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Identifying Indoor Air Quality: A Case Study of Healthcare Facilities in Tropical Area

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ABSTRACT

A building requires good ventilation planning, especially for health facility buildings. Ventilation plays a role in supplying clean air and creating good indoor air quality. This research applied descriptive quantitative methods by doing direct measurements in the field. The measurements were taken when registration room of the Pudukpayung Health Center, Semarang City, at Payung Mas Raya Street, was in service. This study identifies the air change rate that improves indoor air quality in health facility buildings in tropical areas. Direct field measurements were conducted in this study and then analyzed based on the appropriate recommendation standards. The results of this study show that some variables still need to meet the recommendation standards in meeting the requirements of good air quality. This proves that ventilation has an essential role in air conditioning in the room, creating clean and healthy air.

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1. INTRODUCTION

A well-ventilated building design is essential for a healthy indoor environment. It allows fresh air from outside to enter the room and influence the indoor climate. This is especially relevant for tropical climates like Indonesia, where the humidity and sunlight are relatively high all year round. The fresh air can alter the indoor climate through ventilation; for instance, it can reduce the room's temperature and relative humidity (Zhao, Sun, and Tu 2018). As fresh air comes in, it lowers the room temperature and relative humidity in an inverse proportion. This also reduces fatigue and headache symptoms and improves performance when the room temperature and relative humidity are slightly lower (Hong, Kim, and Lee 2018), this is also related to the contaminants that come from indoor and outdoor sources. Therefore, it is necessary to know how to find solutions for optimizing air movement through natural ventilation suitable for tropical climates to create healthy air quality by lowering contaminants in the room.

1.1. Ventilation

Ventilation is a place where air freely enters and exits (Hoetomo, 2005). According to (EPA (United States Environmental Protection Agency) 1990), ventilation is "a combination of processes that result in the supply and removal of air from inside a building". Outdoor air is brought in, conditioned, mixed with indoor air, and distributed in the building. Some indoor air is also moved outside. The indoor air quality depends on how well these processes are done. If they are done well, the indoor air quality will improve.

There are two main categories of ventilation: natural and mechanical. Mechanical ventilation involves central AC (like AHU, FCU, and AHU mix FCU) and non-central AC (like window and single split types). AC can influence how infectious agents spread and cause diseases in buildings and health facilities (Jung et al. 2015). Based on the research conducted by Baurès et al, it shows low pollution in health facility buildings likely related to ventilation and air conditioning systems (Baurès et al. 2018).

Ventilation plays a vital role in indoor air quality. This study will focus more on natural ventilation. This is when the wind and temperature differences create a pressure difference outside a building, which makes hot gases flow through the ventilation ducts. Natural ventilation consists of permanent openings, windows, doors or other open means (Rahim 2012). Wide and open ventilation and better airflow. Adding exit holes improves air quality.

How well the ventilation system works relies significantly on how it distributes the air. Many studies have shown that raising the ventilation rate is insufficient to eliminate pollutants in the room if the air distribution system is inappropriate (Deng, Feng, and Cao 2018).

1.2. Ventilation Rate and Air Changes per Hour

Ventilation rate is influenced by the average air speed, strong wind direction, variation of speed and wind direction seasonally and daily, and local obstacles, such as adjacent buildings, hills, and trees (Rahim 2012). The ventilation rate is based on the number of air changes per hour if the number of users has yet to be discovered. This depends on the building type and function (Szokolay 1980). Air changes per hour mean how much air in a room is replaced every hour. It is when fresh or clean air takes the place of dirty air. Air changes per hour significantly impact how temperature and air quality are controlled in the house. The formula below can be used to calculate air changes per hour:

$$N = \frac{3600 Q}{V} \quad (1)$$

where:

N is the air change rate for each hour (times/hour)

Q is the ventilation rate or air flow rate (m^3/s)

V is the volume of the room (m^3)

3600 is the conversion factor (from second to hour)

Air exchange through building ventilation is needed to provide oxygen for breathing and remove respiratory products (CO_2 , water vapour) and contaminants produced by various processes (Szokolay 1980). According to (ANSI/ASHRAE/ASHE 2017), the total air changes per hour for health facility buildings is at least 12 times/hour. According to (U.S. Department Of Health And Human Services and Control 2019) *Guidelines for Environmental Infection Control in Health-Care Facilities*, the air changes per hour is ≥ 12 times/per hour.

1.3. Indoor Air Quality

By bringing in fresh air from the outside, ventilation creates a healthy indoor environment. The fresh air entering the room can influence the indoor climate. The room's temperature and relative humidity can be lowered by the fresh air entering the room, which can also decrease fatigue and headache symptoms and increase performance (Zhao, Sun, and Tu 2018). The humidity level and the humidity risk in the room also depend on the ventilation rate. The humidity can be reduced by raising the ventilation rate, but it also varies with different climate zones (Tang et al. 2020).

Much time is spent by people indoors. IAQ is still a significant problem affecting occupants' health, such as Sick Building Syndrome, especially with the impact of the COVID-19 pandemic. The need to focus on design strategies to enhance IAQ is highlighted by the health conditions of the room users because inefficient ventilation causes poor air quality. It is claimed that occupants have a higher chance of getting diseases in rooms with lousy ventilation than in rooms with good ventilation. Moreover, new proof has been discovered that indicates high infection rates in rooms with inadequate ventilation (CIBSE 2020). Ventilation is essential for reducing the spread of diseases (Lipinski et al. 2020).

IAQ has always been a critical factor in evaluating how different buildings perform and can be measured by the number of air pollutants in the indoor environment. However, this approach must be backed up by specific policy changes in the public health, urban planning, and architectural design sectors (Megahed and Ghoneim 2020).

2. RESEARCH METHODS

This research applied descriptive quantitative methods by doing direct measurements in the field. The measurements were taken when registration room of the Pudukpayung Health Center, Semarang City, at Payung Mas Raya Street, was in service. The registration room is essential because various patients with possible diseases gather in the room before seeing the doctor. Registration room in this building has natural ventilation and a fan and does not use AC (Air Conditioner)—a research instrument used for direct measurements in the field. A descriptive analysis was done after the measurement based on the suggested standard.

3. RESULTS AND DISCUSSION

The registration room of the Pudukpayung Health Center has natural cooling with a fan as an addition, and these are the measurements of the room.

Room Area	92,41 m ²
Ceiling Height	4,2 m
Ventilation Area	11,12 m ² (12% of floor area)
Room Volume	377 m ³
Room Capacity	40 people
Occupancy Density	40/92,41 m ² = 0,43/m ²
Building Orientation	East-West Building openings on the north-south side

Figure 1. Measurements of the room
Source: Analysis, 2024

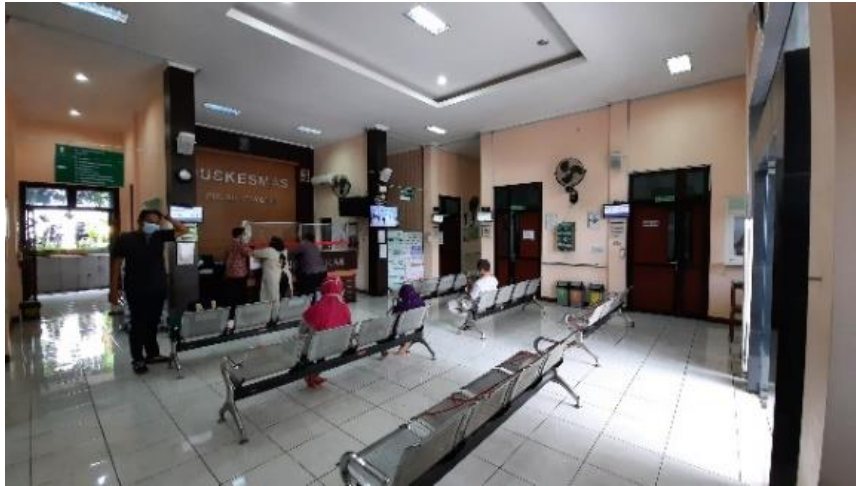


Figure 2. Existing Conditions of the Pudakpayung Health Center
Source: Documentation, 2024

We can see that the existing building condition has a ventilation area of 12%, which should be at least 15% of the floor area, according to The Minister of Health Regulation no 75 of 2014. The position of the ventilation is seen in Figure 2, and its details are shown in Figure 3. Meanwhile, the existing room density is 0.43/m², which is still too crowded according to ANSI / ASHRAE Standard 62.1-2019. The high density of the occupant in indoor spaces can cause an increase in carbon dioxide (CO₂) levels in the air. CO₂ is a gas humans produce when breathing and burning fossil fuels. If CO₂ accumulates indoors, it can lower air quality and disrupt the health of occupants. To reduce the risk of CO₂ accumulation indoors, it is by optimizing ventilation in the room (ASHRAE 2022).

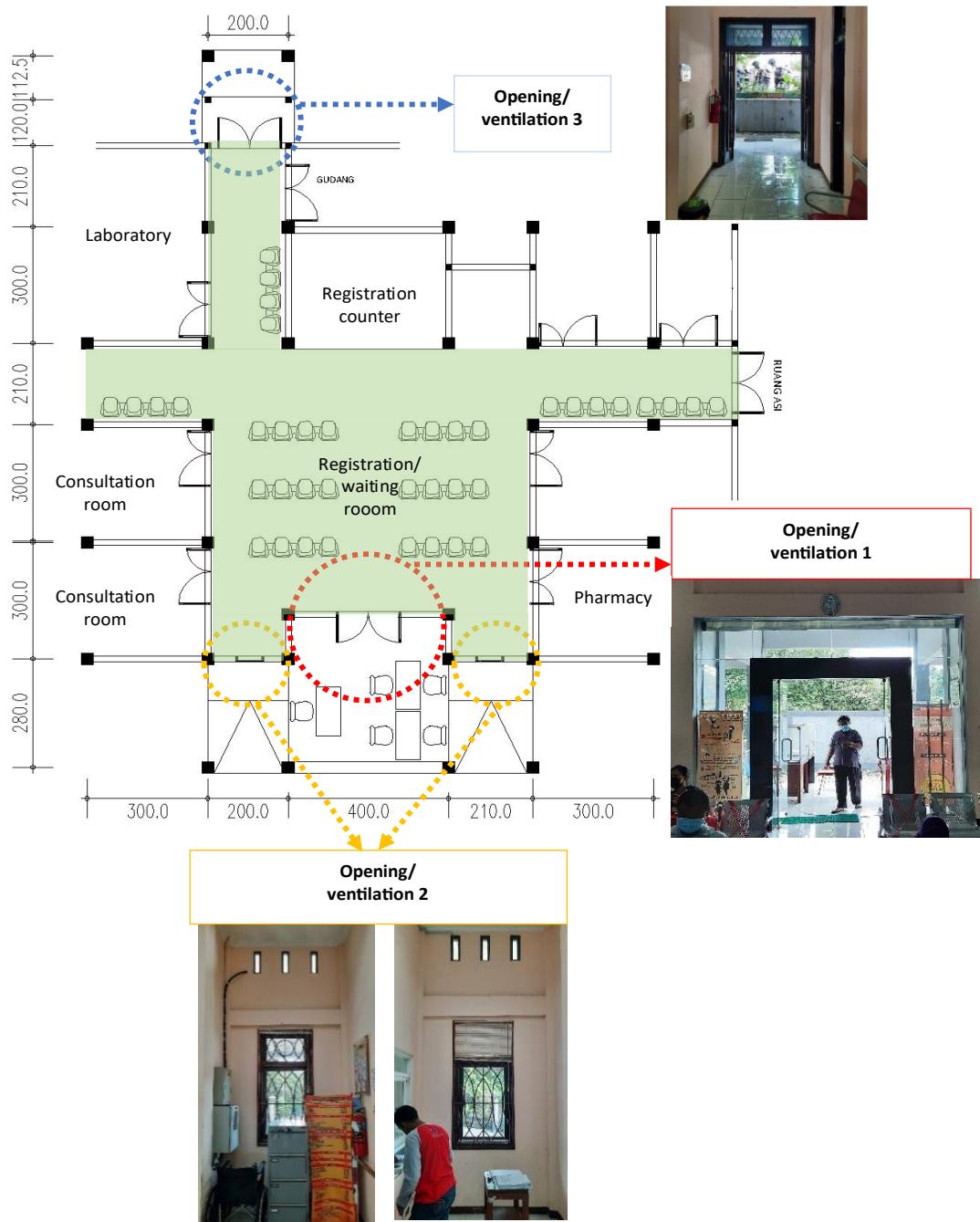


Figure 3. Pudakpayung Health Center Waiting Room Plan
Source: Documentation, 2024

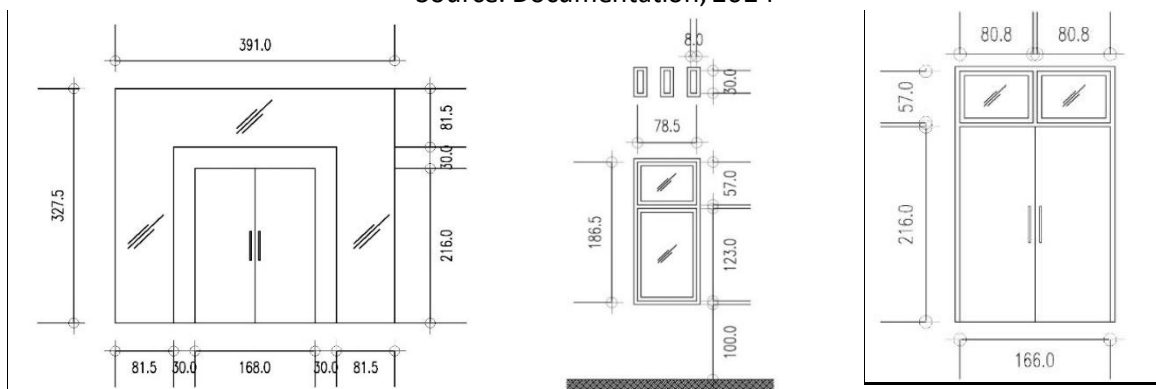


Figure 4. Detail of Openings/Ventilation in the Pudakpayung Health Center Registration room.
(a) Opening/ventilation 1, (b) Opening/ventilation 2, (c) Opening/ventilation 3

Measurements in this study were carried out four times, namely at 8AM WIB (T1) with a capacity of ±15-20 visitors, at 10AM WIB (T2), at 12PM WIB (T3) with a capacity of ±5-10 visitors and at 2PM WIB (T4) with a capacity of ±0-5 visitors. The measurement points are at positions that are expected to change, with a height of ±50cm according to the height of the visitors when sitting/waiting. The initial data collection of the study used the measurement position shown in Figure 4 below.

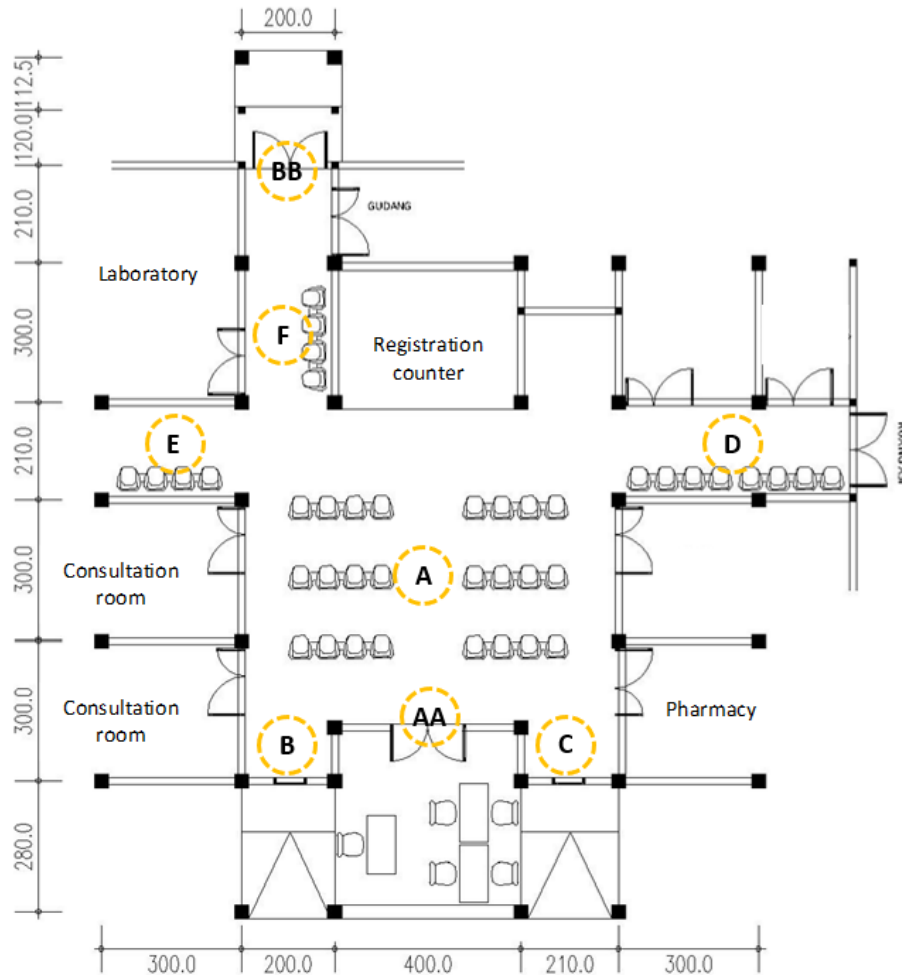


Figure 5. Position of Measurement Points in the Pudakpayung Health Center Registration room
Source: Documentation, 2024

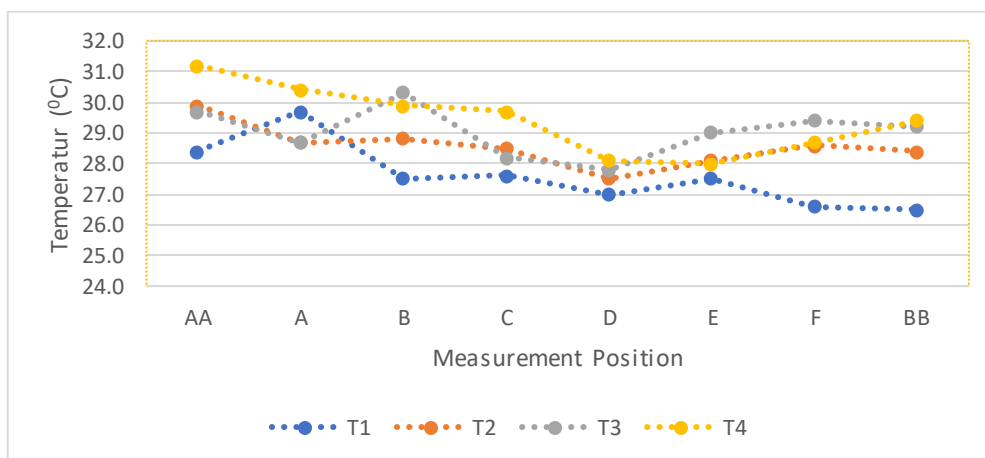


Figure 6. Temperature Measurement of Pudakpayung Health Center
Source: Analysis, 2024

Natural ventilation and four fans are used in the registration room of the Pudukpayung Health Center. The temperature in the room is exceptionally fluctuating. Point AA, outside the room, has the highest temperature, while Point BB, also located outside the room, has a low temperature compared to other points. This is caused by shade in the form of tree vegetation, canopy/shading and a wall approximately 1.5 meters high near Point BB. There is also a canopy/shading at Point AA without other shade, such as vegetation, so there is a possibility that solar radiation heat will enter the room. It can also be seen in Graph 5 that the room temperature tends to decrease from point A to point F. Some fluctuations can be influenced by the density of visitors at the point of occurrence of fluctuations or the influence of air movement and air flow rate in the room. When the measurement was done, the fan was not turned on.

The room's temperature is from 27°C to 28.9°C, which is higher than the ANSI/ASHRAE/ASHE Standard 170-2017 Ventilation of Healthcare Facilities with a temperature of 21°C-24°C and also higher than the standard of Permenkes RI No 216/Menkes/SK/1998 on Environmental Health Requirements for Work which is from 18°C-26°C. This is because the air conditioning only uses natural ventilation and no AC. The room's heat and humidity will be lowered by bringing in fresh air with the ventilation design, which will reduce the risk of people feeling tired and having headaches and improve their work performance (Zhao, Sun, and Tu 2018).

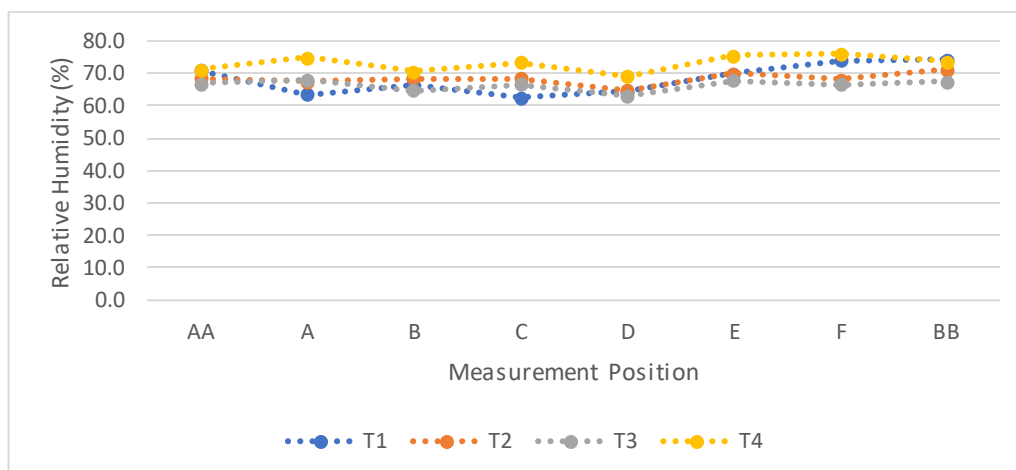


Figure 7. Relative Humidities Measurement of Pudukpayung Health Center
Source: Analysis, 2024

The relative humidity in the registration room of the Pudukpayung Health Center does not vary much among the points, as shown in Figure 6, with the lowest relative humidity of 60% and the highest of 72.8%. According to Minister of Health Regulation in Indonesia and ANSI/ASHRAE/ASHE Standard 170-2017, the humidity in the registration room of the Pudukpayung Health Center is higher than the standard, which is between 40%-60% or not be more than 65%. The room's humidity level and humidity risk also depend on the ventilation rate. The humidity can be lowered by increasing the ventilation rate, but it also varies with different climate zones (Tang et al. 2020).

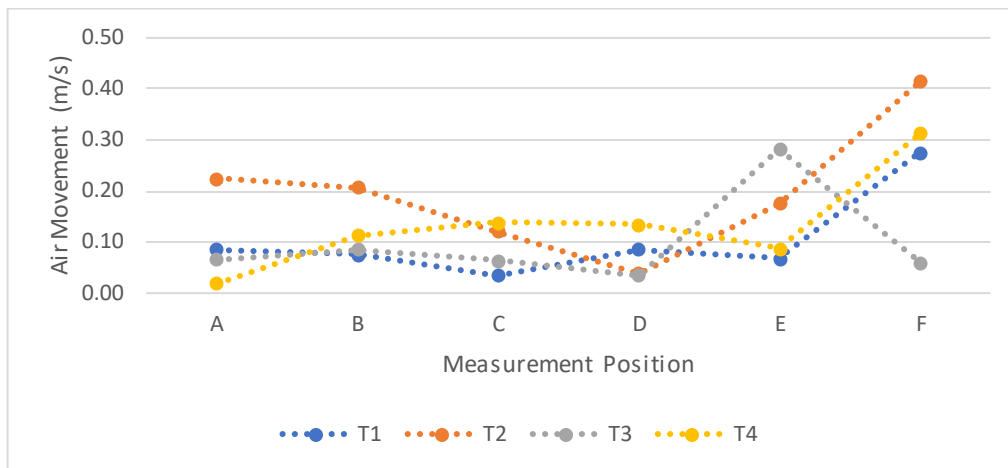


Figure 8. Air movement Measurement of Pudakpayung Health Center
Source: Analysis, 2024

In registration room of the Pudakpayung Health Center, the air movement fluctuates (see Figure 7) between 0.02m/s and the highest 0.41 m/s at point BB. The fluctuating air movement is influenced by the wind that blows when the measurement is done. The room only relies on natural ventilation in the form of doors, windows and boven open wide during service hours. Fans can aid air movement, but the measurement was done without them to understand better how well the natural ventilation moves the air.

The air movement in the registration room of the Pudakpayung Health Center does not fully comply with the Indonesian National Standard (National Standardization Agency of Indonesia 2001) on the procedures for designing ventilation and air conditioning systems (SNI 03-6572-2001) and the Minister of Health Regulation of the Republic of Indonesia Number 261/Menkes/SK/II/1998 on Environmental Health Requirements for Work, which recommend that the air movement should be from 0.15-0.25 m/s. This air movement is required to bring fresh air into the room and remove dirty air. This movement of air will affect the flow rate and the air change value in the room.

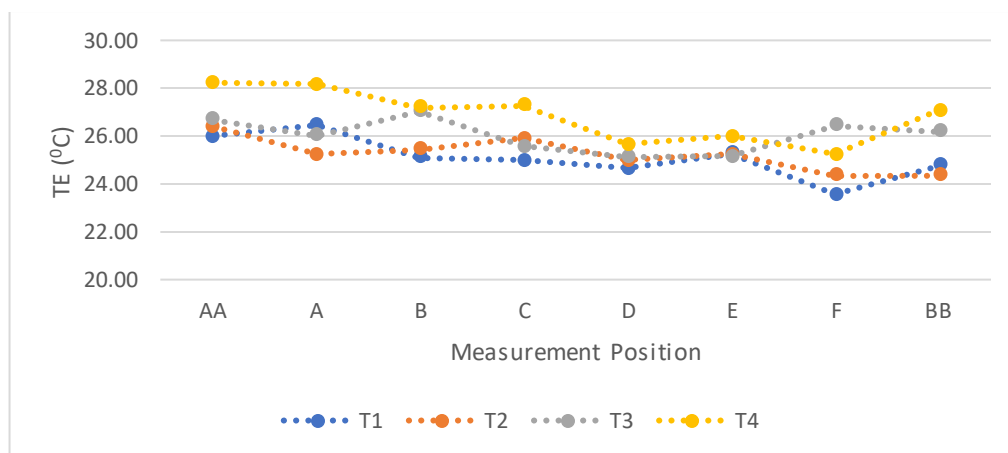


Figure 9. Effective Temperature Measurement of Pudakpayung Health Center
Source: Analysis, 2024

Based on the calculation results, the effective temperature of registration room of the Pudakpayung Health Center fluctuates quite a bit, but there is no extreme difference (see Figure 8). The effective temperature at each point ranges between 24°C and 28°C. According to Mom (Lippsmeier 1997) , the effective temperature of the Pudakpayung Health Center meets the comfort standard in Indonesia, which is 20°C- 28°C. Meanwhile, according to (Badan Standarisasi Nasional 2001), the effective temperature of 22.8°C-25.8°C is in the best comfort category. Therefore, the registration room of the Pudakpayung Health Center is

sufficiently comfortable for visitors. The humidity and natural air exchange through ventilation affect the effective temperature, which can also influence the IAQ condition (Mengqiang Lv, Sumei Liu, Qing Cao 2022).

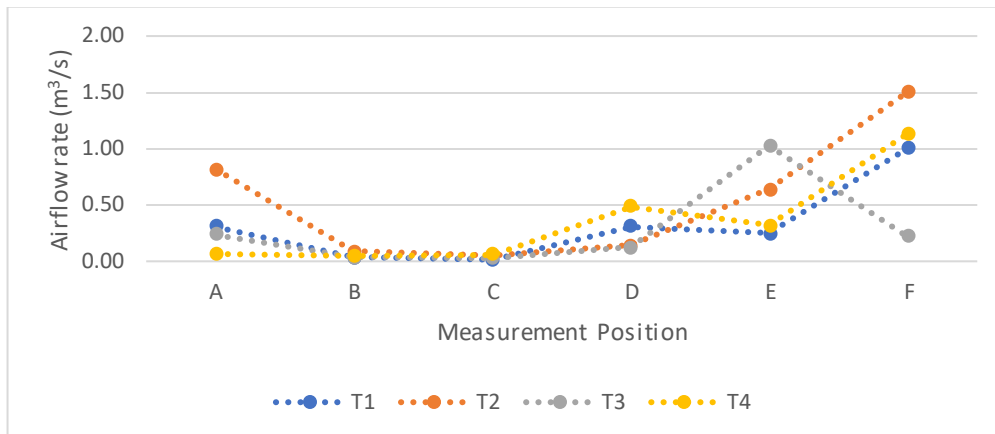


Figure 10. Airflow Rate Measurement of Pudakpayung Health Center
Source: Analysis, 2024

The airflow rate measures the amount of fresh air that comes into the room. The wind outside the room can affect the airflow rate, as shown by the varying results in Figure 9. The airflow rate also depends on the size and location of the opening where the air enters the room. The stronger the wind that comes in, the higher the airflow rate; using a fan can also improve the airflow in and out of the room. The airflow rate at the Pudakpayung Health Center varies from 0.03 m³/s to 1.13 m³/s. The centre has 20 rooms, each with one person, so the airflow rate per person ranges from 0.0015 m³/s/person to 0.0565 m³/s/person or 0.09 m³/minute/person to 3.39 m³/minute/person. This airflow rate is essential for indoor air quality, as it helps to remove pollutants from the room and to replace the air with fresh air.

The minimum exchange for work environments is 0.283 m³/minute/person, according to the Minister of Health Regulation of the Republic of Indonesia Number 261/Menkes/SK/II/1998 on Environmental Health Requirements. The ANSI/ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality suggests an airflow rate of 3.8 litres/second/person or 0.0038 m³/second/person. This means that the Pudakpayung Health Center needs to increase the airflow rate in the room to meet the minimum standard, while the area outside or near the opening is already adequate. A high airflow rate in the room can help to reduce the humidity, harmful bacteria, viruses, and chemical compounds, as well as the amount of particulate matter (PM) in the air (Trompeter et al. 2018).

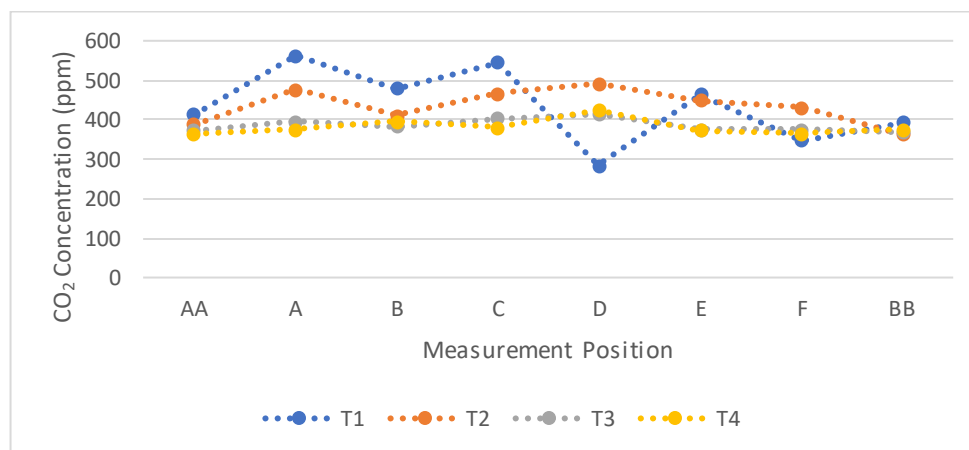


Figure 11. CO₂ Concentration Measurement of Pudakpayung Health Center
Source: Analysis, 2024

Based on the results obtained, it can be seen in Figure 10 that the CO₂ concentration level in registration room of the Pudukpayung Health Center fluctuates quite a bit, ranging from 285 ppm to 563 ppm. This meets the standard recommended by DOSH (Department of Safety and Health, Malaysia) and ANSI/ASHRAE Standard 62.1-2019, which is below 1000 ppm. The CO₂ level in the room will rise based on various factors, such as the number and activity of users, the room's density or occupancy, how long they stay in the room, and the amount of fresh air (air flow rate) coming into the room (Talarosha 2018).

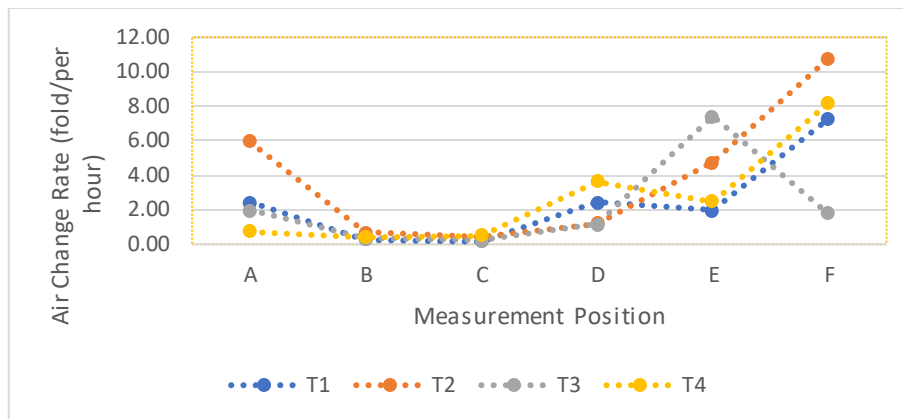


Figure 12. Air Change Rate of Pudukpayung Health Center
Source: Analysis, 2024

The air change value in registration room of the Pudukpayung Health Center, seen in Figure 11, tends to decrease from point A to point B, then stabilize until point C and start to increase at point D. At T1 (8AM) and T4 (12PM) point D decreases to point E and increases again at point F. In contrast, at T2 (10AM), point D increases to point F. However, at T3 (12PM), point D increases to point E and decreases at point F. The highest air change occurs at the point position near the opening. Meanwhile, the air change value is lower at points B and C, which are also close to the opening. This can be influenced by the type of window, a casement window that allows less optimal air to enter.

The ventilation depends on the natural air from outside, which causes the results to vary. The air change value increases when the wind brings fresh air into the room and down when there is no wind. The fan can assist in circulating the air in and out of the room, improving the comfort of the visitors.

According to ANSI/ASHRAE/ASHE Standart 170-2017 Ventilation of Healthcare Facilities and the 2019 Guidelines for Environmental Infection Control in HealthHealthcare Facilities by the U.S. Department Of Health And Human Services and Control, the air change per hour should be at least 12 times. The registration room of the Pudukpayung Health Center needs to meet this standard. The air change value depends on the airflow rate and the impact of the outside air. Without cross ventilation, there is not enough air exchange between the room and the outside, which leads to the build-up of polluted air from the outside environment in the room and affects the Indoor Air Quality.

4. CONCLUSION

This research showed that insufficient natural ventilation resulted in the room not meeting the standards related to air quality and comfort. The ventilation conditions influence the conditions in the room. Proper ventilation can lower the room's temperature and relative humidity to optimise the occupant's comfort. It also affects the air change rate, which is essential for maintaining clean and healthy air quality. This research also demonstrated that ventilation strongly correlates with air change rate. Ventilation should be given more

attention in buildings, not only to save energy but also to enhance comfort and indoor air quality.

REFERENCES

- ANSI/ASHRAE/ASHE. 2017. *ANSI/ASHRAE/ASHE Standard 170-2017 Ventilation of Health Care Facilities*.
- ASHRAE. 2022. *ASHRAE Position Document on Indoor Carbon Dioxide*.
- Badan Standarisasi Nasional. 2001. "SNI - 03 - 6572 - 2001 Tata Cara Perancangan Sistem Ventilasi Dan Pengkondisian Udara Pada Bangunan Gedung." : 1–55. <http://staffnew.uny.ac.id/upload/132100514/pendidikan/perencanaan-pendingin.pdf>.
- Baurès, Estelle et al. 2018. "Indoor Air Quality in Two French Hospitals : Measurement of Chemical and Microbiological Contaminants." *Science of the Total Environment* 642: 168–79.
- CIBSE. 2020. "CIBSE COVID-19 Ventilation Guidance." (October).
- Deng, Hua Yan, Zhuangbo Feng, and Shi Jie Cao. 2018. "Influence of Air Change Rates on Indoor CO₂ Stratification in Terms of Richardson Number and Vorticity." *Building and Environment* 129(December): 74–84. <https://doi.org/10.1016/j.buildenv.2017.12.009>.
- EPA (United States Environmental Protection Agency). 1990. "Ventilation and Air Quality in Offices." *Air and Radiation (6609J)*.
- Hong, Taehoon, Jimin Kim, and Myeonghwi Lee. 2018. "Integrated Task Performance Score for the Building Occupants Based on the CO₂ Concentration and Indoor Climate Factors Changes." *Applied Energy* 228: 1707–13. <https://doi.org/10.1016/j.apenergy.2018.07.063>.
- Jung, Chien-cheng, Pei-chih Wu, Chao-heng Tseng, and Huey-jen Su. 2015. "Indoor Air Quality Varies with Ventilation Types and Working Areas in Hospitals." *Building and Environment* 85: 190–95.
- Lipinski, Tom, Darem Ahmad, Nicolas Serey, and Hussam Jouhara. 2020. "Review of Ventilation Strategies to Reduce the Risk of Disease Transmission in High Occupancy Buildings." *International Journal of Thermofluids* 7–8(100045).
- Lippsmeier, G. 1997. *Bangunan Tropis*. Jakarta: Erlangga.
- Megahed, Naglaa A, and Ehab M Ghoneim. 2020. "Indoor Air Quality : Rethinking Rules of Building Design Strategies in Post-Pandemic Architecture." (October).
- Mengqiang Lv, Sumei Liu, Qing Cao, Tengfei Zhang & Junjie Liu. 2022. *Handbook of Indoor Air Quality Influence of Ventilation on Indoor Air Quality*. Singapore: Springer.
- Rahim, H.M. Ramli. 2012. *Fisika Bangunan Untuk Area Tropis*. Bogor: IPB Press.
- Szokolay, S V. 1980. *Environmental Science Handbook*. New York: Halsted Press.
- Talarosha, Basaria. 2018. "Konsentrasi Co₂ Pada Ruang Kelas Dengan Sistem Ventilasi Alami Sebuah Penelitian Awal." *Jurnal Lingkungan Binaan Indonesia* 6(1): 22–27.
- Tang, Shengyi et al. 2020. "Unhealthy Indoor Humidity Levels Associated with Ventilation Rate Regulations for High-Performance Buildings in China." *Building and Environment* 177(April).
- Trompetter, W J et al. 2018. "The Effect of Ventilation on Air Particulate Matter in School Classrooms." *Journal of Building Engineering* 18(March): 164–71.
- U.S. Department Of Health And Human Services, and Disease Control. 2019. "Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) Guidelines for Environmental Infection Control in Health-Care

Facilities.” (July).

Zhao, Yi, Hejiang Sun, and Daixin Tu. 2018. “Effect of Mechanical Ventilation and Natural Ventilation on Indoor Climates in Urumqi Residential Buildings.” *Building and Environment* 144: 108–18. <https://doi.org/10.1016/j.buildenv.2018.08.021>.