

# FIELD MEASUREMENT ON THE PERFORMANCE OF VRV SYSTEM BY PROBE INSERTION METHOD

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**Abstract:** This paper reports on the Probe Insertion Method for On-site Evaluation of the Variable Refrigerant Flow (VRF) system and the evaluation results for both Gas Engine-Driven (GHP) and Electrical Motor-Driven (EHP) VRF systems. The probe insertion method consists of both computer modelling and direct measurements of the heat exchange of the outdoor unit. The actual measurements were conducted in the prefectures of Tokyo, Osaka, Kochi and Hokkaido, Japan. These candidate buildings consisted of an office, a government office and a school cafeteria. The experiment was carried out from summer to winter to see both the effects of cooling and heating. In this study, the authors detail the probe insertion method, which is a simple measurement technique, and also present the results from the actual measurements.

**Key Words:** VRF system, actual measurements, COP, outside unit

## 1 INTRODUCTION

Recently, VRF systems for air-cooled heat exchangers are being augmented for use in middle-rise office buildings. These VRF systems are considered to perform strongly. However, the characteristics that affect the performance of the equipment during actual operation are not well understood. The performance of VRF systems are examined by settled loading in test chambers. However, this examination does not provide accurate results because it is not carried out under actual conditions. The fact is that under existing circumstances, on-site evaluations are less than ideal. The reason for this is because it is too difficult to measure the performance of indoor units without causing difficulties for office workers. Given this background, the authors have created a simple measurement technique that evaluates the performance of a VRF system by measuring the performance of outdoor units. The results of an on-site evaluation of a VRF system can help predict the success or failure of the design of a facility.

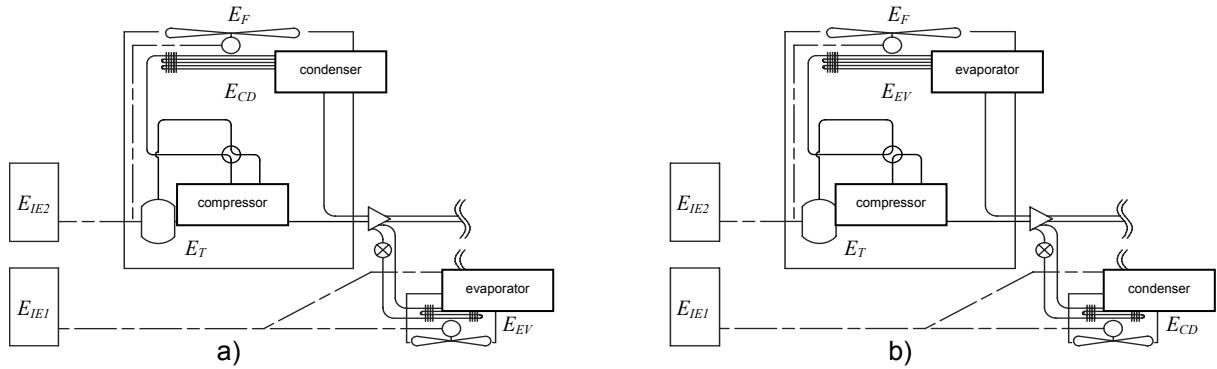
## 2 METHODS

### The Probe Insertion Method

The probe insertion method consists of computer modelling and direct measurements of the heat exchange of the outdoor unit. The computer model of the heat exchange of the outdoor unit is configured by using figures for the system energy supply, and an income and expenditure equation. The measurement of the heat exchange of the outdoor unit is calculated by the actual measurements and thermal and air volume calculations.

### 2.1 Method of computing the heat exchange of the outdoor unit

The authors measured outdoor units of Gas Engine-Driven (GHP) and Electrical Motor-Driven (EHP) VRF systems, which had already been installed in a variety of buildings at different locations. Figures 1 a) and b) show the energy-distribution diagram of an artificial air cooling and heating system (EHP). Figures 2 a) and b) show the energy income and expenditure equation for an artificial air cooling and heating system (EHP). Figures 3 a) and b) show the energy-distribution diagram of an artificial air cooling and heating system (GHP). Figures 4 a) and b) show the energy income and expenditure equation for an artificial air cooling and heating (GHP). Using these energy-distribution diagrams, and the income and expenditure equations, the authors calculate the efficiency of the unit, such as its coefficient of performance (COP).



**Figure 1: The energy-distribution diagram of EHP**  
a) artificial air cooling b) artificial air heating

$$\begin{aligned} E_P &= E_{EV} \\ E_T &= E_{IE2} - E_F \\ E_{EV} &= E_{CD} - E_T \\ E_P &= E_{CD} - (E_{IE2} - E_F) \end{aligned}$$

$$COP_C = \frac{E_P}{E_I} = \frac{E_P}{E_{IE2}}$$

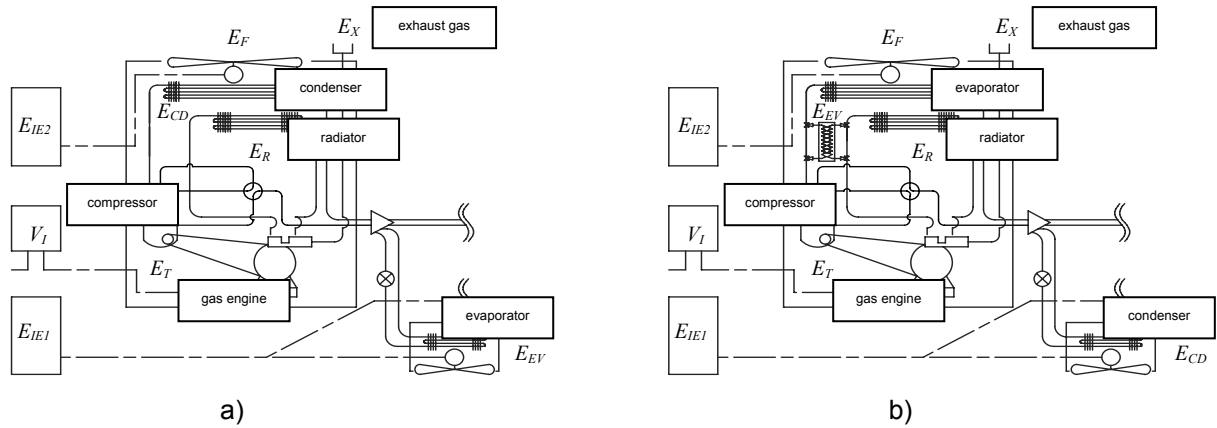
a)

$$\begin{aligned} E_P &= E_{CD} \\ E_T &= E_{IE2} - E_F \\ E_{CD} &= E_{EV} + E_T \\ E_P &= E_{EV} + (E_{IE2} - E_F) \end{aligned}$$

$$COP_H = \frac{E_P}{E_I} = \frac{E_P}{E_{IE2}}$$

b)

**Figure 2: The energy income and expenditure equation for EHP.**  
a) artificial air cooling b) artificial air heating.



**Figure 3: The energy-distribution diagram of the GHP**  
a) artificial air cooling b) artificial air heating

$$\begin{aligned} E_P &= E_{EV} \\ E_{IG} &= E_T + E_X + E_R \\ E_T &= E_{IG} - E_X - E_R \\ E_T &= E_{CD} - E_{EV} \\ E_{IG} - E_X - E_R &= E_{CD} - E_P \\ E_P &= E_{CD} + E_R + E_X - E_{IG} \end{aligned}$$

$$COP_C = \frac{E_P}{E_I} = \frac{E_P}{E_{IG} + E_{IE2}}$$

a)

$$\begin{aligned} E_P &= E_{CD} \\ E_{IG} &= E_T + E_X + E_R + E_S \\ E_T &= E_{IG} - E_X - E_R - E_S \\ E_T &= E_{CD} - E_{EV} - E_S \\ E_{IG} - E_X - E_R &= E_P - E_{EV} \\ E_P &= E_{EV} - E_R - E_X + E_{IG} \end{aligned}$$

$$COP_H = \frac{E_P}{E_I} = \frac{E_P}{E_{IG} + E_{IE2}}$$

b)

**Figure 4: The energy income and expenditure equation for GHP**  
a) artificial air cooling b) artificial air heating.

## 2.2 The heat exchange measurement of the outdoor unit

Air that flows into the heat exchanger of the outside unit passes over fins after which it is blown out of the unit by fans. Aspects of air that pass over the fins commutate and the air state quantity is changed by the heat exchangers. In the probe insertion method, the authors calculate the heat exchanger efficiency by measuring the difference between the air of the outside heat exchangers and the air of the inside heat exchangers. Figure 5 shows the measurement of heat exchange of an outdoor unit.

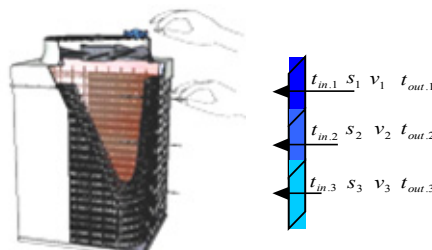


Figure 5: Measurement of heat exchange of an outdoor unit

### Equations

$$q_{all} = \sum_{n=1}^n \alpha_n \times V_{FAN,1} \times S_n \times \rho \times C_P \times (t_{in,n} - t_{out,n})$$

### Names and unit

$E_I$  is the dissipation power,  $E_{IE1}$  is the dissipation power for inside the unit,  $E_{IE2}$  is the dissipation power for inside the unit,  $E_T$  is the motive energy for the compressor,  $\alpha$  is the inverter efficiency,  $E_F$  is the dissipation power for the fan,  $E_{EV}$  is the heat quantity of the evaporator,  $E_{CD}$  is the heat quantity of the condenser,  $E_P$  is the heat exchanger efficiency,  $E_R$  is the heat quantity of the radiator,  $E_X$  is the exhaust heat quantity,  $COP_C$  is the coefficient of the performance in air cooling,  $COP_H$  is the coefficient of the performance in air heating,  $V_{fan}$  is the wind velocity from the fan,  $S_n$  is the delegating area of the heat exchanger,  $p$  is the air density,  $C_p$  is the constant pressure specific heat,  $t_{out,n}$  is the air temperature of the inside heat exchangers,  $t_{in,n}$  is the air temperature of the outside heat exchangers,  $\alpha_n$  is the wind velocity ratio.

## 3 OUTLINE OF ACTUAL MEASUREMENTS

The authors conducted a long-term on-site performance evaluation of VRF systems at nine sites nationwide, from 2007 through 2010, using the probe insertion method. Table 1 shows a summary of the survey.

Table 1: A summary of the survey

	Location	Use Building	Floorage (m <sup>2</sup> )	Candidate	term
Tokyo(K)	Warm	Office	385	GHP 30hp×1	07.7.11 ~ 08.2.13
Tokyo(U)	Warm	School cafeteria	205	EHP 18hp×1	09.7.14 ~ 10.12.22
Tokyo(Y1)	Warm	Office	65	EHP 5hp×1	09.1.14 ~ 09.10.1
Tokyo(Y2)	Warm	Office	65	EHP 5hp×1	09.1.14 ~ 09.10.1
Tokyo(Y3)	Warm	Office	65	EHP 5hp×1	09.1.14 ~ 09.10.1
Osaka(O)	Warm	Office	226	GHP 20hp×1	07.8.23 ~ 08.1.7
Kochi(Y)	Warm	Government office	280	EHP 20hp×1	09.7.2 ~ 09.4.5
Hokkaido(A)	Cold	Office	373	GHP 30hp×1	08.7.9 ~ 09.3.31
Hokkaido(K)	Cold	Office	342	GHP 20hp×1	09.7.2 ~ 10.7.13
Hokkaido(Y)	Cold	Office	211	GHP 16hp×1	08.7.10 ~ 09.2.4
Hokkaido(T)	Cold	Office	714	EHP 12hp×4	09.7.9 ~ 10.7.14

## 4 RESULT

Figure 6 shows the relationship between the cooling capacity of the outdoor unit and the floorage of the building being investigated. The larger the cooling capacity of the outdoor unit, the greater the floorage is. The rated cooling capacity per unit area is approximately  $200\text{W/m}^2$ .

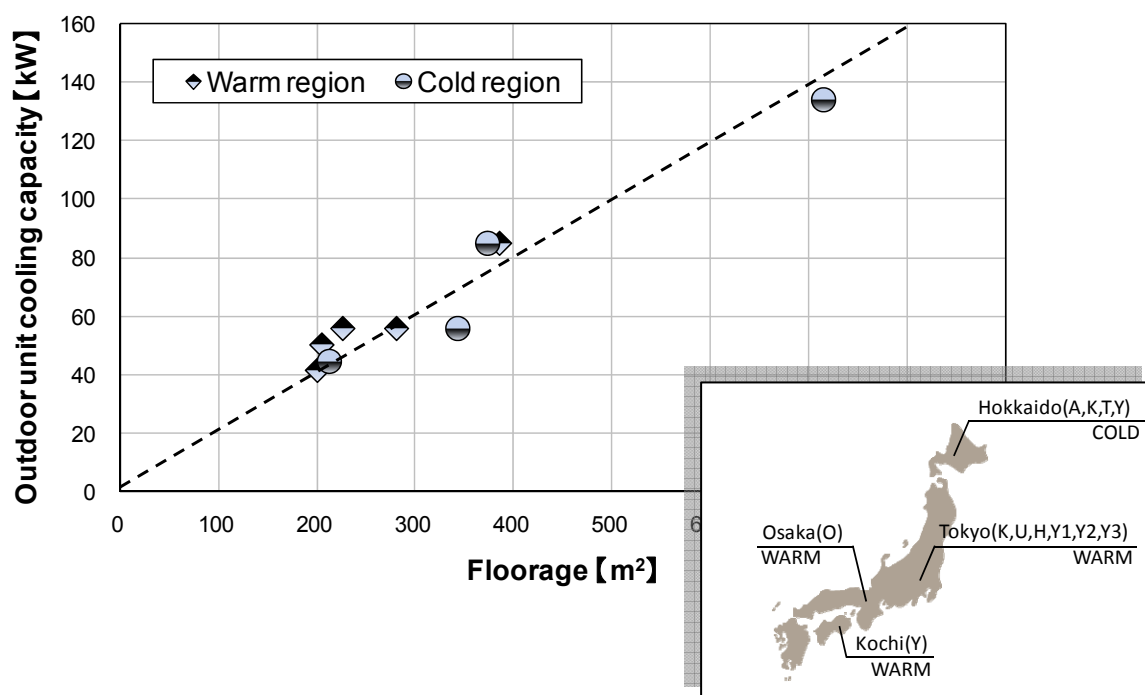


Figure 6: Rated cooling capacity per unit area

Figure 7 shows the frequency of a loading factor of 25 percent or less at each site surveyed. 70 percent of the cooling period (Tokyo(Y2), Tokyo(Y3) and Hokkaido (T)) and heating period (Tokyo(K), Tokyo(Y3) and Osaka(O)) was operated at a load factor of 25 percent or less. In addition, in warm regions, the operation form varies greatly from place to place. However, in cold regions, air heating is in great demand. A great deal of the survey was carried out on VRF systems in operation in a low loading factor.

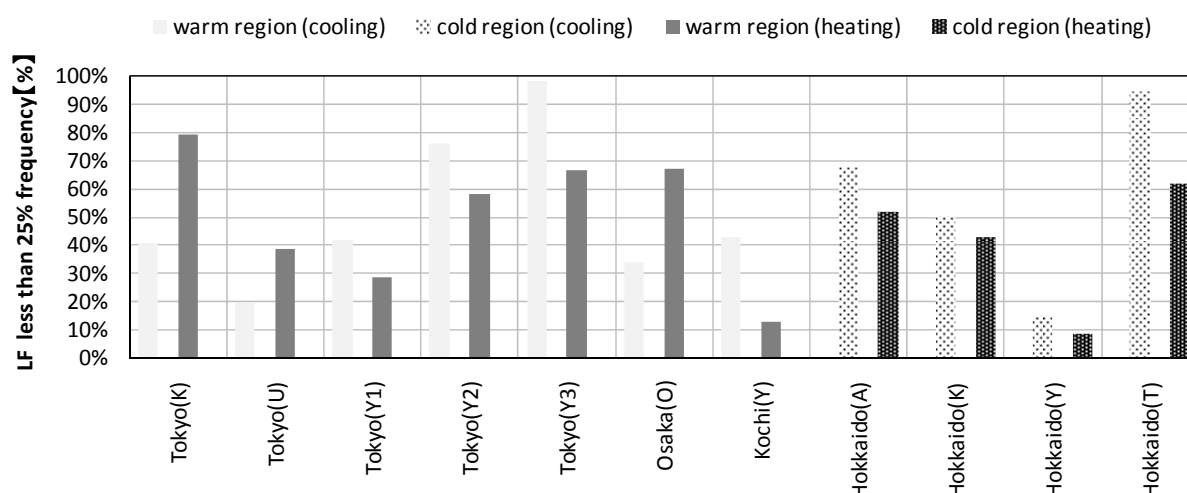


Figure 7: Frequency of loading factor 25% or less

Figure 8 shows the relationship between the COP and the loading factor in the cooling period. The load factor is a value in which the heat production quantity is divided by the rated ability. The COP decreases along with the decrease in the load factor. If there is a high-frequency low loading factor, the COP of a cold region is lower than that of those in warm regions.

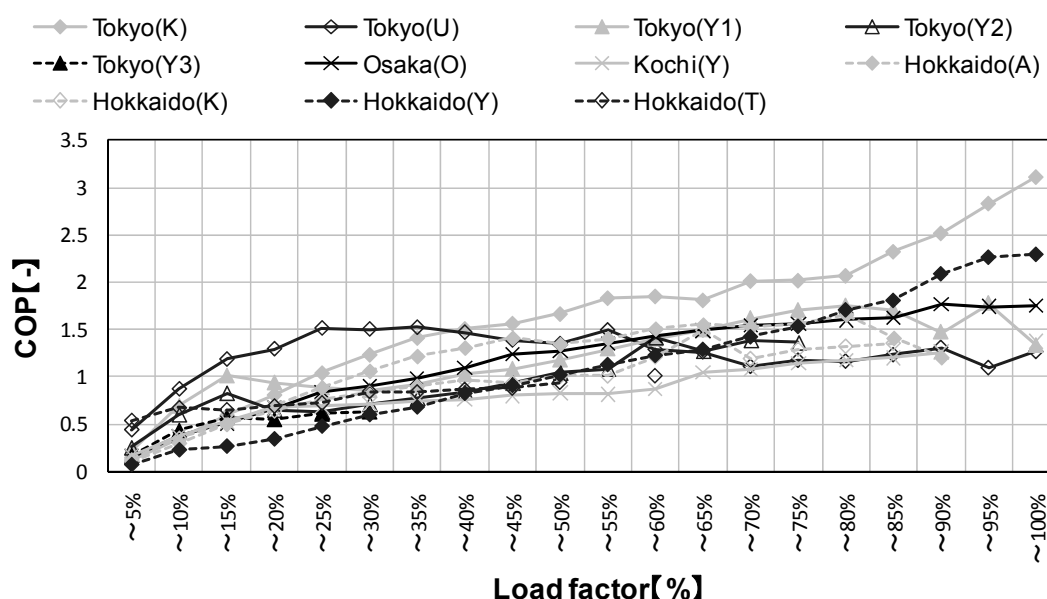


Figure 8: Relationship between the COP and the loading factor in cooling period

Figure 9 shows the relationship between the COP and the loading factor in a heating period. In a cold region, the COP of Hokkaido(A), Hokkaido(K) and Hokkaido(Y) is higher than that of Hokkaido(T). That means that GHP is more appropriate than EHP in colder regions. In addition, in warm regions, the maximum loading factor is 70 percent. So air heating is in high demand in cold regions. As for the cooling period, the COP decreases along with a decrease in the load factor.

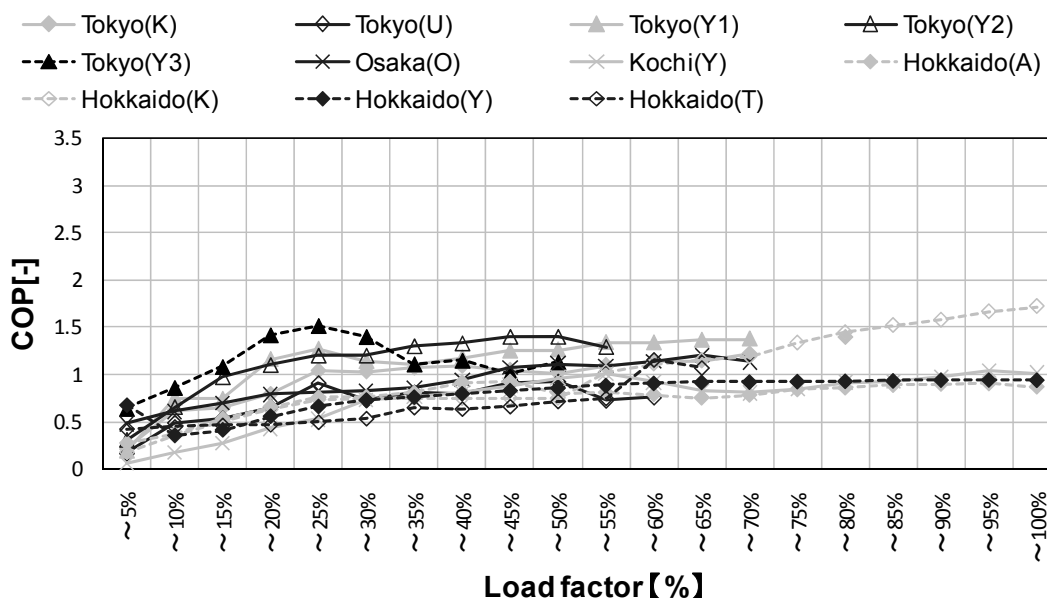


Figure 9: Relationship between COP and the loading factor in the period of heating

Figure 10 shows the relationship between the loading factor and the outdoor temperature in warm and cold regions. Figure 11 shows the relationship between the COP and the outdoor temperature in warm and cold regions. The higher the outdoor temperature in the cooling

period, the higher the load factor. On the other hand, the load factor is lower when the temperature is lower. This means there is strong correlation. Meanwhile, there is a weak correlation between the COP and the outdoor temperature. This is especially true in the heating period in cold regions, where there is no correlation.

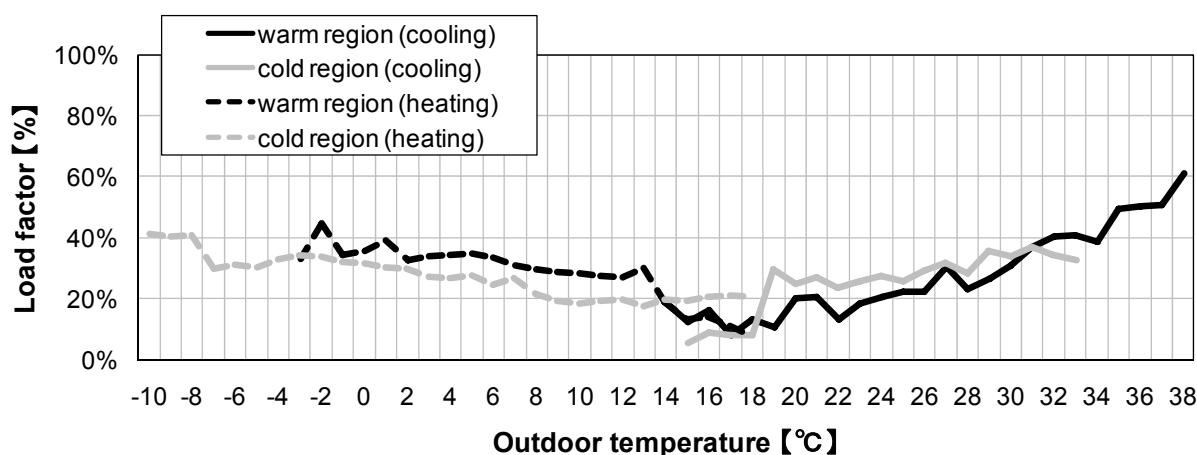


Figure 10: Load factor according to the outdoor temperature

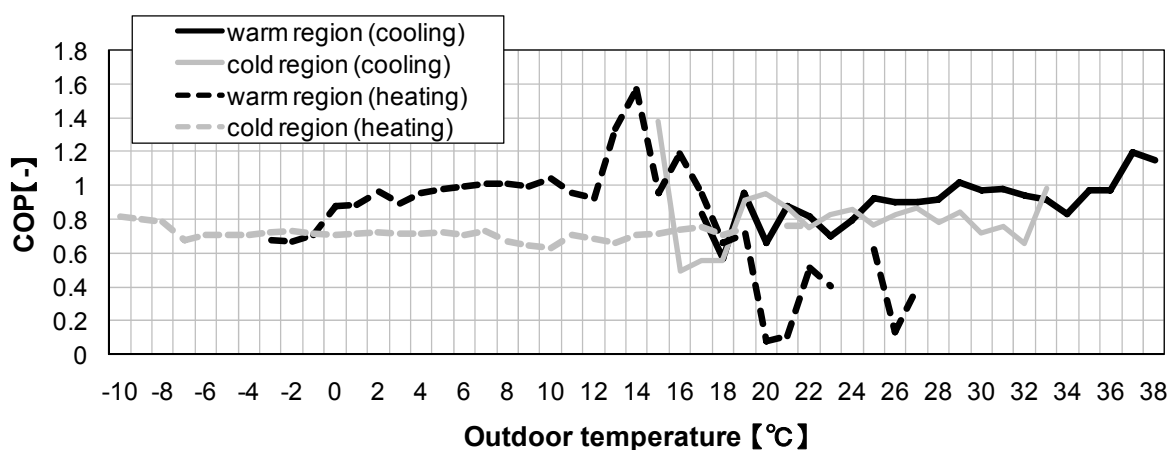


Figure 11: COP according to the outdoor temperature

## 5 CONCLUSIONS AND DISCUSSION

This study describes a probe insertion method for the on-site evaluation of VRF systems and demonstrates the usefulness of actual measurements. According to the on-site evaluation, the authors found that there are some certain characteristics. The authors have found a strong association between the loading factor and the COP. Most of the actual operation was at a low load factor and a low COP. It is very difficult to achieve a high-performance VRF system. These results may make important feedback to architects and manufacturers who make these VRF systems. Furthermore, expansion to the VRF measurement example is very important.

## 6 REFERENCES

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