Study of In Situ Performance of the VRF Multi-split Air Conditioner for the Commercial Building

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Abstract

When variable refrigerant flow multi-split air conditioning and heat pump equipment for commercial buildings (VRF system) is selected, a capacity greater than the air conditioning load is often selected. As a result, it is said that it often operates in the low load factor region, and that the catalog performance is not achieved. In this report, a field monitoring result that includes an actual capacity and efficiency is reported. The monitoring instrument, comprising an ultrasonic flowmeter, Coriolis mass flowmeter, thermocouples, pressure sensors, current frequency meter, and a wattmeter, were actually installed in the VRF system (2015 model year, Daikin Industries) at Kanagawa Pref. in Japan. We estimated performance using the compressor curve (CC) method and the refrigerant enthalpy (RE) method. Although the equipment was operating in the low load factor, results show that efficiency between the rating point and a load factor of 20% was higher than the rated efficiency.

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Keywords: VRF; In Situ Performance; Commercial Building;

INTRODUCTION

The pace of performance improvement in the VRF system, and of their widening use, is remarkable, and they are increasingly being chosen even for facilities with floor areas in the tens of thousands of square meters. Central air conditioning has been the mainstream for such facilities. But in many cases, models are selected that have too much capacity for the air conditioning loads they handle. These systems then run in the low load factor region, so it is possible that they may not achieve the catalog performance.

This paper reports the results of our research of the actual capacity and efficiency levels of the VRF system. For this research, we installed a measurement system comprising a Coriolis mass flowmeter, thermocouples, pressure sensors, and power meter to the VRF system in use in the field.

1. MEASUREMENT METHOD

The product under test was the VRF system installed in TEPCO Research Institute. A measurement system was

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built that was able to calculate generated heat quantities (cooling capacity, heating capacity), power consumption, and coefficient of performance. Table 1 states the main specifications of the VRF system, and Table 2 shows the measured parameters. Figure 1 shows the VRF system and a summary of the instruments installed around the refrigerant pipes.

Table 1. Specifications of the product under test

Instrument	Outdoor Unit	Indoor Unit
Number of Units	1	3
Power supply	Three-phase 200V, 50/60Hz	Single-phase 200V, 50/60Hz
Rated cooling capacity [kW/Unit]	28.0/28.0	11.2
Rated cooling power consumption [kW/Unit]	8.58	0.165/0.194
Rated heating capacity [kW/Unit]	31.5/31.5	12.5
Rated heating power consumption [kW/Unit]	8.34	0.132/0.161
Maximum low-temperature heating capacity [kW/Unit]	26.7/26.7	—
Refrigerant	R410A	

Table 2.The measured parameters

Instrument	**Measurement location during cooling**
T-type thermocouple	Surface temperature of liquid piping of outdoor unit [°C]
	Surface temperature of vapor piping of outdoor unit [°C]
Pressure sensor	[High pressure] Outdoor unit liquid line pressure [MPa]
	[Low pressure] Outdoor unit vapour line pressure [MPa]
Coriolis flow meter	Mass flow rate [kg/min] and density [kg/L] of liquid refrigerant
Power meter	Electric power consumption [kW]
T-type thermocouple	Atmospheric temperature
Hygrometer	Atmospheric humidity

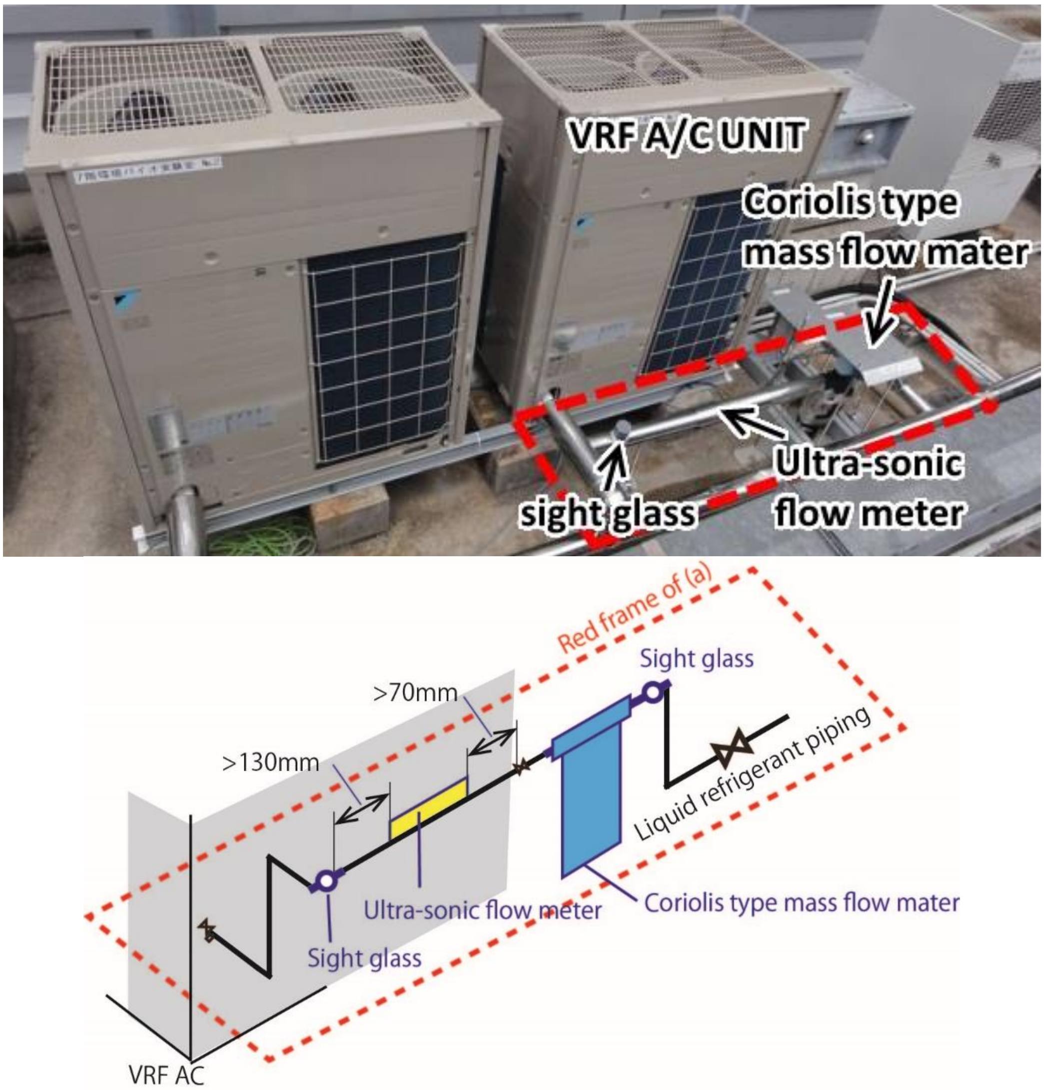

Fig.1. The VRF system and a summary of the instruments installed around the refrigerant pipes

Calculation of the heating and cooling capacity and coefficient of performance (COP) used the refrigerant enthalpy (RE) method and the compressor curve (CC) method [1].
The RE method finds the refrigerant mass flow and the difference between refrigerant enthalpy levels at the inlet and outlet of the outdoor unit, to estimate generated heat. “CC method” is a general name for methods constructed by equipment manufacturers, using their proprietary expertise, to estimate generated heat, etc. In this research, the internal data from the VRF system was recorded on a PC, separately from the measurement system data, and used to calculate generated heat and coefficient of performance (COP) by the CC method.

2. ASCERTAINING COOLING PERFORMANCE

This section describes cooling performance based on data obtained during cooling. Cooling capacity $Q_{C,RE}$ and coefficient of performance $COP_{C,RE}$ are estimated from measured data. The RE method is used to estimate cooling capacity $Q_{C,RE}$, and $COP_{C,RE}$ is calculated from that estimated value and the measured power consumption. Then, these values were compared with the cooling capacity $Q_{C,CC}$ and coefficient of performance $COP_{C,CC}$ that were estimated by the CC method from internal data from the VRF system.

2.1 Comparison of Cooling Capacity Values

Figure 2 shows the comparison of estimated cooling capacity values calculated by the CC method and the RE method. The $Q_{C,CC}$ estimated value of cooling capacity by the CC method was plotted on the *x* axis, and the difference between Measurement and CC method estimates of cooling capacity ($Q_{C,RE}$ - $Q_{C,CC}$) was plotted on the *y* axis, Comparison indicated that values matched within ±10% in the high load factor region, with a very slight disparity between the CC method estimated value and the RE method estimated value. In the low load factor region, however, measurement estimated value was larger than CC method estimated value. Concerning the difference in the low load factor region, the error in refrigerant flow due to the Coriolis flow meter is estimated to be very small, while the error in temperature measurements using thermocouples affixed to the surface is estimated to be large, with a major impact.

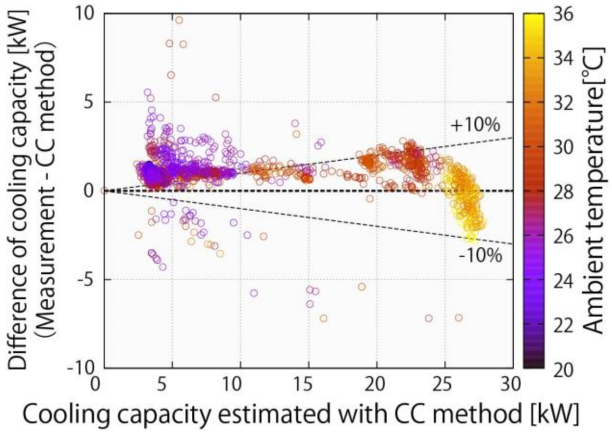

Fig.2. Comparison of Cooling Capacity Values Between the Measurement and the CC Method

2.2 Comparison of Power Consumption Values

Figure 3 compares the measured value of power consumption using RE method estimation and the power consumption value from internal data, using CC method estimation. Cooling capacity estimated with CC method, $Q_{C,CC}$, was plotted on the *x* axis, while P_{RE}-P_{CC}, the difference between the measured power consumption value, P_{RE}, and the power consumption value estimated by the CC method, P_{CC}, was plotted on the *y* axis.
For power consumption, the measured value P_{RE} was smaller than internal data P_{CC} for the whole range. P_{RE} was lower than P_{CC} by 0.3~0.5kW over the whole range.

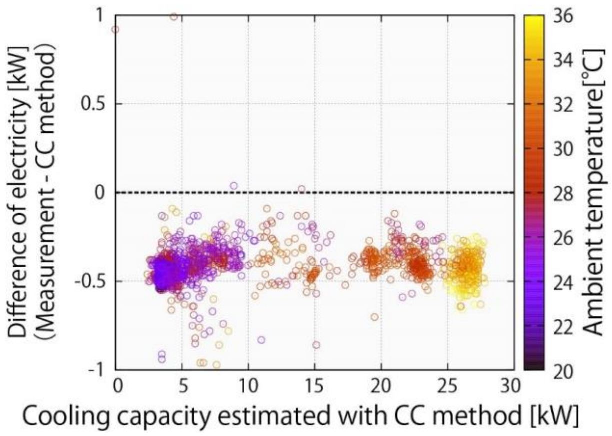

Fig.3. Comparison of Power Consumption Values

2.3 COP Comparison

For COP, the CC method estimated values and Measurement were compared. In Figure 4, Cooling capacity estimated with CC method, $Q_{C,CC}$, was plotted on the x axis, and the difference between Measurement and CC method estimates of COP, ($COP_{C,RE}$ - $COP_{C,CC}$), was plotted on the y axis.
For COP, Measurement is larger than CC method estimated value over the whole range. The divergence between Measurement and CC method estimated value was particularly large in the low load factor region.
The preceding section indicated that the difference between power consumption values was similar over the whole range, and that a slight difference in power consumption in the low load factor region had a large impact on COP. That suggests that the difference in power consumption is a major factor.

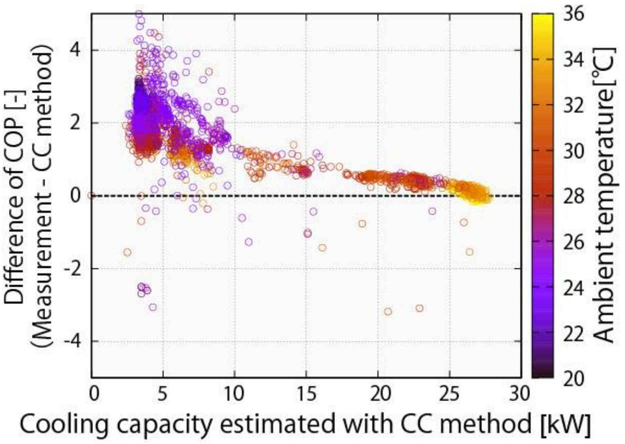

Fig.4. COP Comparison

2.4 Ascertaining COP Under Partial Load

This section describes the relationship between COP and load factor. The load factor was calculated from cooling capacity $Q_{C,RE}$ estimated from measured values by the RE method, and the rated cooling capacity, to find the relationship to coefficient of performance $COP_{C,RE}$.
The load factor L_f[-] is defined by the formula below.

$$L_f = \frac{Q_{C,RE}}{Q_{C,RAT}}$$

Where $Q_{C,RAT}$ is the rated cooling capacity.

Figure 5 shows the relationship between load factor L_f and $COP_{C,RE}$.
In the high load factor region, $COP_{C,RE}$ is close to the catalog value of 3.26 (*rated cooling capacity/rated power consumption), but $COP_{C,RE}$ increased as load factor approached 30% in the low load factor region.

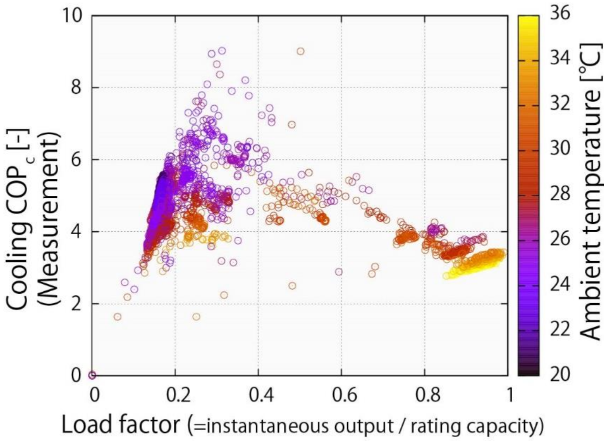

Fig.5. Relationship Between Load Factor and COP

2.5 Relationship Between Load Factor and Power Consumption

Figure 6 shows the relationship between load factor calculated in the preceding section, and power consumption. The results indicate that lower the load factor, the lower the power consumption. In particular, in the 0.2~0.9 load factor range, power consumption is lower than the straight line between the rated value and 0.

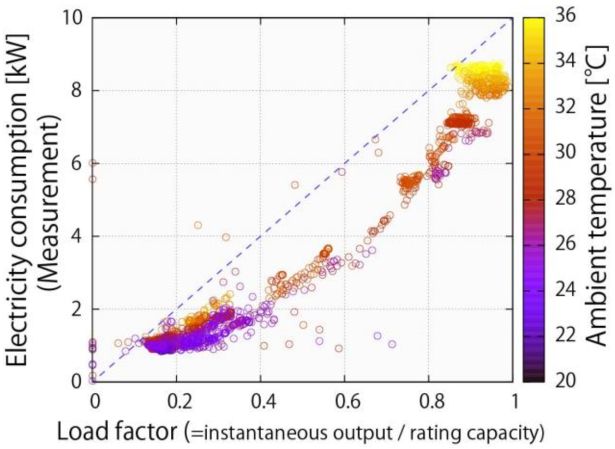

Fig.6. Relationship Between Load Factor and power in Cooling

3. ASCERTAINING HEATING PERFORMANCE

This section describes ascertaining performance during heating.
When the state of the refrigerant was observed through the sight glass during heating, it could be confirmed that bubbles of gaseous refrigerant were mixed with liquid refrigerant, and that gaseous refrigerant existed as a separate flow above the liquid refrigerant. Figure 7 shows the view of sight glass.
Measurement of refrigerant mass flow in this kind of situation, with separation between gas and liquid, is known to be impossible, or extremely imprecise, with a Coriolis flow meter. So the flow volume measured by the Coriolis flow meter was compared against the flow volume estimated by the CC method from 11am to 5pm on November 26, 2015. As shown in figure 8, there was a large variation in the flow volume measured by the Coriolis flow meter. And the flow volume measured had deviate from the flow volume estimated by the CC method. Hence it follows that measurement of Coriolis flow meter is not accurate in the state of liquid and gaseous phases of refrigerant are mixed.

Fig.7. View of sight glass

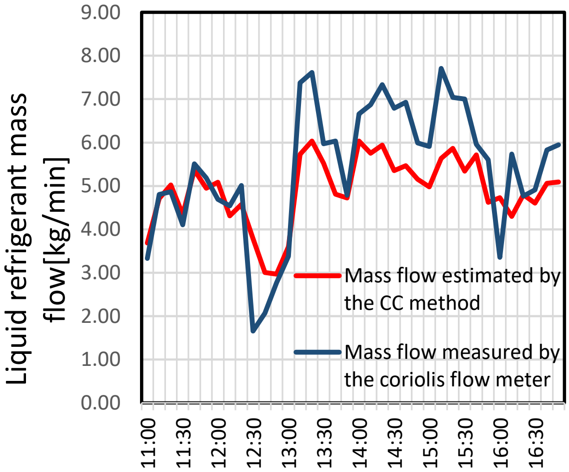

Fig.8. Comparison of refrigerant mass flow during heating

Fig.9. Comparison of Estimated Heating Capacity Values

Figure 9 compares $Q_{H,CC}$ values estimated by the CC method with $Q_{H,RE}$ values estimated by the RE method, for heating capacity. The $Q_{H,CC}$ values estimated by the CC method are plotted on the x axis, and the $Q_{H,RE}$ values estimated by the RE method are plotted on the y axis. The results show a divergence of between -52% and +28% between the $Q_{H,CC}$ values estimated by the CC method and the $Q_{H,RE}$ values estimated by the RE method. Compared to the $Q_{H,CC}$ values estimated by the CC method, the $Q_{H,RE}$ values estimated by the RE method are lower overall.

4. CONCLUSION

An on-site measurement system for the VRF system was built by mounting a Coriolis mass flowmeter, thermocouples, pressure sensors, and power meter, and the cooling and heating performance were analyzed using the RE method and the CC method, obtaining the following results:

(1) Ascertaining cooling performance

Comparison between RE method estimated values and CC method estimated values of cooling capacity, coefficient of performance COP, and power consumption, based on measured data, obtained the following results:

- In the comparison of estimated values for cooling capacity, the difference was within ±10% in the high load factor region, indicating that there was only a very slight disparity between the CC method estimated values and the RE method estimated values. But in the low load factor region, RE method estimated value was larger than CC method estimated value.
- The result for the relationship between cooling load factor and COP was that COP rose with movement from the high load factor region to the low load factor region (*down to 30% load factor). Advances in compressor control technology in recent years appear to have made a large contribution to this result.
- Comparison between load factor and power consumption produced the result that power consumption increases with rising load factor. In particular, in the 0.2~0.9 load factor range, power consumption was lower than the straight line between the rated and 0.

(2) Ascertaining heating performance

The presence of a separate flow of gaseous refrigerant above the liquid refrigerant caused inadequate measurement of refrigerant by the Coriolis mass flowmeter, so it was not possible to fully ascertain heating performance. This revealed the necessity of further investigative research on how to ascertain device performance in conditions where liquid and gaseous phases of refrigerant are mixed.

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