Study on Running Performance of a Split-type Air Conditioning System Installed in the National University Campus in Japan

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Abstract
Split-type air conditioning systems, or heat pump systems with multiple indoor and outdoor units, are becoming very popular for room cooling and heating of small or middle-sized non-residential buildings in Japan. However, their running performance is yet to become known due to the difficulty of measuring the actual amount of heat transferred by the system. Mixed irregular flow of vapor and liquid refrigerant prevents building engineers from obtaining accurate heat flow data between indoor and outdoor units. This study introduces an alternative method to calculate heat transferred by the system from air volume and enthalpy measured with simple sensors attached to the indoor units. Experimental results on a national university campus in suburban Tokyo showed unexpectedly low COP values both in summer and winter mainly due to the prevailing low partial load factors under 20-30% of the system capacity.

Keywords: split-type package air conditioners; COP; measurement; load; energy conservation

1. Introduction
The recent rise in environmental problems and deteriorating state of the Earth combined with approaching deadlines for public commitments to reduce CO₂ emissions, and increasing energy consumption has emphasized the importance of developing and promoting methods for conservation and efficient use of energy.

In this situation, recently, split-type package air conditioners (PACs for short) have rapidly gained popularity from the aspect of cost saving and convenience and are now installed even in buildings with several tens of thousand square meters of floor area in major Japanese cities. From the aspect of energy efficiency however, it is suspected that their high COP rating based on the Japanese Industrial standard does not represent actual values in practice. It is also suggested that PACs may be a primary cause of urban heat islands, because unlike centralized air-conditioning systems equipped with cooling towers discharging latent heat, PACs exclusively discharge sensible heat into surrounding urban environs, directly increasing local air temperature. PAC efficiency therefore is also a primary interest from the aspect of urban environment. In order to obtain some knowledge regarding these pending questions, this research has tried to measure energy efficiency of a typical PAC under actual operating conditions. The results will help design more efficient PAC applications.

2. Methods
A multiple type package air conditioning unit installed on a national university campus in a western suburb of Tokyo was chosen to conduct the experiment. A multi point measurement method was applied to examine PAC efficiency in daily operation. Summer measurement was conducted with an indoor setting temperature of 27°C, and winter measurement with a temperature of 24°C, 22°C and 20°C (24°C: February 14-16; 22°C: February 17-19; 20°C: February 20-22). During measurement, airflow was set at "strong" mode while wind direction was set to the "no swing with middle low angle" blowout position. Weather information of the measurement periods is provided in Tables 1. and 2.

3. Measurement Contents
(1) Indoor thermal environment
In order to measure indoor temperature distribution, 15 representing points were designated each with three vertical measurements making up 45 altogether as
(2) Thermal flow at Indoor units

Dry-bulb and wet-bulb temperature of the inlet and outlet airflow were measured at all seven indoor units using thermocouples and data loggers (Fig.2.), while air velocity was measured with the traverse developed for this study. Heat exchange quantity was then calculated by multiplying inlet and outlet temperature difference and air volume calculated by the air velocity distribution (described later). In addition, outdoor temperature, humidity, solar radiation, wind direction, wind velocity, atmospheric pressure and precipitation were measured with a Davis Weather Station.

(3) Electricity consumption by outdoor and indoor units

Electricity consumption of seven indoor units, four outdoor units and the respective control systems were measured every minute by attaching clamp watt meters to the power line.

Tables 4. and 5. indicate specifications of the measured PAC. The rated COP on the specification is 2.64 for cooling and 2.90 for heating.

Table 1. Weather Information of Summer Measurement Period at the Yokohama Weather Station
(Friday, August 26 through Sunday, September 5, 2005)

| 26. Aug | 27. Aug | 28. Aug | 29. Aug | 30. Aug | 31. Aug | 1. Sept | 2. Sept | 3. Sept | 4. Sept | 5. Sept |
|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Maximum temperature (°C) | 33.1 | 31.5 | 28.2 | 30.2 | 30.1 | 27.4 | 30.9 | 31.6 | 31.2 | 31.7 | 25.6 |
| Minimum temperature (°C) | 23.8 | 25.2 | 22.9 | 22.5 | 22.6 | 22.9 | 22.5 | 23.4 | 23.8 | 23.8 | 21.9 |
| Precipitation (mm) | 38.5 | -- | 0 | 0 | 0.5 | 0 | -- | -- | -- | 5 | 81.5 |

Table 2. Weather Information of Winter Measurement Period at the Yokohama Weather Station
(Tuesday, February 14 through Wednesday, February 22, 2006)

| 14. Feb | 15. Feb | 16. Feb | 17. Feb | 18. Feb | 19. Feb | 20. Feb | 21. Feb | 22. Feb |
|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Maximum temperature (°C) | 18.2 | 18.5 | 11.8 | 9 | 6.3 | 9.1 | 7.4 | 10.5 | 15.6 |
| Minimum temperature (°C) | 2.2 | 9.6 | 6 | 2.8 | 0.6 | 3.8 | 3.5 | 3.9 | 6.7 |
| Precipitation (mm) | -- | 0 | 10 | 0.5 | 0 | -- | 22 | -- | -- |

4. Results

(1) Airflow calculation

Airflow volume was calculated by airflow distribution model (Fig.3.) based on a three dimensional velocity distribution measured by the traverse unit equipped with measuring devices developed by professor Shigeki Kametani of Tokyo University of Marine Science.

Wind inlet and outlet velocity distribution measured by the traverse were expressed with an approximate curved line which gives a wind velocity ratio at a random point to the central point. Using the curve,
the mean wind velocity of each measured point and its relevant area were calculated and applied to the thermal flow calculation. A sum of the calculated airflow volume was adjusted to match the rated volume for "strong wind" mode.

(2) Result of summer measurement

Outside air temperature, humidity and electricity consumption of indoor and outdoor units throughout summer measurement are shown in Figs.5. and 6. Room temperature is shown in Fig.7. for reference.

The change of COP during operating time (10am-9pm) in summer measurement is shown in Fig.8. Measured COP was considerably lower than nominal COP (=2.64).
COP was calculated by the following formula.

\[
COP = \frac{\text{Heat exchange quantity}}{\text{Electric power consumption of in-outdoor equipment}} \quad (1)
\]

\[
= \frac{715.806 \text{ [kWh]}}{411.382 \text{ [kWh]}} = 1.74 \quad (10\text{am}-9\text{pm, August 26-September 5, 2005})
\]

Figs. 5, 6, 7, 8, 9, and 10 show load factor distributions. Most of the load is concentrated within 30% of PAC capacity.

(3) Result of winter measurement

Outside air temperature, humidity and electricity consumption of indoor and outdoor units throughout winter measurement are shown in Figs. 11 and 12.

Room temperature is shown in Fig.13 for reference.

The change of COP during operating time (10am-9pm) in winter measurement calculated by formula (1) is shown in Fig.14. Measured COP was quite lower than nominal COP (=2.90).

\[
\text{COP} = \frac{92.700 \text{ [kWh]}}{153.898 \text{ [kWh]}} = 0.60 \quad (10\text{am-9pm, February 14 - 22, 2006})
\]
Load factor distribution during winter measurement is shown in Figs. 15. and 16. Most of the load is concentrated under 20% of PAC capacity. Load factor was lower in winter because relatively high outdoor air temperatures occurred during measurement and the inevitable problem of excess heating capacity for a PAC designed to meet maximum summer peak load was also a factor.

5. Discussion

In this study PAC energy efficiency under actual operating conditions was measured using a multi point measurement method. The results revealed considerably low COP for cooling and very low COP for heating in comparison with the nominal values. It also became clear that the PAC capacity far exceeded the actual load, causing the unit to operate under an extremely low load factor and preventing optimal efficiency. In addition, if global warming worsens, imbalances between summer and winter loads will increase, creating even lower partial loads for heating. To solve these problems, accurate load calculations with reliable software is required. Also, a technological breakthrough to integrate PAC's heat load into a fewer number of outdoor units in order to allow operation at higher load factors is called for.

References

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