# The Effect of Inlet-Outlet Position and Ratio on Airflow Patterns and Privacy in Low-Cost Flat Units in Surabaya

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**Abstract**. A low-cost rental flat is a vertical building with natural ventilation as the primary ventilation source for its units. In practice, residents do not use room openings optimally because it tends to reduce room privacy. The consideration of the position and inlet-outlet area ratio is essential to create better privacy with airflow patterns that support room activities. The research consists of two stages. The first stage was carried out using qualitative methods, which proved the utilization of openings in the hallway side influenced user privacy. This paper discusses the results of the second stage, which was carried out using quantitative methods. The research aims to solve low-cost flats' cross-ventilation problem. Data collection using quantitative methods based on observations, data analysis using simulations of airflow patterns, and distribution analysis tables. The results show that the airflow pattern in the existing design does not support the resident's activities with the applied room openings having poor privacy. The proposed designs with privacy parameters consideration, an opening area ratio of 1 (inlet): 1.6 (outlet) and a ratio of 1 (inlet): 2 (outlet) shows an average increase of 50% in airflow velocity and privacy in the unit room compared to the existing design.

## 1. Introduction

A low-cost rental flat known as rusunawa, comprises repetitive room units and a more limited area than apartments to make rental costs affordable. The Minister of Public Works developed it in order to help low-income urban communities. The guidelines for living in the flats stated that using and installing artificial cooling such as air conditioners is prohibited by the municipal government because it is not considered a basic need for residents [1]. This regulation makes most of the ventilation units become passive ventilation that relies on window and door openings.

Window ratios and dimensions considered of floor or wall area, opening position, and building orientation are essential factors in the success of natural ventilation [2]. The ratio of the area of the inlet and outlet openings in the room influences the air's velocity. The more significant the difference in inlet and outlet area, the wind velocity formed tends to increase, however, to a certain extent it may also cause the wind velocity to decrease [3][4]. Cross ventilation is generally carried out by utilizing the widest possible openings in the walls, such as windows and vents [5]. This method may be effective in a single house with a large yard, but in vertical housing, it becomes limited due to considerations of comfort, privacy, and safety in the unit room.

In Low-cost flats Grudo and Rungkut Sier, which are located in the East Java area, the utilization of opening dimensions in the unit room is partly still below the SNI 03-6572-2001 standard, about 5% - 10% of the floor room area[6]. In some case, unit rooms that apply opening dimensions according to SNI standards with a window effectiveness of 75% does not guarantee the fulfillment need for comfortable airflow in the room unit [7]. This is due to the tendency when use unit windows or openings to affect the level of privacy and safety in the room [6]. Research about the dimensions and position of low-cost flat unit openings tends to focus only on airflow efficiency and pays less attention to other aspects. It can be seen from some case studies that found openings in low-cost flat unit rooms are not utilized optimally because residents prioritize aspects of privacy and safety to feel secure.

The utilization of window openings to achieve privacy, and comfort when doing activities in the room tends to have opposite characteristics. Sometimes openings such as windows and doors need to be opened widely to optimize passive ventilation in the room, but wide openings reduce the level of room privacy [8,9]. The previous research found that in determining spatial boundaries, openings in the unit act as limitations that control human senses from forming responses against their surroundings. It happens because residents can restrict and minimize things that their five senses receive from outside the room by closing or opening windows and doors. The utilization of windows and doors in the flat, especially near the hallway side, significantly influences the privacy of the unit room. Window position and size affect room privacy regarding visibility and proximity, while window type affects room accessibility. In this case, window and door openings dominantly affect 3 out of 5 privacy parameters: visibility, accessibility, and proximity [8].

In response to this, the utilization of the area ratio and the position of the inlet-outlet openings should not only focus on improving airflow patterns that meet the needs of the room unit and the activities within it. Applying the area ratio and the position of the inlet-outlet also requires consideration of privacy aspects and parameters so that users can use the openings more efficiently. The objective of this study is to solve the cross-ventilation problem by finding the area ratio and the position of the cross-ventilation inlet and outlet that are effective in creating a more stable wind velocity that spreads evenly in the unit room with consideration of the privacy parameters. Likewise, to find airflow patterns that can meet the needs of resident's activities in the room.

## 2. Research Methods

The study was conducted in Grudo Low-cost flat, Tegalsari District, Surabaya, East Java, in 3 units at different locations and heights (figure 2). This research consists of two research stages. The first stage from the previous study was carried out using qualitative methods, which proved that the utilization of window and door openings on the hallway side significantly influenced user privacy. The second research stage used quantitative methods for data collection based on observations, documentation, field measurements, and data analysis using simulations of airflow patterns and distribution analysis tables. The processing results of questionnaires and short interviews from the first stage, observations, and documentation will form residents' interior room spatial arrangement patterns, patterns of how residents utilize their openings in the unit, locations, and patterns residents tend to do activities from morning to evening. The pattern and position of residents' activities determine variations in applying openings and wind speed measurement location points in unit rooms. Results of field measurements used in distribution analysis tables will point to the wind potential in the unit, which is used as a base for applying inlet-outlet area ratio and position. The pattern of how residents utilize unit room openings is used as a simulation model with Ecotect Analysis 2011- WinAir4 CFD software. The simulation results were compared with the result from field measurement for validity. Based on the airflow pattern formed in the simulation results with data analysis airflow patterns and consideration of activity points, the required airflow pattern that supports the resident's activities in the unit is obtained. The airflow pattern from the simulation is also used as a consideration when applying the proposed inlet-outlet area ratio and position in the unit.

Integrating considerations of privacy parameters and the required airflow pattern will form the base concept of the proposed unit room opening designs. In implementing the design, it will produce the inlet-outlet ratio area and position that receives a potential wind source and supports the required airflow pattern for activities in the unit room with a good level of privacy. The results are then simulated again and compared with the existing design to show how much the wind velocity increased and the formed airflow patterns changed with a good level of room privacy.

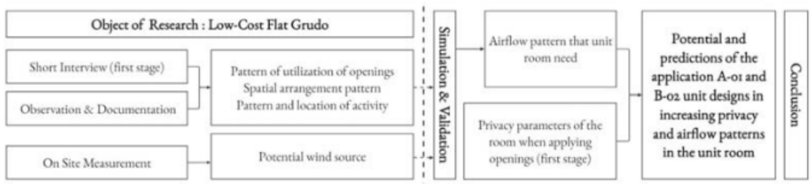



**Figure 1.** Methods framework

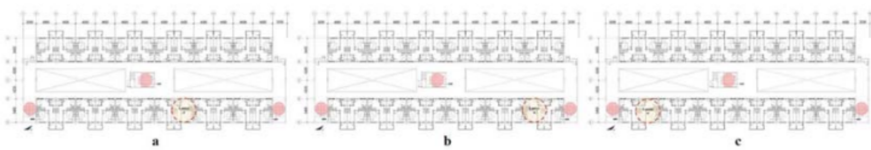


**Figure 2.** Location of the room unit that was measured (a) 3rd floor, (b) 4th floor, and (c) 5th floor

## 3. Spatial Arrangement Pattern, Location of the Occupant's Activities, and Potential Wind Source in the Flat Room Unit

Location points for measurement consider the furniture's location and habits of how the residents utilize opening or closing doors and ventilation. Based on spatial arrangement patterns, occupants tend to do their activities in the middle of the room. It can be seen from the arrangement of the mattress, which is placed in the center of the room as a base mat when resting or doing activities from morning to evening (figure3).

**Figure 3.** Documentation of the spatial arrangement pattern in unit room flat

The limited unit area makes residents adapt to the furniture arrangement so that they not only get enough space for their activities but also make it possible to accommodate many of the items they need. Seeing the condition of the utilized openings formed airflow patterns that do not support cross circulation and the dense interior spatial arrangement sometimes makes the room stuffy.

The results of points B and B II measurement data show that the velocity in the room increases when opening doors and using hallway windows. In point B and B II, the room velocity with the door clo-


**Figure 4.** (a) Location point of the occupants tend to do activities and (b) Flat spatial arrangement pattern with on-site measurement point

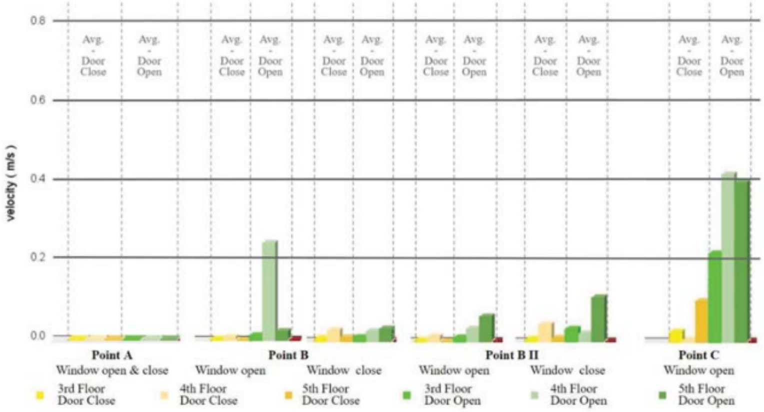
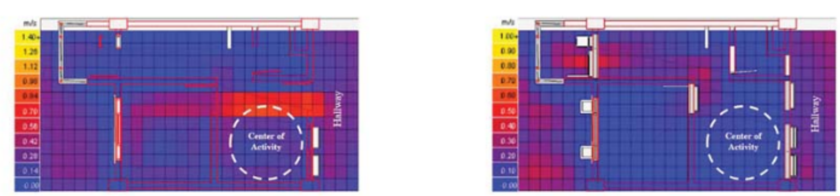



**Figure 5.** Bar chart of on-site wind velocity measurement results

sed have the highest average speed of 0.009 m/s while using hallway windows increase to 0.055m/s. When the door condition opens, the velocity in the room increases with the highest average of 0.26 m/s. The results and comparison show that airflow on the hallway side of the unit room is a potential wind that can be utilized for indoor airflow patterns. The wind velocity in point C is high because it is near the balcony that uses a fully-height trellis.

However, the airflow barely moved to the room as the center activity, which showed from the result of points B and B II when the door near the hallways closed, in contrast, the balcony door always opened during measurement. Figure 5 shows the difference in the increased wind speed in a room unit when the hallway side unit door is used and not.




Door Open with a slight window opening at the hallway side    Door Close with a no window opening at the hallway side

**Figure 6.** Simulation results of the existing flat unit room design

In figure 6, the simulation results of the existing interior unit design show that the volume airflow velocity increases when the door is open, but the airflow pattern inside the room is unstable and uneven. Most of the airflow is moving toward the edge of the room, while the center of activities that need airflow are in the middle of the room.

### *3.1. Integrated unit design between airflow pattern and privacy parameters*

Openings with different elevations in cross-ventilation support form a more evenly wind circulation for thermal comfort [10]. In figure 7, the openings on the hallway side, which are the source of airflow or inlet, are placed at the same level as the height of human activity in this case when residents resting, while the outlet side is higher than the inlet. It is done to create a wind flow pattern evenly distributed vertically. The purpose of implementing a design with privacy parameters is to minimize visual interaction and control accessibility from outside. The hallway side openings were rearranged in positioning and minimizing the size of the openings, but also in an effort to maintain the width of the existing design openings.

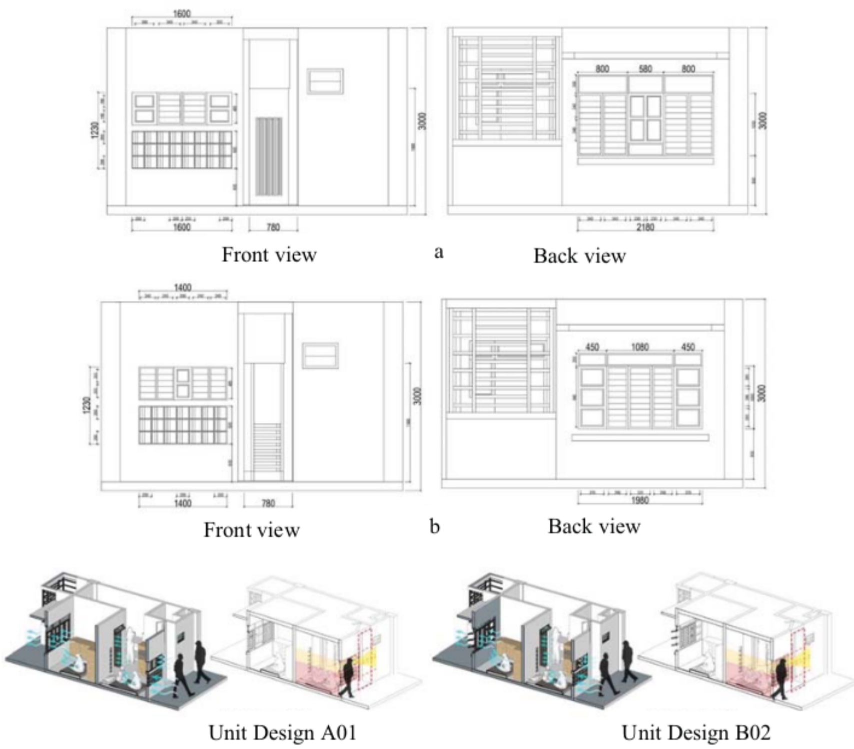



**Figure 7.** Alternative units are designed in response to the needs of room airflow patterns with consideration of privacy parameters, (a) Alternative design A 01 and (b) Alternative design B 02

Utilization openings with the height of the resident's activities while resting using a slanted hole roster with a position below the human standing visual area. The roster is applied along the side walls of the hallway to receive airflow that is evenly distributed horizontally. At the height of the resident's activities when standing, using a louver and top-hung type windows with sandblast glass material (figure 7). This implementation minimizes visual access and spatial interruption from the outside unit but also maintains the resident getting a natural light and controls the interaction they want.

### *3.2. Design Unit A 01 and Design Unit B 02*
The existing unit has a ratio opening area of 10 (hallway side or inlet): 1 (outer side of the building or outlet) when the door and window open and 5 (hallway side): 1 (outer side of the building) when the door closed but the window opens. The result of field measurements that show the highest average wind speed of 0.26 m/s with the door opened, and 0.055 m/s with the door closed may show that the existing unit ratio opening area is not very suitable for creating airflow and wind velocity that supported the resident's unit. Applying the ratio in the design aims to increase the velocity of airflow with consideration inlet airflow circulation direction will form a more evenly pattern of airflow in the room unit. In this research, there are two implementations of the inlet-outlet area ratio. In the first alternative, design A 01, the ratio of the opening area is 1 (hallway side): 1.6 (outer side of the building), and in the second alternative, design B 02 ratio of 1 (hallway side): 2 (outer side building). The widened openings focused on the outer side or outlet of the unit. In contrast, openings on the hallway side or inlet are more focused on dividing the opening area into sizes and types of openings to increase the privacy of the room based on privacy parameters (figure 7).

## 4. Potential and predictions of the application A-01 and B-02 unit designs in increasing privacy and airflow patterns in the unit room
In figure 8, compared to the existing design, the simulation results of the two alternative unit designs (A 01 and B 02) experience an increase in airflow volume and velocity entering the unit room, with airflow more evenly spread. In contrast, the existing one does not spread evenly (figure 6). The source of the airflow pattern that is formed in the proposed alternative unit, comes not only from the door but also from the windows and roster which are arranged on the side walls of the unit. The airflow that enters through the roster wall will go directly to the center of the room. The airflow coming from the door opening is diverted by the door leaf so that it does not enter the room directly but rotates first in the living room.

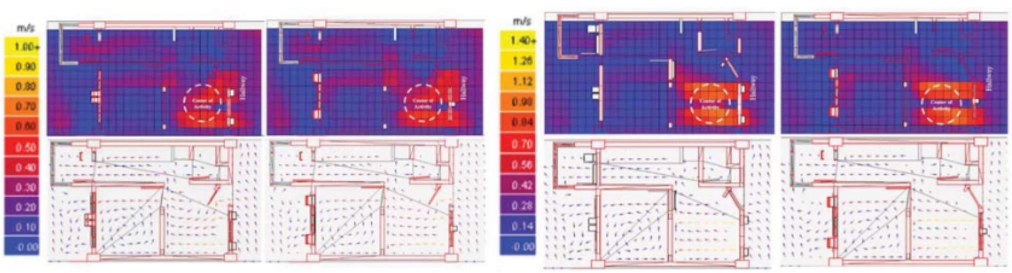



**Figure 8.** Simulation results of the alternative flat unit room design with airflow pattern.

The airflow formed in the two alternative unit designs (A 01 and B 02) has a pattern that supports residents activities, both when the door is open or closed (figure 8). It can be seen from the simulation result that show movement of airflow pattern, especially in the living room unit when the door is closed the wind velocity and volume increases quite significant as does the level of room privacy (figure 9). Figure 9 Show the comparison simulation result of average wind velocity between the proposed alternative designs unit and the existing unit.

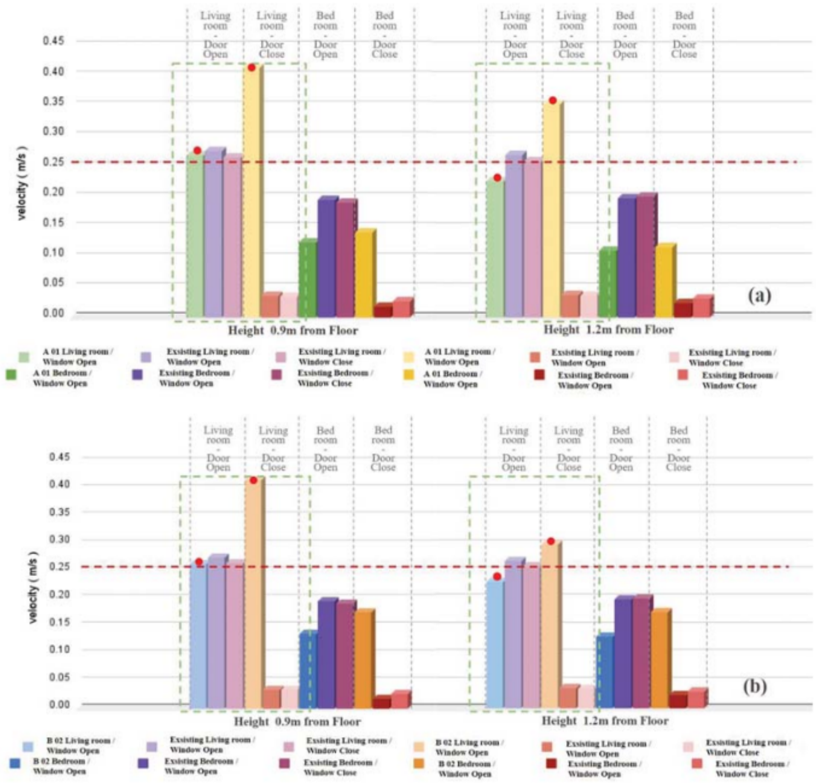



**Figure 9.** Bar chart of comparison wind speed between an existing unit with the proposed alternative design, (a) alternative A 01 and (b) alternative B 02

The alternative design A 01, with the condition door closed, has an average wind velocity of 0.413 m/s, while the alternative design B 02 has an average velocity of 0.416 m/s. Compared to the existing unit with the highest average wind velocity of 0.26 m/s with the condition that the door must open, the proposed alternative design units show an increase of 50% wind velocity from the existing one with better privacy inside the room. Alternative unit designs A 01 and B 02, in practice, have the potential to create better residential spaces in response to activities adaptation, spatial planning, and residents' privacy needs. In achieving privacy needs, residents often sacrifice the comfort of the room when doing activities and resting. To increase the comfort of their room, they tend to rely on a fan, but it also sometimes does not have a significant effect. The utilization of windows and doors is highly needed in air exchange and user-social interaction to create a healthy living environment for residents.

## 5. Conclusion

The simulation results show that the airflow pattern formed in the existing design does not support activities and the applied openings made the unit room have poor privacy. Proposed alternatives design A 01 with an opening area ratio of 1 (inlet): 1.6 (outlet) and design B 02 with an opening area ratio of 1 (inlet): 2 (outlet) with consideration of privacy parameters sufficiently answer the problem and research objectives. Simulation results of design unit A 01 and unit B 02 show an increase in airflow velocity of 50% compared to the existing unit, from the highest average wind speed of 0.26 m/s to 0.413 m/s and 0.416 m/s. Alternative designs with the door closed also increase the privacy in the unit room compared to the existing design that needs to open the door to get more airflow. Different opening area ratios are proven to affect the airflow velocity in the unit. It shows when comparing the existing unit airflow, a ratio opening area of 10 (inlet): 1 (outlet) and 5 (inlet): 1 (outlet) with alternatives design airflow in simulation results that used 1 (inlet): 1.6 (outlet) and 1 (inlet): 2 (outlet). The position, dimensions, and type of opening applied to the alternative unit designs allow the unit to obtain an evenly distributed airflow pattern and meet the needs of area activities with better room privacy.

Improvements in the velocity, airflow patterns, and unit privacy show the potential to create a better residential environment for low-cost flat residents. Using window openings, rosters, and door leaf positions in the proposed alternative designs allows residents to get better air exchange in the room with a better level of privacy and control access to the required social interaction as residents need. This research shows that the right changes in the position, dimensions, and types of openings can make a limited-space unit a better residential environment for its users.

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