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## Effect of evaporating temperature rising operation for multi-split type air-conditioner on energy conservation and thermal comfort

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### Abstract

In commercial buildings, the energy consumption by air conditioning amounts to 30% -40% of the entire building. Therefore, the energy saving of air-conditioning in those buildings is important to reduce their total energy consumption. In this background, the evaporating temperature rising operation of multi-split type air conditioner during cooling have been applied as one of the energy saving operations.

In general, the increase of the evaporating temperature can improve the efficiency of the air conditioner, and the reduction of the energy consumption can be expected. On the other hand, since the cooling latent heat capacity decreases in this operation, the humidity of the air-conditioned room may increase and the thermal comfort may decrease.

In this study, the energy saving effect and the thermal comfort of evaporating temperature rising operation in the air conditioning system for offices and a store were investigated by simulation. It was found that 7% -17% cooling energy saving effect can be obtained by the rising the evaporating temperature in consideration of thermal comfort in the room, and larger energy saving effect can be obtained in the building having a high cooling sensible heat ratio.

*Keywords: Air conditioner, Evaporating temperature, Energy saving, Thermal Comfort ;*

### 1. Introduction

In order to prevent global warming, it is important to reduce air conditioning energy, which accounts for a large proportion of building energy. In this background, the performance improvement of air conditioners and appropriate air conditioning operation have been conducted. As examples of energy saving operation of multi-split type air conditioner, rising operation of the evaporating temperature during cooling or reducing operation of the condensation temperature during heating have been reported[1][2]. Among them, the rising of the evaporating temperature is attracting operation because a greater effect can be expected.

In general, the evaporating temperature for cooling is controlled to be about 6 °C due to dehumidify indoor air and create a comfortable environment. As shown in Fig.1, by rising the evaporating temperature of the refrigerant, the efficiency of the air conditioner can be improved and the equipment energy consumption can be reduced. On the other hand, since the cooling latent heat capacity is reduced, the humidity of the air conditioned area increases depending on the state of the air conditioning load, and the thermal comfort of the resident is impaired.

Conventionally, commercial multi-air conditioners have been adjusted for capacity by the “refrigerant circulation rate control” method in order to perform individual operation for each indoor unit and to maintain the comfort of each indoor unit. In this method, the refrigerant temperature (evaporating temperature) cannot basically be changed, but it is possible to reduce the equipment energy consumption by forcibly increasing the

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evaporating temperature with a control software. Recently, it has been developed some air conditioning systems that can increase the evaporating temperature when the refrigerant evaporating temperature is controlled by the dedicated controller of the air conditioner manufacturer according to the air conditioning load and it is determined that the air conditioning load becomes low.

This study focuses on the effect of the rising in the evaporating temperature of the commercial air conditioner on the energy saving effect and the thermal comfort of the air-conditioned room. In particular, the energy efficiency and thermal comfort were evaluated for the building type and air conditioner capacity as parameters.

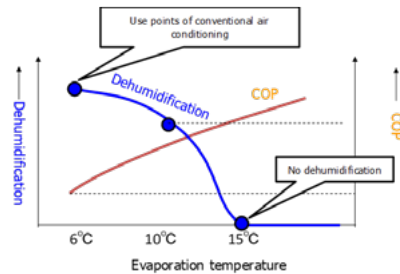


Fig. 1. Relation between evaporating temperature, dehumidification and COP

## 2. Calculation conditions

### 2.1. Building conditions

It is considered that the energy saving effect due to the increase in evaporating temperature is greater for buildings with higher sensible heat loads. Therefore, energy simulations are conducted for the office and the business store models which have different cooling sensible ratios (annual cooling sensible heat load/ total cooling load) with total floor area of about 1,000m<sup>2</sup>.

Table 1 shows the calculation conditions for these buildings. Two cases for offices are considered. One is Office A which has a conventional specification and the other is Office B which has a nearly ZEB (net Zero Energy Building) specification as next-generation building. Office B not only has better skin performance than Office A, but also has low emissivity (low-e) glass and light shelf near the ceiling (Fig. 2.), which actively uses daylight and has reduced internal air-conditioning load.

These offices are operated to light up from 8:00 to 19:00 except from 12:00 to 13:00, and the occupancy rate and equipment usage rate gradually decrease from 17:00. The specifications of the store model were determined with reference to the previously reported home appliance mass sales store [3]. In this study, we used meteorological data in Nagoya area of Japan. AMeDAS(Automated Meteorological Data Acquisition System) were used for the data [4].

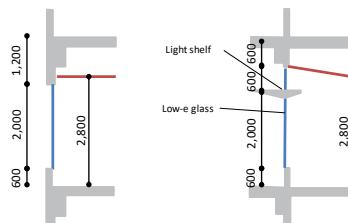


Fig.2 Window shape comparison (Left: Office A, Right: Office B)

Table 1. Model of buildings

		Office A	Office B	Store
Air-conditioning area		1,038m <sup>2</sup>	1,038m <sup>2</sup>	1,000m <sup>2</sup>
Ceiling height		2.8m	2.8m	4m
Outer wall performance	Thickness of insulation	25mm	50mm	-
	Glass	6mm (Single layer)	Low-e (Double layer)	8mm (Single layer)
	Blind	Blind	No Blind	Blind
	Gap wind	0.2number/h	0.1number/h	0.1number/h
	Eaves	No eaves	Eaves	No eaves
Internal heat generation	Lights	14W/m <sup>2</sup>	1.6W/m <sup>2</sup>	25W/m <sup>2</sup>
	Equipment	20W/m <sup>2</sup>	10W/m <sup>2</sup>	20W/m <sup>2</sup>
	Standby power	5W/m <sup>2</sup>	2.5W/m <sup>2</sup>	-
	Human density	0.1human/m <sup>2</sup>	0.1human/m <sup>2</sup>	0.1human/m <sup>2</sup>
Outside air condition	Amount of outside air	3CMH/m <sup>2</sup>	3CMH/m <sup>2</sup>	4CMH/m <sup>2</sup>
	Outside air cut	Summer 1h	Summer 1h	Summer 1h
		Winter 2h	Winter 2h	Winter 2h
Air-conditioning condition	Period	Cooling May~October	Cooling May~October	Cooling April~November
		Heating November~April	Heating November~April	Heating December~March
	Operation time	Cooling 8~19	Cooling 8~19	Cooling 9~21
		Heating 7~19	Heating 7~19	Heating 9~21
	Inside air condition (Tem./Relative Humidity)	Summer 26°C/50%	Summer 26°C/50%	Summer 26°C/60%
		Winter 22°C/40%	Winter 22°C/40%	Winter 20°C/40%
Mid-season 24°C/45%		Mid-season 24°C/45%	Mid-season 24°C/60%	

## 2.2 Air conditioning load

At first, the air-conditioning loads for each hour were calculated using the BEST (Building Energy Simulation Tool) program for the conditions of Table 1 [5]. The BEST program was developed in Japan as a simulation tool for building air conditioning load and annual energy consumption. The program has the same accuracy in terms of room temperature and air conditioning load of the building as the simulation tools (BLAST, DOE2, ESP, SERIRES, etc.) which commonly used in Europe and the United States [6],[7].

Figure 3 shows the calculation results of the annual air conditioning load in each case. Generally, latent heat is affected by amount of outside air and human density, and sensible heat is affected by internal heat generation and the insulation performance of buildings. Since the store has a longer operating time and larger internal heat generation than the offices, the air-conditioning load and cooling sensible heat have the largest among them. In Office B oriented to nearly ZEB, the internal heat generation is smaller than that of Office A, so that the cooling sensible heat load is small and the heating sensible heat load is large. As a result, the sensible heat ratio during the cooling period (= cooling sensible heat load/cooling total load) tends to be Store > Office A > Office B.

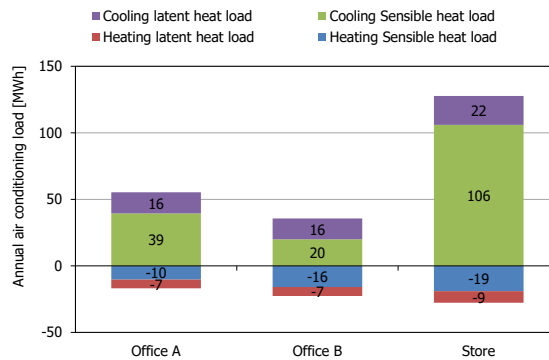


Fig.3. Comparison of annual air-conditioning load

### 2.3 Air conditioner assumption

In general, the capacity of air conditioners is set with a margin for the maximum air conditioning load. In this calculation, the capacities of 100%, 120%, 140%, and 160% were set for the maximum air conditioning load calculated in each case in order to confirm the effect of the installed capacity.

Figure 4 shows the relationship between the evaporating temperature and the cooling capacity normalized by the total cooling capacity at 6 °C. This relationship between the cooling capacity of the air conditioner and the evaporating temperature of refrigeration which published by the manufacturer were used [8]. As the evaporating temperature rises, the total cooling capacity gradually decreases, reaching a capacity of about 60% at an evaporating temperature of about 15 °C. Although the sensible heat capacity does not change much, latent heat capacity decreases as the amount of dehumidification decreases, and the latent heat capacity becomes 0 at 15 °C.

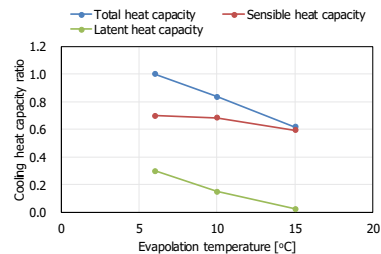


Fig.4. Relationship between the evaporating temperature and the cooling capacity

### 2.4 Energy consumption / comfort calculation method

Figure 5 shows the calculation procedure. At first, we determined the air-conditioner rated capacity based on the air-conditioning maximum (peak) load calculated by the BEST program. And then, the capacity was corrected by the evaporating temperature and the outside air temperature at each time, and the sensible heat capacity/latent heat capacity and power consumption of the equipment were calculated. Here, when the sensible heat/latent heat capacity is insufficient with respect to the air-conditioning load, the indoor temperature and humidity air-conditioning are changed. When the air conditioning load cannot be processed at the calculation time, the unprocessed load was added to the next time. PMV (Predicted Mean Vote) which considered to be most recognized in thermal comfort standard was used as the thermal comfort index in the air-conditioned room [9]. PMV was calculated with indoor temperature, humidity, radiation temperature, wind velocity and so on, and the values based on experimental results in Table 2 were used for this calculation.

We calculated four conditions for the evaporating temperature. Three of these conditions fixed the evaporating temperature at 6 °C, 9 °C, and 12 °C, and one of them changed the evaporating temperature. That is, the evaporating temperature was changed within ± 0.5 which is the comfortable range of PMV. In this paper, this condition is called “PMV control”.

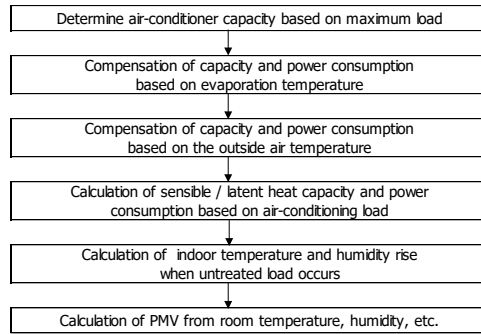


Fig.5. Calculation procedure

Table.2. Calculation condition of PMV

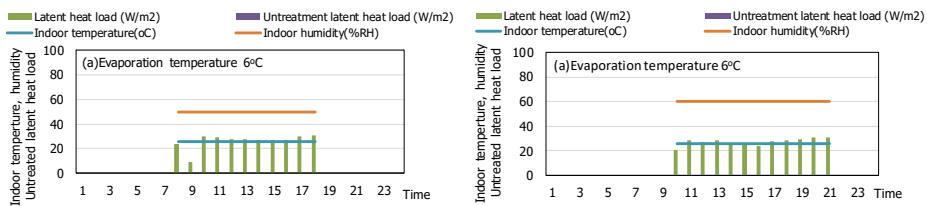
	Indoor temperature and humidity	Radiation temperature (°C)	Wind Velocity (m/s)	clo	Mets
Office	Calculated value	Indoor temperature+0.5	0.05	0.43	1.1
Store	Calculated value	Indoor temperature	0.05	0.3	1.4

### 3. Calculation results

#### 3.1 Calculation results for Office A

Figures 6(a) to (d) show temporal changes of latent-heat load, untreated latent heat load, indoor temperature, and indoor humidity on the summer representative day (August 1) when the evaporating temperature is fixed at 6 °C (standard), 9 °C, and 12 °C and PMV controlled. Figure 7 shows temporal changes of PMV in each case. In all cases, the capacity of the air conditioner is 120%, which is close to the actual condition. As shown in Fig. 6(a), at the standard evaporating temperature of 6 °C, all the sensible heat and latent heat load can be processed, so the temperature and humidity do not change during the day. When the evaporating temperature is set as high as 9 °C and 12 °C, though the sensible heat load is processed, the untreated latent heat load increases with time, and the indoor humidity and PMV shift to the warmer side. In particular, when the evaporating temperature is fixed at 12 °C, the untreated load increases, and the indoor humidity becomes extremely high at 10:00 (Fig.6(c)).

Actually, humidity is not expected to rise to nearly 100% due to mixing of outside air and room air due to ventilation not considered in this calculation, but it is expected that the environment will become extremely uncomfortable. On the other hand, in the case of PMV control as shown in Fig. 5(d) and Fig.6, the PMV is maintained within 0.5, and although untreated load occurs, thermal comfort is maintained. It is noted that similar trends were seen in Office B.



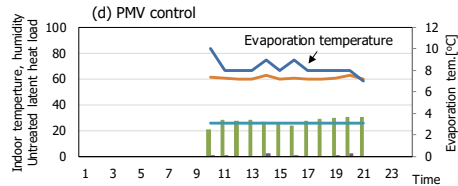
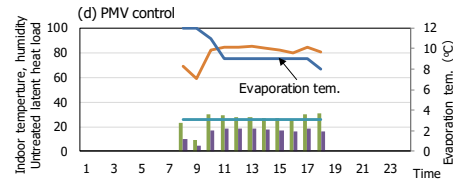
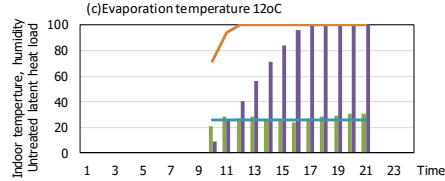
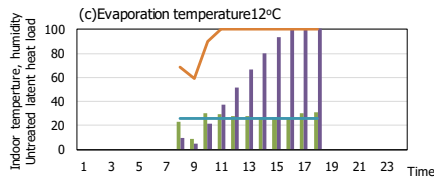
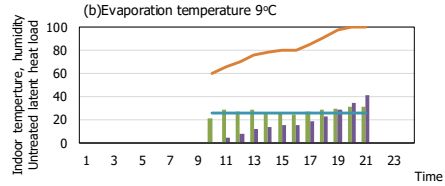
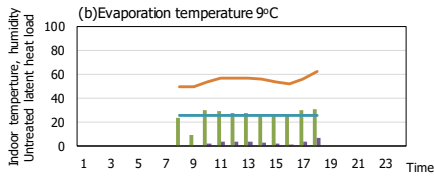


Fig.6. Temporal change of temperature/humidity and latent heat load (Office A)

Fig.8. Temporal change of temperature/humidity and latent heat load (Store)

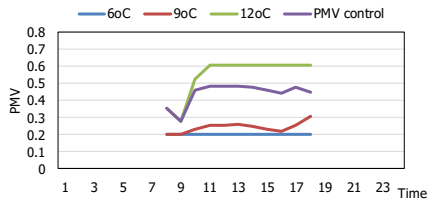


Fig.7. Temporal change of PMV (Office A)

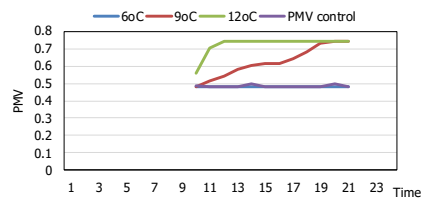


Fig.9. Temporal change of PMV (Store)

### 3.2 Calculation results for Store

Figures 8(a) to (d) show temporal changes of latent-heat load, untreated latent heat load, indoor temperature, and indoor humidity on the summer representative day (August 1) when the evaporating temperature is fixed at 6 °C (standard), 9 °C, and 12 °C and PMV controlled, and Figure 9 shows temporal changes of PMV. Similar to Office A, in the case of the evaporating temperature 6 °C, the sensible heat and latent heat load can be processed, so both the temperature and humidity are stable. However, when the evaporating temperature is set to 9 °C and 12 °C, the untreated latent heat load increases with time, the indoor humidity and PMV shift to the warmer side, and PMV finally becomes about 0.75 as shown in Fig.9. On the other hand, in the case of PMV control, since PMV is high at the time of air conditioning start-up, the air conditioner quickly decreases the evaporating temperature and almost no untreated load occurs.

### 3.3 Influence on power consumption and thermal comfort (Office A)

Figure 10 shows a comparison of the cooling power consumptions in Office A. In these case, cooling period is from May to October. Comparison parameters are evaporating temperature and air-conditioner capacity.

When the evaporating temperature is increased from 6 °C to 9 °C and 12 °C, the power consumption during cooling decreases. For example, in the case of 100% for air-conditioner capacity, cooling power consumption is reduced by 26% at evaporating temperature of 12 °C compared to evaporating temperature of 6 °C. In the

case of PMV control, a reduction effect of 17% can be obtained.

Figure 11 and Fig.12 show time that PMV exceeds 0.5 (uncomfortable time) and cooling COP, respectively. In the case of evaporating temperature 12 °C, the time that PMV exceeds 0.5 increases in the midsummer season, and the uncomfortable time increases significantly. Basically, the air-conditioner load which can be processed increases as the installed air-conditioner capacity increases. Therefore, as shown in Fig. 10 and Fig.11, an increase in the air-conditioner capacity leads to a decrease uncomfortable time and an increase in the cooling power consumption.

When the evaporating temperature is fixed, the COP is almost the same regardless of the capacity of the air conditioner. This is because air-conditioning capacity is small relative to the air-conditioning load, and high-load operation continues. On the other hand, in the case of PMV control, as the air conditioner capacity increases, the cooling power consumption decreases and COP increases as shown in Fig.10 and Fig.12. This is because the air conditioner is operated at an efficient medium load.

3.4 Considerations for further energy saving

In order to investigate further energy saving effect by PIV control, the cases where PMV is allowed to 0.6 (slightly uncomfortable region) were calculated. Table 3 shows comparison of the power consumption reduction rates at Office A, Office B, and Stores in the case of PMV<0.5 and PMV<0.6. These power consumptions at each case were normalized by that of the evaporating temperature 6 °C. Compared to the standard evaporating temperature of 6 °C, the power consumption can be reduced by 7-17% in the case of PMV<0.5 considering energy saving and thermal comfort. In either case, even if PMV<0.6 is allowed, the energy saving effects only increase by 1 to 4 points compared to those in the case of PMV<0.5.

Figure 13(a) and (b) show the relationship among indoor temperature, relative humidity, and PMV in the Office and Store, respectively. In this calculation, the sensible heat load could be processed in all cases, so the room temperature did not change from 26 °C and only the relative humidity increased. In addition, even if PMV=0.5 (green circle in the figure) or PMV=0.6 (red circle in the figure) is allowed for the standard temperature and humidity conditions (blue circle in the figure) in this calculation, there is no significant difference. Therefore, it seems that the increase in energy saving effect has become small. However, if the temperature/humidity setting is set to a low value, the temperature/humidity control range is increased, and it is considered that a large energy saving effect can be obtained by introducing PMV control.

Figure 14 shows the relationship between the cooling sensible heat ratio and the cooling power consumption reduction rate in the PMV control. Although there is a difference in the power consumption reduction rate due to the difference in temperature and humidity settings between the office and the store, the higher the sensible heat ratio in summer, the higher the energy saving effect. Therefore, a large power consumption reduction effect can be expected in commercial buildings such as warehouses and data centers with large sensible heat ratio.

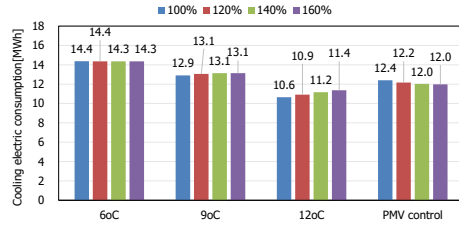


Fig.10. Cooling power consumption

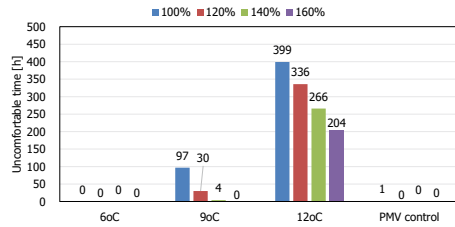


Fig.11. Uncomfortable time

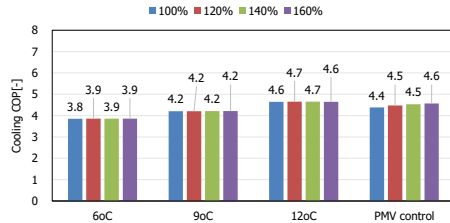


Fig.12. Cooling COP

Table.3. Power consumption reduction rate (Cooling season)

Air-conditioning	Office A		Office B		Store	
	PMV<0.5	PMV<0.6	PMV<0.5	PMV<0.6	PMV<0.5	PMV<0.6

Capacity						
100%	-14%	-15%	-7%	-10%	-11%	-13%
120%	-15%	-16%	-8%	-10%	-14%	-15%
140%	-16%	-17%	-9%	-12%	-15%	-16%
160%	-17%	-17%	-9%	-13%	-16%	-17%

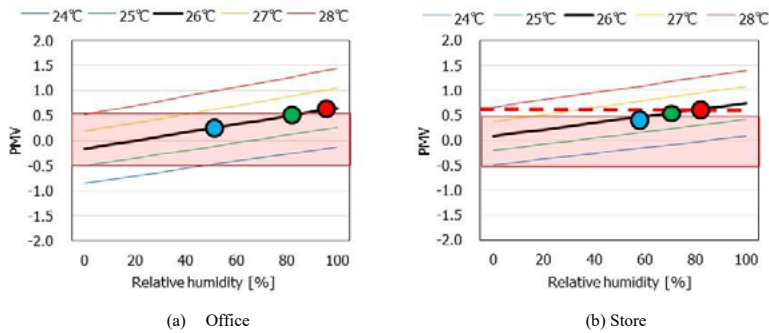


Fig.13. Relationship among temperature, relative humidity, and PMV

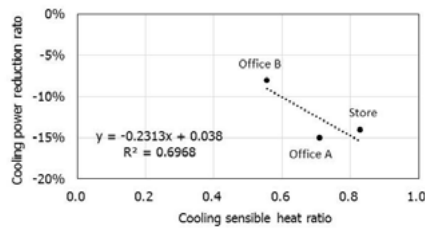


Fig.14. Relationship between cooling sensible heat ratio and cooling power reduction ratio

#### 4. Summary

In this study, we calculated on the effect of the rising in the evaporating temperature of the multi-type air conditioner on the energy saving effect and the thermal comfort of the air-conditioned room. The main results are as follows,

Compared to the standard evaporating temperature of 6 °C, the power consumption can be reduced by about 21-26% in the case of the evaporating temperature 12 °C, and 7-17% in the case of PMV control considering energy saving and thermal comfort. When the evaporating temperature is fixed at 12°C, a large energy saving effect is obtained, but the thermal comfort is significantly deteriorated.

When the evaporating temperature is fixed, the COP is almost the same regardless of the capacity of the air conditioner. An increase in the air-conditioner capacity leads to a decrease uncomfortable time and an increase in the cooling power consumption.

When PMV control is used, a large energy consumption reduction effect can be expected in commercial buildings with a large cooling sensible heat ratio.

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