The Impact of Building Mass Configuration Towards Wind-Driven Natural Ventilation in Apartment in Jakarta

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Abstract. Recently, based on the data released by Ministry of Energy and Mineral Resources (ESDM), housing is the second most energy-consuming sector after industry sector in Indonesia. Furthermore, the biggest energy consumption in housing is for air conditioner. Meanwhile, the rise of temperature cause people to use artificial ventilation more often, leaning to higher energy consumption. In order to reduce that, architects need to provide a design option, so people can achieve thermal comfort through natural ventilation by utilizing wind forces. Cilincing District is selected as case study for its microclimate characteristic. Since it is located in the coastal area of North Jakarta, the prevailing wind that comes from north-east can be utilized for wind-driven natural ventilation. There are some factors related to natural ventilation, one of them is building mass configuration. The aim of this paper is to find the optimum building mass configuration inside the given site area in order to achieve the optimum air movement around the buildings. The methodology in this research was design iteration using Ansys Fluent CFD simulator of 5 design models; each consisted of 6 building blocks. The results showed that model 5 with un-linear (zig-zag) building layout and combination of various building distances (wide – narrow – wide), which narrowed building distance in the middle of the site, provided optimum air movement around the buildings because it could create a kind-of tunnel/ trap that strengthened the wind which produced a constant wind velocity along the site.

Keywords: wind-driven natural ventilation, passive thermal comfort, green design, walk-up apartment

1. Introduction

Based on the data provided by Southeast Asia Energy Outlook [1], Indonesia plays a major role in energy consumption, accounting for over 35% of the region’s total energy demand. Household has become the second most energy-consuming sector after industry in this country, which mostly used for air conditioning (ventilation). Meanwhile, with the rise of temperature nowadays, the tendency of people to use active strategy to achieve thermal comfort, becomes inevitable. This energy consumption will keep rising along with the increase number of housing, especially in big city like DKI Jakarta.

According to this challange, architects need to develop a housing design solution that can save more energy especially for ventilation by reducing cooling load. Bioclimatic design, utilizing passive design strategies, have been considered as the main solution to achieve sufficient degree of thermal comfort with less energy consumption. Idham [2] mentioned that there are five principles of thermal control, i.e. thermal insulation (related to heat), air movement (related to wind), cooling and heating (related to temperature), also dehumidification and humidifaction (related to humidity). Due to high humidity and temperature levels in tropical-climate building, heat avoidance and natural ventilation cooling could be the best options to adapt comfort in indoor spaces [3].

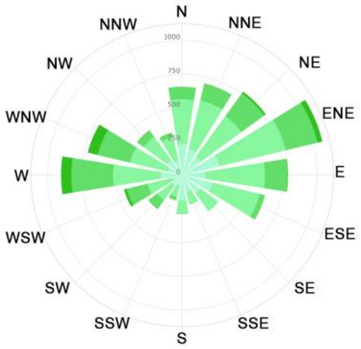


Figure 1. Wind rose of North

This research object is a walk-up apartment building located in Cilincing District, North Jakarta, only 550 meters from Marunda Beach. Adjacent to Java Sea, this location has a strong character of coastal region, where the prevailing wind is potential to use as natural ventilation that can achieve thermal comfort, thus create energy-efficient building design.
Based on local data from Indonesian Agency for Meteorology, Climatology and Geophysic (BMKG) Tanjung Priok Station, this area has monsoon climate with average wind velocity 3,3 m/s which mostly comes from north-east, average temperature 28,96^{o}C, and average humidity 107,83% around the year.

In early design process, some design factors were used to determine building form that can affect air movement around the building. Busato [4] explained that *shape and orientation* of the building relative to direction of the wind are both directly related to the way in which air movement behaves around building. Rectangular plan alongside east-west, limiting the exposure on east and west sides, is the best *building shape* in the tropics [5]. Shallow floor plan (narrow *building depth*) is more efficient where it encourages more air-flow inside the building [6]. The optimum *building proportion* for hot-humid climate is 1 : 1,7, elasticity 1 : 3 [7] with the most effective *building orientation* should be defined based on prevailing wind and sun angle [8]. There are plenty of researches about building shape, proportion, or orientation but few have discussed about the significancy of *building configuration/ layout* towards air movement around building. The aim of this paper is to find the optimum building mass configuration on a spesific walk-up apartment complex, to achieve the optimum air movement around the buildings for natural ventilation.

2. Methods

2.1 Determine the basic mass model

Walk-Up Apartment is a vertical housing which use stair as the main vertical transportation system with the units type chosen are one bedroom 24 m^2 unit and two bedroom 36 m^2. The site has 1.4 Ha area with maximum 35% built floor area. Density that will be achieved is 460 persons/Ha, so there are six blocks of five-storeys buildings with 288 room units/block.

This research was preceded by preliminary analysis of building shape and orietation simulation, followed by the main simulation topic in this research, building layout/configuration. The first preliminary analysis was completed to find the basic mass model for further simulation, which was obtained from the adjustment between number of units needed, the desired unit area, and built area, with the following criterion as fixed variables.

Table 1. Preliminary criterion for the building

Unit	Shape	Square & Rectangular	Based on market trends analysis
	Size / Poportion	4x6 (24 m2) & 6x6 (36m2)	Based on market trends analysis
Massa	Circulation	Single-loaded	[3] & Based on market trends analysis
	Basic shape	Rectangular (Box) Atrium	[5][7][14]

2.2 Set up the simulation

The computational wind simulations were completed by Ansys Fluent Simulator to investigate the effect of building mass configuration, which received the optimum airflow for wind-driven naturally ventilated housing. In order to model the air movement of the site area, the simulations used a scaled model, scaled to 1:100. As a result, adjustment should be done in the boundary conditions, especially the wind speed. Similarity of the simulation on the scaled model to the real scale model depended of the Reynolds Number [9]. In this study, the wind speed of the real scale was 3.3 m/s, which in the scaled models should be stated as 330 m/s due to Reynolds Number formula.

The analysis of airflow behaviour around the buildings was conducted by the emphasis of qualitative analysis, which confirmed by quantitative analysis. Hence, visual analysis of wind and temperature contour images were selected. Two-plane level was selected as a sample for the velocity and temperature magnitude, where plane at 2 represent(s) the ground level and 10 represents the high level.

3. Discussion

3.1 Wind-driven natural ventilation

Generally, pressure discrepency can be generated by wind (wind-driven ventilation) and temperature/ thermal bouyancy (stack effect ventilation) or by combination of both [4]. The stack effect occurs when indoor temperature is higher than outdoor temperature where the warm indoor air will be risen up and replace the cooler, denser air from below. Wind-driven natural ventilation occurs when higher wind velocity hits the building surface and creates gher air pressure (+) on the inlet and lower pressure (-) on the other side that will initiate air to move across the building, bring the fresh air and also reduce room temperature [10].

Naghman K. et al. [11] observed that in hot-humid conditions, where the temperature differences between indoor and outdoor of buildings (diurnal variation) are small, stack effect is reducesd so stack ventilation is insufficient to achieve thermal comfort. Therefore, Lim [12] suggested that wind-induced natural ventilation design has a great potential to achieve the desirable air speed in the indoor building environment to improve thermal comfort for building occupants especially in tropical climatic conditions. Since this research located adjacent to North Jakarta sea which the prevailing wind is potential for natural ventilation, this paper will be focus on wind-induced natural ventilation.

3.2 The effect of building mass configuration on airflow around building

Besides building shape and orientation, other factors affecting the airflow pattern around the buildings are the physical relationship to surrounding volumes and obstacle such us other building mass, fences, vegetation, etc. In a building complex where there are multi – building masses, every building mass can affect each other's airflow pattern. For example, the positioning of buildings within the suction zone (negative pressure – shaded area) of other structures can impact on the velocity of air coming into the inlets of the naturally ventilated building [4].

In order to avoid this 'shadow effect', the *distance between buildings* has to be adjusted. Markus [13] proposed that the distance between each building mass should be minimum six times the height of the first obstructiong volume, which actually quite a wide (if it is assumed that the obstrcuting volume is a one-storey building). Other technique mentioned by Markus is using a *staggered layout* to organize the masses.

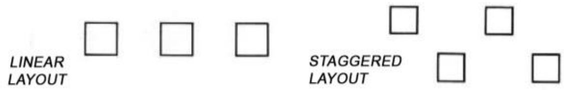


Figure 2. Proposed staggered layout

Other research conducted by Hong [14] found that trees arrangement, buildings layout patterns and their orientations with respect to wind have significant effects on the outdoor wind environment. Furthermore, long facades of building, which are parallel to the prevailing wind direction, can accelerate horizontal vortex airflow at the edges and obtain pleasant thermal comfort and wind environment at pedestrian level. In line with Hong, Olgyay [7] stated that in tropic areas the buildings are freely elongated. The houses are separated to utilize air movements which generate a scattered and loose layout.

3.3 Preliminary analysis

The preliminary criterion mentioned at **Table *1***, generated two building shape options, i.e. the rectangular plan with the size of 35x15x16 m and the square plan (25x20x16 m). However, the rectangular plan was chosen because it could reduce the building heat gains. This is in line with Konya [5] who said that it is better for tropic-climate to have rectangular plan where wind can be distributed evenly along the building surface and gives less east-west exposed units which can reduce heat gain. Then, followed by building orientation simulation to determine the chosen shape for further analysis. Burnett [16] proposed to test three different orientation 0^o, 45^o, 90^o. From the simulation, model which is parallel to wind direction 0^o is chosen because it has the least facade facing east – west.

3.4 Mass-Configuration Factor

From the previous reseaches mentioned before, it can be summarize that there are two main suggestions related to building mass configuration, *pararrel layout* [7] [14] and *staggered or zig-zag layout* [13]. Those are used as the basis of the building mass configuration simulation.

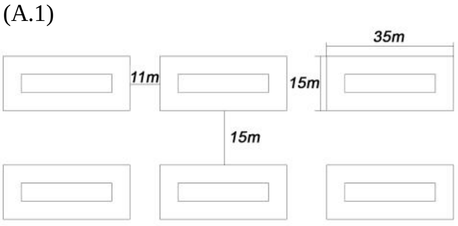
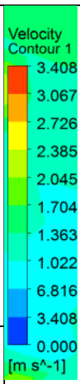
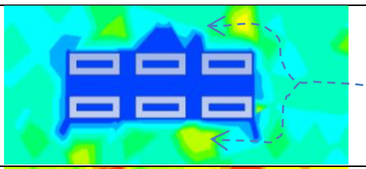
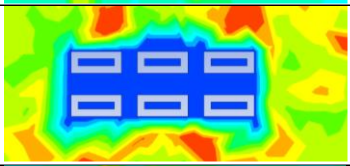
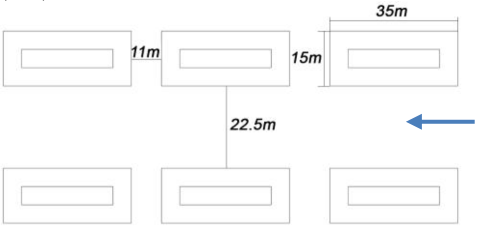
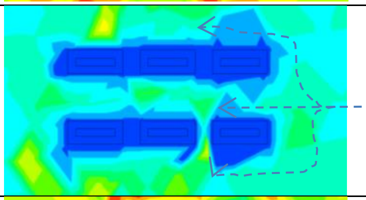
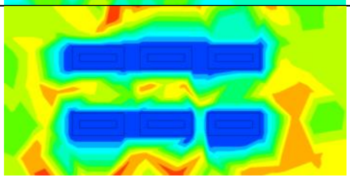
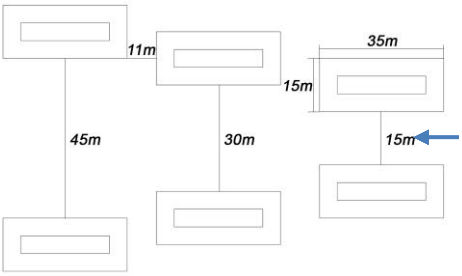
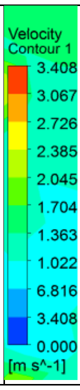
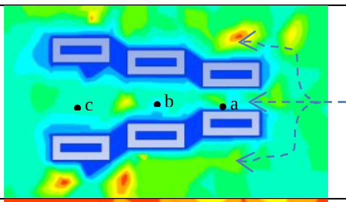
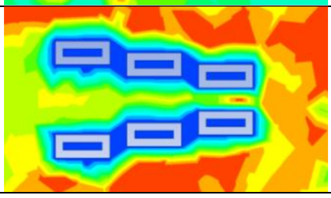
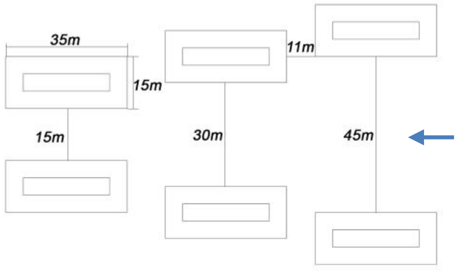
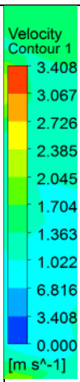
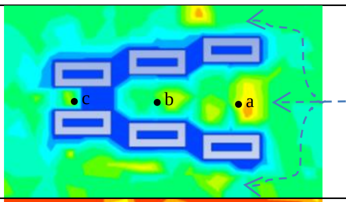
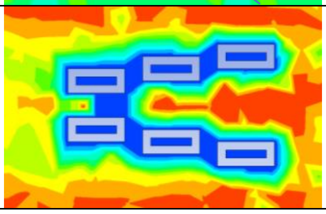
Beforhand, minimum distance between masses was determined based on technical guidelines from building permit issued by Indonesian goverment [17]. For two opposite buildings that both have large openings or transparant facades, the distance must be minimum twice of the clearance number determined.

Table 2. Minimal distance between buildings

Min.distance between buildings	Transparant facades / facades with large openings Clearence (Y) for each 5-storeys building is 5.5m	D = Ya + Yb = 5.5 + 5.5 = **11 m**

From the standard above, some model options were developed for the simulation.

Table 3. Comparison for each configuration

Case	v (m/s)	lv.	Contours	Data
Configuration A				
(A.1)  v average = 3.132 m/s		2m		3.11 m/s 27°C
		10m		3.15 m/s 27°C
(A.2)  average = 3.109 m/s		2m		3.09 m/s 27°C
		10m		3.13 m/s 27°C
Configuration B				
 average = 3.066 m/s		2m		3.03 m/s 27°C
		10m		3.10 m/s 27°C
Configuration C				
 average = 3.062 m/s		2m		3.03 m/s 27°C
		10m		3.10 m/s 27°C

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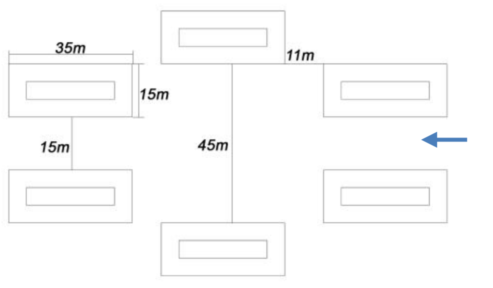
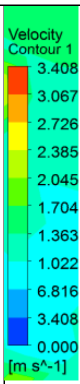
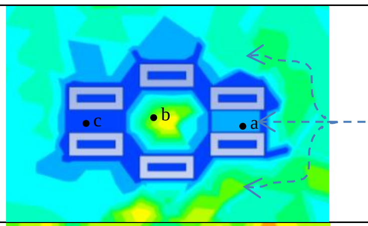
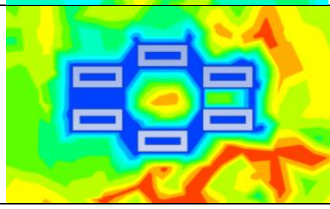
<tr><td rowspan="2">

average = 3.106 m/s</td><td rowspan="2">
</td><td>2m</td><td>
</td><td>3.09 m/s
28°C</td></tr>
<tr><td>10m</td><td></td><td>3.13 m/s
27.5°C</td></tr>
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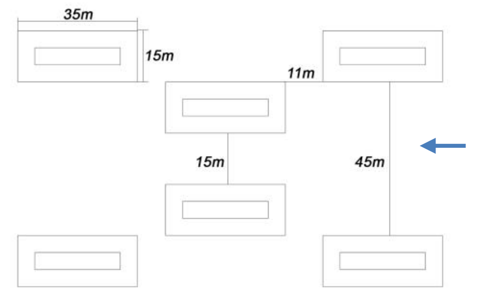
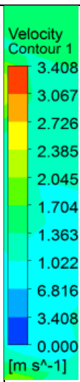
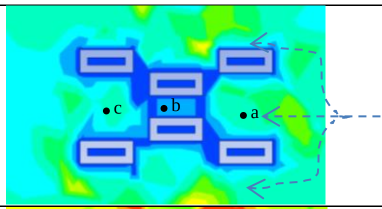
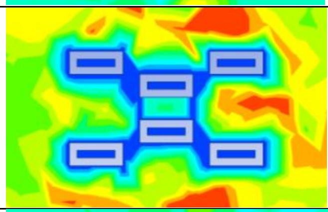


average = 3.110 m/s</td><td rowspan="2">
</td><td>2m</td><td>
</td><td>3.09 m/s
28°C</td></tr>
<tr><td>10m</td><td></td><td>3.13 m/s
27.5°C</td></tr>
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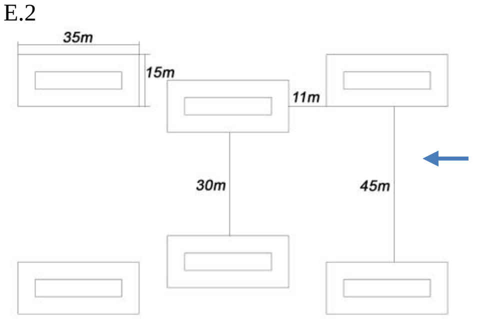
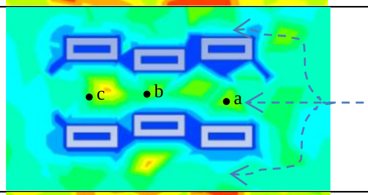
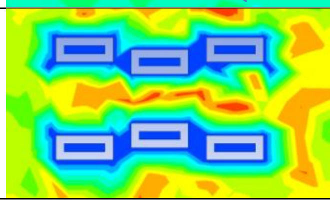


average = 3.121 m/s</td><td rowspan="2"></td><td>2m</td><td>
</td><td>3.10 m/s
28°C</td></tr>
<tr><td>10m</td><td></td><td>3.14 m/s
27,5°C</td></tr>
</table>

3.4.1 Configuration A

The first model represented the basic parallel layout where the distance between the two-row buildings was constant (15 m). The result simulation showed that the incoming wind did not occur much deflection as it was immediately split into two directions. The distance between the two-row buildings was narrow so airflow did not appear at the central space, creating wide shaded area, thus experiencing a low air movement.

Therefore, the other model alternative was conducted to investigate whether wider distance would give better velocity. In simulation A.2, distance between the long-side facade was widened to one a half of building's height (22.5 m). The result showed that wind could go across the middle area and give more evenly wind contour. However, because of this layout wind was split into 3 directions, the velocity produced was slightly lower that in A.1 (0.02 m/s difference).

3.4.2 Configuration B

Model B was a modification of model A, in which the distance between the long-side facade slowly widened from east to west. From the contour it could be seen that wind speed spread more evenly indicated by less shaded – blue area. However, the colour in the middle changed from green to light blue. It showed that wind speed decreased slightly from east to west because the distance was widened.

3.4.3 Configuration C

Model C was a contradiction of model B, in which the distance between the long-side facade slowly narrowed from east to west. However, it showed the same wind behaviour where wind speed in the middle also decreased from east to west like model B. It happened because wind lost its strenght as it met more obstructions along the site.

3.4.4 Configuration D

Model D represented a courtyard – like layout, in which the distance changed from narrow (15m) – wide (45m) – narrow (15m). Apparently it caused more shaded area in between the long-side facades except in the middle which is 45 meters wide. This model confirmed the result from model A.1 that distance of 1x height of the building (15 m) gave more shaded area which was not enough to supply airflow for natural ventilation.

3.4.5 Configuration E

Model E.1 was the opposite of model D, in which the distance changed from wide (45m) – narrow (15m) – wide (45m). It gave much better airflow distribution than model D but still had shaded area in the very middle since it was only 15 meters wide. So, model E.2 was tested. In fact, this layout eliminated the shaded area in model A.1. Interestingly, unlike the other options, wind speed in between the long-side facades was slightly increased from east to west. Presumably, this result was caused by wind tunnel effect created by distance combination of wide (45m) – narrow (30m) – wide (45m).

3.4.6 Comparison

From all the options tested above, model A.1 had the biggest value of wind speed. But it did not mean that model A.1 was the best option since visually it hasdwide shaded area and very low wind speed in the middle of the blocks. This high wind speed occured because the windward (short – side) facade was very narrow giving the least obstruction.

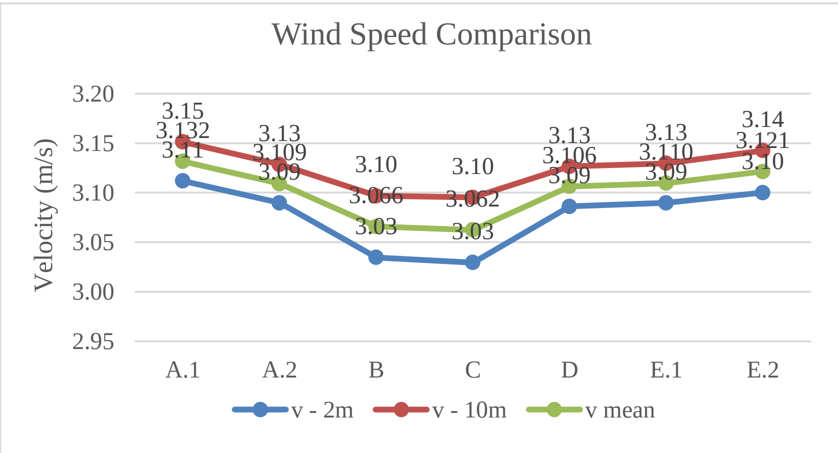


Figure 3. Wind speed comparison for each configuration

Model A.2, D, and E.1 had similiar wind speed value, but visually option D (courtyard – like layout) did not give great impact since it had more shaded area in the middle of the buildings. Meanwhile option A.2 (linear layout) and model E.1 (staggered layout) visually had a decent airflow distribution.

Model E.2, where distance changes from 15 m to 30 m wide with the combination of distance wide – narrow – wide, gave the most optimum result since it gave higher wind speed with the best airflow distribution visually.

4. Conclusion

In order to supply enough airflow inside the building for natural ventilation, 0.1 – 0.35 m/s (SNI 03-6572-2001), it required sufficient wind speed around the building. Shaded area, which was shown by dark blue in colour, indicated area with verly low wind speed. Therefore, some options were explored to find the best wind speed value and also the best wind distribution visually.

Between parallel and staggered layout which were mentioned in the literature study, for this project, model E.2 was the most optimum. Zig-zag configuration allowed wind to move in the small gaps between buildings because it created bouncing pattern of the wind since the buildings directed the wind to subsequent structures. Besides that, the configuration of building distances (wide – narrow – wide) created a kind of trap or wind tunnel – like feature that strengthened the wind in the middle of the site, so it received a constant (even bigger) wind velocity along the site.

Other than that, there were some conclusions about the effect of building configuration to the behaviour of airflow around buildings. High wind velocity did not always represent the best condition since the airflow distribution played big role in the building. The smaller winward blocks area (wind-facing facades), the less deflection would occur, thus the bigger value of velocity, and vice versa. Distance between masses should be more than one of building's height so airflow could to go through it. Widening the distance would produce less shaded area, but slightly lower velocity number and vice versa, which is the bernoulli principle in fluid. But there was also condition where wider distance gave higher velocity, which happened because wind had less obstuctions. In fluid dynamic like natural ventilation, each case would have unique airflow pattern that must be specifically simulated. To sum up, the study summarized that building mass configurations could impact air movement around the buildings to provide natural ventilation.

5. Acknowledgments

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