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Determination of Window Dimensions Using Mathematical and Simulation Methods to Improve Window Performance: A Case Study on the Jatinegara Barat Flats, Jakarta

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Abstract: The construction of flats is one of the steps toward fulfilling the need for housing in Jakarta and other big cities in Indonesia. This study investigated the thermal problems that focus on air movement in residential units of flats due to window dimensions that cannot accommodate the air velocity that surrounds the buildings because of monotonous window dimensions and the high elevation of the residential units. The position of the interest of this research is on the search for window dimensions that allow comfortable air movement in the residential unit. Based on these problems and interest, the pertinent issue is the design of window dimensions within the facades of the buildings according to the actual air velocity and the elevation of the residential units. The selected object of study was the Jatinegara Barat flats, a block of high-rise flats located in the middle of East Jakarta, Indonesia, which is adjacent to the river. We used a quantitative deductive methodology for the problem analysis via mathematical and simulation methods that use the Ansys R1 2020 software. The final results showed that the relationships between window dimensions, air velocity, and the elevation of residential units can be mapped horizontally and vertically by paying attention to the locations of the window openings with respect to the wind direction and building layout. The horizontal and vertical maps showed repetition of the window dimensions every four floors, with the four floors in the center of the building (read vertically) having window dimensions one-quarter smaller than the four floors above and four floors below.

Keywords: air velocity; air movement; flats; mathematic method; simulation method; thermal; vertical housing; window; window dimension

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1. Introduction

Vertical housing in Indonesia consists of four types: public flats, particular needs flats, state flats, and commercial flats. Public flats are buildings that function as housing needs for low-income people; particular needs flats are buildings that function to meet particular needs (i.e., flats for disaster victims, fisherman's flats, and flats for elderly residents); state flats are state-owned flats for civil servants or officials; and commercial flats aim to make a profit (in Indonesia, commercial flats are also called apartments) [1,2]. Public and commercial flats are the most common types of flats built in Indonesia. Based on the Central Statistics Agency, by 2021, the number of flats in Jakarta will reach 51 towers with 28,766 units (there are no definite records regarding the number of apartments, but according to local reports issued by the local daily news, until 2018, the supply of apartments was 228,000 units). The increase in the construction of the two types of flats is due to the need for residential houses being greater than the vacant land for residential functions.

The difference between public and commercial flats lies in the person in charge of development and the limitations in planning. Commercial flats are private parties with various residential units, namely studio, one-bedroom, two-bedroom, three-bedroom, and penthouse units while public flats built by the government have one residential unit type. Limitations regarding planning of public flats makes the planning of public flats complex.

Public flats are subsidized housing for low-income communities and urbanized communities. Based on the Regulation of the Minister of Public Works No. 05/PRT/M/2007, the planning for residential units of these flats focuses on human activities, consisting of a living room, two bedrooms, bathroom, kitchen, and laundry room with a room size of 30 to 36 m^2 [3,4] in a prototype form that is used at all locations for flats in Indonesia. Apart from human activities, the construction volume determines the use, with sizes of 30 and 36 m^2 for each flat. Based on the Law of the Republic of Indonesia No. 20 of 2011, residential units must reach at least 20% of the construction volume of the flats to reach the maximum number determined by the building height coefficient and the number of people who will live in the flats (in contrast to apartments, the government determines the occupants of each flats, such as the eviction community in Kampung Pulo, who live in the Jatinegara Barat flats).

The arrangement for the size of flats is that flats only consist of one type of dwelling. If the analysis of the flats shows that a size of 30 m^2 is the right size in terms of the fulfilment of residential units, the basic coefficient of the building, and the coefficient of the building height, then the flats will only use the 30 m^2 type in all residential units. Each tower of flats will have the same unit size. The purpose of using this prototype is to speed up development and reduce development costs. However, this prototype can create problems for the residents of the flats, especially in terms of fulfilling human thermal requirements.

The problems begin with the basic design, which is not focused on the environment and is unresponsive to the climate. Factors related to the environment and climate are assessed in softscape planning and ventilation calculation based on the Indonesian National Standard 03–6572-2001 concerning the Procedures for Planning for Ventilation and Air Conditioning Systems in Buildings [5,6]. This prototype has characteristics such as precast walls on the facade, monotonous window dimensions, and a limited size. The use of this prototype results in the performance of the building being poor, especially the performance of the windows on the facades of the buildings. The window dimensions, which have a monotonous size from the lower floors to the upper floors, cannot accommodate pressure differences, which affects the air velocity [7,8].

Window performance is a complex process that is affected by several factors and is often associated with the passive performance of low-rise and high-rise buildings. The performance of windows as inlets is one of the main factors affecting cross ventilation, the quality of air movement, and energy use [9–11]. For flats users, window performance is essential because it is related to the expenses that they must spend every month. Natural ventilation helps residents to reduce the cost of using cooling technologies, such as air conditioning and fans. In addition, natural ventilation supports air exchange, which helps to improve occupants' health.

Window performance also relates to Indonesia's emission reduction goals. Iwan Prijanto (chairman of the Green Building Council Indonesia), in the Sustainable Finance for Net Zero Green Building seminar, stated that the housing sector emits approximately 80% of carbon emissions [12]. High carbon emissions from residential houses occurs due to their daily use. In addition, high emissions are released by residential homes because there is a variety of energy being used in one place.

The window dimensions in high-rise flats are determined using the wind force ventilation formula listed in the Indonesian National Standard 03–6572-2001 concerning the Procedures for Planning for Ventilation and Air Conditioning Systems in Buildings, which calculates the airflow rates using area variables, inlet-free areas, air velocity, and the effectiveness of openings [13]. However, this calculation for airflow rates cannot establish the airflow rates within the comfort zone and instead provides new problems that threaten the safety of residents in the form of loose window connections due to a high air velocity. The main reason that the wind force ventilation formula cannot determine the window dimensions is that there is no variable height of the buildings (or elevation of the room), which affects the air velocity.

The wind is observed through pressure in both pure and building physics. Gravity affects the pressure and at different heights, gravity is different. The taller the height, the lower the pressure and the higher the air velocity. Another thing that affects the relationships between wind and buildings is temperature. Temperature affects the volume of air molecules and cause different speeds of wind under different temperature conditions [14–18]. Especially, in high-rise flats, the elevation of the residential units represents the height.

This study aimed to investigate the relationships between these four factors and their influence on the planning design of high-rise flats, especially in terms of the dimensions of the windows on building facades. Theoretically, windows on buildings allow wind and solar radiation to enter the residential units. Therefore, a poor window performance results in poor thermals in the rooms. Bernoulli's principle of wind and height states that windows on the facades of high-rise flats do not function optimally because the window dimensions are the same from the lower floors to the upper floors even though the pressure from gravity affects the air velocity at different magnitudes [19].

Several studies on the performance of windows on the facades of flats in Indonesia have shown that four factors prevent windows from working optimally: the window location, wind direction, planning location, and elevation of residential units. Window location and wind direction are interrelated factors; for windows to have maximum wind suction capabilities, the location and placement of the windows must be in a positive field (i.e., facing the wind direction) [20,21]. The third and fourth factors indicate that the location and elevation of the residential units affect the responses of the flats' design through air velocity changes, which affect the building facades [22]. Globally, studies on the relationship between air velocity and building height are still lacking. The relationship between air velocity and building height is a component of thermal comfort. Studies on thermal compliance, wind tunnels, and air movement have focused on heat transfer, represented by temperature differences [23], surface cooling [24], airflow [25,26], window location and position [27–29], and ventilation strategies [30], but have ignored the relationship between air velocity and building height.

Other research on windows as ventilation has shown other factors affecting ventilation performance: climate and form [31,32]. The climate factor that most affects the performance of windows in buildings is wind. Temperature and pressure are the main factors that affect the speed of the wind that hits buildings while altitude is the main factor affecting temperature and pressure. The factor that affects window performance the most is the angle of the opening, the type of the window, and the building form. The angle and type of window affect the size of the inlet-free area, which is how wind enters the room. Meanwhile, the building form and the placement of the buildings within one area affect the air velocity around the buildings.

Based on the existing phenomena, problems, and studies, the correct hypothesis is that the higher the building, the smaller the window dimensions, depending on the locations of the windows within the layout of the building, the direction of the wind, the actual wind speed, and the elevation of the residential units. This study aimed to determine the relationship between the air velocity and building height by comparing theories, mathematical calculations, and simulation results. This study specifically aimed to determine the best dimensions of windows in flats, in particular the Jatinegara Barat flats, Jakarta. The results provide preliminary ideas for further research on the same topic but in different locations and on different building forms. Long-term research aims to obtain new foundations that could become a theory for academics and practitioners.

Research on window dimensions has used mathematical and simulation methods. The mathematical methods use the power law, Torricelli, and MacFarlane formulae while the simulations use computational fluid dynamics (CFD). CFD simulation programs can describe the velocity of air movement and fluid flow around the surfaces of buildings, which are created by the actual boundaries in plans [33,34] and [35] (pp. 1–12). The variables used in both methods are the air velocity, size of existing residential units, dimensions of existing windows, temperature, humidity, and experimental windows. The novelty of this research lies in the horizontal and vertical mapping of window dimensions based on the relationships between air velocity, wind direction, the location of residential units, and the elevation of residential units.

2. Materials and Methods

The window in the Jatinegara Barat flats is a tipping window with a one-way opening (outward). The maximum window opening angle is 10 degrees, with the airflow entering through the window following the window opening angle. Based on Boutet's theory, the tipping window allows the wind to move to the upper area of the room when it enters the room and split when it collides with the ceiling area (Figure 1).

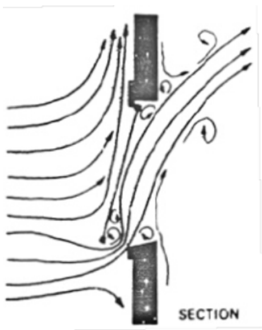
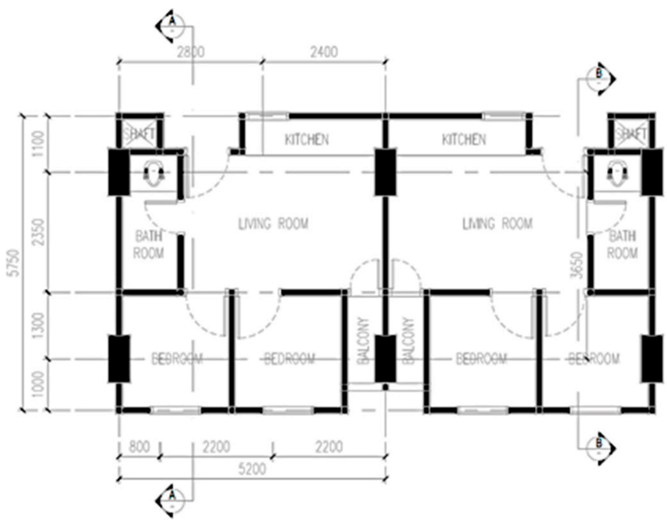


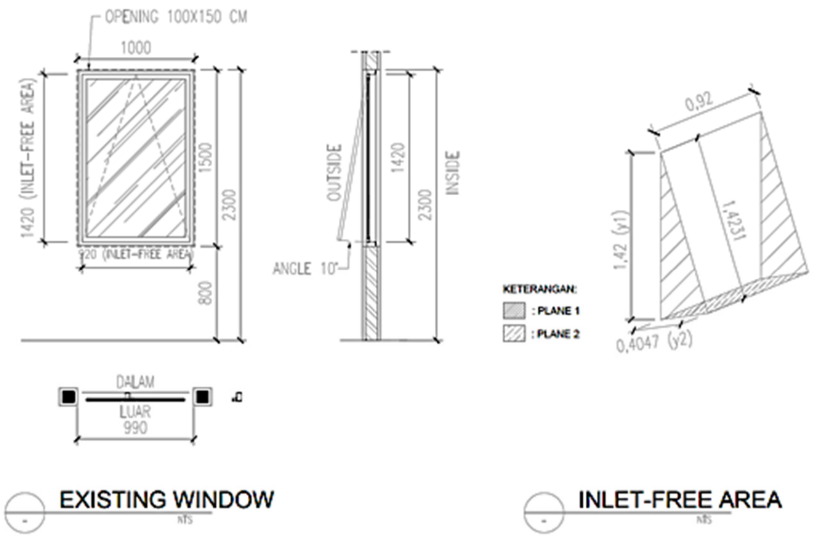
Figure 1. Airflow on the tipping window.

The material object used in this study was the Jatinegara Barat flats, which has 16 floors with a unit size of 30 m^2 (Figure 2a), tipping windows, and an existing inlet-free area of 0.941750378 m^2 (Figure 2b). The Jatinegara Barat flats building has a zigzag shape with a floor finish level (FFL) height of 2.65 m for each residential unit (Figure 2c). The zigzag shape of the building allows for various kinds of wind motion (parallel, oblique, and turbulent) around the building (Figure 2d).



(**a**)

Figure 2. *Cont*.



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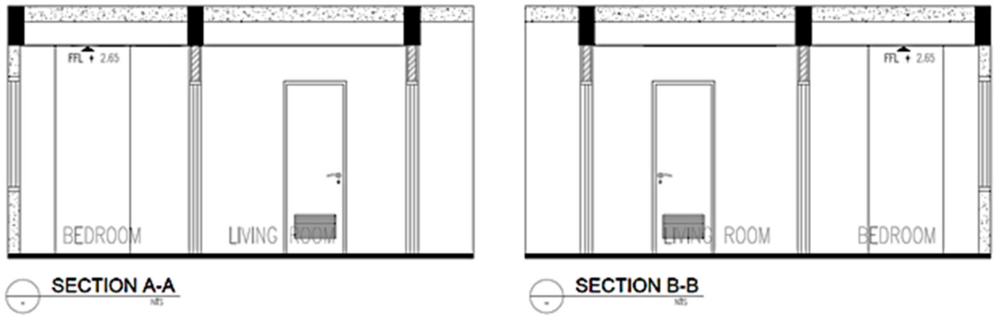

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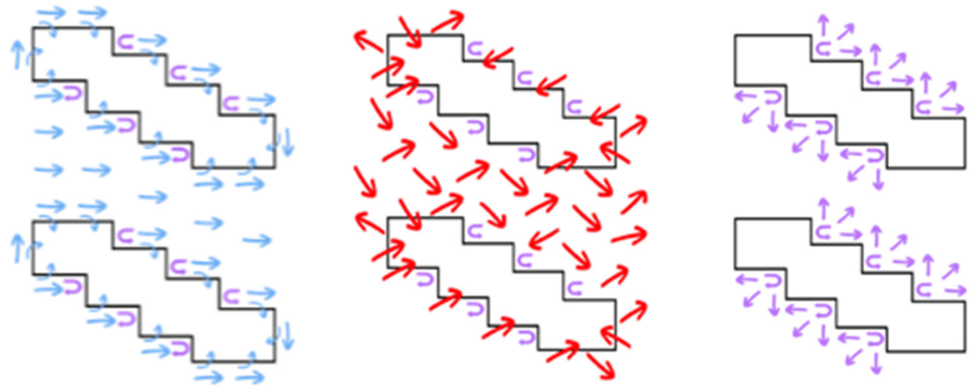


(**d**)

Figure 2. General data for the Jatinegara Barat flats: (**a**) residential unit plan (30 m^2/unit); (**b**) existing windows and inlet-free areas; (**c**) residential unit sections; (**d**) illustration of the air velocity around the Jatinegara Barat flats (inspired by the basic theories of Szokolay, DeKay, and Boutet [36–38]).

The variables used in this study of window dimensions were the actual air velocity, measured residential unit elevation, existing residential units, existing window dimensions, alternative window dimensions, dominant wind direction over 3 years (Figure 3), existing temperature of the residential units, and existing humidity of the residential units. The mathematical calculations used all variables, divided into two parts (as discussed in the method description). In contrast, the simulation experiments used the variables of the actual air velocity, dominant wind direction, existing residential units, dimensions of existing windows, and dimensions of alternative windows.

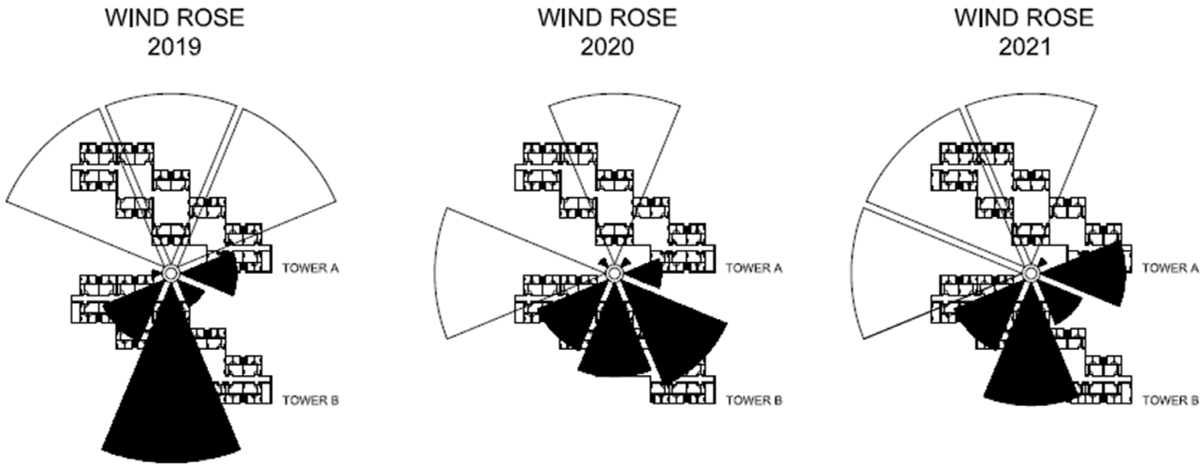


Figure 3. Wind rose data for the last 3 years.

2.1. Basic Theory and Research Data

The basic factor that affects the determination of window dimensions is pressure. Pressure affects air velocity by differences in the gravity (in this study, represented by the elevation of the residential units), temperature, humidity, and roughness length [39] (Table 1). Theoretically, the comfortable air velocity for humans is 0.4 to 3.1 m/s (Beaufort theory) [40,41]; however, in tropical areas, the comfortable air velocity for humans is 0.25 to 1.5 m/s [42]. Air velocity measurements need to be carried out at a minimum height of 30 feet or ±9.4 m [43] above the ground; so, in the context of this study, these measurements started from the fourth floor of the flats (Figure 4). The control variables consisted of the comfortable limits for air movement, temperature, and humidity (Table 2).

Table 1. Values for the roughness length [39].

Variable	Z_g (m)	Z_o (m)	α
Open sea, ice, tundra, desert	250	0.001	0.11
Open country with low bushes	200	0.03	0.15
Suburban areas, small towns, well-wooded areas	400	0.3	0.25
Numerous tall buildings, city centers, dense industrial developments	500	3	0.36

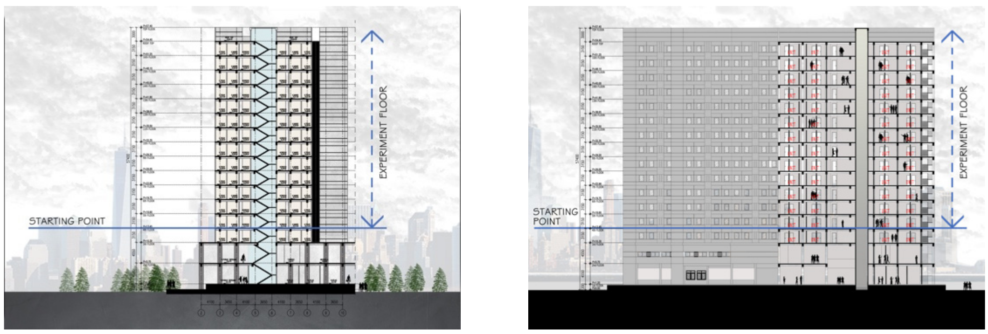


Figure 4. Experiment floors and starting point of measurements.

Table 2. Research control variables.

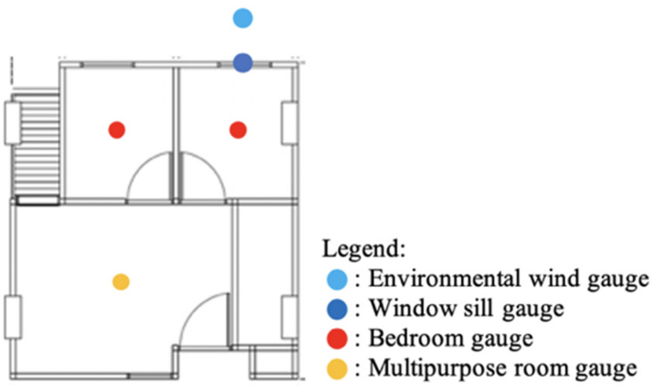
Variable	Comfort Zone
Air movement [44,45]	0.2–0.6 m/s
Temperature [42]	21–27 °C
Humidity [46–48]	17–80%

The initial data for this study came from field measurements based on data from the Meteorology, Climatology, and Geophysics Agency. The determination of the elevation measurement points for the field measurements was based on horizontal and vertical simulations of the area using a maximum average air velocity of 5.6 m/s and the conditions around the Jatinegara Barat flats while the timing of the field measurements used the culmination time of 2021, which was 20 March 2021 and 23 September 2021. The field measurements used a hot wire anemometer to measure the air movement in the residential unit (Figure 5a) and a vane anemometer (multifunction) to measure the air velocity outside the building and the indoor temperature (Figure 5b).

(**a**) (**b**)

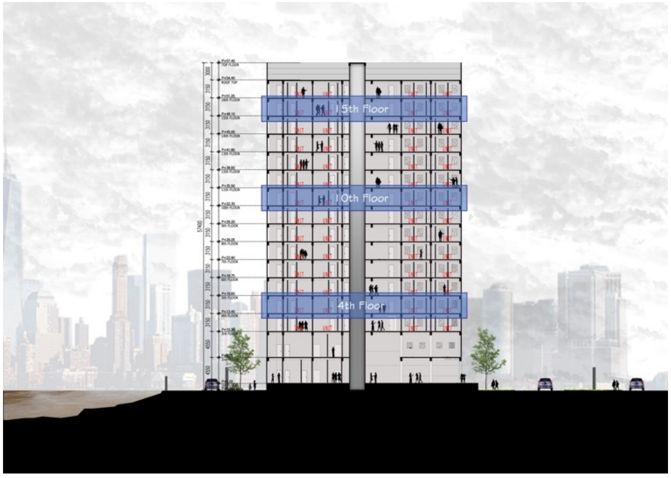
Figure 5. Measurement tools: (**a**) Hot wire anemometer; (**b**) vane anemometer.

The area outside the window, the window sill, the two bedrooms, and the living room were used as the measuring points for the field measurement (Figure 6a). The fourth floor is the first floor that has no obstructions (trees, buildings, etc.), the tenth floor is one of the floors in the middle of the building (read vertically from building section), and the fifteenth floor is on the top floor (Figure 6b), with the metric units facing the wind tunnel area and the urban area (Figure 6c).

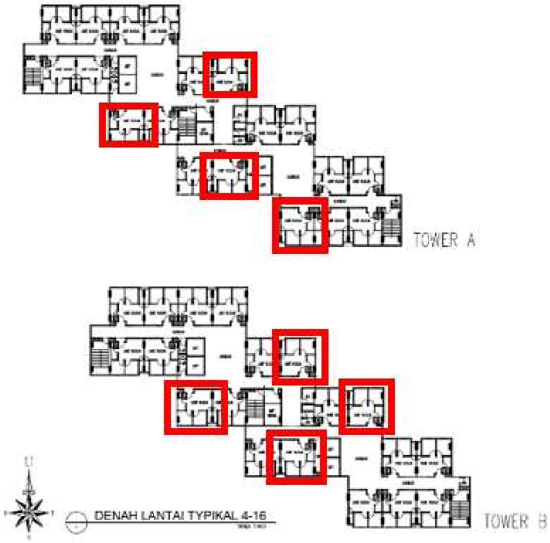


(a)

Figure 6. *Cont.*



(**b**)



(**c**)

Figure 6. General data of the field measurement: (**a**) Field measurement points on residential units; (**b**) field-measured floor position; (**c**) field-measured residential unit.

2.2. Research Methods

This study of window dimensions based on the air velocity and elevation of residential units used two methods: mathematical and simulation methods. The mathematics method was divided into two stages while the simulation consisted of only one stage and this is a method that bridges the stages of mathematics 1 and mathematics 2.

Mathematics 1 consisted of a search for air velocity references and air movement references while mathematics 2 consisted of a search for the window dimension change range, determination of the vertical window dimension (section), and validation of the window dimension mapping generated by stage 1 and the simulation stage. The simulation process consisted of a search for air movement in the residential unit based on the alternative window. The simulation used a residential unit plan (2D drawing), with the final result of the simulation being the determination of the horizontal dimensions of the window (plan) (Figure 7).

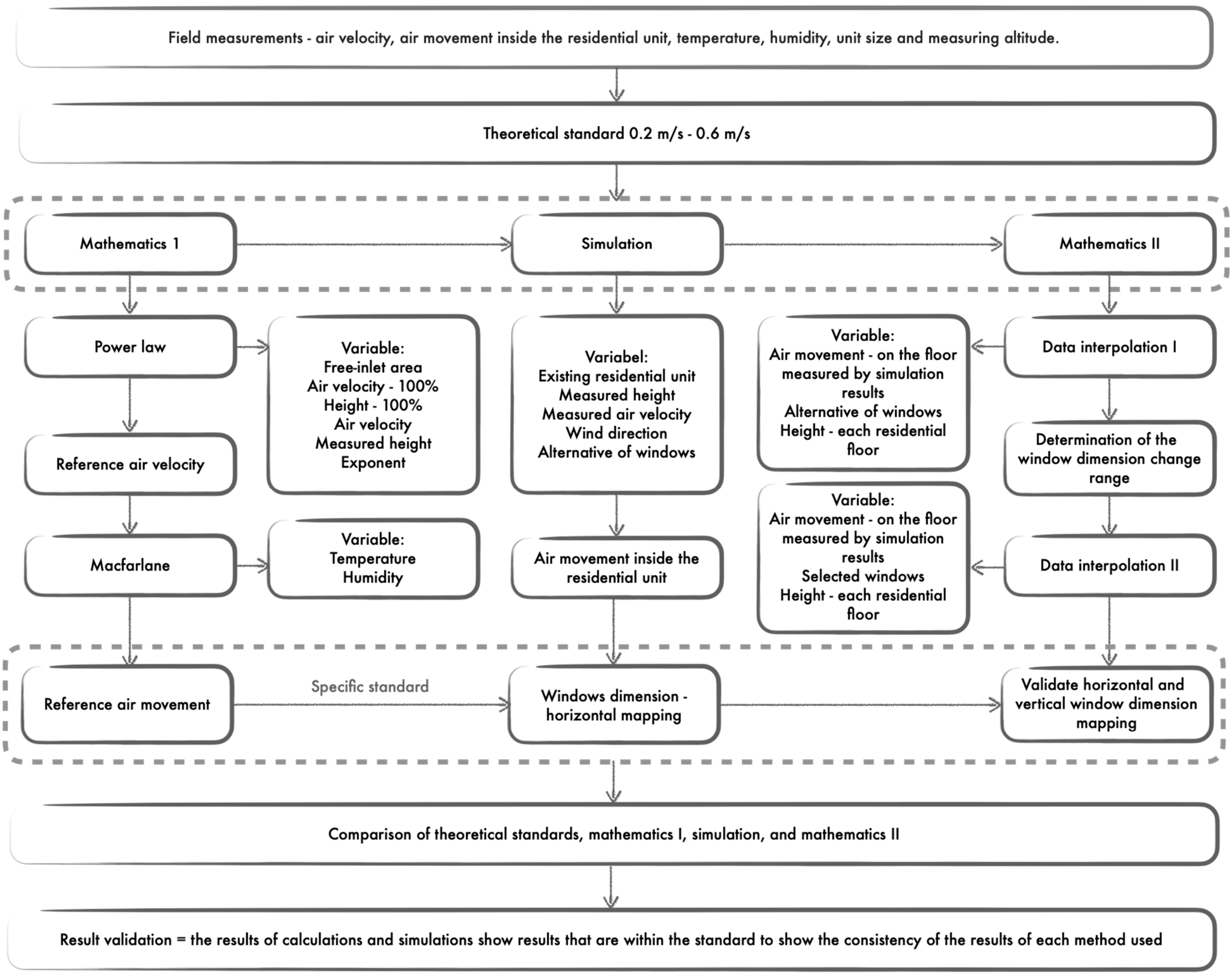


Figure 7. Research workflow.

2.2.1. Mathematical Calculation

The mathematical calculations consisted of two stages: before the simulations and after the simulations. The first stage of the mathematical calculations used the wind force ventilation from the Indonesian National Standard 03–6572-2001, power law formula, Torricelli formula, Bernoulli formula, and Macfarlane formula. The wind force ventilation used the free-inlet area, air velocity, and opening effectiveness (Equation (1)). The wind force ventilation formula was used to show the inability of the existing window to provide comfortable air movement:

$$Q = C_v \times A.V \tag{1}$$

where Q is the airflow rate, C_v is the aperture effectiveness (0.5–0.6 for perpendicular wind and 0.25–0.35 for skewed wind), A is the free-inlet area, and V is the air velocity.

The power law formula uses air movement variables at low elevations, air movement at reference elevations, low elevations, comparison elevations, and wind shear exponents [49]. The first step of the power law formula (Equation (2a)) aims to determine the 100% speed and the second step (Equation (2b)) aims to show the ideal reference air movement at each measured height, thereby becoming a validation tool for existing conditions:

$$V_z = V_g \left(\frac{Z}{Z_g} \right)^{\alpha} \tag{2a}$$

where V_z is the mean air velocity at the height Z, V_g is the mean air velocity at the height Z_g, Z is the height, Z_g is the gradient height, and α is the wind shear exponent:

$$V_{ref} = V_g \left(\frac{Z_{ref}}{Z_g} \right)^{\alpha} \tag{2b}$$

where V_{ref} is the reference speed, V_g is the mean of an area's 100% air velocity, Z_{ref} is the reference height, $Z_{g\ i}$s the gradient height, and α is the wind shear exponent.

The following formulae are the Torricelli and Bernoulli formulae, which were used to determine the pressure and velocity, respectively. The Torricelli formula (Equation (3)) uses the residential unit elevation variable and aims to find the pressure at the measured height. In contrast, the Bernoulli formula uses the variables of gravity acceleration with a magnitude of 9.8067 m/s^2 [50,51], air movement at a measured elevation, height at a measured elevation, and enthalpy (Equation (4)) to calculate the difference between the field measurement and theoretical calculations:

$$P = 76\ cmHg - \frac{h}{100} \tag{3}$$

where P is the air pressure and h is the height (in this study, it is the elevation of the measured residential unit):

$$\frac{v^2}{2} + gh + \omega \tag{4}$$

where g is acceleration of gravity, ϑ is the air velocity, h is the height, and ω is the enthalpy, with a value of 77.43 kJ/Kg (at 30 °C).

The Macfarlane formula (Equation (5)) calculates the reference air movement. The Macfarlane formula uses the variables of the temperature of the existing residential units and the humidity of the existing residential units. In the final results, the reference air movement is a control variable that validates the simulation results and data interpolation:

$$C_v = 0.15\ \{DBT - 27.2 + ([RH - 60]/10)0.56\} \tag{5}$$

where C_v is the air movement reference, DBT is the dry-bulb temperature, and RH is the relative humidity.

The second stage of the mathematical calculations was data interpolation, which determined the air motion in the residential units on unmeasured floors. The data interpolation formula (Equation (6)) uses the variables of the von Karman constant, in the range of 0.4 to $\pm$ 0.02, the elevation of residential units, and the roughness length:

$$U(z) = \frac{U^*}{K} \times ln \left(\frac{Z + Z_0}{Z_0} \right) \tag{6}$$

where U_z is the friction velocity, K is the von Karman constant, z is the elevation of the occupancy unit, and Z_0 is the roughness length.

2.2.2. CFD Ansys Simulation

In determining the window dimensions using the air velocity and elevation of residential units, simulation analysis has limited scope because the study object has already been built, and it is not possible to use simulations with total changes in its interior. The simulation focused on the window size and air velocity to enhance the finish details. The wall and door layouts were considered according to the existing conditions and did not change in the simulation. The limitation of the simulation is that the final results show the difference in the airflow that occurs when the size of the window dimensions are reduced while the interior conditions are the same as the existing conditions.

Ansys CFD is a simulation program that shows air movement and ventilation performance [35] (pp. 1–2) and [52,53]. This study used Ansys R1 2020 to measure the air motion formed by the window dimensions. The simulations used set equations for fluid dynamics, namely the continuity equation (Equation (7a,b), the x-y-z momentum equation (Equation (8a–c), and the energy equation (Equation (9)), which were solved automatically by the system in the simulation program. The simulations used polyhedral meshing and focused on local meshing to accommodate the flow around the model. The mesh around the building was denser compared to that in areas that were far from the building to increase the computational efficiency. In the residential unit model of the Jatinegara Barat flats, the model produced a mesh with 104,997 nodes and 476,716 elements, as shown in Figure 8:

$$\frac{\partial}{\partial t}\iiint_V \rho dV + \iint_A \rho \vec{V}\cdot d\vec{A} = 0 \tag{7a}$$

$$\frac{\partial \rho}{\partial t} + \rho \vec{\nabla}\cdot\vec{V} = 0 \tag{7b}$$

$$\frac{\partial(\rho u)}{\partial t} + \vec{\nabla}\cdot\left(\rho u \vec{V}\right) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \tag{8a}$$

$$\frac{\partial(\rho v)}{\partial t} + \vec{\nabla}\cdot\left(\rho v \vec{V}\right) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \tag{8b}$$

$$\frac{\partial(\rho w)}{\partial t} + \vec{\nabla}\cdot\left(\rho w \vec{V}\right) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \tag{8c}$$

$$\frac{\partial}{\partial t}\left[\rho\left(e + \frac{V^2}{2}\right)\right] + \vec{\nabla}\cdot\left[\rho\left(e + \frac{V^2}{2}\right)\vec{V}\right] = \rho\dot{q} - \frac{\partial(\rho p)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} + \rho\vec{f}\cdot\vec{V} \tag{9}$$

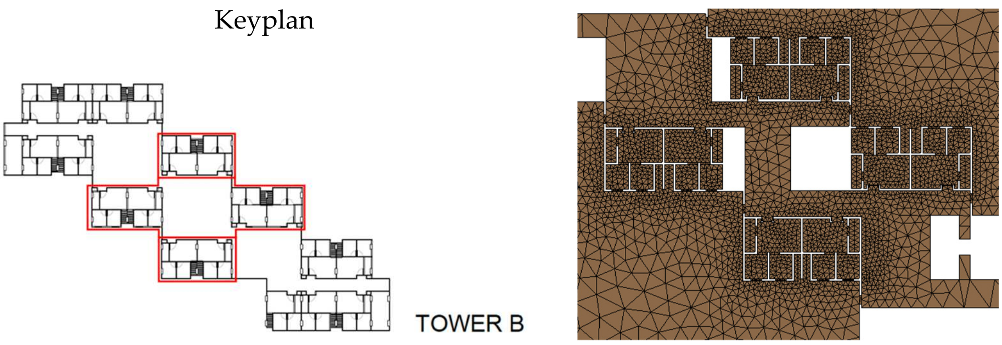


Figure 8. Local meshing at tower B as a depiction of the local meshing in the simulation.

The computational settings of Ansys R1 2020 consisted of the following turbulence, pressure, and boundary conditions, and hybrid initialization settings:

- Turbulence: k-omega SST (Share Stress Transport)

This study used k-omega modeling to model narrow slits, details, and high-pressure gradients. K-omega SST is a refinement of the k-epsilon model. The k-omega model is combined with k-epsilon to achieve good capability in the area around the wall, a low Reynold number value, flow with a low adverse pressure gradient, and insensitivity in the free stream area. The combination of k-omega and k-epsilon is then constructed b considering the turbulent shear stress transport equation, thereby increasing the predictive ability of flow separation in the adverse pressure gradient. This model is called k-omega SST [54]. This modification of SST served to accommodate free streams that were far away from the object;

- Pressure-based

This study on the window dimensions in the Jatinegara Barat flats building used a couple models, so the approach to setting the proper pressure settings was pressure based. The pressure-based approach was the result of solving the continuity and momentum equations and could simultaneously solve all object coordinates;

- Boundary conditions

Boundary conditions consist of two types: inlets and walls. For inlets, the input data were the air velocity outside the building, with the wind direction settings based on the wind rose analysis. The wind direction settings used vector settings. For the walls, we used a no-slip condition to represent the friction between the flow and the wall;

- Hybrid initialization

The hybrid initialization method technically interpolates the values of boundary conditions by solving the Laplace equation to produce a velocity field that follows the geometry and a pressure field that smoothly corresponds.

The simulation data consisted of the existing residential units, existing windows, two alternative windows, elevation of the existing residential units (Table 3), actual air velocity, and wind direction (Table 4). On each measured floor, there were 9 simulated units in tower A and 8 simulated units in tower B, providing a total of 27 simulated units in tower A and 24 simulated units in tower B. All simulated residential units used for the experiments included three dimensions of the windows and the dominant wind direction.

Table 3. Simulation data.

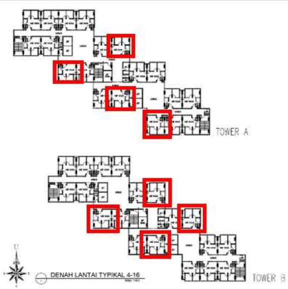
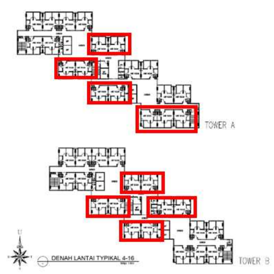
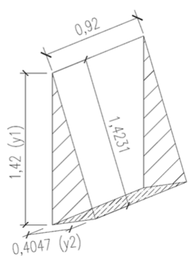
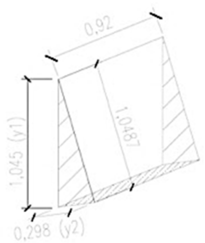
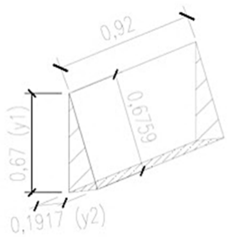
Variable	Data		
Residential unit	 Field measurement		 Simulated unit
Keyplan 			
Inlet-free area dimensions	Window 1 (Existing) 0.941750378	Window 2 0.5829214228	Window 3 0.3355409635
Elevation	4th floor 14.65 m	10th floor 33.55 m	15th floor 49.3 m

Table 4. Field measurement data used in the simulation.

Elevation	Air Velocity (m/s)			
	Southwest	South	Southeast	East
4th floor	4.9	3.94	6.57	7.37
10th floor	10.9	6.72	7.26	12.18
15th floor	7.59	5.92	7.25	7.94

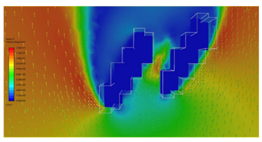
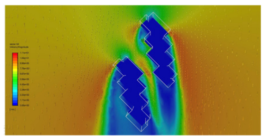
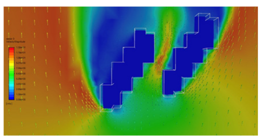
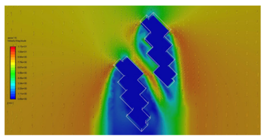
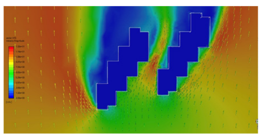
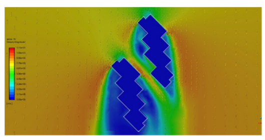
3. Results

This study on the window dimensions in the facades of the Jatinegara Barat flats consisted of three parts: the air velocity patterns outside the building, the horizontal mapping of the window dimensions, and the vertical mapping of the window dimensions. The air velocity patterns outside the building were calculated from the results of the initial area simulations, initial simulations with the existing conditions, field measurements, power law calculations, Torricelli calculations, and Bernoulli calculations. The horizontal window dimension mapping was calculated from the simulations of the measured floors and the Macfarlane calculations. The vertical window dimension mapping was calculated from the data interpolation, which aimed to determine the air movement that was created in the residential units on the unmeasured floors.

3.1. Air Velocity Patterns

The initial simulations were area simulations using the average air velocity data from the Meteorology, Climatology, and Geophysics Agency, with a focus on the direction of the wind coming through the wind tunnel, namely west and east (Table 5). The regional simulation results showed that when the wind came from the east, the streamlined area on the 10th floor is longer than that on the 4th and 15th floors. The streamlined area on the 15th floor widened and produced the following two options: either the air velocity on the 15th floor was lower than that on the 10th floor or the air velocity on the 15th floor was faster than that on the 4th and 10th floors. According to Bernoulli's pressure theory, both possibilities can occur in field measurements. This theory states that when streamlined areas are close together, the pressure decreases and the air velocity increases.

Table 5. Regional simulation results.

Elevation	Air Velocity (m/s)	
	East	West
4th floor		
10th floor		
15th floor		

The Torricelli and Bernoulli calculations showed that the pressure and air velocity at the elevation of the measured residential units changed following the theory, namely, the higher the elevation of the measuring unit, the lower the pressure and the higher the air velocity. This result was different from the field measurements, which showed that the 10th floor had the highest air velocity (Table 6) and proved that the streamline areas were close to each other in the wind tunnel on the 10th floor (Figure 9).

Table 6. Results of the Torricelli and Bernoulli equations.

Floor	Height	Torricelli (cmHg)	Bernoulli
4	14.65	75.8535	228.5173
10	33.55	75.6645	440.038
15	49.3	75.507	578.1401

Figure 9. Comparison of the field calculations and measurements: (**a**) Air velocity from the field measurement; (**b**) Torricelli equation; and (**c**) Bernoulli equation.

3.2. Existing Window and Calculation of the Indonesian National Standard

The calculations using the Indonesian National Standard show that the existing window can allow comfortable air movement when the wind speed reaches 7.5 m/s in the perpendicular wind condition (Table 7). The field conditions show that the residents close the windows at a wind speed of 7.5 m/s; so, the existing windows are not functioning optimally. Another thing that makes the calculation using the wind force ventilation formula in the Indonesian National Standard less precise is that the wind does not continuously have the same direction of motion; so, it is difficult to determine how often the wind is perpendicular wind or skewed wind.

Table 7. Existing window: Indonesian National Standard Calculations.

A (m^2)	Floor	Wind Direction	V (m/s)	C_v	Q	Standard
0.941750378	4th	Southwest	4.9	0.6	2.768	Min: 4.250 cfs Max: 13.034 cfs
				0.35	1.615	
		South	3.94	0.6	2.226	
				0.35	1.298	
		Southeast	6.57	0.6	3.712	
				0.35	2.165	
		East	7.37	0.6	4.164	
				0.35	2.429	

Table 7. *Cont.*

A (m^2)	Floor	Wind Direction	V (m/s)	C_v	Q	Standard
	10th	Southwest	10.9	0.6	6.159	
				0.35	3.592	
		South	6.72	0.6	3.797	
				0.35	2.214	
		Southeast	7.26	0.6	4.102	
				0.35	2.392	
		East	12.18	0.6	6.882	
				0.35	4.014	
	15th	Southwest	7.59	0.6	4.288	
				0.35	2.501	
		South	5.92	0.6	3.345	
				0.35	1.951	
		Southeast	7.25	0.6	4.096	
				0.35	2.389	
		East	7.94	0.6	4.486	
				0.35	2.617	

3.3. Window Dimensions: Horizontal Mapping

The comparison of the existing conditions to the power law calculations was the first step in the simulation experiments, which aimed to model the worst conditions. The worst conditions were modeled by the initial data from the experiment simulations of the residential units and alternative window dimensions in the building. The power law calculations showed that one of the problems is that the window performance of the building was not optimal. The existing air velocity is above the reference air velocity. The calculations of the 100% air velocity are shown in Table 8 for the following conditions:

- 4.9–8.6 m/s on the 4th floor of tower A;
- 8.6–9.3 m/s on the 10th floor of tower A;
- 8.3–9.4 m/s on the 15th floor of tower A;
- 5–8.2 m/s on the 4th floor of tower B;
- 7.5–10 m/s on the 10th floor of tower B;
- 7.6–10.2 m/s on the 15th floor of tower B.

Table 8. The 100% air velocity values at an altitude of 400 m.

Tower	Floor	Unit	V_z (m/s)	V_g (m/s)
A	4th	1	2.185	4.994
		2	2.177	4.9
		3	2.663	6.087
		4	3.761	8.597
	10th	1	4.698	8.636
		2	4.135	7.683
		3	4.901	9.107
		4	4.99	9.272
	15th	1	4.943	8.342
		2	3.763	6.350
		3	4.853	8.1905
		4	5.568	9.397
B	4th	1	2.191	5.008
		2	2.867	6.553
		3	2.13	4.868
		4	3.555	8.126

Table 8. *Cont.*

Tower	Floor	Unit	V_z (m/s)	V_g (m/s)
	10th	1	4.058	7.540
		2	5.801	10.779
		3	3.445	6.401
		4	5.383	10.002
	15th	1	4.551	7.6808
		2	5.143	8.68
		3	4.445	7.501
		4	6.055	10.219

The 100% air velocity produced a reference air velocity that was lower than the field measurements, namely 2.1–3.8 m/s on the 4th floor of tower A, 4.6–5 m/s on the 10th floor of tower A, 4.9–5.6 m/s on the 15th floor of tower A, 2.1–3.6 m/s on the 4th floor of tower B, 4–5.4 m/s on the 10th floor of tower B, and 4.5–6.1 m/s on the 15th floor of tower B as shown in Table 9.

Table 9. Reference air velocity at the measured elevations.

Tower	Floor	Unit	V_{ref} (m/s)	Actual Air Velocity (m/s)
A	4th	1	2.184	3.81
		2	2.143	3.86
		3	2.662	4.90
		4	3.7608	6.57
	10th	1	4.647	8.34
		2	4.134	6.76
		3	4.9009	10.90
		4	4.989	7.26
	15th	1	4.943	7.21
		2	3.762	7.08
		3	4.853	7.59
		4	5.567	7.25
B	4th	1	2.1908	4.31
		2	2.866	4.90
		3	2.129	3.94
		4	3.554	7.37
	10th	1	4.057	6.72
		2	5.8007	12.18
		3	3.444	5.12
		4	5.382	7.39
	15th	1	4.5509	5.92
		2	5.1429	7.56
		3	4.44	5.92
		4	6.054	7.94

Examination of the existing conditions using the power law calculations shows that the existing conditions were worse than the power law calculations. Therefore, the data used in the simulations consisted of the existing conditions that occurred in the field. According to the existing temperature and humidity conditions in the Macfarlane calculations, the appropriate dimensions for windows on the facades of high-rise buildings require data on the reference air movement. The Macfarlane calculation results show that the units located on the 4th floor of tower A required air movement of 0.41–0.45 m/s, those on the 10th floor of tower A required air movement of 0.46–0.54 m/s, those on the 15th floor of tower A required air movement of 0.29–0.46 m/s, those on the 4th floor of tower B required air movement of 0.29–0.54 m/s, those on the 10th floor of tower B required air movement of 0.36–0.39 m/s, and those on the 15th floor of tower B required air movement of 0.41–0.57 m/s, as shown in Table 10.

Table 10. Reference air movement at the measured elevation.

Tower	Floor	Unit	C_v (m/s)
A	4th	1	0.41
		2	0.44
		3	0.44
		4	0.45
	10th	1	0.46
		2	0.54
		3	0.53
		4	0.49
	15th	1	0.4
		2	0.46
		3	0.29
		4	0.46
B	4th	1	0.29
		2	0.36
		3	0.39
		4	0.54
	10th	1	0.38
		2	0.39
		3	0.37
		4	0.36
	15th	1	0.46
		2	0.43
		3	0.41
		4	0.57

The simulations showed two results: the maximum and minimum air movement formed through the dimensions of the window in the facades of the residential units. The control variable used was the academic standard and the results of the Macfarlane calculations with air movement coupled with the control variable showed the minimum air movement. The main reason for only using the minimum air movement is that maximal air movement never occurs under actual conditions. In air movement conditions of more than 0.5–0.55 m/s, occupants tend to close the windows (actual conditions are conditions that occur in the field with non-verbal data because the data come from the experience of researchers after repeatedly observing the objects under study for one year). In the simulations, there were four simulated units on each floor in each tower. Each unit was simulated with the highest air velocity based on the wind direction as shown in Figure 10.

The number of residential units was chosen according to the order of the field measurements to ensure that the data and simulations produced followed the field measurement process. The simulation results showed the final results, as shown in Table 11.

Based on the simulation analysis of the measured units on the 4th floor, 10th floor, and 15th floor, the properties of the dimensions of the inlet-free area were (Figure 11):

1. The window dimensions on the 4th floor were the same as those on the 15th floor, except for unit 2 in tower A, which faced away from the wind direction;
2. The window dimensions of unit 1 in tower A were the same as those of unit 4 in tower B;
3. The window dimensions of unit 3 and unit 4 in tower A were the same as those of unit 2 in tower B;
4. The windows dimensions of unit 1 in tower B were the same as those of unit 3 in tower B.

Table 11. CFD simulation results.

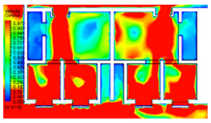
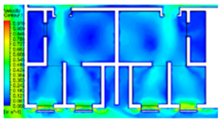
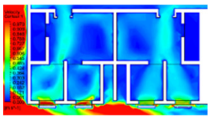
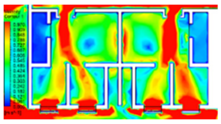
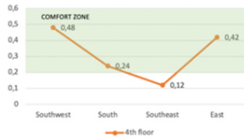
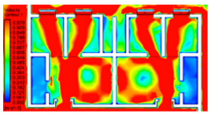
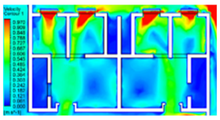
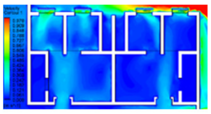
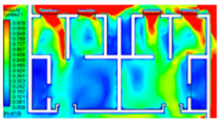
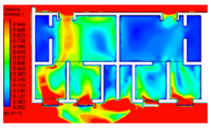
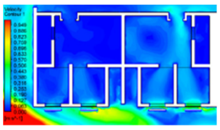
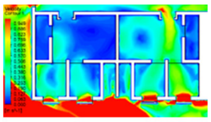
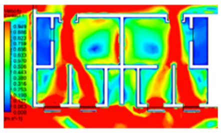
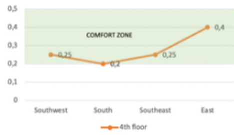
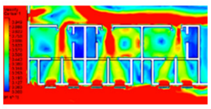
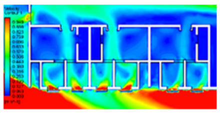
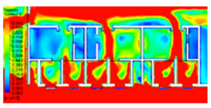
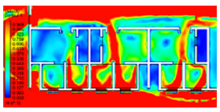
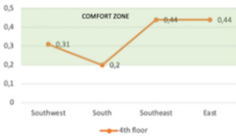
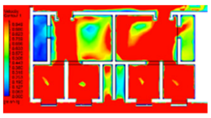
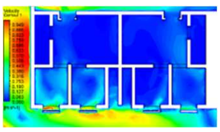
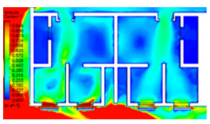
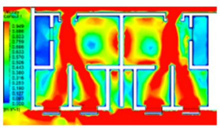
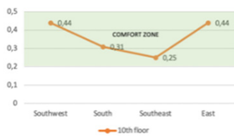
Tower	Floor	Unit	Simulation	Result	Standard
A	4th	1	 Southwest  South  Southeast  East	Window 1 	Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.45 m/s
		2	 Southwest  South  Southeast  East	Window 1 	Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.45 m/s
		3	 Southwest  South  Southeast  East	Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.45 m/s
		4	 Southwest  South  Southeast  East	Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.45 m/s
	10th	1	 Southwest  South  Southeast  East	Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.46–0.54 m/s

Table 11. *Cont.*

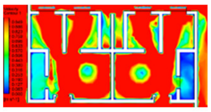
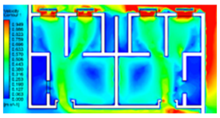
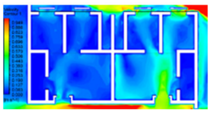
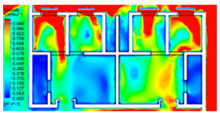
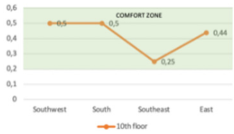
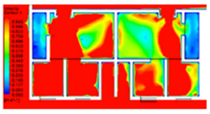
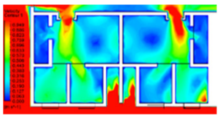
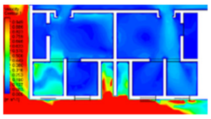
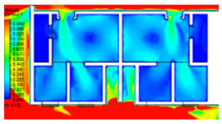
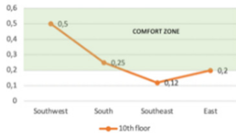
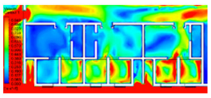
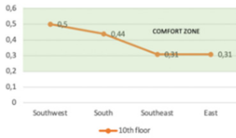
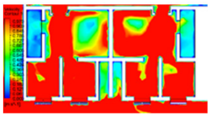
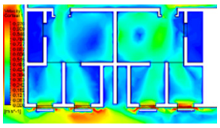
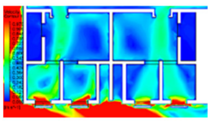
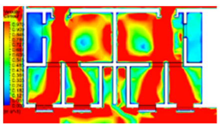
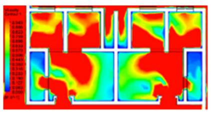
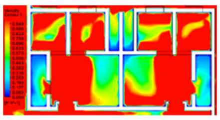
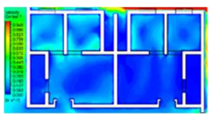
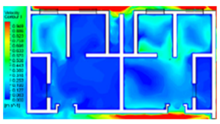
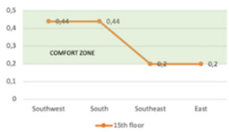
Tower	Floor	Unit	Simulation	Result	Standard
		2	 Southwest  South  Southeast  East	Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.46–0.54 m/s
		3	 Southwest  South  Southeast  East	Window 3 	Theory: 0.2–0.6 m/s Macfarlane: 0.46–0.54 m/s
		4	 Southwest  South  Southeast  East	Window 3 	Theory: 0.2–0.6 m/s Macfarlane: 0.46–0.54 m/s
	15th	1	 Southwest  South  Southeast  East	Window 1 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.46 m/s
		2	 Southwest  South  Southeast  East	Window 3 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.46 m/s

Table 11. *Cont.*

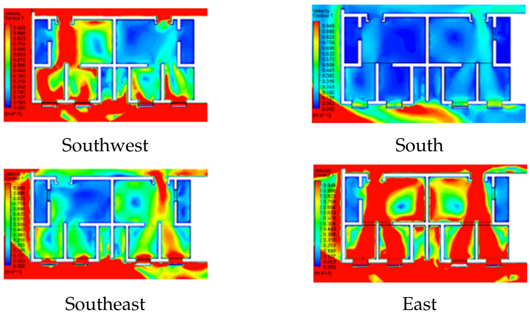
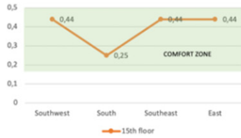
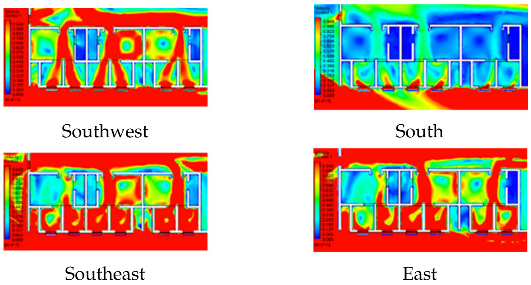
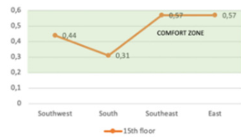
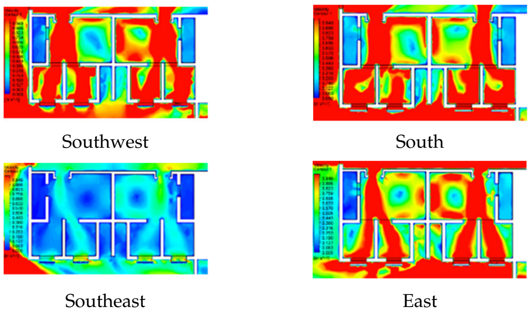
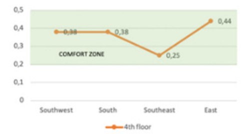
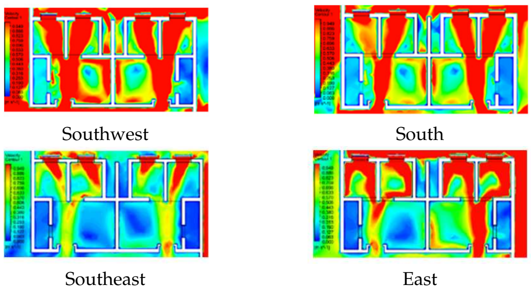
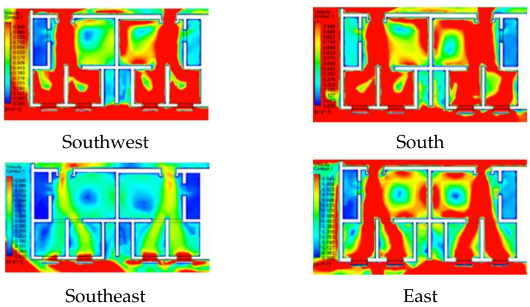
Tower	Floor	Unit	Simulation	Result	Standard
		3		Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.46 m/s
		4		Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.46 m/s
		1		Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.54 m/s
B	4th	2		Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.54 m/s
		3		Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.54 m/s

Table 11. *Cont.*

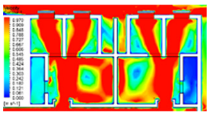
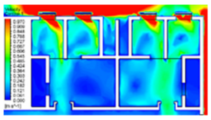
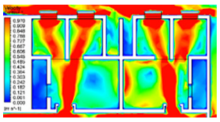
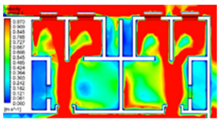
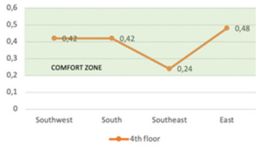
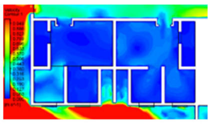
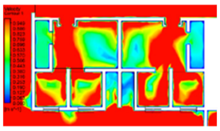
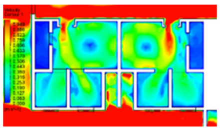
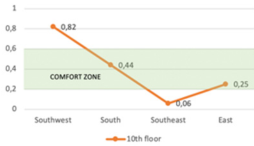
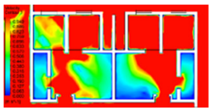
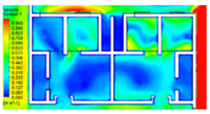
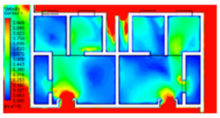
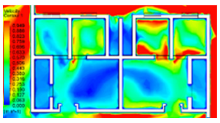
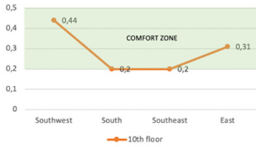
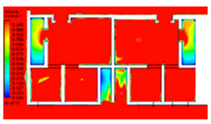
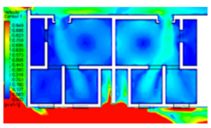
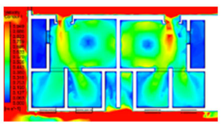
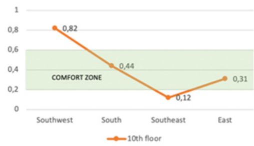
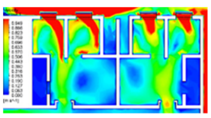
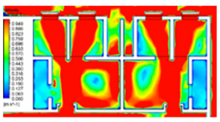
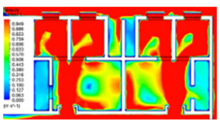
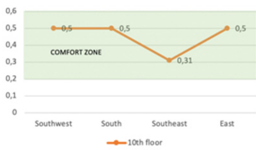
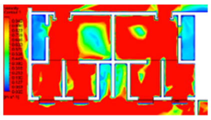
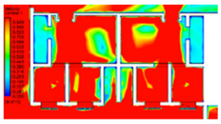
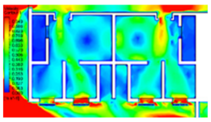
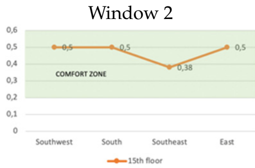
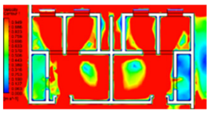
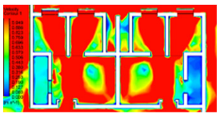
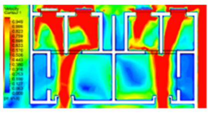
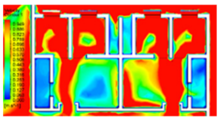
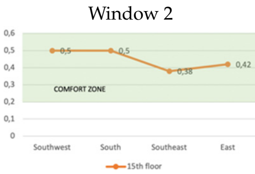
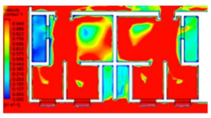
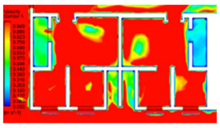
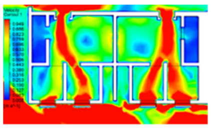
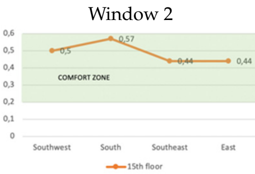
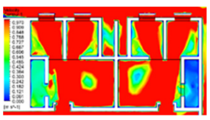
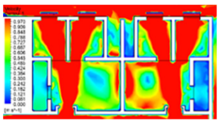
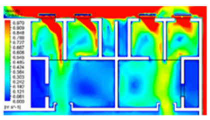
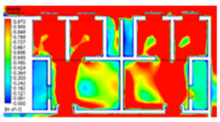
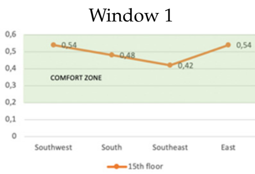
Tower	Floor	Unit	Simulation		Result	Standard
		4	 Southwest  Southeast	 South  East	Window 1 	Theory: 0.2–0.6 m/s Macfarlane: 0.29–0.54 m/s
		1	 Southwest  Southeast	 South  East	Window 3 	Theory: 0.2–0.6 m/s Macfarlane: 0.36–0.38 m/s
		2	 Southwest  Southeast	 South  East	Window 3 	Theory: 0.2–0.6 m/s Macfarlane: 0.36–0.38 m/s
	10th	3	 Southwest  Southeast	 South  East	Window 3 	Theory: 0.2–0.6 m/s Macfarlane: 0.36–0.38 m/s
		4	 Southwest  Southeast	 South  East	Window 2 	Theory: 0.2–0.6 m/s Macfarlane: 0.36–0.38 m/s

Table 11. *Cont.*

Tower	Floor	Unit	Simulation	Result	Standard
B	15th	1	 Southwest  South  Southeast  East		Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.57 m/s
		2	 Southwest  South  Southeast  East		Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.57 m/s
		3	 Southwest  South  Southeast  East		Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.57 m/s
		4	 Southwest  South  Southeast  East		Theory: 0.2–0.6 m/s Macfarlane: 0.41–0.57 m/s

The simulation results indicate that the window dimensions could be determined horizontally based on the unit position within the building layout, wind direction, air velocity, and the elevation of the residential unit. Data interpolation was carried out in the next step to validate the horizontal mapping and the repetition of the window dimensions on the 4th and 15th floors.

3.4. Window Dimensions: Vertical Mapping

The data interpolation aimed to validate the results of the horizontal mapping and determine the air movement that occurred on all floors of the residential units. The data interpolation consisted of two stages. The first stage aimed to determine the range of the repetition of the vertical window dimensions. In contrast, the second stage aimed to validate the repetition range of the window dimensions generated by the first stage of data interpolation. The first stage of data interpolation used data on the height of each residential floor (in the case of the Jatinegara Barat flats, the initial residential floor is the 3rd floor) and the air movement generated by the simulations on the measured floors (4th floor, 10th floor, and 15th floor).

The first stage showed that the window dimensions were repeated every four floors, i.e., floors 3 to 6 had larger window dimensions than floors 7 to 10 and had the same window dimensions as floors 11 to 16. Floors 15 to 16 had the same window dimensions as floors 7 to 10, as shown in Table 12; however, due to the limitation of the construction costs of the flats, the window dimensions on floors 15 and 16 were the same as those on floors 11 to 14, with the condition of air movement within the comfort zone.

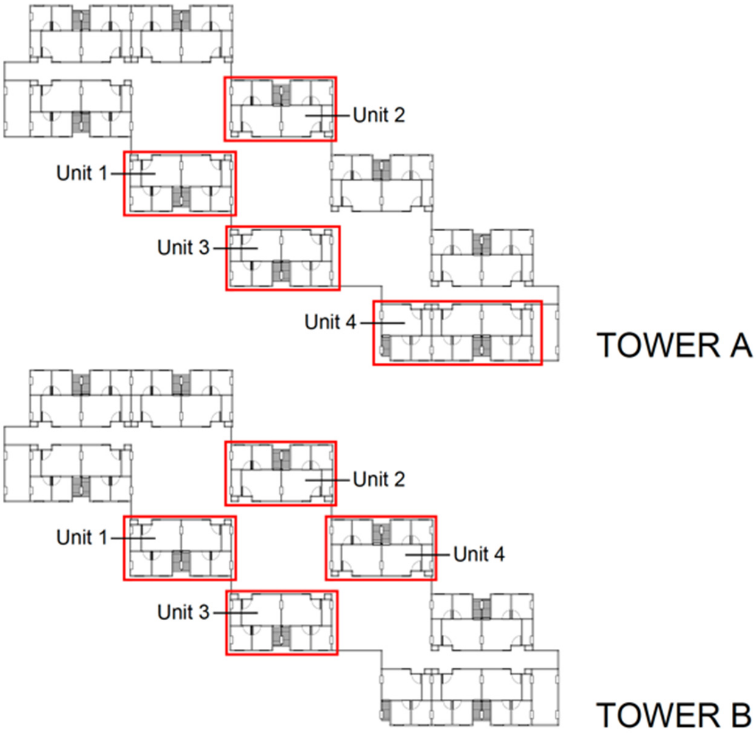


Figure 10. Residential unit numbers in the simulation.

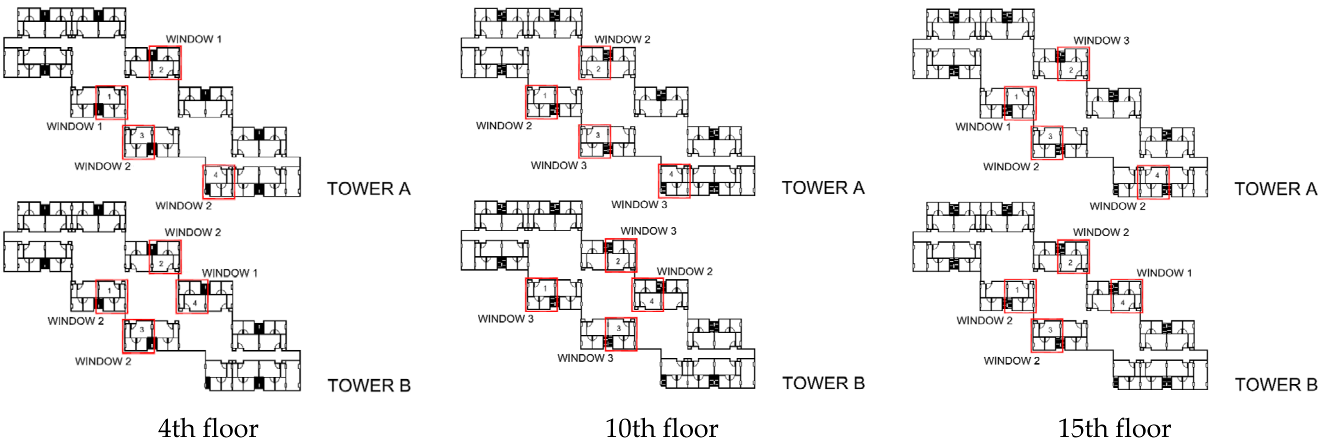


Figure 11. The horizontal mapping of the window dimensions.

Table 12. First-phase data interpolation results.

Tower	Unit 1	Window 1	Window 2	Window 3	Air Movement (m/s)
A	Southwest	Floors 3–6 and 11–16	Floors 7–10	–	0.46–0.6
	South	Floors 3–6 and 11–16	Floors 7–10	–	0–0.3
	Southeast	Floors 3–6 and 11–16	Floors 7–10	–	0.2–0.3
	East	Floors 3–6 and 11–16	Floors 7–10	–	0.33–0.41
	Unit 2	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
	Southwest	Floors 3–6	Floors 7–10	Floors 11–16	0.4–0.5
	South	Floors 3–6	Floors 7–10	Floors11–16	0.2–0.4
	Southeast	Floors 3–6	Floors 7–10	Floors 11–16	0–0.2
	East	Floors 3–6	Floors 7–10	Floors 11–16	0.2–0.4
	Unit 3	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
	Southwest	–	Floors 3–6 and 11–16	Floors 7–10	0.2–0.5
	South	–	Floors 3–6 and 11–16	Floors 7–10	0.29–0.37
	Southeast	–	Floors 3–6 and 11–16	Floors 7–10	0
	East	–	Floors 3–6 and 11–16	Floors 7–10	0.23–0.45
	Unit 4	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
	Southwest	–	Floors 3–6 and 11–16	Floors 7–10	0.3–0.6
	South	–	Floors 3–6 and 11–16	Floors 7–10	0.2–0.3
	Southeast	–	Floors 3–6 and 11–16	Floors 7–10	0.2–0.6
	East	–	Floors 3–6 and 11–16	Floors 7–10	0.2–0.54
Tower	**Unit 1**	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
B	Southwest	–	Floors 3–6 and 11–16	Floors 7–10	0.4–0.8
	South	–	Floors 3–6 and 11–16	Floors 7–10	0.5–0.6
	Southeast	–	Floors 3–6 and 11–16	Floors 7–10	0.2–0.3
	East	–	Floors 3–6 and 11–16	Floors 7–10	0.25–0.48
	Unit 2	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
	Southwest	–	Floors 3–6 and 11–16	Floors 7–10	0.3–0.5
	South	–	Floors 3–6 and 11–16	Floors 7–10	0.3–0.5
	Southeast	–	Floors 3–6 and 11–16	Floors 7–10	0.3–0.4
	East	–	Floors 3–6 and 11–16	Floors 7–10	0.3–0.6
	Unit 3	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
	Southwest	–	Floors 3–6 and 11–16	Floors 7–10	0.4–0.9
	South	–	Floors 3–6 and 11–16	Floors 7–10	0.5–0.6
	Southeast	–	Floors 3–6 and 11–16	Floors 7–10	0
	East	–	Floors 3–6 and 11–16	Floors 7–10	0.28–0.44
	Unit 4	**Window 1**	**Window 2**	**Window 3**	**Air Movement (m/s)**
	Southwest	Floors 3–6 and 11–16	Floors 7–10	–	0.4–0.5
	South	Floors 3–6 and 11–16	Floors 7–10	–	0.3–0.5
	Southeast	Floors 3–6 and 11–16	Floors 7–10	–	0.2–0.33
	East	Floors 3–6 and 11–16	Floors 7–10	–	0.4–0.54

The results from the first-phase data interpolation showed the occurrence of air movement that was not within the comfort zone due to the repetition of the window dimensions every four floors, namely, unit 1 in tower A with a southerly wind direction, unit 2 in tower A with a southeasterly wind direction, unit 3 in tower A with a southeasterly wind direction, unit 1 in tower B with a southwesterly wind direction, and unit 3 in tower B with a southwesterly or southeasterly wind direction. Therefore, to validate the horizontal mapping and repetition generated by the first-phase data interpolation, a second interpolation was carried out using the measured floor height data and the simulated air movement generated by the first-phase data interpolation on the measured floors and selected window dimensions, as shown in Table 13.

Table 13. Second-phase data interpolation: basic data.

Tower	Floor	Unit	Window	Air Movement (m/s)			
				Southwest	South	Southeast	East
A	4th	1	1	0.47	0.2	0.1	0.36
		2	1	0.4	0.2	0	0.4
		3	2	0.3	0.29	0	0.38
		4	2	0.3	0.2	0.26	0.29
	10th	1	2	0.6	0	0.2	0.41
		2	2	0.5	0.3	0.2	0.3
		3	3	0.5	0.33	0	0.23
		4	3	0.6	0.2	0.24	0.23
	15th	1	1	0.45	0.3	0.3	0.47
		2	3	0.5	0.4	0	0.2
		3	2	0.4	0.37	0	0.45
		4	2	0.5	0.3	0.6	0.52
B	4th	1	2	0.48	0.5	0.2	0.42
		2	2	0.4	0.4	0.3	0.5
		3	2	0.4	0.49	0	0.44
		4	1	0.4	0.3	0.19	0.42
	10th	1	3	0.8	0.6	0.2	0.29
		2	3	0.3	0.3	0.3	0.3
		3	3	0.9	0.61	0	0.3
		4	2	0.5	0.5	0.33	0.49
	15th	1	2	0.48	0.5	0.3	0.48
		2	2	0.5	0.5	0.4	0.5
		3	2	0.5	0.58	0	0.44
		4	1	0.5	0.5	0.31	0.53

The second-phase data interpolation shows that the air movement that occurred on the 3rd floor to the 16th floor was within the comfort zone according to academic standards and the Macfarlane calculations, except for unit 3 in both tower A and tower B with a southeasterly wind direction, which showed air movement of 0 m/s. The second-phase data interpolation results show that overall, the air movement in the units was in the range of 0.2 to 0.6 m/s, with air movement in tower A ranging from 0.2 to 0.52 m/s and air movement in tower B ranging from 0.2 to 0.62 m/s, as shown in Figure 12.

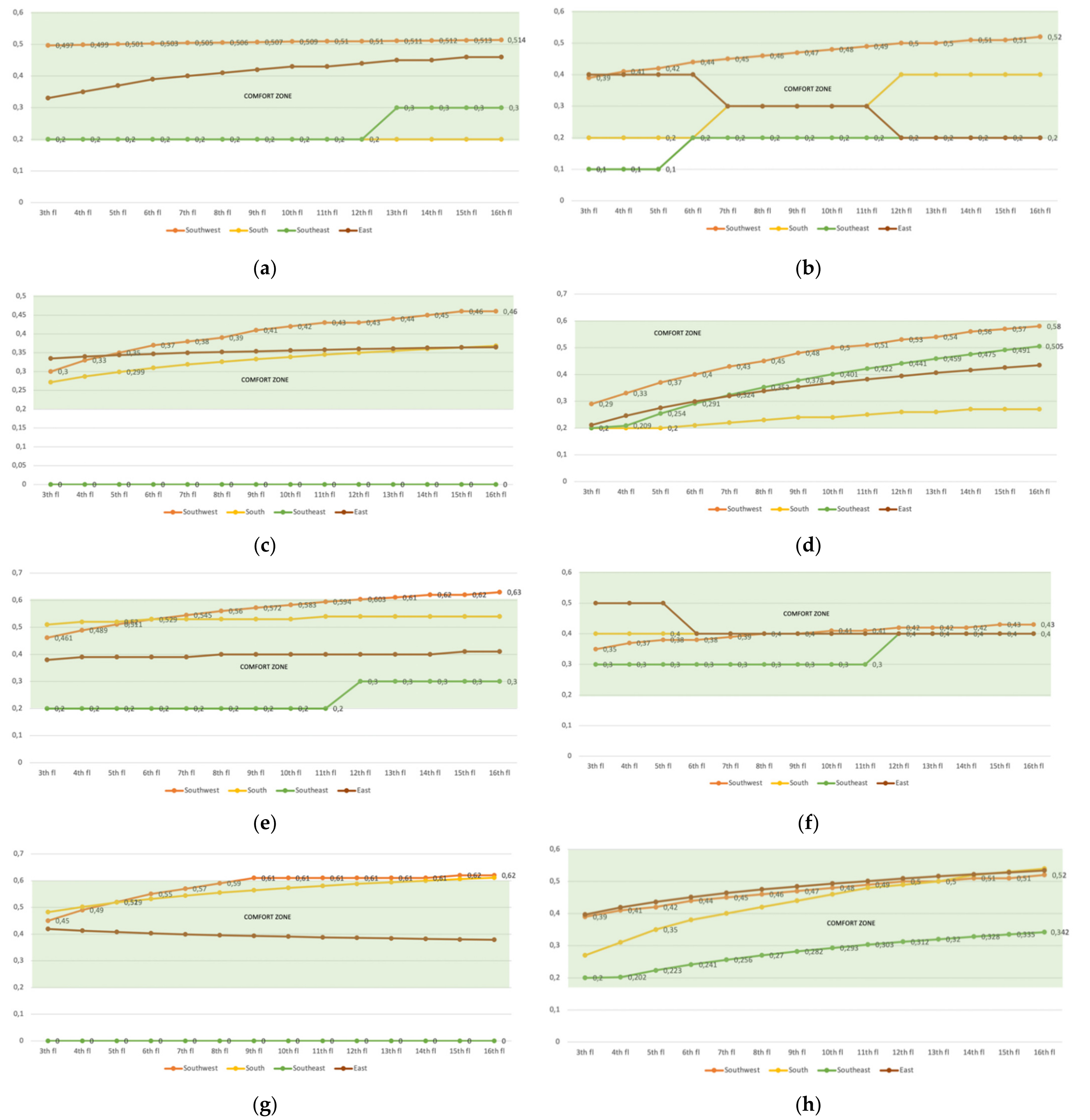


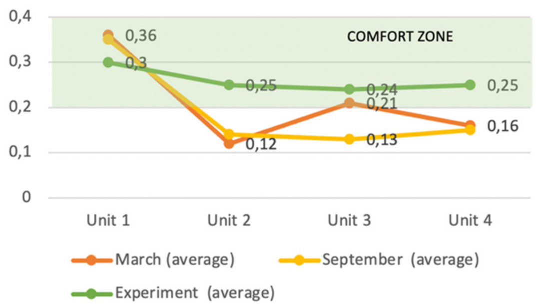
Figure 12. Second-phase data interpolation results: (**a**) unit 1—tower A; (**b**) unit 2—tower A; (**c**) unit 3—tower A; (**d**) unit 4—tower A; (**e**) unit 1—tower B; (**f**) unit 2—tower B; (**g**) unit 3—tower B; (**h**) unit 4—tower B.

4. Discussion

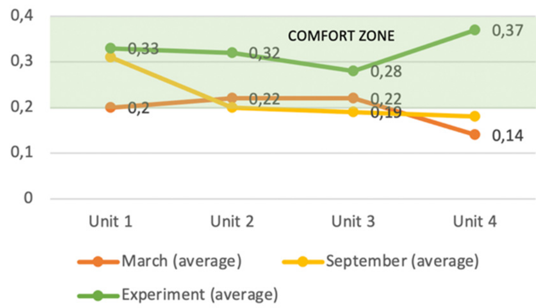
The final results from each analysis process, i.e., both the mathematical and simulation methods, showed consistent results and supported each other. The final results showed that the window dimensions were repeated every four floors, with the window dimensions of the top floor being repeated for six floors. The consistency of the results from each method was as follows:

- The results of the comparison of the first-phase data interpolation (with simulated air movement) in the southwesterly direction with the control variable showed that the air movement was predominantly within the comfortable limit, with the lowest air movement being 0.2 m/s and the highest being 0.6 m/s. In the simulated sections of units 1 and 3 in tower B on floors 7 to 10, the air movement exceeded the standard; however, the second-phase data interpolation showed that the speed reduced to 0.39–0.63 m/s;
- The results of the comparison of the first-phase data interpolation in the southerly direction with the control variable showed that the air movement was predominantly within the comfortable limit, with the lowest air movement being 0.2 m/s and the highest being 0.61 m/s. The second-phase data interpolation showed that the air movement stayed within the same range, namely 0.2 to 0.61 m/s;
- The comparison results of the first-phase data interpolation in the southeasterly direction with the control variable showed that the air movement was predominantly within the comfortable limit, with the lowest air movement being 0 m/s and the highest being 0.6 m/s. The second-phase data interpolation showed that the air movement was reduced and stayed within the comfort zone, i.e., 0.2 to 0.505 m/s;
- The comparison results of the first-phase data interpolation in the easterly direction with the control variable showed that the air movement was predominantly within the comfortable limit, with the lowest air movement being 0.2 m/s and the highest being 0.6 m/s; however, the second-phase data interpolation showed that the air movement was lower, i.e., 0.2 to 0.534 m/s.

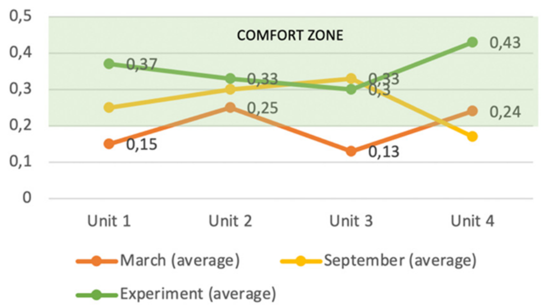
The comparison data for the southwest, south, southeast, and east directions showed that the air movement produced by the experiments (simulations and mathematical calculations) was better than the existing conditions (average air movement for March and September) as shown in Figure 13.



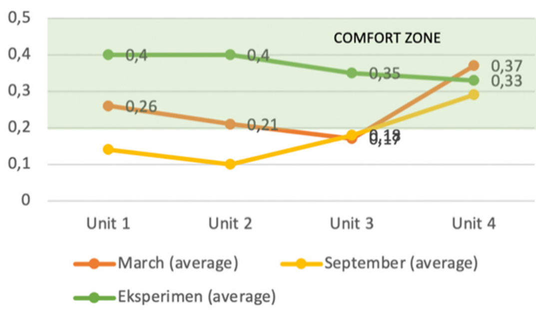
(**a**)



(**b**)

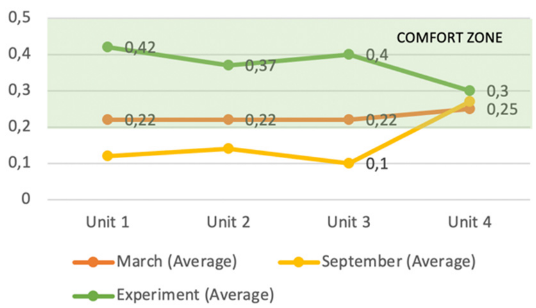


(**c**)

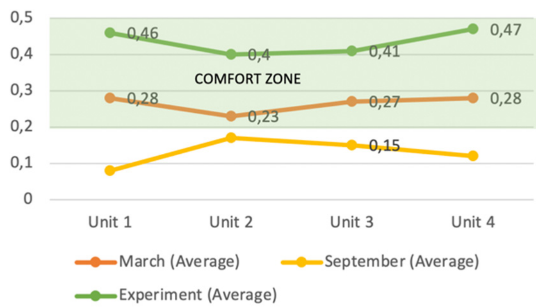


(**d**)

Figure 13. *Cont*.



(**e**)



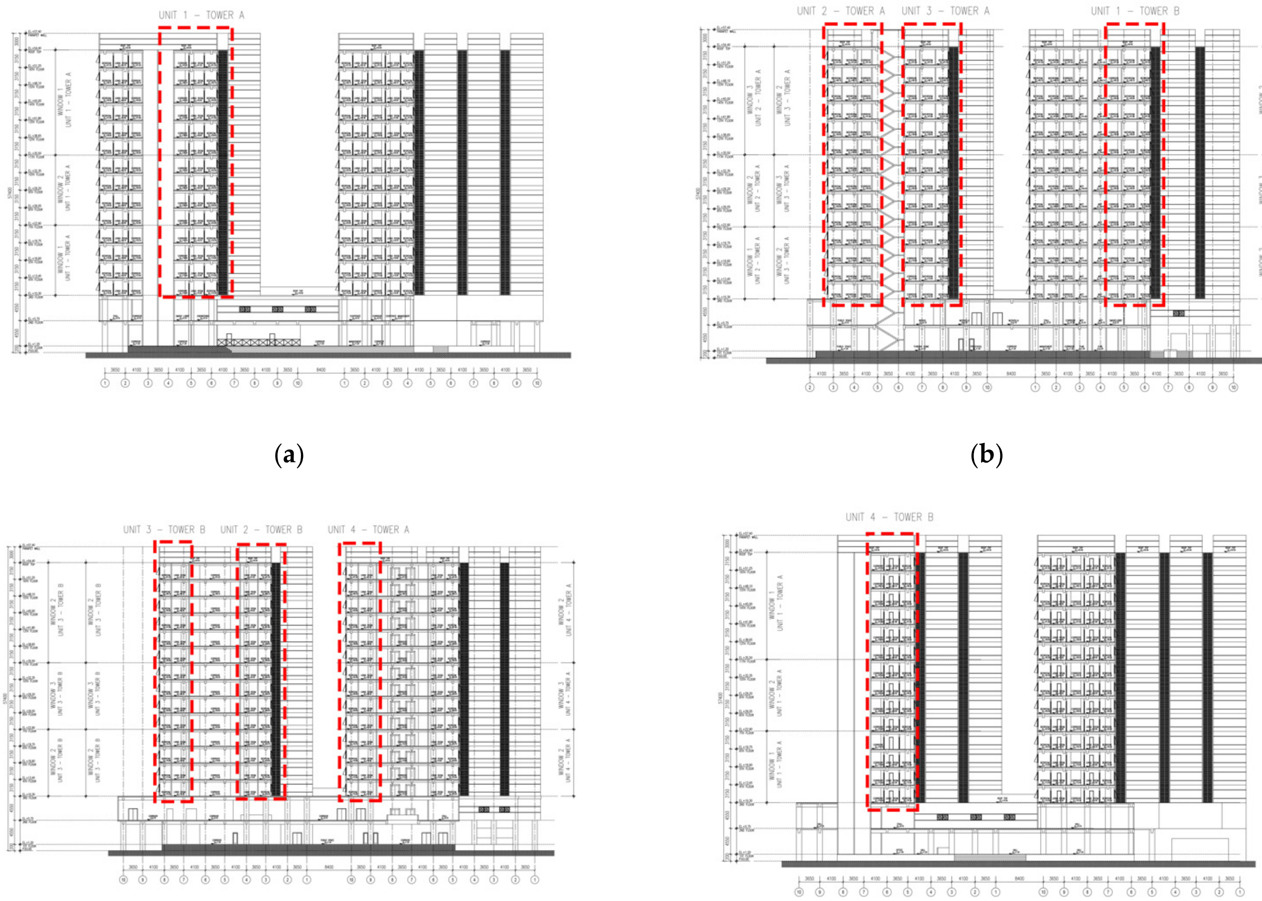
(**f**)

Figure 13. Comparison of the field measurement and experimental results: (**a**) 4th floor—tower A; (**b**) 10th floor—tower A; (**c**) 15th floor—tower A; (**d**) 4th floor—façade B; (**e**) 10th floor—tower B; (**f**) 15th floor—tower B.

Based on the results of the experiments using mathematical methods and CFD Ansys, the design for window dimensions on the facades of high-rise buildings (in this study, the Jatinegara Barat flats) must pay attention to several things, namely:

- Building placement;
- Wind direction (records are needed for at least the last three years to establish the dominant wind direction);
- The actual air velocity at measured altitudes (not only at an altitude of ±9.14 m);
- The elevation of the residential units.
- For the vacant land, the layout of buildings around the planned location provides the existing conditions. The layout of buildings is a factor that aims to create a comfortable wind flow around the buildings so that the air movement inside the buildings is within the comfort zone. For land that already has buildings, the layout of the existing buildings provides the existing conditions. Buildings affect the direction of wind that hits the buildings. The building placement also needs to consider the orientation of the buildings with respect to the direction of wind and sun, which affects the thermal conditions of the residential units [31,55–57].

The building placement, direction of the wind, actual wind speed, and measured height are the four main factors because they are directly related to the pressure that affects the wind around buildings. In addition, these four factors affect the formation of negative and positive pressure areas around the inlets and outlets. This pressure affects the wind density and suction areas. The final results of this study show that the window dimensions on the 10th floor were one-quarter smaller than those on the 4th and 15th floors. The window dimensions were repeated every four floors. In addition, the window dimensions of the units that had inlets facing away from the direction of the wind were different; namely, the window dimensions on the 4th floor were one-quarter larger than those on the 10th floor and the window dimensions on the 10th floor were one-quarter smaller than those on the 15th floor as the window dimensions were repeated every 4 floors (10th floor < 4th floor = 15th floor), as shown in Figure 14. Based on the final results, the initial hypothesis stating that window dimensions are reduced depending on the position of the window with respect to the direction of the wind, the layout of the building, the actual wind speed, and the elevation of the residential unit was proven correct.



(**a**) (**b**)

(**c**) (**d**)

Figure 14. The vertical mapping of the window dimension: (**a**) Unit 1 in tower A; (**b**) Unit 2, 3 in tower A and unit 1 in tower B; (**c**) unit 3 in tower B, unit 2 in tower B, and unit 4 in tower A; (**d**) unit 4 in tower B.

Determining the window dimensions on flats' facade (which is the function of the object of study used) in the planning of new buildings can increase the quality of the room through the layout of the room. This increase occurs because the dimensions of the window affect the location of the walls and doors in the inner room so that each part of the building (windows, doors, and walls) supports each other to form of a thermal comfort zone in the interior through cross ventilation (this statement is the basis for hypotheses in further research). In contrast to the new building, the determination of the window dimensions on the facade of the old building can improve the quality of the room by adjusting the window dimensions to the existing layout. The layout of the walls and doors cannot be changed.

5. Conclusions

The problem with the Jatinegara Barat high-rise flats is that the performance of the windows on the building's facade is not optimal. The leading cause of this sub-optimal window performance is the window dimensions, which cannot accommodate the air velocity around the building. The main concern with high-rise buildings is the gradation of air velocity around the buildings due to different pressures at specific heights.

In the case of the Jatinegara Barat flats, the location of the building forms a wind tunnel between the two towers, meaning that pressure differences occur in the wind tunnel area. In the field measurements, the air velocity in the wind tunnel area was the highest at the 10th floor. The height of the 10th floor was used as the specific height for the center area of the building when viewed vertically. The highest speed at the 10th floor showed that the streamline was closer and provided a pressure difference, with the air velocity at the 10th floor being higher than that at the 15th floor.

The mathematical methods and simulations showed that the window dimensions could be read horizontally and vertically. The horizontal mapping showed a relationship between the locations of the residential units with respect to the wind direction and the building layout. The horizontal mapping of the window dimensions also showed the following results:

- Units located at the end of the wind tunnel had the same window dimensions (unit 1 in tower A and unit 4 in tower B);
- Units located in the wind tunnel area had the same window dimensions (unit 3 in tower A, unit 4 in tower A, and unit 2 in tower B);
- Units facing the urban area and the direction of the wind had the same window dimensions (unit 1 and unit 3 in tower B);
- Units facing the urban area and facing away from the direction of the wind had the same window dimensions but were different from those of the units in the wind tunnel and the units facing the urban area and the direction of the wind (unit 2 in tower A).

The vertical mapping showed that the horizontal mapping is the basis for vertical mapping. The vertical mapping showed that the window dimensions were repeated every four floors, i.e., the window dimensions on the 4th floor were the same as the window dimensions on the 3rd floor to 6th floor and the 11th floor to 16th floor, and the window dimensions on the 10th floor were the same as the window dimensions on the 7th floor to the 9th floor. The vertical mapping showed a relationship between the locations of the residential units, the elevation of the residential units, and the actual wind speed that occurred around the facade of the residential units.

The final results showed that the windows on the 10th floor were one-quarter smaller than those on the 4th and 15th floors. Knowledge of this tendency to reduce window dimensions could be used for further research that is more specific to the pressure that occurs in the inlet free-area of the window dimensions used. Further research should be carried out to validate the horizontal and vertical window dimension mapping of the Jatinegara Barat flats by mapping other flats with different building shapes and locations. Long-term research aims to obtain a new formula that can be used as a calculation tool and a planning concept for flats that accounts for the surrounding environmental conditions. In addition, long-term research can also be carried out with different objects of study such as:

- Office buildings, malls, and other public buildings (objects of study have been built): analysis of window dimensions based on building shape, building thickness, building height, and building user activities;
- Urban (study object has been built): analysis of the existing condition of an area based on the layout of the building part of each existing building function, changes in the thermal condition of the area (urban heat island issue) through changes in window dimensions, and the window layout of each existing building function;
- Vernacular: window dimension analysis based on the shape and position of the window (height and location). Several traditional Indonesian houses have sloping walls, so the window angle is also crucial in this case.

This research will provide benefits to several related parties, such as:

- Researchers, as a starting point for knowledge about the pattern of window dimensions in high-rise buildings that is focused on wind, especially high-rise flats;
- Academics, as a basic idea that can be used for the development of science, especially in the fields of building comfort science, building physics, building technology, and environmental engineering;
- Practitioners, as a reference and basic conception in the design of a high-rise residential building;
- Stakeholders, as a basis of reference, which can be used in developing standards used in high-rise buildings.

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