Field Survey on Indoor Thermal Environment in Small to Medium Sized Building with Packaged Air Conditioners

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Abstract

Recently, a lot of multiple packaged unit system is adopted in small to medium sized buildings in Japan. This system enables to control each packaged air conditioner (PAC) individually because multiple packaged units are placed decentrally. However, it is not clarified sufficiently how indoor environment is formed when PAC is working. This paper shows the measurement results of indoor thermal environment in a medium sized building with PAC in all season for the purpose of clarifying the current status of indoor environment and its issue. In indoor thermal environment, there was no issue throughout the year though measurement conditions made difference in temperature and humidity distribution. In indoor units operation, it was clarified that supply air temperature of PAC is different from each PAC and way. In addition, it was clarified that short circuit of supply air from PAC to inlet of the ventilation devices happen.

Keywords: multiple packaged unit system, field survey, indoor thermal environment

1. Introduction

Recently, energy consumption in civilian sector is increased in Japan. Saving of energy consumption in general buildings is required as a solution of global warming. Thus, energy conservation law concerning buildings is changed from a total floor space of more than 2000 m^2 to more than 300 m^2 [1]. However, the running situation of the air conditioners in real buildings are not clarified, because they don’t have monitoring control system such as central monitor system. Furthermore, it is not applicable in small to medium sized buildings though standards of indoor environment are established in building hygienic maintenance law for large sized buildings of a total floor space of more than 3000 m^2 [2]. Therefore, standards of indoor environment in small to medium sized buildings are needed and the way to conserve the energy consumption under keeping a comfortable indoor environment has to be discussed. In addition, it is not enough though some field surveys has been done on indoor thermal environment with packaged air conditioners (PAC). [3]

This study is intended for small to medium sized buildings with PAC because a lot of multiple packaged unit system is adopted in such small sized buildings. This system enables to control each PAC individually because multiple packaged units are placed decentrally. However, it is not clarified sufficiently how indoor environment is generated when PAC is running.

This paper shows the measurement results of indoor thermal environment in a medium sized building with PAC in all season for the purpose of clarifying the current situation of indoor environment and its issue.

2. Method of investigation

Measurements were taken in summer (Jul.21 to Sep.4, 2009), moderate season (Oct.13 to Nov.6, 2009) and winter (Feb.8 to Mar.5, 2010). The office room, the target of this study, is located in the 5th floor of 7-storied office building in Osaka, Japan. There are adjacent buildings in the east-west direction, the parking in the north direction and the road in the south direction. Table1 shows building summary. The air conditioning system of this building is so-called multiple packaged unit system, and there are 6 indoor units of 4-way ceiling mounted cassette type (PAC1-6) in the office room. Cooling capacity is 9.0kW (PAC1, 3, 5) and 7.1kW (PAC2, 4, 6), while heating capacity is 10.0kW (PAC1, 3, 5) and 8.0kW (PAC2, 4, 6). Thermostats of room temperature are in indoor units. In addition, there are 3 ventilation equipments (VENT1-3) which have 2 inlets and 2 outlets. They are switchable for total heat exchanger mode (HEX) and desiccant mode (DEC). Figure1 shows 5th floor plan and measurement points of horizontal temperature and humidity. Table2 shows measurement items. Measurement conditions are determined by the setting temperature and ventilation mode. Table3 and 4 shows measurement conditions of representative weeks in summer (Aug.17 to Aug.21, 2009), moderate season (Nov.2 to Nov.6, 2009) and winter (Feb.15 to Feb.19, 2010). Aug.17 and Nov.2 is representative days of 27^{o}C&HEX, and Feb.15 is a representative day of 22^{o}C&HEX because measurement conditions are same for Aug.17 and 18, Nov.2 and 3, Feb.15 and 16.

Table 1 Building summary

Use	Office
Total floor area	2614m^2
Office area(5F)	216m^2
Stories	7F
Number of packaged air conditioner per office room	6
Number of total heat exchanger / desiccant per office room	3

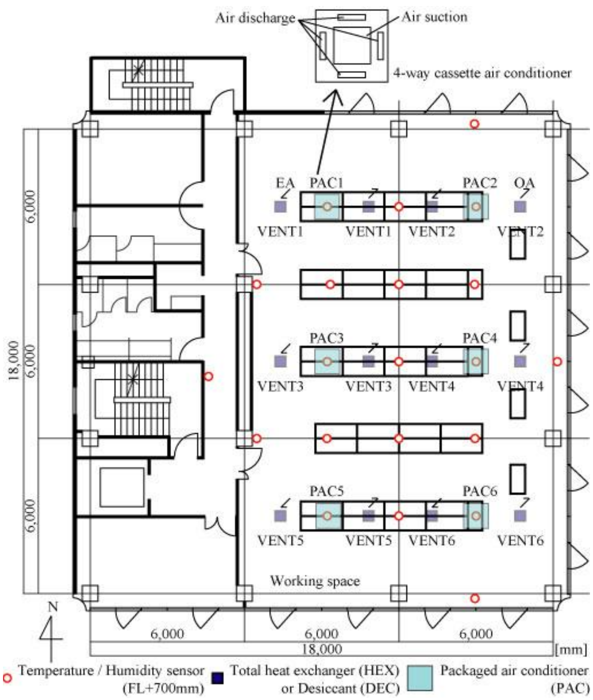

Figure 1 Building Plan

Table 2 Measurement items

Measurement item	Number of measurement points	Measurement interval
Temperature/Humidity (Horizontal distribution)	20	5min.
Temperature/Humidity (Vertical distribution)	Interior:5, Perimeter:5	5min. (FL+100,600,1100,1700,2900mm)
Temperature/Humidity (Packaged air conditioner)	Air inlet:6, Air outlet:6	5min.
Temperature/Humidity (Total heat exchanger)	Air inlet:6, Air outlet:3	5min.
PMV	2	10min.
CO_2 concentration	2	10min.
Horizontal illuminance	10	1min.
Vertical illuminance	2	1min.

Table 3 Measurement conditions (cooling)

Summer	Autumn	Setting temperature	Ventilation system
Aug.17, 18	Nov.2, 3	27^{o}C	Total heat exchanger (HEX)
Aug.19	Nov.4	26^{o}C	Total heat exchanger (HEX)
Aug.20	Nov.5	27^{o}C	Desiccant (DEC)
Aug.21	Nov.6	26^{o}C	Desiccant (DEC)

Table 4 Measurement conditions (heating)

Winter	Setting temperature	Ventilation system
Feb.15, 17	22^{o}C	Total heat exchanger (HEX)
Feb.18	20^{o}C	Total heat exchanger (HEX)
Feb.16	22^{o}C	Desiccant (DEC)
Feb.19	20^{o}C	Desiccant (DEC)

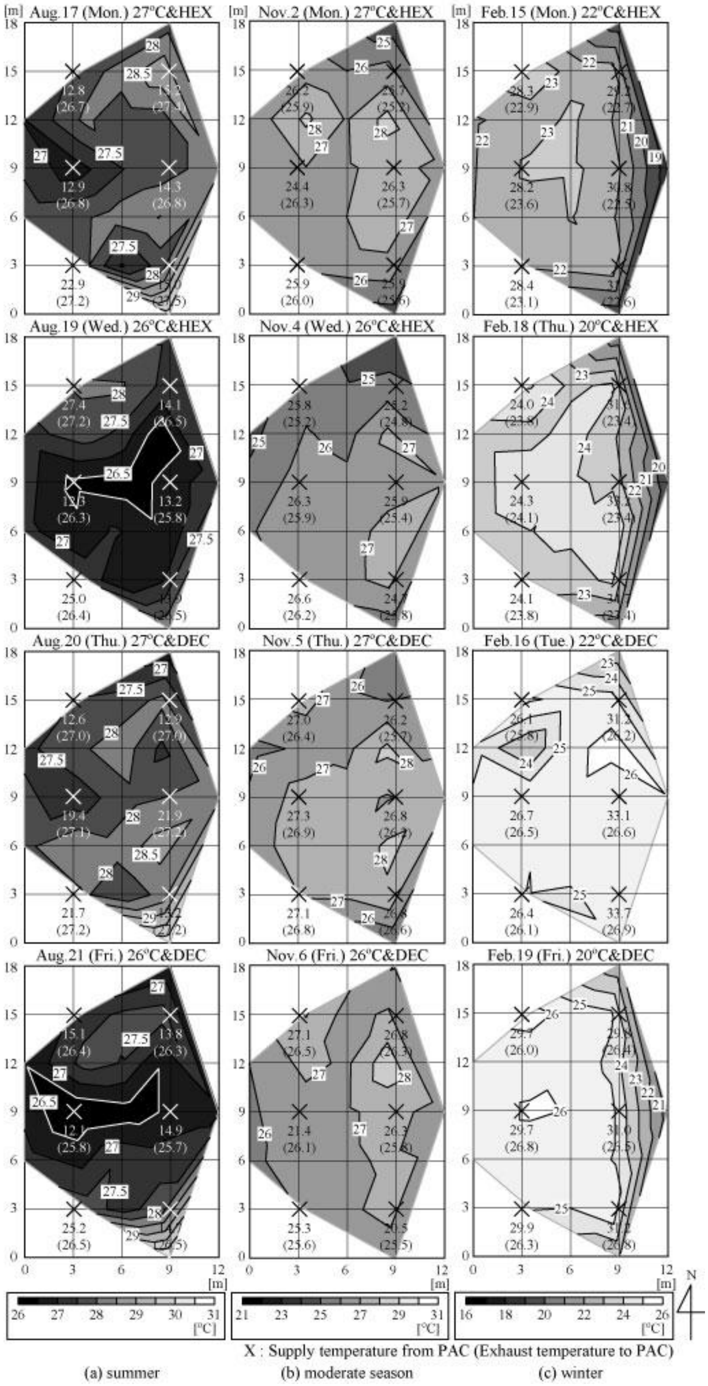

Figure2 Horizontal temperature distribution
((a) summer, (b) moderate season, (c) winter)

3. Indoor thermal environment

3.1 Indoor temperature distribution

Figure2 shows horizontal temperature distribution (FL+700mm) in summer, moderate season and winter respectively which is average of 2 hours (15:00 to 17:00). This figure is indicated as coordinate where southwest point of office room is origin coordinate (see Figure1). X-mark means PAC1-6 and values under the each X-mark represent each average temperature of supply and exhaust air. Supply air temperature shows one-way temperature in summer and average of 4-way temperature in moderate season and winter.

In summer (Figure2 (a)), room temperature is higher than setting temperature by 1°C. Specifically, room temperature is about 27.5 to 28.5°C at 27°C of setting temperature, about 26.5 to 28°C at 26°C of setting temperature. Decrease in temperature around center of the office room is especially larger than any other parts of room by 1 to 1.5^{o}C which is resulted from operational situation of PAC3 and 4 because decrease in temperature is small on Aug.20 when PAC3 and 4 is under on-off control. It is also similar to PAC1. PAC2 and 6 is always cooling, while PAC5 is under on-off control. HEX and DEC make no difference in temperature distribution.

In moderate season (Figure2 (b)), setting temperature makes no difference since room temperature is about 26 to 28^{o}C at 27^{o}C of setting temperature and about 25 to 28^{o}C at 26^{o}C of setting temperature. It is caused by rare PAC operation because of little cooling load. Compared with summer survey, it is inclined to be smaller effect of solar radiation in the south direction and greater effect of ambient temperature in the north direction.

In winter (Figure2(c)), room temperature is about 20 to 23^{o}C at 22^{o}C of setting temperature on Feb.15 and room temperature is higher than setting temperature by about 3 to 6^{o}C in other days. It is thought that PAC is heating operation on Feb.15 and room temperature was out of control in other days because of forced heating operation though cooling operation was needed actually. In addition, supply air temperature is high in these days. This is because there is heating demand not in this room, but in the other room where indoor units are connected with same outdoor units. Therefore, more analysis is needed in the near future. It is needed to pay attention to switch of operation in the room where internal load is large such as the target of this study because there are cooling demand and heating demand at the same time.

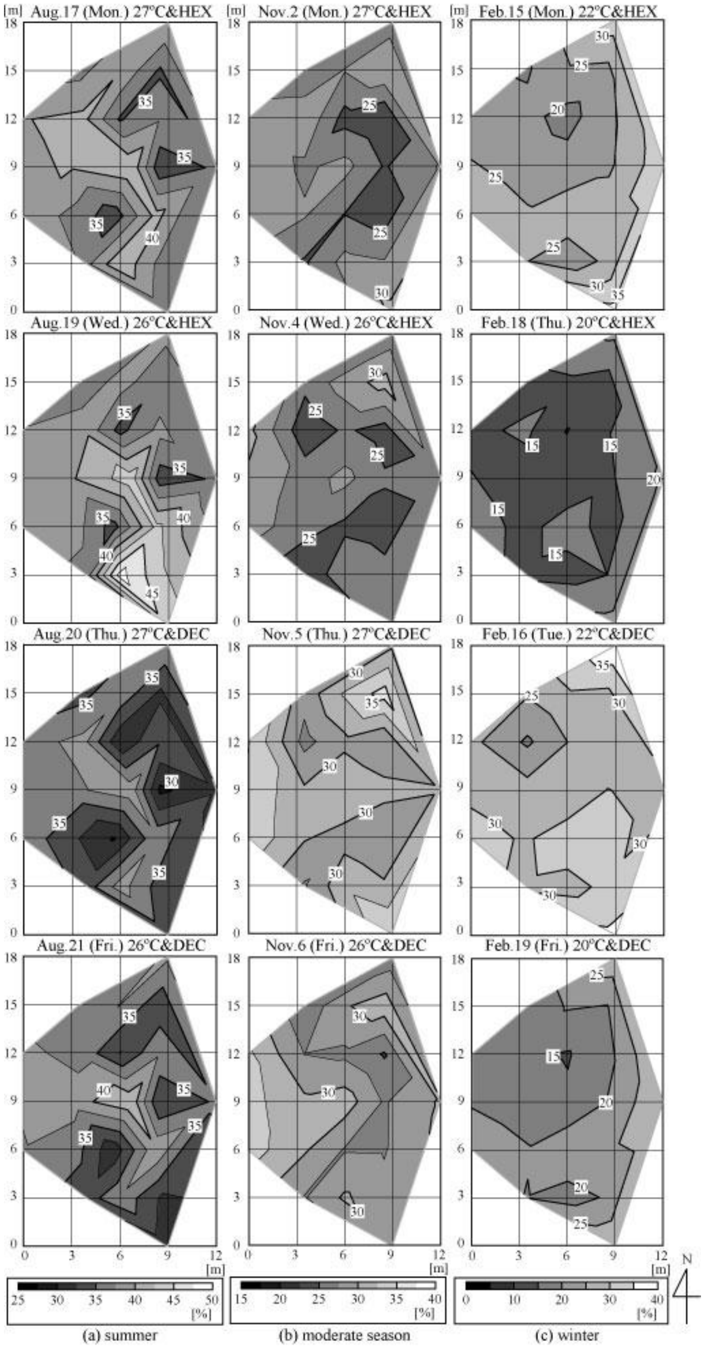

Figure3 Horizontal humidity distribution
((a) summer, (b) moderate season, (c) winter)

3.2 Indoor humidity distribution

Figure3 shows horizontal humidity distribution (FL+700mm) in summer, moderate season and winter respectively which is average of 2 hours (15:00 to 17:00).

In summer (Figure3 (a)), setting temperature makes no difference in humidity distribution. However, room relative humidity in DEC is lower than in HEX. Specifically, room relative humidity is about 35 to 45% in HEX and about 30 to 40% in DEC. This is the effect of dehumidification in DEC.

In moderate season (Figure3 (b)), there is no effect of dehumidification because ambient humidity was low. However, all relative humidity in this room is lower than 40%.

In winter (Figure3(c)), room relative humidity in DEC is higher than in HEX by about 5 to 10%. This is the effect of humidification in DEC. However, it is inclined to be low relative humidity in this room. It is resulted from no humid operation because there was not heating demand but cooling demand.

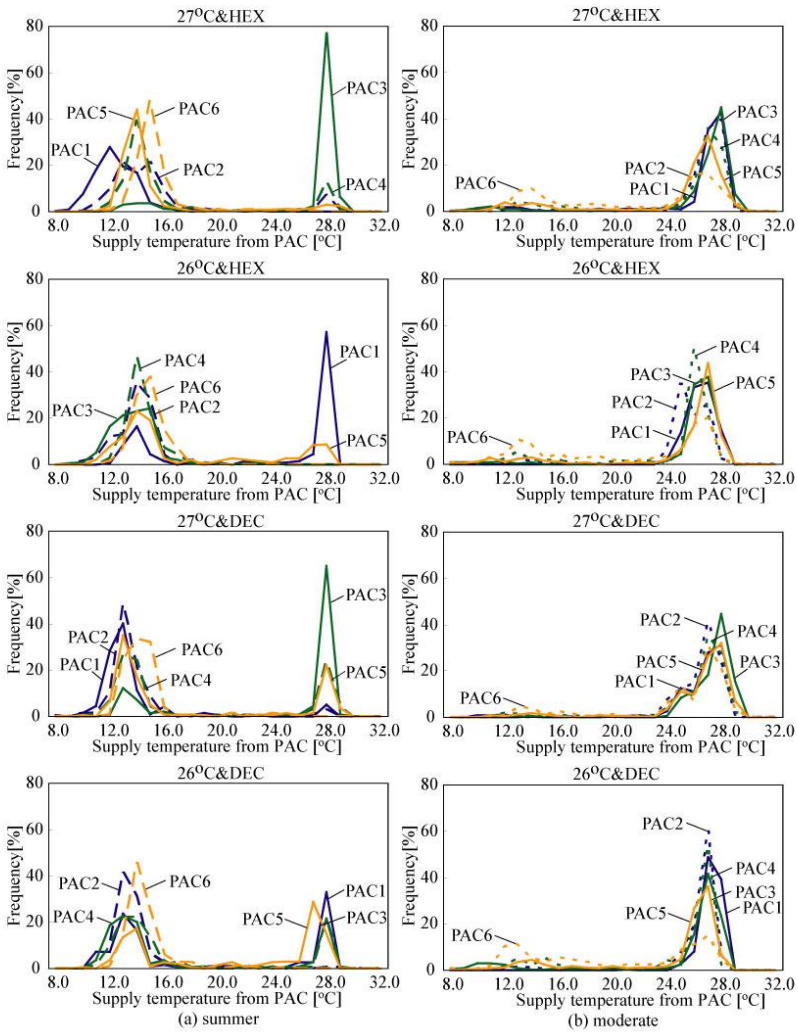

Figure4 The frequency of supply air temperature from PAC by every PAC ((a) summer, (b) moderate season)

4. Indoor units operation

4.1 Supply air temperature from PAC

(1)Difference from PAC

Figure4 shows the frequency distribution of supply air temperature of PAC by every measurement conditions when it is working hours (9:00 to 17:00) in summer and moderate season. The values of supply air temperature at intervals of 5 minutes are one-way temperature in summer and 4-way temperature in moderate season.

In summer (Figure4 (a)), supply air temperature is 12 to 14^{o}C when the thermostat is on, and 27 to 28^{o}C when the thermostat is off. In addition, supply air temperature is different from each PAC. It is thought that there is a mutually complementary relationship between PAC1 and 3. The thermostat is likely to be off in PAC3 when on in PAC1 at 27^{o}C of setting temperature, while the thermostat is likely to be off in PAC1 when on in PAC3 at 26^{o}C of setting temperature. PAC2 and 6 in the perimeter zone is cooling almost all the time. Supply air temperature of PAC4 and 5 is different from HEX and DEC. The thermostat is likely to be on in HEX, while the thermostat is likely to be on and off in DEC.

In moderate season (Figure4 (b)), supply air temperature is 26 to 28^{o}C almost all the time. PAC6 is sometimes cooling because it locates at south direction. Compared with summer survey, measurement conditions make no difference because thermostat is inclined to be off.

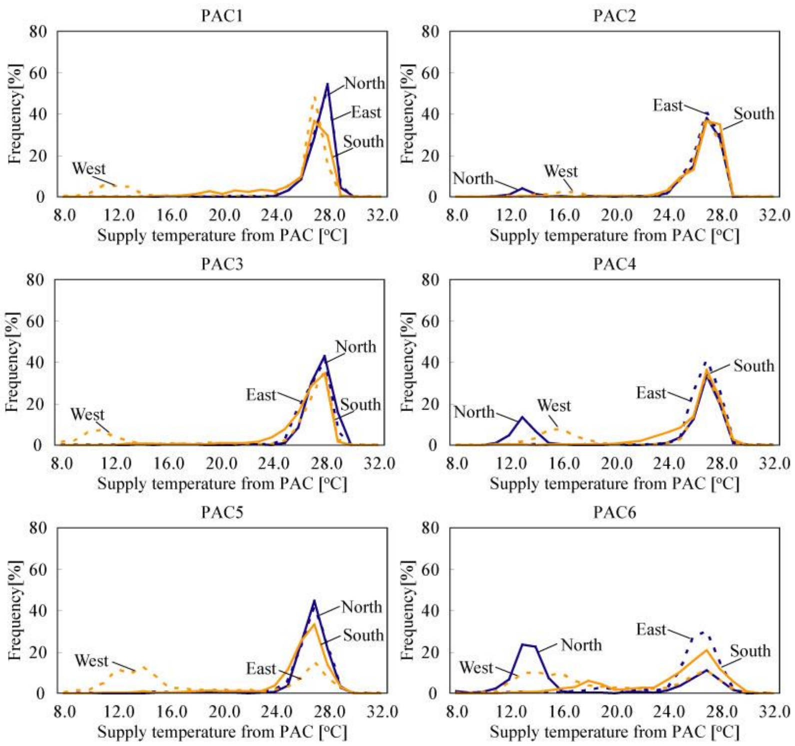

Figure5 The frequency of supply air temperature from PAC by every ways

(2)Difference from ways of supply air

Figure5 shows the frequency distribution of supply air temperature of PAC by every ways of supply air when it is working hours (9:00 to 17:00) in moderate season. In moderate season, the thermostat is likely to be off (see Figure4), however, it is different from ways of supply air. Supply air temperature of PAC1, 3, 5 in the interior zone is 10 to 13^{o}C at the west direction, 26 to 28^{o}C at the other direction. Supply air temperature of PAC2, 4, 6 in the perimeter zone is 12 to 14^{o}C at the north and west direction, 26 to 28^{o}C at the other direction. Though PAC6 is higher frequency of cooling than PAC2 and 4, it is different from supply air temperature and frequency by ways. This can cause by the positional relationship between internal heat exchanger of PAC and outlets. Especially, it can cause in moderate season when refrigerant mass flow rate is low because of low cooling load. This chapter is clarified supply air temperature of PAC is different from each PAC and way, however, there is no effect of indoor thermal environment.

4.2 Short circuit of Supply Air from PAC

Figure6 shows the diagram of airflow from PAC and VENT. It is thought that there is airflow from two directions into inlets of VENT. One is airflow mixed by supply air from PAC and indoor air, the other is airflow which comes from PAC directly. Because of this effect, it is expected that exhaust air temperature to VENT is lower than to PAC. This paper considers short circuit of supply air from PAC in summer when this effect is great.

Figure7 shows relation between exhaust air temperature to PAC2 and VENT2 to the west of PAC2 in case of 27^{o}C&HEX when it is working hours (9:00 to 17:00).

Exhaust air temperature to PAC is 26 to 28^{o}C that is plus or minus 1^{o}C of setting temperature, while exhaust air temperature to VENT is lower than setting temperature by 4^{o}C. Therefore, there is possibility that short circuit of supply air from PAC to inlet of VENT happens. This effect is shown in the other relation between exhaust air temperature to PAC and to VENT.

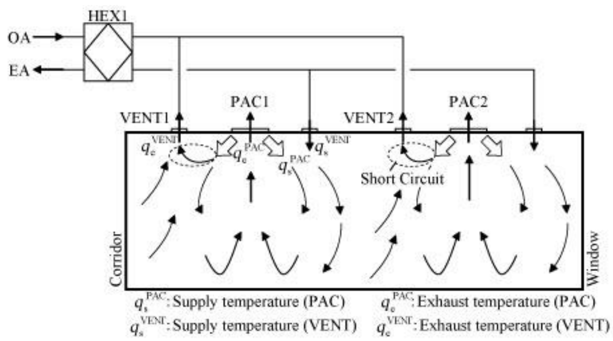

Figure6 The diagram of airflow from PAC and VENT

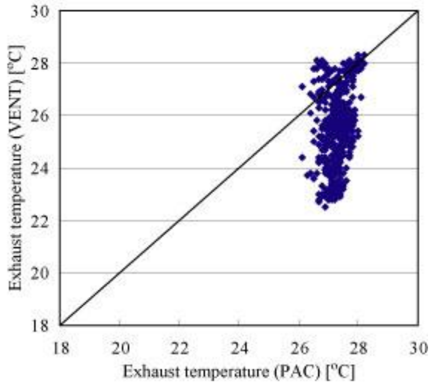

Figure7 Relation between exhaust air temperature to PAC2 and VENT2

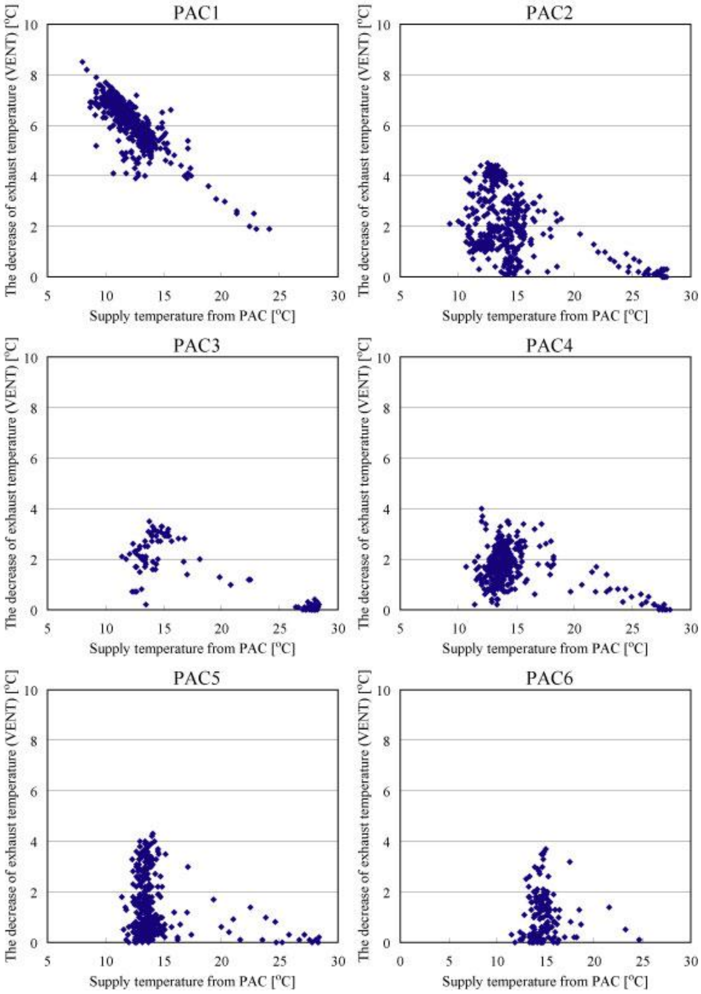

Figure8 Relation between supply air temperature from PAC and the decrease of exhaust air temperature to VENT

Figure8 shows relation between supply air temperature from PAC and the decrease of exhaust air temperature to VENT (Exhaust air temperature to PAC ($=q_e^{PAC}$) - Exhaust air temperature to VENT ($=q_e^{VENT}$), see Figure6). There is possibility that short circuit of supply air from PAC to inlet of VENT happens if the decrease of exhaust air temperature to VENT is greater than 0°C because exhaust air temperature to PAC is plus or minus 1°C of setting temperature (see Figure7). All decrease of exhaust air temperature to VENT is about 4°C when supply air temperature from PAC is 12 to 14°C. For this reason, short circuit is likely to happen. Especially in PAC1, decrease of exhaust air temperature to VENT is the greatest up to 9°C. Short circuit ratio is defined as the ratio of short circuit (decrease of exhaust air temperature to VENT>2°C) to PAC operating (supply air temperature from PAC<20°C). However, not all supply air from PAC short-circuits because it is different from supply air flow rate of PAC and exhaust air flow rate of VENT. However, more consideration is needed for this definition because the definition of 2°C is just a supposition.

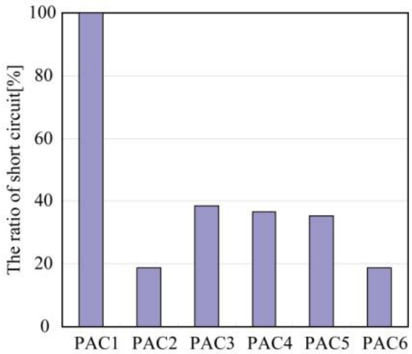

Figure9 The ratio of short circuit

Figure9 shows the ratio of short circuit from outlets of PAC to inlets of VENT on Jul.28 to Aug.28. Compared with PAC1-6, the ratio of short circuit is highest in PAC1. It is thought that supply air from PAC may short-circuit. More consideration is needed for short circuit in the future because many factors affect short circuit. In addition, consideration including heat-transfer efficiency is needed because there is heat recovery in HEX.

5. Conclusion

There was no issue in indoor thermal environment throughout the year though measurement conditions made difference in temperature and humidity distribution. In indoor units operation, it was clarified supply air temperature from PAC is different from each PAC and way. In addition, it was clarified that short circuit of supply air from PAC to inlet of VENT happens. More detailed indoor environment by means of CFD analysis is recommended in the future study.

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