

RESEARCH ON THE ADVANCED USE OF MULTI-SPLIT TYPE AIR-CONDITIONING SYSTEM

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Abstract: An energy performance of a multi-split type air-conditioning system was evaluated based on BEMS data and an investigation under actual operation. A simulation model developed in other research was verified. In accuracy evaluation of model based on BEMS data, it was confirmed that output values of the model are highly similar to BEMS data. In addition, it was confirmed that outdoor DB temperature is connected to a compression work because a heat exchange increases due to decrease in outdoor DB temperature. The indoor thermal environment in summertime of Building A under the multi-split type air-conditioning system that uses developed models was investigated. By a continuous measurement and punctual measurement, it was confirmed that the air temperature in task zone didn't fluctuate rapidly, and an air draft didn't influence comfort in task zone.

Key Words: *multi-split type air conditioning system, BEMS, ADPI*

1 INTRODUCTION

Recently, a multi-split type air-conditioning system has treated as the energy saving air-conditioning system with high flexibility which can correspond to the wide range of building use. It is important to consider the energy performance of a multi-split type air-conditioning system as well as the handiness and the cost of building. Rated COP in the specific condition is set as the standard about an index of energy saving, but the operating characteristic undergoes influence by the outside temperature and the heating or cooling load. A gap forms between the rated performance and the real performance in operation. Therefore rated COP is not an enough index to evaluate energy saving in actual operation.

In this paper, a multi-split type air-conditioning system was evaluated in both side of energy performance and indoor comfort. The energy calculation model developed by other research (Togashi et al. 2008) was verified, and the energy performance of the system was evaluated by analyzing the response of the system based on BEMS data according to the building use situations. The indoor comfort was considered to evaluate general performance of the system quantitatively based on actual investigation.

2 THE FACILITY UNDER STUDY

Table 1 shows the information of the facility under study. Building A is constructed in Tokyo as office and residence. This 8th floor is the floor under study, and the floor area is about 2,000m².

To save energy, keeping indoor air quality and thermal comfort, this building uses an air-conditioning system logs indoor air temperature. Air-conditioner in task zone treat sensible heat load, and air-conditioner in ambient zone treat latent heat load. Figure 1 shows the air-conditioning system in Building A. Air-conditioner in task zone is controlled by the remote

sensor logs temperature of the zone, and it operates only a presence part by occupant sensors on the ceiling. Types of supply air outlet which can be chosen are directional and diffusion, and they can effect on thermal comfort in task zone.

Table 1; The information of the facility under study

Building	Building A	
Location	Minato-ku, Tokyo, Japan	 appearance
Site area	14,587m ²	
Building area	2,721m ²	
Total floor area	33,512m ²	
Structure	SRC/RC	
Height	58m	
Number of stories	above the ground ; 15 stories underground ; 2 stories	
Uses	office, residence	

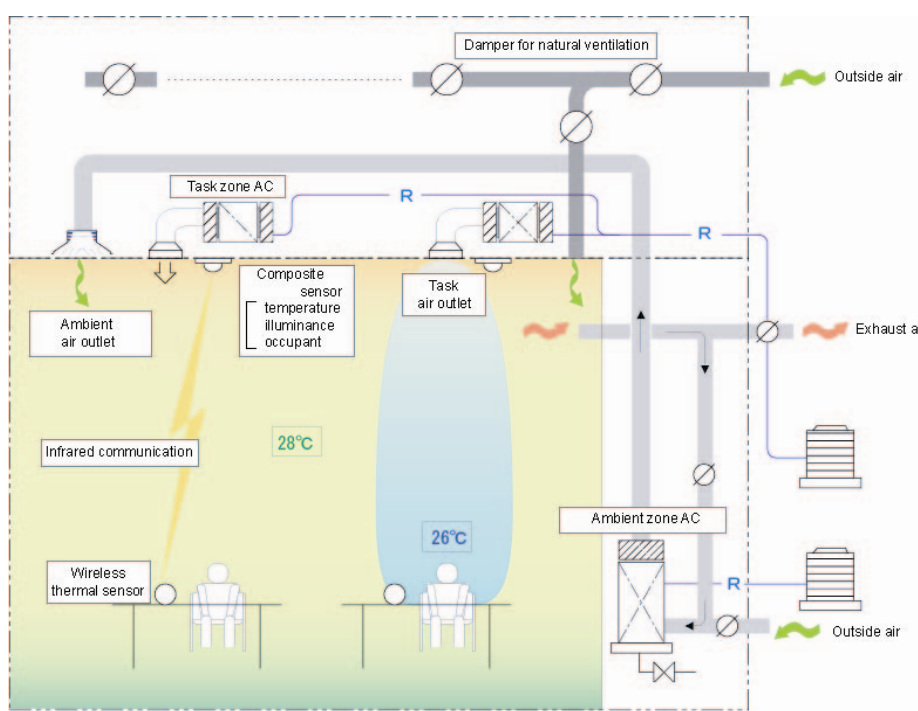


Figure 1; The air-conditioning system in Building A

3 ACCURACY EVALUATION OF MODEL BASED ON BEMS DATA

Predicting values simulated based on BEMS data were compared with the data of heat source system during summertime, and the developed model was evaluated.

3.1 DATA SELECTION FOR ANALYSIS

The BEMS data that was collected from Building A was used. This data was collected in summertime (from 8:00 to 16:00, in August and September). However, the data collected on Saturday and Sunday was excepted, and the data in the period when the system often stopped was excepted too. Table 2 shows the data for analysis.

To grasp the actual condition of the heat source system, indoor heat load was estimated by using the inlet air state of indoor unit. Based on inlet/outlet DB temperature and relative humidity, the inlet air state was estimated. It was supposed that the sensible heat was removed to 95% RH, and the outlet air state was specified. Differences between inlet and outlet enthalpy was specified by inlet/outlet air state of indoor unit, and removed heat load of every indoor unit was calculated.

Table 2; The data for analysis

August	181 points	From 8/8 to 8/30 (except Saturday, Sunday, 13th , 17th, 24th)
September	110 points	From 9/3 to 9/28 (except Saturday, Sunday, 5th, 12th, 14th, 24th)

3.2 OPERATION ANALYSIS

Characteristics of the heat source system under the real operation were estimated by using BEMS data and calculated indoor heat loads in 3.1.

Figure 2 shows load factor duration curves of indoor unit and outdoor air processing unit. In all indoor units, the time under the operation whose load factor was lower than 50% was more than 50% of the operating time. That time of indoor units (2, 3, and 6) was longer than that of other units. A load of an outdoor unit is a total of loads of all indoor units. The load under most operations was less than half of 40kW that was the rated performance.

Figure 3 shows the relationship between an indoor heat load, a condensing temperature, and a evaporating temperature. As the indoor heat load increases, the condensing temperature increases, and the evaporating temperature decrease. In addition, the condensing temperature in relation to the indoor heat load in August is higher than that in September. The reason for this difference is that the outdoor temperature in August is higher than that in September. Table 3 shows average of outdoor air state, indoor heat load, and electric consumption in August and September. The average of outdoor DB temperature in September is more than 3°C lower than that in August. Figure 4 shows the relationship between outdoor temperature and condensing temperature, and between condensing temperature and compression work. Outdoor DB temperature in September is lower than that in August, and the electric consumption in September is lower than that in August. The reason for this difference is that a heat exchange increases due to decrease in outdoor DB temperature.

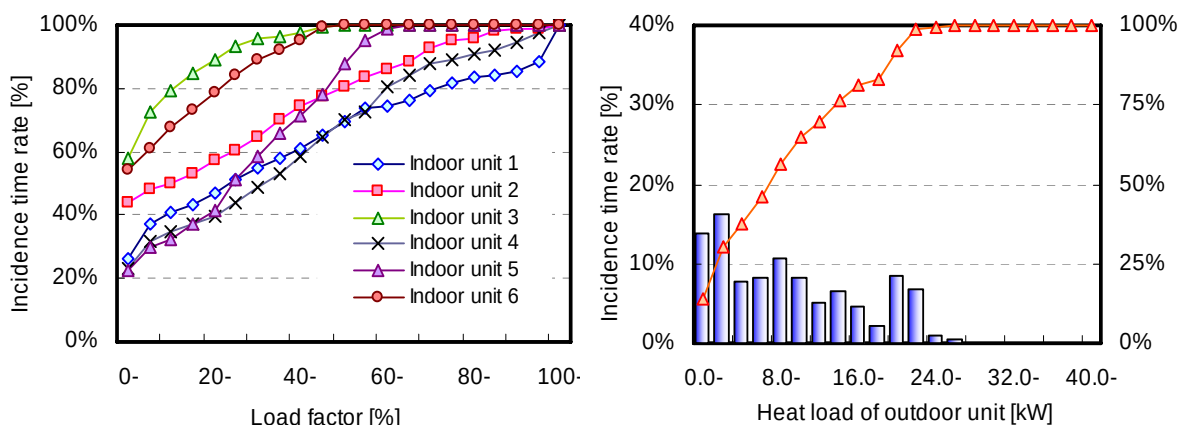


Figure 2; Load factor duration curves of indoor unit and outdoor air processing unit

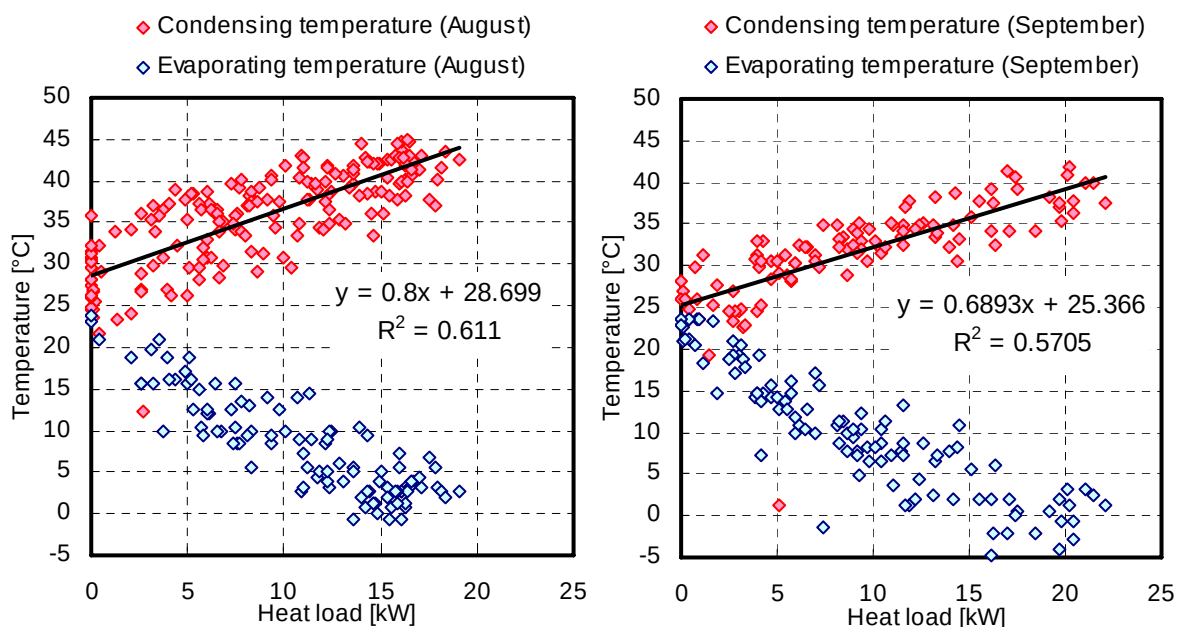


Figure 3; The relationship between a indoor heat load, a condensing temperature, and a evaporating temperature

Table 3; Average of outdoor air state, indoor heat load, and electric consumption

	Outdoor DB temperature [°C]	Outdoor absolute humidity [°C]	Indoor heat load [kW]	Electric consumption [kW]
August	32.62	0.021	8.80	3.08
September	29.26	0.020	9.26	2.79

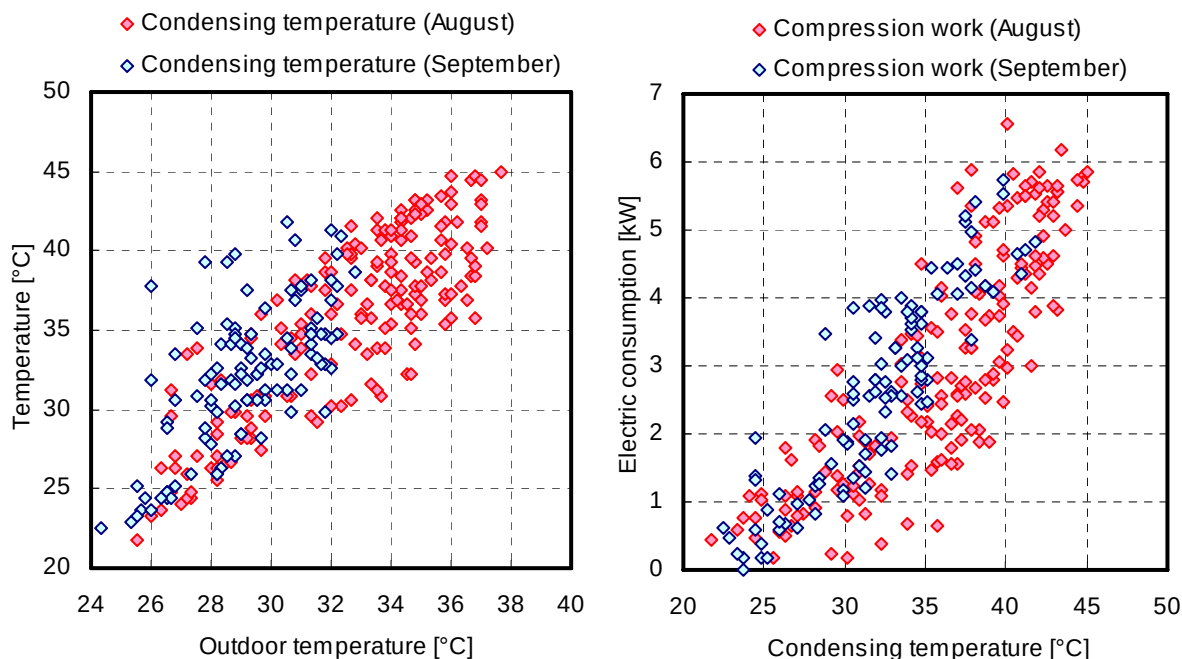


Figure 4; The relationship between outdoor temperature and condensing temperature, and between condensing temperature and compression work

3.3 COMPARISON BEMS DATA WITH OUTPUT OF MODEL

Figure 5 shows the relation between indoor heat load and compression work. For analysis, the data in August was used. Output values of model are approximately lower than BEMS data, and especially the margin of error is large in the range of low load operation. When the indoor heat load is lower than 5kW, output values of model don't change. The reason for this error is that compressor revolution speed of model can't be less than 10rps that is a setting value. The value is produced by manufacturer data. However, in the other range, output values of model are highly similar to BEMS data.

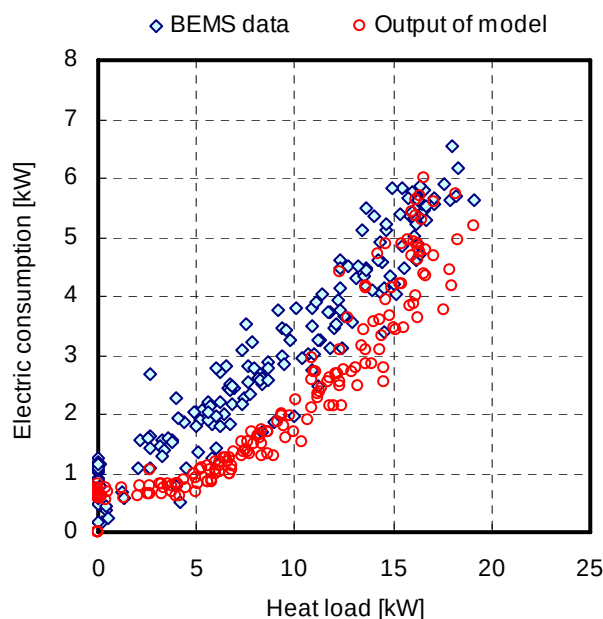


Figure 5; The relation between indoor heat load and compression work

4 INVESTIGATION OF INDOOR THERMAL ENVIRONMENT

The indoor thermal environment in summertime of Building A under the multi-split type air-conditioning system that uses developed models was investigated. This building that uses task ambient air-conditioning system, aims to accomplish the efficient energy performance through segmented processing of building loads. Every floor is divided into six zones and for each zone exist an outdoor air processing unit for task zone and an outdoor air processing unit for ambient zone. For each outdoor unit for ambient zone, one indoor unit is connected.

4.1 OUTLINE OF INVESTIGATION

Measurement of horizontal distribution of temperature, vertical distribution of temperature, and airflow rate was carried out at the typical floor. Figure 6 shows the plan at the typical floor and each measurement point. Table 4 shows measurement items. During the investigation, there are two conditions for preset temperature, and for each of those conditions, there are two types of air outlet. Table 5 shows preset conditions during the investigation.

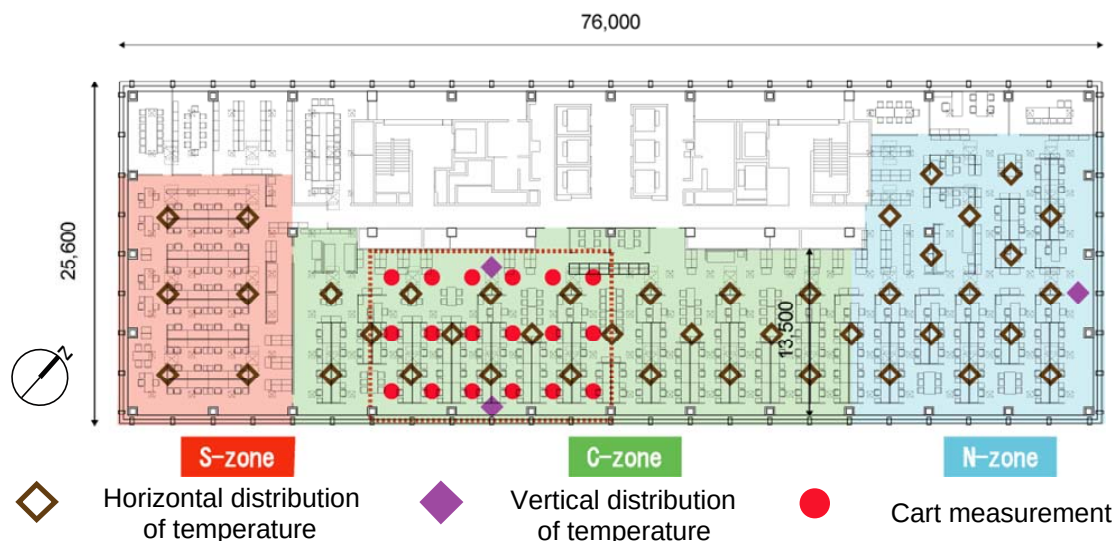


Figure 6; The plan at the typical floor and each measurement point

Table 4; Measurement items

	Measurement items	Measuring instrument	Measurement interval
Continuous measurement	Air temperature/RH	Thermo Recorder RS-12	5min
	Vertical distribution of temperature		
Punctual measurement	Air temperature	KANOMAX1560	10:00/13:30 16:00/18:00
	Airflow rate		

Table 5; Preset conditions during the investigation

	8/22(Wed)	8/23(Thu)	8/24(Fri)	8/25(Sat)
Ambient air-conditioning	Outlet temperature 18°C	Outlet temperature 18°C	Outlet temperature 18°C	Outlet temperature 18°C
Task air-conditioning	Indoor temperature 26°C	Indoor temperature 26°C	Indoor temperature 28°C	Indoor temperature 28°C
Task air outlet	100%diffusion	100%directional	100%directional	100%diffusion

4.1.1 CONTINUOUS MEASUREMENT

Measurement of Horizontal distribution of temperature consists of forty-two points that are set on the partitions (FL+1.1m). Each measuring instrument is equally spaced from every air outlet. Measurement of vertical distribution of temperature consists of three points in perimeter and interior zone.

4.1.2 PUNCTUAL MEASUREMENT

To grasp the environment of the task zone, punctual measurement was carried out using a cart pushed by an investigator. In order to investigate the impacts caused by the airflow from task air diffusion, air temperature and airflow rate were measured in three points for every six aisle between desks (18 points in total). At each point, measurement of vertical directions in four points (FL+0.1, 0.6, 1.1, 1.7m) took place simultaneously. Measurement took more than three minutes for every point.

Through this measurement, EDT (Effective Draft Temperature) was worked out and using these values, ADPI (Air Diffusion Performance Index) was calculated.

4.2 MEASUREMENT RESULT

4.2.1 HORIZONTAL DISTRIBUTION OF TEMPERATURE

Horizontal distribution of temperature at 13:00 on 23th August represents all data during the investigation. Figure 7 shows horizontal distribution of temperature (13:00, 23th August). A margin of error between most average air temperatures and preset air temperature was lower than 1°C, and during investigation, the maximum error between average air temperature and preset air temperature was lower than 2°C. Temperature in perimeter was higher than that in interior. This trend stood out when preset air temperature was 28°C.

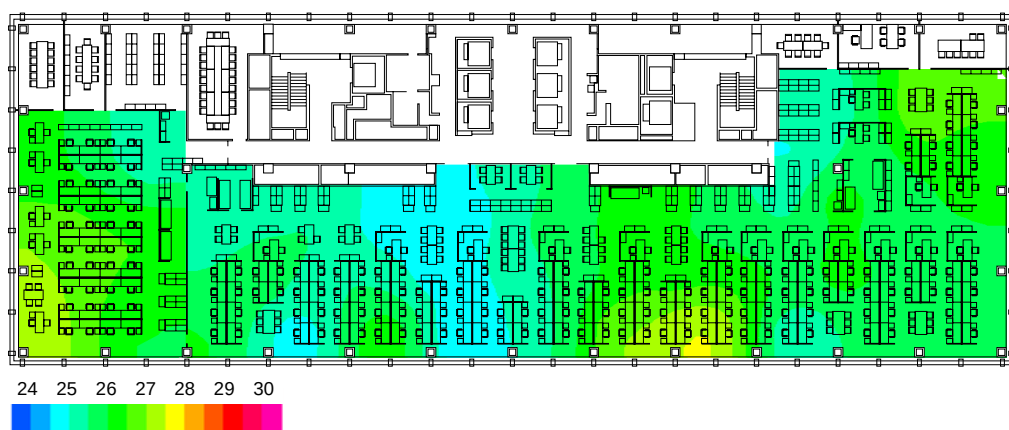


Figure 7; Horizontal distribution of temperature (13:00, 23th August)

4.2.2 VERTICAL DISTRIBUTION OF TEMPERATURE

During the investigation, temperature difference between 0.1m and 1.7m was lower than 3°C, and satisfied ASHRAE standard 55-2004.

4.2.3 DISTRIBUTION OF AIRFLOW RATE

During the investigation, most average airflow rates was moderate (within 0.2m/s), and vertical difference in airflow rate was moderate too. There was not so much influence by the type of air outlet at the respective measuring spots. Even if the type was changed to directional from diffusion, the airflow rate didn't rise effectively.

Figure 8 shows distribution of airflow rate at respective measuring spots at 13:00 and 15:00 on 23th August. Preset air temperature on 23th August was low, and the type of air outlet was directional, so there was a possibility that it's felt discomfort by the airflow. But in that case, the maximum airflow rate was lower than 0.25m/s, and design condition was satisfied.

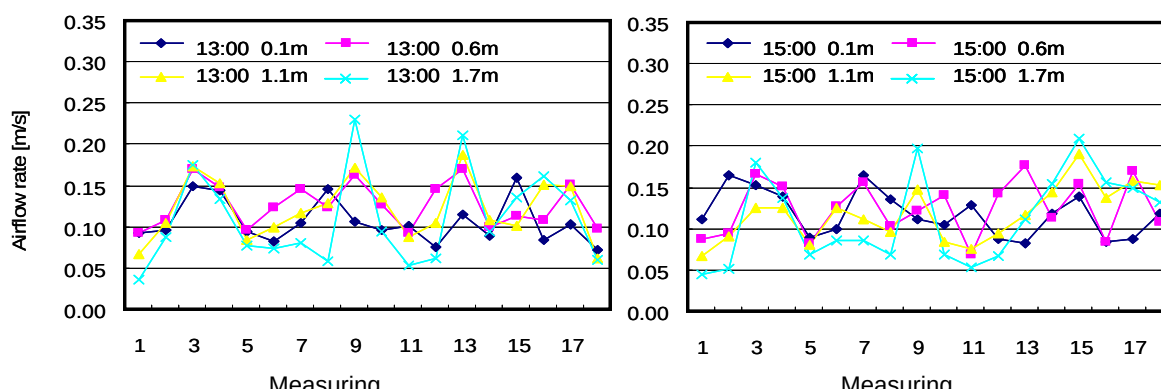


Figure 8; Distribution of airflow rate at respective measuring spots (13:00, 15:00, 23th August)

4.2.4 ADPI (Air Diffusion Performance Index)

EDT was worked out based on air temperature and airflow rate measured by cart, and using these values, ADPI was calculated. Modified air temperature and temperature correction for ADPI referred to ANSI/ASHRAE standard 113-2005 (ASHRAE. 2005). Table 6 shows ADPI during the investigation. ADPI at most measuring spots was higher than 90%, and design condition was totally satisfied. Distribution of measuring spots where the EDT didn't satisfied standard values was sparse, and it was not characteristic.

Table 6; ADPI during the investigation

	8/22(Wed)	8/23(Thu)	8/24(Fri)	8/25(Sat)
10:00	94.4%	100.0%	97.2%	98.6%
13:00	97.2%	98.6%	98.6%	94.4%
15:00	100.0%	100.0%	97.2%	100.0%
17:00	95.8%	98.6%	86.1%	100.0%
Average	96.9%	99.3%	94.8%	98.3%

4.2.5 ANALYSIS BASED ON BEMS DATA

Operation conditions of Indoor units were made sure based on BEMS data during the investigation, and was compared with the measurement result. About arbitrary indoor units for task and ambient, figure 9 shows temporal changes of supply/return air temperature based on BEMS data and air temperature in task zone which was near each air outlet. The data on 23th August represents all data because the heat load on 23th August was the largest in all day. While air-conditioning systems were operated (from 7:00 to 18:00), supply air temperatures of task and ambient indoor units fluctuated due to their operation conditions. The supply air temperature of the ambient indoor unit hovered around 17°C, but that of the task indoor unit often fell below 10°C. Table 7 shows average of supply air temperature of each indoor unit during operation.

In average of supply air temperature, supply air temperature of ambient indoor unit was lower than that of task indoor unit because of amount of thermo ON operation (processing heat load) time. But in minimum temperature, supply air temperature of task indoor unit was lower than that of ambient indoor unit, so the cool draft may be uncomfortable. Meanwhile, air temperature in task zone didn't undergo influence by supply air temperature, and didn't fluctuate rapidly.

When outdoor air processing unit stopped, indoor unit was under thermo OFF operation (not processing heat load, but blowing). In this case, supply air temperature was sometimes higher than return air temperature by heat quantity of fans. Indoor heat load that is input for developed simulation model is calculated on the basis of supply/return air temperature. So to modify the error between supply and return air temperature can made heat load accurate, and might made predicting performance of simulation model accurate too.

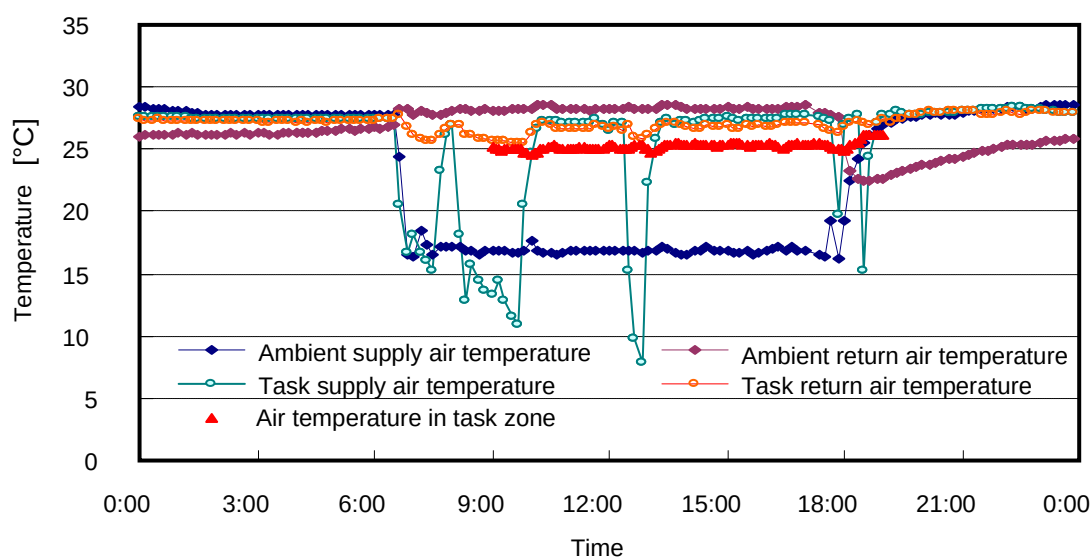


Figure 9; Temporal changes of supply/return air temperature and air temperature in task zone

Table 7; Average of supply air temperature of each indoor unit

		8/22(Wed)	8/23(Thu)	8/24(Fri)	8/25(Sat)
Preset temperature [°C]		26.00	26.00	28.00	28.00
Average supply air temperature [°C]	Task 1	18.82	21.81	27.17	29.76
	Task 2	23.37	23.20	27.10	28.45
	Task 3	26.55	26.27	27.01	28.30
	Task 4	17.94	20.01	26.68	29.01
	Task 5	19.96	21.57	26.57	28.25
	Task 6	23.78	24.93	25.37	27.96
	Ambient	16.93	17.01	17.19	28.79
Minimum temperature [°C]	Task 1	9.80	8.00	12.80	19.70
	Task 2	7.80	7.70	15.70	20.10
	Task 3	14.70	14.10	16.80	20.40
	Task 4	10.70	11.20	13.40	27.60
	Task 5	13.60	14.30	17.00	17.70
	Task 6	14.10	16.90	17.60	22.90
	Ambient	16.20	16.30	16.40	28.00

5 CONCLUSION

The energy calculation model developed by other research was verified, and the energy performance of the system was evaluated by analyzing the response of the system based on BEMS data according to the building use situations. The indoor comfort was considered to evaluate general performance of the system quantitatively based on actual investigation.

Predicting values simulated based on BEMS data were compared with the data of heat source system during summertime, and the developed model was evaluated.

In operation analysis, as the indoor heat load increases, the condensing temperature increases, and the evaporating temperature decrease. The evaporating temperature changes based on outdoor air state, and influences the compression work.

In calculation of compression work, output values of model are approximately lower than BEMS data, and especially the margin of error is large in the range of low load operation. When the indoor heat load is lower than 5kW, output values of model don't change. The reason for this error is that compressor revolution speed of model can't be less than 10rps. However, in the other range, output values of model are highly similar to BEMS data.

The indoor thermal environment in summertime of Building A under the multi-split type air-conditioning system that uses developed models was investigated. A margin of error between most average air temperatures and preset air temperature was lower than 1°C, and during investigation, the maximum error between average air temperature and preset air temperature was lower than 2°C. During the investigation, most average airflow rates were moderate (within 0.2m/s), and the maximum airflow rate was lower than 0.25m/s, and design condition was satisfied. There was not so much influence by types of air outlet at the respective measuring spots.

ADPI was calculated based on EDT. ADPI at most measuring spots was higher than 90%, and design condition was totally satisfied.

The supply air temperature of the task indoor unit often fell below 10°C, but the air didn't influence the air temperature in task zone so much. And the air temperature in task zone didn't fluctuate rapidly.

6 REFERENCES

Please list all references according to the following examples.

Eisuke Togashi and Shin-ichi Tanabe, 2008. "Development of energy calculation model of Multi-split type air-conditioning system", Heat Pump Conference 2008(plan)

ANSI/ASHRAE Standard 113-2005. "Method of Testing for Room Air Diffusion", American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.