Study on energy loss through door open while air conditioner running in commercial store

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Abstract. While air conditioner is running, leaving doors and windows open is a great way to reduce operating efficiency and undermine the air conditioning system's ability to bring the indoor to a comfortable temperature. However, merchants want to business with open the door to attract more customers and to increase sales. The purpose of this study is to evaluate the heat loss and thermal environment through the door open while air conditioner running. To achieve this goal, using full-scale measurement with the commercial store during the cooling period, the infiltration rate, thermal environment and energy consumption of air conditioner with door opened and door closed state were measured. The measured results show that the infiltration rate at the door opened state was increased by about 21.3 times compared to the door closed state. When the set temperature of the air conditioner was 24 °C, the room temperature with open the door was measured to be about 5 °C higher than the cases of close the door. However, the energy consumption was measured approximately 12 kWh/day and there was not difference with door state. This means that the energy consumption is not increased if the indoor air temperature would not reach the set point temperature of air conditioner.

1. Introduction

Commercial store such as shop in district, department store, convenience store, outdoor cafes, restaurants, etc., is often business leaving doors and opening windows while air conditioner is running to attract more customers and to increase sales. However, that brings a great way to reduce operating efficiency and undermine the air conditioning system's ability to bring the indoor to a comfortable temperature. It also increases the cooling and heating load due to the air leakage caused by the temperature difference. Figure 1 shows a visible image and an infrared thermal image in case of door open while air conditioner running in a commercial store. If there is a significant temperature difference between indoor air and outdoor air, the air leakage will increase significantly. Figure 2(a) shows the principle of natural convection through single vertical rectangular openings. The steady-state infiltration calculation method of single-side opening is proposed by various experimental and numerical studies and it is used to calculate the heat loss in the opening [1-6]. Recently, Pham and Oliver [7] proposed a steady-state equation as shown in Eq. 1. Using this equation, the heat loss is calculated as shown in Fig. 2(b). It means that the heat loss across the opening of 3.0 m in height and 1.2 m in width is calculated approximately 10 kW, when the air temperature difference between indoor and outdoor is 10 °C.

\[
Q = 0.226A(gH)^{0.5} \left[ \frac{\rho_i}{\rho_o} \right]^{0.5} \left[ \frac{2}{1+\left(\frac{\rho_o}{\rho_i}\right)^{0.333}} \right]^{1.5}
\]

Here, \( Q \) [m³/s] is the infiltration rate out of the indoor area, \( g \) [m/s²] is the gravity acceleration, \( H \) [m] is the height of opening, \( W \) [m] is the width of opening, \( A \) [m²] is the opening area, \( \rho \) [kg/m³] is the air density. The subscript ‘i’ used in this equation means indoor or cool climate area, and ‘o’ means outdoor or hot climate area.
To solve the problem, many facilities for entrance with vestibule, revolving door, entry heater, door closer, air curtain and shopping arcade are utilized to reduce the energy loss [8]. Several countries have established policies to impose fines on commercial store with the door open while air conditioner running. New York in the United States is a law [9] passed in 2015 to keep store and restaurant doors closed when their air conditioning is on. According to law, violators face fines of $250 for a first offense and up to $1,000 for an egregious violation.

The purpose of this study is to investigate the infiltration rate and energy loss across the door in a commercial store. To achieve this goal, the infiltration rate across the door were investigated quantitatively by actual measurement in summer and the results were compared with the steady-state calculation method. Moreover, the heat loss characteristic and the indoor thermal environment also investigated.

2. Methods

The target commercial store is a flower shop located in Nagano city (36°38′40.3″N, 138°11′20.5″E), Japan. Figure 3 shows a three-dimensional schematic model of the store. The store has a total floor area of 36.3 m², a volume of 89.6 m³ (actual volume: 65.0 m³ (excluding furniture, equipment, etc.)). The indoor space is consisted in a sales space, a cash register space, and a work space. There are 2 openings in the store, the main entrance (3.52 m²) in the west side, the sub entrance (1.61 m²) with a semi-circular window (0.37 m²) in the northwest side. Figure 4 shows photographs of the main entrance and the indoor status.

| Item          | Contents                                                  |
|---------------|-----------------------------------------------------------|
| Cases         | Door opened case (10:00~19:00, 18. July 2018)             |
|               | Door closed case (10:00~19:00, 19. July 2018)              |
| Cooling capacity | Air conditioner (Cooling capacity: 3.6 kW x 2 ea)        |
| Measurements  | SF₆, Infrared thermal image, Temperature, Humidity, Electric power consumption |
To investigate the infiltration rate, energy loss, and thermal environment of the store, the measurement conditions are shown in Table 1. The measurement cases are 2 cases, in cases of opened door and closed door. The measurement is conducted from 10:00 to 19:00 which is the opening hours to business. The data analysis is used just 2 days acquired data in a similar outdoor thermal condition comparatively as shown in Fig. 4. Figure 4 shows the infrared thermal image of surface temperature at the main entrance at 15:00. By comparison with these images the data analysis days are set to 18-19 July 2018, because the outdoor wall temperature was similar on that days. The air conditioning for a cooling operation is conducted by 2 air conditioners with a cooling capacity of 3.6 kW (rated power consumption: 0.74 kW) respectively, and the set-point temperature is 26 °C. Internal load connected electric socket is conducted by 1 flower refrigerators (rated power consumption: 0.30 kW), lightings of 0.30 kW. The person load and heat transmission load of walls are not considered in this study. Measurement items are the infiltration rate, the indoor and outdoor temperature, external wall surface temperature, and electric power consumption.

2.1. Infiltration rate across the door

The infiltration rate was measured by dispersing sulfur hexafluoride (SF₆) as a tracer gas. Because the flower shop has many flowers and plants, the SF₆ was used as a tracer gas instead of the carbon dioxide (CO₂) in consideration of the possibility of fluctuation of flowers and plants. Among the tracer gas dilution method [10], we used the constant concentration test method, in which the tracer injection is changed so that the indoor concentration becomes constant as shown in Fig. 5. Measurement of the SF₆ gas concentration was carried out by constantly monitoring the tracer gas concentration in the indoor area using a real-time multi-gas monitor (LumaSense Technologies, INNOVA 1312) through plastic tubes. In addition, the tracer injection rate was performed with an indoor concentration as a target value of 10.0 ppm using a multipoint doser and sampler (LumaSense Technologies, INNOVA 1303). The tracer injection point was set to a plurality so that the concentration in the store was sufficiently uniform. The infiltration rate is calculated by Eq. 2.

\[ Q = \frac{G}{\bar{c}} \]  

(2)

Here, \( Q \) [m³/s] is the infiltration rate out of the indoor area, \( G \) [m³/s] is the steady rate of tracer injection, \( \bar{c} \) [ppm] is the time-mean concentration.

2.2. Thermal environment and energy consumption

Figure 6 shows the measured devices. The thermal environment in the store is investigated with the measurement cases by measuring air temperature and relative humidity. Thermal recorders (T&D Corporation, TR-72wf, range: -10 to 60°C) are used for temperature data recording. The measurement data were collected from 10:00 to 19:00 which is the opening hours to business at a sampling frequency of 10 s. Moreover, to investigate the difference of the energy loss by opening and closing the door, the electric power consumption of each device is also examined by measuring the electric current and voltage using clamps and clamp loggers (HIOKI, LR5051, range: AC500.0mA to 1000Arms).
3. Results

3.1. Results of infiltration rate across the door

Figure 7 shows the measurement results of infiltration rate compared with the case of the closed door and the opened door. The infiltration rate across the door in door opened case was measured approximately 1,414.6 m³/h as the average value. In case of the closed door, the infiltration rate was measured approximately 66.5 m³/h. As a result, it was found that the infiltration rate in the opened door case was increased by about 21.3 times compared with the case of the closed door.

3.2. Results of thermal environment and energy consumption

Figure 8 shows the transition of indoor and outdoor temperature in case of the closed door and in case of the opened door. When the set-point temperature of the air conditioner is 26 °C, the indoor temperature of the store in case of the opened door is measured as 35 °C to 27 °C and in case of the closed door is measured as 31 °C to 25 °C. Although the indoor temperature of the store has not maintained the set-point temperature of 26 °C in both cases, the temperature in case of the opened door is more increased than in case of the closed door.

Figure 9 shows the indoor temperature distribution of the store in case of the opened door and the closed door. When the outdoor air temperature was the highest, at 15:00, the result shows that the sales space is maintained approximately 34 °C to 35 °C in case of opened door. Whereas in case of closed door, the selling space is maintained at the temperature of about 28 to 30 °C. That is a reason that increasing of the infiltration rate with increasing the temperature difference is caused thermal environment in the store. In case of the opened door, it is not stable to 26 °C, because the cooling capacity of the air conditioner is not enough. That is also probably because of not only the cooling capacity of the air conditioner but also the problem with the arrangement position and airflow direction of the air conditioner.
Figure 10 shows the electric power consumption of 2 air conditioners and socket. As the results, the electric power consumption of 2 air conditioners was measured approximately 12.21 kWh/day in case of the opened door (no consideration of socket power consumption) and 12.04 kWh/day in case of the closed door (no consideration of socket power consumption). It had not a big difference with evaluated cases unlike thermal environment. This is a similar reason like indoor thermal environment that the cooling capacity of the air conditioner was insufficient to remove the cooling load of the store. It means that the air conditioner was full operated at all time, thus it also means that the electric power consumption is not increased when the indoor air temperature is not reached the set-point temperature of the air conditioner.

![Electric power consumption](image)

(a) Door opened case  
(b) Door closed case  
(c) Comparison of accumulated value

**Figure 10. Electric power consumption**

4. Discussion

Measured infiltration rates were compared to the calculated results to verify that the Pham and Oliver’s equation as shown in Eq. 1 were consistent with the actual findings. Figure 11 shows the comparison between the measured value and the theoretical value of the infiltration rate by using Eq. 2. The theoretical value of the infiltration rate is calculated by using the outdoor temperature and averaged temperature of selling space. The average value of the theoretical infiltration rate in case of the opened door was calculated approximately 1,148.2 m³/h. Although the infiltration rate was smaller than the measurement value because the theoretical value is not considered the effect of wind pressure, the transition of the infiltration rate for a day was the same pattern with the measured value.

Using the infiltration rate by using Pham and Oliver's equation, the infiltration load is also considered when the indoor temperature is maintained at 26 °C. Pham and Oliver's equation is an effective way to calculate infiltration load because the infiltration rate was almost the same as the actual measurement value and the indoor temperature could not be maintained at the set-point temperature at all time in actual measurement. Figure 12 shows the comparison between the infiltration load required to maintain the indoor temperature at 26 °C and the infiltration load generated from the actual measurement. The infiltration load is calculated as 9.12 kW by using Pham and Oliver's equation when the indoor temperature is maintained at 26 °C. Whereas the infiltration load in case of the opened door was measured approximately 0.57 kW in actual measurement because the indoor temperature was maintained higher than 26 °C. Therefore, to business with the door open while air conditioner running in summer, removing process of infiltration load is needed at least 9.12 kW in the store. It means that it is necessary for additional consideration of the infiltration load with opening door to design for air conditioning.

![Comparison with Pham & Oliver equation](image)

**Figure 11. Comparison with Pham & Oliver equation**  
**Figure 12. Infiltration load in case of opened door**
5. Conclusions
From the point of view to reduce energy consumption, door open while air conditioner running on buildings have a problem. However, merchants want to business with open the door to attract more customers and to increase sales. This paper had investigated the infiltration rate and energy loss across the door in the commercial store by actual measurement. The following conclusions can be drawn from the results of the study:

(1) The infiltration rate across the door while air conditioner running for cooling was about 21.3 times larger than the case of the closed door on the target store.
(2) The infiltration rate in case of the opened door using Pham and Oliver's equation was consistent with the actual findings. However, the infiltration rate was smaller than the actual finding because the theoretical value is not considered the effect of wind pressure.
(3) Although the electric power consumption was not increased in case of opened door in target store, the indoor thermal environment is deteriorated. That is also probably because not only the cooling capacity of the air conditioner but also the problem in the arrangement position and airflow direction of the air conditioner.
(4) To business with the door open while air conditioner running in summer, it is necessary for additional consideration of the infiltration load with opening door to design for air conditioning.

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