A Method for On-Going Commissioning of VRV Package Systems Using a Simulation Model

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Abstract: Variable refrigerant volume (VRV) systems, which have several indoor units and a single outdoor unit, have become very popular HVAC systems in Japan. However, some systems may be operated under inefficient conditions and consume excessive energy, since verification of system performance is not conducted. Although the performance of systems should be evaluated by some indices such as coefficient of performance (COP), calculating such a value is difficult, because the heat load handled by machines is not known. A simulation model based on a refrigeration cycle was proposed to evaluate system performance. Basic conditions for evaporation and condensation were defined from conditions provided in Japanese Industrial Standards (JIS). Flow rate of refrigerant was calculated from heat load under full occupancy and enthalpy difference of the evaporator. If power consumption exceeds the calculated value, malfunctions or inadequate conditions are considered to occur. The method presented here can be used for on-going commissioning of VRV package systems.

1. INTRODUCTION

At present, VRV systems are commonly used to provide air conditioning to office buildings in Japan. A VRV system has several indoor units, or evaporators, and a single condensing unit. The indoor units of respective room can be operated independently of each other, and they do not require pumps, piping and ducts, and air handling units. Consequently, as compared with conventional systems, installation cost is lower and operations are easier.

Moreover, some VRV systems have ice thermal storage tanks that make ice during the night. These systems use stored ice for sub-cooling of the refrigerant to increase the cooling capacity of the system. As a result, they can reduce power consumption of the compressor during the day, thus achieving peak shaving of power consumption.

However, commissioning of VRV systems is seldom completed, because of the difficulty in measuring the actual cooling capacities of systems in operation. Therefore, demand exists for new Functional Performance Testing (FPT) methods, which include verification of energy performance of systems.

In this study, a method for evaluating performance of VRV systems for on-going commissioning is proposed, by way of comparing simulation and measurement results. A simulation model considering the refrigeration cycle of a VRV system is proposed and used to evaluate system operations.

2. OUTLINE OF THE SYSTEM

The system evaluated in this study is a VRV ice storage package air conditioner installed in No. 10 building at Chubu University. Figure 1 shows the floor plan of the system, and Table 1 shows total area and maximum occupancy of the rooms. System specifications for cooling operation are shown in Table 2.

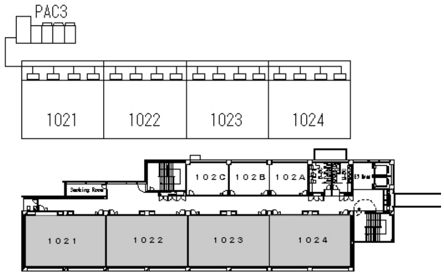


Fig. 1. Second floor lecture rooms (PAC3)

Tab. 1. Details of the building measured.

Building name	Chubu University Building No. 10
Air conditioned rooms	Lecture rooms on 4th floor
Room max. occupants	431 students
Conditioned floor area	511 m^2

The measurements were conducted in 2004, from the end of May until December. The measurement periods were classified into three periods on the basis of the operative conditions; namely, the spring semester, from May 25 to Jul. 14; summer vacation, from Jul. 15 to Sept. 20; and the fall semester, from Sept. 21 to Dec. 22. In both systems, the cooling period was from May 25 to Nov. 10, whereas the heating period was after Nov. 11. Table 3 shows the measured quantities and their respective measuring devices.

Tab. 2. Details of the VRV system

Compressor	Electrically driven scroll type
Cooling capacity	120 kW
Capacity per area	235 W/m^2
Rated power consumption	33.9 kW
Compressor output	23.75 kW
Fan power	1.2 kW
Refrigerant	R22
Number of compressor	1 variable speed and 5 constant speed

Tab.3. Measured quantities ・Measuring devices

Measured quantities	Measuring devices	
Indoor temperature and humidity	Hand-held Temperature and humidity recorders	±0.5°C ±5%(RH)
Outdoor temperature and humidity		
Power consumption of each system	Watt meters	±3%rdg.
Amount of direct solar radiation	Solar radiation meter	4mV/(kW/m^2)
Power consumption in the entire building	Power meters	±2.0%

The evaluation was conducted by comparing measured power consumption and predicted power consumption from a simulation model. The simulation model could calculate power consumption from heat load calculation. For comparison, the measured weather conditions were used for load calculation by TRNSYS.

The conditions for load calculation were as follows:

- outdoor temperature, humidity, and solar radiation from measurements
- infiltration rate was 0.5 times/hour
- full occupancy
- operating hours: 9:00 to 17:00 Monday to Friday. (15:00 to 17:00 on Wednesday was eliminated, since there was no class on the school calendar.).

Since occupancy rate was impossible to estimate, full occupancy was taken to calculate the upper limit of heat load.

3. SIMULATION MODEL

The VRV package system has characteristics of a heat source machine rather than air-handling units, because it contains compressors. The simulation model was formulated in consideration of a refrigeration cycle. Figure 2 shows the refrigeration cycle of the VRV system in this study. Two cycles are presented on the diagram, because the system produced ice during the night. The refrigerant was sub-cooled by stored ice downstream of a condenser, thereby increasing cooling capacity. The model was made for both processes.

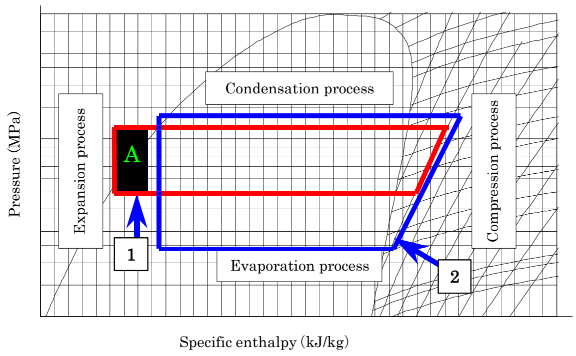


Fig. 2 Morier diagram of refrigeration cycle

Each point of the chart can be defined by temperature and pressure of the refrigerant. In consideration of manufacturer's documents and Japanese Industrial Standards, the temperature for the condensing process was set to 10 K above outdoor temperature. The evaporative temperature was set to a constant value of 5.5˚C, and the temperature of sub-cooled refrigerant was set to 8˚C.

From the pressure and temperature set above, density and specific enthalpy were calculated from state equations of the refrigerant (JSRAE, 1975). Since the equations were non-linear and simultaneous, the values were calculated by the solver function of MS Excel. Mass flow rate was obtained by Equation (1), dividing the calculated heat load by specific enthalpy difference between the inlet and outlet of the evaporator.

$$F_{ref} = L_r / (h_2 - h_1) \qquad (1)$$

Heat load L_r is a value corresponding to full occupancy. Therefore, predicted power consumption is the highest possible value.

Compression work could be calculated from F_{ref} and an enthalpy difference in the compression process.

$$E_{comp} = F_{ref} \times (h_3 - h_2) \times 3600 \qquad (2)$$

Considering efficiency of the compressor, power consumption was calculated by Equation (3). Efficiency in Equation (3) is ratio of work done by the compressor to input power, or the product of motor efficiency and compressor efficiency. (SHASE, 2001)

$$P_{sys} = E_{comp} / \eta_{sys} + P_{fan} \qquad (3)$$

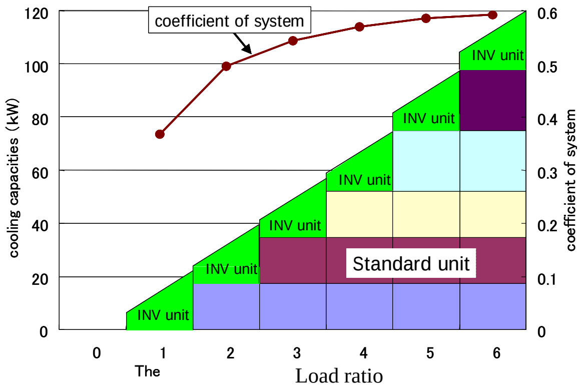


Fig. 3. Relation between system efficiency and load ratio.

The VRV system evaluated in this study had one variable-speed compressor and five constant-speed compressors, which were controlled to match heat load. Considering the effect of partial system load, an average of working compressor efficiency was taken as the system efficiency in Equation (3). The machine control method and calculated system efficiency to load ratio are shown in Figure 3.

In view that the system had an ice storage tank, storage operations should be considered. The stored cold was used for sub-cooling of refrigerant downstream of the condenser, as shown in Figure 2. The enthalpy difference between the outlet of the compressor and the inlet of the evaporator was produced by stored ice. Therefore, discharged heat was calculated by Equation (4).

$$E_{T1hour} = (h_1 - h_1') \times F_{ref} / 3600 \qquad (4)$$

Heat loss during the day was predicted by Equation (5), which was based on measurements (Sekiyama, 2005).

$$E_{Tlos} = (T_{day} \times 0.4727\text{-}2.9814) / P_{st\,max} \times E_{T\,max} \qquad (5)$$

Therefore, heat to charge was the sum of the above. From the measurement, power consumption during charging operation was around 20 kW, which was equivalent to operation of four out of six compressors. System efficiency was determined to be the value for four compressors.

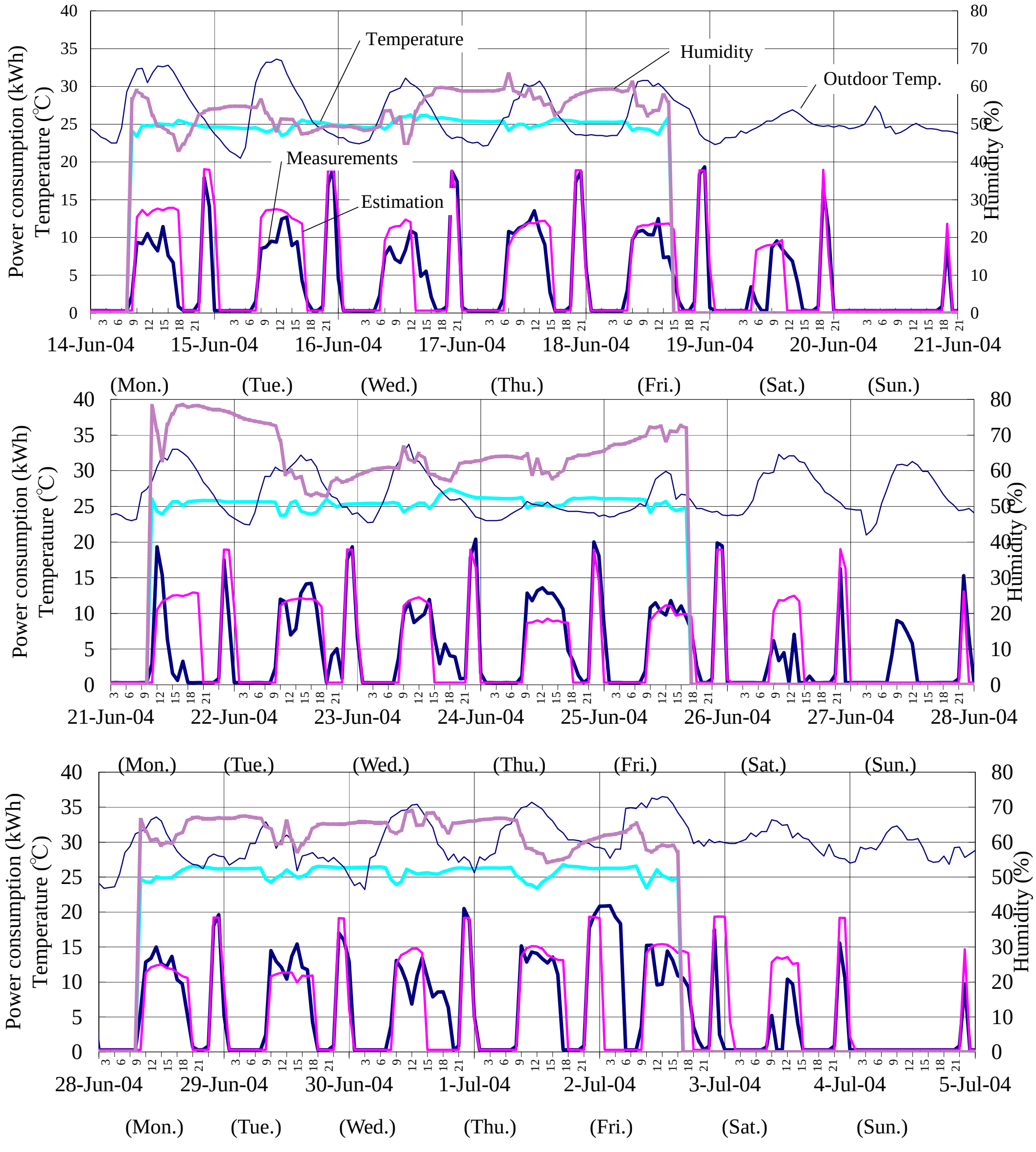
The conditions of charging operation were condensing temperature of 45˚C and evaporative temperature of –10˚C. The sub-cooling temperature

ESL-IC-06-11-188

was determined from condensing and outdoor temperatures, and the degree of super cool after evaporation was set to 5˚C.

4. RESULTS

Comparison between the calculated and measured power consumption during the period June 14 to July 14, 2004 is shown in Figure 4. Indoor temperature and humidity are also shown in the figure to consider their influence on power consumption. The measured power consumption fell below the estimated value from 9:00 to 18:00, which was the condition of calculation for most of the operation hours. On 27th of June and 11th of July, energy consumption appeared despite of no calculated value because irregular operations of the rooms were occurred on these Sundays when calculation was not conducted.



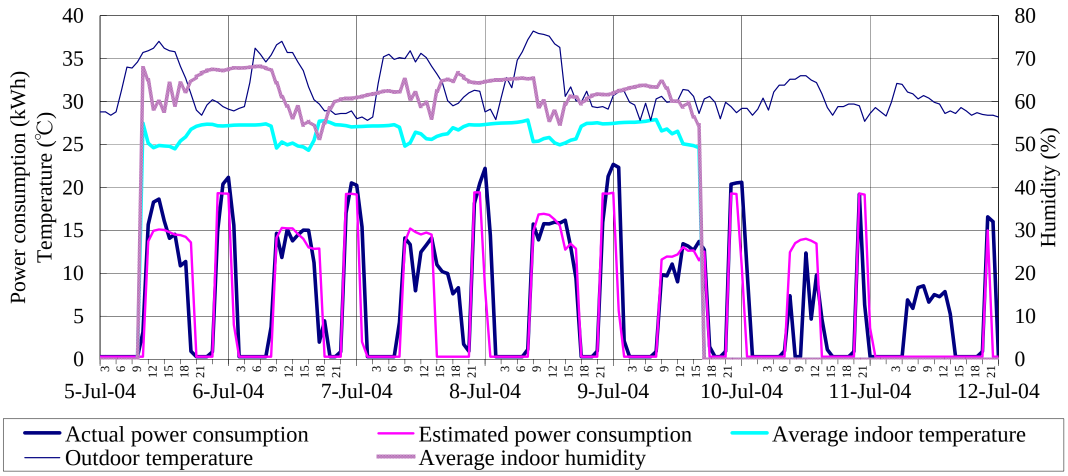


Fig. 4. Comparison between calculation and measurements (2004/6/14～7/11)

However, operation hours when the measured power exceeded the prediction were found; nevertheless, the calculation was conducted for full occupancy. Since the indoor temperature was observed to be below 25˚C for such cases, inadequate operations could be detected by using the model proposed above. The humidity of rooms was sometimes relatively high, because the period shown in Figure 4 was rainy season of Japan, when outside humidity sometimes reached to 100 %. The VRV systems don't have reheaters for dehumidication.

Although the predicted power consumption during the night was almost the same as the measured value, excesses in measured power consumption were found from the middle of July, when the outdoor temperature went up.

5.CONCLUSIONS

A method for estimating power consumption of a VRV system is proposed for evaluation in on-going commissioning. In view that all components for air-conditioning were packed in the system and heat was conveyed by refrigerant, heat treated in the system was very difficult to measure. Therefore, a calculation model based on a refrigeration cycle is proposed.

Assuming a calculation condition of full occupancy, maximum possible power consumption could be calculated. By comparing calculation and measurement, inadequate operational conditions could be pointed out when measurement results exceeded calculation results.

Verification of the model was conducted in lecture rooms at Chubu University in one month for cooling operation. Excesses in measured power consumption were found in cases where room temperature was inadequately low. The model can be said to be an effective tool for on-going commissioning of VRV systems.

NOMENCLATURE

E_{comp}: work of compressor [kWh],

E_{T1hour}: Disharge heat per hour [kWh],

E_{Tloss}: daily heat loss from storage tank [kWh],

E_{Tmax}: Storage capacity (=294) [kWh]

F_{ref}: flow rate of refrigerant [kg/h],

h_1: specific enthalpy of sub-cooled refrigerant [kJ/kg],

h_1':specific enthalpy of liquid at outlet of condenser [kJ/kg],

h_2: specific enthalpy of low pressure gas [kJ/kg],

h_3:specific enthalpy of high pressure gas [kJ/kg],

L_r: heat load of the rooms [kJ/h],

P_{fan}: power consumption of fan,

P_{stmax}: rated power consumption for storage (=139) [kW],

P_{sys}: power consumption of system [kWh],

η_{sys}: system efficiency [-]

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