Conversion Factors for Comparing the Performance of Variable Refrigerant Flow Systems

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ABSTRACT

Due to the growing concern about energy savings in recent years the Japan Industrial Standards (JIS) committee revised the performance rating of industrial air conditioning systems in October, 2006. The coefficient of performance (COP), the conventional factor, does not consider the actual operation of air conditioning systems corresponding to seasonal temperature changes. Instead it is evaluated under constant temperature conditions. In actual operation, the capacity and power consumption of cooling and heating varies according to outside air temperatures. As a result, the annual performance factor (APF) was adopted as the new criteria to evaluate energy savings performance. Under this method, model cases were designed in order to conduct proper evaluations that are approximately equal to real operation. Factors were estimated by calculations of annual total energy consumption and building thermal load. As the efficiency characteristics of the APF and COP are respectively indicated, calculation of conversion factors became necessary in order to compare their energy saving capabilities. In this study, the energy consumption and its characteristics of the APF and COP machines were calculated using the annual operating data of electric driven heat pumps (EHP) under equivalent load conditions. Effective efficiency was defined as a parameter to estimate conversion factors as follows:

Effective efficiency = Annual effective generated heat / Annual energy consumption

Using these conversion factors, the performance of machines can be easily compared when evaluation standards change and new air conditioning systems are installed. Furthermore, this approach can also be applied to gas engine driven heat pumps (GHP).

1. INTRODUCTION

Energy consumption of the building sector exceeds 30% of the total consumption and CO_2 emissions reached 88 hundred million tons in 2010 according to the IPCC Fifth Assessment Report. Specifically, the ratio of air-conditioning energy consumption in office buildings approached 40% and its reduction potential is quite considerable. The JIS committee revised the performance rating of industrial air conditioning systems in October, 2006. The COP, the conventional factor, does not consider the actual operation of air conditioning systems corresponding to seasonal temperature changes. Instead it is evaluated under stable temperature conditions. The capacity and power consumption of cooling and heating varies according to outside air temperatures in real operation. As a result, the APF was accepted as the new criteria to evaluate energy savings performance. Under this method, model cases in the Tokyo area were designed in order to conduct proper evaluations that are approximately equal to actual operating conditions. Furthermore, intermediate cooling and heating capacities were added as an evaluation point and factors were calculated by annual total energy consumption and building thermal load. Although the production of the APF machines began in 2006, the COP machines still exist in Japan. The APF values are slightly higher than the COP values. The APF is in the range of 4 to 6 and the COP is in the range of 2 to 3 for most air conditioners. As the efficiency characteristics of the APF and COP are respectively indicated, calculation of conversion factors became necessary in order to compare their energy saving capabilities.

In this study, we plotted energy efficiency characteristic diagrams using load factor and coefficient of performance as parameters in both APF and COP machines. The comparison was conducted using the annual operating data of EHP under equivalent load conditions. Building thermal load was calculated by determining a building model and air-conditioning energy was estimated by simulations. Ultimately, effective efficiency values and conversion factors were derived. These conversion factors would play a significant role in promoting energy savings as the performance of the machines can be easily compared when evaluation standards of air conditioners change and air conditioning systems are renewed.

2. METHODOLOGY

2.1 Procedure

The following actual measurement data and analytical method were used in this study:

1) Some building model was defined and hourly building thermal load was calculated using HASP, Heating, Air-conditioning, and Sanitary engineering Program.
2) Energy efficiency characteristic diagrams were plotted using load factor and coefficient of performance as parameters which were obtained by remote monitoring data.
3) Simulations were run by the hourly building thermal load and the efficiency characteristic diagrams to estimate air-conditioning energy consumption using an energy consumption calculation program.
4) Effective efficiency values were estimated by annual effective generated heat and the simulation results and conversion factors were derived from the effective efficiency values and rated COP/APF values.

Calculation flow is shown in Figure 1.

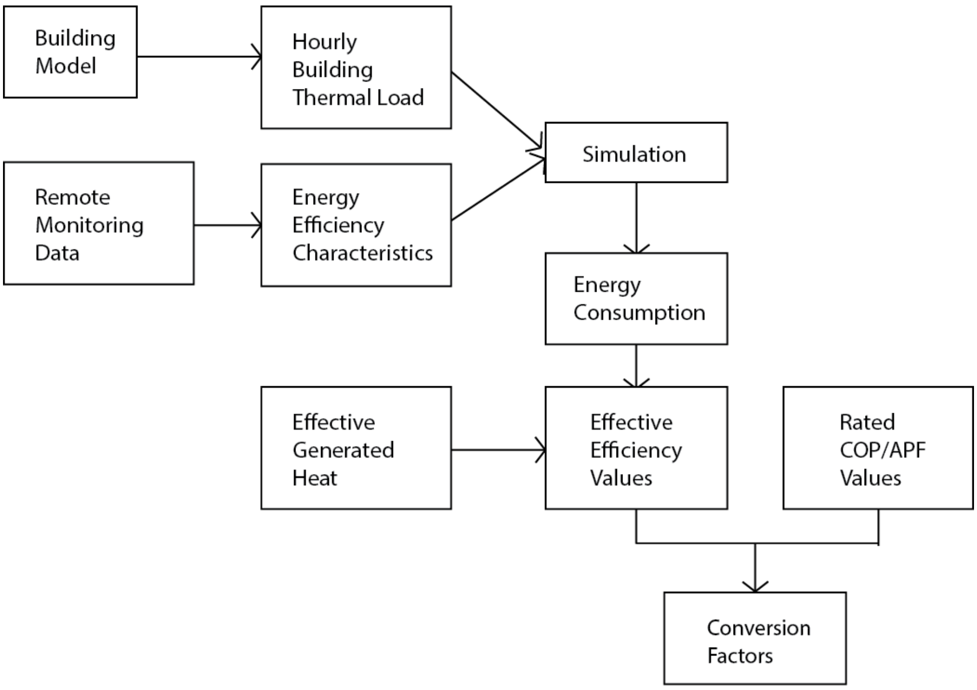

Figure 1: Floor plan (1st)

2.2 Definition of Terms

The COP machine evaluates one performance point when air conditioning systems are operated under constant temperature conditions. This machine is evaluated from the rated cooling, rated heating and low temperature heating capacities. The APF machine indicates the efficiency which is close to the actual condition when the building usage and duration of use are set. Intermediate cooling and heating capacities are added to the evaluation. Conversion factors were used for accessing energy performance of VRF systems in both cooling and heating operations. The conversion factors indicate the effective efficiency ratio of rated and actual operations. Terms for performance evaluation of air conditioners are defined as follows:

1) COP = Rated capacity (kW) / Rated power consumption (kW)
2) APF = Annual total capacity of cooling and heating periods (kWh) / Annual total consumption of cooling and heating periods (kWh)
3) Conversion factor = Effective efficiency / Rated average COP or APF values
4) Effective efficiency = Annual effective generated heat / Annual energy consumption
5) Cooling load factor = Total cooling capacity / Rated cooling capacity
6) Heating load factor = Total heating capacity / Rated heating capacity
7) Operating time of outdoor unit = Compressor running time

2.3 Simulation Model

The HASP is utilized in this study, which has been a major simulation program in Japan. It performs not only the calculation of room temperature, humidity but also building thermal load. Energy consumption is estimated by conducting hourly operating simulations with an energy consumption calculation program using the building thermal load, equipment configurations and specifications, control methods and operation schedules. Floor plans of an office building with a total floor space of 5000m^2 are shown in Figure 2 and 3. Monthly thermal load is shown in Figure 4 and a histogram of load factor is shown in Figure 5. Installed capacity is set to 120% in regard to the maximum cooling load. According to Figure 4, cooling operation is applied from May to October and heating operation is applied from November to April. Figure 5 indicates that it performs low load operation around from 10% to 40% in cooling and lower load operation of less than 20% in heating. Annual cooling load is 362 MJ/m^2 and heating load is 84 MJ/m^2. We applied meteorological data in the Tokyo area which represents the typical weather conditions in Japan.

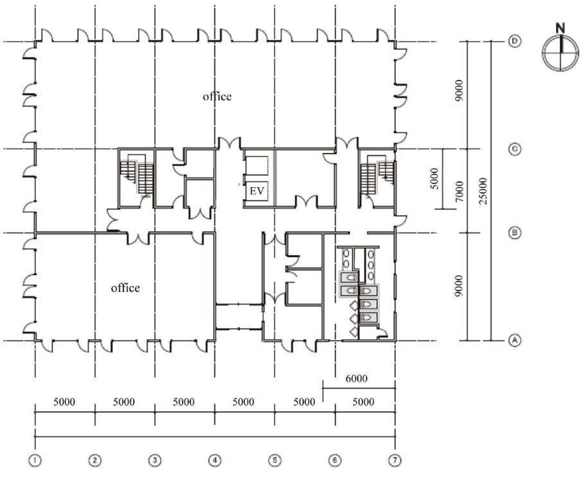

Figure 2: Floor plan (1st)

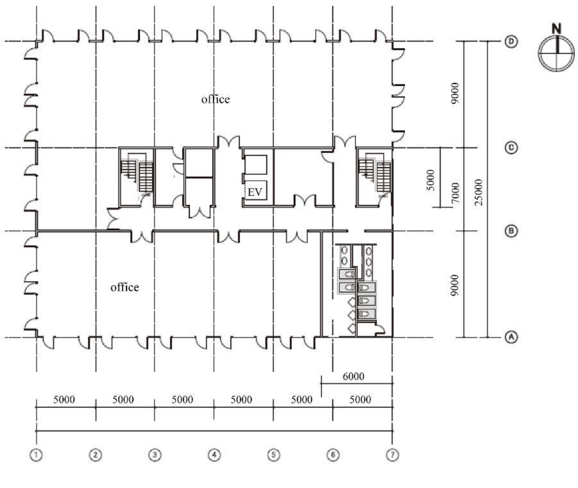

Figure 3: Floor plan (2nd-6th)

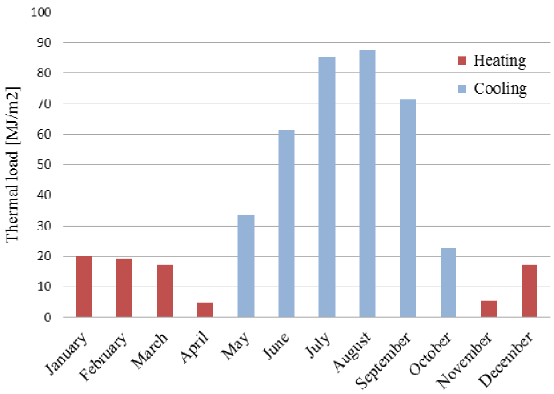

Figure 4: Monthly thermal load

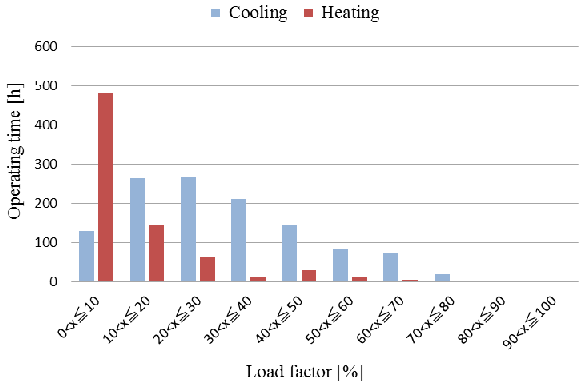

Figure 5: Histogram of load factor

2.4 Overview of Analysis

Operating data of VRF systems by a remote monitoring system was employed in this study. The system used state of the art advancements in data processing and communication technology to monitor the air conditioning systems. Actual operating data of VRF systems across the country was sent to the headquarters once every other hour via the Internet. We analyzed the collected data and estimated effective generated heat and energy consumption.

We selected 16 locations for office usage data in the east and west regions of Japan for the COP machines. The collection period was from January 1st to December 31st in 2007. For the APF machines, we selected 27 locations for office usage data in the east, west and middle regions. The collection period was from January 1st to December 31st in 2012. We utilized air conditioners where the capacities were mainly 56kW in both machines. Using the acquired data from the system we calculated values as follows:

1) Total energy consumption data
2) Outdoor unit energy consumption data
3) Indoor unit effective generated heat
4) Refrigerant mass flow of a compressor per unit time
5) Indoor suction temperature
6) Preset temperature
7) Refrigerant physical quantity
8) On-off time of defrost
9) On-off time of thermostat
10) Standby power

3. RESULTS

3.1 Comparison Results of APF and COP Machines

Energy efficiency characteristic diagrams of both cooling and heating operations are shown in Figure 6 and 7. The diagrams were plotted using load factor and coefficient of performance which were obtained by the actual measurements under equivalent load conditions. Average coefficient of performance of the COP machine was 2.9 and the APF machine was 3.6 for the cooling operation and the former was 3.2 and the latter was 3.4 respectively for the heating operation. From the results, we acquired a linear approximation equation and a maximum efficiency point at 100% load for the COP machine while we obtained a secondary approximation equation and a maximum efficiency point in the range of 40% to 50% load for the APF machine.

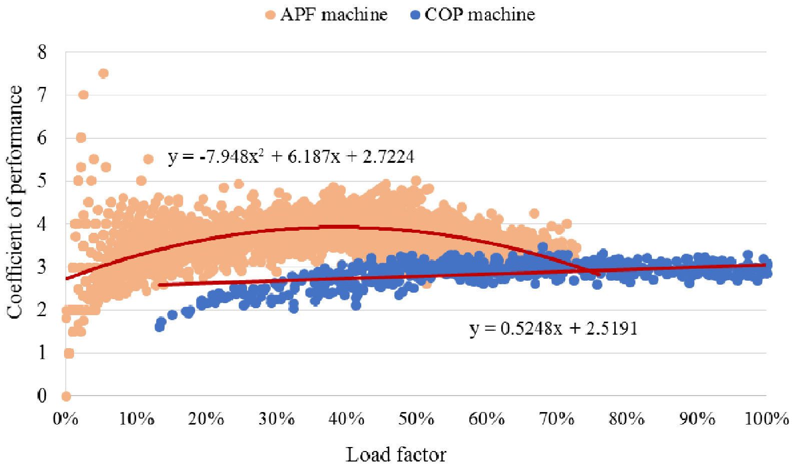

Figure 6: Comparison of the COP and APF machines in cooling operation

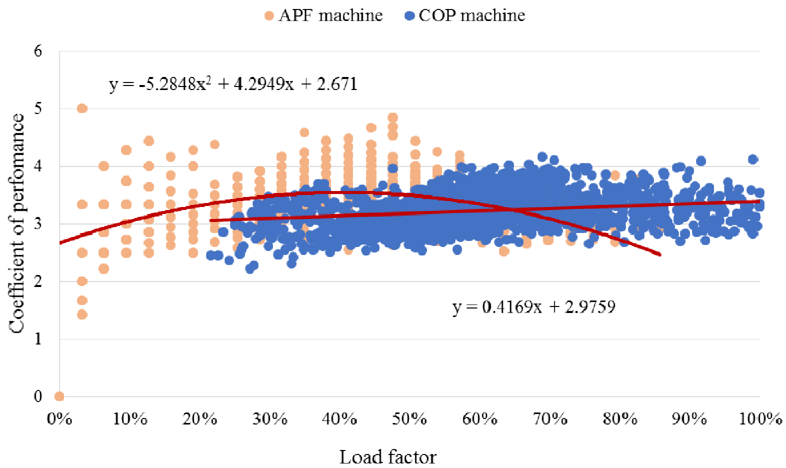

Figure 7: Comparison of the COP and APF machines in heating operation

3.2 Simulation Results

Simulations were run by an energy consumption calculation program using the data of the hourly building thermal load and the efficiency characteristic diagrams. Air conditioning energy consumption was then estimated. Simulation results of monthly air-conditioning energy consumption are shown in Figure 7, 8 and Table 1. According to Figure 8 and 9, high energy consumption is observed from June to September in both COP and APF machines although the APF machine has much less energy consumption overall. Annual energy consumption is 702.6 MJ/m^2 in the COP machine and 447.6 MJ/m^2 in the APF machine, and the former consumes approximately 1.6 times more energy than the latter. As the load factor in regard to actual load mainly appears in the range of 20% to 30%, the APF machine exhibits efficiency improvement in the low load area and has an advantage in contributing to energy savings.

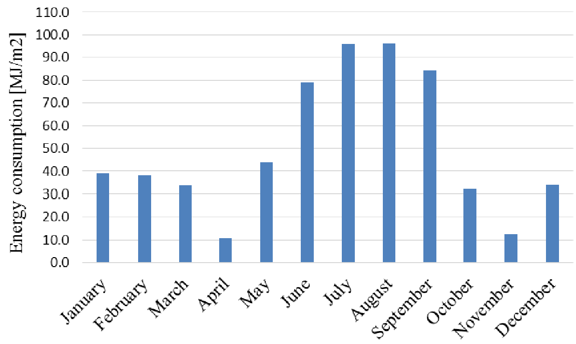

Figure 8: Energy consumption of COP machine

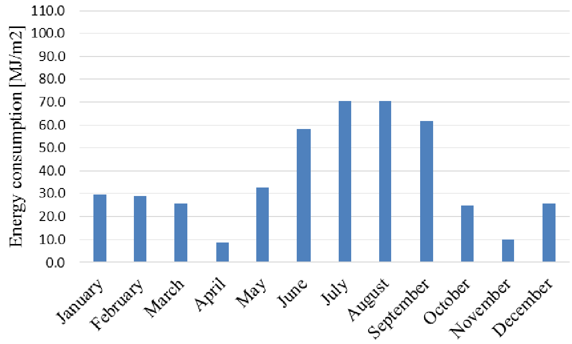

Figure 9: Energy consumption of APF machine

Table 1: Monthly air-conditioning energy consumption

Month	COP machine (MJ/m^2)	APF machine (MJ/m^2)
January	45.6	29.4
February	42.9	29.0
March	39.8	25.8
April	15.9	8.9
May	48.9	32.8
June	87.9	58.4
July	106.9	70.2
August	115.2	70.4
September	92.4	62.0
October	40.9	24.5
November	19.3	10.4
December	46.9	25.8
Total	702.6	447.6

Calculation results of conversion factors are shown in Table 2. We selected air conditioners where the capacities were mainly 56kW as catalog values for both machines. The catalog value of the COP machine was 3.17 and the catalog value of the APF machine was 3.71. Effective efficiency values were estimated by dividing annual effective generated heat by annual energy consumption obtained from the simulations and the conversion factors were then calculated by the effective efficiency values and rated COP or APF values.. As a result, we obtained a factor of 0.22 for the COP machine and a factor of 0.29 for the APF machine.

Table 2: Conversion factors

Values	COP machine	APF machine
Catalog value	3.17	3.71
Effective efficiency value	0.69	1.08
Conversion factor	0.22	0.29

4. CONCLUSIONS

The energy efficiency characteristic diagrams of the APF and COP machines were plotted and compared using the annual operating data of EHP under equivalent load conditions. Hourly building thermal load was calculated by determining a building model, and air-conditioning energy was estimated from the simulations. Accordingly, we estimated effective efficiency values and conversion factors to compare the performance of the machines. Two major conclusions are as follows:

- The performance of the COP and APF machines were different when comparing the energy efficiency characteristic diagrams obtained by load factor and coefficient of performance.
- According to the conversion factors obtained from the simulations, the efficiency of the COP machine was 0.22 and the efficiency of the APF machine was 0.29.

We obtained the conversion factors which enabled us to compare the performance of the COP and APF machines. Using the conversion factors for COP and APF machines, the performance of the machines can be easily compared for when evaluation standards of air conditioners change and new air conditioning systems are installed. These conversion factors can play an important role in promoting energy savings in the future. Moreover, this approach can also be applied to GHP which has been expanding in market share.

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