APPLICATION OF COMMISSIONING PROCESS TO VRF SYSTEM USING ENERGY SIMULATION

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ABSTRACT

This paper describes the investigation of the existing VRF system renewal using energy simulation. Both the renewal to the latest VRF systems and to proper capacity VRF systems were examined. The effect of changing the evaporating temperature of the VRF systems was also examined as an example to evaluate the energy saving effect by the operation improvements.

In the simulation, the annual energy saving effect of the renewal to the latest VRF systems was 31%. In addition, the energy saving effect increased to 40% by applying the renewal to proper capacity VRF systems and changing the evaporating temperature.

INTRODUCTION

The reduction of the energy consumption at buildings has become a big issue to achieve the low-carbon society these days. Among the total energy consumption in buildings, the ratio of the energy consumed by air-conditioning systems (AC systems) is large. This is why proper design and operation of air-conditioning systems are required. Therefore, it is important to apply the commissioning processes to keep high energy efficiency of AC systems for the entire life cycle of buildings.

So far, the commissioning processes have been carried out for central AC systems. Energy simulation tools in the design phase and data analysis tools in the operation phase for central AC systems are developed and utilized. In recent years, the higher energy efficiency of multi-sprit AC systems, represented by Variable Refrigerant Flow systems (VRF systems), has begun to be recognized. And so the needs for carrying out the energy simulation of VRF systems are increasing. It can be said that the necessity of commissioning tools for VRF systems is growing. Especially in the design phase, logical system design (such as proper capacity equipment selection and zoning of the floors in the building, proper combination of indoor and outdoor units) can be achieved by executing energy simulation of VRF systems. So the logical design is expected to improve the energy efficiency in the operation phase.

This paper describes the investigation of the existing VRF system renewal using energy simulation. Life Cycle Energy Management tool (LCEM tool: Japanese official energy simulation tool) was used for the energy simulation. Main input data of LCEM tool is an AC load of the building. To identify the AC load of the actual building, the cooling and heating capacities supplied by the VRF system were calculated from the measured data. Cooling and heating capacities were calculated by the Compressor Curve method (CC method).

Both the renewal to the latest VRF systems and the renewal to proper capacity VRF systems were examined. The effect of changing the evaporating temperature of the VRF system was also examined as an example to evaluate the energy saving effect by the operation improvements.

PROFILE OF THE BUILDING

The standard floor plan of the building to which the commissioning process was applied is shown in Figure 1. It is an office building in Osaka, Japan. The building has 9 stories above ground and 2 below. The total floor area is approximately 9,000 m^2.

The building entirely adopts the VRF system. The equipments configuration of the VRF system in each floor is shown in Table 1. In each standard floor, there are 2 zones (zone: an area which is air-conditioned by one outdoor unit), east zone and west zone. All the equipments are old models and installed in 1996.

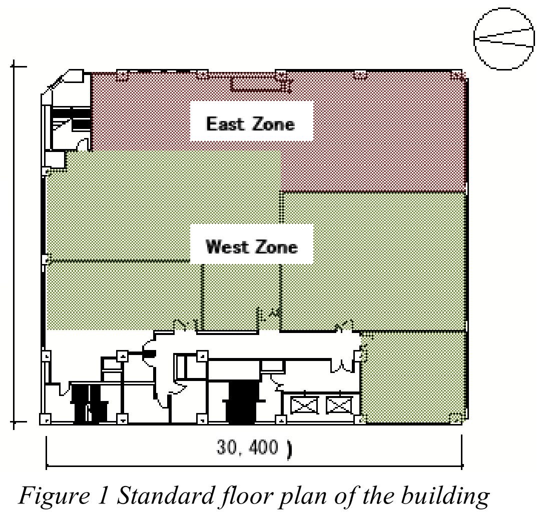

Figure 1 Standard floor plan of the building

Table 1 Equipments configuration of VRF system

Floor	Major use	Zone	Outdoor Unit Capacity [kW]	Indoor Units Number	Indoor Units Total Capacity [kW]
B2nd	Electric room	West	36.4	5	39.9
B1st	Parking lot	–	–	–	–
1st	Office	East	84	16	89.9
2nd		West	56	13	65.3
		East	28	7	33.7
3rd		West	56	12	61.8
		East	28	7	32.6
4th		West	56	14	68.1
		East	28	6	29.2
5th		West	56	11	69
		East	28	6	34.4
6th		West	56	12	66.2
		East	28	6	33.6
7th		West	56	13	68.1
		East	28	7	33.7
8th		West	56	17	68.9
		East	28	6	33.7
9th		West	56	10	59.1
		East	67.2	12	64.5

MEASUREMENT PROCEDURE

Measurement period and items

The cooling and heating capacities supplied by the VRF system were calculated from the measured data around a year, from January 1 to December 31, 2009. The Compressor Curve method (CC method) was utilized for the calculation of the capacity. The operating hours of the outdoor units were also measured.

By checking the annual operating hours of the outdoor units in each floor, the floors in which the operating hours were especially long were selected for the renewal target zones. In addition, by examining the part-load ratio distribution of the renewal target zones, the necessity of the renewal to proper capacity VRF systems was considered.

Compressor Curve method

VRF systems have internal sensors for their own operation. In CC method, cooling and heating capacities are calculated from the refrigerant flow rate, which is derived from the measured data (such as refrigerant temperature and pressure) of the sensors and the compressor characteristics curve. The operating hours of equipments are also available from those sensors.

The cooling capacity of outdoor unit is calculated by multiplying the enthalpy difference of evaporator and the refrigerant flow rate.

$$Qc = \Delta ic \times G \tag{1}$$

The heating capacity of outdoor unit is calculated by multiplying the enthalpy difference of condenser and the refrigerant flow rate.

$$Qh = \Delta ih \times G \tag{2}$$

The refrigerant flow rate is derived from the frequency of compressor and the equivalent saturation temperatures of evaporating pressure and condensing pressure by the compressor characteristics curve (Compressor Curve). The saturation temperatures of evaporating pressure and condensing pressure are variables which are uniquely decided by the evaporating pressure and the condensing pressure, respectively.

$$G = f(freq, Te, Tc) \tag{3}$$

The enthalpy differences of the evaporator and the condenser can be estimated from the evaporating pressure, the condensing pressure, and the control target values (degree of superheat, degree of subcool). The relation of these data is shown in Figure 2.

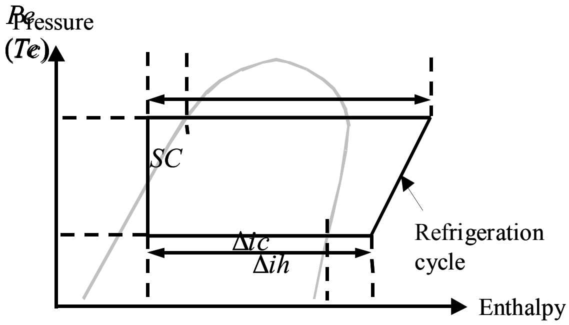

Figure 2 Enthalpy differences of the evaporator and the condenser

MEASUREMENT RESULTS

Operating hours on each floor

The annual operating hours of the outdoor units on each floor are shown in Figure 3. 4th, 5th, and 8th floors were found to have especially longer operating hours. The 6 zones on these 3 floors were selected as the renewal target.

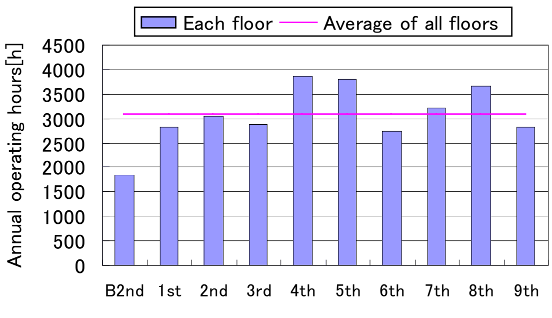

Figure 3 Annual operating hours of the outdoor units

Distribution of Part-load ratio

Figure 4 shows the annual part-load ratio distribution of the outdoor units in the 6 renewal target zones (East and West zones on 4th, 5th, and 8th floors).

As shown in Figure 4-(b), the outdoor unit in 4th floor East zone mainly operated at low part-load ratio. The ratio of operating below part-load ratio 0.3 was 86 % in cooling, and also 86 % in heating. Figure 5 shows the relation between part-load ratio and COP of the outdoor unit in 4th floor West zone. At low part-load ratio, the compressor mainly operates below the lower limit value of inverter controlled frequency, and the efficiency losses become relatively bigger because of on/off driving. Therefore, the COP of the outdoor unit in 4th floor East zone was low as a whole.

In the 4th floor East zone, the energy saving effect of changing system capacity from 28.0kW to 22.4kW was examined by the energy simulation.

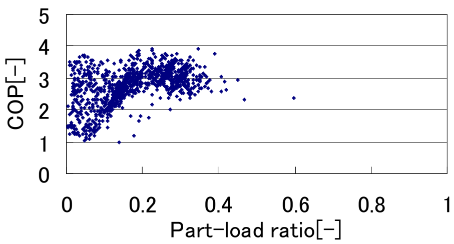

Figure 5 Relation between part-load ratio and COP of the outdoor unit in 4th floor West zone

SIMULATION PROCEDURE

Simulation cases

Using the heat load calculated from the measured data as an input condition, the annual energy simulations by LCEM tool were carried out for the 6 target zones selected by the measurement results. The load obtained from the measured data was total heat load.

It was divided into sensible and latent heat loads using the sensible heat fraction from the indoor unit engineering data.

Energy simulations of the following 4 cases, Case 1 to Case 4, were carried out. In Case 4, the evaporating temperature was raised from standard 6deg-C up to 9deg-C depending on the part-load ratio.

- Case 1 ：Existing System
  (Old model ：installed in 1996)
- Case 2 ：Renewal to the same capacity
  (Old model →New model)
- Case 3 ：Renewal to proper capacity
  (In 4th floor East zone, the capacity was changed from 28.0kW to 22.4kW.)
- Case 4 ：Renewal to proper capacity and the evaporating temperature change
  (6deg-C→9deg-C)

The energy saving effects of Case 2 to Case 4 compared with Case 1 were evaluated from the simulation results. The equipments tables of the outdoor and indoor units which were the simulation objects are shown in Table2 and Table3, respectively.

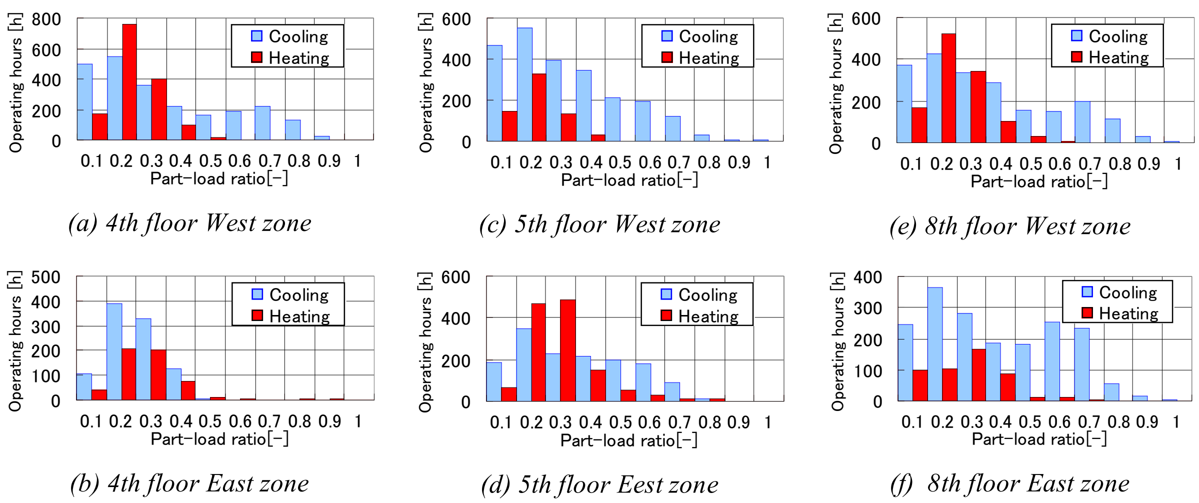

Figure 4 Annual part-load ratio distribution of the outdoor units

Table 2 Equipment table of the outdoor units

Type of Outdoor Unit	Rated specification	
Old model, 56kW Case 1, West zone	Capacity	Cooling 56.0kW, Heating 63.0kW
	Electricity consumpiton	Cooling 21.3kW Heating 19.6kW
	COP	Cooling 2.63 Heating 3.21
Old model, 28kW Case 1, Eest zone	Capacity	Cooling 28.0kW Heating 31.5kW
	Electricity consumpiton	Cooling 11.8kW Heating 10.5kW
	COP	Cooling 2.37 Heating 3.00
New model, 56kW Case 2, West zone	Capacity	Cooling 56.0kW, Heating 63.0kW
	Electricity consumpiton	Cooling 15.4kW Heating 16.7kW
	COP	Cooling 3.64 Heating 3.77
New model, 28kW Case 2 to 4, Eest zone (Except Case 3 and 4, 4th floor East zone)	Capacity	Cooling 28.0kW Heating 31.5kW
	Electricity consumpiton	Cooling 7.64kW Heating 8.45kW
	COP	Cooling 3.66 Heating 3.73
New model, 22.4kW Case 3 and 4, 4th floor East zone	Capacity	Cooling 22.4kW Heating 25.0kW
	Electricity consumpiton	Cooling 5.24kW Heating 6.33kW
	COP	Cooling 4.27 Heating 3.95

Table 3 Equipment table of the indoor units

Case	Zone	Number	Sum of rated specification	
Case 1	4th floor West	14	Capacity	Cooling 68.1kW, Heating 76.3kW
			Electricity consumpiton	Cooling 2.17kW Heating 1.71kW
	4th floor East	6	Capacity	Cooling 29.2kW, Heating 32.6kW
			Electricity consumpiton	Cooling 0.97kW Heating 0.77kW
	5th floor West	11	Capacity	Cooling 69.0kW, Heating 77.3kW
			Electricity consumpiton	Cooling 1.87kW Heating 1.51kW
	5th floor East	6	Capacity	Cooling 34.4kW, Heating 38.6kW
			Electricity consumpiton	Cooling 1.01kW Heating 0.81kW
	8th floor West	17	Capacity	Cooling 68.9kW, Heating 77.2kW
			Electricity consumpiton	Cooling 2.16kW Heating 1.60kW
	8th floor East	6	Capacity	Cooling 33.7kW, Heating 37.6kW
			Electricity consumpiton	Cooling 1.05kW Heating 0.85kW
Case 2 to 4	4th floor West	14	Capacity	Cooling 68.1kW, Heating 76.3kW
			Electricity consumpiton	Cooling 0.72kW Heating 0.55kW
	4th floor East	6	Capacity	Cooling 29.2kW, Heating 32.6kW
			Electricity consumpiton	Cooling 0.27kW Heating 0.21kW
	5th floor West	11	Capacity	Cooling 69.0kW, Heating 77.3kW
			Electricity consumpiton	Cooling 0.64kW Heating 0.51kW
	5th floor East	6	Capacity	Cooling 34.4kW, Heating 38.6kW
			Electricity consumpiton	Cooling 0.31kW Heating 0.25kW
	8th floor West	17	Capacity	Cooling 68.9kW, Heating 77.2kW
			Electricity consumpiton	Cooling 1.08kW Heating 0.74kW
	8th floor East	6	Capacity	Cooling 33.7kW Heating 37.6kW
			Electricity consumpiton	Cooling 0.29kW Heating 0.23kW
Case 2	4th floor East	6	Capacity	Cooling 29.2kW, Heating 32.6kW
			Electricity consumpiton	Cooling 0.27kW Heating 0.21kW
Case 3, Case 4	4th floor East	6	Capacity	Cooling 23.4kW, Heating 26.0kW
			Electricity consumpiton	Cooling 0.22kW Heating 0.18kW

Overview of LCEM tool

LCEM tool is the energy simulation tool which is developed and distributed by Ministry of Land, Infrastructure and Transport of Japan for the purpose of performing consistent energy management for the entire life cycle of buildings. LCEM tool is mainly used for energy simulations of AC systems in governmental buildings, but it is also applicable for private-sector buildings

In LCEM tool, AC load calculations by modeling of buildings are not performed. Only AC systems are modeled, and using previously prepared AC loads and outdoor air conditions in each time step as input values, electricity consumptions of AC systems are calculated. Therefore, it is necessary to get AC loads from other AC load calculation tools or measurement data. In this research, as mentioned above, the cooling and heating capacities supplied by the VRF system were calculated from the measured data using CC method and identified to the AC loads.

Modeling of VRF system in LCEM tool

In LCEM tool, all modeling of AC systems is done on the Excel sheets. AC systems are modelled by connecting objects of equipments (sets of cells to which equations and specifications of epuimpents are input) on the Excel sheets. The image of the modelling of VRF system in LCEM tool is shown in Figure 6.

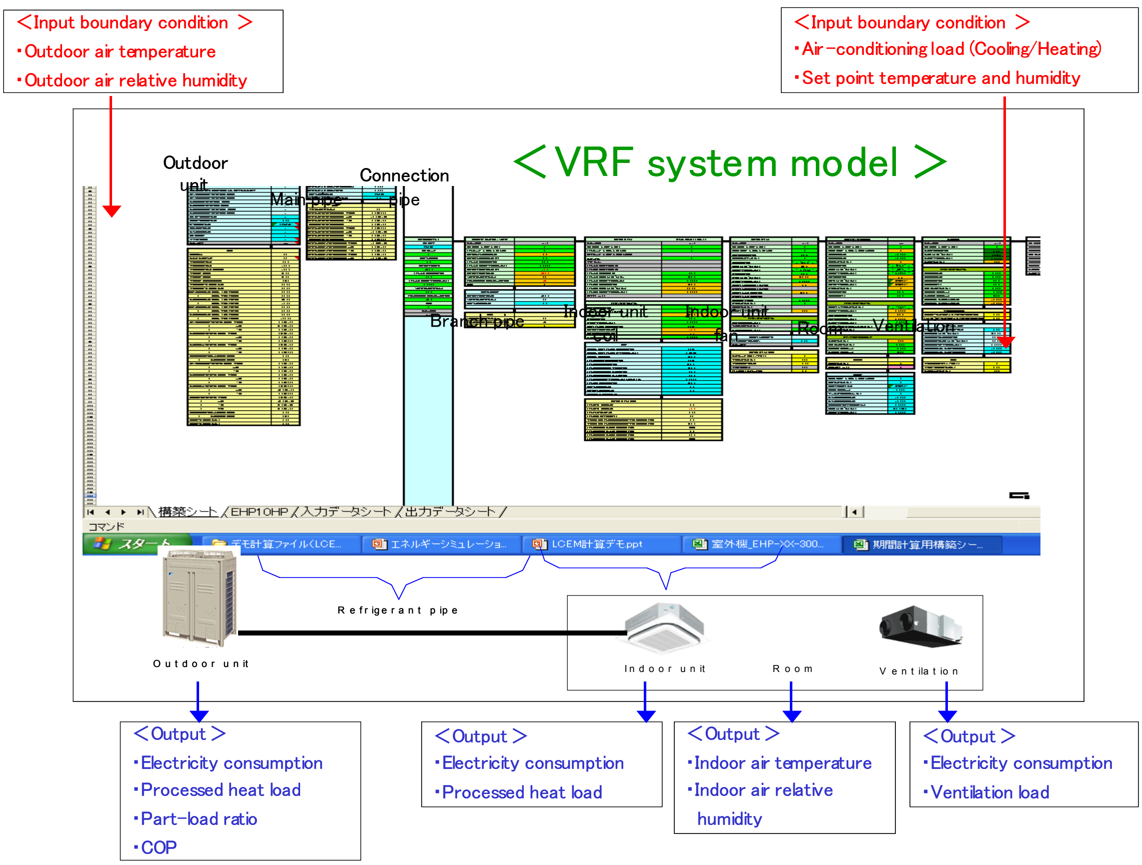

Figure 6 Image of the modelling of VRF system in LCEM tool

Calculation logic of VRF system in LCEM tool

In this section, the main equations used for energy simulations of VRF systems in cooling operation are shown.
The available capacity of outdoor unit is calculated by multiplying the rated capacity of outdoor unit and the capacity modifier (function of temperature).

The modifier (function of temperature) for cooling capacity of outdoor unit is calculated using a bi-quadratic equation of outdoor air dry-bulb temperature and indoor air wet-bulb temperature.

$$Q_{avail} = Q_{rated} \times CapFTemp \quad (5)$$

$$CapFTemp = a_1 + a_2(T_{wb,i}) + a_3(T_{wb,i})^2 + a_4(T_{db,o}) + a_5(T_{db,o})^2 + a_6(T_{wb,i})(T_{db,o}) \quad (6)$$

The part-load ratio of outdoor unit is calculated by dividing the cooling load by the available capacity of outdoor unit.

$$PLR = Qc_{load} / Q_{avail} \quad (7)$$

The electricity consumption of outdoor unit is calculated by multiplying rated electricity consumption of outdoor unit and the electricity consumption modifiers (functions of temperature and part-load ratio).

The modifier (function of temperature) for electricity consumption of outdoor unit is calculated using a bi-quadratic equation of outdoor air dry-bulb temperature and indoor air wet-bulb temperature. And the modifier (function of part-load ratio) for electricity consumption of outdoor unit is calculated using a quadratic equation of part-load raito.

$$Wo = Wo_{design} \times ECFTemp \times ECFPLR \quad (8)$$

$$ECFTemp = b_1 + b_2(T_{wb,i}) + b_3(T_{wb,i})^2 + b_4(T_{db,o}) + b_5(T_{db,o})^2 + b_6(T_{wb,i})(T_{db,o}) \quad (9)$$

$$ECFPLR = c_1 + c_2(PLR) + c_3(PLR)^2 \quad (10)$$

The total electricity consumption of VRF system is the sum of the electricity consumptions of indoor units and outdoor unit.

$$W = \Sigma Win + Wo \quad (11)$$

Building temperature characteristics of old model into LCEM tool

In LCEM tool, the capacity and electricity consumption modifiers (functions of temperature) of the new model are originally built into the VRF system model. So in order to do the simulation of Case 1, the characteristics equations of the old model were made from the engineering data and built into the VRF system model.

Figure 7 shows the comparison between the capacity and electricity consumption of the old model (28.0kW) from the engineering data and those from the characteristics equations in cooling operation. It is confirmed that the characteristics equations can express the temperature characteristics of the outdoor unit well.

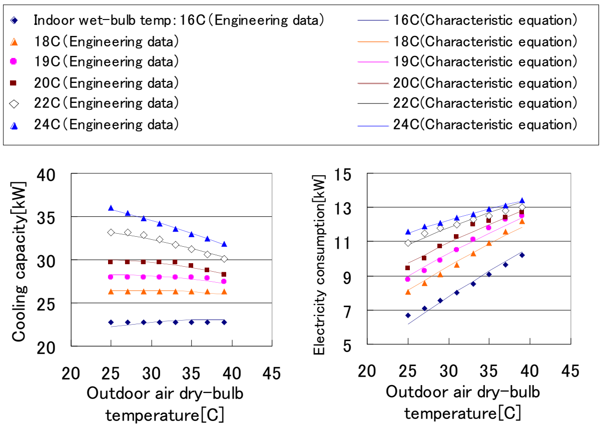

Figure 7 Temperature characteristics of the old outdoor unit from the engineering data and those from the characteristics equations

Building evaporating temperature change logic into LCEM tool

In order to carry out the simulation of Case 4, the new object of LCEM tool in which the energy simulation logic considering the evaporating temperature change was built.

The electricity consumption of outdoor unit considering the evaporating temperature change is calculated by the equation which adds the electricity consumption modifiers (function of evaporating temperature change) to the aforementioned equation(8). The modifier (function of evaporating temperature change) for electricity consumption of outdoor unit is calculated using a quadratic equation of evaporating temperature change. The modifier (function of evaporating temperature change) for electricity consumption of outdoor unit is shown in Figure 8.

$$Wo = Wo_{design} \times ECFTemp \times ECFPLR \times ECFTe \quad (9)$$

$$ECFTe = d_1 + d_2(Te_{change}) + d_3(Te_{change})^2 \quad (10)$$

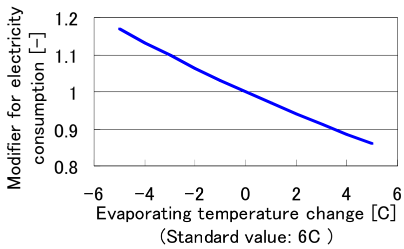

Figure 8 Modifier (function of evaporating temperature change) for electricity consumption of outdoor unit

SIMULATION RESULT

Annual electricity consumption

Table4 shows the simulation result of the annual electricity consumption and the energy saving effect of the improvement in each case.

The annual energy saving effect of the renewal to the same capacity systems (Case 2) was calculated to 31% in total of the 6 zones. It may be said that the electricity consumption was reduced by the renewal because the COP of the outdoor unit rose.

Moreover, by the renewal to proper capacity systems in 4th floor East zone (Case 3), the energy saving effect in 4th floor East zone and total of 6 zones increased from 33% to 44% and 31% to 32%, respectively. It may be said that the energy saving effect increased because the operating hours at low part-load and the rated electricity consumption of the indoor units decreased by reducing capacity.

The annual energy saving effect of renewal to proper capacity systems and the evaporating temperature change (Case 4) was calculated to 40% in total of the 6 zones. It may be said that the energy saving effect increased more from Case 3 because the COP of the outdoor unit rose and the processed latent heat load decreased by raising the evaporating temperature in cooling operation.

Indoor thermal environment

Figure 9 shows the simulation result of the indoor air relative humidity on July 19, 2009. It was calculated that the indoor air relative humidity in cooling operation rose 4.8% on average by rising evaporating temperature 3deg-C because the processed latent heat load decreased. There was a little rise in the relative humidity, but it is thought that there was no big problem in the indoor thermal environment.

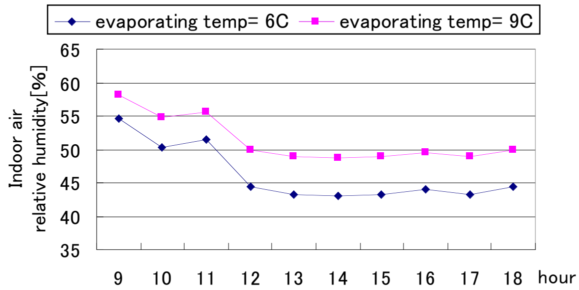

Figure 9 Simulation result of the indoor air relative humidity (July 19, 2009)

CONCLUSION

In this research, the commissioning process was applied to the actual VRF system. Using the actual operating data of the VRF system, the annual energy simulations by LCEM tool were carried out and the energy saving effects of the improvements were investigated.

In total of the 6 zones, the annual energy saving effect of the renewal to the same capacity systems was calculated to 31%, and the energy saving effect of the renewal to proper capacity systems (in 4th floor East zone, 28.0kW→22.4kW) was calculated to 32%. In addition, the energy saving effect increased to 40% by applying the renewal to proper capacity systems and changing the evaporating temperature (6deg-C→9deg-C).

Table 4 Simulation result of the annual electricity consumption and the energy saving effect of the improvement in each case

Zone	Case	Electricity consumption[GJ]									Energy saving effect	
		Cooling			Heating			Cooling and Heating				
		Outdoor Units	Indoor units	Total	Outdoor Units	Indoor units	Total	Outdoor Units	Indoor units	Total	[GJ]	[%]
4th floor West	Case1	52.1	6.8	58.9	22.9	2.3	25.2	75.0	9.2	84.1	–	–
	Case2, Case3	37.3	2.2	39.5	19.4	0.8	20.2	56.6	3.0	59.6	24.5	29%
	Case4	30.4		32.6				49.8		52.8	31.3	37%
4th floor East	Case1	9.6	0.9	10.5	5.7	0.5	6.2	15.4	1.4	16.7	–	–
	Case2	6.2	0.3	6.5	4.6	0.1	4.8	10.8	0.4	11.2	5.5	33%
	Case3	4.9	0.2	5.1	4.2	0.1	4.3	9.1	0.3	9.4	7.4	44%
	Case4	4.0		4.2				8.1		8.5	8.3	49%
5th floor West	Case1	47.2	6.7	53.9	10.5	1.7	12.2	57.8	8.4	66.1	–	–
	Case2, Case3	33.8	2.2	36.0	9.0	0.6	9.6	42.8	2.8	45.6	20.6	31%
	Case4	27.6		29.8				36.6		39.4	26.7	40%
5th floor East	Case1	19.5	3.9	23.4	14.5	2.7	17.2	34.0	6.6	40.6	–	–
	Case2, Case3	12.6	1.2	13.8	11.6	0.9	12.5	24.2	2.1	26.3	14.3	35%
	Case4	10.2		11.4				21.8		23.9	16.7	41%
8th floor West	Case1	47.5	6.6	54.1	19.7	2.6	22.2	67.2	9.2	76.4	–	–
	Case2, Case3	34.0	3.0	37.0	16.6	1.1	17.7	50.7	4.1	54.8	21.6	28%
	Case4	27.9		30.9				44.5		48.6	27.8	36%
8th floor East	Case1	27.3	4.6	31.9	6.4	1.7	8.2	33.7	6.3	40.1	–	–
	Case2, Case3	17.6	1.3	18.9	5.2	0.5	5.7	22.8	1.8	24.5	15.5	39%
	Case4	14.4		15.7				19.6		21.3	18.7	47%
Total	Case1	203.4	29.5	232.9	79.7	11.5	91.2	283.1	41.0	324.1	–	–
	Case2	141.5	10.1	151.6	66.4	4.0	70.4	207.9	14.1	222.0	**102.1**	**31%**
	Case3	140.1	10.1	150.2	66.0	4.0	69.9	206.1	14.1	220.2	**103.9**	**32%**
	Case4	114.5		124.6				180.5		194.5	**129.5**	**40%**

The next step would be to develop the logical method of dividing the measured total heat load into sensible and latent heat loads and to evaluate the adequacy of the simulation result by inspecting the actual energy saving effect after the improvement.

NOMENCLATURE

Measurement

Qc : Cooling capacity of outdoor unit [kW]
Qh : Heating capacity of outdoor unit [kW]
G : Refrigerant flow rate [kg/s]
Δic : Enthalpy difference of evaporator [kJ/kg]
Δih : Enthalpy difference of condenser [kJ/kg]
Te : Equivalent saturation temperature of evaporating pressure (Evaporating temperature) [deg-C]
Tc : Equivalent saturation temperature of condensing pressure (Condensing temperature) [deg-C]
$freq$: frequency of compressor [Hz]
Pe : Evaporating pressure [Mpa]
Pc : Condensing pressure [Mpa]
SH : Degree of superheat [deg-C]
SC : Degree of subcool [deg-C]
Wo : Electricity consumption of outdoor unit [kW]

Simulation

Q_{avail} : Available capacity of outdoor unit [kW]
Q_{rated} : Rated capacity of outdoor unit [kW]
$CapFTemp$: Modifier (function of temperature) for capacity of outdoor unit [-]
a_1 - a_6 : Equation coefficients for capacity modifier (function of temperature)
$T_{db,o}$: Outdoor air dry-bulb temperature [deg-C]
$T_{wb,i}$: Indoor air wet-bulb temperature [deg-C]
PLR : Part-load ratio of outdoor unit [-]
Qc_{load} : Cooling load of outdoor unit [kW]
Wo : Electricity consumption of outdoor unit [kW]
Wo_{rated} : Rated electricity consumption of outdoor unit [kW]
$ECFTemp$: Modifier (function of temperature) for electricity consumption of outdoor unit [-]
$ECFPLR$: Modifier (function of part-load ratio) for electricity consumption of outdoor unit [-]
b_1 - b_6 : Equation coefficients for electricity consumption modifier (function of temperature)
c_1 - c_3 : Equation coefficients for electricity consumption modifier (function of part-load ratio)
W : Total electricity consumption of VRF system [kW]
Win : Rated electricity consumption of indoor unit [kW]
$ECFTe$: Modifier (function of evaporating temperature) for electricity consumption of outdoor unit [-]
Te_{change} : Evaporating temperature change （standard value = 6 deg-C） [deg-C]
d_1 - d_3 : Equation coefficients for electricity consumption modifier (function of evaporating temperature)

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