The influence on the power consumption for air-conditioning equipment by the ventilation

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***Abstract*— In recent years, the necessity of energy conservation in the electrical energy field to achieve a zero-carbon society has been established. Energy conservation requires the effective use of electric energy, and energy management systems (EMS) have been attracting attention as one of the technologies for energy conservation. In this study, we have focused on air-conditioning equipment, which consumes a large amount of energy in homes and offices, and have examined the factors that affect their power consumption. We investigated the influence of the presence or absence of ventilation on the power consumption of air-conditioning equipment.**

Keywords—Air conditioning equipment, Energy management system, Power consumption, Ventilation

I. Introduction

In recent years, energy conservation has become important in the electric energy field to realize a zero-carbon society. Energy management systems (EMS) have been attracting attention as one of the technologies to achieve energy conservation[1]-[9]. For energy management, it is necessary to understand the electricity consumption characteristics of consumers accurately. Therefore, this study focuses on air-conditioning equipment, which has a have high energy consumption in households and offices, and examines the factors that affect their power consumption[10]-[13]. We focus on the fact that regular ventilation is recommended in buildings as part of infection prevention measures following the spread of the novel coronavirus infection (COVID-19). We expect that there will be a behavioral change in consumers in terms of differences in ventilation in buildings before and after the COVID-19 spread. Therefore, we examined the impact of ventilation on the power consumption of air-conditioning equipment.

II. About the facilities under study

Fig.1 shows the building that is the subject of this study. The building consists of eight above ground levels (two above ground levels and six above ground levels), with a total floor area of 8699 [m^2] and a receiving transformer capacity of 1000 [kVA]. The basement level uses gas heat pump air conditioners (GHP), and the ground level uses electric heat pump air conditioners (EHP). The air conditioning units in the building are multi-unit air conditioners with multiple indoor units connected to one outdoor unit. Power consumption data were measured and collected for the electrical outlet system, lighting system, and air-conditioning system in the building. The measured and collected data were displayed on the monitors in the building to visualize the energy consumption. Fig.2 shows the status of the energy consumption displayed on the monitors. The set temperature and inlet temperature of the air-conditioning equipment were also measured and collected for the air-conditioning system. Table 1 lists the ratings of the air conditioning equipment under study. Fig.3 shows the cumulative power consumption of the facility under study for each hour of the year. Fig.3 shows that power consumption tended to increase from 8:00 a.m. and reached its peak at noon. The power consumption tended to decrease from 13:00. Power consumption showed a decreasing trend from 13:00 and reached a value close to the one measured at 7:00 at 20:00. There is a significant difference in power consumption between the times when consumers are active and inactive. This is thought to be due to the fact that air-conditioning equipment is more affected by the behavior of consumers than outlet systems and lighting systems. This suggests that consumers start their activities at 8:00 and end their activities around 20:00. Fig.4 shows the annual power consumption by type for the facility under study. From Fig.4, it can be observed that the most significant largest amount of electricity is consumed by the air-conditioning equipment, followed by the outlet and lighting systems. Therefore, only the air-conditioning equipment was considered in this study.

Fig. 1. Facility for the study

Fig. 2. Visualization of energy consumption

Table 1. Equipment specifications

Use	Installation position	Airflow [m³/h]	Motor [kW]	Cooling capacity [kW]	Heater capacity [kW]
Outdoor unit	**Rooftop**			**56**	**63**
Indoor equipment	**603 room**	**930**	**0.05**	**7.1**	**8**

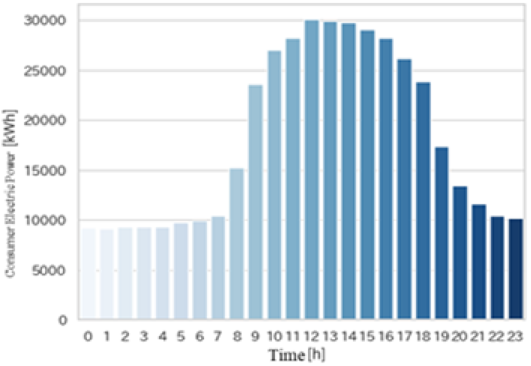

Fig. 3. Cumulative energy consumption of air-conditioning equipment by time

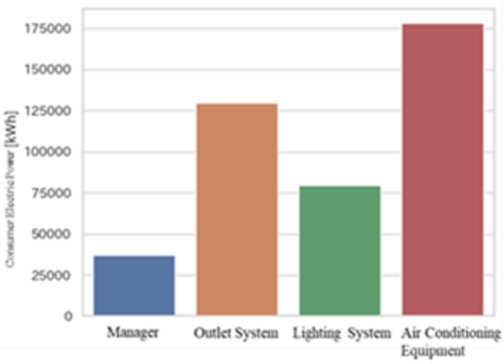

Fig. 4. Types of consumer power

III. METHOD OF INVESTIGATION

In this study, we examined a six-story building with an EHP in the research facility shown in Fig.1. The air conditioning equipment in the building is a multi-air conditioner with multiple indoor units connected to the outdoor unit. The layout of the indoor units in relation to one outdoor unit and the layout of the rooms where the indoor units are located were established, and the rooms to be studied were determined. Fig.5 shows the layout of the rooms that were considered. Table 2 lists the volume of each room. The study subjects consisted of three rooms and a lounge. There were in total six indoor units comprised to an outdoor unit, which consisted of one indoor unit in room 602, two in room 603, two in room 604, and one in the lounge. The rooms under study were automatically ventilated using a 24-hour ventilation fan. In-Room 603, ventilation was also provided by opening and closing doors and windows when the room was in use.

In this study, it was difficult to analyze the difference in power consumption because many factors affect the power consumption of air conditioning equipment, such as the outside temperature, inlet temperature, and set temperature. Therefore, we extracted air conditioners with the same set temperature during operation and examined the relationship between the outdoor temperature and power consumption. In this study, the period before the COVID-19 was set from 2018 to 2019, and the period for the COVID-19 disaster was set to 2020 in order to measure the difference in power consumption of air-conditioning equipment due to the difference in ventilation between before and after the COVID-19 expansion. For each period, we used the power consumption data of the air-conditioning systems measured and collected at the studied facilities, as shown in Fig.1.

For the outdoor temperature, we used the daily average temperature at the location of the facility under study extracted from the historical meteorological data published by the Japan Meteorological Agency. Fig.6 shows the number of data points by temperature setting of indoor units from 2018 to 2019, and Fig.7 indicates the number of data points by temperature setting of indoor units in 2020. Figs.6 and 7 show the number of data points by temperature setting for the six indoor units during air conditioning operation. The vertical axes of the graphs in Figs.6 and 7 are arranged as (602, 603_West, 603_East, 604_West, 604_East, and Lounge6F). Zero indicates that the air-conditioning equipment is not in operation.

From Figs.6 and 7, it was decided to extract the data when the combination of the set temperature was (0, 23, 23, 0, 0, 0), based on the fact that the air conditioning equipment operation and the set temperature were consistent and that the data included the air conditioning equipment operating in room 603, which was expected to have better ventilation than the other rooms. The combination of temperature setpoints was determined to be (0,23,23,0,0,0). The combination of the set temperatures indicates that the air conditioning equipment in Room 602, Room 604, and the lounge are not in operation, and only the air conditioning equipment in Room 603 is in operation. The relationship between the outdoor temperature and power consumption was examined by extracting the power consumption and outdoor temperature data. In addition, to observe the differences depending on the temperature setting, the same study was conducted when the temperature setting in room 603 was constant at 20°C.

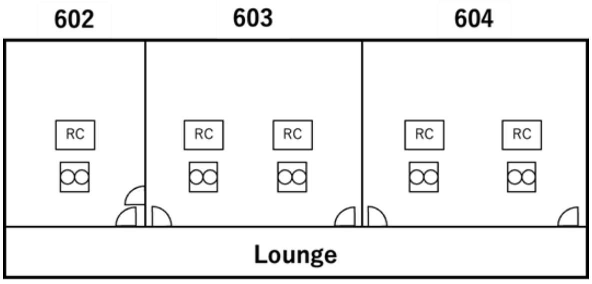

Fig. 5. Floor plan of the rooms where the experiment was conducted with one outdoor unit

Table.2. Volume of each room

	Depth[m]	Width [m]	Height [m]	Area [m^2]	Volume [m^3]
602	**7.65**	**3.3**	**2.7**	**25.3**	**68.3**
603,604	**7.65**	**6.6**	**2.7**	**50.6**	**136.6**

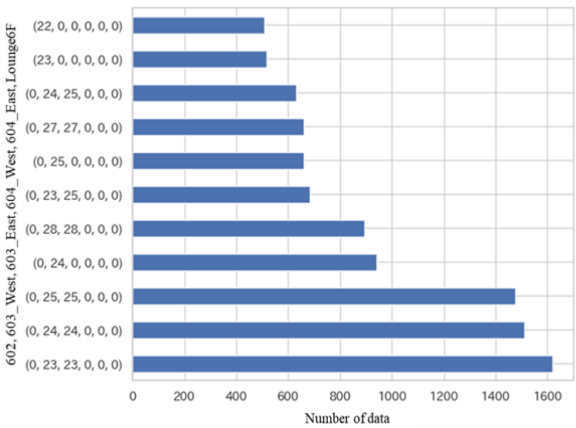

Fig. 6. Number of data by temperature setting for indoor units (2018-2019)

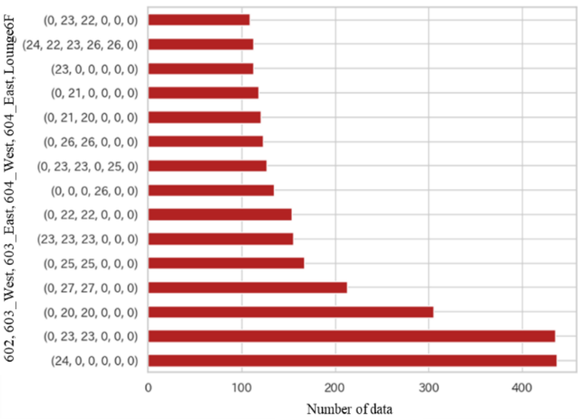

Fig. 7. Number of data by temperature setting for indoor units (2020)

IV. RESULT OF INVESTIGATION

Fig.8 shows the relationship between outdoor temperature and power consumption at a constant set temperature of 23°C. Fig.3 plots the data at 10-minute intervals with power consumption on the vertical axis and outdoor temperature on the horizontal axis. Fig.8 shows that from 2018 to 2019 (before COVID-19), outdoor temperatures were widely distributed between 10°C and 30°C. In 2020 (COVID-19 disaster), the distribution was concentrated between 20°C and 30°C of outdoor temperatures. For outdoor temperatures below 22°C, there was no significant difference in power consumption between 2018-2019, and 2020. However, for outdoor temperatures above 23°C, power consumption appears to be higher in 2020 than in 2018-2019. Fig.9 shows the relationship between outdoor temperature and power consumption at a constant set temperature of 20°C. Fig.9 shows that from 2018-2019, the distribution was concentrated between 0°C and 20°C of outside temperature, while in 2020, the distribution was concentrated between 4°C and 18°C of the outside temperature. Comparing 2018-2019 and 2020 for outdoor temperatures between 0°C and 10°C, power consumption appears to be higher in 2020 than in 2018-2019.

To further examine the data in detail, the data were narrowed down to the outside temperature from 23°C to 29°C when the temperature was 23°C and from 3°C to 15°C when the temperature was 20°C. A box-and-whisker diagram and a graph showing the 95% confidence intervals for the average power consumption were created and used to examine the data further. Fig.10 shows the box-and-whisker diagram and 95% confidence interval for the average power consumption at a set temperature of 23°C. Fig.11 shows the box-and-whisker diagram and 95% confidence interval for the average power consumption at a set temperature of 20°C. Fig.11 shows the box-and-whisker diagram and the 95% confidence interval for the average power consumption at a set temperature of 20°C. Fig.10 indicates that the average value for 2018-2019 was 1.64 [kW] and for 2020 was 2.98 [kW]. The median value for 2018-2019 was 1.63 [kW], and the median value for 2020 was 2.54 [kW]. Fig.11 shows that the mean value for 2018-2019 was 1.79 [kW] and the mean value for 2020 was 2.32 [kW]. The median value for 2018-2019 was 1.78 [kW], and the median value for 2020 was 2.15 [kW]. The mean and median values at a set temperature of 23°C and a set temperature of 20°C are larger in 2020 than in the period between 2018 and 2019. These results suggest an increase in the power consumption of air conditioning equipment due to ventilation in the COVID-19 disaster compared to taht before the COVID-19 expansion.

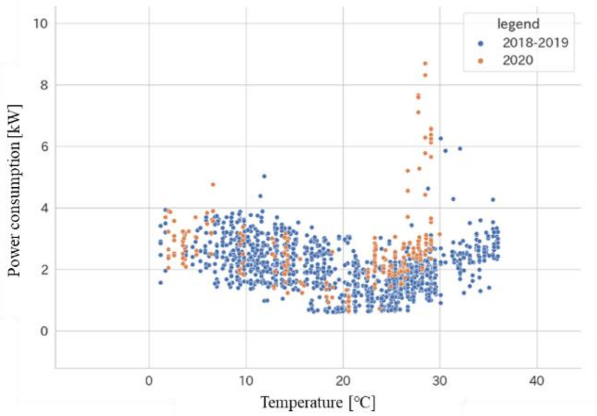

Fig. 8. Relationship between outside temperature and power consumption
(set temperature [0, 23, 23, 0, 0, 0])

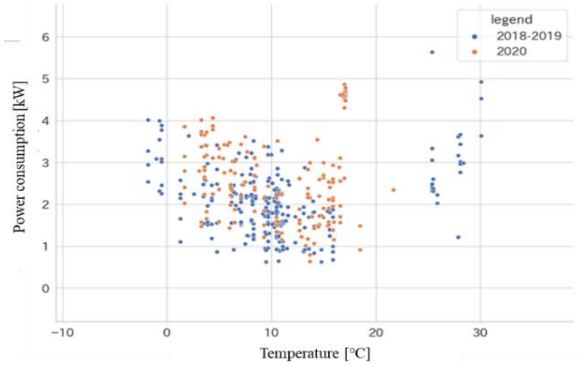

Fig. 9. Relationship between outside temperature and power consumption
(set temperature [0, 20, 20, 0, 0, 0])

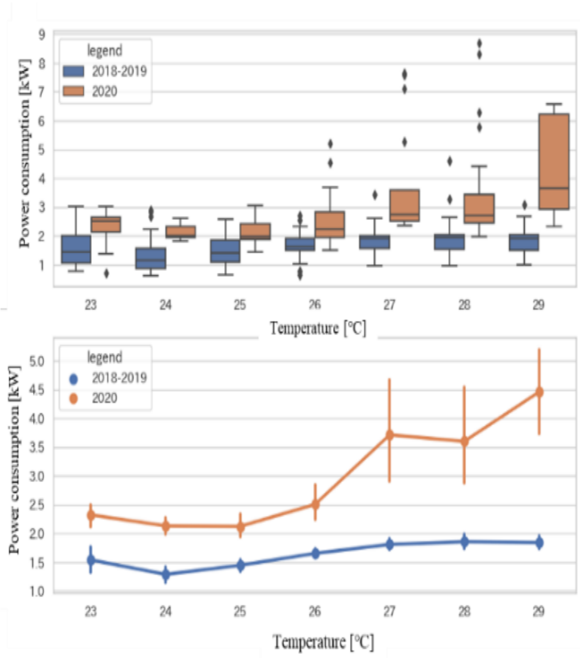

Fig. 10. Box-and-whisker diagram (top) and average power consumption (bottom)
(set temperature [0, 23, 23, 0, 0, 0])

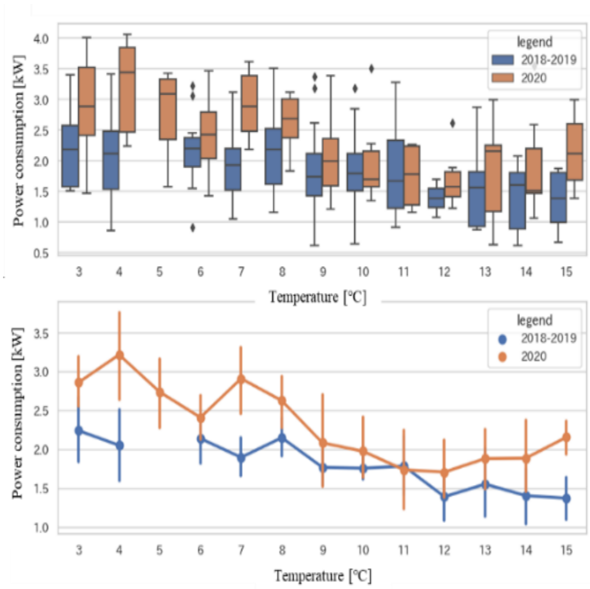

Fig. 11. Box-and-whisker diagram (top) and average power consumption (bottom)
(set temperature [0, 20, 20, 0, 0, 0])

V. CONCLUSION

This study focuses on the fact that regular ventilation is recommended in buildings as part of infection prevention measures following the expansion of COVID-19 and examines the impact of differences in ventilation in buildings before and after COVID-19 expansion on the power consumption of air conditioning equipment. The results showed, that power consumption tended to be higher in 2020 (COVID-19 disaster) compared to the period before COVID-19(2018-2019). In the future, we plan to conduct studies that consider expanding the scope of coverage and human behavior.

ACKNOWLEDGMENT

This research was conducted using the facilities and equipment of the "Aichi Institute of Technology Eco-Electricity Research Center". The research was also supported by Aichi Institute of Technology research projects, cross-disciplinary research, and basic research on electricity considering energy demand science. We would like to express our gratitude to all the parties concerned.

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