Journal of Architectural Research and Education

Journal homepage:
https://ejournal.upi.edu/index.php/JARE/index

The Effect of Opening Design on Natural Ventilation in Classrooms of Elementary School 02 Ciputat

Annisa Fitriani [1], Ardhiana Muhsin [2]*

[1, 2] Architecture Department, National Institute of Technology, Bandung, Indonesia

*Correspondence: E-mail: annisa.fitriani@mhs.itenas.ac.id

ABSTRACT

Schools are facilities to meet educational needs and will continue to develop over time. Based on the Basic Education Data from the Ministry of Education and Culture of South Tangerang City, the number of elementary schools in the city is 344. Thermal comfort in the classroom will affect students' learning effectiveness. One of the factors that affects the effectiveness of a room is the suitability of openings in the building for natural ventilation. Poor ventilation will result in suboptimal air circulation in the classroom, which will affect students' concentration during the learning process in the classroom. This study aims to determine the effectiveness of natural ventilation using air opening calculations in a room, specifically the classroom of SDN 02 Ciputat. The results of these calculations will be analyzed and reviewed further, and adjusted to meet the standard values set by SNI 03-6572-2001. The results of the initial design calculations do not meet the standards, so an alternative design that meets the standards is required. The alternative design that was analyzed sufficiently meets the standards with an Inlet Efficiency value of 19.6% and an Outlet Efficiency of 5.9%. This research is expected to provide useful guidelines in constructing more comfortable and efficient elementary school classrooms for building users.

ARTICLE INFO

Article History:
Submitted/Received 3 Jan 2025
First Revised 5 February 2025
Accepted 16 March 2025
First Available online 1 April 2025
Publication Date 1 April 2025

Keyword:
natural ventilation,
opening design,
air opening calculation

1. INTRODUCTION

Indonesia is one of the countries that falls within the humid tropical region with a warm and humid climate. Based on the Gramedia website, there are several characteristics of the tropical climate, including relatively high humidity levels of around 60% to 90%, no clear distinction between the rainy and dry seasons, generally low wind speeds, relatively high solar radiation, and annual temperatures ranging from 18 to 38 degrees during the dry season.

Ciputat District, located in South Tangerang City, is an area with a tropical climate. Hot weather is a dominant issue, as almost the entire year has summer, cloudy, and rainy seasons. Thermal comfort in a building is one of the important aspects that must be met. According to the (Wheater Spark, 2024) website, the air temperature in the city of South Tangerang usually ranges from 73°F to 91°F or equivalent to 22°C to 32°C throughout the year. This can affect thermal comfort.

Based on the Basic Education Data from the Ministry of Education and Culture of South Tangerang City, the number of elementary schools in the city amounts to 344 elementary schools. Elementary education is the basic level of education that starts from the age of six to thirteen years. Natural ventilation generated from strategically designed openings has proven to enhance the flow of fresh air (Bayoumi, 2021). According to studies, good natural ventilation can improve student comfort by lowering the room's CO_2 and other pollution levels in the room (Razak, 2015) (Setiati, 2023). Natural ventilation can produce high-quality air that lowers stress levels and boosts occupant productivity (Idowu et al., 2016). According to the Thermal Comfort Standard, (SNI 03-6572-, 2001), the effective temperature to achieve thermal comfort ranges from 20.5°C to 27.1°C, and a good wind speed is 0.25 m/s.

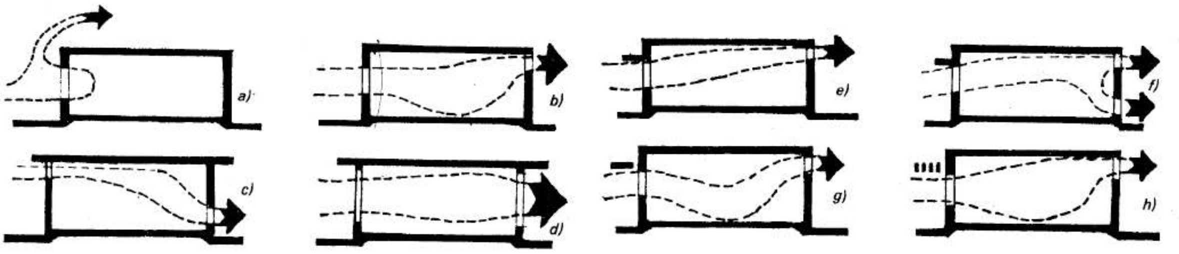

Figure 1. Cross Ventilation (horizontal) Research Results from the Texas Engineering Experiment Station (Source by Mangunwijaya (1988)).

People usually spend more than 90% of their time indoors, so the rooms where they carry out their activities require comfortable air (Lee & M.Chang, 2000). Therefore, the appropriate indoor air velocity is very beneficial for them. Openings or windows serve to provide air circulation, natural light, and the necessary ventilation in every classroom within a building. In addition, the presence of ventilation in the building aims to allow air to enter and exit optimally and to flow within the space, thereby facilitating the process of cross ventilation. Cross ventilation enhances thermal comfort by circulating fresh air and expelling heat, in addition to reducing pollutant and CO_2 levels in classrooms (Rosbach, 2016) (Bain-Reguis, 2022) . Additionally, cross ventilation is an environmentally friendly passive solution that is energy-efficient because it does not require electricity (Reda, 2021). Therefore, to achieve effective comfort in the classroom, it is necessary to consider factors to prevent user discomfort, one of which is determining the design and placing openings and ventilation appropriately.

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

2. BACKGROUND DIMENSION OF DESIGN COMPETENCE

2.1. Natural Ventilation

Ventilation according to the Great Dictionary of the Indonesian Language comes from the word "hawa," which means air, so it can be interpreted that ventilation means air circulation. Ventilation can also be referred to as “penghawaan”. Ventilation is the process of air exchange within a building space that functions to regulate air movement and temperature within that room. Ventilation is divided into two parts: natural ventilation and mechanical ventilation. Natural ventilation is the process of air exchange within a building through the assistance of open building elements (Sudiarta, 2016). Natural ventilation is the process of using physical building components like windows, ventilation, and other openings to let in fresh air from the outside and release hot or dirty air from within a space (Zaniboni & Albatici, 2022). By using natural forces to sustain air circulation, natural ventilation can reduce reliance on mechanical air conditioning systems and save energy (Yang, 2024)

According to (Liddament, 1996), there are several initial requirements for natural ventilation, namely:

a. The availability of fresh outdoor air (free from unpleasant odors, dust, and other disturbing pollutants),
b. The outside air temperature is not too high (maximum 28°C),
c. There are not many buildings around that will obstruct horizontal air, so the wind can blow smoothly.
d. The surrounding environment is not noisy.

The factors for assessing natural ventilation measured by thermal comfort standards according to (Satwiko & Prasasto, 2003) are as follows:

1) Environmental factors include
    a. Air temperature, temperature (T), °C;
    b. Wind speed, Velocity (V), m/s;
    c. Air humidity, Relative Humidity (RH), %;
    d. Average surface temperature of the room, Mean Surface Radiant Temperature (MRT), °C.
2) Human factors include
    a. Human activity, metabolism (Met), w/m2;
    b. Clothing, Clothing (Clo), m2k/w (1 clo=0.155)

In essence, ventilation has three functions according to (Sangkertadi, 1999), among others:

a. Health Function, to meet the need for clean air exchange in a room (WHO requires a minimum air exchange rate for each type of room),
b. The function of air cooling is expected to provide fresh air with a lower temperature than the room temperature.
c. The function of aerothermal comfort, through the breeze on human skin, serves to enhance comfort through the process of sweat evaporation on humans.

2.2. Natural Ventilation Standards

The standard related to natural ventilation is found in the Indonesian National Standard (SNI). The standard used in this research is (SNI 03-6572-, 2001), which contains guidelines for the design of ventilation and air conditioning systems in buildings. This standard provides instructions and guidelines for understanding ventilation systems and how these systems are designed to ensure adequate thermal performance and enhance the comfort quality for users

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

and building occupants. Factors affecting thermal comfort based on (SNI 03-6572-, 2001) include:

1) **Dry Air Temperature There are levels of comfortable temperature for Indonesians**, namely:
   a. Cool and comfortable, effective temperature around 20.5°C - 22.8°C
   b. Optimal Comfort, effective temperature around 22.8°C - 25.8°C
   c. Warm and comfortable, effective temperature around 25.8°C – 27.1°C

2) Relative Humidity

Tropical regions are recommended to have a relative humidity of around 40%-60%. Whereas for rooms with a high number of people, such as meeting rooms, it is recommended to have a relative humidity of around 55%-60%.

3) Air Speed

The air should be less than 0.15 m/s and not more than 0.25 m/s to provide comfort. The design dry air temperature will determine whether this air velocity is 0.25 m/s or higher.

Table 1. Air Velocity and Dry Bulb Temperature (Source by (SNI 03-6572-, 2001))

Air Speed (m/s)	0,1	0,2	0,25	0,3	0,35
Dry Air Temperature (^{0}C)	25	26,8	26,9	27,1	27,2

(SNI, 2001), natural ventilation occurs due to differences in air pressure outside the building caused by wind and temperature differences. The advantages of ventilation in buildings are its ability to save energy, reduce indoor humidity, and eliminate heat and excess heat. Studies show that larger openings do not always result in ideal ventilation and lighting conditions, and the location and orientation of openings must be considered in the design (Vidiyanti, 2020). The natural ventilation provided must consist of:

a. The amount of ventilation required does not approach 5% of the total amount of money required.
b. Open area to the ceiling, or walled yard of suitable dimensions,
c. Open terrace, parking lot,
d. Adjacent room

The design of a natural ventilation system can be carried out as follows:

a. Determining the air ventilation needs according to the function of the room,
b. Determining the wind-driven ventilation or thermal-driven ventilation to be used.

Adjustment of the architectural environment within a building can be done in various ways, including:

a) Placement of building orientation towards sunlight,
b) The placement of buildings in relation to the direction of the wind,
c) The use and utilization of architectural and landscape elements,
d) Use of building materials.

2.3. Types of Ventilation

According to (Sudiarta, 2016), there are 2 types of ventilation opening methods, namely permanent natural ventilation or temporary natural ventilation that can be adjusted for use at any time. There are 4 types of natural ventilation, including:

2.3.1. Window

According to Claude-Alain Roulet and Cristian Ghiaus in Francis Allard (2005), it is stated that windows are adjusted to provide a level of airflow, reduce pollutants

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

generated by activities in the room, reduce heat, and enable passive cooling. The following are types of windows based on the direction of opening, among others:

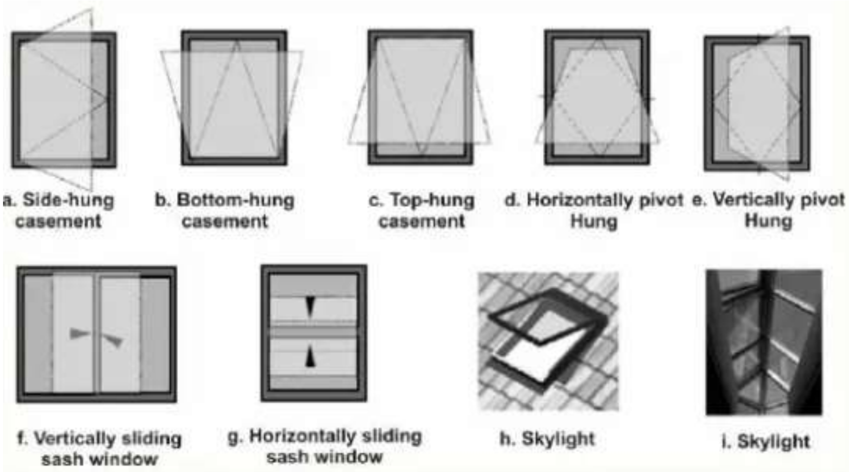

Figure 2. Types of Windows Based on Opening Direction (Source by Claude-Alain Roulet and Cristian Ghiaus in Francis Allard (2005))

Based on SNI, the minimum standard for window openings is 20% of the room area and ventilation is 5% of the room area. The formula for calculating the dimensions of openings or windows based on (Neufert, 1993) (1993)includes: Window dimension = 1/10 (M+N+O+P)

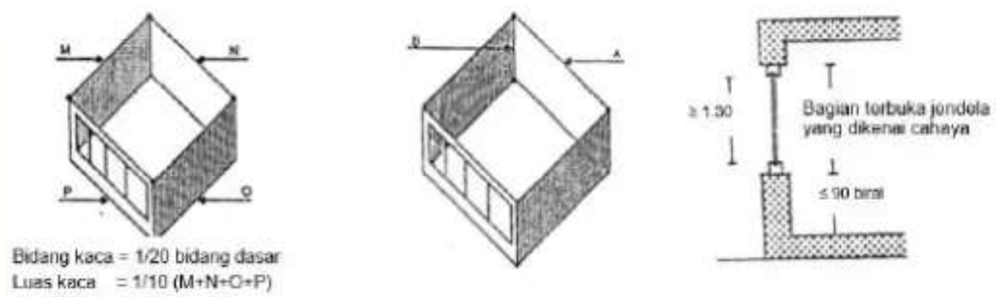

Figure 3. Formula for Calculating Opening Dimensions
(Source by (Neufert, 1993))

2.3.2. Louver

Louver, also known as horizontal Krepyak (jalousie louver), has an outward tilt to prevent rainwater from entering the room. the horizontally mounted louver model, when paired with the appropriate tilt angle and dimensions, optimizes natural lighting (Ardianti Sabtalistia, 2023).

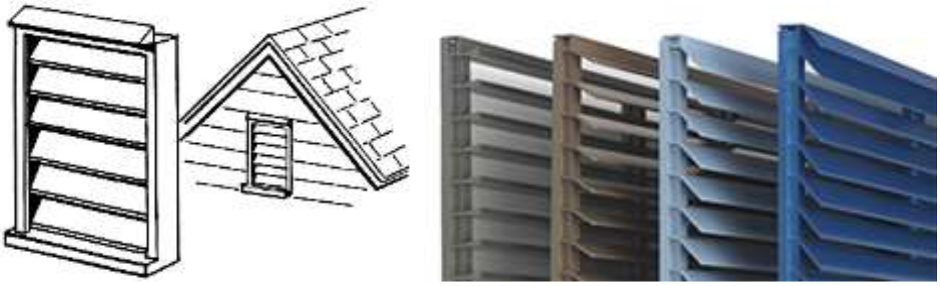

Figure 4. Louver (Source by Google)

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

2.3.3. Vents or Air Holes (Loster)

Air vents can control airflow and prevent the infiltration of rainwater, dust, and insects to reduce noise.

Figure 5. Air Hole
(Source by Google)

2.3.4. Bouvenlight

Bouven is usually located above the window or door frame, and can be a single piece or separate. The types of boven vary, some have leaves like regular windows, while others are filled with two glass panels, leaving an air gap. Haryadi and Sukmawati's research indicates that ventilation and lighting systems can improve the comfort and health of the surroundings (Syahrul & Akhyan, 2021).

Figure 6. Bouvenlight
(Source by google)

2.3. Cross Ventilation

The most influential climate factors include air and wind. (Widyanto, 2018) stated that the movement of horizontal and vertical winds has different speeds. The movement of the wind is caused by differences in air pressure when it moves from high pressure to low pressure. According to (Melita et al., 2017), wind speed affects thermal comfort, and one of the factors that reduces indoor temperature, resulting in a cooling effect, is air speed. Research indicates that cross-ventilation design can lower CO2 concentration and increase thermal comfort (Wiranata, 2023) (Suhendri & Koerniawan, 2017). According to a study, when compared to traditional cooling systems, cross-cooling systems can reduce a building's energy consumption by up to 30% (Aseyan, 2025). Cross ventilation can be effectively incorporated to increase thermal comfort without adding to the expenses of running a sophisticated HVAC system (Gharakhani, 2014).

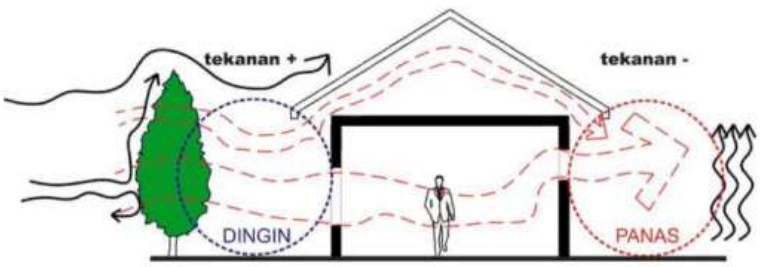

Figure 7. Ventilation Scheme
(Source by (Sudiarta, 2016))

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

Quoted from the book "Fisika Bangunan 1" (Laela, 2013) Cross Ventilation or Ventilasi Silang is a type of ventilation where the movement of air crosses the room in a crisscross manner, from the air inlet to the air outlet. The requirements for placing the inlet and outlet include:

1) The inlet is located in the windward area,
2) The outlet is located in the leeward area,
3) In terms of layout and section, the allocation of the inlet is not directly facing the outlet,
4) The outlet elevation should be higher than the inlet (warm air moves up the space).

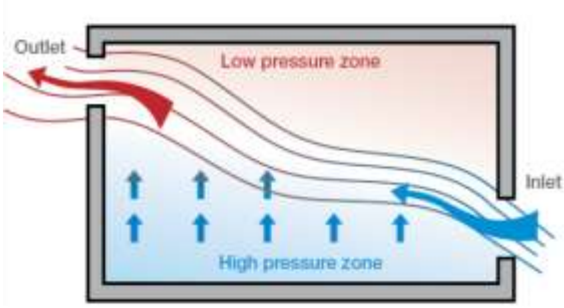

Figure 8. Natural Air Conditioning
(Source by http://passivesolar.sustainablesources.com/#cool)

3. METHODOLOGY

The methodological approach used in this research is both qualitative and quantitative methods. The qualitative method is often associated with case studies. This method is used to generate data from various sources as well as literature in the form of written data (Ambarawati, 2021). Based on the theory of positivism, which argues that people can acquire knowledge by observing and measuring things in the real world (Susilowati, 2023). Whereas quantitative data is data that can be measured and calculated directly, regarding information or explanations in the form of numbers or statistics (Kuncoro, 2021).

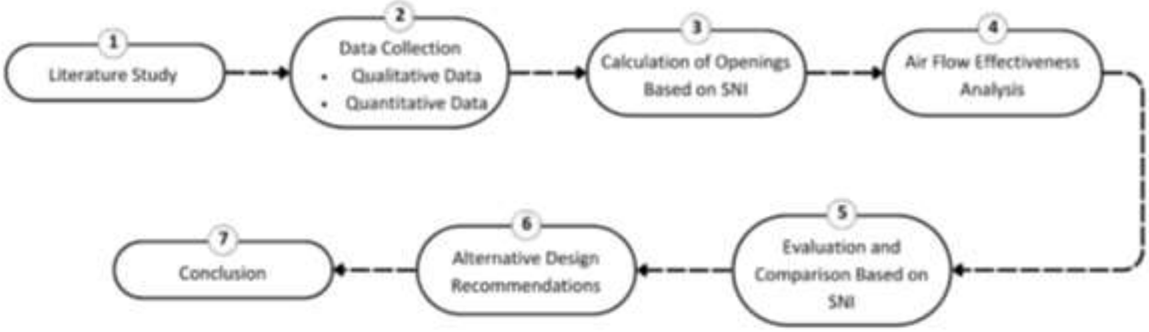

Figure 9. Research Stages Based on Methodology
(Source by by Author, 2024)

To strengthen the methodological foundation regarding natural ventilation and SNI standards, this research began with a literature review. Data were collected qualitatively through observations and written documents, as well as quantitatively through direct measurements such as opening area, floor area, and classroom volume at SDN 02 Ciputat. The results of the object to be studied in data collection use air opening calculations based on formulas aimed at analyzing the effectiveness of air flow in a room, specifically the classroom of SDN 02 Ciputat. The calculation results will be analyzed and adjusted to meet the natural

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

ventilation standards. From the tested calculation results, alternatives or opening recommendations will be made if the initial design does not meet SNI standards.

4. EVALUATION FINDINGS AND INSIGHTS

4.1. Site Analysis

SDN 02 Ciputat is located at Jl. Pemuda No.7, Ciputat, Kec. Ciputat, Kota Tangerang Selatan, Banten. This building is located at the coordinates latitude -6.309718562182197 and longitude 106.74672472400907. The area of this school is approximately 1186 m2. As seen in Figure 11, the area shaded in yellow is the existing land of the SDN 02 Ciputat building.

Figure 10. Existing Land Location
(Source by Author, 2024)

SDN 02 Ciputat is surrounded by commercial buildings, public facilities, places of worship, and other educational buildings. As seen in Figure 11, there are several buildings around the existing structure, including SMAN 1 Tangerang Selatan located to the northwest, TK Aisyiyah 42 located to the north of the existing structure, a commercial area located to the north and northeast, SD Negeri 6 Ciputat located to the east of the existing structure, Masjid Agung Al-Jihad located to the southeast, GOR Ciputat located to the south of the existing structure, a residential area located to the southwest, and Stadion Mini Ciputat located to the west of the existing structure, as well as other buildings surrounding the existing land of SDN 02 Ciputat.

Figure 11. Analysis of the Existing Surrounding Environment and Existing Condition
(Source by Author, 2024)

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

The existing building condition consists of 2 floors with only 11 classrooms, which is insufficient to support the teaching and learning activities. In addition, there is no Scout Room, and the Computer Lab and Teacher's Room are very small. Therefore, PT. Yodya Karya Branch Bandung has been assigned to revise this building to improve both its design and functionality by renovating the school building into three floors. Figure 11 shows the existing condition of the SDN 02 Ciputat building.

Figure 12. Isometry and Land Analysis
(Source by Author, 2024)

As seen in Figure 12, the front facade of the building is elongated and faces west. This results in a significant amount of light and heat hitting the building, necessitating the design of a facade that minimizes sunlight and heat by creating overhangs on each floor. This aims to create a shade so that the sun does not directly enter the building. The main access to the site is quite difficult for four-wheeled vehicles to navigate because the road width is only 3.5 meters. The entrance and exit for pedestrians and vehicles, as shown in the picture, have the same entry area. The most dominant noise is on the west side because the building is close to Jl. Pemuda, which is a vehicle circulation route and the main access to the area.

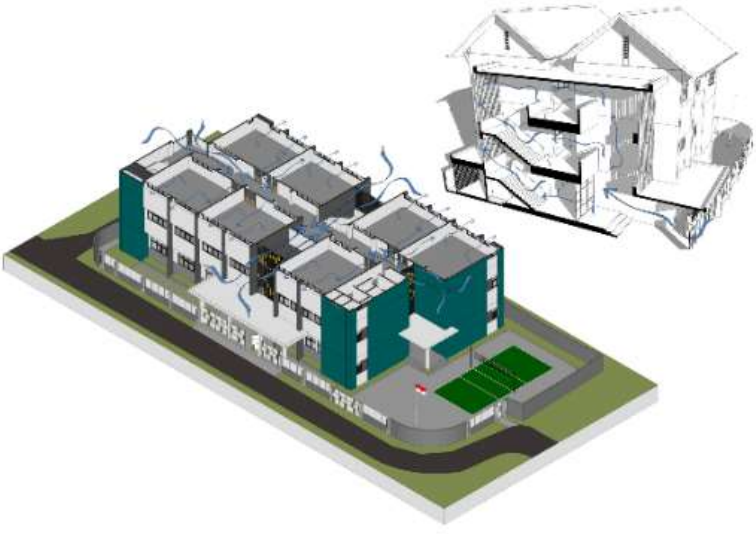

Figure 13. Axonometric Scheme of Cross Ventilation in the Building
(Source by Author, 2024)

According to the Weatherspark website, the highest average wind speed occurs in January with an average wind speed of around 7.30 mph or equivalent to 11.75 km/h. Meanwhile, the

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

lowest or calmest wind speed occurs in October with an average wind speed of around 4.70 mph or equivalent to 7.56 km/h. This building consists of 4 building masses connected by corridors, forming a single unit. In this design, air flows through the connecting corridors between the building masses and enters and exits through window openings, creating cross ventilation as shown in Figure 13.

4.2. Opening Analysis

The analysis of the size and position of openings in educational buildings must be conducted to meet comfort standards and SNI natural ventilation because it will affect air quality, student concentration, and energy efficiency in the classroom.

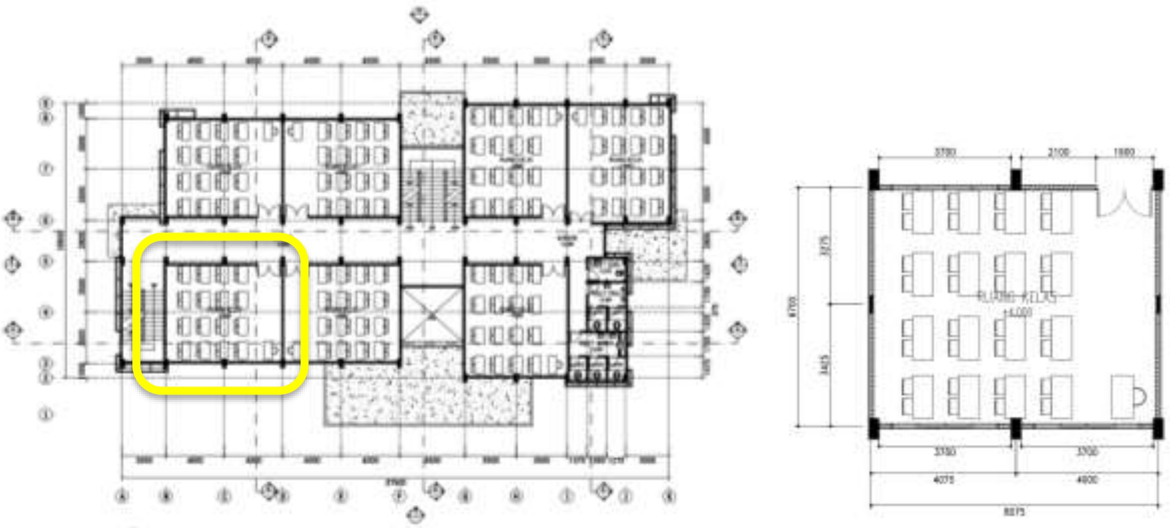

Figure 14. Second Floor Plan and Classroom Layout
(Source by Author, 2024)

The analyzed space is the second-floor classroom along axes 2-5 and B-D, marked with a yellow dashed box. As seen in the analyzed classroom layout, the inlets and outlets face each other, allowing for cross ventilation within the classroom space. The building openings on the west side have operable windows and a vent. Meanwhile, on the east side of the classroom, there are fixed windows, operable windows, a vent, and a door. There are no openings on the north and south sides. The area of this classroom is 54.10 m². The minimum inlet opening area in this elementary school classroom is 10.82 m² and the minimum outlet opening area is 2.71 m². The area of these openings must comply with (SNI 03-6572-, 2001), which states that the number of ventilation openings should be no less than 5% of the area of the room requiring ventilation, and the minimum standard for inlet opening area is 20%.

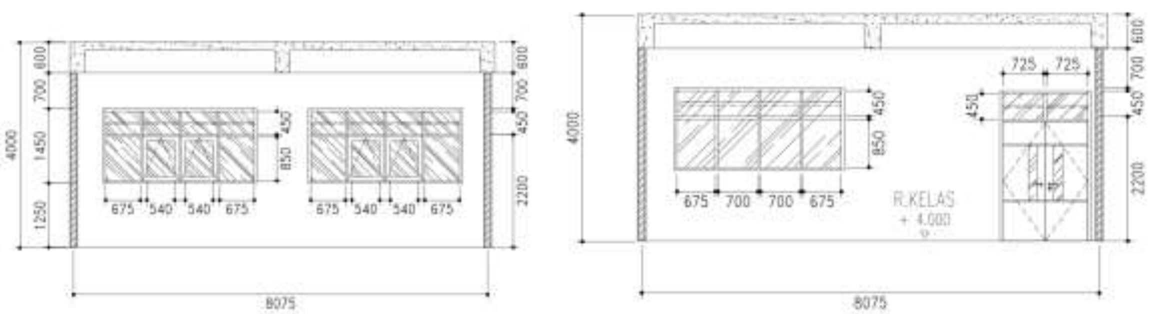

Figure 15. Top-Hung Classroom Window
(Source by Author, 2024)

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

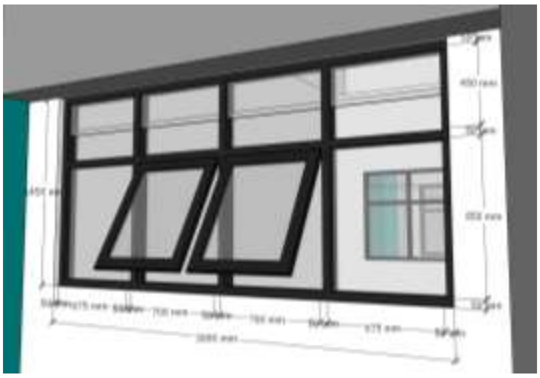

Figure 16. Top-Hung Classroom Window
(Source by Author, 2024)

The windows of this elementary school classroom use top-hung casement types designed with hinges at the top. This window can be opened outward away from the frame or casing. There are 2 top-hung windows and a fixed window on the wall of this building. The type of top-hung window is often used in modern building designs due to its minimalist shape and greater opportunity for natural light to enter. As for the zig-zag glass above the window.

Different architectural approaches to opening designs must take both functional and aesthetic factors into account in order to provide students with an engaging and productive learning environment (Prasetya, 2021). Therefore, a comprehensive airflow analysis, such as that conducted by Tandafatu, can provide guidance for designing comfortable and supportive classroom environments (Maria Carolin Tandafatu, 2021).

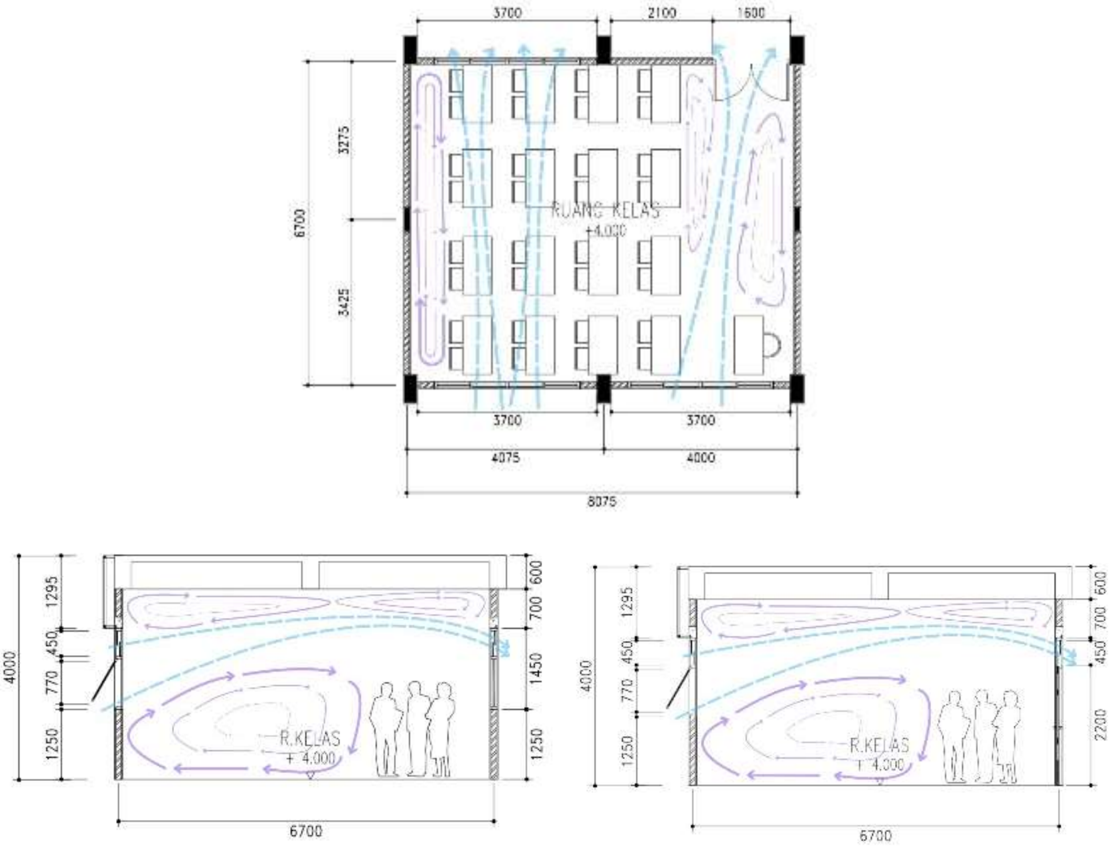

Figure 17. The Movement of Cross-Ventilation Wind in The Plan and Section
(Source by Author, 2024)

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

The image above is a scheme of horizontal and vertical wind cross ventilation in the floor plan and section of the classroom. There are wind flow patterns in the image, namely laminar and turbulent flows. The blue color indicates that the wind has a laminar flow pattern because its direction is orderly, while the purple color represents a turbulent flow pattern where the direction is irregular.

4.3. Calculation of Air Openings

The area of this opening must comply with (SNI 03-6572-, 2001), which states that the number of ventilation openings should be no less than 5% of the area of the room requiring ventilation, and the minimum standard for inlet opening area is 20%. The area of this classroom is 54.10 m². The minimum inlet opening area in this elementary school classroom is 10.82 m² and the minimum outlet opening area is 2.71 m². The effectiveness of the air flow at both the inlet and outlet is 75%. It is known that the air velocity (v) is 0.1 m/second. The results of the aperture calculations, among others:

- Effective Area Inlet = 75% x design inlet area = 75% x 3,6650 m2 = 2,75 m²
- Inlet Opening Percentage = 2,75 m² / 54,10 x 100% = 5,08%
- Effective Outlet Area = 75% x design outlet area = 75% x 1,8850 m² = 1,41 m²
- Outlet Opening Percentage = 1,41 m² / 54,10 x 100% = 2,61%
- Volume of Space (V) = 8,0750 x 4,0000 x 6,7000 = 216,41 m³
- The air flow that occurs (Q) = 0,5682 x A x V = 0,5682 x 2,75m² x 0,1m/s = 0,1562 m³/second = 9,37 m³/min
- ACH that Occurs at the Inlet = 60 Q / V = 60 x 9,37 m³/min / 216,41 m³ = 2,62

Based on the results of the calculations, the air changes per hour (ACH) in this design do not meet the existing standards. The standard ACH for classrooms ranges from 3-4, whereas this design only has 2,62. This can affect the thermal comfort in the room.

4.4. Alternative Opening

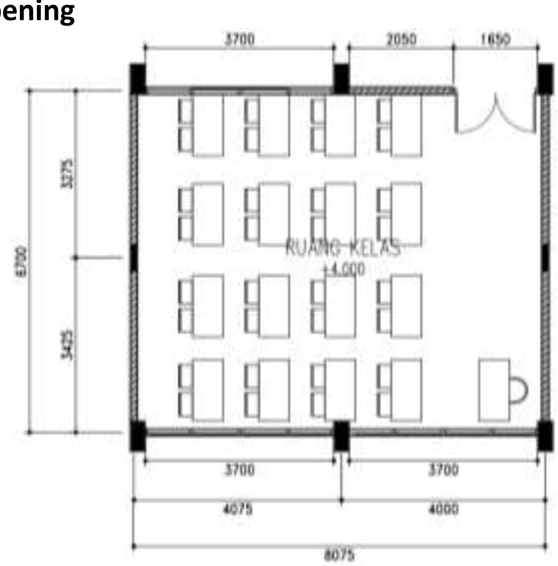

Figure 18. Floor Plan of Opening Dimension Changes
(Source by Author, 2024)

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

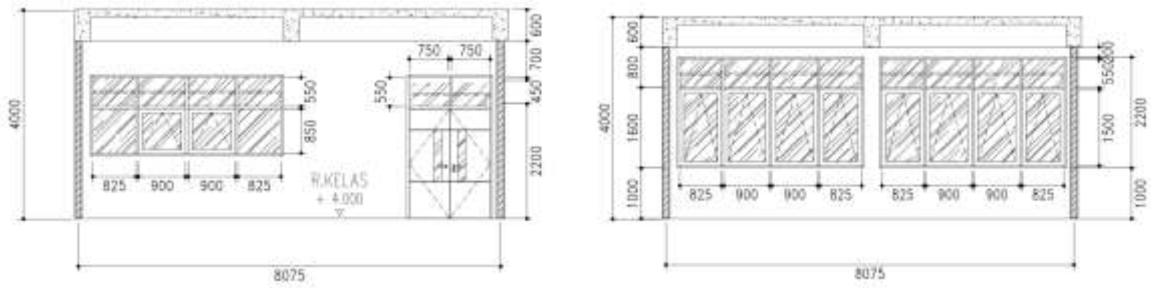

Figure 19. Section of Opening Dimension Changes
(Source by Author, 2024)

To create an even distribution of air, it is necessary to design openings that are appropriate and meet the (SNI 03-6572-, 2001) standards. There are recommended openings that have been calculated and are expected to be the right solution to achieve optimal thermal comfort and natural ventilation in the classroom. To address the issues with the initial opening design, larger window and ventilation dimensions are needed. This can affect the final calculation results.

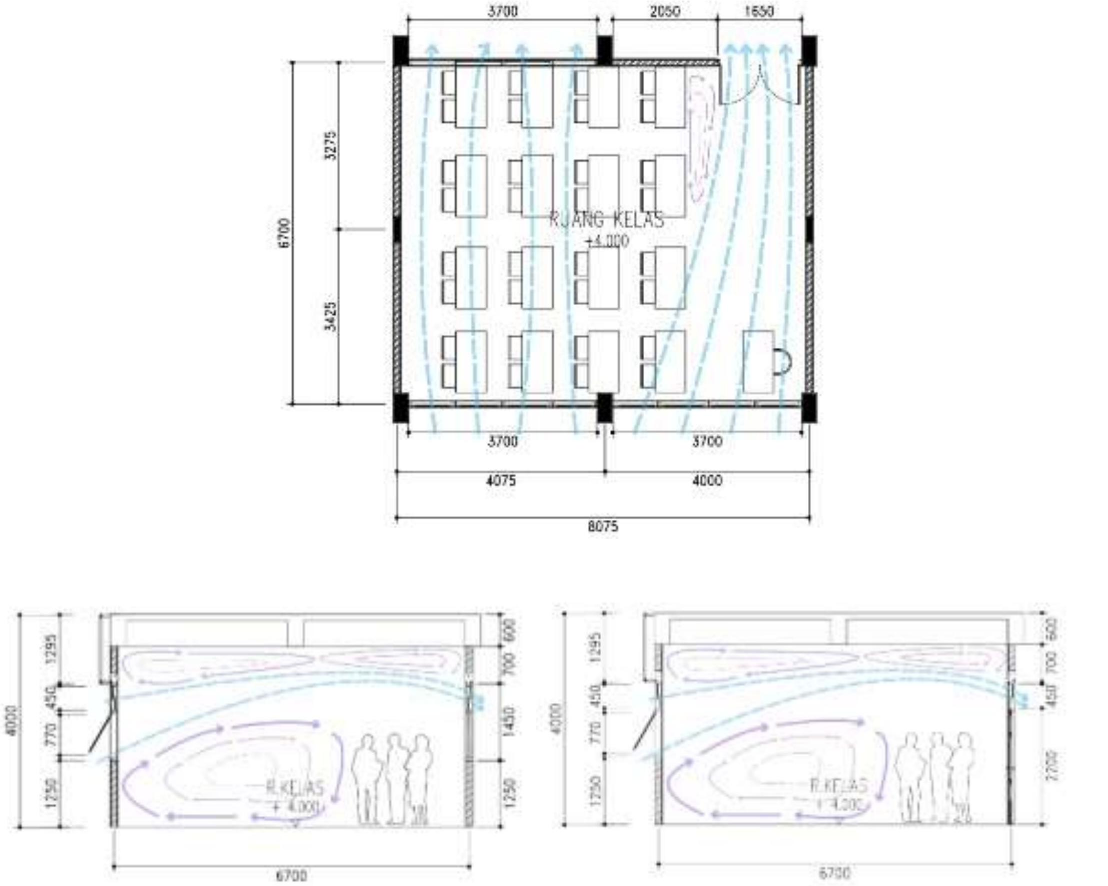

Figure 18. Plan and Section of The Changes in Cross-Ventilation Wind Movement
(Source by Author, 2024)

As seen in Figure 18, the airflow slightly changed due to the alteration of opening dimensions and the addition of operable windows in the classroom. The pattern of turbulent flow seen in the image is less than the initial design, and vice versa. the following are the results of the opening recommendation calculations, among others:

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

- Effective Area Inlet = 75% x design inlet area = 75% x 14,1450 m2 = 10,61 m^2
- Inlet Opening Percentage = 10,61 m^2 / 54,10 x 100% = 19,6%
- Effective Outlet Area = 75% x design outlet area = 75% x 4,2525 m^2 = 3,19 m^2
- Outlet Opening Percentage = 3,19 m^2 / 54,10 x 100% = 5,89%
- Volume of Space (V) = 8,0750 x 4,0000 x 6,7000 = 216,41 m^3
- The Air Flow that Occurs (Q) = 0,5682 x A x V = 0,5682 x 10,61 m^2 x 0,1m/s = 0,6029 m^3/second = 36,17 m^3/min
- ACH that Occurs at the Inlet = 60 Q / V = 60 x 36,17 m^3/min / 216,41 m^3 = 10,03

Based on the results of the alternative opening calculations, the air changes per hour (ACH) in this design reach 10.03, exceeding the existing standard. ACH is the air change rate that functions to achieve thermal comfort and Indoor Air Quality (IAQ), which affects the teaching and learning process in classrooms. Even though it exceeds the standard, there is still a solution to address the excess air entering by closing the ventilation that is deemed unnecessary. For the effective area of the inlet opening, it is almost up to standard, and the effective area of the outlet has already met the SNI standard.

5. CONCLUSION

Natural ventilation in the classroom will affect students effectiveness in the learning process. One of the physical conditions of the classroom that must be considered is the openings and air circulation from inside and outside, which must be sufficient and meet the standards. Based on the analysis and discussion of the research on the objects studied, it can be concluded that the initial design of the classroom at SDN 02 Ciputat did not meet the standards. This is evidenced by the calculation results of air openings from the effectiveness of openings to Air Changes Per Hour (ACH) which are below the (SNI 03-6572-, 2001) standard. Therefore, there is an alternative opening that has better results than the initial design, but the Air Changes Per Hour (ACH) in this alternative design exceeds the existing standards. To address the excess incoming air, the unnecessary windows should be closed.

REFERENCES

Boutet, T.S. (1987) Controlling Air Movement: A Manual for Architects and Builders. McGraw Hill Book Company, New York.

Ambarawati, M., Pujinugroho, M. A., Burat, T., N.M, A. R., Munika, M., Bondi, A., & Sawe, M. (2021). Analisis Kesulitan Siswa Dalam Mempelajari Diagram Lingkaran. Prismatika: Jurnal Pendidikan Dan Riset Matematika, 4(1), 1–7. https://doi.org/10.33503/prismatika.v4i1.1276

Ardianti Sabtalistia, Y. (2023). Pengaruh Dimensi dan Sudut Kemiringan Louver Terhadap Pencahayaan Alami. Pawon: Jurnal Arsitektur, 7(1), 79–94. https://doi.org/10.36040/pawon.v7i1.4559

Aseyan, B., Babatunde, M., Shittu, A., & Agboola, S. (2025). Strategies and Elements of Natural Ventilation for Energy Efficient Buildings Used in Selected Universities in South Western Nigeria. IOP Conference Series: Earth and Environmental Science, 1492(1), 012012. https://doi.org/10.1088/1755-1315/1492/1/012012

Bain-Reguis, N., Smith, A., Martin, C. H., & Currie, J. (2022). Indoor CO2 and Thermal Conditions in Twenty Scottish Primary School Classrooms with Different Ventilation

Systems during the COVID-19 Pandemic. Pollutants, 2(2), 180–204. https://doi.org/10.3390/pollutants2020014

Bayoumi, M. (2021). Improving Indoor Air Quality in Classrooms via Wind-Induced Natural Ventilation. Modelling and Simulation in Engineering, 2021, 1–14. https://doi.org/10.1155/2021/6668031

Gharakhani, A., Sediadi, E., Hayat Khan, T., & Sabzevar, H. B. (2014). Use of Natural Ventilation in Malaysia's Future Green Housing. Advanced Materials Research, 935, 316–319. https://doi.org/10.4028/www.scientific.net/AMR.935.316

Idowu, I. A., Shari, Z., & Jaafar, M. F. Z. (2016). Evaluating Natural Ventilation Provisions and Occupants' Ventilation Behavior in Five Terrace Housing Types In Putrajaya, Malaysia. International Journal of Architectural Research: ArchNet-IJAR, 10(2), 130. https://doi.org/10.26687/archnet-ijar.v10i2.868

Laela, N. L. (2013). Fisika Bangunan I. Jakarta: Griya Kreasi.

Lee, S. C., & M.Chang. (2000). Indoor and Outdoor Air Quality Investigation at Schools in Hong Kong. PERGAMON Journal, Chemosphere.

Liddament, M. A. (1996). Guide to Energy Efficient Ventilation. Air Infiltration and Ventilation Centre, Coventry.

Maria Carolin Tandafatu, Noralita M. Soludal, & Febryanti Alwisye Wara. (2021). Analisis Aliran Udara untuk Meningkatkan Kenyamanan Termal pada Ruang Kelas di Maumere – Nusa Tenggara Timur. Seminar Nasional Teknologi Dan Multidisiplin Ilmu (SEMNASTEKMU), 1(1), 300–307. https://doi.org/10.51903/semnastekmu.v1i1.122

Melita, A. H., Adhitama, M. S., & Nugroho, A. M. (2017). Pengaruh Bukaan Terhadap Kenyamanan Suhu Pada Masjid Jakarta Islamic Center. Jurnal Mahasiswa Jurusan Arsitektur Universitas Brawijaya.

Neufert, Ernst. (1993). Data Arsitek: Jilid 2. Jakarta : Penerbit Erlangga.

Prasetya, A. D. D. (2021). Penghawaan dan Pencahayaan Alami. Jurnal Ilmiah Arsitektur, 11(1), 28–32. https://doi.org/10.32699/jiars.v11i1.1876

Razak, H. (2015). Pengaruh Karakteristik Ventilasi dan Lingkungan Terhadap Tingkat Kenyamanan Termal Ruang Kelas SMPN di Jakarta Selatan. AGORA:Jurnal Penelitian Dan Karya Ilmiah Arsitektur Usakti, 15(2). https://doi.org/10.25105/agora.v15i2.2024

Reda, I., AbdelMessih, R. N., Steit, M., & Mina, E. M. (2021). Quantifying Fenestration Effect on Thermal Comfort in Naturally Ventilated Classrooms. Sustainability, 13(13), 7385. https://doi.org/10.3390/su13137385

Rosbach, J., Krop, E., Vonk, M., Van Ginkel, J., Meliefste, C., De Wind, S., Gehring, U., & Brunekreef, B. (2016). Classroom ventilation and indoor air quality-results from the FRESH intervention study. Indoor Air, 26(4), 538–545. https://doi.org/10.1111/ina.12231

Sangkertadi, F. R. (1999). Pembuatan program simulasi penghawaan alami Ventila.1.0 untuk pengembangan praktikum pada mahasiswa Arsitektur S-1.

Satwiko, & Prasasto. (2003). Fisika Bangunan 1. Yogyakarta: Penerbit Andi.

Setiati, T. W., Febrina, S. E., & Islami, F. S. (2023). Investigasi Kualitas Udara Ruang Kelas dengan Perubahan Ventilasi Aktif Menjadi Alami Pasca Pandemi di Daerah Tropis Lembab. Arsir, 6(2), 126. https://doi.org/10.32502/arsir.v6i2.5167

SNI 03-6572-. (2001). Tata Cara Perancangan Sistem Ventilasi dan Pengkondisian Udara pada Bangunan Gedung. In Sni 03—6572—2001.

Sudiarta, I. N. (2016). Penghawaan Alami. Faculty of Law Arts and Social Sciences. School of education. Universitas Udayana; Indonesia.

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279

Suhendri, S., & Koerniawan, M. D. (2017). Investigasi Ventilasi Gaya-Angin Rumah Tradisional Indonesia dengan Simulasi CFD. Jurnal Lingkungan Binaan Indonesia, 6(1), 39–44. https://doi.org/10.32315/jlbi.6.1.39

Susilowati, H., Lering, M. E. D., Laru, M. M., & Bela, M. Y. (2023). Penerapan Metode Pembelajaran "Vakt "Untuk Mengatasi Kesulitan Membaca Peserta Didik Di Sos Children's Villages Flores Kabupaten Sikka. Sentri: Jurnal Riset Ilmiah, 2(5), 1747–1750. https://doi.org/10.55681/sentri.v2i5.885

Syahrul, R., & Akhyan, A. (2021). Pengaruh Kecepatan Fluida Pendingin (Udara) Terhadap Unjuk Kerja Dan Karakteristik Perpindahan Panas Pada Radiator Sepeda Motor Yamaha Nmax 155CC. Jurnal Teknik Mesin, 14(2), 106–111. https://doi.org/10.30630/jtm.14.2.671

Vidiyanti, C., Siswanto, R., & Ramadhan, F. (2020). Pengaruh Bukaan Terhadap Pencahayaan Alami dan Penghawaan Alami pada Masjid Al Ahdhar Bekasi. Jurnal Arsitektur Zonasi, 3(1), 20–33. https://doi.org/10.17509/jaz.v3i1.18621

Wheater Spark. (2024). Rata-rata Kecepatan Angin di Tangerang Selatan.

Widyanto, H. B. (2018). Sistem Monitoring Kecepatan dan Arah Angin Berbasis Internet of Thing (IOT) Sebagai Peringatan Dini Bencana Alam. Skripsi. Fakultas Teknik. Teknik Elektro. Universitas Brawijaya: Malang.

Wiranata, T. A. (2023). Persepsi Masyarakat dalam Penerapan Rumah hemat Energi. Jurnal Lingkungan Binaan Indonesia, 6(1), 38–42. https://doi.org/10.32315/jlbi.6.1.22

Yang, L., Zhang, Q., & Zhai, H. (2024). Comparative efficacy of different concentrations of chlorhexidine for prevention of ventilator-associated pneumonia in intensive care units: A systematic review and network meta-analysis. Nursing in Critical Care, 29(2), 246–254. https://doi.org/10.1111/nicc.12849

Zaniboni, L., & Albatici, R. (2022). Natural and Mechanical Ventilation Concepts for Indoor Comfort and Well-Being with a Sustainable Design Perspective: A Systematic Review. Buildings, 12(11), 1983. https://doi.org/10.3390/buildings12111983

DOI: https://doi.org/10.17509/jare.v7i1.79033
p- ISSN 2776-9909 e- ISSN 2580-1279