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https://doi.org/10.5109/4774237

出版情報：Evergreen. 9 (1), pp.219-225, 2022-03. Transdisciplinary Research and Education Center for Green Technologies, Kyushu University
バージョン：

The Impact of Ventilation on Indoor Air Quality and Air Change Rate

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(Received February 11, 2022; Revised March 22, 2022; accepted March 22, 2022).

Abstract: This research aims to investigate the influence of ventilation on indoor air quality and air change rate in healthcare facilities where contamination would likely have happened. The research method used a quantitative-descriptive approach and investigated a polyclinic waiting room according to the Regulation and Indonesian Standard, then analyzed using SPSS software. The result shows that some variables were not suitable with the standards caused by lack of natural ventilation, which also reduces the air change rate to comply with clean and healthy air quality. In line with that, air movement and volumetric airflow rate have a significant relationship with air change rate. Well-designed ventilation needs to be considered in the design process.

Keywords: air change rate; hospital; indoor air quality; ventilation

1. Introduction

Based on the National Institute Of Occupational Safety and Health (NIOSH) in 1997, several things can cause indoor air quality problems, such as insufficiency of air ventilation (52%), outside contaminants (10%), microbes or microorganisms (5%), the material of the building (4%), and other causes (3%)[1,2]. The lack of ventilation has the worst possibility of no air circulation process inside or outside the room; in other words, the existing ventilation system only circulates "bad air" in the room[3]. Ventilation can be more effective with an efficient design of spatial airflow distribution[4]. Well-ventilated rooms are needed to comply health and productivity of the occupant, while human occupancy does associate with airborne microbial fingerprint. Ventilation can affect microbial in the air quality[5]**.** Ventilation also can be used to increase the air change rate. The higher air change rate can reduce the contaminant concentration to improve indoor air quality[6].

1.1. Indoor Climate and Indoor Air Quality

A healthy indoor environment can be achieved through ventilation, especially natural ventilation in the tropical climate, which has widely preferred replacing an air conditioning system, to reduce energy consumption, provide comfort and healthy indoor thermal conditions[7,8]. Good ventilation would supply fresh and clean air into the room, which impacted the indoor climate. For example, it can reduce relative humidity and room temperature[9]. There are four factors of indoor climate such as; the temperature of the room, mean radiant temperature, relative humidity, and air movement. According to the results[10] in[11], fresh air intake increases in the opposite way to the relative humidity or temperature of the room. The symptoms of headache and fatigue decreased when the relative humidity and temperature of the room levels were decreasing, while the performance and productivity were increasing.

Indoor air quality is also influenced by ventilation conditions and the accumulation of air pollutants from indoors and outdoors. Humans can inhale these dangerous substances if air circulation in the room is lacking and can cause disease to the occupants, or it could increase the risk of sick building syndrome (SBS)[12,13]. During this pandemic, it is crucial to keep healthy and clean air quality. Researchers, including engineers and architects, are working to reduce the spreading of disease and find a sustainable solution in various fields as a responsibility to help people and provide them with feasible living possibilities[14,15].

The previous research by N Kartikawati et al. showed the most dominant pollutant that had a significant role related to indoor air quality is carbon dioxide (CO_2)[13]. The ventilation would bring more fresh air also widen the green, and open space provides more oxygen and lower densification, improving a healthier environment and reducing carbon dioxide concentration[16,17,18].

1.2. Air Change Rate

For evaluating the ventilation efficiency of air distribution, there is an important factor called air change rate. The air change rate would obtain the number of times the air in the room is based on the volumetric airflow rate divided by the room volume[6]. The following formula was used to do the calculation of the air change rate per hour (ACH):

$$N = 3600\ Q/V \qquad (1)$$

The N is the air change per hour (-fold/hour), Q is the volumetric flow rate (m^3/s). V is the room or building volume (m^3), and 3600 is the conversion factor from sec to an hour. Meanwhile, air as a dynamic fluid component uses the following equation:

$$Q = V/t \qquad (2)$$

$$Q = A\ v \qquad (3)$$

where Q is the volumetric airflow rate (m^3/s), V is the volume of the room or building (m^3), t is the time interval (s), A is the total area of the ventilation/ opening (m^2) and v is air movement (m/s). Based on the Technical Guidelines for Air Conditioning System Infrastructure in Hospital Buildings[19], the total air change rate per hour for the hospital administration room and the waiting room is a minimum of 6 folds/hour.

This research aims to investigate the influence of ventilation related to indoor air quality (IAQ) and air change rate with the case study in healthcare facilities, especially in the polyclinic waiting room area. In this area, contamination can happen from one patient to another. According to the Health Ministry Regulation of the Republic of Indonesia about Hospital Environmental Health Requirements, minimum natural ventilation area required 15% of the floor area, as well as temperature and humidity standards according to the function of the room and unit as an administrative room, required 21-24^{0}C for dry bulb temperature and 40-60% for relative humidity[20]. Meanwhile, based on the Ruling of the Health Ministry No.261/MENKES/SK/II/1998 a healthy room temperature ranges from 18^{0}C-26^{0}C[21]. According to the Indonesian National Standard (Indonesian National Standardization Agency 2001) on the procedure for designing a ventilation and air conditioning system (SNI 03-6572-2001), an effective temperature for a comfortable room ranges from 20^{0}C-28^{0}C, this is also following with the Mom standard for Indonesia[22]. The recommended air movement ranges from 0.15-0.25 m/s[23]. Besides, air change that provides fresh air is also needed; a hospital should have a volumetric airflow rate of 0.9-1.2 m^3/minute/person along with a room volume of 5.5 - >30 m^3/person[24,25].

2. Method

This research investigated a polyclinic waiting room of Regional Public Hospital in Ungaran, Semarang district, Central Java, Indonesia (Figure 1.) with a quantitative-descriptive method approach. This waiting room does not use any mechanical ventilation and only relies on natural ventilation or openings.

Fig. 1: Location of Regional Public Hospital (RSUD) in Ungaran as a case study of this research

Direct field measurements were carried out on this research on May 19th, 2019, at three different times during the activity; at 09.00 A.M (t1) with ±60 visitors, 11.00 A.M. (t2) with ±30 visitors, and 01.00 P.M (t3) with ±5 visitors. The measurement position is in the middle of the room, with the height of people while sitting down (±60 centimeters). The outdoor weather condition is shown in the outdoor position, positions A and C. The detail of the measurement position shown in Figure 2 below.

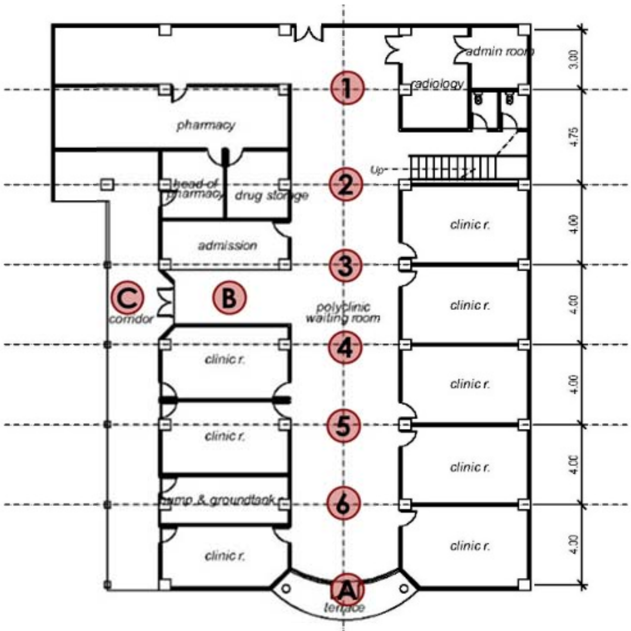


Fig. 2: Measurement position in Regional Public Hospital (RSUD) of Ungaran

The variables required are in the form of physical quality data for indoor air, such as relative humidity (RH), temperature (T), air movement (v), and volumetric airflow rate (Q). Based on these data, the number of air changes per hour can be obtained using equation 1, while the effective temperature of the room is obtained using a psychrometric chart. The measuring instrument needed in this research is shown in Tabel 1. Furthermore, the descriptive method is used to do the data analysis based on the applicable standards related to indoor air quality and statistically analyzed using a bivariate correlation test in SPSS software.

Table 1. Measuring instruments used in the current research

Instruments	Branded	Function
Hot Wire Anemometer	Krisbow 0.1-25 m/s	Measures indoor air movement and volumetric airflow rate
4 in 1 Environment Meter	Lutron Lm-8000	Measures temperature and relative humidity
Laser Distance Meter	Bosch DLE-40	Measures the area of the opening/ventilation and dimension of the room

3. Result and Discussion

The polyclinic waiting room of the Regional Public Hospital in Ungaran uses natural air conditioning assisted by 5 (five) fans. Table 2 explains the existing data in the waiting room of Regional Public Hospital in Ungaran.

Table 2. Polyclinic Waiting Room of Regional Public Hospital in Ungaran Existing Data

Parameter	Data
Room Area	27.75 x 6 = 166.5 m^2
Ceiling Height	3.2 m
Room Capacity	60 people
Room Volume	(166.5 x 3.2) = 532.8 m^3 (532.8 m^3/ 60) = 8.88 m^3/orang
Area of the opening	(1.2 x 2.2) x 2 = 5.28 m^2 3.2 % of floor area
Opening Orientation	Southwest – Northwest

The area of the ventilation or openings in this waiting room is only 3.2% of the floor area, which can be seen in Table 2. While the room volume of 8.88 m^3/person with a capacity of 60 people complies with the minimum standard, which is 5.5 - >30 m^3/person[24,25]). Figure 3 below shows the position and dimensions of the openings in the polyclinic waiting room.

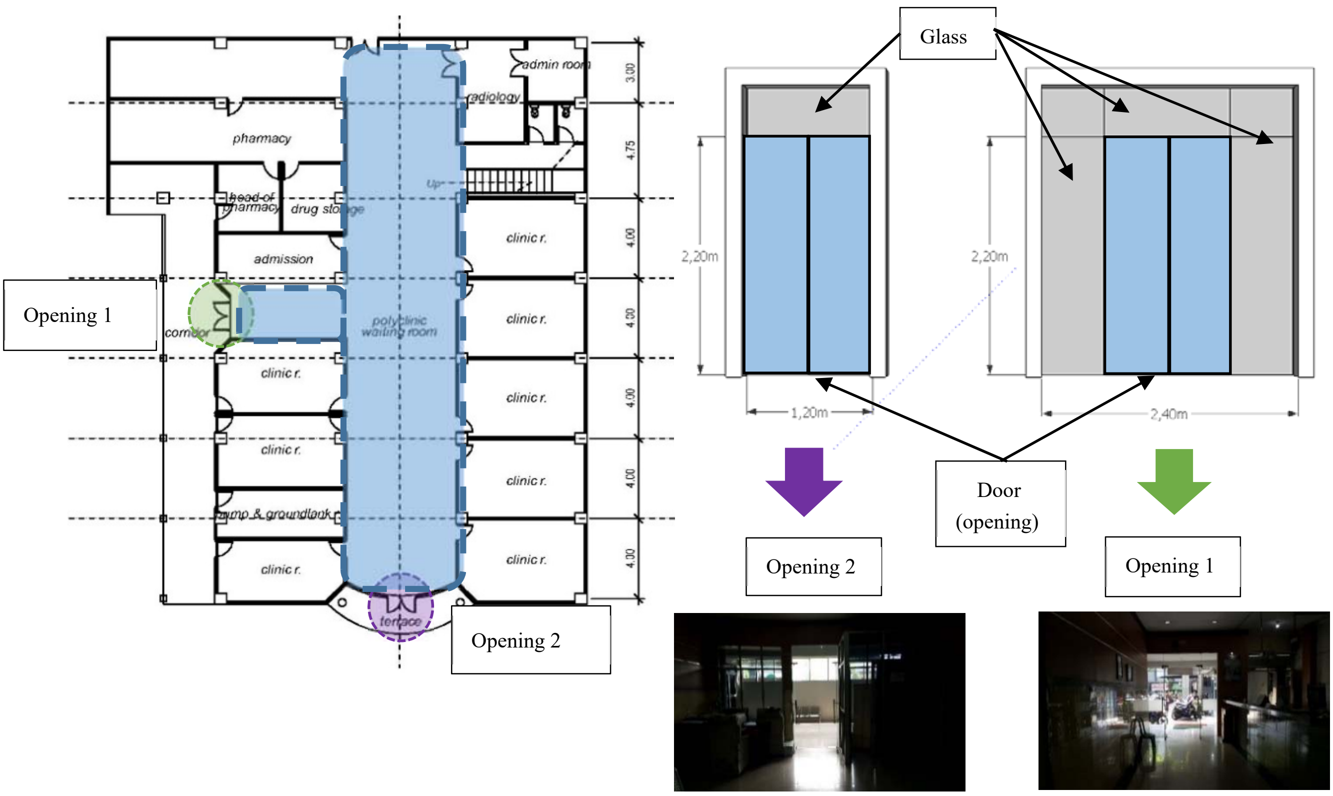


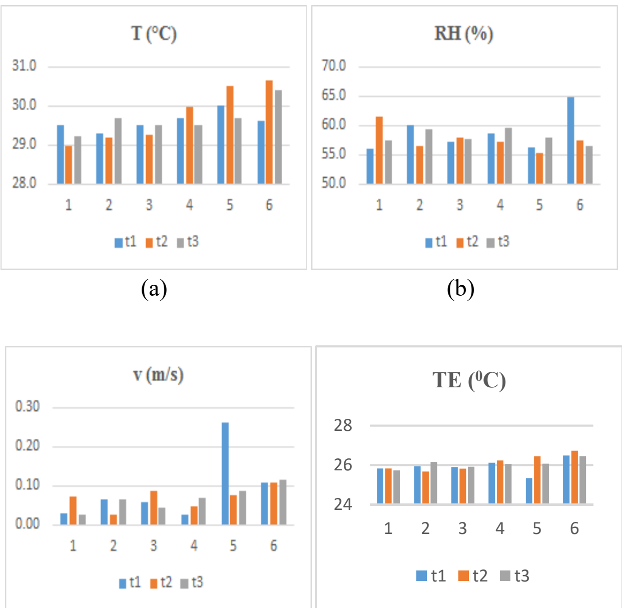
Fig. 3: Floor Plan of Polyclinic Waiting Room of Regional Public Hospital (RSUD) in Ungaran with the existing ventilation/opening

Table 3. Field Measurement in Regional Public Hospital (RSUD) of Ungaran

Variable	Measurement Position									Time
	1	2	3	4	5	6	A	B	C	
T (°C)	29.5	29.3	29.5	29.7	30.0	29.6	29.5	30.6	30.6	
RH (%)	55.9	60.0	57.1	58.6	56.3	64.8	55.5	55.4	55.3	
v (m/s)	0.03	0.06	0.06	0.02	0.26	0.11	0.11	0.11	0.08	t_1
TE (^{0}C)	25.8	25.9	25.9	26.1	25.3	26.5	25.8	26.5	26.5	
Q (CMM/ person)	0.36	0.47	0.42	0.29	2.31	1.22	2.02	1.22	0.93	
T (°C)	29.0	29.2	29.3	30.0	30.5	30.7	31.1	30.7	30.8	
RH (%)	61.5	56.5	58.0	57.1	55.3	57.5	57.5	52.6	53.0	
v (m/s)	0.07	0.02	0.09	0.05	0.07	0.11	0.13	0.21	0.24	t_2
TE (^{0}C)	25.8	25.7	25.8	26.2	26.4	26.7	27.0	25.8	25.8	
Q (CMM/ person)	0.80	0.33	0.87	0.53	0.84	0.93	1.40	2.35	2.67	
T (°C)	29.2	29.7	29.5	29.5	29.7	30.4	30.7	30.5	30.7	
RH (%)	57.5	59.2	57.5	59.6	57.8	56.5	57.6	54.7	53.8	
v (m/s)	0.03	0.06	0.04	0.07	0.09	0.11	0.08	0.07	0.14	t_3
TE (^{0}C)	25.7	26.2	25.9	26.1	26.1	26.5	26.7	26.4	26.4	
Q (CMM/ person)	0.29	0.71	0.47	0.78	0.96	1.27	0.93	0.73	1.58	

Table 3 shown field measurements from each position at three different times. The future discussion of this data would be shown with the visual graphics below.

3.1. Dry Bulb Temperature, Relative Humidity, Air Movement, Effective Temperature, Volumetric Airflow Rate



(a) (b) (c) (d)

Fig. 4: Field Measurement Graphic (a) Dry bulb temperature; (b) Relative Humidity; (c) Air Movement and (d) Effective Temperature

The indoor temperature tends to be high and exceeds the recommended standards. From Figure 4a, at position 6, the temperature seems to be getting higher; this is because position 6 is far from the source of the effective opening, like position C, and is close to the opening of position A which is blocked by walls as high as ± 3-4 meters, so heat accumulation occurs at that position. The temperature in the room exceeds the standard of the Health Ministry Regulation of the Republic of Indonesia about Hospital Environmental Health Requirements which is 21- 24^{0}C[20]. It is influenced by air conditioning which only utilizes natural ventilation without the aid of air conditioning. Meanwhile, the polyclinic waiting room has minimal openings, only 3.2% of the floor area. The use of the fan itself is not enough to help the air circulation in the room and cannot optimize the room temperature comfort.

Meanwhile, the average relative humidity in the room shown in Figure 4b still meets the recommended standards and tends to be balanced, and does not experience significant changes between each position. The relative humidity in this waiting room complies with the recommended standards by Health Ministry Regulation of the Republic of Indonesia about Hospital Environmental Health Requirements, which is 40-60%[20].

The air movement in this waiting room is quite volatile, shown in Figure 4c. The number of them reached more than 0.15 m/s, but it is generally still below 0.15 m/s. Thus air movement was not suitable with the Indonesian National Standard (Indonesian National Standardization Agency 2001) on the procedure for designing a ventilation and air conditioning system (SNI 03-6572-2001), which is ranges from 0.15-0.25 m/s[23].

From these field measurement data, we obtained the effective temperature of the polyclinic waiting room is relatively stable, which is around 25^{0}C (Figure 4d). According to Mom[22], the effective temperature in this room complies with the comfort standard in Indonesia, which is 20^{0}C- 28^{0}C. Meanwhile, according to[23] the effective temperature of 22.8^{0}C-25.8^{0}C is included in the optimal comfort category. That way, the polyclinic waiting room is comfortable enough for visitors. This effective temperature is influenced by humidity as well as fresh air exchange through ventilation.

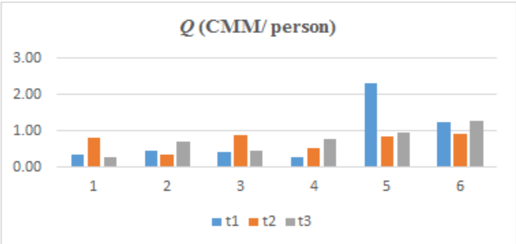


Fig. 5: Field Measurement Graphic of Volumetric Airflow Rate

The fresh air enters through the openings at positions A and C. But at position A, it is blocked by walls as high as ± 3-4 meters. So that the fresh air enters the most effectively through the door opening at position C. It can be seen in the graph (Figure 5) that position 5 has the highest airflow rate compared to other positions. It is because position 5 is close to the opening at position A and also position C. A hospital should have a volumetric airflow rate of 0.9-1.2 m^3/minute/person[24,25], so this waiting room generally complies with the recommended standard, especially the position near the openings.

3.2. Indoor Climate and Indoor Air Quality

From the field measurement data above, the air change rate per hour calculation was carried out by using the equation 1;

Table 4. Calculation Result of Air Change Rate per hour

Measurement Position	Time		
	t_1	t_2	t_3
1	2.40	5.40	1.95
2	3.15	2.25	4.80
3	2.85	5.85	3.15
4	1.95	3.60	5.25
5	15.61	5.70	6.46
6	8.26	6.31	8.56
A	13.66	9.46	6.30
B	8.26	15.91	4.95
C	6.31	18.01	10.66

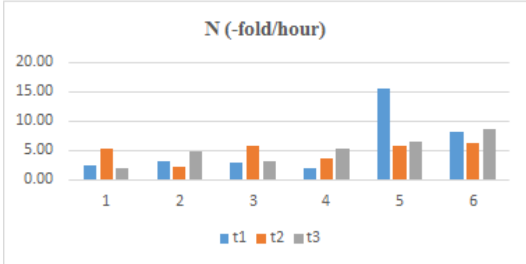


Fig. 6: Calculation Graphic of Air Change Rate per hour

The air change rate is affected by the airflow rate and the volume of the room, so position 5 also has the highest air change value according to the airflow rate data discussed above. Based on the standard[19] regarding the Technical Guidelines for Air System Infrastructure in Hospital Buildings, there are still several points that are not suitable with the predetermined standards, which is minimum of 6 folds/hour (look at Table 4 and Figure 6). The number of them that meet the standard is due to their position near the opening.

3.3. Statistical Analysis

The calculation of the air change value results was then analyzed statistically using the bivariate correlation test in SPSS software. This analysis was conducted to determine the relationship between the value of air change with indoor climate parameters (T, RH, v, TE, and Q), which can affect indoor air quality conditions.

Table 5. Pearson Correlation Analysis Result

Parameter	Pearson Correlation	Relationship with Air Change Rate (N)
Temperature (T)	0,883	Less Significant
Relative Humidity (RH)	-0,280	Not Significant
Air Movement (v)	0,996	Significant
Effective Temperature (TE)	0,464	Not Significant
Volumetric Airflow Rate (Q)	1,000	Significant

Note: The relationship is not significant at α = 0.05 or more; less significant at α = 0.02-0.04; siginificant at α = 0.01

Table 5 shows that air movement and volumetric air flowrate have a significant relationship with air change rate with a positive relationship at α = 0.01. It can be interpreted that the higher the air movement and the volumetric airflow rate will increase the number of air changes in the room. The amount of air change rate will affect the air quality in the room. Therefore, it is necessary to maximize the opening/ventilation so that the minimum air change in the room can be fulfilled and create a healthier indoor air quality.

3.4. Recommendation

Based on the data, the polyclinic waiting room of the

Regional Public Hospital in Ungaran has a total opening area of 5.28 m^2 (3.2% of the room's floor area). To achieve the standard volumetric airflow rate of at least 0.9 CMM/person, and the total air change rate per hour for the hospital administration room and the waiting room is a minimum of 6 folds/hour, we can use these following equations:

$$Q = A\ \frac{l}{t} \quad (4)$$

$$t = \frac{A\ l}{Q} \quad (5)$$

$$\frac{1}{N} = \frac{A\ l}{Q} \quad (6)$$

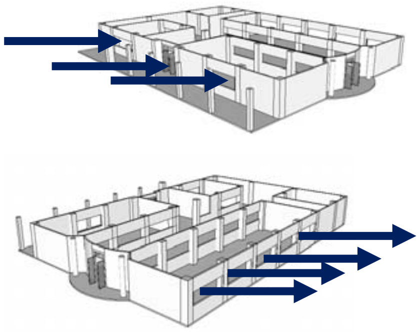
$$N = \frac{Q}{A\ l} \quad (7)$$

$$A = \frac{Q}{N\ l} \quad (8)$$

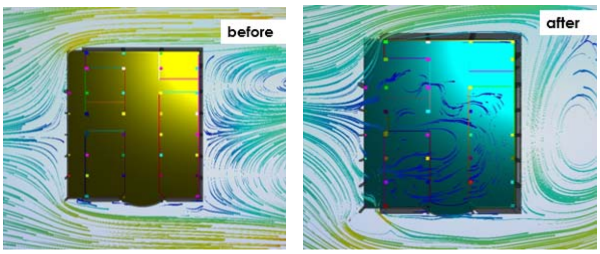
where Q is the volumetric airflow rate (m^3/s), A is the total area of the ventilation/ opening (m^2), v is air movement (m/s), l is the length of the room (m), t is the time interval (s), N is the air change per hour (-fold/hour). From equation 8, the result of the ideal opening area is:

$$A = \frac{\left(^{0,9}/_{60}\right)60}{\left(^{6}/_{3600}\right)\ 27{,}75} = \mathbf{19{,}5\ \ m^2}$$

This case study's ideal total opening area is 19.5 m^2 which is 12% of the floor area or at least 3.7 times larger than the entire existing opening. From the visualization example in Figure 7, better air circulation can be seen after adding some ventilation to the room. It would increase the air change rate and provide a healthier indoor air quality.



(a)



(b) (c)

Fig. 7: (a) Examples of recommended design applications; (b) air circulation from existing ventilation; (c) a better air circulation after adding some ventilation.

4. Conclusion

Based on this research, it can be seen that the number of variables was not suitable with the recommended standards caused by the lack of natural ventilation. The conditions of ventilation affect the indoor climate. Adequate ventilation can reduce the temperature and relative humidity of the room, while the lack of natural ventilation would decrease the effective temperature and indoor air quality. The lack of natural ventilation results in a lack of volumetric airflow rate too. It also reduces the air change rate to comply with clean and healthy air quality. This research also proved that air movement and volumetric airflow rate have a significant relationship with air change rate. Well-designed building ventilation needs to be considered more seriously. Besides being able to reduce energy consumption as well as improve comfort and indoor air quality.

Acknowledgements

The authors would like to give gratitude to the Regional Public Hospital of Ungaran, Semarang district, Central Java, Indonesia, for allowing us to conduct this research on their institution. We also would like to thank the Department of Architecture, Faculty of Engineering, Universitas Diponegoro for providing facilities for this research.

Nomenclature

N	air change per hour (-fold/hour)
Q	volumetric airflow rate (m^3/s).
V	volume (m^3)
t	time interval (s)
A	total area of the ventilation/opening (m^2)
v	air movement (m/s)
l	length of the room (m)

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