Investigating natural ventilation performance on apartment units in Jakarta based on field test measurements

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The COVID-19 pandemic has changed the way of living of many people across the planet. In the beginning of the pandemic, when the strict lockdown was implemented, numbers of individual were encouraged to work from home. In the city living, high rise living was apparent and became a global phenomenon. This paper evaluates natural ventilation performances of existing apartment units in Jakarta, Indonesia by measuring the indoor temperature, indoor airflow and relative humidity. This research studied three different apartment units in Jakarta in the form of single-sided ventilation or cross ventilation. This study conducted by field test measurement on three different apartment units across Jakarta with various natural ventilation strategy and room volume. Statistical analysis was carried out to investigate the relationship and influence between the results of field test measurement and external weather data collected from ERA5. The results of the analysis suggested that external weather influence the indoor air condition, especially indoor temperature where significant influence was apparent. Furthermore, the field test data measurement in this paper contributed to validation study in predicting indoor airflow.

Keywords: high-rise residential buildings, natural ventilation, field test measurements, indoor airflow, statistics

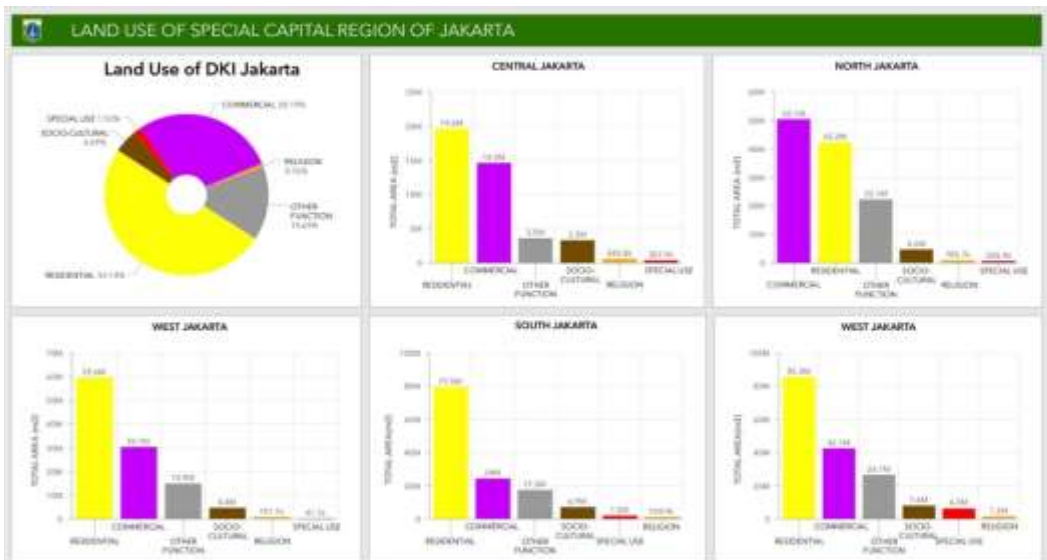
1. INTRODUCTION

Over the past few decades (1971-2013), the world's energy consumption has increased by more than 50 percent (Liping and Hien, 2007; Ljungberg, 2007; International Energy Agency, 2019), primarily due to population and economic growth [3]. This rapid increase in non-renewable energy consumption is costly and harmful to the environment (greenhouse gas emissions, climate change, global warming). Building maintenance and operation consume 20%–40% of global energy (Pérez-Lombard, Ortiz and Pout, 2008). In the case of South Asian countries, space cooling takes up a larger part of the energy use in buildings (International Energy Agency, 2019) and are expected to use 50% more by 2100 (Isaac and van Vuuren, 2009). Many countries' building regulations prioritise energy efficiency due to high energy consumption and greenhouse gas emissions (Pérez-Lombard, Ortiz and Pout, 2008; Belussi *et al.*, 2019; Chen *et al.*, 2019). Passive cooling and heating in cooling- and heating-dominant climates can reduce HVAC energy use.

High rise buildings have densified cities due to economic growth and population growth (Al-Kodmany, 2018). These buildings are energy-intensive because they ignore passive strategies for local climate (Kennedy, Buys and Miller, 2015). Thus, effective passive design strategies for space heating and cooling can save energy in multi-storey buildings. High-rise buildings or some called it 'skyscrapers' has been a construction trend since the emergence of steel structure in late 19th century. Nowadays, the skyscrapers have covered many megapolitan cities such as Hong Kong, New York City, Tokyo, Shanghai, etc. like a concrete jungle. Such high-rise buildings comprise of commercial, service, and residential buildings. However, compared to aforementioned major cities, the capital of Indonesia, Jakarta; and the capital of Malaysia, Kuala Lumpur; there still are many low-rise housing settlements in the city centre among the later constructed high rise apartment. Megapolitan cities such as Hong Kong, New York City, Tokyo, Shanghai, etc. have been familiar with the scenery of skyscrapers. Many of the people live in high rise apartments due to the lack of housing space (Yeh and Yuen, 2011). Emerging economic countries such as Indonesia and Malaysia started to follow suit in developing high rise residential buildings in their major cities (Wiryomartono, 2020). Although the phenomenon was similar, there are a plethora of other aspects that are different from each city, namely the urban situation and the climatic condition.

Passive design strategy, including natural ventilation, passive solar energy applications, thermal mass, etc., can reduce total energy use by more than 50% (Feist *et al.*, 2005). Natural ventilation is air exchange between indoor and outdoor environments without mechanical assistance like ventilation fans and cooling. Natural ventilation can improve thermal comfort and indoor air quality by replacing used air with fresh air (Etheridge and Sandberg, 1996; Etheridge, 2011). Natural ventilation saves energy and money compared to mechanical ventilation because it requires no maintenance and uses no energy (Aynsley, 2014). Buildings with natural ventilation aim at achieving three main objectives: indoor air quality, thermal comfort, and energy savings (Germano, Ghiaus and Routlet, 2005). Since the virus (SARS-CoV 2) spread by droplets and airborne, the need of good ventilation is important to recirculate the air inside the building with fresh air and to stop the virus remain inside the building and further infecting other people. Various studies explored the role of ventilation during pandemic era (Zheng *et al.*, 2021; Zorzi *et al.*, 2021; Fan *et al.*, 2022; Franceschini and Neves, 2022; Piscitelli *et al.*, 2022)

Despite the different climate and urban typology, the typology of an apartment tower, however, almost have a similar interior layout or the floor plan all over the world. This research selected two most used typologies, namely vertical point, and corridor The selected apartment units were middle class apart unit. One of them was vertical point and two of them was double loaded corridor. Core centre. Vertical point refers to the internal building layout where the circulation core placed in the centre or periphery of the building. The core can house only circulation space or can be designed more generously to incorporate common/shared spaces (e.g., living room/common space as a circulation centre). This type of centre core circulation allowed more privacy for the tenant compared to the second type, namely corridor centre. Often called double-loaded corridor, the corridor centre type provides the circulation on a long and narrow corridor with a linear organization of housing units on both sides. Such type of layout allows the tenant to meet with the neighbours compared to the vertical one. The benefit of such circulation is the efficiency of circulation and the number of housing units facilitated by the elevator or stairs. On the other hand, the challenge of each typology is daylighting and natural ventilation due to the limited exposure of the façade. This research will use the term vertical point type and double-loaded corridor type. Since both types of internal layout do not have more façade thus cross ventilation is relatively difficult to achieve.



(source: (Pemerintah DKI Jakarta, 2020) accessed on 11 Desember 2021)

Figure 1: Jakarta Land Use

According to the report, the land use of Jakarta Province is dominated by residential function by 50.14 % (Figure 1). Among five cities of Jakarta: Central Jakarta, North Jakarta, West Jakarta, South Jakarta, and East Jakarta; almost the land use of all of them were dominated by Residential function, as illustrated in the Figure 1 with yellow colour, except North Jakarta where the commercial use (violet colour) slightly dominated over residential use. Among five cities of Jakarta, the top three cities where residential use dominated the most are West Jakarta, South Jakarta and East Jakarta with 59.6 million m^2, 79.5 million m^2 and 85.3 million m^2, respectively. In this research, one building each from those three cities were selected and they pertained similar urban typology where each apartment building is situated within apartment blocks.

2. METHODOLOGY

For this study, experimental field measurement was carried out to observe the existing conditions of the building units. The results will be compared to the numerical simulation carried out later in the next step to evaluate the effectiveness of the current natural ventilation situation in the given units.

Full-scale measurements were carried out under the given environmental conditions of Jakarta city centre and including the surrounding site. The selected units have been elaborated in the previous section which represents a typical middle-class development in terms of building physics and characteristics. The unit selected was on the halfway up the building – to obtain results characteristic of the middle levels of the selected building which would be more useful in determining the likely conditions on the lower and upper floors as well.

According to a study in Malaysia, on average only 10% of occupants operate air-conditioners during the daytime in living, dining, and study rooms. Moreover, around 80% of occupants usually open windows from 10am to 6pm when they are carrying out activities in the living and dining rooms (Kubota, Chyee and Ahmad, 2009). We, therefore, carried out experimental tests only in the main living area which comprises living, dining, and kitchen. During the measurement period, mechanical ventilation equipment including air-conditioning systems and ceiling fans were switched off. All units were kept vacant during the measurement period in November to December 2021.

To collect on-site weather data including solar radiation, air temperature, wind speed and direction and rainfall; we collected the weather data provided by The European Centre for Medium-Range Weather Forecasts (ECMWF) namely ERA5. Furthermore, the results of field measurements and the weather data from ERA5 were analysed using SPSS to investigate the relationship and influence between variables.

2.1 Experimental apparatus

Due to availability of the apparatus, we conducted the data measurement using several apparatuses. Data loggers were used to record the temperature changing and air velocity during the measurement period. Most data logger only measure temperature and relative humidity in designated interval. Accordingly, to measure the air velocity, a sensor must be plugged into the data logger as well to record the change in air speed in the building. All the data from the sensors was transmitted into data loggers at intervals of 1 minute over a 24-hour period for three days. The recorded data was employed to analyse the influence of outdoor wind speed on indoor airflow velocity. Below are several instruments used to conduct data measurement in this study.

Table 1:Instruments specifications

Apparatus	Specification
Extech 42270 Temperature and Humidity Logger	Temperature range: -40 to 85°C Temperature accuracy: ±0.6°C from -20 to 50°C; ±1.2°C Humidity range and accuracy: 0.0 to 99.9% relative humidity; accuracy ±3%

	
Extech SDL310 Thermo-Anemometer/Datalogger 	Temperature range: 32 tp 122 ‘F (0 tp 50 ‘C), resolution 0.1°, accuracy ±1.5ºF (±0.8ºC) Velocity range: 0.4 to 25 m/s (80 to 4950 fpm) Logger memory: 20,000K data records on 2GB SD card

Figure 2 Aluminum pole

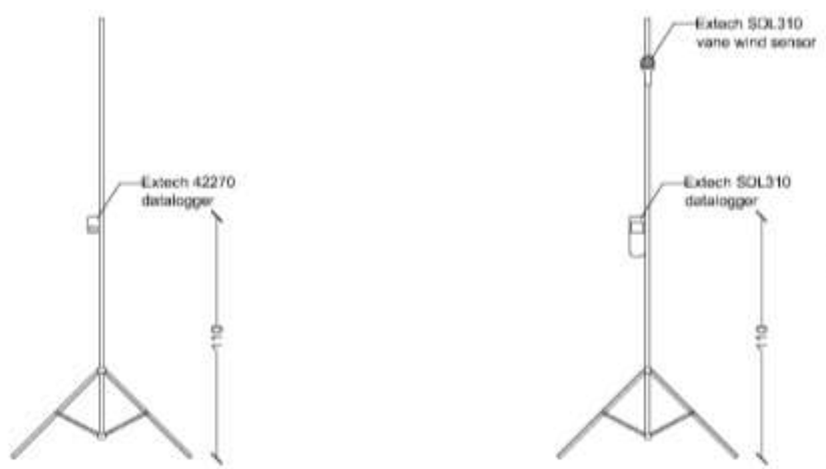


Figure 3 Setup of apparatus on aluminum pole

Aluminium poles (with clamps were set to hold the data loggers (Extech 42270 and SDL 310) and air velocity sensors (Extech SDL310). The thermo-anemometer logger, Extech SDL310 has an air velocity sensor in blade type with aluminium vane. This model capable of measuring wind speed ranges between 0.4 to 25 m/s (Table 1).

As shown in Figure 2, a total of three poles: consists of two temperature data loggers (Extech 42270) and one thermo-anemometer datalogger (SDL 310) were positioned in a range of different positions and elevations within the unit in order to record the indoor air velocity. All the poles were positioned at least 0.8m away from any internal walls to avoid wall effects (Etheridge and Sandberg, 1996). In addition, as shown in Figure 3, the air velocity was measured on the height where human normally would sense the wind speed and temperature change, designated as H, at the height of 0.9m (Tong *et al.*, 2019) to 1.1 m (Aflaki *et al.*, 2019) from the floor surface. Figure 3 illustrates the equipment installed on each pole. Therefore, the air velocity sensor and temperature sensor were placed at 1.5 m high. In addition, the data was used to set the boundary conditions for CFD modelling and to validate the numerical simulations.

3. CASE STUDY

The building case selected for this research were: Taman Rasuna Apartment in Epicentrum, Taman Anggrek Residences in Podomoro City and Viola Tower in Kalibata City Superblock. The following sections described the apartment blocks and elaborated the results of the conducted field measurements.

3.1 Taman Rasuna Apartment

The first object studied is a unit in Taman Rasuna Apartment located in area called Epicentrum in Jalan HR Rasuna Said, RT. 16 / RW. 1, Karet, Setiabudi, South Jakarta, Jakarta 12960. Completed in 1997, this apartment block located in Epicentrum Area consists of not only the apartment complex but also high-rise commercial buildings developed by PT Bakrie Swasakti Utama (BSU). Low-rise settlements and cemetery ground were nearby. Taman Rasuna is an apartment complex consists of 18 towers with average of 22 floors high, adjacent to other high-rise buildings and low-rise buildings as seen on Figure 4. the building highlighted in green is Tower 2. Unit 21 E located in Tower 2 were selected to conduct the field measurement. The unit elevation is around 50 meters from sea level.

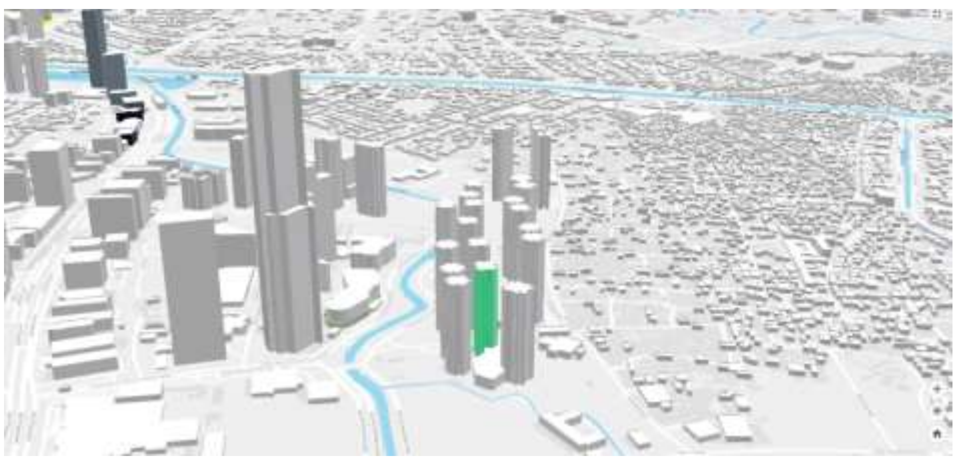


Figure 4: Three-dimensional urban view of Taman Rasuna Apartment Complex

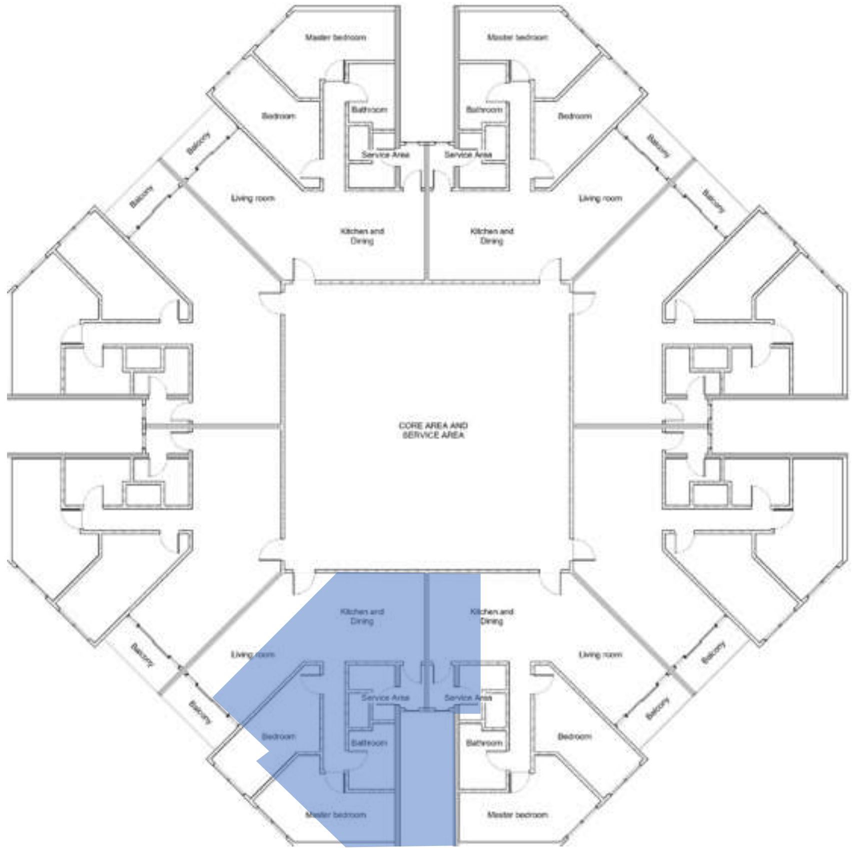


Figure 5: Typical floor plan of Taman Rasuna Apartment

The internal layout typology of every building is vertical point type (Figure 5). The building selected for this case was Tower 2 and will further be called Building Case 1. The apartment unit located in 21nd floor were selected to investigate whether there is a significant difference in air movement characteristics. Figure 6 illustrated the unit consisted of two bedrooms, two bathrooms with one attached to the master bedroom, an open-plan living dining kitchen area and a small storeroom. Almost all the room that accommodate activities had potential natural ventilation because the floor plan of the apartment provided more building envelope to each unit in the floor that enable them to have more window opening that could potentially harness the natural ventilation.

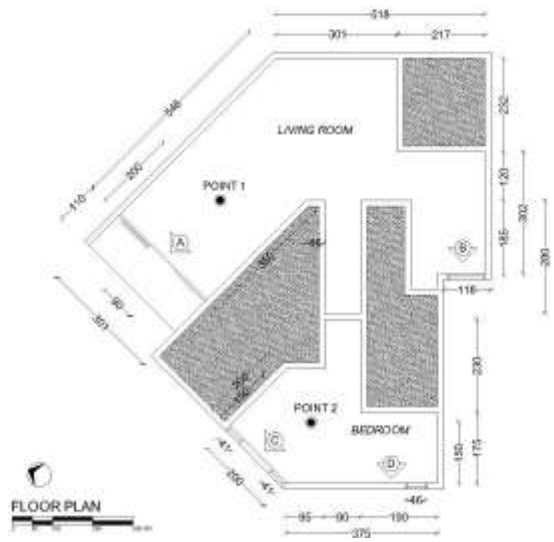


Figure 6: Two-bedroom unit of Taman Rasuna Apartment

The living room and the master bedroom in this unit were selected to conduct field measurements. The living room had bigger opening in the form of sliding door facing balcony (Figure 7) and the kitchen had small awning window (Figure 8), which further referred as opening A and opening B, respectively. Guest bedroom have two windows opening, although it was not included in our research. Master bedroom, however, two set of window openings namely opening C (Figure 9) and opening D (Figure 10). Opening A allowed natural air to enter the living area and the kitchen. Opening B, however, was unable to open during the measurement time. In the case of living area, the opening A and opening B could allow cross ventilation. On the other hand, the opening C and opening D allow cross ventilation in the master bedroom. Therefore, Building Case 1 had potential cross ventilation occurred in the unit.

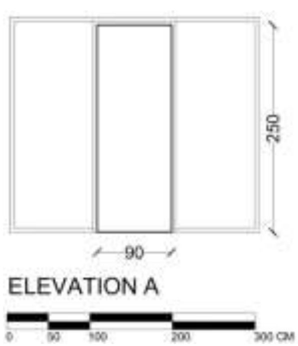


Figure 7 Opening A

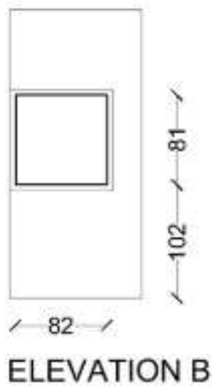


Figure 8 Opening B

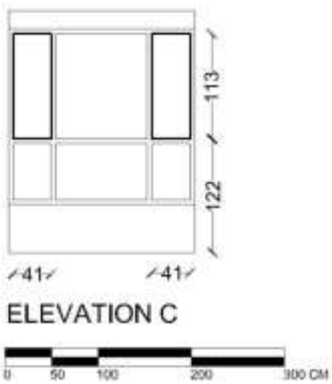


Figure 9 Opening C

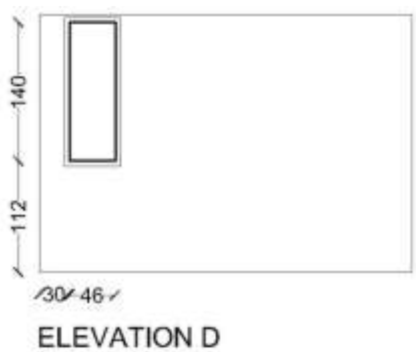


Figure 10:Opening D

3.2 Taman Anggrek Residence

The second location is Taman Anggrek Residences located on the coast of West Jakarta. Located in Jalan Tanjung Duren Timur 2 No.12, RT.12/RW.1, Grogol Petamburan, West Jakarta, Jakarta 11470, the building of study case is also part of an apartment complex like the previous ones. Developed by Agung Sedayu Group, this apartment complex was completed in 2017 consists of six towers namely, Azalea, Beech, Calypso, Daffodil, Espiritu and Fragrant. This apartment is situated in the Podomoro City Superblock. Same as other building cases, the selected tower was also situated among other apartment complex as well as low rise settlements. Each tower amounts to 50 floors and total 740 units. The typology of the apartment is in the shape of double-loaded corridor.

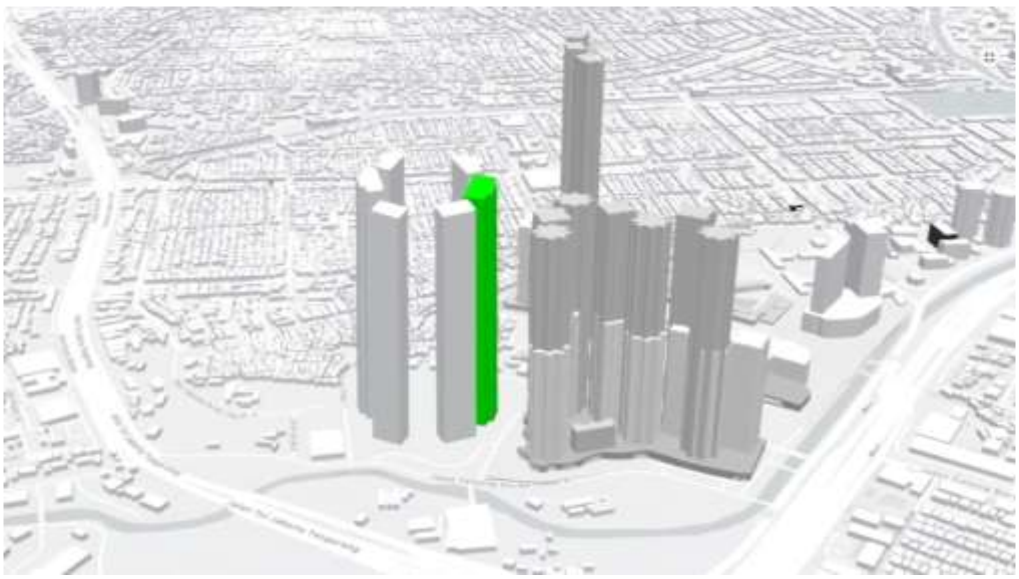


Figure 11: Three dimensional urban view of Taman Anggrek Residences apartment complex

Building Case 2 was a unit located in Tower Fragrant (highlighted building in Figure 11) level 38. The unit 38 E elevation is 120 m above sea level. Similar to Building Case 1, the apartment unit consists of two bedrooms, one bathroom and one living dining kitchen area with adjacent balcony (Figure 12).The unit is a corner unit. The sliding door in the living area (opening A) only allows single-sided ventilation occurs in it. While in the bedroom, the awning windows of opening B and C allow cross ventilation. Therefore, two types of ventilation occurred in the Building Case 2. Measurement took in the living area and the master bedroom.

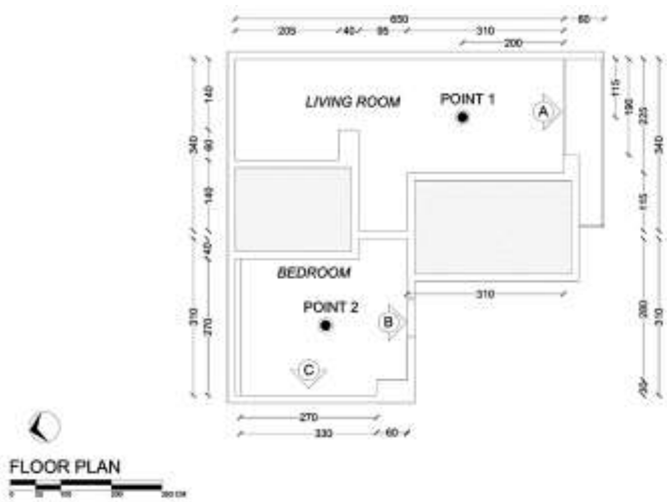


Figure 12 Floor plan of Taman Anggrek Residence Tower Fragrant Unit 38E

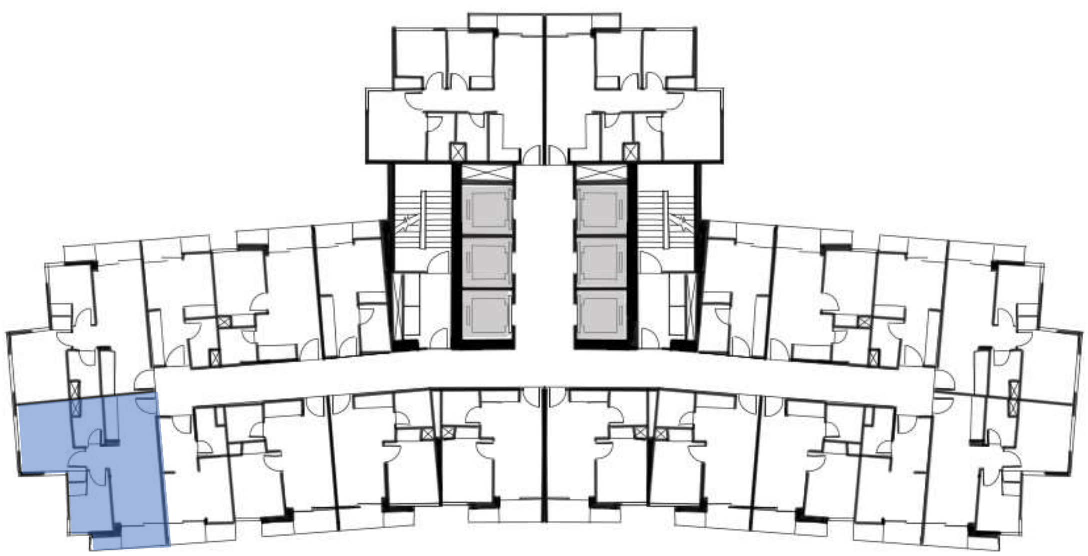


Figure 13 Typical floor plan of Taman Anggrek Residences

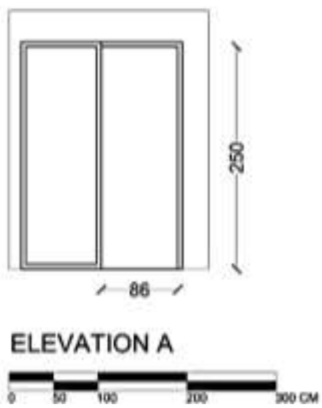


Figure 14 Opening A

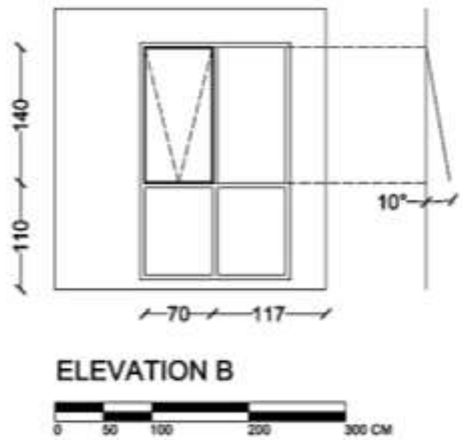
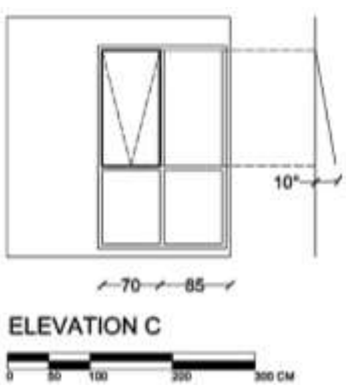


Figure 15 Opening B



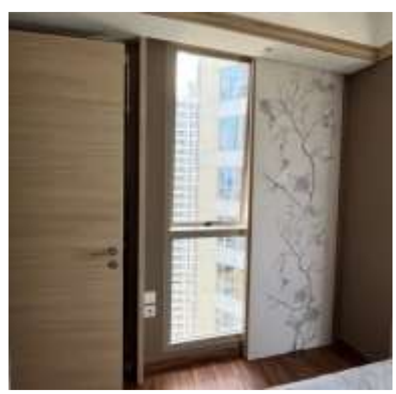


Figure 16 Opening C

3.3 Kalibata City

The third location, which further be mentioned as Building Case 3, was Kalibata City Apartment complex or often referred as Kalibata City superblock located in RT.9/RW.4 Rajawati, Pancoran, South Jakarta City 12750. This apartment complex has almost similar urban typology as Building Case 1, which is surrounded by high rise buildings, low-rise settlements and cemetery ground (Figure 17). The floor layout of Kalibata City apartment building was double-loaded corridor. Unit 17 AD in Tower Viola with total 25 floors were selected for this research. The elevation of the unit was 70 m.

Figure 17 Three-dimensional urban view of Kalibata City superblock

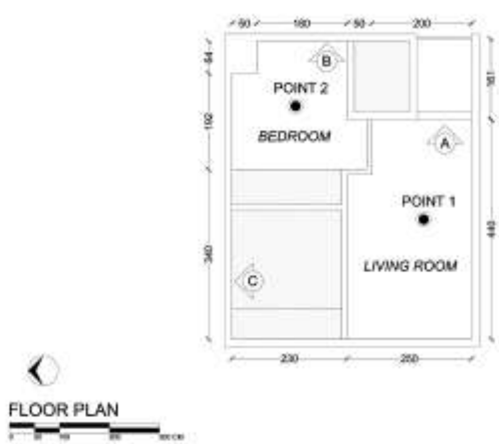


Figure 18 Typical 2-bedroom unit plan

Almost similar to previous building cases, Building Case 3 consists of two bedrooms, one bathroom, and one living dining kitchen area with adjacent balcony. However, unlike the other two, the balcony in this unit served as service area only. The unit was the smallest among three with only 28 m^2 of living area. There are three opening in this unit, opening A facing the balcony was a door (Figure 19), opening B was an awning window in the master bedroom (Figure 20) and opening C was an awning window in the smaller bedroom (Figure 21). Since the measurements were taken places in the living area and master bedroom, only opening A and opening B were taken into account, although, opening C could possessed potential natural ventilation for the living area. During the measurements, the guest bedroom was not separated to the living room by solid wall. Therefore, opening C can allow cross ventilation in the living area. However, since the opening C faced directly to the prevalent wind from the north, it remained closed due to high pressure. Thus, it was not possible to keep the opening C open.

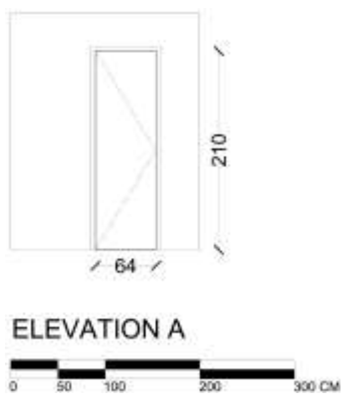


Figure 19 Opening A

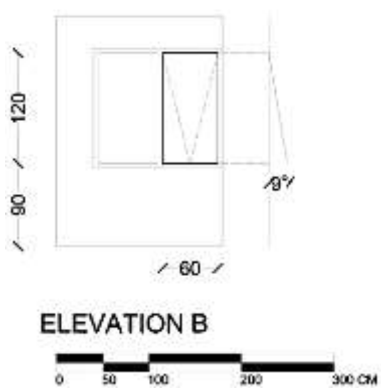


Figure 20 Opening B

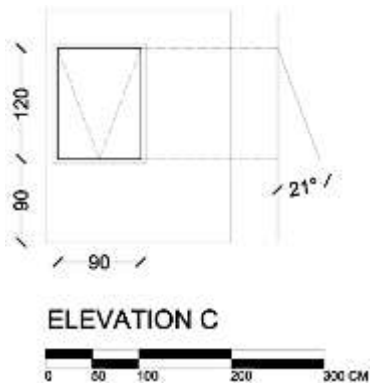


Figure 21 Opening C

4. RESULTS AND DISCUSSION

4.1 The results of field measurements

As mentioned in previous chapter, two set of instruments were placed each in bedroom and living room of the selected units. The instruments were placed at the height 150 cm from the floor and positioned two meters from window for the larger ones (Figure 22,Figure 24 and Figure 26) or in the middle of the room (Figure 23, Figure 25 and Figure 27). Two dataloggers that recorded wind velocity, temperature and relative humidity were set to record for three times 24 hours with 1-minute interval. Having conducted measurement in the living room and master bedroom in each building, there are six rooms measured in total on different time. In total there are over 4000 readings for each room (Table 2).

Figure 22 Instrument took place 2 meter from the opening

Figure 23 Instrument was placed in the middle of the room

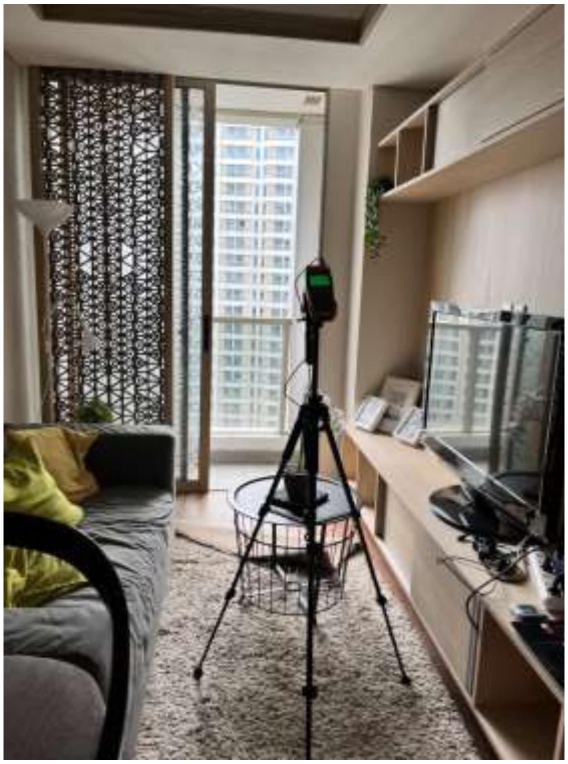


Figure 24 Instrument was placed 2 meter from the window

Figure 25 Instrument was placed in the middle of the room

Figure 26 Instrument was placed 2 meters from the opening

Figure 27 Instrument was placed in the middle of the room

Two instruments were equipped to measure each point, namely Extech 42270 Temperature and Humidity Logger, and Extech SDL310 Thermo-Anemometer/Datalogger. Since both instruments recorded temperature inside the room, the results need to be compared to see whether they both measured the same thing. Figure 28, Figure 29, Figure 30, Figure 31, Figure 32, and Figure 33 illustrated the results of temperature recorded in each point of the buildings measured by two instruments. The line in those graphs suggested that both measurements yielded similar results and the difference were not significant. Therefore, we can conclude that both instruments' tools were valid. Even though, there was slight degree difference between instrument (Figure 33), the graph line of both instruments, however, were similar. It may suggest that one of the instruments needed to be recalibrated.

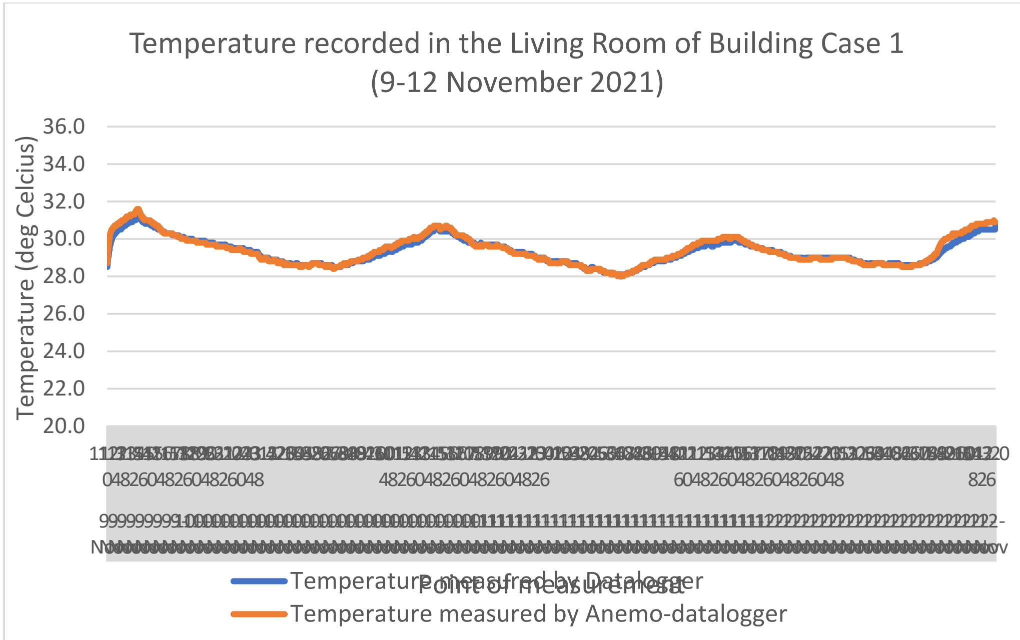


Figure 28 Temperature recorded in the Living Room of Building Case 1 from 9 to 12 November 2021

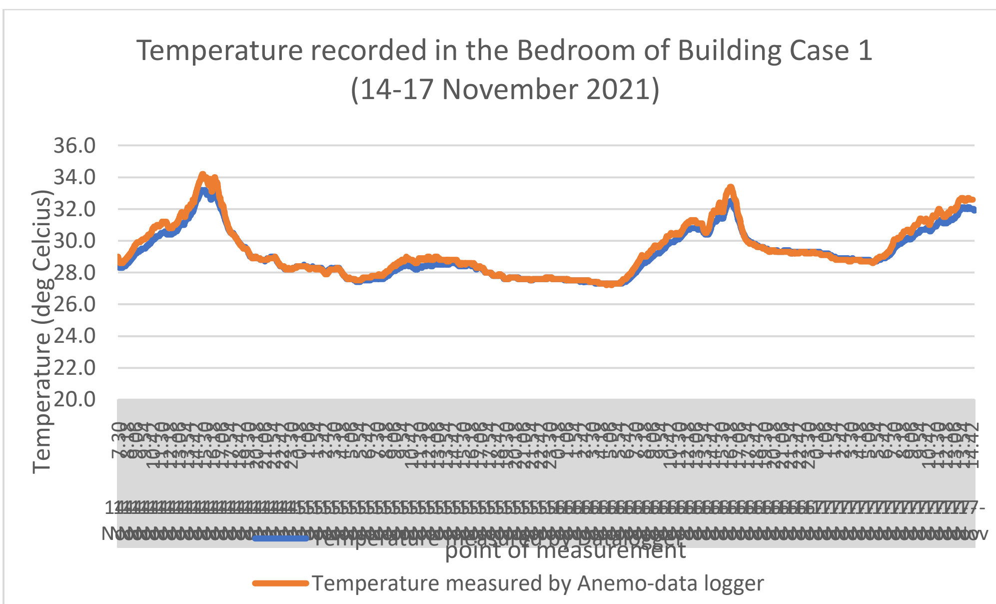


Figure 29 Temperature recorded in the Bedroom of Building Case 1 from 14 to 17 November 2021

In the case of Building 1, which is Taman Rasuna Apartment unit, most of the time indoor temperature peaked during in the afternoon at around 15.30, except on the November 15 when the temperature was not quite as high as another day. Data from ERA5 showed that during that time the wind speed at 100 m was quite high at around 4,1 – 4,2 m/s and it was raining during the day (precipitation up to 2.80 – 3.20 mm).

Figure 30 Temperature recorded in the Living Room of Building Case 2 from 30 November to 3 December 2021

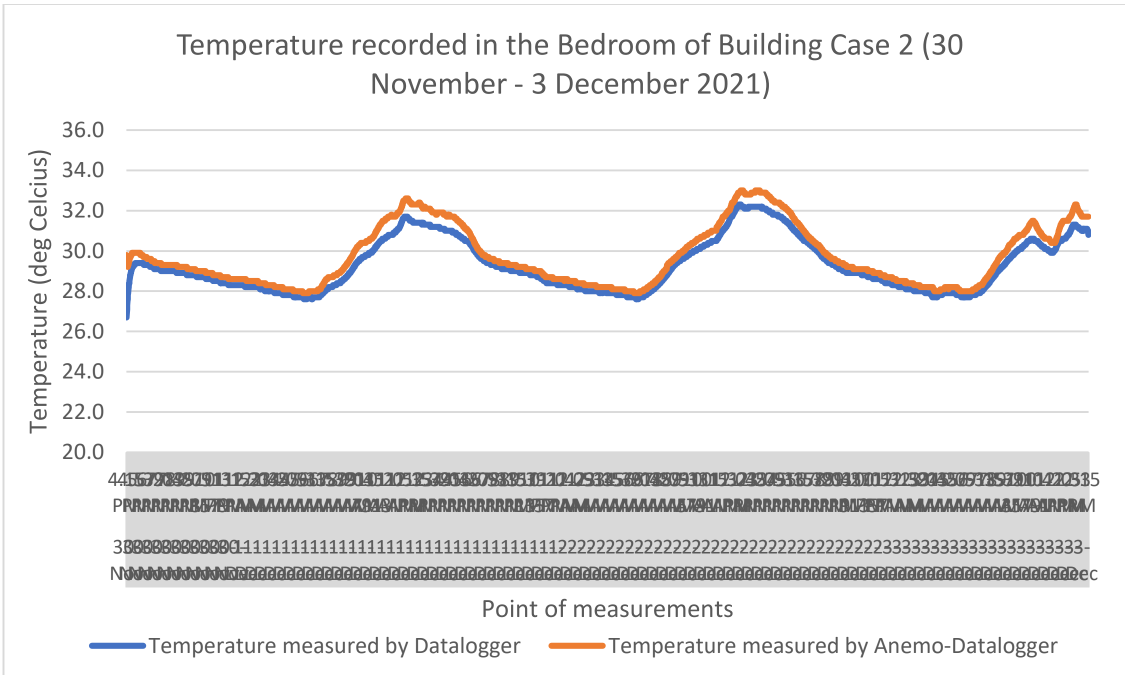


Figure 31 Temperature recorded in the Bedroom of Building Case 2 from 30 November to 3 December 2021

Similar trend was captured in Building Case 2 where indoor temperature peaked during mid-day at around 12 pm to 1 pm and temperature went down until morning at around 8 am. Although measurements were conducted only for three days, the results suggested similar trend every day.

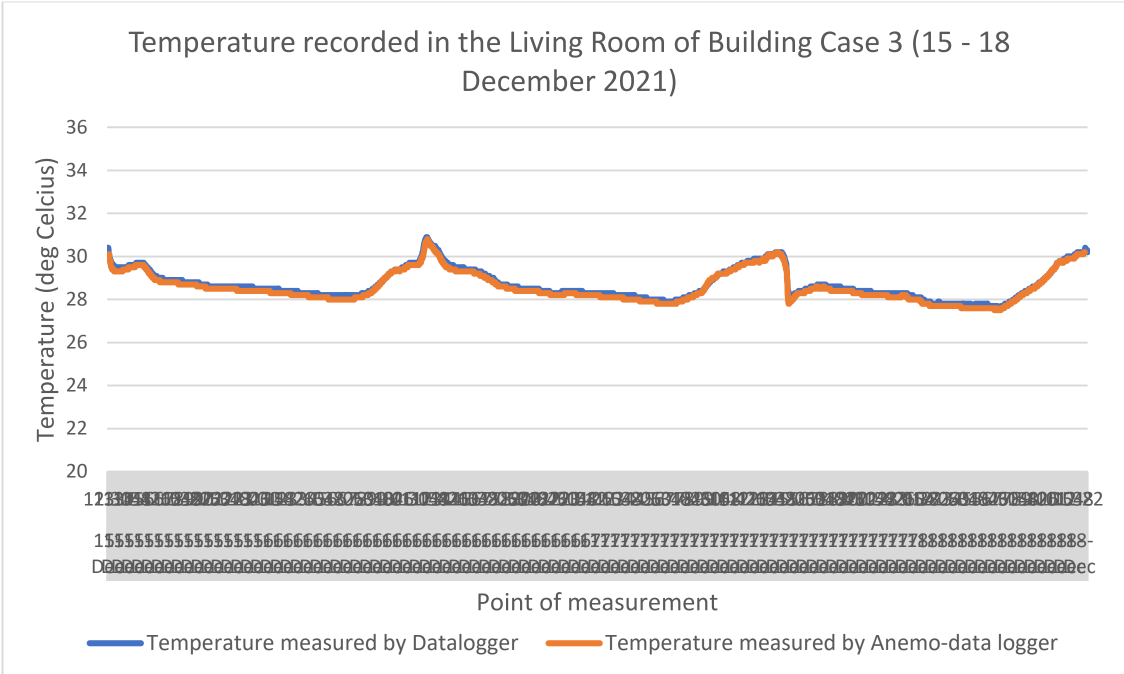


Figure 32 Temperature recorded in the Living Room of Building Case 3 from 15 to 18 December 2021

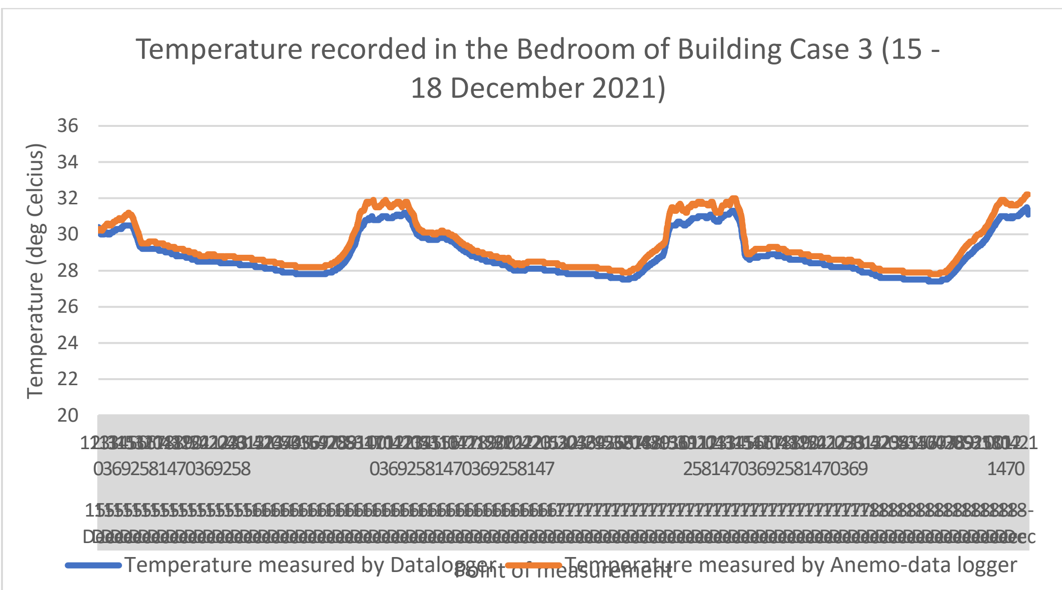


Figure 33 Temperature recorded in the Bedroom of Building Case 3 from 15 to 18 December 2021

Furthermore, indoor temperature also peaked at mid-day in Building Case 3. Similar to Building Case 2, it lower until around 5 in the morning before it went up again. Similar trend occurred almost every day during measurement period. This corroborated with the pattern happening with Building Case 1 and 2. Daily temperature change does not differ much in

Indonesia due to the tropical climate, which makes any energy technique measures (ETM) applied in Indonesia can be applicable all year round. Numerical description of the field measurements result is explained in Table 2.

Still airflow (wind speed below 0,1 m/s) occurred during measurements in all building cases. The highest wind speed recorded occurred in the living room because the opening was bigger than in the bedroom, with the highest average wind speed occurred in the living room of Building Case 2. Compared to the other building cases, Building Case 2 located closer to the sea which was windier.

In general, maximum temperature recorded in the bedroom of all buildings are usually higher than in the living rooms. The lowest temperature of the bedroom was higher than in the living room in Building Case 1 while lowest temperature in the living room of Building Case 2 were higher than in the bedroom and the temperature in both room in Building Case 3 were similar. On one hand, recorded average temperature between living room and bedroom were similar in Building Case 1 and 3, on the other hand, the average temperature of bedroom in Building Case 2 were 1 degree Celsius higher than in the living room.

Relative humidity affects indoor thermal comfort. In all building cases, the relative humidity was higher in the living rooms than in the bedrooms. Compared to other building cases that located more to the south of Jakarta, Building Case 2 had higher relative humidity than the other two. Inferential statistics were carried out to determine how the outdoor weather data influenced the indoor condition using regression analysis. ERA5 weather data were selected because it provide more weather data than weather data from BMKG that only provided daily weather data.

Table 2 Measurement's summary

	Building Case 1		Building Case 2		Building Case 3	
	Living	Bedroom	Living	Bedroom	Living	Bedroom
Measurement date	9 -12 November 2021	14 – 17 November 2021	30 November – 3 December 2021		15 – 18 December 2021	
Total readings	4388	4772	4252	4232	4358	4352
Wind speed recorded						
Highest	0,6 m/s	0,3 m/s	0,6 m/s	0,6 m/s	0,4 m/s	0,0 m/s
Lowest	0,0 m/s	0,0 m/s	0,0 m/s	0,0 m/s	0,0 m/s	0,0 m/s
Mean	0,000376 m/s	0,000105 m/s	0,0016 m/s	0,000354 m/s	0,00051 m/s	0,0 m/s
Temperature recorded						
Highest	31,6 °C	34,2 °C	31,8 °C	33 °C	30,9 °C	31,5 °C
Lowest						

Mean	26,1 °C	27,2 °C	27,1 °C	26,7 °C	27,5 °C	27,4 °C
	29,4 °C	29,4 °C	28,7 °C	29,7 °C	28,7 °C	28,9 °C
Relative Humidity recorded						
Highest	79,5 %	76,2 %	76,2 %	73,3 %	79,6 %	79,4 %
Lowest	52,3 %	48,2 %	41,2 %	41,8 %	57,1 %	55,4 %
Mean	65 %	64,2 %	64,1 %	61,6 %	72,0 %	72,0 %

Furthermore, ERA5 provided hourly weather data, compared to the measurement result that was taken with one minute interval. To compare the outdoor hourly weather data with the indoor readings by finding the correlation between them, the number of data must be comparable. To equate the number of data, the for every hour measurement were sampled for every hour. The sampled measurement readings or the internal factors would be the dependent variable. The hourly weather data provided by Shiny Weather was the external factors acted as independent variables. Statistical analysis on correlation was carried out to examine the correlations between external factors and internal factors. Regressions analysis to investigate the influence of external factors to the internal factors were carried out based on significant correlations between external and internal factors. The following sections elaborated the statistical analysis results. Appendix 1-3 illustrated the field measurement results and corresponding external hourly data by ERA5 on each buildings.

4.2 Inferential statistics of field test measurements

The next step is to analyze whether there is any correlation between external factors, namely: outdoor wind speed (WS10 and WS100), outdoor temperature (T2m) and outdoor relative humidity (RH2m); and the internal factors or indoor data from measurements results. These data were collected from ERA5. However, since ERA5 only provided hourly data, the measurement data were sampled to every hour to match the amount of data from ERA5. There were two instruments used in the field measurements, thus there are four variables gathered from the measurement results, namely: indoor temperature measured by instrument 1 (T1), temperature measured by instrument 2 (T2), indoor relative humidity measured by instrument 1 (RH1) and indoor airflow measured by instrument 2 (WS2). All six rooms (bedrooms and living rooms) from all three building cases were each investigated. The next step was to investigate whether the outdoor data influence indoor measurement by using regression analyses.

4.3 Taman Rasuna Apartment

Recorded indoor temperature in point 1 (T1) was positively correlated to T2m ($r = 0.882$, $p < .001$) and negatively correlated to WS100 ($r = -.0444$, $p < .001$), RH1 ($r = -0.624$, $p < .001$) and RH2m ($r = -0.752$, $p < .001$) (Table 3**Error! Not a valid bookmark self-reference.**). Similarly, T2 was also strongly correlated to and T2m ($r = 0.929$, $p < .01$) and negatively correlated to WS100 ($r = 0.475$, $p < .001$), RH1 ($r = -0.649$, $p < .001$) and RH2m ($r = -0.824$, $p < .001$). While indoor relative humidity (RH1) was positively correlated with outdoor relative humidity (RH2m $r = 0.758$, $p < 0.001$) and negatively correlated with T2m ($r = -0.689$, $p <0.001$). WS2 was only positively significant with T2m ($r = 0.233$, $p < 0.05$). It suggested that the higher the wind speed and the higher the RH, the lower the indoor temperature.

Table 3 Descriptive Statistics and Correlations for Study Variables Taman Rasuna living room

Variable	n	M	SD	T1	T2	RH1	WS2	WS10	WS100	T2m	RH2m
Indoor temperature measured by instrument 1 (T1)	73	29.323	0.7	-							
Indoor temperature measured by instrument 2 (T2)	73	29.379	0.787	0.985***	-						
Indoor relative humidity measured by instrument 1 RH1	73	.65	.053	-0.624***	-0.649***	-					
Indoor airflow measured by instrument 2 (WS2)	73	.005	.047	.250*	.257*	-.088	-				
Outdoor wind speed at 10 m high (WS10)	73	2.158	.649	-0.161	-0.131	-0.187	.081	-			
Outdoor wind speed at 100 m high (WS100)	73	3.593	1.298	-0.444***	-0.475***	0.042	-.036	0.828***	-		
Outdoor temperature at 2 m high (T2m)	73	27.311	1.877	0.882***	0.929***	-0.689***	.233*	-0.100	-0.478***	-	
Outdoor relative humidity at 2 m high (RH2m)	73	.801	.080	-0.752***	-0.824***	0.758***	-.193	-0.016	0.352**	-.939***	-

* p < .05, ** p < .01, *** p < .001

The next step is to run regression analysis to investigate whether the external factor or the outdoor weather data influence the results of indoor measurement (

Table 4). The dependent variables were T1, T2, and RH2m. Based on the results of correlation analysis, the significant predictors were WS100, RH2m and T2m. The findings of the regression indicated the three predictors together (WS10, RH2m and T2m) explained 82.9% of the variance T1 (R^2=.829, p<.001), 88.2% of the variance T2 (R^2=.882, p<.001) and

63.5% of the variance RH1 (R^2=.635, $p<.001$) in the living room of Building Case 1. Although WS100 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others. Furthermore, the three predictors did not influence WS2 significantly (R^2=0.074, p=0.149).

Table 4 Predictor living room of Building Case 1

Predictor	T1		T2		RH1	
	β	p	β	p	β	p
T2m	.582	.000	.555	.000	-.005	.493
RH2m	6.027	.000	4.068	.002	.467	.002
WS100	.031	.339	.008	.804	-.012	.002

Recorded bedroom indoor temperature in point 1 (T1) was positively correlated to WS10 (r = 0.235, $p < 0.05$) and T2m (r = 0.812, $p < .001$) and negatively correlated to RH1 (r = -0.832, $p < 0.001$) and RH2m (r = -0.760, $p < .001$) (Table 5). Similarly, T2 was also positively correlated to WS10 (T2 and WS10 r = 0.264, $p < .05$) and T2m (r = 0.839, $p < .001$) and negatively correlated to RH1 (r = -0.849, $p < 0.001$) and RH2m (r = -0.794, $p < 0.001$). While indoor relative humidity (RH1) was positively correlated with outdoor relative humidity (RH2m r = 0.771, $p < 0.001$) and negatively correlated with T2m (r = -0.760, $p < 0.001$) and WS10 (r = -0.345, $p < 0.01$). Indoor air velocity (WS2) was positively correlated with WS10 (r = 0.285, $p < 0.05$) and T2m (r = -0.760, $p < 0.01$) and negatively correlated with RH2m (r = -0.270, $p < 0.05$). Another thing to be noted was that the unit was at 50 m high, therefore, WS10 were correlated instead of WS100.

Table 5 Descriptive Statistics and Correlations for Study Variables Taman Rasuna bedroom

Variable	n	M	SD	T1	T2	RH1	WS2	WS10	WS100	T2m	RH2m
Indoor temperature measured by instrument 1 (T1)	80	29.1925	1.43930	-							
Indoor temperature measured by instrument 2 (T2)	80	29.4163	1.65793	.993***	-						
Indoor relative humidity measured by instrument 1 RH1	80	.6421	.06542	-.832***	-.849***	-					

Indoor airflow measured by instrument 2 (WS2)	80	.0000	.00000	.367***	0.375***	-.356**	-				
Outdoor wind speed at 10 m high (WS10)	80	2.0125	.79275	.235*	.264*	-.345**	.285*	-			
Outdoor wind speed at 100 m high (WS100)	80	3.0650	1.25467	-.001	.009	-.185	.159	.875***	-		
Outdoor temperature at 2 m high (T2m)	80	27.2925	2.35285	.812***	.839***	-.760***	.290**	.395***	.111	-	
Outdoor relative humidity at 2 m high (RH2m)	80	.8055	.09736	-.760***	-.794***	.771***	-.270*	-.395***	-.138	-.987***	-

*p < .05. **p < .01.

The next step is to run regression analysis to investigate whether the external factor or the outdoor weather data influence the results of indoor measurement (Table 6). The dependent variables were T1, T2, and RH1. Based on the results of correlation analysis, the significant predictors were WS10, RH2m and T2m. The results of the regression indicated the three predictors together (WS10, RH2m and T2m) explained 73.3% of the variance T1 (R^2=.733, p<.001), 75.4% of the variance T2 (R^2=.754, p<.001) and 59.7% of the variance RH1 (R^2=.597, p<.001) in the bedroom of Building Case 1. Although WS10 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others. However, the three predictors did not influence WS2 significantly (R^2=.131, p=0.013).

Table 6 Predicting bedroom of Building Case 1

	T1		T2		RH1	
Predictor	β	p	β	p	β	p
WS10	-.168	.449	-.063	.415	-.004	.276
RH2m	23.225	.000	21.329	.001	.477	.123
T2m	1.468	.000	1.466	.000	-.001	.912

4.4 Taman Anggrek Residence

Recorded living room indoor temperature in point 1 (T1) was positively correlated to WS2 (r = 0.420, p < .001), WS10 (r = 0.748, p < .001), WS100 (r = 0.438, p < .001), T2m (r = 0.921, p < .001) and negatively correlated to RH1 (r = -0.814, p < .001) and RH2m (r = -0.877, p < .001) (Table 7). Similarly, T2 was also positively correlated to WS2 (r = 0.432, p < .001), WS10 (r = 0.734, p < .001), WS100 (r = 0.400, p < .001), T2m (r = 0.933, p < .001) and negatively correlated to RH1 (r = -0.838, p < .001) and RH2m (r = -0.897, p < .001). While indoor relative humidity (RH1) was positively correlated with outdoor relative humidity (RH2m r = 0.861, p < 0.001) and negatively correlated with WS2 (r = -0.287, p < 0.01), WS10 (r = -0.703, p < .001), WS100 (r = -0.420, p < .001), and T2m (r = -0.820, p < .001). WS2 was positively correlated with WS10 (r = 0.440, p < .001) and T2m (r = -0.437, p < .001), and negatively correlated with RH2m (r = -0.379, p < .001). It suggested that external factors, which was outdoor weather, and indoor condition were correlated.

Table 7 Descriptive Statistics and Correlations for Study Variables Taman Anggrek Residence living room

Variable	n	M	SD	T1	T2	RH1	WS2	WS10	WS100	T2m	RH2m
Indoor temperature measured by instrument 1 (T1)	71	28.732	1.323	-							
Indoor temperature measured by instrument 2 (T2)	71	28.791	1.364	0.993***	-						
Indoor relative humidity measured by instrument 1 RH1	71	.641	.073	-0.814***	-0.838***	-					
Indoor airflow measured by instrument 2 (WS2)	71	.025	.076	0.420***	0.432***	-0.287*	-				
Outdoor wind speed at 10 m high (WS10)	71	2.489	1.034	0.748***	0.734***	-0.703***	0.440***	-			
Outdoor wind speed at 100 m high (WS100)	71	4.027	1.523	0.438***	0.400***	-0.420***	0.223	0.869***	-		

Outdoor temperature at 2 m high (T2m)	71	28.141	2.571	0.921***	0.933***	-0.820***	0.437***	0.736***	0.373**	-	
Outdoor relative humidity at 2 m high (RH2m)	71	.734	.114	-0.877***	-0.897***	0.861***	-0.379***	-0.723***	-0.378**	-0.974***	-

*p < .05. **p < .01. ***p < .001

The next step is to run regression analysis to investigate whether the external factor or the outdoor weather data influence the results of indoor measurement (Table 8). The dependent variables were T1, T2, RH1 and WS2. Based on the results of correlation analysis, the significant predictors were WS10, WS100, RH2m and T2m. The findings of the regression indicated the three predictors together namely, WS100, RH2m and T2m, explained 86.7% of the variance T1 (R^2=.867, $p < .001$), 87.6% of the variance T2 (R^2=.876, $p < .001$), 75.8% of the variance RH1 (R^2=.758, $p<.001$) and 24.1% of the variance WS2 (R^2=.241, $p<.001$) in the living room of Building Case 2. In this case, both WS10 and WS100 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others.

Table 8 Predicting living room of Building Case 2

Predictor	T1 β	p	T2 β	p	RH1 β	p	WS2 β	p
WS100	.102	.017	0.058	.166	-.005	.088	.006	.457
T2m	.665	.000	0.608	.000	.010	.176	.051	.006
RH2m	4.974	.034	2.934	.205	.750	.000	.819	.050

Furthermore, based on the results of correlation analysis, with the significant predictors were WS10, RH2m and T2m, the findings of the regression indicated the three predictors together (WS10, RH2m and T2m) explained 86.7% of the variance T1 (R^2=.867, $p < .001$), 87.8% of the variance T2 (R^2=.878, $p < .001$), 76.6% of the variance RH1 (R^2=.766, $p<.001$) and 26.8% of the variance WS2 (R^2=.268, $p<.001$) in the living room of Building Case 2.

In this case, both WS10 and WS100 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others. Reviewing the p value (Table 8 and Table 9), WS10 was a better predictor compared to WS100

Table 9 WS10 Predicting living room of Building Case 2

Predictor	T1 β	p	T2 β	p	RH1 β	p	WS2 β	p

WS10	.202	.019	.141	.094	-.014	.024	.026	.084
T2m	.620	.000	.576	.000	.014	.077	.045	.016
RH2m	4.784	.042	2.853	.214	.756	.000	.824	.044

In case of bedroom of Building Case 2, recorded indoor temperature in point 1 (T1) was positively correlated to WS10 ($r = 0.747$, $p < .001$), WS100 ($r = 0.423$, $p < .001$), T2m ($r = 0.961$, $p < .001$) and negatively correlated to RH1 ($r = -0.847$, $p < .001$) and RH2m ($r = -0.930$, $p < .001$) (Table 10). Similarly, T2 was also positively correlated to WS10 ($r = 0.728$, $p < .001$), WS100 ($r = 0.385$, $p < .001$), T2m ($r = 0.965$, $p < .001$) and negatively correlated to RH1 ($r = -0.855$, $p < .001$) and RH2m ($r = -0.934$, $p < .001$). While indoor relative humidity (RH1) was positively correlated with outdoor relative humidity (RH2m $r = 0.876$, $p < 0.001$) and negatively correlated with WS10 ($r = -0.703$, $p < .001$), WS100 ($r = -0.432$, $p < .001$), and T2m ($r = -0.823$, $p < .001$). WS2 was positively correlated to WS10 ($r = 0.269$, $p < .05$) and WS100 ($r = 0.354$, $p < .01$). It suggested that external factors, which was outdoor weather, and indoor condition were correlated.

Table 10 Descriptive Statistics and Correlations for Study Variables Taman Anggrek Residence bedroom

Variable	n	M	SD	T1	T2	RH1	WS2	WS10	WS100	T2m	RH2m
Indoor temperature measured by instrument 1 (T1)	70	29.287	1.308	-							
Indoor temperature measured by instrument 2 (T2)	70	29.726	1.463	0.996***	-						
Indoor relative humidity measured by instrument 1 RH1	70	.616	.072	-0.847***	-0.855***	-					
Indoor airflow measured by instrument 2 (WS2)	70	.021	.090	.163	.141	.025	-				
Outdoor wind speed at 10 m high (WS10)	70	2.487	1.042	0.747***	0.728***	-0.703***	.269*	-			

Outdoor wind speed at 100 m high (WS100)	70	4.036	1.532	0.423 ***	0.385 ***	-0.432 ***	.354**	0.871 ***	-		
Outdoor temperature at 2 m high (T2m)	70	28.130	2.588	0.961 ***	0.965 ***	-0.823 ***	.094	0.736 ***	0.375 **	-	
Outdoor relative humidity at 2 m high (RH2m)	70	.734	.114	-0.930 ***	-0.934 ***	0.876 ***	-.055	-0.723 ***	-0.379 **	-.975***	-

*p < .05. **p < .01. ***p < .001

The next step is to run regression analysis to investigate whether the external factor or the outdoor weather data influence the results of indoor measurement (
Table **11**). The dependent variables were T1, T2, RH1 and WS2. Based on the results of correlation analysis, the significant predictors were WS10, WS100, RH2m and T2m.

The findings of the regression indicated the three predictors together namely, WS100, RH2m and T2m, explained 92.9% of the variance T1 (R^2=.929, $p < .001$), 93.2% of the variance T2 (R^2=.932, $p < .001$), and 79.8% of the variance RH1 (R^2=.798, $p<.001$) in the bedroom of Building Case 2. In this case, WS100 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others. However, the three predictors did not influence WS2 significantly (R^2=.162, p=0.008)

Table 11 Predicting bedroom of Building Case 2

Predictor	T1		T2		RH1	
	β	p	β	p	β	p
WS100	.064	.040	.028	.407	-.006	.047
T2m	.540	.000	.613	.000	.017	.014
RH2m	1.598	.347	1.710	.356	.901	.000

Furthermore, based on the results of correlation analysis, with the significant predictors were WS10, RH2m and T2m, the findings of the regression indicated the three predictors together (WS10, RH2m and T2m) explained 92.7% of the variance T1 (R^2=.927, $p < .001$), 93.2% of the variance T2 (R^2=.932, $p < .001$), 80.3% of the variance RH1 (R^2=.803, $p<.001$) in the bedroom of Building Case 2. However, the three predictors did not influence WS2 significantly (R^2=.127, p=0.029)

In this case, both WS10 and WS100 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others. Reviewing the p value (

Table **11** and Table 12), WS10 was a better predictor compared to WS100.

Table 12 WS10 Predicting bedroom of Building Case 2

Predictor	T1		T2		RH1	
	β	p	β	p	β	p
WS10	.110	.080	.058	.387	-.013	.020
T2m	.517	.000	.600	.000	.020	.005
RH2m	1.485	.385	1.671	.366	.907	.000

4.5 Kalibata City

Recorded indoor temperature in point 1 (T1) in the living room of Building Case 2 was positively correlated to T2m (r = 0.898, p < .001) and WS2 (0.441, p < 0.01) but weakly correlated to WS10 (r = 0.265, p < 0.05) and negatively correlated to RH1 (r = -0.672, p < .001) and RH2m (r = -0.858, p < .001) (Table 13). Similarly, T2 was also was positively correlated to T2m (r = 0.910, p < .001) and WS 2 (r = 0.427, p < .001) but weakly correlated to WS10 (r = 0.270, p < 0.05), and negatively correlated to RH1 (r = -0.659, p < .001) and RH2m (r = -0.874, p < .001). While indoor relative humidity (RH1) was positively correlated with outdoor relative humidity (RH2m r = 0.726, p < 0.001) and WS100 (r = 0.375, p < 0.01) and negatively correlated with T2m (r = -0.699, p <0.001) and WS2 (r = -0.336, p < 0.01). WS2 was positively correlated to WS10 (r = 0.343, p < 0.01) and T2m (r = 0.390, p <0.001), and negatively correlated to RH2m (r = -0.378, p <0.01). This suggested that in the living room of Building Case 2, outdoor temperature influence indoor temperature, but the outdoor wind give little contribution to indoor airflow.

Table 13 Descriptive Statistics and Correlations for Study Variables Kalibata City living room

Variable	n	M	SD	T1	T2	RH1	WS 2	WS 10	WS 100	T2m	RH2 m
Indoor temperature measured by instrument 1 (T1)	72	28.693	0.679	-							
Indoor temperature measured by instrument 2 (T2)	72	28.588	0.702	0.987***	-						
Indoor relative humidity measured by	72	0.721	0.040	-0.67	-0.65	-					

instrument 1 RH1				2***	9***						
Indoor airflow measured by instrument 2 (WS2)	72	0.018	0.074	0.441***	0.427***	-0.336**	-				
Outdoor wind speed at 10 m high (WS10)	72	1.446	0.584	0.265*	0.270*	0.224	0.343**	-			
Outdoor wind speed at 100 m high (WS100)	72	2.089	0.837	0.053	0.057	0.375**	0.224	0.901***	-		
Outdoor temperature at 2 m high (T2m)	72	27.121	2.105	0.898***	0.910***	-0.699***	0.390***	0.235*	0.032	-	
Outdoor relative humidity at 2 m high (RH2m)	72	0.828	0.087	-0.858***	-0.874***	0.726***	-0.378***	-0.176	0.002	-.988***	-

*p < .05. **p < .01. ***p < .001

The next step is to run regression analysis to investigate whether the external factor or the outdoor weather data influence the results of indoor measurement (Table 14). The dependent variables were T1, T2, RH1 and WS2. Based on the results of correlation analysis, the significant predictors were WS10, RH2m and T2m. The results of the regression indicated the three predictors together (WS10, RH2m and T2m) explained 84.3% of the variance T1 (R^2=.843, p<.001), 85.6% of the variance T2 (R^2=.856, p<.001), 65.6% of the variance RH1 (R^2=.656, p<.001) and only 22.2 % of the variance WS2 (R^2=.222, p<.001) in the living room of Building Case 3. Although WS10 alone can predict significantly, together with RH2m and T2m it gave little contribution compared to the others. Furthermore, the external weather data give little influence to WS2 with one of the reason due to the less accuracy of the measuring instrument since the value recorded were majority 0 m/s.

Table 14 Predicting living room of Building Case 3

Predictor	T1		T2		RH1		WS2	
	β	p	β	p	β	p	β	p
WS10	-.021	.741	-.006	.923	.026	.000	.036	.018

T2m	0.696	.000	0.666	.000	-.004	.697	-.001	.968
RH2m	9.893	.000	8.853	.001	.276	.235	-.303	.634

Recorded indoor temperature in point 1 (T1) in the bedroom of Building Case 3 was positively correlated to T2m ($r = 0.969$, $p < .001$) and negatively correlated to RH1 ($r = -0.870$, $p < .001$) and RH2m ($r = -0.952$, $p < .001$) (Table 15). Similarly, T2 was also was positively correlated to T2m ($r = 0.959$, $p < .001$) and negatively correlated to RH1 ($r = -0.886$, $p < .001$) and RH2m ($r = -0.949$, $p < .001$). While indoor relative humidity (RH1) was positively correlated with outdoor relative humidity (RH2m $r = 0.852$, $p < 0.001$) and weakly correlated to WS100 ($r = 0.287$, $p < 0.05$) and negatively correlated with T2m ($r = -0.829$, $p <0.001$). This suggested that in the bedroom of Building Case 3, outdoor temperature influence indoor temperature, but the outdoor wind give little contribution to indoor airflow.

Table 15 Descriptive Statistics and Correlations for Study Variables Kalibata City bedroom

Variable	n	M	SD	T1	T2	RH1	WS2	WS10	WS100	T2m	RH2m
Indoor temperature measured by instrument 1 (T1)	72	28.885	1.151	-							
Indoor temperature measured by instrument 2 (T2)	72	29.351	1.258	0.996***	-						
Indoor relative humidity measured by instrument 1 RH1	72	.721	.054	-0.870***	-0.886***	-					
Indoor airflow measured by instrument 2 (WS2)	72	.0000	.00000	0	0	0	-				
Outdoor wind speed at 10 m high (WS10)	72	1.446	.584	0.180	0.133	0.107	0	-			
Outdoor wind speed at 100 m high (WS100)	72	2.089	0.837	-0.045	-0.091	0.287*	0	0.901***	-		

Outdoor temperature at 2 m high (T2m)	72	27.121	2.105	0.969***	0.959***	-0.829***	0	0.235*	0.032	-	
Outdoor relative humidity at 2 m high (RH2m)	72	.828	.087	-0.952***	-0.949***	0.852***	0	-0.176	0.002	-.988***	-

*p < .05. **p < .01. ***p < .001

The next step is to run regression analysis to investigate whether the external factor or the outdoor weather data influence the results of indoor measurement (Table 16). The dependent variables were T1, T2, and RH1. Based on the results of correlation analysis, the significant predictors were WS100, RH2m and T2m

The results of the regression indicated the three predictors together (WS100, RH2m and T2m) explained 94.6% of the variance T1 (R^2=.946, p < .001), 93.5% of the variance T2 (R^2=.935, p<.001), and 80.7% of the variance RH1 (R^2=.807, p<.001) in the bedroom of Building Case 3. WS100 together with RH2m and T2m it gave little contribution to T1 T2 and RH2.

Table 16 Predicting bedroom of Building Case 3

Predictor	T1		T2		RH1	
	β	p	β	p	β	P
WS100	-.119	.004	-.190	.000	0.018	.000
T2m	0.704	.000	0.650	.000	0.003	.741
RH2m	4.233	.092	1.827	.542	0.596	.008

During the measurements, there were some days where the external wind was more extreme than usual (outdoor wind were up to 4 m/s) and cause higher velocity magnitude inside the measured room. Rooms with less ventilation, such as Kalibata City bedroom, did not show any readings because the external wind was not extreme and the unit height was lower (70 m) compared to Taman Anggrek Residences (120 m) where more extreme outdoor wind speed might occurred.

The statistical analysis conducted between the measured indoor condition and related outdoor weather condition suggested that external weather influence the indoor climate, where significant correlation was more apparent in the case of T1 and T2, and RH2. In case of WS2, where the data is important for this study, there were little data available due to the accuracy of the measurement tools where the instrument can only show one decimal, while in most case, calm airflow can read below 0,1 m/s. Therefore, further study using CFD that provided more accurate results is required to study the correlation between outdoor condition and indoor airflow. However, the inferential statistical analysis sufficiently illustrated that external weather factor give influence to indoor air condition. The significance was different in each building cases because every building cases encompasses different other factors such as location, height location, opening size and design, and surrounding environment.

5. CONCLUSION AND FURTHER STUDIES

Based on the above investigation of natural ventilation performance in Jakarta typical apartment unit, the following significant results are generated

1) The outdoor temperature significantly influences the indoor temperature. The significance, however, on each building are different because they encompassed different other factors such as location, height location, opening size and design, and surrounding environment.
2) The height of every apartment unit was varied, therefore the predictor of outdoor wind varied among them. In some cases, the wind speed influenced the indoor airflow. However, as a predictor among other variable, it gave less significance in predicting the indoor airflow and temperature.
3) The limitation of this research was the quantity and the need of more accurate tools to record the wind speed. This resulted on the less significant number of p-value on indoor airflow.

The results of this measurement contributed to further research on natural ventilation particularly in high rise buildings, tropical countries, and growing cities.

Further studies, preferably using CFD, is recommended to further investigate the impact of outdoor weather to the indoor airflow and temperature, and by using the data of this study to validate the model, since this study provided comprehensive data on the weather, measurements results and building drawings. Research on encompassing factors on each buildings should be conducted to gain insight on the influence of those factors on natural ventilation performance. Single-sided ventilation occurred at the time of measurements on some rooms with cross ventilation possibility. Therefore, comparing existing condition with further studies on cross ventilation is expected.

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7. APPENDICES

APPENDIX 1 Field measurement result of Taman Anggrek Residence bedroom and external weather data on respected time

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
30/11/21	17.00	29,4	29,9	0,634	0	2	3,90	28,10	0,74	SW
30/11/21	18.00	29,2	29,6	0,63	0	1,90	3,30	28	0,73	SW
30/11/21	19.00	29	29,3	0,642	0	1,20	2,40	27,50	0,74	SW
30/11/21	20.00	28,9	29,2	0,674	0	1,20	2,00	27,40	0,75	S
30/11/21	21.00	28,8	29,1	0,687	0	0,80	1,10	26,60	0,78	SE

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
30/11/21	22.00	28,7	29	0,695	0	0,70	0,80	26,40	0,80	S
30/11/21	23.00	28,5	28,8	0,688	0	1,10	1,60	26,10	0,82	S
01/12/21	0.00	28,3	28,6	0,68	0	0,90	1,70	25,90	0,84	S
01/12/21	1.00	28,2	28,6	0,694	0	1	1,80	25,6	0,85	SW
01/12/21	2.00	28,2	28,4	0,691	0	1	1,90	25,4	0,87	SW
01/12/21	3.00	28	28,3	0,703	0	1,4	2,70	24,9	0,88	SW
01/12/21	4.00	27,8	28,1	0,686	0	1,6	3,30	24,8	0,89	SW
01/12/21	5.00	27,7	28	0,667	0	2,4	4,70	25,4	0,87	SW
01/12/21	6.00	27,7	28	0,656	0	2,4	4,70	25,6	0,86	SW
01/12/21	7.00	28,1	28,6	0,645	0	2,3	4,10	26,2	0,82	S
01/12/21	8.00	28,5	29	0,634	0	2,4	3,20	26,8	0,79	S
01/12/21	9.00	29,3	30	0,586	0	2,6	3,40	29,3	0,64	SW
01/12/21	10.00	29,8	30,5	0,517	0	3	3,90	29,7	0,62	SW
01/12/21	11.00	30,6	31,4	0,493	0	3,2	4,20	29,9	0,62	W
01/12/21	12.00	31	31,8	0,482	0	3,4	4,40	31,5	0,56	W
01/12/21	13.00	31,5	32,4	0,428	0	3,9	5,10	31,9	0,55	W
01/12/21	14.00	31,4	32,1	0,478	0	4,3	5,60	32,4	0,53	W
01/12/21	15.00	31,2	31,8	0,508	0	4,2	5,70	32	0,56	W
01/12/21	16.00	31	31,7	0,531	0	3,9	5,50	32	0,56	W
01/12/21	17.00	30,6	31,2	0,56	0	3,8	6,10	29,7	0,65	W
01/12/21	18.00	29,8	30,1	0,576	0	3,8	6,60	29,2	0,66	SW
01/12/21	19.00	29,3	29,6	0,567	0	3,3	6,10	28,7	0,67	SW
01/12/21	20.00	29,1	29,4	0,567	0	3,2	6,00	28,3	0,67	SW
01/12/21	21.00	29	29,2	0,59	0	2,8	5,50	27,2	0,72	SW

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
01/12/21	22.00	28,8	29,1	0,608	0	2,4	4,90	26,9	0,74	SW
01/12/21	23.00	28,5	28,7	0,61	0	2,3	4,80	26,7	0,76	SW
02/12/21	0.00	28,3	28,6	0,609	0	2	4,40	25,9	0,79	SW
02/12/21	1.00	28,2	28,5	0,609	0	1,8	3,80	25,8	0,8	SW
02/12/21	2.00	28	28,3	0,622	0	1,8	3,40	25,3	0,83	SW
02/12/21	3.00	27,9	28,2	0,616	0	2	3,60	24,9	0,85	S
02/12/21	4.00	27,9	28,1	0,624	0	2,1	4,00	24,9	0,85	S
02/12/21	5.00	27,7	28	0,639	0	1,9	3,60	25,4	0,85	SW
02/12/21	6.00	27,7	28	0,665	0	2	3,30	25,3	0,86	S
02/12/21	7.00	28,2	28,5	0,663	0	1,7	3,20	26,2	0,83	S
02/12/21	8.00	28,9	29,4	0,638	0	1,9	2,60	27,4	0,78	SW
02/12/21	9.00	29,6	30	0,621	0	2,6	3,40	30,7	0,63	SW
02/12/21	10.00	30	30,5	0,601	0	3,5	4,50	31,3	0,6	SW
02/12/21	11.00	30,4	30,9	0,581	0	4,2	5,40	31,6	0,59	W
02/12/21	12.00	31	31,7	0,559	0	4,4	5,60	32,5	0,56	W
02/12/21	13.00	32,2	32,8	0,515	0	4,4	5,60	33	0,55	W
02/12/21	14.00	32,2	32,9	0,526	0,1	4,3	5,60	33,1	0,55	W
02/12/21	15.00	32,1	32,9	0,51	0,2	4,4	5,80	32,9	0,56	W
02/12/21	16.00	31,8	32,4	0,51	0,1	4,2	5,90	32,6	0,59	W
02/12/21	17.00	31,2	31,7	0,473	0	3,3	5,50	30,2	0,67	W
02/12/21	18.00	30,5	30,8	0,574	0	3,4	6,30	29,5	0,69	W
02/12/21	19.00	29,9	30,2	0,644	0,6	3,6	6,70	28,3	0,74	W
02/12/21	20.00	29,3	29,6	0,682	0,1	3,4	6,50	27,7	0,76	SW
02/12/21	21.00	28,9	29,2	0,686	0,4	3,1	6,10	27	0,79	SW

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
02/12/21	22.00	28,9	29,1	0,685	0	2,8	5,50	26,8	0,81	SW
02/12/21	23.00	28,6	28,9	0,682	0	2,7	5,30	26,4	0,83	SW
03/12/21	0.00	28,4	28,7	0,68	0	2,4	4,90	26,2	0,84	SW
03/12/21	1.00	28,2	28,5	0,688	0	2,2	4,50	26,1	0,85	SW
03/12/21	2.00	28	28,3	0,702	0	1,9	4,00	25,8	0,86	SW
03/12/21	3.00	27,9	28,2	0,703	0	1,7	3,50	25,6	0,88	SW
03/12/21	4.00	27,8	28,1	0,725	0	1,4	2,80	25,3	0,9	SW
03/12/21	5.00	27,9	28,2	0,725	0	1,9	3,80	25,3	0,89	SW
03/12/21	6.00	27,7	28	0,732	0	2,1	3,60	25,5	0,87	SW
03/12/21	7.00	28	28,4	0,701	0	1,6	2,80	26,4	0,84	S
03/12/21	8.00	28,9	29,5	0,641	0	1,1	1,50	27,2	0,8	SW
03/12/21	9.00	29,6	30,3	0,59	0	1	1,20	29,8	0,67	SW
03/12/21	10.00	30,2	30,9	0,551	0	1,4	1,70	30,3	0,63	W
03/12/21	11.00	30,5	31,1	0,563	0	2	2,40	30,7	0,61	W
03/12/21	12.00	29,9	30,4	0,606	0	2,4	2,90	31,7	0,58	W
03/12/21	13.00	30,6	31,5	0,582	0	2,6	3,10	31,6	0,6	W
03/12/21	14.00	31,2	32	0,568	0	2,5	3,20	30,8	0,66	W

Note: T1: indoor temperature measured by instrument 1; T2: temperature measured by instrument 2; RH1: indoor relative humidity measured by instrument 1; WS2: indoor airflow measured by instrument 2 ws10: outdoor wind speed at 10-m high (m/s) ws100: outdoor wind speed at 10-m high (m/s) T2m: outdoor temperature RH2m: outdoor relative humidity; wdir: wind direction. Weather data provided by ERA5

APPENDIX 2 Field measurement result of Kalibata City living room and external weather data on respected time

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
15/12/21	13.00	29,5	29,4	0,737	0	3,1	3,79999995	30,1	0,72	N
15/12/21	14.00	29,5	29,4	0,733	0	2,8	3,5999999	29,4	0,76	NW
15/12/21	15.00	29,7	29,6	0,717	0	2,5	3	28,7	0,79	W
15/12/21	16.00	29,1	29	0,733	0	2,2	2,79999995	28,7	0,77	W
15/12/21	17.00	28,9	28,8	0,729	0	1,7	2,5999999	27,2	0,82	S
15/12/21	18.00	28,9	28,7	0,718	0	1,6	2,70000005	27,1	0,85	SE
15/12/21	19.00	28,8	28,7	0,729	0	1,8	2,9000001	27,1	0,82	SE
15/12/21	20.00	28,6	28,5	0,733	0	1,8	2,79999995	26,7	0,84	SE
15/12/21	21.00	28,6	28,5	0,707	0	1,5	2,0999999	26,4	0,87	S
15/12/21	22.00	28,6	28,5	0,732	0	1,2	1,5	26,2	0,87	S
15/12/21	23.00	28,6	28,4	0,739	0	1	1,39999998	25,9	0,89	S
16/12/21	0.00	28,5	28,4	0,738	0	1	1,29999995	25,4	0,91	S
16/12/21	1.00	28,5	28,3	0,713	0	1,3	1,70000005	25,4	0,92	S
16/12/21	2.00	28,4	28,3	0,739	0	1,3	1,89999998	25,3	0,9	S
16/12/21	3.00	28,3	28,2	0,748	0	1,5	2,29999995	25,3	0,9	S
16/12/21	4.00	28,3	28,1	0,755	0	1,6	2,5999999	25,3	0,91	S
16/12/21	5.00	28,2	28	0,758	0	1,7	2,70000005	25,3	0,92	S
16/12/21	6.00	28,2	28	0,754	0	1,8	2,5999999	25,3	0,92	S
16/12/21	7.00	28,2	28,1	0,741	0	1,4	2,29999995	25,9	0,9	S
16/12/21	8.00	28,4	28,3	0,73	0	1,1	1,39999998	26,9	0,84	S
16/12/21	9.00	29	28,9	0,699	0	1	1,20000005	29,9	0,7	SW
16/12/21	10.00	29,4	29,4	0,67	0	0,5	0,69999999	30,4	0,66	SW
16/12/21	11.00	29,7	29,6	0,649	0	0,8	0,89999998	30,7	0,66	NW

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
16/12/21	12.00	30,7	30,3	0,641	0,4	1,9	2,29999995	31,1	0,66	N
16/12/21	13.00	30,2	30,675	0,684	0	1,1	1,5	30,6	0,69	N
16/12/21	14.00	29,6	29,4	0,713	0	1,4	1,79999995	30,5	0,71	NW
16/12/21	15.00	29,4	29,3	0,691	0	1,1	1,39999998	28,3	0,79	SW
16/12/21	16.00	29,3	29,2	0,707	0	1,7	2,0999999	27,3	0,83	S
16/12/21	17.00	29	28,9	0,732	0	2,1	2,9000001	27,5	0,8	SW
16/12/21	18.00	28,7	28,6	0,749	0	1,3	2,29999995	26,9	0,84	S
16/12/21	19.00	28,5	28,4	0,75	0	1,4	2,5	26,5	0,85	S
16/12/21	20.00	28,5	28,4	0,765	0	1,5	2,79999995	26,2	0,87	SE
16/12/21	21.00	28,4	28,3	0,769	0	1,4	2,29999995	25,6	0,9	SE
16/12/21	22.00	28,3	28,2	0,73	0	0,9	1,39999998	25,4	0,91	S
16/12/21	23.00	28,4	28,3	0,747	0	0,9	1,39999998	25,3	0,91	SW
17/12/21	0.00	28,3	28,2	0,751	0	0,8	1,20000005	25	0,92	SW
17/12/21	1.00	28,3	28,1	0,748	0	0,7	0,89999998	24,9	0,93	S
17/12/21	2.00	28,2	28,1	0,75	0	0,9	1,20000005	24,7	0,93	S
17/12/21	3.00	28,2	28	0,752	0	1	1,29999995	24,4	0,93	S
17/12/21	4.00	28,1	27,9	0,75	0	1,2	1,39999998	24,3	0,93	S
17/12/21	5.00	28	27,9	0,755	0	1,6	1,89999998	25	0,93	S
17/12/21	6.00	27,9	27,8	0,761	0	1,8	1,89999998	24,8	0,93	S
17/12/21	7.00	28	27,9	0,758	0	1,5	1,79999995	25,2	0,92	S
17/12/21	8.00	28,3	28,2	0,737	0	0,9	1,10000002	26,3	0,87	SW
17/12/21	9.00	28,8	28,8	0,706	0	0,5	0,60000002	29,7	0,72	W
17/12/21	10.00	29,2	29,2	0,676	0	0,9	1,10000002	30,3	0,69	NW
17/12/21	11.00	29,5	29,4	0,655	0	1,3	1,5	30,6	0,67	NW

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
17/12/21	12.00	29,8	29,7	0,646	0,4	1,9	2,20000005	30,9	0,68	NW
17/12/21	13.00	29,9	29,8	0,684	0,1	2,7	3,5	30,8	0,7	NW
17/12/21	14.00	30,2	30,1	0,671	0,2	2,9	3,5999999	30,6	0,7	W
17/12/21	15.00	28,2	28,6666667	0,746	0,2	2,8	3,70000005	27,8	0,79	W
17/12/21	16.00	28,4	28,3	0,782	0	2,7	3,70000005	28,2	0,78	SW
17/12/21	17.00	28,7	28,6	0,795	0	1,8	2,79999995	27,5	0,81	SW
17/12/21	18.00	28,6	28,5	0,763	0	1,9	3,29999995	27,3	0,82	SW
17/12/21	19.00	28,5	28,4	0,746	0	1,8	3,20000005	27	0,83	SW
17/12/21	20.00	28,4	28,3	0,729	0	1,8	3,0999999	26,8	0,83	SW
17/12/21	21.00	28,3	28,2	0,741	0	1,7	3,20000005	26,2	0,85	S
17/12/21	22.00	28,3	28,2	0,701	0	1,3	2,5999999	26	0,85	S
17/12/21	23.00	28,3	28,1	0,701	0	1,2	2,29999995	25,8	0,87	S
18/12/21	0.00	28,2	28	0,745	0	1,3	2,4000001	25,4	0,89	S
18/12/21	1.00	27,9	27,8	0,734	0	1,2	2,29999995	25,4	0,89	S
18/12/21	2.00	27,9	27,7	0,737	0	1,2	2,29999995	25,2	0,9	S
18/12/21	3.00	27,8	27,7	0,741	0	1,1	2,4000001	24,7	0,91	S
18/12/21	4.00	27,8	27,6	0,745	0	1,3	2,4000001	24,7	0,91	S
18/12/21	5.00	27,8	27,6	0,72	0	1,2	2	24,9	0,9	SE
18/12/21	6.00	27,7	27,6	0,717	0	0,9	1,20000005	25	0,9	S
18/12/21	7.00	27,8	27,7	0,714	0	1,1	1,5	25,6	0,88	S
18/12/21	8.00	28,2	28,1	0,671	0	0,8	1	26,3	0,84	SW
18/12/21	9.00	28,6	28,5	0,665	0	0,9	1	29,2	0,73	W
18/12/21	10.00	29,1	29	0,655	0	0,8	1	29,4	0,73	SW
18/12/21	11.00	29,8	29,7	0,594	0	1	1,20000005	29,9	0,7	SW

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
18/12/21	12.00	30	29,9	0,589	0	0,8	1,10000002	31,1	0,67	SW

Note: T1: indoor temperature measured by instrument 1; T2: temperature measured by instrument 2; RH1: indoor relative humidity measured by instrument 1; WS2: indoor airflow measured by instrument 2 ws10: outdoor wind speed at 10-m high (m/s) ws100: outdoor wind speed at 10-m high (m/s) T2m: outdoor temperature RH2m: outdoor relative humidity; wdir: wind direction. Weather data provided by ERA5

APPENDIX 3 Field measurement result of Kalibata City bedroom and external weather data on respected time

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
15/12/21	13.00	30,1	30,4	0,724	0	3,1	3,79999995	30,1	0,72	N
15/12/21	14.00	30,3	30,8	0,708	0	2,8	3,5999999	29,4	0,76	NW
15/12/21	15.00	30,5	31,1	0,686	0	2,5	3	28,7	0,79	W
15/12/21	16.00	29,2	29,5	0,736	0	2,2	2,79999995	28,7	0,77	W
15/12/21	17.00	29,2	29,5	0,722	0	1,7	2,5999999	27,2	0,82	S
15/12/21	18.00	29	29,3	0,72	0	1,6	2,70000005	27,1	0,85	SE
15/12/21	19.00	28,8	29,2	0,734	0	1,8	2,9000001	27,1	0,82	SE
15/12/21	20.00	28,6	29	0,733	0	1,8	2,79999995	26,7	0,84	SE
15/12/21	21.00	28,5	28,8	0,715	0	1,5	2,0999999	26,4	0,87	S
15/12/21	22.00	28,4	28,8	0,74	0	1,2	1,5	26,2	0,87	S
15/12/21	23.00	28,4	28,8	0,747	0	1	1,39999998	25,9	0,89	S
16/12/21	0.00	28,3	28,7	0,748	0	1	1,29999995	25,4	0,91	S
16/12/21	1.00	28,2	28,6	0,729	0	1,3	1,70000005	25,4	0,92	S
16/12/21	2.00	28,1	28,5	0,756	0	1,3	1,89999998	25,3	0,9	S
16/12/21	3.00	27,9	28,3	0,769	0	1,5	2,29999995	25,3	0,9	S
16/12/21	4.00	27,8	28,2	0,778	0	1,6	2,5999999	25,3	0,91	S
16/12/21	5.00	27,8	28,2	0,778	0	1,7	2,70000005	25,3	0,92	S

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
16/12/21	6.00	27,8	28,2	0,771	0	1,8	2,5999999	25,3	0,92	S
16/12/21	7.00	28,1	28,5	0,754	0	1,4	2,29999995	25,9	0,9	S
16/12/21	8.00	28,8	29,3	0,73	0	1,1	1,39999998	26,9	0,84	S
16/12/21	9.00	30,4	31,3	0,659	0	1	1,20000005	29,9	0,7	SW
16/12/21	10.00	30,8	31,7	0,63	0	0,5	0,69999999	30,4	0,66	SW
16/12/21	11.00	30,9	31,7	0,618	0	0,8	0,89999998	30,7	0,66	NW
16/12/21	12.00	31	31,7	0,638	0	1,9	2,29999995	31,1	0,66	N
16/12/21	13.00	30,5	31,1	0,69	0	1,1	1,5	30,6	0,69	N
16/12/21	14.00	29,8	30,1	0,709	0	1,4	1,79999995	30,5	0,71	NW
16/12/21	15.00	29,8	30,1	0,682	0	1,1	1,39999998	28,3	0,79	SW
16/12/21	16.00	29,6	30	0,703	0	1,7	2,0999999	27,3	0,83	S
16/12/21	17.00	29,1	29,4	0,733	0	2,1	2,9000001	27,5	0,8	SW
16/12/21	18.00	28,7	29,1	0,752	0	1,3	2,29999995	26,9	0,84	S
16/12/21	19.00	28,5	28,9	0,756	0	1,4	2,5	26,5	0,85	S
16/12/21	20.00	28,3	28,7	0,778	0	1,5	2,79999995	26,2	0,87	SE
16/12/21	21.00	28	28,4	0,783	0	1,4	2,29999995	25,6	0,9	SE
16/12/21	22.00	28,1	28,5	0,746	0	0,9	1,39999998	25,4	0,91	S
16/12/21	23.00	28,1	28,5	0,765	0	0,9	1,39999998	25,3	0,91	SW
17/12/21	0.00	28	28,4	0,771	0	0,8	1,20000005	25	0,92	SW
17/12/21	1.00	27,8	28,2	0,771	0	0,7	0,89999998	24,9	0,93	S
17/12/21	2.00	27,8	28,2	0,774	0	0,9	1,20000005	24,7	0,93	S
17/12/21	3.00	27,8	28,2	0,773	0	1	1,29999995	24,4	0,93	S
17/12/21	4.00	27,7	28,1	0,77	0	1,2	1,39999998	24,3	0,93	S
17/12/21	5.00	27,6	28	0,775	0	1,6	1,89999998	25	0,93	S

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
17/12/21	6.00	27,6	28	0,78	0	1,8	1,89999998	24,8	0,93	S
17/12/21	7.00	28,1	28,6	0,765	0	1,5	1,79999995	25,2	0,92	S
17/12/21	8.00	28,6	29,2	0,73	0	0,9	1,10000002	26,3	0,87	SW
17/12/21	9.00	30,5	31,2	0,66	0	0,5	0,60000002	29,7	0,72	W
17/12/21	10.00	30,6	31,3	0,636	0	0,9	1,10000002	30,3	0,69	NW
17/12/21	11.00	30,9	31,6	0,616	0	1,3	1,5	30,6	0,67	NW
17/12/21	12.00	31	31,6	0,606	0	1,9	2,20000005	30,9	0,68	NW
17/12/21	13.00	30,9	31,4	0,651	0	2,7	3,5	30,8	0,7	NW
17/12/21	14.00	31,2	32	0,64	0	2,9	3,5999999	30,6	0,7	W
17/12/21	15.00	28,7	29	0,728	0	2,8	3,70000005	27,8	0,79	W
17/12/21	16.00	28,8	29,2	0,771	0	2,7	3,70000005	28,2	0,78	SW
17/12/21	17.00	28,9	29,3	0,788	0	1,8	2,79999995	27,5	0,81	SW
17/12/21	18.00	28,7	29,1	0,761	0	1,9	3,29999995	27,3	0,82	SW
17/12/21	19.00	28,6	29	0,748	0	1,8	3,20000005	27	0,83	SW
17/12/21	20.00	28,4	28,8	0,732	0	1,8	3,0999999	26,8	0,83	SW
17/12/21	21.00	28,3	28,7	0,74	0	1,7	3,20000005	26,2	0,85	S
17/12/21	22.00	28,2	28,6	0,711	0	1,3	2,5999999	26	0,85	S
17/12/21	23.00	28,2	28,6	0,713	0	1,2	2,29999995	25,8	0,87	S
18/12/21	0.00	27,9	28,3	0,757	0	1,3	2,4000001	25,4	0,89	S
18/12/21	1.00	27,7	28,1	0,746	0	1,2	2,29999995	25,4	0,89	S
18/12/21	2.00	27,6	28	0,75	0	1,2	2,29999995	25,2	0,9	S
18/12/21	3.00	27,6	28	0,755	0	1,1	2,4000001	24,7	0,91	S
18/12/21	4.00	27,5	27,9	0,759	0	1,3	2,4000001	24,7	0,91	S
18/12/21	5.00	27,5	27,9	0,738	0	1,2	2	24,9	0,9	SE

Date	Time	T1	T2	RH1	WS2	ws10	ws100	T2m	RH2m	wdir
18/12/21	6.00	27,4	27,9	0,732	0	0,9	1,20000005	25	0,9	S
18/12/21	7.00	27,9	28,3	0,719	0	1,1	1,5	25,6	0,88	S
18/12/21	8.00	28,7	29,3	0,665	0	0,8	1	26,3	0,84	SW
18/12/21	9.00	29,4	30	0,652	0	0,9	1	29,2	0,73	W
18/12/21	10.00	30,2	30,9	0,63	0	0,8	1	29,4	0,73	SW
18/12/21	11.00	31	31,9	0,579	0	1	1,20000005	29,9	0,7	SW
18/12/21	12.00	31	31,6	0,572	0	0,8	1,10000002	31,1	0,67	SW

Note: T1: indoor temperature measured by instrument 1; T2: temperature measured by instrument 2; RH1: indoor relative humidity measured by instrument 1; WS2: indoor airflow measured by instrument 2 ws10: outdoor wind speed at 10-m high (m/s) ws100: outdoor wind speed at 10-m high (m/s) T2m: outdoor temperature RH2m: outdoor relative humidity; wdir: wind direction. Weather data provided by ERA5