Improving natural ventilation for an energy-efficient low-income apartment in the tropic

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Abstract. The increasing number of populations in large cities such as Jakarta led to increased demand for low-income housing, and it leads to the need of low-cost apartment buildings as well. Generally, based on the needs of healthy indoor environment and thermal comfort in the tropic, low cost housing in Jakarta uses single loaded corridor to draw air through two-way opposite openings for cross ventilation in promoting natural ventilation. In high rise apartment buildings, the use of double loaded corridor will be more efficient in space and construction costs but has limitations in providing ideal conditions for cross ventilation. This study focused on assessing the effect of the openings on double-loaded corridor, in high-rise low-income housing to promote better natural ventilation. This study aims to obtain the opening and corridor for natural ventilation in low income vertical housing. The research method is developed by the experimental research with Computational Fluid Dynamics (CFD) simulation. The simulation uses Ecotec and Winair program to meet the wind profile inside the building. The variable data is observed from design typology, dimension of opening and corridor, and wind data. To refine the objective, this study focuses on high-rise low-income housing design typology (20 floors).

1. Introduction
In global perspective, sustainability in architecture has close relation to energy use, since it leads to climate change. Low carbon architecture is being an important part of sustainable architecture because of the highly intensity carbon impact from buildings will cause climate change and global warming. UK code for sustainable home requires energy and CO$_2$ emission as the category for sustainable design [1]. One of low carbon architecture strategy is minimizing the energy consumption through passive design. Minimize the energy consumption through passive design is the basic approach to minimize the energy use in building.

The housing need for low-income communities in metropolitan encourage the development of high-rise building height up to 20 floors. These buildings should be space efficient and low cost in hence to be affordable as low-income housing. It should be low energy consumption also. Moreover, energy conservation mandates for building with the use of low energy (low energy building). Natural ventilation is becoming the key feature for energy efficiency strategy to achieve thermal comfort in the tropic. Studies have revealed that in hot humid climatic region can accommodate high temperature and adequate comfort can be achieved through natural ventilation [2].

In most cases, to induce natural ventilation in hot humid tropic, building use single loaded corridor to draw air through two-way opposite openings for cross ventilation. However single loaded corridor
serves only one side, in contrast with the double-loaded corridors. In consequence, double-loaded corridor is more space efficient than single loaded corridor but, it has limitations in providing ideal conditions for cross ventilation. It has a weakness to the supply of natural ventilation that can meet the need for fresh air. Most of the development of high-rise low-cost apartments / RUSUN lead to apartment with air-conditioned design that consume much more energy for user. The existing apartment are generally not effective in harnessing the wind, wind flows into the residential unit is very low (0.01 - 0.03 m/s) [3].

This study is expected to be a reference in planning low cost apartment with the use of cross ventilation more energy efficient. This study aims to obtain a correlation between the opening and the corridor to reach the better cross ventilation. The results can be used to determine the design of the opening, and corridors for natural ventilation in low cost apartment.

2. Methods

In this experimental study with simulation, a simplified approach was carried out. It is used as in average condition or critical value on environmental conditions.

Wind analyzes were conducted in two stages, first stage is simulation in 40 m of typical model with closed unit (air conditioned). Next stage is performing test the result of first stage. This study has completed at least four procedures:

Firstly, finding the typical building lay out. Three typical low-cost apartments were examined with the mostly effective in area and in opening for cross ventilation with basic criteria analysis.

Secondly, modeling by simplifying the building with rectangular basic shape with the opening for ventilation. This opening ideally located in every unit to allow cross ventilation from outside to the corridor.

Thirdly, climatic condition for Jakarta were reviewed based on secondary data from weatherspark with result the highest solar radiation for Jakarta as critical condition for thermal comfort.

Finally, running the simulation on CFD program for wind analysis and Ecotec for modelling and reading the CFD simulation result.

2.1. Modeling

In the Ecotec program, the building is simplified as follows: building typology is expressed in a simple square geometry with zoning system. A 20 floors high rise building with 3 m floor to floor height. Each floor is divided into unit zones, and 1 corridor zone. The opening for cross ventilation in each unit are simplified as a 24-hours opening above the window and an opened balcony door on the exterior wall and a 24-hours opening on the corridor side. Units are configured to minimize the solar heat gain by north - south orientation, with building mass axis along the east - west direction.

Building have 40 m long corridor with full opening as 1.5 m width and 3 m height, and an open space area with dimension of 5 m × 5.5 m. Following basic model apartment namely model A, it was developed under two different east opening corridor, while one with opening, others without opening (figure 1c). Figure 1 shows building model A as apartment with 40 m double loaded corridor from south view. Figure 1h, model A with opening in both side corridor and open space from west view and figure 1c, model A with opening in windward area of corridor (west) and in open space (south) from east view.

2.2. Simulation

Natural ventilation analysis performed using Winair program for CFD to analyze the wind profile on the object of research.

In this study, building assumed as a single building. The real condition in urban as a building lay on a built environment with the surrounding buildings have been embodied in the value of surface roughness on wind speed.

The comparison from monthly average temperature and wind speeds data based on weatherspark indicate September as the warmest month with highest wind speed. Wind analysis was conducted in

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September as the month with the highest temperature as critical condition to achieve thermal comfort. The simulation runs with wind flow come from west to east.

The last step was reading the Winair result in the Ecotect simulation were setting for September as the highest solar radiation month for Jakarta.

![Figure 1](image_url)

**Figure 1.** Building model (a) South orientation (b) West orientation (c) East orientation

3. Result and Discussion

3.1. Typical Lay out for natural ventilation

Low income apartment has many limitations, especially in terms of economic considerations. It has to be affordable, low cost construction and have a good IAQ. Three typical lay out of apartment at Jakarta, has reviewed based on area size and ventilated room. Table 1 shows the apartment A and C with the same total bedrooms have more compact size area as 30 m² for more affordable price than apartment B with 36 m². Apartment A and B has living area and only one main bed room covered by fresh air. Apartment C has living room and all bed rooms have fresh air for better IAQ. Based on area and fresh air coverage, alternative C was the chosen alternative with area size 5 m x 5.5 m to studied as unit model for simulation.

3.2. Wind profile

Figure 2 indicates wind profile on natural ventilated apartment with 40 m corridor. Figure 2a shows at 36 m height, better flow rate occurs in the unit with opening to the corridor compared to units that have no opening (unit 1 south). A good flow occurs on unit 1 and decreases to unit 4. In unit 5 the air flow is not satisfactory. A significant increasing airflow occurs at the unit 7, resulting from the open area in front of unit 8. A good air flow at unit 8 due to the position of the unit in front of the open space.

Figure 2b shows wind flow on 18 m height. A good flow occurs on unit 1 decreases to unit 3 and it is not satisfactory on unit 4, 5 and 6. Unit 7 has a significant increasing airflow due to large opening (open area) in front of unit 8. A good air flow at unit 8 due to the position of the unit in front of the open space.

The figure 2 concludes that air flow occurs as far as 15 m, with the speed increases according to the height. Open space has a significant effect of increasing the wind flow into the building and inside the unit’s apartment around the open space area.

The next stage, the building length is shortened to 30 m in accordance with the previous analysis results. The wind analysis run under two different conditions on east opening. The result shows building with close end corridor with side open space providing better wind speed (figure 3). For both
cases, on the lower level under fifth floor, the wind velocity on the corridor is below 0.1 m/sec to 0 m/sec. From the tenth floor to the top floor, the wind penetrates into the corridor up to 15 m with initial velocity 0.4 m/sec then decreased. However, air flow distribution in these housing units is better in two openings corridor than close end corridor. The leeward opening causes widen wind stream driven by the wind coming out of the outlet. It increases the pressure difference between inlet and outlet of the housing units (figure 4). The result shows, the maximum opening on the design typology will give optimum wind flow condition in 3 units long corridor or 15 m and poor ventilation for more than 5 units corridor.

**Table 1. Typical lay out apartments**

| Lay out | A | B | C |
|---------|---|---|---|
| **Area** | 30 m² | 36 m² | 30 m² |
| **Ventilated room** | Main bedroom, toilet, kitchen, balcony | Main bedroom, toilet, living room, balcony | Bedrooms, living room, balcony |

![Diagram](a)

![Diagram](b)
Figure 2. Air flow on natural ventilation apartment (a) 36 m height (b) 18 m height.

Figure 3. Air flow across the corridor (a) close end corridor and open space (b) two opening corridor and open space.

Figure 4. Air flow at the upper floor (a) one opening corridor and open space. (b) two opening corridor and open space.

4. Conclusion
Under cross ventilation of two openings corridor, the wind flow reaches effectively in 15 meters (3 units) and with the open space area can reach up 30 m. Apartment with more than 30 m corridor is not effective to provide sufficient wind flow for cross ventilation in each unit.

On a double loaded corridor, there can be exchanges of cross ventilation through corridor and openings in the balcony of the unit, however it cannot be expected to provide satisfactory thermal comfort in residential units, since the speed under 0.1 m/sec.

Ideally, in every 15 m (3 units) providing open space to promote better cross ventilation in corridor and housing unit.

References
[1] Department for Communities and Local Government 2010 Code for Sustainable Homes p 17
[2] Ibiyeye A I, Shari Z and Jaafar M F Z 2016 Evaluating natural ventilation provisions and occupant’s ventilation behavior in five terrace housing types in Putrajaya Malaysia Archnet-IJAR 10 130
[3] Sujatmiko W, Dipojono H K, Soelami F X N, and Soegijanto 2015 The 5th Sustainable Future for Human Security (Procedia Environmental Sciences 28) p 360-369