of wind movement related to architecture in Table 1. Generally, air flows from high to low pressure, has momentum, tends to stay in its direction and has huge overall effect, until it is altered by an obstruction then immediately returns to its original direction. As air needs pressure to flow, a space needs an inlet and an outlet to encourage airflow. Altogether, there are three effects in airflow, which are stack effect, Bernoulli effect and Venturi effect.

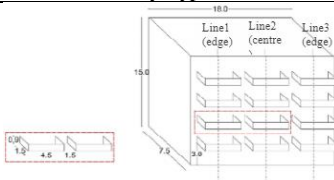
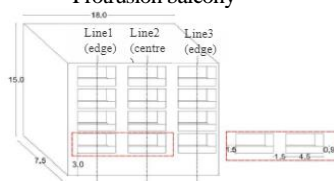
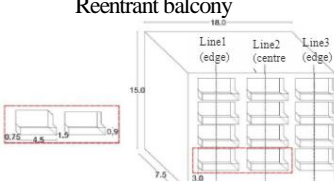

In its function in vertical building, balcony has an important role in delivering wind movement into living space as the only source of fresh air. Previous researches have studied balcony types and their impacts to wind movement into buildings. Amongst general balcony types, that are protrusion balcony, reentrant balcony and mixed balcony, the second encouraged wind movement the most, with the biggest pressure difference to drive airflow. Mixed balcony showed a good pressure distribution but there was no significant difference in pressure. The protrusion balcony showed the smallest pressure difference and so, the least drive in airflow.

Table 1. Wind movement principal

Wind Movement	Illustration
Air flows from high to low pressure.	
Air has mass (and momentum) and stays in its original direction until it is altered by obstructions or adjacent airflow. Wind effect in an area is huge, changed wind movement from local obstruction immediately returns to its original direction.	
Laminar flow can be preserved by gentle, slow changes. Sudden changes turn it to turbulent flow, swirling in different directions.	
Stack effect occurs as indoor air is heated and becomes lighter than outdoor air, which then is pushed out from higher building opening.	
Cross ventilation needs an outlet and an inlet.	
Bernoulli effect causes pressure to decrease and wind to accelerate to cover a greater distance than adjacent airflow.	
Venturi effect causes wind acceleration as laminar flow is obstructed to pass an opening (same volume through smaller area). Sudden obstruction makes turbulent flow and minimizes Venturi effect.	

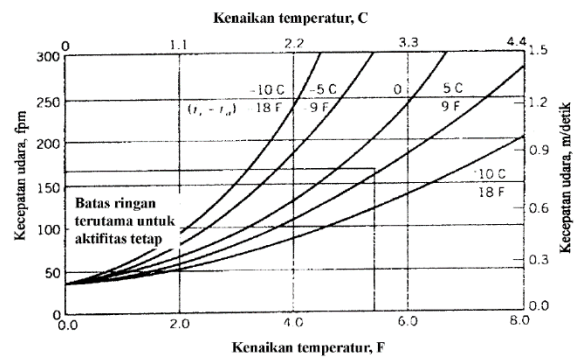
(Source: Moore, 1993)

Table 2. Balcony types effect in wind movement

Balcony Types	Wind Movement
	Bad pressure coefficient, least pressure difference, wind speed does not change much in entering the space.
Protrusion balcony 	Well distributed pressure coefficient with the largest pressure difference, wind speed increased, better indoor natural ventilation.
Reentrant balcony 	Good distributed pressure coefficient, no significant difference in pressure.
Mixed balcony 	

(Source: Mirabi and Nasrollahi, 2020)

Indonesia has tropical humid climate, with dominant wind direction from east and northwest in rainy season and from east in dry season; and 1-4m/s wind speed all year long (Windfinder.com, 2021). As thermal comfort standard, Indonesia implements SNI 03-6572-2001 (Tata cara perancangan sistem ventilasi dan pengkondisian udara pada bangunan gedung, 2001) which stated that comfortable indoor wind speed is 0.25m/s, could be higher, depends on indoor dry air temperature. For average temperature of 30°C, comfortable indoor wind speed is 0.8-1.2m/s.

**Fig 1.** Indoor wind speed comparison with the increase of room temperature (Source: Tata cara perancangan sistem ventilasi dan pengkondisian udara pada bangunan gedung, 2001)

In wind movement simulation, the wind profile power law equation, proposed by Hellmann, could be used to create a similar situation with the existing case study. The definition of α is based on surface roughness, categorized by Aynsley et al. (1977). The case study Aparna Siwalankerto is categorized as suburban areas, whose α value is 0.25. The u value is acquired from BMKG climate data, that is local dominant wind speed, 4m/s.

$$u = u^{ref} \left(\frac{z}{z^{ref}} \right)^{\alpha} \quad (1)$$

Where:

 u = wind speed (m/s) u^{ref} = referenced wind speed (m/s) z = height (m) z^{ref} = referenced height (m) α = surface roughness coefficient

In examining the performance of balcony geometries against wind movement, there are several factors, as explained above, which have some influences in the study. As the focus of the study, wind movement principal is used as the scalpel analysis. Wind movement is affected by obstructions, which in this study a balcony, as well as local climate, that is tropical humid with Indonesian comfort standard, the SNI. With the acquired climate data, the Hellmann wind profile power law could create this climate in the CFD (Computational Fluid Dynamics) simulation for more accurate results.

METHODOLOGY

A quantitative, descriptive and experimental simulation study was conducted by Ansys Workbench CFX 2021 on a case study of Aparna Siwalankerto Surabaya. Modelling was done by Rhino 7 before being simulated by Ansys Workbench CFX 2021. Climate data were gathered through literature study and direct measurement, which were applied to Hellmann wind profile power law in the simulation setup. The study steps and sequences are shown in Figure 2.

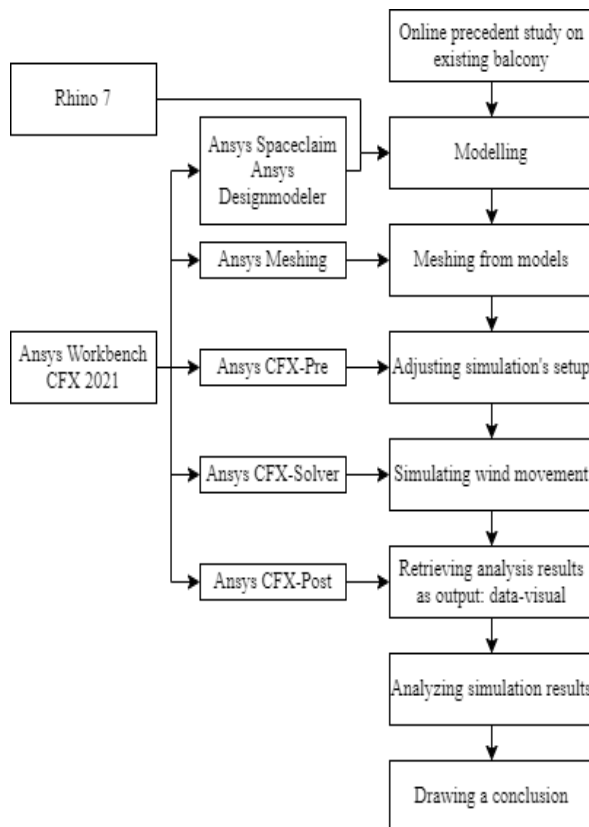


Fig 2. Methodology diagram

Balcony Geometries Preferences

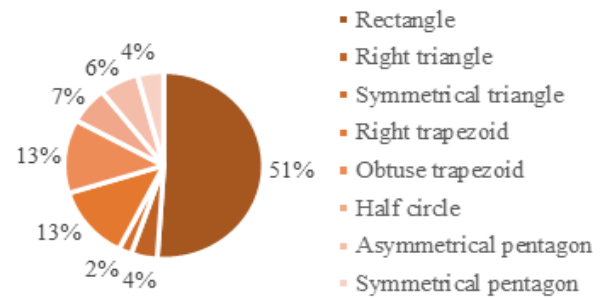


Fig 3. Balcony geometries preferences percentage (Source: “10 Examples of Unique Balcony Architecture,” 2021; *DYEJI / Costa Lopes*, 2017; *Nieuw Leyden Block / Arons En Gelauff Architecten*, 2014; “*North Star*” Apartments by Nice Architects / Inspirationist, 2014; *Port Apartment Suzhou Shilu Community Project / GPT Architectural Design*, 2019; *Spectrum Apartments / KAVELLARIS URBAN DESIGN*, 2016; Chakota, 2021; Ganea, 2016; Hicon, n.d.; Ibrahim, 2017; Media, 2015; Mistry, 2020; Pacheco, 2020)

Author has done an online precedent study on 45 vertical building regarding unique balcony geometries to determine geometry models to be simulated. It was found that there are 8 preferences of balcony geometries, whose majority, 51%, is rectangle balconies, with size ratio mostly (34%) 1:2.

To specifically examine balcony geometries against wind movement, there were several elements to be locked in the models:

- Each balcony model had 1.1m balustrade as the existing model
- Flat units were set in 3 parallel arrangements to understand balcony geometries performance as a whole flat rather than individual units, with a 5 floors height as the existing case study.
- Balustrade was solid to examine the geometries.
- Living space was considered empty to observe indoor wind movement, with openings as existing case study (front door closed, windows opened).

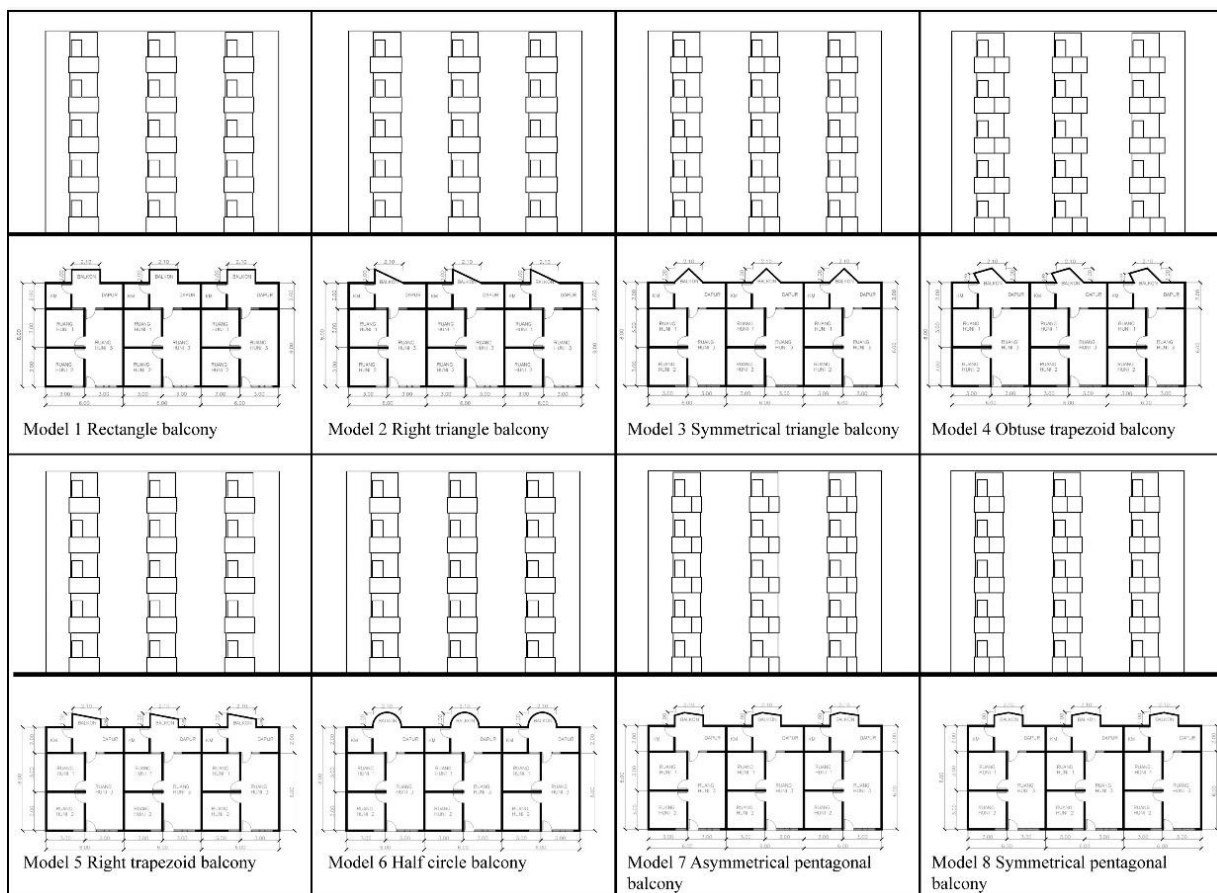


Fig 4. Balcony geometry models (elevation and plan)

Each model was tested against 3 wind angles, 0° , 45° , and 90° , to understand the performance of balcony geometries as wind comes perpendicular of, parallel to and angled from the building.

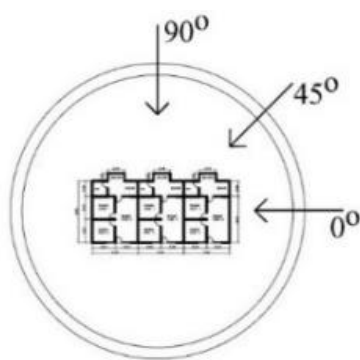


Fig 5. Wind angles to be simulated

RESULTS AND DISCUSSION

The analysis of simulation results was divided to 2 sections, wind speed analysis and wind distribution and penetration analysis. The eight balcony geometry models were compared to the existing model of Aparna Siwalankerto as a case study.

Wind Speed Analysis

From simulation results, average wind speed in balcony was compared to max wind speed of living space to find out the speed difference in delivering wind. Data were taken from 1.5m height of each floor. The max wind speed in living space was also compared to comfort standard of the SNI, at room temperature 30°C (measured average existing temperature), which required 0.8-1.2 m/s wind speed to achieve comfort. The aim was to find out if balcony geometry could carry comfortable wind into living space.

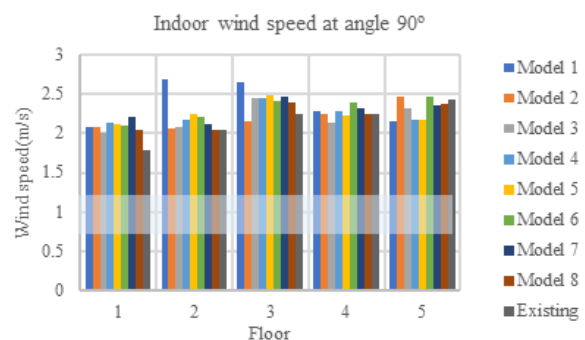


Fig 6. Max indoor wind speed at angle 90°

At angle 90°, max indoor wind speed on all floors of all models far surpassed the SNI range, with the average of 2m/s. This showed that at this angle, there was no need to increase wind speed too much or it was even required to decrease wind speed received by balcony. As such, balcony needed complementary elements, such as balustrade or wingwall, which were able to obstruct the occurred wind acceleration so the wind received in living space is in the SNI range. Even so, wind speed above the SNI range could still be useful when local temperature increases, thus in turn also will need higher wind speed for comfort.

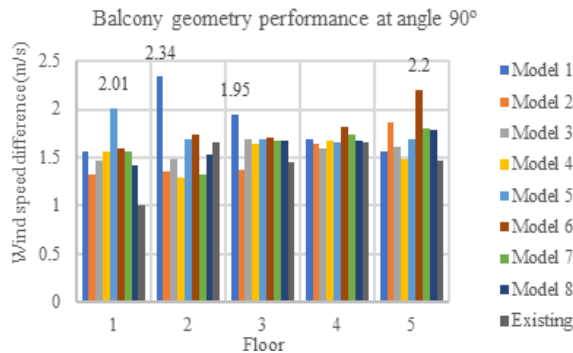


Fig 7. Balcony geometries performance at angle 90°

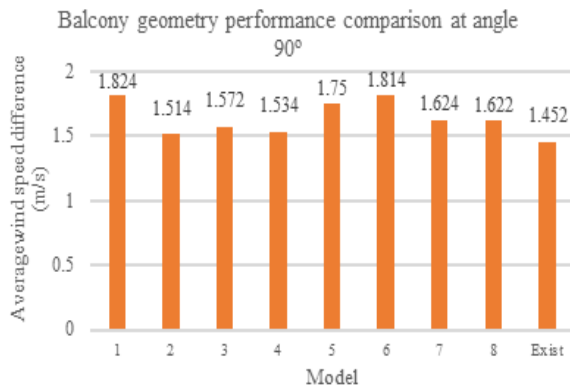


Fig 8. Overall performance of all models at angle 90°

Generally, the performance of every balcony underwent wind acceleration in the distribution to living space. Seen on Figure 7 and Figure 8, model 1 and 6 had the highest performance in wind acceleration of 1.824m/s and 1.814m/s respectively. This high acceleration was actually not needed in this angle, as the perpendicular wind direction has already supported cross ventilation to occur. Furthermore, Figure 7 showed that both models had unstable performance in wind acceleration on each floors, such as high wind acceleration on floor 2 and drastic wind deceleration on floor 5 of model 1; and high wind acceleration on floor 5 of model 6.

In performance stability, Figure 7 showed that model 8 had a stable wind acceleration on every floor

(1.42m/s, 1.54m/s, 1.68m/s, 1.68m/s, 1.79m/s) with an average overall performance of 1.622m/s. Model 8 had a symmetrical pentagonal balcony. The solid five sides, which became wind receiving planes, directed wind better in each floor than other models with its symmetrical shape and highest number of sides. Moreover, main wind receiving planes (which face incoming wind direction) had sloping angle, which did not break wind momentum sharply, as for example, model 1 did. Instead, they diverted wind into living space symmetrically.

Overall, at this angle, balcony geometries did not affect wind movement as much as at other angles and there was a need to equip the balcony with a complementary element to obstruct wind speed received by balcony, for the comfort of wind speed in living space.

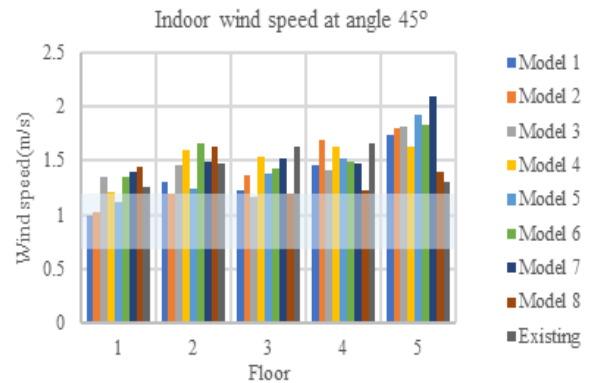


Fig 9. Max indoor wind speed at angle 45°

At angle 45°, it was found that max indoor wind speed overall were above the SNI range of 0.8-1.2m/s. Only a few models on lower floors showed wind speed in the SNI range. From average max indoor wind speed acquired, only model 1 and 8 could get close enough to the SNI range, that were 1.346m/s and 1.38m/s respectively. This showed that at this angle, there was no need for high wind acceleration, or it was even required to decelerate wind from balcony to living space. As such, balcony needed a complementary element which could obstruct wind speed at this angle.

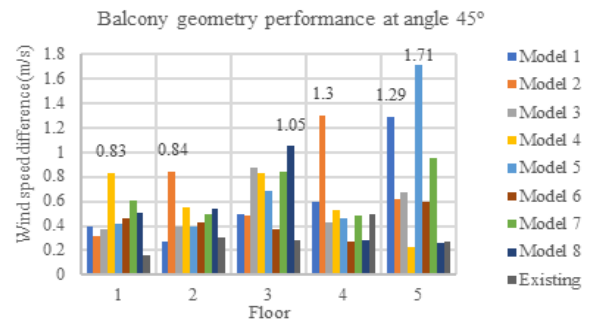


Fig 10. Balcony geometries performance at angle 45°

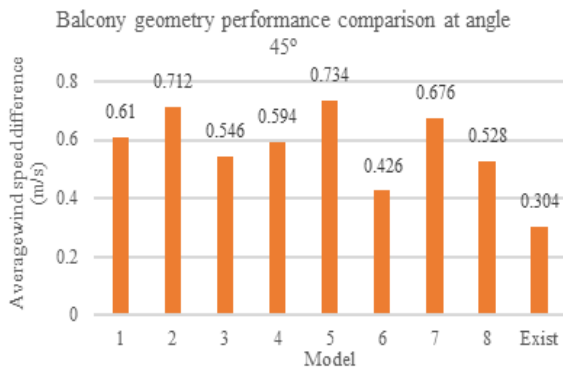


Fig 11. Overall performance of all models at angle 45°

Based on Figure 10 and 11, model 5, 2, and 7 showed higher performances than others. All three showed unstable wind acceleration though, such as significant wind acceleration or drastic wind deceleration on certain floors, for example, wind acceleration on floor 2 and 4, but drastic wind deceleration on other floors of model 2; or high wind acceleration on floor 5 but low wind speed on other floors of model 5 and 7. Their performances were so unstable, and so the overall performances shown in Figure 8 could not reflect for their performances in each floor. Furthermore, the max indoor wind speed of model 2, 5 and 7 were both excessive for residents comfort. All three models had similar wind receiving planes which had sloping angle. These planes received wind directly and brought it into balcony more smoothly because of the sloping angle.

On the other hand, model 1 and 8 which had max indoor wind speed closest to the SNI range, showed average performance in wind acceleration, 0.61m/s and 0.528m/s respectively. Both models showed more stable wind accelerations than the previous 3 models, whilst there were some floors which had quite high wind speed, such as on floor 5 of model 1 and on floor 3 of model 8. Both models had 2 wind receiving planes on this angle, that wind could be diverted neatly than the previous 3 models.

Overall, on this angle, there was a need to equip complementary element to obstruct wind speed received by balcony, based on relevant balcony geometry.

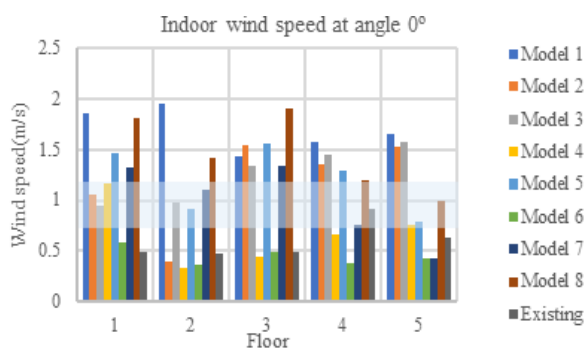


Fig 12. Max indoor wind speed at angle 0°

At angle 0°, Figure 12 showed that there were models whose max indoor wind speed were above the SNI range, and others were under SNI (0.8-1.2m/s). Based on simulation results, model 2 and 7 succeeded in bringing average max wind speed in the SNI range 1.174m/s and 0.992m/s respectively. Unfortunately wind speed value at this angle could not represent overall room comfort as the max indoor wind speed occurred near outlet and did not cover the activity area.

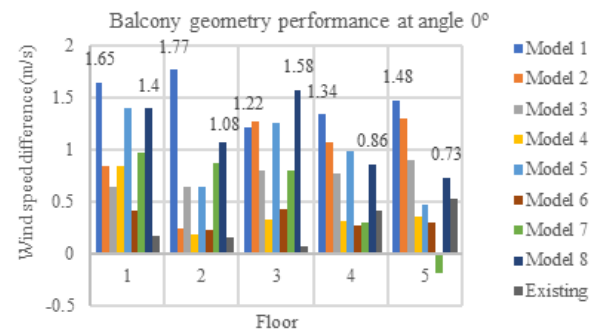


Fig 13. Balcony geometries performance at angle 0°

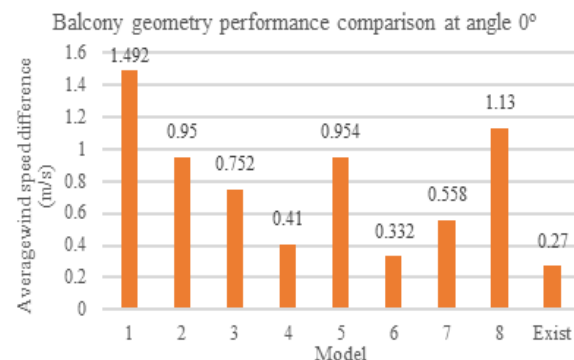


Fig 14. Overall performance of all models at angle 0°

At this angle, just like at angle 45°, there were wind acceleration and deceleration on some models. Seen in Figure 13 and 14, model 1 and model 8 showed highest wind speed difference, though it was still required to further analyse indoor wind distribution to ensure model 1 and 8 truly had positive potentials in their performance at this angle. This is because wind received by balcony was turbulent flow at this angle, and so the indoor wind speed was more uncertain than at the other angles.

Wind Distribution and Penetration Analysis

For further wind distribution and penetration analysis, plane and vector visuals were taken horizontally and vertically. Horizontally, floor 3 (middle of the building) was chosen at 1.5m height where residents' activity took place. Vertically, the middle unit was taken and the living space 3 was cut through to observe wind movement from balcony to living space all at once.

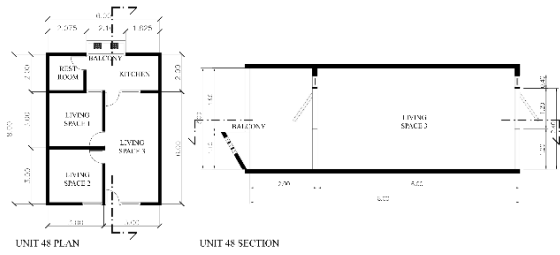


Fig 15. Plane placement for simulation results' output visuals (vertical, horizontal)

At perpendicular angle, based on the simulation, every model could bring wind into living space with good distribution and penetration. The best ones were model 4, 5, and 8. All three succeeded in distributing wind with speed in the SNI range from inlet to outlet (6m) on floor 1-3 and as far as 3m on floor 4-5. Figure 16 showed that the comfortable wind in the SNI range at least covered residents' activity area (1.5m height). Furthermore from Figure 17, it could be seen that all three models had wind receiving planes with a sloping angle which could divert wind in without breaking it and reducing its speed significantly.

At angle 45°, wind distribution and penetration to living space weakened than at angle 90°. Even if wind penetrated into living space and distributed, the speed in the SNI range could only reach 0.5m from inlet. The only difference from wind angle 90°, was that wind

with speed above the SNI range could reach the balcony area. With the appropriate complementary elements, this wind flow could be used and diverted into living space so that the wind speed in the living space could be higher for room comfort.

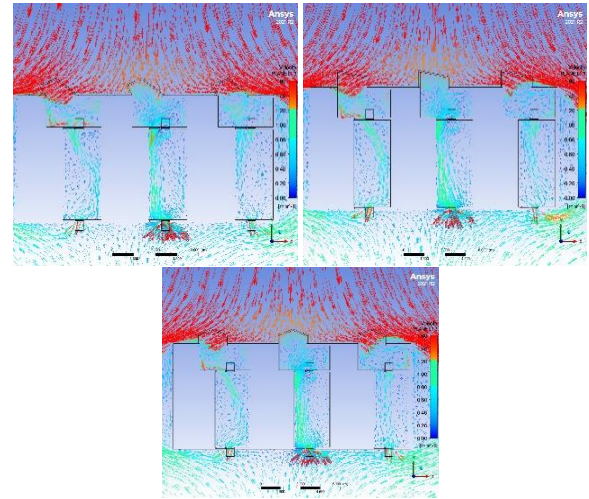


Fig 17. Wind movement on model 4, 5, 8 plans at angle 90°

Model 5-8 had good enough performance in their wind distribution and penetration. Wind with speed in the SNI range could penetrate as far as 1m from living space's inlet, though on floor or wall surfaces. Model 7 and 8, which had the most sides and model 6 with

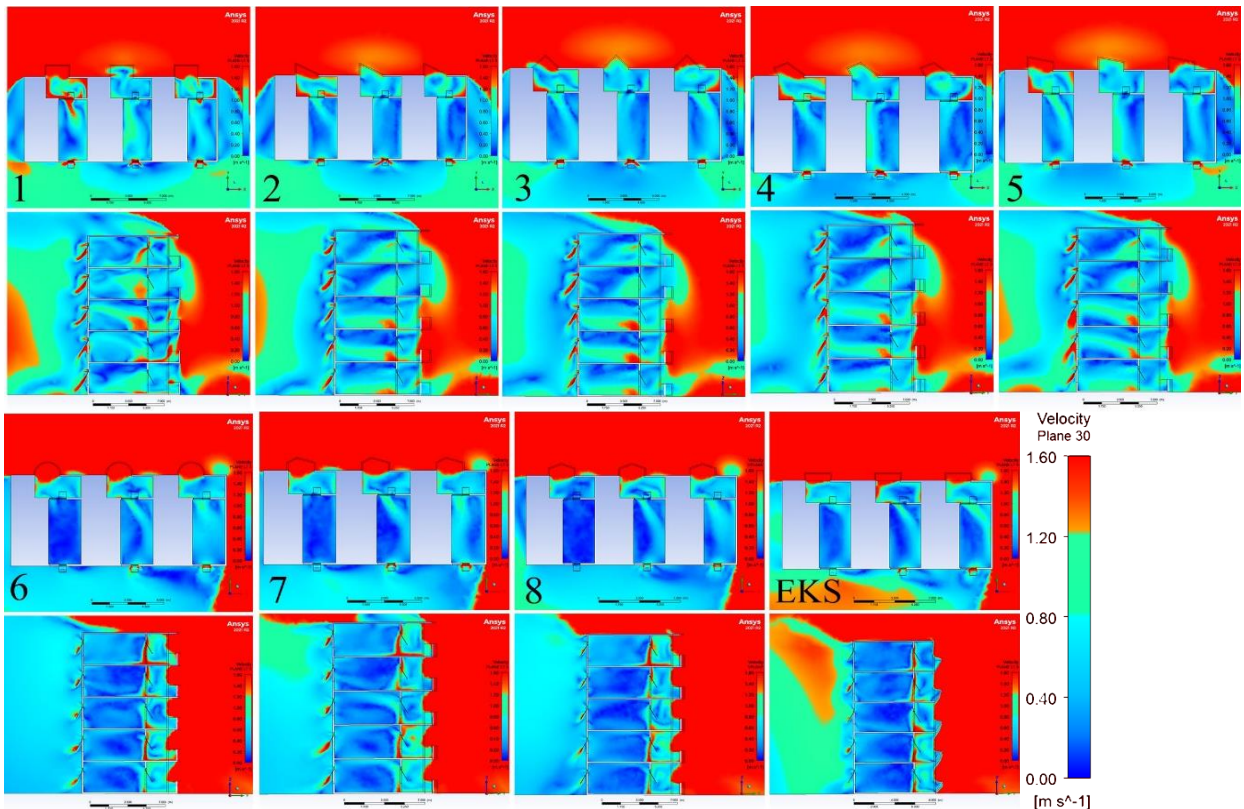


Fig 16. Plane visuals of wind distribution and penetration on floor 3 at angle 90°

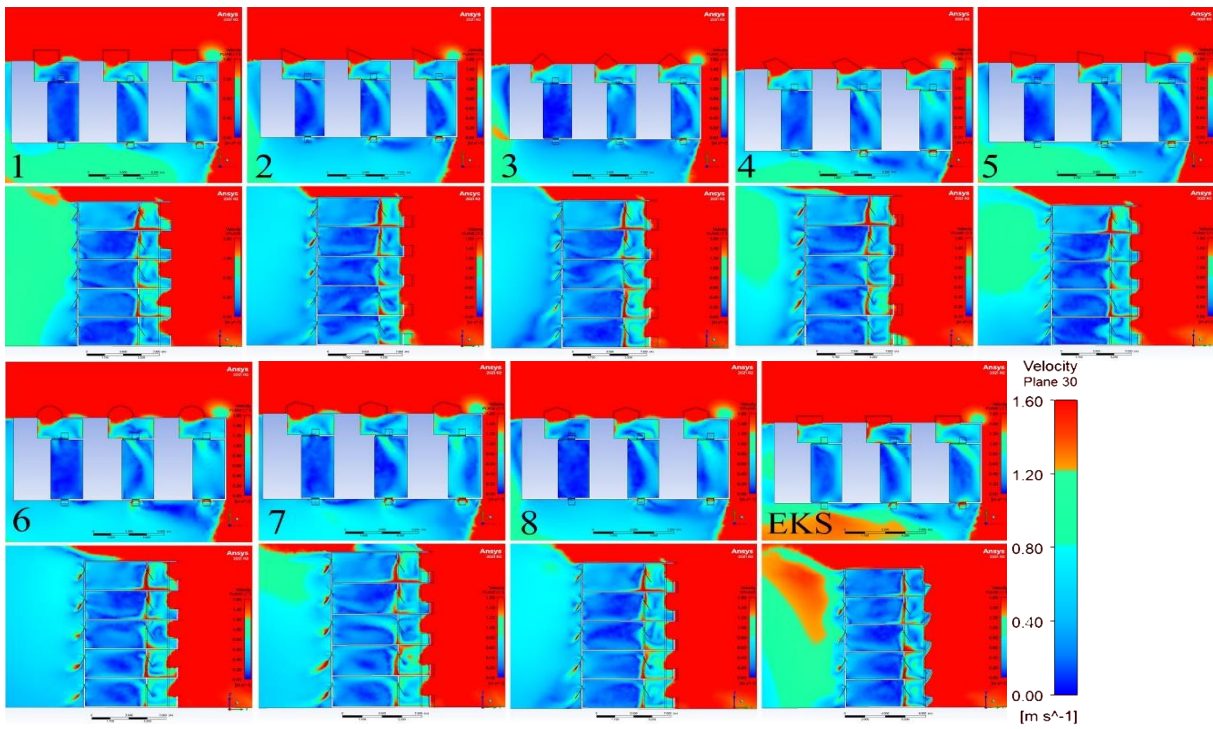


Fig 18. Plane visuals of wind distribution and penetration on floor 3 at angle 45°

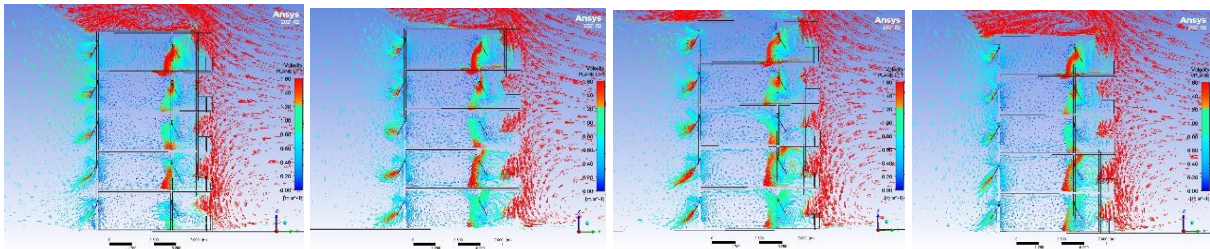


Fig 19. Wind movement in model 5-8 at wind angle 45°

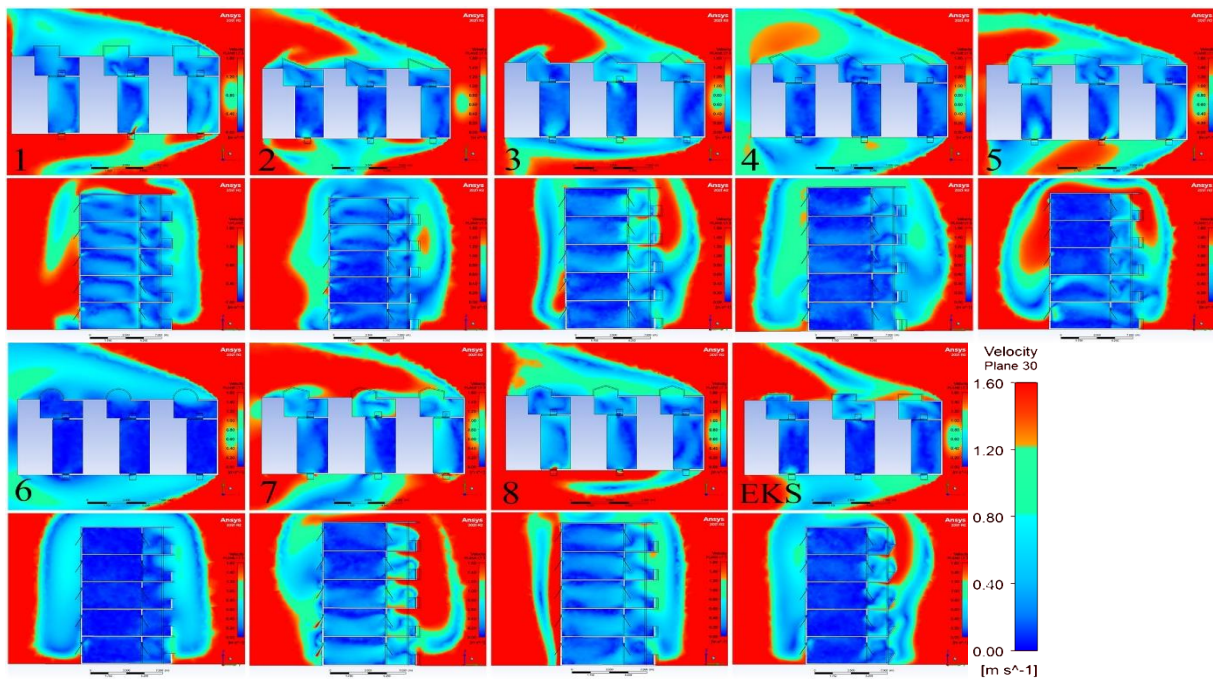


Fig 20. Plane visuals of wind distribution and penetration on floor 3 at angle 0°

organic geometry, showed better performance in directing wind at this angle. Two wind receiving planes of model 7 and 8 had sloping angles at wind direction at 45°, so the wind received by balcony could be diverted well. Model 5, which had wind receiving planes quite similar to model 8 at this angle, could also distribute wind better than model 1-4 and the existing one, following model 6-8's performances.

At angle 0°, in general, wind speed was under the SNI range in all models. Hence wind distribution and penetration performance could only be seen from wind movement existence in living space on each model. It was seen on model 1 and 8, which previously also had good performance on wind speed, on every floor. And so, both models had potential to be developed at this angle. Model 6 and existing model on the contrary, did not show any wind movement in living space.

Table 3. Analysis Recap of Balcony Geometry Performance

No	Model	Wind speed			Wind distribution and penetration			Total
		90°	45°	0°	90°	45°	0°	
	Existing							0
1	Rectangle	Highest performance 1.824 m/s, <i>unstable on floor 1-3, indoor wind speed is above the SNI</i>	Average performance 0.61m/s, <i>drastic acceleration on floor 5, closest indoor wind speed to the SNI</i> 1.38m/s	Highest performance 1.492m/s			Shows air movement, indoor wind speed under the SNI, accelerated around outlet (suction effect)	4(3)
2	Right triangle		2 nd highest performance 0.712m/s, <i>unstable on all floors, indoor wind speed is above the SNI</i>	Max wind speed is in the SNI range 1.174m/s, <i>near outlet</i>				2(2)
3	Symmetrical triangle						Wind penetrated equally, <i>indoor wind speed is under the SNI</i>	1(1)
4	Obtuse trapezoid				Wind distributed equally, wind based on the SNI penetrated fully on floor 1-3, half on floor 4-5, on activity height 1.5m			1(0)
5	Right trapezoid		Highest performance 0.734m/s, <i>unstable on floor 4-5, indoor wind speed is above the SNI</i>		Wind distributed equally, wind based on the SNI penetrated fully on floor 1-3, half on floor 4-5, on activity height 1.5m	Wind distributed well, wind based on the SNI penetrated max 1m on floor/wall surfaces	Wind penetrated equally, <i>indoor wind speed is under the SNI</i>	4(3)
6	Half circle	2 nd highest performance 1.814 m/s, <i>unstable on floor 4-5, indoor wind speed is above the SNI</i>				Wind distributed well, wind based on the SNI penetrated max 1m on floor/wall surfaces		2(2)
7	Asymmetrical pentagon			Max wind speed is in the SNI range 0.992m/s, <i>near outlet</i>		Wind distributed well, wind based on the SNI penetrated max 1m on floor/wall surfaces		2(2)
8	Symmetrical pentagon	Average performance 1.622 m/s, <i>stable on all floors, indoor wind speed is above the SNI</i>	Average performance 0.528m/s, <i>drastic acceleration on floor 3, closest indoor wind speed to the SNI</i> 1.38m/s	2 nd highest performance 1.13m/s	Wind distributed equally, wind based on the SNI penetrated fully on floor 1-3, half on floor 4-5, on activity height 1.5m	Wind distributed well, wind based on the SNI penetrated max 1m on floor/wall surfaces	Shows air movement, indoor wind speed under the SNI, accelerated around outlet (suction effect)	6(4)

CONCLUSION

Based on simulation and analysis conducted, it can be concluded that wind distribution, penetration and speed contribute equally in achieving indoor comfort, where the right balcony geometry can affect wind in acceleration or deceleration according to comfort needs. Even so, it was found that a good performance of wind speed, does not mean a good performance of wind distribution and penetration, whereas in the contrary, a good performance of wind distribution and penetration will generally mean a good performance of wind speed. In conclusion, to carry wind into the living space with a good speed and distribution, a balcony is to be designed with more evenly ordered wind receiving planes/sides. This conclusion is described in several patterns of balcony geometries' performance as a windcarrier, as such:

- Generally, balconies with symmetrical geometries show a better and more stable performance in each floor as windcarriers into living space.
- Balconies with symmetrical geometries always show a good performance of wind speed if the wind distribution and penetration is good as well, but not the other way around.
- The more sides/wind receiving planes a balcony with symmetrical geometry has, the better its performance as a windcarrier.
- The more sides/wind receiving planes a balcony has with symmetrical geometry, the more equal its good performance of both wind speed and wind distribution and penetration.
- Changes in the number of sides/wind receiving planes of a balcony with asymmetrical geometry does not affect its unstable performance in each floor between wind speed and wind distribution and penetration.

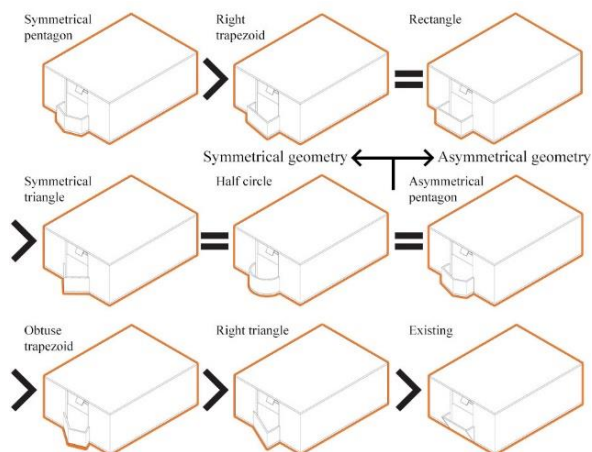


Fig 21. Optimization order of balcony geometries performances as windcarriers

Based on Table 3, the existing model showed no stand out performance and even the worst performance in some simulations. The model which showed the most optimal performance is symmetrical pentagonal balcony, showing 6 good performances of 6 aspects with a total of 4 attention notes. It was followed by rectangle balcony and right trapezoid balcony, showing 4 good performances of 6 aspects and a total of 3 attention notes.

Every balcony geometries model needs wind receiving planes that could obstruct wind to decelerate its speed to reach the comfort range of the SNI as it enters living space at wind angle 90° and 45° . The said plane is also needed to divert wind to enter the balcony area and into living space at wind angle 45° and 0° . Balcony geometries showed a good performance at wind angle 90° and 45° . Yet at wind angle 0° , balcony geometries did not present significant effect in wind performance, thus units needs mechanical support, such as electric fan, to encourage air movement in living space. The findings of this study is expected to be of use as a basis and consideration when designing buildings with balconies in a humid tropical climate.

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