A NEW TEST AND EVALUATION METHOD OF ANNUAL ENERGY EFFICIENCY OF MULTIPLE AIR-CONDITIONERS FOR BUILDINGS

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Abstract: We made the partial load performance tests of multiple air-conditioners for buildings powered by electric motors, the rating cooling performance of which was 56 kW, by using the air-enthalpy method testing apparatus. The coefficient of performance (COP) and annual energy consumption measured by those tests were closely compared with those predicted by the current calculating method provided by Japanese Industrial Standards (JIS B 8616:2006). The performance of the air-conditioner changed depending on the outdoor air temperature and the indoor thermal load. The current calculating method could not reproduce the deteriorations of COPs that appeared under the low thermal load operating conditions in both the cooling and heating seasons. As a result it seriously underestimated the annual energy (electricity) consumption; the error amounted to about 20 % of the measured value of the annual electric energy consumption. Based on these results, we proposed new testing conditions for the performance evaluation and a calculation method of the annual electricity consumption that could improve noticeably the accuracy of the estimation of the annual electricity consumption.

Key Words: ***heat pump, coefficient of performance, partial load performance, office building, annual energy consumption***

1 INTRODUCTION

It is known that in office buildings 30% - 40% of total energy consumption is used for the air-conditioning. Therefore, the development of air-conditioners with higher performance and lower energy consumption is crucial for the energy saving in buildings. Since the performance of the air-conditioners has been evaluated based on the coefficient of performance (COP) in rating operating conditions, air-conditioners with high COPs under the rating conditions have been developed to date. In actual operations of air-conditioners through a year, however, they are mostly operated under the indoor thermal load lower than their rating capacities; this situation is called partial thermal load operation. Therefore, in order to pursue the further energy saving of air-conditioners, it is indispensable to evaluate accurately their performance in the partial thermal load operations as well as that in the rating operations. Against the background of this point, in Japan, the calculation method of the annual energy consumption that took into account the performance in the partial thermal load operation was provided by Japanese Industrial Standards (JIS) in 2006 for electric-motor driven heat pumps (EHP) with a rating cooling capacity smaller than 28 kW (JIS B 8616:2006; this is called JIS B 8616 hereafter in this paper).

In order to evaluate and predict the annual energy consumption of an air-conditioner accurately, one has to fully understand its detailed performance in the partial thermal load operations (Watanabe 2004). Generally, however, the estimation of the energy efficiency of air-conditioners operated under this condition is very difficult because it changes depending on the indoor thermal load and the outdoor air temperature in quite a complex manner (Nagamatsu et al. 2004, Watanabe 2007). In particular, the multiple air-conditioners for buildings with a rating cooling capacity larger than 28 kW are outside the scope of JIS B 8616, and their partial thermal load performance has not been clarified yet. Moreover, the applicability of JIS B 8616 to EHPs with larger capacities has never discussed to date.

With these points as background, we have carried out the partial thermal load performance tests of electric-motor driven multiple air-conditioners for buildings by using the air-enthalpy-method testing apparatus that can control the indoor thermal load and the outdoor air temperature independently and arbitrarily. The rating cooling and heating capacities of the tested air-conditioners are 56 kW and 63 kW, respectively. The indoor thermal load has been changed from 25 % to 100 % of the rating cooling or heating capacity. The outdoor air temperatures have been changed from 20 °C to 35 °C in cooling operation and from 2 °C to 12 °C in heating operation for each indoor thermal load ratio. Under these conditions, we have measured the performance of the air-conditioners, energy consumptions, pressures and temperatures of refrigerant, revolutions of compressors, etc., and made clear the detailed performance of the air-conditioners operated under the partial thermal load condition. Based on the results of the tests, we have evaluated the applicability of JIS B 8616 to the estimation of COPs and annual energy (electricity) consumptions for these air-conditioners with large capacity. Then, we propose new testing and evaluation methods that can improve the accuracy of the annual electricity consumption calculation for these large air-conditioners.

2 TESTING APPARATUS AND METHOD

Figure 1 shows a schematic diagram of the testing apparatus of air-conditioners. The testing apparatus consists of the outdoor test room (16.8 m (L) × 16.4 m (W) × 11.7 m (H)) and indoor test room (11.8 m (L) × 8.8 m (W) × 4.0 m (H)). In the indoor test room, four indoor units of an air-conditioner with a ceiling-mounted cassette type can be equipped. Cooling and heating thermal loads are given to air in the indoor test room by the thermal load equipment. The performance of an air-conditioner with a cooling capacity up to 56 kW and a heating capacity up to 67 kW can be measured with the air-enthalpy method. The air temperature and humidity in the outdoor test room can be controlled independently of the thermal load in the indoor test room; the former can be changed from -20 °C to 60 °C, and the latter 30 % - 90 % in RH. Thus one can evaluate the performance of the air-conditioner operated under the partial thermal load conditions at various outdoor air temperatures.

Table 1 shows the detailed specifications (nominal values listed in brochures) of the tested air-conditioners. In this study, we have tested two air-conditioners powered by electric motors (EHPs) manufactured by different companies (Machines A and B), both of which have a rating cooling capacity of 56 kW and a rating heating capacity of 63 kW. An inverter is used to control the revolutions of the compressors. Both machines have one outdoor unit and four indoor units of ceiling-mounted cassette type. It was found from the experiments that the results obtained with Machine A agreed quantitatively with those of Machine B. Therefore, in this paper, we mainly show the results obtained with Machine A.

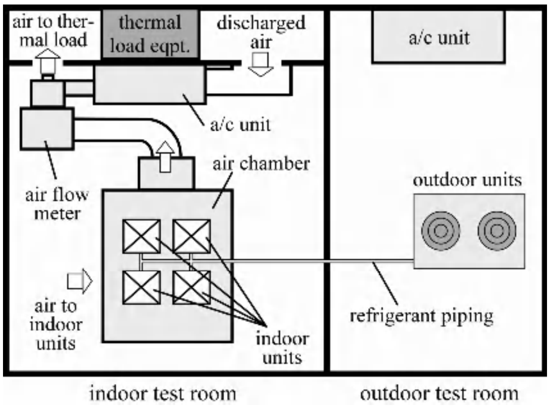


Figure 1: Schematic Diagram of Testing Apparatus

Table 1: Specifications of Tested Air-Conditioners

Type	Machine A	Machine B
Rating Cooling Capacity	56 kW	
Rating Heating Capacity	63 kW	
Refrigerant	R 410A	
Type of Indoor Unit	Ceiling-mounted Cassette	
Compressor Control	Variable Speed by Inverter or Variable Speed by Inverter + Constant Speed	

Table 2: Conditions of Rating Capacity Tests

Type of Test	Outdoor Air		Indoor Air	
	D.B.T	W.B.T.	D.B.T.	W.B.T.
Cooling	35 °C	-	27 °C	19 °C
Heating	7 °C	6 °C	20 °C	15 °C (max)

Table 3: Conditions of Partial Load Tests

Type of Test	Outdoor Air Temperature D.B.T. / W.B.T.	Thermal Load Ratio (%)
Cooling	20 °C / -	25, 50, 75, 100
	25 °C / -	25, 50, 75, 100
	30 °C / -	25, 50, 75, 100
	35 °C / -	25, 50, 75, 100
Heating	2 °C / 1 °C	25, 50, 75, 100
	7 °C / 6 °C	25, 50, 75, 100
	12 °C / 11 °C	25, 50, 75, 100

In this study, in addition to the partial thermal load performance, we measured the rating performance of these air-conditioners based on the method prescribed in JIS B 8615-1:1999 and the conditions of indoor and outdoor air temperatures are shown in Table 2. In these tests, the performance of the air-conditioner was measured keeping the revolutions of the compressors at a rating value.

The conditions of the partial thermal load performance tests are shown in Table 3. In the cooling operation test, the outdoor air temperature t_j (dry-bulb temperature) was changes from 20 °C to 35 °C at 5 °C intervals, and the indoor thermal load BL_c was changed from 25 % to 100 % of the rating cooling capacity of the tested air-conditioner for each outdoor temperature (SHF = 0.85). The temperature in the indoor test room was controlled at 27 °C

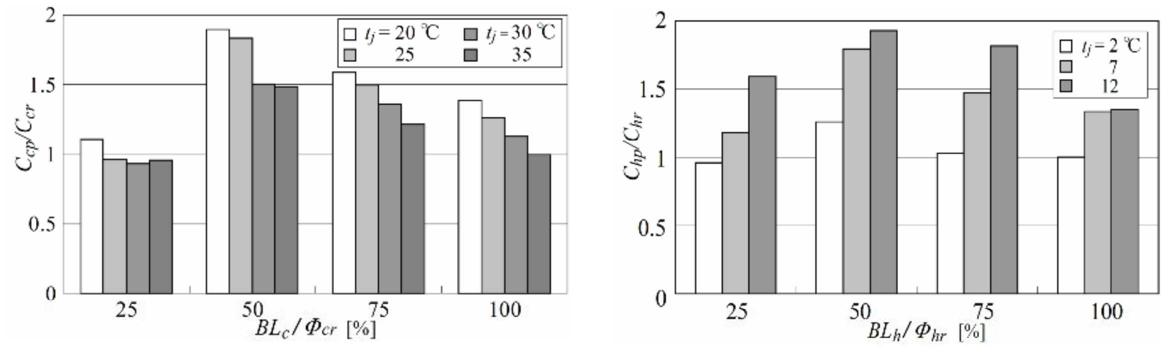
Table 4: Conditions of Performance Tests Provided in JIS B 8616:2006

Cooling Performance Tests				
Capacity	Outdoor Air		Indoor Air	
	D.B.T.	W.B.T.	D.B.T.	W.B.T.
Rating	35 °C	-	27 °C	19 °C
Half (50 %)	35 °C	-	27 °C	19 °C
Heating Performance Tests				
Capacity	Outdoor Air		Indoor Air	
	D.B.T.	W.B.T.	D.B.T.	W.B.T.
Rating	7 °C	6 °C	20 °C	15 °C (max)
Half (50 %)	7 °C	6 °C	20 °C	15 °C (max)
Standard (Low temp.)	2 °C	1 °C	20 °C	15 °C (max)

by the air-conditioner itself to simulate its actual operating situation. In the heating operation test, t_j was changed from 2 °C to 12 °C, and the indoor thermal load BL_h was changed from 25 % to 100 % of the rating heating capacity of the tested machine. The temperature in the indoor test room was controlled at 20 °C by the air-conditioner. The values of thermal loads in these partial load performance testes were determined based on the measured values of the rating cooling and heating capacities of each air-conditioner, not on the nominal rating values described in the brochure. In addition to the performance of the air-conditioners, we measured the pressures and temperatures of refrigerant, revolutions of compressors, etc., at every 10 seconds. COPs of the air-conditioners were calculated based on the data obtained under the steady-state condition. In a very low thermal load condition, however, intermittent operations of the compressors were observed (Watanabe et al. 2007). In this case, we confirmed that a periodicity appeared in the operations of the compressors and COP was calculated based on the average in one cycle. In order to examine the applicability of JIS B 8616 to the multiple air-conditioner with a large capacity, we carried out the tests provided in this regulation as well. Table 4 shows the testing conditions. The half load test is conducted keeping the revolution of the compressors at a constant value at which the air-conditioner can work with its half capacity. Thus, this test is different from the partial thermal load performance test with 50% cooling or heating thermal load, in which the air-conditioner itself controls the air temperature in the indoor test room at 27 °C or 20 °C.

3 RESULTS OF PARTIAL THERMAL LOAD PERFORMANCE TESTS

Figure 2(a) shows the results of COPs obtained in the partial thermal load performance tests for the cooling operation. The abscissa of the figures shows the thermal load ratio BL_c/Φ_{cr}, where BL_c and Φ_{cr} denote the indoor thermal load imposed on the air-conditioner by the thermal load equipment of the testing apparatus and the measured value of the rating cooling capacity of the air-conditioner, respectively. The parameter t_j is the dry-bulb temperature of outdoor air. COPs measured under the conditions in Table 2 (C_{cp}) are normalized by that obtained under the condition of t_j = 35 °C and BL_c/Φ_{cr} = 100 % (denoted as C_{cr}). In all the thermal load ratios, COP decreases as the outdoor air temperature becomes higher. This decrease of COP is caused because the pressure of the refrigerant in the condenser becomes higher to keep enough temperature difference between the refrigerant and outdoor air for heat exchange. Under the constant outdoor air temperature, on the other hand, COP increases gradually as the thermal load is decreased and attains the maximum at BL_c/Φ_{cr} = 50 %, but it decreases to the minimum at BL_c/Φ_{cr} = 25 %. This deterioration of the



(a) Cooling Operation **(b) Heating Operation**

Figure 2: Coefficients of Performance (COPs) obtained in the partial thermal load tests

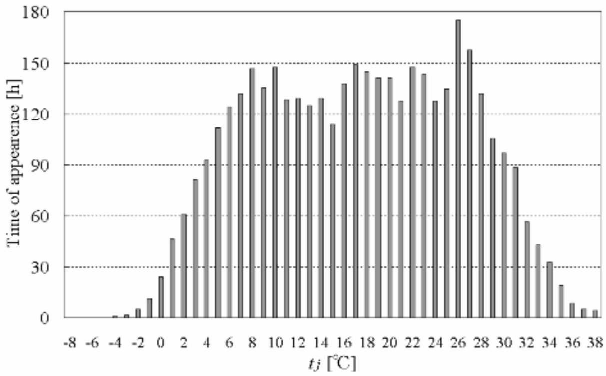


Figure 3: Time of Appearance of Outdoor Temperature

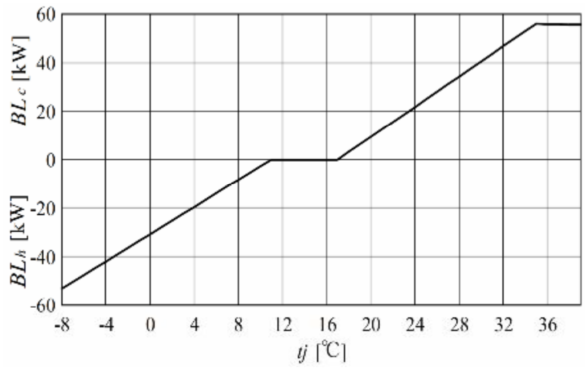


Figure 4: Indoor Thermal Load

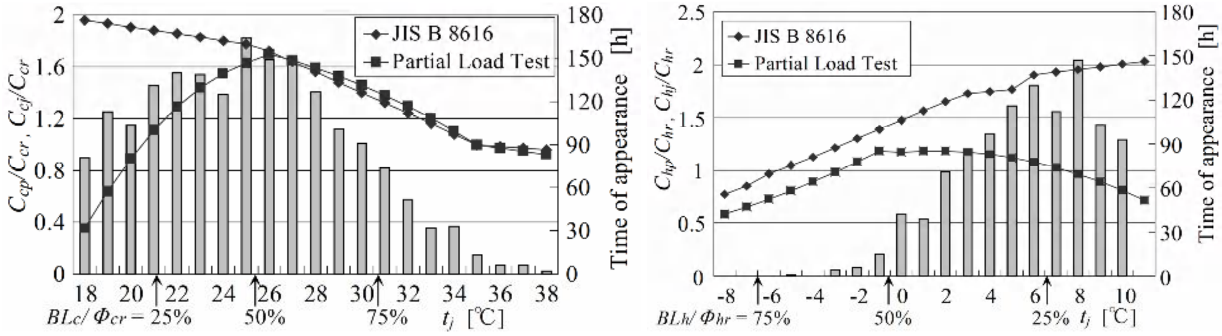
performance at the low thermal load is caused by the intermittent on-off operation of the compressors (Watanabe et al. 2007). The results of COP obtained in the heating operation tests (C_{hp}) are shown in Figure 2(b). In this figure, COP is normalized by that measured under the condition of t_j = 2 °C and BL_h/Φ_{hr} = 100 % (C_{hr}). COPs were calculated involving the electricity consumed in the defrosting operation. COP increases as the outdoor air temperature rises. Under constant t_j, similar to the results of the cooling performance test, COP increases as the thermal load is decreased and attains the maximum at BL_h/Φ_{hr} = 50 %, but it decreases to the minimum at BL_h/Φ_{hr} = 25 %. Based on these results of the partial thermal load tests, we made the empirical correlations that express COPs as functions of the outdoor air temperature and the indoor thermal load ratio, and evaluated the applicability of JIS B 8616 to the present air-conditioner with large capacity.

4 EVALUATION OF COP AND SEASONAL ENERGY CONSUMPTION

In this chapter, based on the results of the partial thermal load performance tests described above, we evaluate the applicability of JIS B 8616, which is provided for EHPs with the maximum cooling capacity of 28 kW, to the multiple air-conditioners for buildings with larger capacity. In these evaluations, one has to give the distributions of outdoor air temperatures and indoor thermal loads that can simulate the actual operating condition of the air-conditioner in a year, because both of them influence the performance of the air-conditioner. Thus, in the next section, we explain the atmospheric data (outdoor air temperature) and indoor thermal loads used in this study.

4.1 Outdoor Air Temperature and Indoor Thermal Load

As an actual outdoor temperature distribution in a year, we adopted the standard atmospheric data that are recommended by JIS B 8616, which is based on the atmospheric data in ten years released by the Meteorological Agency of Japan. It is assumed that the air-



(a) Cooling Season **(b) Heating Season**

Figure 5: Comparison of COPs Obtained by Partial Thermal Load Tests and JIS B 8616

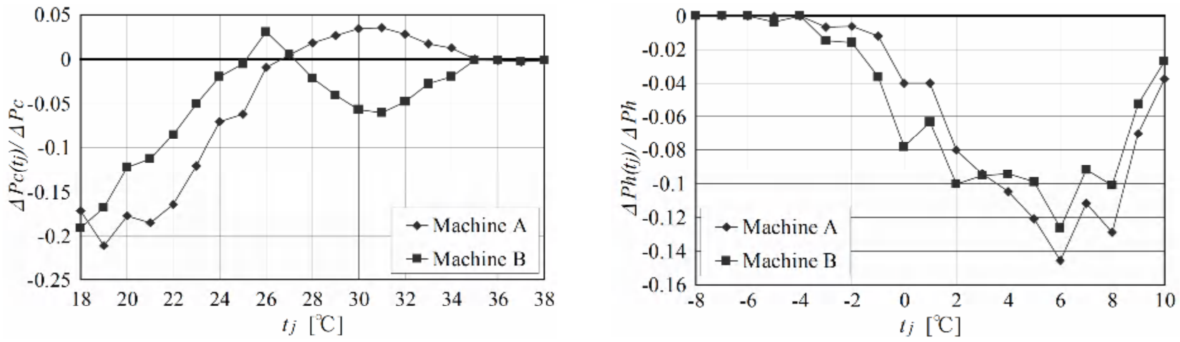
conditioner is used in an office and the city is Nagoya, which is the fourth largest city in population and located in the geometrical center of Japan. In this case, the cooling season is from April 26 to October 26 and the heating season is November 29 to March 26. The air-conditioner is operated from 8 a.m. to 9 p.m. in a day, and six days in a week. Figure 3 shows the annual frequency (hours) of appearance of outdoor temperature t_j extracted under these conditions.

The indoor thermal load is combined with the above-mentioned outdoor temperature distribution. In this study, we also adopted the thermal load model for an office provided in JIS B 8616. Figure 4 shows the variation of the thermal load against the outdoor air temperature. The cooling load BL_c is assumed to increase in proportion to the outdoor temperature; it is zero at t_j = 17 °C and is equal to the rating cooling capacity of the air-conditioner Φ_{cr} at t_j = 35 °C. The heating load BL_h is zero at t_j = 11 °C and 0.55 Φ_{cr} at t_j = 0 °C, and it changes linearly against t_j. The room temperature is assumed to be controlled at 27 °C in the cooling season and 20 °C in the heating season by the air-conditioner itself.

4.2 Evaluation of COP Predicted by JIS B 8616

From the outdoor air temperature and indoor thermal load described above, we calculated COPs of the air-conditioner based on the method provided in JIS B 8616 and compared them with those obtained from the measured results of the partial thermal load operation tests (results of Fig. 2). Figure 5(a) shows the variations of COPs in the cooling season against the outdoor air temperature t_j: C_{cp} and C_{cj} denote the COPs in the cooling operation measured in the partial thermal load performance test and calculated based on JIS B 8616, respectively. The frequency (hours) of appearance of the outdoor air temperature t_j in the cooling season prescribed in JIS B 8616 is also shown by a histogram in the figure. As described above, the indoor thermal load is assumed to increase linearly against t_j, thus it follows that COPs shown here reflect the influences of both the outdoor temperature and the indoor thermal load. The values of t_j at which BL_c/Φ_{cr} corresponds to 25 %, 50 % and 75 % are marked by arrows in the figure.

It is found that COP in the cooling season predicted by JIS B 8616 (C_{cj}) increases monotonously as the outdoor temperature (and resulting thermal load) becomes lower. On the other hand, COP measured in the partial thermal load performance test (C_{cp}) shows the maximum around t_j = 26 °C and it decreases as t_j is decreased. Therefore, it follows that COP predicted by JIS B 8616 agrees well with that measured in the partial load test in t_j > 26 °C, but the difference between them increases gradually as t_j becomes lower in t_j < 26 °C. Since the frequency of t_j appearance in the cooling season is deviated to the lower temperature side of t_j < 26 °C, it is thought that the difference of COPs in this temperature region can causes serious error in the estimation of seasonal electricity consumption by JIS B 8616.



(a) Cooling Season **(b) Heating Season**

Figure 6: Prediction Errors of Seasonal Electricity Consumption by JIS B 8616

Figure 5(b) shows the result in the heating season. Similar to the case of the cooling season, C_{hj} predicted by JIS B 8616 increases monotonously as t_j becomes higher (and corresponding heating thermal load $BL_h(t_j)$ decreases), while measured COP C_{hp} shows the maximum around t_j = 0 °C and it decreases with the temperature rise. In the cooling season, the predicted COP agrees well with the measured COP under the relatively high temperature condition of t_j > 26 °C. In the heating season shown here, however, there is a certain amount of difference between C_{hj} and C_{hp} in all t_j and JIS B 8616 overestimates COP throughout the heating season, although the prediction error becomes smaller in lower t_j. Considering that the frequency of t_j in the heating season is quite large in the region of t_j > 0 °C, the prediction error of the electricity consumption can be caused by this overestimation of COP by JIS B 8616 in the heating season.

4.3 Evaluation of Annual Electricity Consumption Predicted by JIS B 8616

As described above, COPs in the low thermal load operation are overestimated by JIS B 8616 when it is applied to the multiple air-conditioner for buildings with large capacity. In order to evaluate quantitatively the influence of the estimation errors of COPs on the annual electricity consumption predicted by JIS B 8616, we calculated the prediction error of the electricity consumption at t_j ($\Delta P_c(t_j)$ and $\Delta P_h(t_j)$) defined by the following equations.

Cooling operation:

$$\Delta P_c(t_j) = \left(\frac{1}{C_{cj}(t_j)} - \frac{1}{C_{cp}(t_j)} \right) \times BL_c(t_j) \times T_c(t_j) \tag{1}$$

Heating operation:

$$\Delta P_h(t_j) = \left(\frac{1}{C_{hj}(t_j)} - \frac{1}{C_{hp}(t_j)} \right) \times BL_h(t_j) \times T_h(t_j) \tag{2}$$

$C_c(t_j)$ and $C_h(t_j)$ are COPs corresponding to the outdoor air temperature t_j and resulting indoor thermal load $BL_c(t_j)$ (cooling operation) and $BL_h(t_j)$ (heating operation), respectively. The subscripts *j* and *p* mean the predicted value by JIS B 8616 and measured value in the partial thermal load operation test, respectively. $T_c(t_j)$ and $T_h(t_j)$ are time (hours) of appearance of the outdoor air temperature t_j in the cooling and heating seasons. Therefore, it follows that $\Delta P_c(t_j)$ and $\Delta P_h(t_j)$ denote the error included in the electricity consumption predicted by JIS B 8616 (predicted value by JIS B 8616 - measured value in the partial load test) at t_j in the cooling and heating seasons, respectively.

Figures 6(a) shows the results in the cooling season. The results obtained with Machines A and B are shown in the figure. The abscissa shows the outdoor air temperature t_j and the ordinate shows the prediction error at t_j defined in Eq. (1) normalized by the total prediction

Table 5: Errors in Electricity Consumption Predicted by JIS B 8616

Power Consumption in Cooling Season (4/26 - 10/26)	
P_{cj}/P_{cp}	0.895 (-10.5 %)
Power Consumption in Heating Season (11/29 - 3/26)	
P_{hj}/P_{hp}	0.703 (-29.7 %)
Annual Power Consumption	
P_j/P_p	0.833 (-16.7 %)

error in the cooling season ΔP_c for each air-conditioner. The negative values of $\Delta P_c(t_j)$ mean that the calculation method provided by JIS B 8616 underestimates the real electricity consumptions of air-conditioners at t_j in the cooling season. It is found that this error is relatively small in the high temperature region of t_j > 26 °C. Although the indoor thermal load and resulting electricity consumption in a unit time is large in this region, the high accuracy of COP predicted by JIS B 8616 contributes to reduce the error in the prediction of the electricity consumption. In the low temperature region, on the other hand, a remarkable increase of the prediction error of the electricity consumption appears because both the error included in COPs calculated by JIS B 8616 and the frequency of the temperature appearance become larger in this region in comparison with the high temperature region. As a result, the calculation method provided by JIS B 8616 considerably underestimates the electricity consumption in the cooling season.

Next, the results in the heating season are shown in Fig. 6(b). As expected from the results of COPs shown in Fig. 5(b), the electricity consumption is underestimated by JIS B 8616 over the whole of t_j in the heating season. The maximum prediction error is observed around t_j = 6 °C at which the frequency of the temperature appearance is the maximum. The error in the lower temperature region of t_j < 0 °C with larger heating indoor thermal load is relatively small, because the frequency of t_j appearance is quite small in this region.

The results of the prediction errors of the seasonal electricity consumptions by JIS B 8616 are summarized in Table 5. *P* denotes the electricity consumption in each season or the annual electricity consumption, and the subscripts *j* and *p* mean the predicted value by JIS B 8616 and measured value in the partial thermal load test, respectively. The values shown here are averages of Machines A and B, but the difference between these two machines is quite small. It is found that JIS B 8616 underestimates the electricity consumption in the cooling season by 10 % and that in the heating season by 30 %. Since the seasonal electricity consumption ratio P_{hp}/P_{cp} in the office in Nagoya is about 0.5, it follows that the annual electricity consumption predicted by JIS B 8616 is about 17 % smaller than the real electricity consumption. In the next chapter, we propose a new testing method to decrease these prediction errors of the annual electricity consumption.

5 NEW TESTING AND EVALUATION METHODS OF ANNUAL ELECTRICITY CONSUMPTION PREDICTION

5.1 Testing and Evaluation Methods for Cooling Operation

As shown in Table 4, in JIS B 8616, the electricity consumption in the cooling season is predicted based on the results obtained with rating and half-capacity tests conducted at t_j = 35 °C. As a result, COP in high thermal load is predicted with high accuracy, whereas that in low thermal load is considerably overestimated as shown in Fig. 5(a). This overestimation of COP causes such a prediction error of the seasonal electricity consumption as described above. Considering this situation, we propose new testing conditions that can improve the accuracy of COP prediction in the lower thermal load operation.

Table 6: Improved Testing Conditions for Power Consumption Evaluation in Cooling Period

	Thermal load ratio BL_c/Φ_{cr}	Temperature of outdoor air t_j
Rating capacity	100 %	35 °C
Half capacity	50 %	26 °C
Low capacity	25 %	22 °C

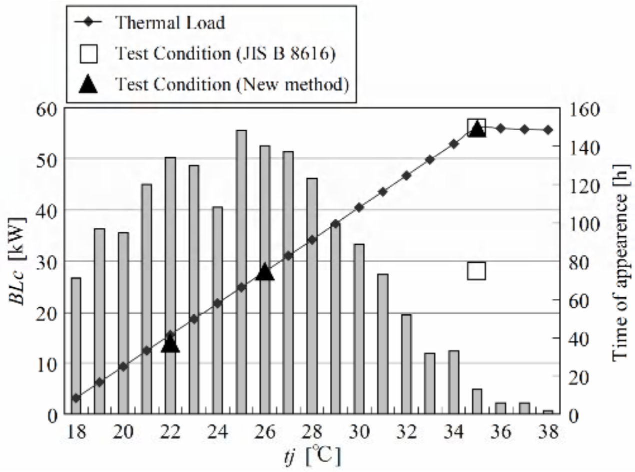


Figure 7: Comparison of Test Conditions in JIS B 8616 and New Method

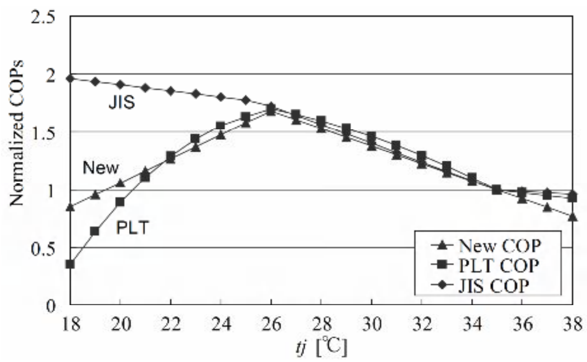


Figure 8: Comparison of COPs in Cooling Operation

The new testing conditions we propose in this study are shown in Table 6. We propose conducting the performance tests under three conditions: namely, rating load test (BL_c/Φ_{cr} = 100 % at t_j = 35 °C), half load test (BL_c/Φ_{cr} = 50 % at t_j = 26 °C) and low load test (BL_c/Φ_{cr} = 25 % at t_j = 22 °C). COPs are measured in these tests under the condition that the indoor air temperature is controlled at 27 °C by the air-conditioner itself. Figure 7 shows the histogram of time (hours) of t_j appearance in the cooling season and the change of the cooling thermal load BL_c against t_j; conditions of the rating and half-capacity tests prescribed in JIS B 8616, and new testing conditions described above are superimposed on them. In JIS B 8616, the half-capacity test is conducted at t_j = 35 °C, but as recognized from this figure this condition is inconsistent with the relation between BL_c and t_j that JIS B 8616 assumes. Hence, in the new testing conditions, we have determined t_j to match with each BL_c. It is ascertained from Fig. 7 that the testing conditions proposed here satisfy the relationship between BL_c and t_j.

Next, the prediction method of COPs based on those measured under these testing conditions is explained. As observed in Fig. 5(a), COP in the cooling season attains the maximum around the thermal load of BL_c/Φ_{cr} = 50 %. Therefore, in the new evaluation method, we assume that COP measured in the half load test (BL_c/Φ_{cr} = 50 %, t_j = 26 °C) is the maximum, and COP in BL_c/Φ_{cr} > 50 % and t_j > 26 °C decreases linearly against t_j to attain that measured in the rating load test (BL_c/Φ_{cr} = 100 %, t_j = 35 °C). For the lower thermal load condition of BL_c/Φ_{cr} < 50 % and t_j < 26 °C, COP is again assumed to change linearly against t_j to the value measured in the low load test (BL_c/Φ_{cr} = 25 %, t_j = 22 °C), and COP for t_j < 22 °C is estimated by the extrapolation of this straight line. Figure 8 shows the comparison of COP variations against t_j estimated by this new method ("New COP" in the figure), measured in the partial thermal load operation test (PLT COP) and calculated by JIS B 8616 (JIS COP). It is found that the prediction accuracy of COP in the region of t_j < 26 °C can be remarkably improved by adding the low load test in the proposed method.

Table 7: Improved Testing Conditions for Power Consumption Evaluation in Heating Period

	Thermal load ratio BL_h/Φ_{hr}	Temperature of outdoor air D.B.T. / W.B.T.
Standard temperature	20 %	7 / 6 °C
Low Temperature	40 %	2 / 1 °C
Extremely Low Temperature	60 %	-3 / -4 °C

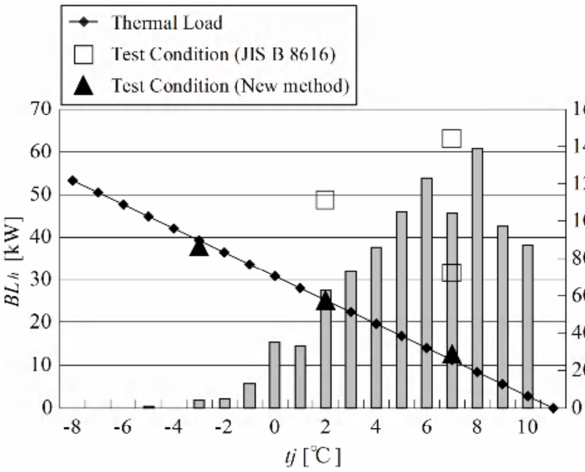


Figure 9: Comparison of Test Conditions in JIS B 8616 and New Method

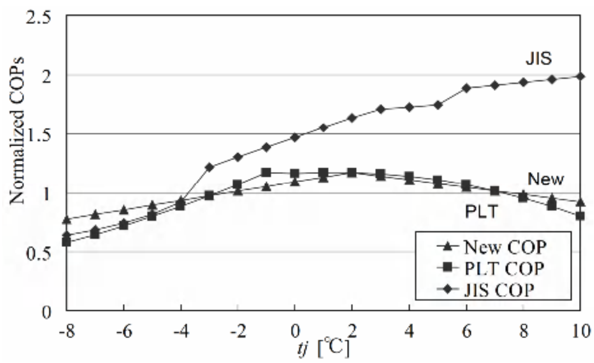


Figure 10: Comparison of COPs in Heating Operation

5.2 Testing and Evaluation Methods for Heating Operation

Next, we propose the new testing and evaluation methods of COP in the heating season. Considering that JIS B 8616 overestimates COPs in low thermal load condition and that the consistency of the testing thermal load and outdoor air temperature must be maintained, we propose three testing conditions shown in Table 7: standard temperature test (BL_h/Φ_{hr} = 20 % at t_j = 7 °C), low temperature test (BL_h/Φ_{hr} = 40 % at t_j = 2 °C) and extremely low temperature test ((BL_h/Φ_{hr} = 60 % at t_j = -3 °C). It is assumed that these heating performance tests are conducted under the condition that the indoor air temperature is controlled at 20 °C by the air-conditioner. Figure 9 shows the frequency of t_j appearance in the heating season, variation of BL_h against t_j, testing conditions prescribed in JIS B 8616 and those proposed here. In the testing conditions of JIS B 8616, the thermal loads are generally far larger than those corresponding to t_j. The proposed testing conditions are on the line that shows the relationship between BL_h and t_j, and thus they maintain the consistency of BL_h and t_j.

Similar to the case of the cooling season, it is assumed that COP measured in the low temperature test is the maximum, and COP changes linearly against t_j to the value measured in the standard temperature test or extremely low temperature test. Figure 10 shows the results of COP predictions. It is ascertained that the accuracy of COP predicted by the proposed method is much improved over the whole t_j. This means that the prediction accuracy of COPs in the heating season can be much improved by changing the testing conditions without increasing the number of tests.

From these results of COPs, we have calculated the prediction errors of the seasonal and annual electricity consumptions caused with the proposed new testing and evaluation methods. The results are shown in Table 8 together with those of JIS B 8616. The errors included in the electricity consumption predicted with the new method are as small as 5 % in the cooling season and 2 % in the heating season. As a result, the annual electricity consumption can be predicted with an error of only 4 %. This means that the testing and

Table 9: Comparison of Electricity Consumptions Predicted by JIS B 8616 and New Method

Electricity Consumption in Cooling Season (4/26 - 10/26)		
P_{cj}/P_{cp}	JIS: 0.895 (-10.5 %)	New: 0.952 (-4.8 %)
Electricity Consumption in Heating Season (11/29 - 3/26)		
P_{hj}/P_{hp}	JIS: 0.703 (-29.7 %)	New: 0.984 (-1.6 %)
Annual Electricity Consumption		
P_j/P_p	JIS: 0.833 (-16.7 %)	New: 0.962 (-3.8 %)

evaluation method we propose in this study can effectively improve the prediction accuracy of COPs and the annual electricity consumptions of multiple air-conditioners for buildings with large capacity.

6 CONCLUSIONS

We have carried out the partial thermal load performance tests of multiple air-conditioners for buildings driven by electric motors with a rating cooling capacity of 56 kW and a rating heating capacity of 63 kW. The influences of the outdoor air temperature and indoor thermal load on the performance of the air-conditioners are clarified. Based on the results of the tests, the accuracies of COPs and seasonal electricity consumptions predicted by JIS B 8616:2006 have been evaluated, which prescribes the calculation method of seasonal electricity consumption of packaged air-conditioners with a rating cooling capacity less than 28 kW. The main results can be summarized as follows.

(1) The coefficient of performance (COP) of air-conditioners in the partial thermal load operation changes depending on the outdoor air temperature and indoor thermal load. Under the constant indoor thermal load, COP in the cooling (heating) operation increases as the outdoor air temperature becomes lower (higher). Under the constant outdoor air temperature, COP shows the maximum around the indoor thermal load ratio (thermal load / rating capacity of air conditioner) of 50%, and it becomes lower as the thermal load is decreased or increased.

(2) The calculation method of COP prescribed in JIS B 8616:2006 tends to overestimate COP under the low indoor thermal load condition in both the cooling and heating operations. As a result, the electricity consumptions in the cooling and heating seasons are underestimated by 10% and 30% with JIS B 8616, respectively, and the annual electricity consumption is underestimated by 17%.

(3) Based on the results of the partial thermal load operation test, we have proposed a new testing and evaluation method of seasonal electricity consumption of air conditioners. This method is designed to improve the accuracy of COP prediction in the low indoor thermal load operation. It has been ascertained that the prediction error of the annual electricity consumption can be reduced to 4% by applying this new method to the air-conditioners with large capacity.

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