Performance of Air Curtain located at the top of entrance opening - Difference among indoor/outdoor/double-sided installation

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Abstract. Large openings of buildings are often used open, which results in heat loss due to intrusion of outdoor airflow and leakage of indoor air through the opening. To reduce air-conditioning load and to improve thermal environment in such a building, installing an air curtain at the opening can be a beneficial technique. The airflow blowing out of the device suppresses the heat exchange by buoyancy-induced convection through the opening. The impact of temperature difference, blowing speed, and installation position of the air curtain on temperature distribution and invasion flow rate of outdoor air was investigated by full-scale experiment under heating operation. Thermocouples were installed to measure vertical temperature distribution. Outdoor air infiltration was measured using tracer-gas method. The amount of outdoor air infiltration was evaluated based on both temperature difference and CO_2 concentration. Comparing the results, it was found that the indoor air curtain was able to suppress the airflow through the opening. The indoor-outdoor temperature difference and CO_2 concentration were highest when the air velocity was 4 m/s, suggesting that there is an optimal air velocity at which the air curtain can effectively suppress the airflow through the opening.

1. Introduction

Air infiltration and leakage occur at building entrances. Exits and other locations that are used under open conditions. Although there have been many studies[1-2)] predicting the effect of air leakage on AC performance, most have focused on the thermal environment, and few have focused on the difference between AC performance and contaminant interception performance. Therefore, in this study, the thermal interception performance will be re-evaluated and then the interception performance of the scalar will be evaluated. In the previous study[3)] , the basic properties of AC airflow were investigated in a reduced-scale model experiment in an isothermal field. In the present study, the vertical temperature distribution and net air infiltration are measured in a full-scale experiment in non-isothermal conditions in order to access the airflow blocking performance of AC and its effect on improving the thermal environment during heating. In addition, the airflow blocking performance of the AC is evaluated.

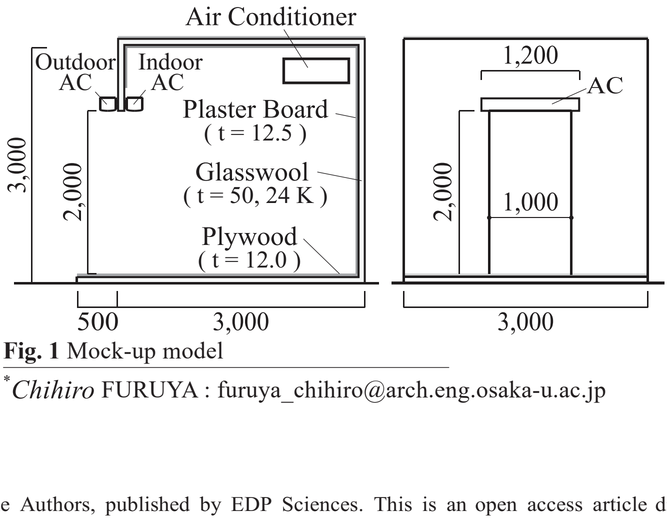
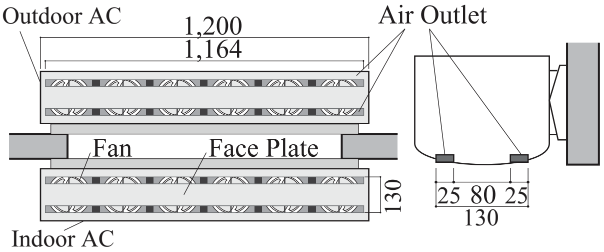


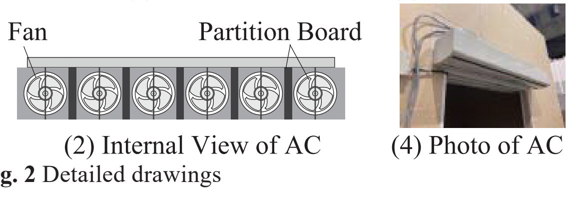
Fig. 1 Mock-up model

2. Experimental setup and equipment

The experiments were conducted in a cubic room with the external dimension of 3000 mm per side, as shown in **Fig. 1**, located in the experimental building at Osaka University. two AC units (Mitsubishi Electric,



(1) Plan (3) Cross-section



(2) Internal View of AC (4) Photo of AC

Fig. 2 Detailed drawings

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GK-3012S) shown in **Fig. 2** were installed above the openings on the outside and inside of the room, and are referred to as the outdoor AC unit and the indoor AC unit, respectively. These AC units blow air from six axial fans through two 25 mm wide air outlets.

3. AC airflow rate

3.1 Measurement overview

To understand the relationship between the AC airflow and voltage, the airflow velocity was measured and the airflow rate was estimated. As shown in **Fig. 3**, a 130 × 1,164 × 500 mm duct was attached to the AC on the indoor side, and the AC was operated at 50, 65, 80, and 100 V using voltage regulator (Yamabishi Electric, S-130-10). Measurements were taken at 11 × 7 points at the lower end of the duct using an I-type hot wire anemometer (Kanomax Japan, 0251R-T5) at a measurement frequency of 1,000 Hz for 60 seconds.

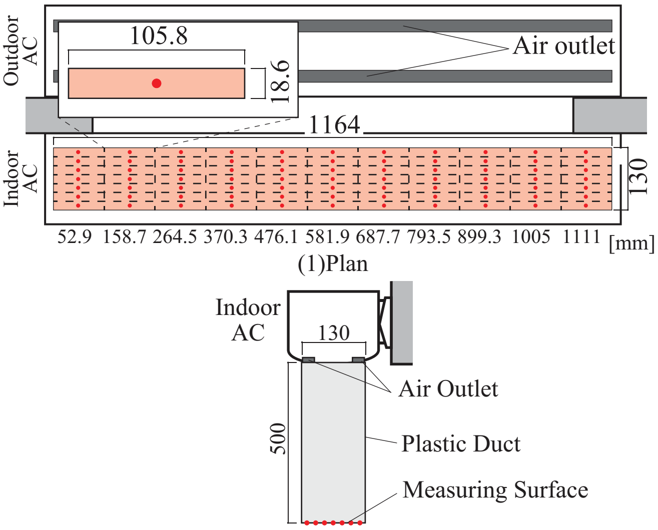


Fig. 3 Measurement point of blowoff airflow quantity

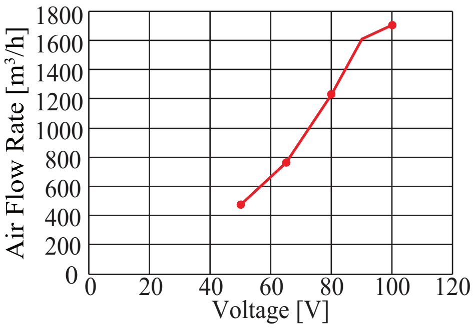


Fig. 4 Relationship between airflow rate and voltage

Table 1 Set up of blowing speed

Case	Voltage [V]	Air Flow Rate [m³/h]	Blowing Speed [m/s]
2 m/s	50	478	2.28
4 m/s	65	762	3.64
6 m/s	80	1233	5.89
8 m/s	100	1706	8.14

3.2 Results and disucussion

Fig. 4 and Table 1 show the airflow calculated by multiplying the air velocity at each measurement point by the cross-sectional area of the duct. The result for the 100 V was 1,706 m^3/h, which was nearly equal to the manufacturer catalog value of 1,720 m^3/h. Hereafter, the voltage conditions of 50, 65, 80, and 100 V will be referred to as the 2, 4, 6, and 8 m/s wind speed conditions, respectively, as shown in **Table 1**.

4. Vertical temperature distribusion

4.1 Measurement overview

Vertical temperature distribution measurement was conducted to explore the impact of changing the parameters such as AC installation position air velocity, and room heating wattage on thermal environment. Oil heaters (IWH-1210M-W, IRIS OHYAMA) were used for heating the room. Three cases of steady heat generation of 2,250 W, 3,350 W, 4,250 W were set in the arrangement shown in **Fig. 5**, Temperature was measured using T-type thermocouple wires at poles A through E for indoor temperature with 12 vertical points and at pole F for outdoor with 3 vertical points. The measurement points are shown in **Fig. 6**. The measurement interval was 1 minute, and the average of 30 minutes after reaching steady state was adopted as representative values. **Table 2** shows the experimental conditions. For 2 and 6 m/s cases, only 4250 W of heating was used. The same three heating conditions were used for the cases without AC.

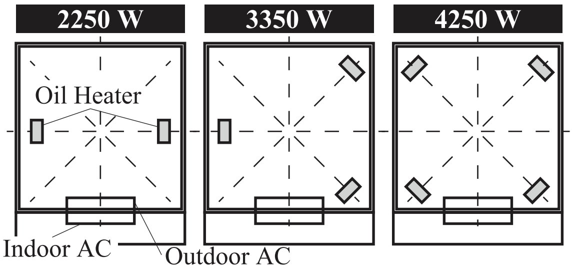


Fig. 5 Position of oil heaters

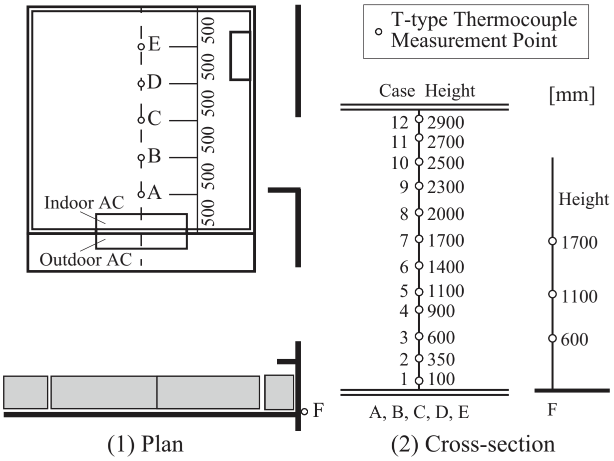


Fig. 6 Temperature measurement point

4.2 Results and Disucussion

4.2.1 Temperature change over time

Fig. 7 shows the temperatures at the 12 points in the height direction at pole A and the average temperatures at the 3 points at F under the 4250 W heating condition. The first 30 minutes is steady with the AC turned off. It can be observed that, the lower part of the room is equal to the outdoor temperature and the upper part of the room is warmer by a vertical temperature difference of about 10 °C. Therefore, it can be said that the thermal comfort of the room is impaired even when the heater is in use. When the indoor AC was turned on at 2, 4, 6, and 8 m/s, the temperature at all measurement points rose sharply even though the supplied rate of the heat remained unchanged, confirming the AC's effect of blocking outdoor air. The vertical temperature difference also decreased, which means that thermal comfort could be improved. The differences between the blowing speeds showed that the higher the speed is the smaller the variation of the 12 points becomes. The largest vertical temperature difference at 2 m/s was about 5 °C. The vertical temperature difference at 4 m/s was about 1.5 °C. In addition, the room temperature increased the most at 4 m/s.

4.2.2 AC air velocity

Fig. 8 shows the results of vertical temperature distribution in different installation position. The graph shows the temperature difference between the average indoor temperature (A~E) and the outdoor temperature (F) at each height of room. Without AC, the difference from the outdoor temperature was small at the bottom of the room, indicating that outdoor air was infiltrating into the room. On the other hand, in all conditions with AC, the difference was larger and the vertical temperature difference was also smaller.

The temperature difference between inside and outside was the largest under the condition of 4 m/s air speed compared to the other conditions. This may be due to the fact that the airflow at 6 and 8 m/s has a higher momentum at the time of impact with the floor surface, resulting in a more mixing of indoor and outdoor air, while at 2 m/s, the airflow did not reach the floor surface due to the low air velocity, resulting in more outdoor air entering the inside of the room.

4.2.3 AC installation position

In **Fig. 8**, the temperature difference between the inside and outside was largest at the indoor AC cases. On the other hand, the temperature in the lower part of the room was almost equal to the outdoor temperature in the outdoor AC as well as in the without AC cases. This may be due to the fact that the indoor AC blows warm and the outdoor AC blows out cold to which causes the temperature distribution near the aperture change. The bilateral AC units had twice as much airflow as

Table 2 Experimental condition of AC

Installation Position	Indoor AC, Outdoor AC Double-sided AC	without AC
Blowing Speed	2*, 4, 6*, 8 m/s	

Notes: Cases with * were only operated when heat load is 4250 W

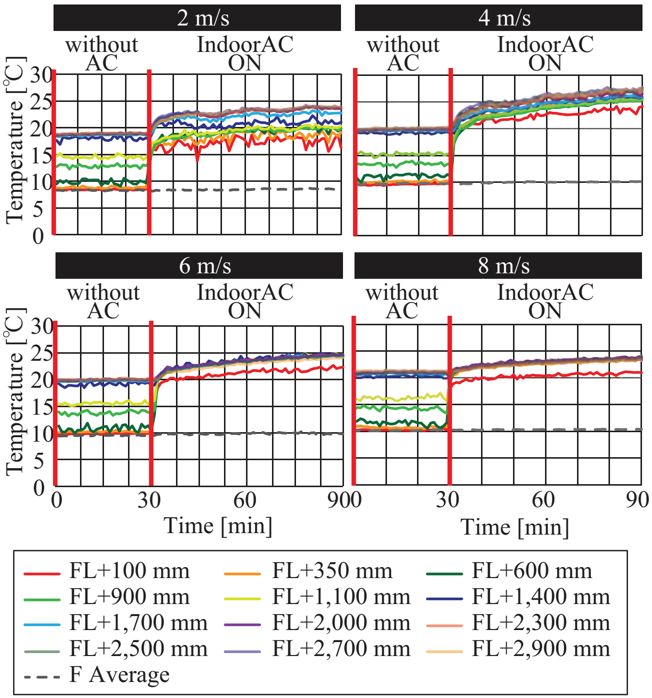


Fig. 7 Temperature change over time

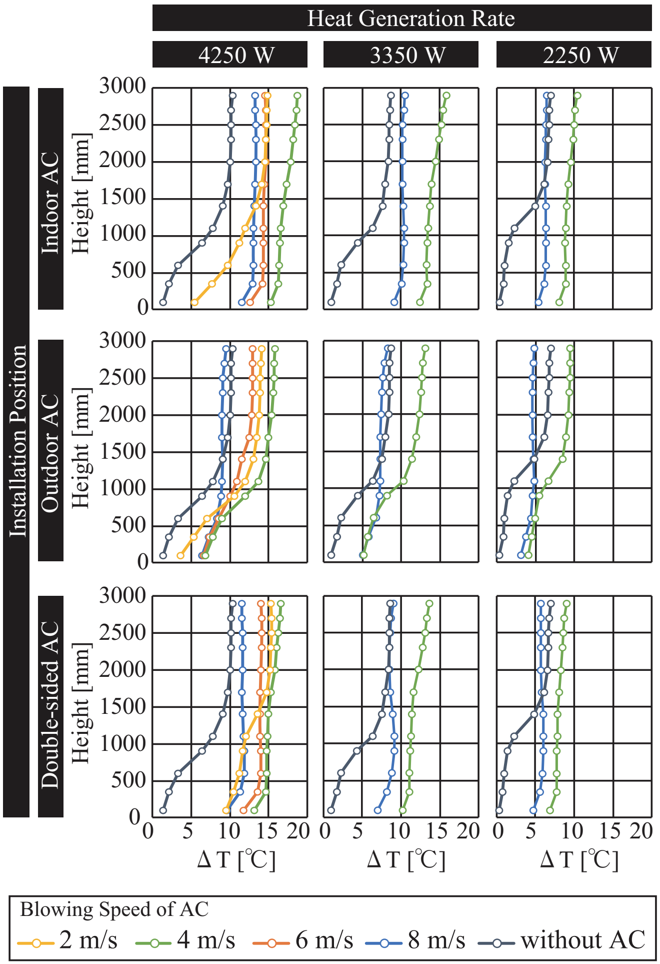


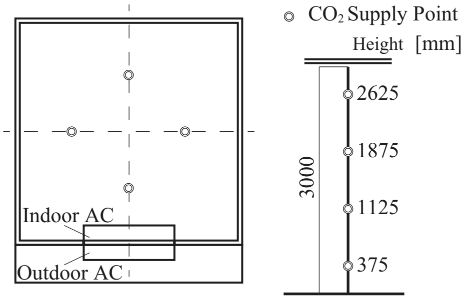
Fig. 8 Temperature change over time

the unilateral AC units but the temperature difference between the inside and outside was similar to that of the indoor ACs. However, under the conditions of 4250 W heating value and 2 m/s air velocity, only the bilateral ACs maintained the temperature difference between inside and outside even at the bottom of the room. In the previous report[3)], it was shown that the horizontal diffusion of the blowing airflow was larger in the bilateral AC than in the unilateral AC, which may have led to the difference in performance under the condition of low blowing velocity 5 m/s.

5. Outdoor air infiltration

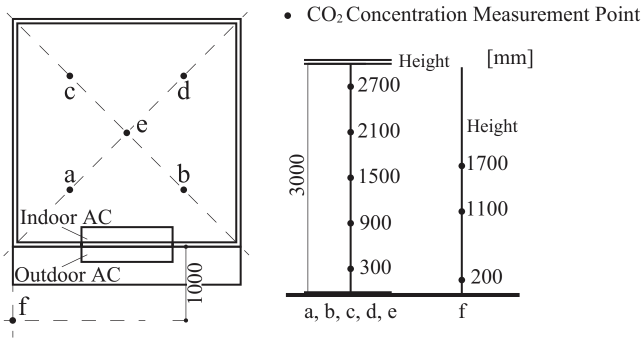
5.1 Measurement Overview

In order to evaluate the performance of the room in intercepting pollutants, the net amount of outdoor air infiltration was measured by tracer gas generation method using CO_2 in steady-state. In the experiment, CO_2 was generated simultaneously at the 16 points shown in **Fig. 9**, and the indoor concentration C_i and outdoor (inside the experimental building) concentration C_o were measured at 5 points in the vertical direction at the indoor poles a ~ e and outdoor pole f for 30 minutes using a CO_2 datalogger (T&D, RTR-576) after reaching steady state. As shown in Table 3, a total of 21 cases were studied, i.e., 3 heat generation conditions, 3 installation positions, 2 blowing velocities, and the no AC case.



(1) Plan (2) Cross Section

Fig. 9 CO_2 supply point



(1) Plan (2) Cross Section

Fig. 10 CO_2 concentration measurement point

5.2 Result and Discussion

The net outside air infiltration rate is calculated by the following equation (1) based on the ventilation rate effectiveness in gas dilution from emission source to the target area.

$$Q_{TG} = \frac{M}{C_i - C_o} \tag{1}$$

Q_{TG} [m^3/h]: Rate of outdoor air infiltration
M [m^3/h]: CO_2 generation rate
C_i [-]: Indoor average CO_2 concentration
C_o [-]: Outdoor CO_2 concentration

Fig. 11 shows the relationship between heat generation and net outdoor air infiltration rate Q_{TG}. In the no AC case, as heat generation increases, the ventilation driving force due to the temperature difference increases, and Q_{TG} increases. On the other hand, with AC, Q_{TG} changed significantly when the AC blowing velocity changed compared to the heat generation value and installation position. Therefore, it can be said that the airflow distribution around the aperture is mainly determined by the AC blowing air velocity, and that the influence of the heat generation and installation position is relatively small. Under the 2250 W heating condition, where the ventilation driving force due to the temperature difference is small, Q_{TG} was larger than that without AC at 8 m/s, indicating that the AC blowing velocity is one factor that determines the amount of outside air infiltration. However, for the 4250 W, 4 m/s, outdoor side AC case, Q_{TG} increased more than for the other 4 m/s cases. This may be due to the greater ventilation driving force from the temperature difference as well as the outdoor air impinging on the floor surface.

Table 3 Experimental condition of AC

Heat Wattage	2250, 3350, 4250 W	
Installation Position	Indoor AC, Outdoor AC Double-sided AC	without AC
Blowing Speed	4, 8 m/s	

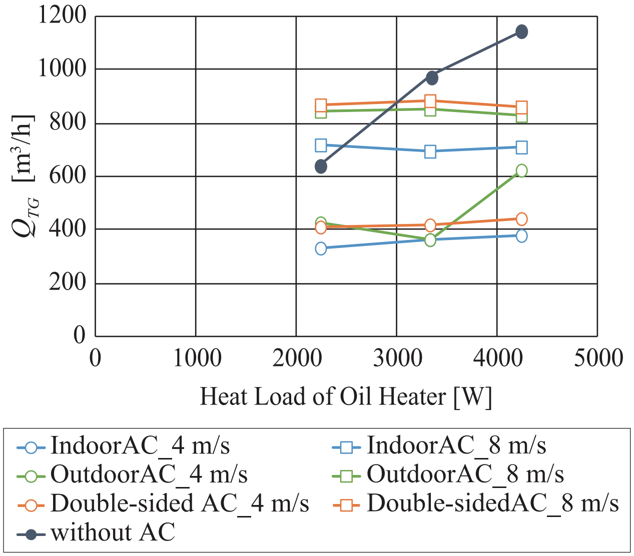


Fig. 11 Relationship between Q_{TG} and heat load of oil heater

5.3 AC Performance Evaluation

5.3.1 Evaluation Index

The airflow blocking performance of the AC is evaluated based on (1) the ratio of advection based on heat balance and (2) the ratio of advection based on CO₂ concentration, respectively using the results of temperature measurements and tracer gas experiments.

(1) Ratio of advection based on heat value, equation (2)

$$Q_{AC\text{-}H}/Q_{0\text{-}H} \tag{2}$$

The advection based on heat balance is calculated from equation (3) and is used to determine the ratio of advection with and without AC.

$$\begin{gathered} C_p\rho \boldsymbol{Q}_{AC\text{-}H}\,\overline{\boldsymbol{\Delta T}_{AC}} - \sum \mathrm{UA}\boldsymbol{\Delta T}_{AC} - \boldsymbol{W} = 0 \\ C_p\rho \boldsymbol{Q}_{0\text{-}H}\,\overline{\boldsymbol{\Delta T}_{0}} - \sum \mathrm{UA}\boldsymbol{\Delta T}_{0} - \boldsymbol{W} = 0 \end{gathered} \tag{3}$$

$C_p\rho$ [J/(Km^3)]: Volumetric heat capacity of air
U [W/m^{2}K] : U-value (Thermal transmittance)
A [m^2] : Area of the wall
$Q_{AC\text{-}H}$ [m^3/s] : Rate of outdoor air infiltration while AC is running
$Q_{0\text{-}H}$ [m^3/s] : Rate of outdoor air infiltration while AC is not running

(2) Ratio of advection based on CO₂ concentration, equation (4)

$$Q_{AC\text{-}TG}/Q_{0\text{-}TG} \tag{4}$$

$Q_{AC\text{-}TG}$ [m^3/h]:Rate of outdoor air infiltration while AC is running
$Q_{0\text{-}TG}$ [m^3/h]: Rate of outdoor air infiltration while AC is not running

The ratio of advection is obtained in the same way from the net outdoor air infiltration rate.

5.3.2 Results and Discussion

The advection ratios obtained from equations (2) and (4) are shown in **Fig. 12**. The results show that blowing AC reduces the advection under most conditions, especially for indoor AC at 4 m/s. The advection ratio based on CO₂ concentration shows that blowing AC increases the advection when the heating value is 2250 W, and in some cases the advection exceeds 100 %. The reason for this difference between the two ratios is that the advection based on heat is affected by the installation position and air velocity to the same degree, while the advection based on CO₂ concentration is extremely affected by the blowing speed. It is necessary to use these indices appropriately, and it is considered appropriate to use (2) the ratio of advection based on heat for the evaluation of air conditioning load reduction and thermal comfort, and (4) the ratio of advection based on CO₂ concentration for the evaluation of interception performance of contaminants.

6. Conclusion

In this paper, we measured the vertical temperature distribution and the infiltration rate in order to understand the airflow interception performance of AC units during heating and their effect on improving the thermal environment. The results show that the location of the AC and the blowing velocity have significant effect on the AC performance. The airflow distribution and temperature distribution near the aperture are considered to have an influence on the AC performance, which needs to be investigated in more detail in the future. It was also clear that the net amount of outside air infiltration depends on the AC blowing velocity. In the future, we intend to examine the AC performance during cooling and to understand the influence of the inside/outside pressure difference, as well as to evaluate the AC performance by CFD analysis.

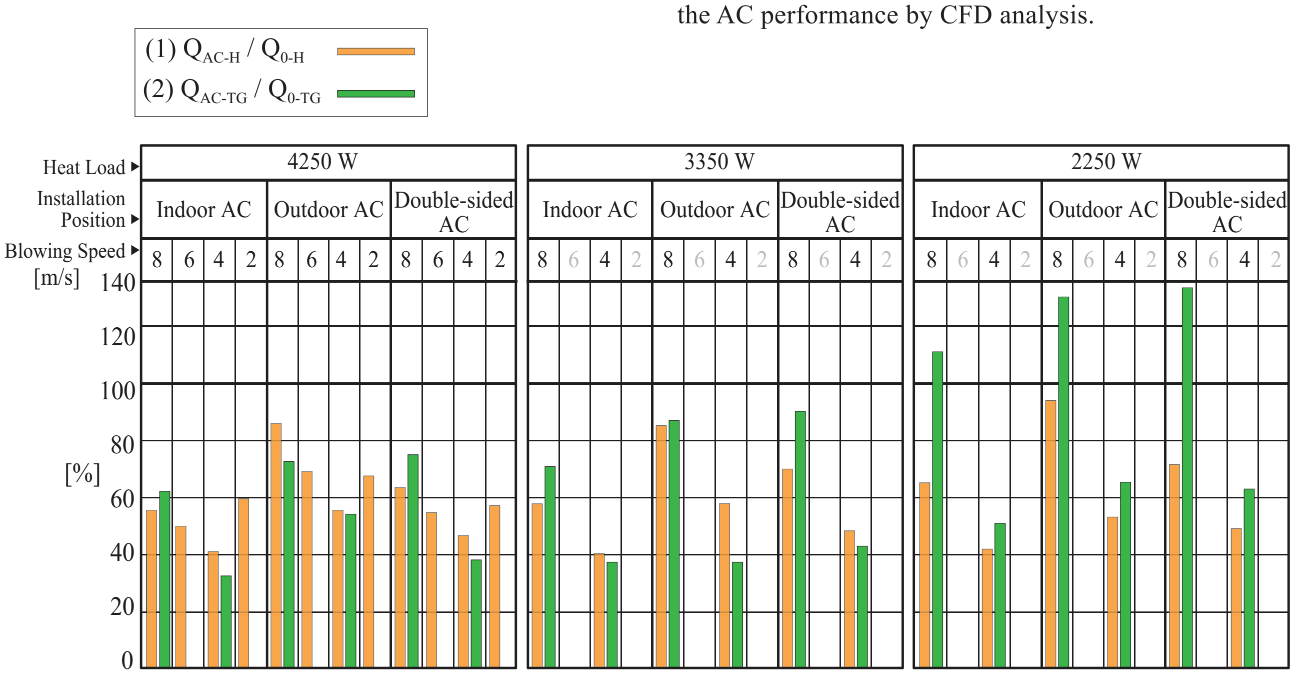


Fig. 12 Bar graph of the ratio between AC and without AC

Note: The rated capacity of the oil heater is 1200 W. However, in this report, the actual values measured by a wattmeter during the experiment, are shown as the heating value.

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