ENERGY SAVING OF AIR-CONDITIONING IN MASS MERCHANDISERS BY OPERATIONAL CHANGE OF AIR-CONDITIONING SYSTEM

Masafumi Hirota, Professor, Department of Mechanical Engineering
Mie University, Kurimamachiya-cho, Tsu-city, Mie 514-8507, Japan

Choyu Watanabe, Senior Research Scientist, Central Research Institute of Electric Power Industry, Nagasaka, Yokosuka 240-0196, Japan

Ichiro Sakuraba, Assistant Managing Research Engineer, Chubu Electric Power Co., Inc.
Odaka-cho, Midori-ku, Nagoya 459-8522, Japan

Yoichi Miyaoaka, Assistant Managing Research Engineer, Chubu Electric Power Co., Inc.
Odaka-cho, Midori-ku, Nagoya 459-8522, Japan

Hiroshi Nakayama, Research Engineer, Chubu Electric Power Co., Inc.
Odaka-cho, Midori-ku, Nagoya 459-8522, Japan

Ei-ichiro Ohashi, Engineer, Toyota Motor Corporation
Toyota-cho, Toyota-city, 471-8571, Japan

Naoki Maruyama, Associate Professor, Department of Mechanical Engineering
Mie University, Kurimamachiya-cho, Tsu-city, Mie 514-8507, Japan

Akira Nishimura, Assistant Professor, Department of Mechanical Engineering
Mie University, Kurimamachiya-cho, Tsu-city, Mie 514-8507, Japan

Abstract: In this study, at first, we measured annual variations of the indoor thermal loads in two mass merchandising stores dealing in clothing based on the results of the partial thermal load performance tests of air-conditioners and field measurements of outdoor air temperatures. Then, on the basis of these indoor thermal loads and COP characteristics of the multi-type air-conditioners for buildings under the partial thermal load operation, we devised an energy-saving method of air-conditioning in those mass merchandising stores. It was found that, by optimizing the number of operating air-conditioners according to the outdoor air temperature and resulting indoor thermal load, the energy consumption in the cooling and heating seasons can be reduced by 12 % and 30 %, respectively. As a result, the annual energy consumption can be decreased by 15 %.

Key Words: air-conditioner, thermal load, partial load performance, energy-saving

1 INTRODUCTION

It is known that in business-related buildings the energy used for air-conditioning amounts to 30% - 40% of their total energy consumption. Therefore, the energy saving of air-conditioning in those buildings is an important issue to reduce their total energy consumption. In order to achieve a further reduction of the energy consumption of air-conditioning, we have to grasp the detailed performance of the air-conditioners in their partial thermal load operations and characteristics of indoor thermal loads of buildings. As for the performance of air-conditioners, we have been conducting the partial thermal load performance tests of various types of A.C. for business uses with relatively large capacities and have made clear their COP characteristics in their partial load operations (Hirota et al. 2007, Watanabe et al. 2008, Watanabe et al. 2009). Detailed experimental data on the indoor thermal loads of business-related buildings are, however, quite scarce because of the difficulty in measuring them under actual operating conditions. In particular, only few measured data are available on the detailed thermal loads in the mass merchandising detached stores such as clothing stores, electrical appliance stores, sports equipment stores, food supermarkets, etc.

With these points as background, in this study, we at first measured the annual variations of the indoor thermal loads in two mass merchandising detached stores (A and B) with floorages of about 6000 m^2 that were placed in Aichi prefecture and mainly sold clothing. In Store A, the packaged-type air-conditioners powered by electric motors (EHP: Electric Heat Pump) were equipped, while Store B was air-conditioned by the multi-type air-conditioners for buildings powered by gas engines (GHP: Gas Heat Pump). We measured outdoor air temperatures and electricity and/or gas consumptions of each air-conditioner in these stores through the year. Then we calculated the indoor thermal loads in those stores based on the partial thermal load performance of air-conditioners equipped in them, on the assumption that the indoor thermal load was in equilibrium with the sum of capacities of air-conditioners operating in them. From these field measurements, we could make clear the detailed annual variations of the indoor thermal loads of those stores.

Next, on the basis of these indoor thermal loads of the stores and COP characteristics of the air-conditioners measured by the partial thermal load performance tests in the preceding studies, we devised an energy-saving method of the air-conditioning in those mass merchandisers by the operational change of the air-conditioners. This method is based on the optimization of the number of operating air-conditioners according to the outdoor air temperature and resulting indoor thermal load. It was found that this method can reduce the annual energy consumption of air-conditioning in the stores by 15 %.

2 DETAILS OF MEASURED STORES

In this study, at first, we measured the indoor thermal loads in two mass merchandizing detached stores that are under the chain-store expansion. Both stores are located in Aichi prefecture, the central area of Japan, and the main merchandises are clothing. The detailed structural characteristics of two stores (Store A and Store B) and types of air-conditioners equipped in them are shown in Table 1. The floorages are about 6000 m^2. They are one-storied buildings but the roof of Store B is a parking area, thus it has quite a larger heat capacity.

In these stores, we measured the outdoor/indoor temperatures, outdoor/indoor humidities, and electricity and/or gas consumptions of each air-conditioner through a year (from January 2007 to December 2007) continuously at every 10 minutes. In Store A, 68 packaged-type air-conditioners powered by electric motors (EHP) are equipped, while Store B is air-conditioned by 23 multi-type air-conditioners for buildings powered by gas engines (GHP). The refrigerants used in EHP in Store A and GHP in Store B are R410A and R407, respectively. Since the rooftop of Store B is a parking area with a large heat capacity, a largeish capacity of air-conditioners is equipped in it based on past experiences. Therefore, the total cooling and heating capacities of the air-conditioners in Store B is 1.2 times as large as those in Store A, although the floorage of Store B is larger only by 5 % than that of Store A. The ceiling height is about 6 m in both stores and the ceiling fans are installed at a height of 4 m from the floor to stir air. Since both stores are located in the same area, the outdoor temperatures around them are almost the same (detailed data are shown later in this paper). The amount of ventilation in Store A is, however, 1.8 times larger than that of Store B.

Table 1: Structural characteristics and air-conditioners of stores

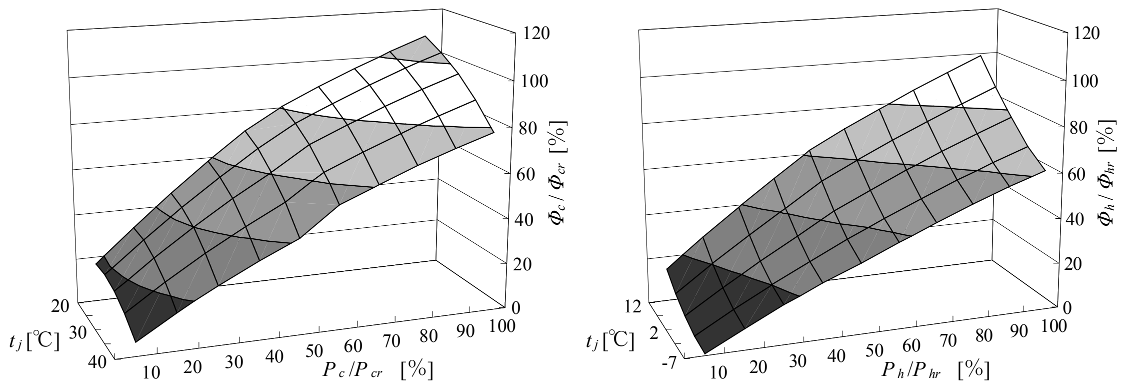
	Store A	Store B
Business hours	7 days / week 10:00 - 21:00	7 days / week 10:00 - 21:00
Location	Nagoya	Komaki
Floorage	6,068 m^2	6,375 m^2
Height of ceiling	6 m	6 m
Roof structure	Sheet steel	Asphalt & cement (Parking)
Heat capacity of roof	40 MJ/°C	1,926 MJ/°C
Amount of ventilation	36,090 m^3/h	20,150 m^3/h
Type of A.C.	PAC EHP: 5HP x 68 MAC EHP: 10HP etc.	MAC GHP: 20HP x 22 MAC GHP: 13HP x 1
Cooling capacity of A.C.	980 kW	1,267.5kW
Heating capacity of A.C.	1,097.5 kW	1,516.5kW

3 HOW TO MEASURE THE INDOOR THERMAL LOAD

The indoor thermal loads of the stores were measured on the assumption that they were in equilibrium with the sum of cooling or heating capacities of air-conditioners operating together in the stores. Since the heat capacities of the tested buildings were quite large, the temporal variations of the indoor air temperatures and thermal loads were quite slow. It is thought that the air-conditioners equipped in the stores could follow the temporal variations of the thermal loads in them.

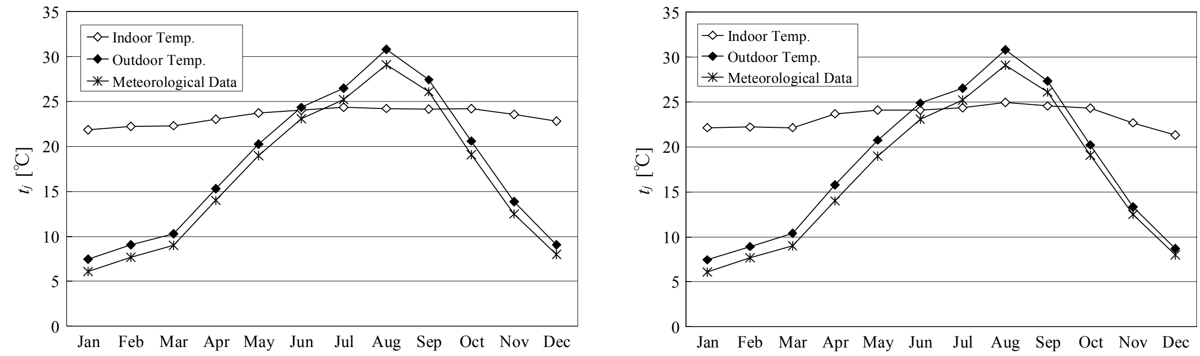
In order to measure the indoor thermal loads in the stores, we at first made the partial thermal load performance tests of the air-conditioners that are the same types as those equipped in the stores. These tests were carried out using the heat pump testing apparatus in Energy Application R&D Center, Chubu Electric Power Co. Inc (Watanabe et al. 2008). Based on the data obtained by those performance tests, we made empirical correlations in which the cooling and heating capacities of the air-conditioners were expressed as functions of outdoor air temperature and energy consumption ratio (energy consumption of A.C. under the partial load operation / that under the rated condition). Figures 1(a) and 1(b) show examples of the cooling capacity curve and heating capacity curve of the packaged air-conditioner used in Store A. The dimensionless cooling (heating) capacity of A.C. Φ_c/Φ_{cr} (Φ_h/Φ_{hr}) is expressed as a function of the electricity consumption ratio P_c/P_{cr} (P_h/P_{hr}) and the dry-bulb temperature of outdoor air t_j. Here Φ_c (Φ_h) is the cooling (heating) capacity of A.C. under the partial load operation and P_c (P_h) is its electricity consumption. The subscript r designates the rated condition. It is found from these figures that the capacity of the air-conditioner increases almost linearly with respect to the electricity consumption ratio, and it also changes depending on the outdoor air temperature.

In this study, we measured the electricity and/or gas consumption of each air-conditioner equipped in the stores and the dry-bulb air temperature outside the stores at every 10 minutes continuously through a year. Then we calculated the capacity of each air-conditioner from these measured data and the capacity curves shown in Fig. 1. We regarded the sum of cooling or heating capacities of all the air-conditioners operating simultaneously in the store as the indoor thermal load in it. Thus, it follows that by this



(a) Cooling operation **(b) Heating operation**

Figure 1: Capacity curves obtained by the partial thermal load performance tests (Packaged EHP equipped in Store A)



(a) Store A **(b) Store B**

Figure 2: Annual variations of indoor and outdoor air temperatures

method we can measure the temporal variation of the indoor thermal load in the store at every 10 minutes through the year.

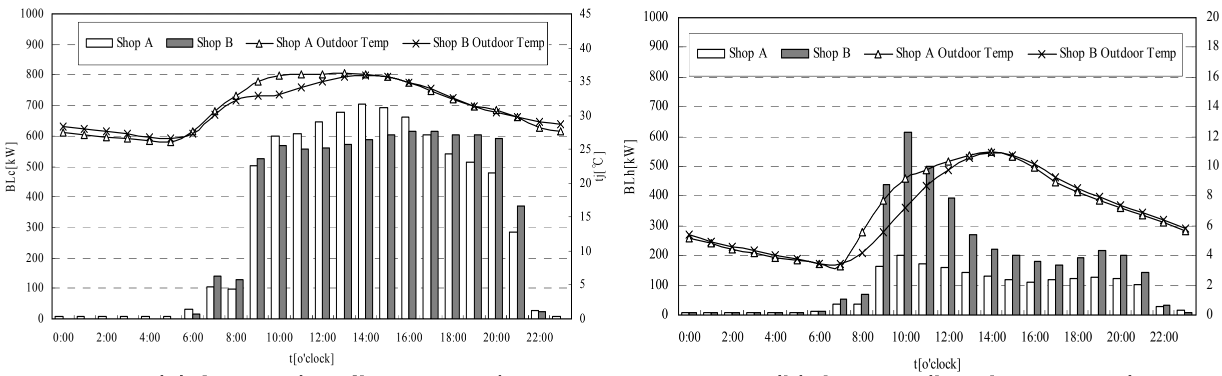
4 RESULTS OF THERMAL LOAD MEASUREMENTS

4.1 Variations of Outdoor and Indoor Temperatures of Stores

Figures 2(a) and 2(b) show the variations of the monthly-averaged indoor and outdoor air temperatures measured in Store A and Store B, respectively. The outdoor air temperature in Nagoya city included in the Expanded AMeDAS Weather Data (Architectural Institute of Japan 2005) is also shown in these figures. The indoor temperature is the average value in the store hours (10:00 - 21:00), and the outdoor temperature is the average value over 24 hours. Although the management of the indoor temperature setting of A.C. was left to each store, the difference of indoor temperatures in Store A and Store B is negligibly small. The average indoor temperature is kept at about 25 °C in summer and at 22 °C in winter. The outdoor air temperatures of two stores also agree well with each other, and they are somewhat higher than that of Nagoya in EA data.

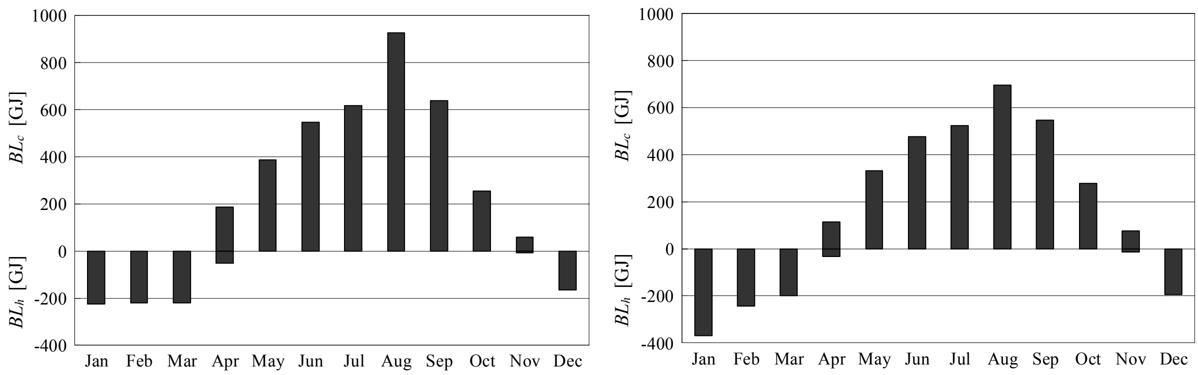
4.2 Characteristics of Hourly and Monthly Thermal Loads in Stores

Figures 3(a) and 3(b) show typical variations of hourly thermal loads measured in both stores in one day in August (cooling season) and January (heating season), respectively. The outdoor air temperatures t_j averaged in every one hour are also shown in the figures. In



(a) August (cooling season) **(b) January (heating season)**

Figure 3: Typical variations of hourly indoor thermal loads in a day



(a) Store A **(b) Store B**

Figure 4: Variations of monthly indoor thermal loads in a year

August, the cooling loads in both stores begin to increase at 9 o'clock, one hour before the opening time, and vary in response to the variations of t_j. The cooling load attains the maximum around 14 o'clock in Store A and 18 o'clock in Store B. These maximum cooling loads occur behind the peak time of the outdoor air temperature (around 13 o'clock). This delay of the thermal load variation to t_j is attributed to the heat capacity of the building. In particular, the heat capacity of the roof of Store B is much larger than that of Store A as shown in Table 1, and this causes longer delay of the peak cooling load in Store B. The maximum cooling load in Store A is 1.2 times larger than that in Store B. This may be caused by the difference of the amount of ventilation (Nakayama et al. 2008).

In January, as is the case in the cooling load, the variations of the heating load generally correspond to those of the outdoor air temperature. After 14 o'clock, however, the variations of the heating load are quite small although t_j decreases quite rapidly. This reflects the effect of the thermal storage by the building. Just after the opening time, the heating load in Store B is considerably larger than that of Store A. This suggests that the roof of Store B with a large heat capacity stores larger amount of cold energy during the night.

Figure 4 shows variations of the monthly thermal loads measured in both stores through a year. Although there is a quantitative difference between the thermal loads in the stores, they show qualitatively similar tendencies. That is, the cooling and heating loads attain the maximums in August and January, respectively, the cooling period is far longer than the heating period, and the annual cooling load is much larger than the annual heating load.

4.3 Variations of Indoor Thermal Load with Outdoor Air Temperature

Referring to the thermal load models adopted in Japanese Industrial Standards JIS B 8616:2006 (Japanese Standards Association 2006), we arranged the indoor thermal load measured in the store as a function of the dry-bulb temperature of outdoor air t_j. Figure 5 shows the variations of the indoor thermal loads per unit floorage BL_{cu} (cooling load) and BL_{hu} (heating load) measured in both stores to t_j. These results were obtained by ensemble averaging the data at every 1 °C: namely, the value of BL_{cu} observed at 35 °C in this figure corresponds to the average cooling load measured in the temperature range of 34.5 °C < t_j < 35.4 °C. This averaging was made for the temperature range in which an appearance time in a year was larger than 10 hours. Thus, the minimum outdoor air temperature in this figure is 2 °C. The heating load is shown by negative values in this figure. The indoor thermal loads of Store A and Store B agree quite well with each other, although there appears some difference in high temperature region of t_j > 30 °C. It is thought that this difference of BL_{cu} at high t_j is attributed to the difference of the ventilation as shown in Table 1.

In both stores, the cooling load BL_{cu} arises from t_j = 16 °C - 18 °C and it increases linearly with t_j. The maximum cooling load that occurs at t_j = 40 °C is about 0.12 kW/m^2 for Store A and 0.09 kW/m^2 for Store B. These values are somewhat smaller than that recommended in CASCADE III (Computer Aided Simulation for Cogeneration Assessment & Design III, The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan 2003), in which the maximum BL_{cu} in a shop is assumed to be 0.1395 kW/m^2.

As the outdoor air temperature drops below 16 °C, the operation of the air-conditioners is switched from the cooling mode to the heating mode continuously and the temperature range of zero thermal loads is not observed in Fig. 5. This point is different from the thermal load model in JIS B 8616:2006, in which the indoor thermal load is assumed to be zero in 15 °C < t_j < 21 °C. The heating load also increases in proportion to the outdoor air temperature. As a whole, however, the heating load is smaller than the cooling load in both stores. It is thought that the larger cooling load measured in the present stores is ascribed to the heat generations of the lighting fixtures inside the stores. By the extrapolation of BL_{hu} against t_j, the heating load at t_j = 0 °C is estimated to be 0.04 kW/m^2 in Store A and 0.06 kW/m^2 in Store B. These values are considerably smaller than the maximum heating load assumed in CASCADE III (0.093 kW/m^2). It thus follows that the existing indoor thermal load models for the stores overestimate the heating load in them.

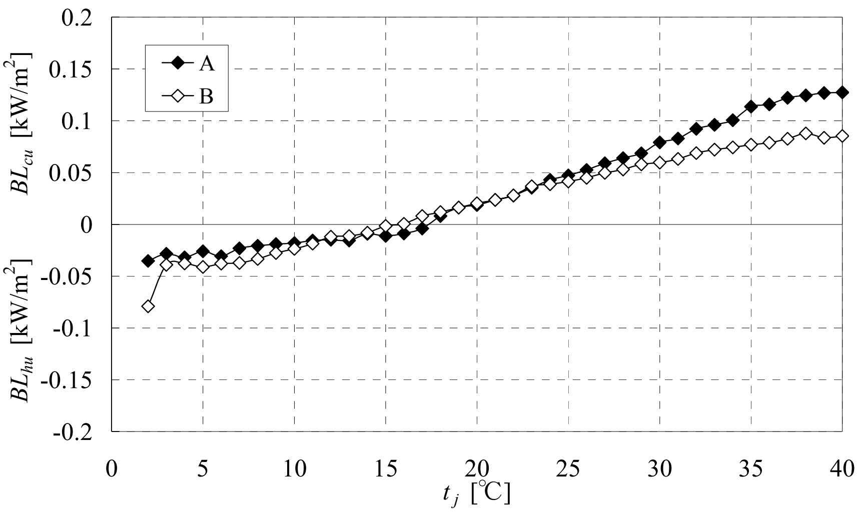


Figure 5: Variations of the indoor thermal load per unit floorage to the outdoor air temperature measured in both stores

5 ENERGY-SAVING METHOD BY THE OPTIMIZATION OF THE NUMBER OF OPERATING AIR-CONDITIONERS

5.1 Indoor Thermal Load Model of Mass Merchandizing Detached Stores

Next, we examine the effectiveness of the energy saving method by the operational change of air-conditioners equipped in stores. Figure 6 shows the histogram of the appearance of the cooling load ratios of air-conditioners (cooling load covered by each A.C. / its rated cooling capacity) measured in Store A in June, July and August. In August with the largest monthly cooling load, the air-conditioners are operated in the whole range of the cooling load ratio, and the peak thermal load ratio is found around 85 %. In June and July with smaller cooling load, however, the peak shifts to 35 %. It is known that the cooling COP of air-conditioners shows the maximum at the cooling load ratio of 50 % - 75 % and deteriorates at lower cooling load ratios (Watanabe et al. 2009). Therefore, it is estimated that the average COP in June and July is lower than that in August. Based on this result, in this study, we have devised an energy-saving method with the optimization of the number of operating air-conditioners according to the variation of the indoor thermal load in a building.

In order to examine the effectiveness of this energy-saving method, we made an indoor thermal load model of the mass merchandizing detached stores on the basis of the measured results shown in Fig. 5. Then, based on this thermal load model and COP characteristics of air-conditioners in their partial thermal load operations, we examined the relationship between the number of operating A.C. in the store and their energy consumptions.

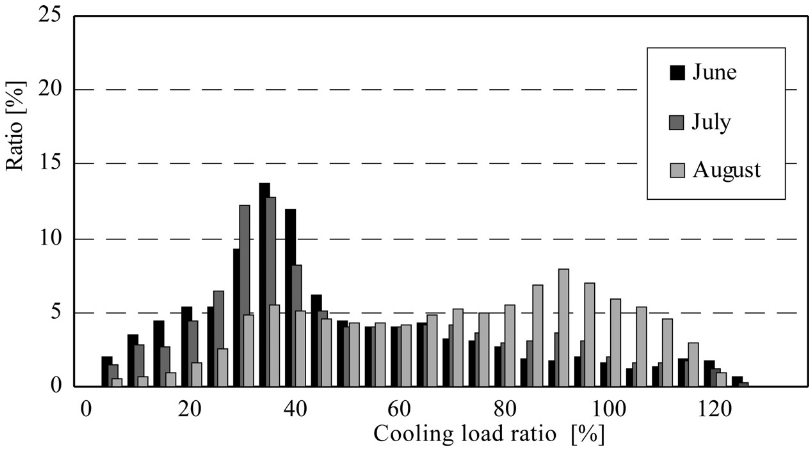


Figure 6: Distributions of the cooling load ratios of A.C. in Store A

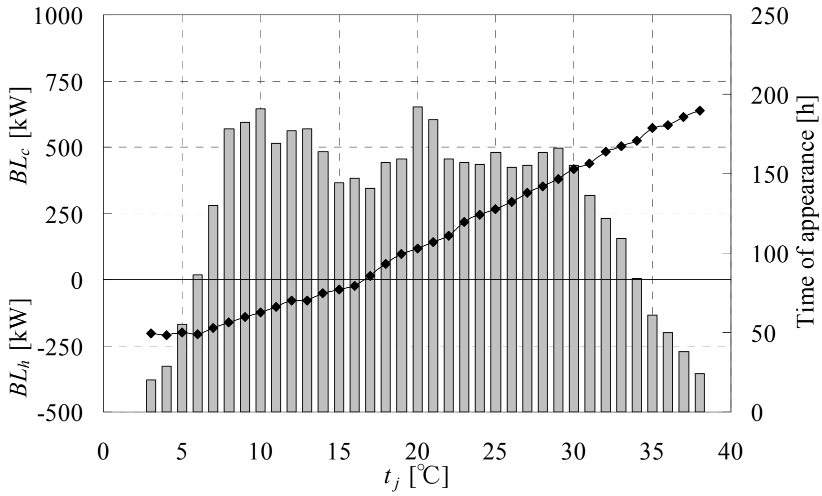
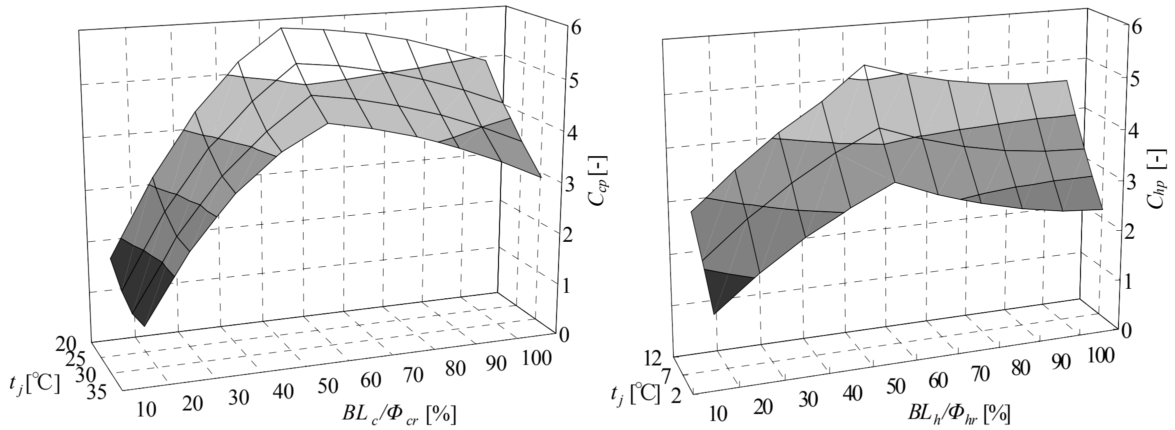


Figure 7: Thermal load model of mass merchandizing detached store

Table 2: Specification of tested air-conditioners

Type of air-conditioner	Multi-type for buildings
Rated Cooling Capacity	56 kW
Rated Heating Capacity	63 kW
Refrigerant	R410A
Compressor Control	Variable Speed with Inverter



(a) Cooling operation **(b) Heating operation**

Figure 8: COP characteristics of the tested air-conditioner in the partial thermal load operations

The indoor thermal load model of the mass merchandizing detached stores was made by averaging arithmetically the measured results of two stores shown in Fig. 5 in the outdoor air temperature range of 3 °C < t_j < 38 °C. We assumed that the floorage of this model store was 6000 m^2 and the business hours were from 10:00 to 21:00 seven days in a week. These conditions are almost the same as those of Store A and Store B. Figure 7 shows the variation of the indoor thermal load of this model store to t_j and the time of appearance of t_j in the business hours in a year. The latter was obtained from the Expanded AMeDAS Weather Data of Nagoya. The indoor thermal load changes in proportion to the outdoor air temperature and the cooling load occurs in t_j > 17 °C. The annual cooling load is about four times larger than the heating load. This model can be regarded as a representative of the indoor thermal load of the mass merchandizing detached stores that deal in goods with no heat radiation such as clothing.

5.2 COP Characteristics of Multi-Type Air-Conditioner for Buildings

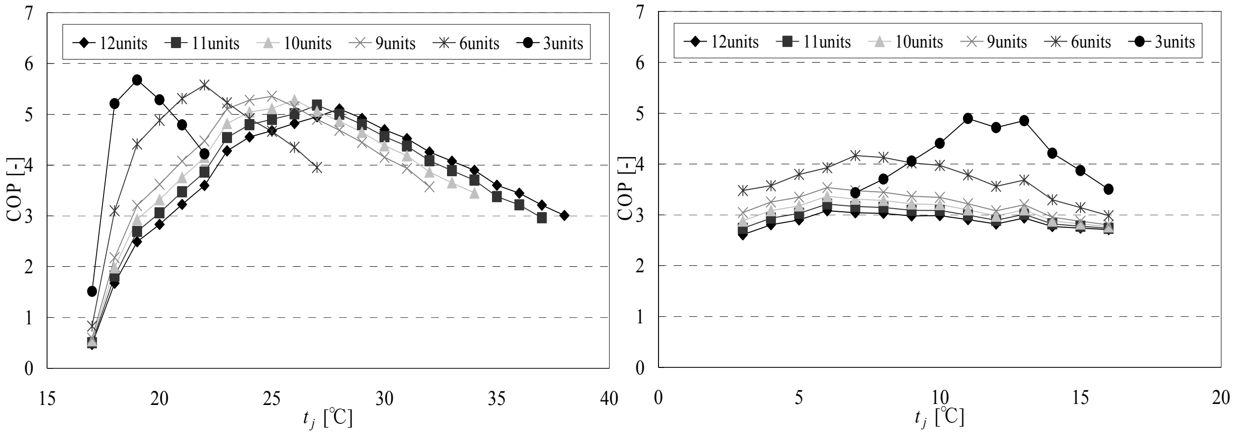
In this study, we assumed that the model store with a thermal load shown in Fig. 7 was air-conditioned by the multi-type air-conditioners for buildings with a rated cooling capacity of 56 kW and a rated heating capacity of 63 kW powered by electric motors (EHP), and examined the effectiveness of the energy-saving method described above. The specification of this air-conditioner is shown in Table 2, and its COP characteristics are shown in Fig. 8 (Watanabe et al. 2008, 2009). In Fig. 8, COP measured by the partial thermal load performance tests is expressed as a functions of the outdoor air temperature t_j and the thermal load ratio BL_c/Φ_{cr} (cooling operation) or BL_h/Φ_{hr} (heating operation), where BL_c and BL_h designate the cooling and heating load imposed upon the A.C., respectively. It is found from this figure that, under the same outdoor air temperature, COP increases as the thermal load ratio is decreased from 100 % and it attains the maximum at BL_c/Φ_{cr} (BL_h/Φ_{hr}) = 50 %. Then, COP decreases as the thermal load ratio is further decreased. Under the same thermal load ratio, the cooling COP shows higher values at lower t_j while the heating COP increases at higher t_j.

5.3 Energy-Saving by the Optimization of the Number of Operating A.C.

In general, the number of the air-conditioners equipped in the store is determined by the balance between the maximum thermal load in it and the rated cooling or heating capacity of the air-conditioner. Therefore, under the low indoor thermal load condition, the thermal load ratio of each air-conditioner decreases as shown in Fig. 6 if all the air-conditioners equipped in the store are operated together. This may cause the deterioration of COP as recognized from Fig. 8. As shown in Fig. 7, the time of appearance in a relatively low thermal load region occupies quite a large part of the air-conditioning hours in a year. Therefore, the deterioration of COP under the low thermal load condition can cause a serious increase of the annual energy consumption of air-conditioners. Considering that COP of EHP adopted here shows the peak at the thermal load ratio around 50 % as shown in Fig. 8, it may be possible to keep high COP through a year by controlling the number of A.C. operating in the store to accommodate their thermal load ratios to the range of high COP. As a result, the annual energy consumption of the air-conditioner may be decreased by this method. With this point as background, in this study, we have devised an energy-saving method with the optimization of the number of operating air-conditioners according to the variation of the indoor thermal load in the store.

Since the maximum thermal (cooling) load of the present model store is about 650 kW as observed in Fig. 7, we assumed that twelve air-conditioners are equipped in it because the rated cooling capacity of A.C. adopted in this study is 56 kW (see Table 2). Then, we calculated the variation of COP to the number of air-conditioners operating in the store. In this calculation, it was assumed that the thermal load in the store is distributed evenly to all the operating A.C. Figure 9(a) shows the results in the cooling period. The variations of COP to the outdoor temperature t_j are shown taking the number of operating A.C. as a parameter. These results were obtained by combining Fig. 7 and Fig. 8(a). That is, the thermal load in the model store at t_j was determined from Fig. 7 and the thermal load ratio of the operating air-conditioners was calculated on the assumption of a uniform distribution of the thermal load. Then, COP of the operating A.C. was obtained from Fig. 8(a). Thus, it follows that the results of Fig. 9(a) reflect the influences of both t_j and BL_c/Φ_{cr} on COP.

Under a large cooling load condition of t_j > 28 °C in Fig. 9(a), the highest COP is expected when all (twelve) air-conditioners are operated uniformly in the model store. In t_j < 28 °C with lower cooling load, however, COP of 12-unit operation decreases as t_j becomes lower. This is because the thermal load ratio of the air-conditioners becomes smaller than 50 % under this low t_j condition. It is recognized from this figure that in t_j < 28 °C COP can be improved by reducing the number of operating A.C. according to the decrease of t_j and resulting



(a) Cooling operation **(b) Heating operation**

Figure 9: Variations of COPs to the number of A.C. operating in the model store

Table 3: Optimized number of operating A.C. according to the outdoor air temperature

(a) Cooling operation

Outdoor temperature range	Number of operating A.C.
27.5°C < t_j	12
26.5°C < t_j < 27.4°C	11
25.5°C < t_j < 26.4°C	10
23.5°C < t_j < 25.4°C	9
20.5°C < t_j < 23.4°C	6
t_j < 20.4°C	3

(b) Heating operation

Outdoor temperature range	Number of operating A.C.
t_j < 8.4°C	6
8.5°C < t_j	3

cooling load. From the results of Fig. 9(a), the optimum number of the operating air-conditioners for the t_j range in the cooling season can be determined as Table 3(a). The highest COP is expected through a year by controlling the number of A.C. operating in the store against the outdoor air temperature range according to this table. Here it should be noted that, because the cooling load in this model store is determined by t_j as shown in Fig. 7, the optimum number of operating A.C. can be determined solely by t_j that can be measured more easily than the thermal load itself in the store. This can be an obvious advantage in the practical application of this energy-saving method to real buildings.

Figure 9(b) and Table 3(b) show the results in the heating operation. Since the heating load in the present model store is considerably smaller than the cooling load, the optimum number of the operating A.C. is smaller than that of the cooling operation. In the next chapter, the energy-saving effects of this method are examined in detail.

6 EVALUATION OF ENERGY-SAVING EFFECT OF THE PROPOSED METHOD

Figure 10 shows the comparison of COPs in the cooling season obtained in the uniform operation of all twelve air-conditioners and in the thinned-out operation with the optimized number of A.C. The former is the same as COP for 12-unit operation in Fig. 9(a). The total cooling load at t_j in the cooling season is also shown in the figure. As described above, COP in the uniform operation of all A.C. attains the maximum around 28 °C but it decreases in lower t_j condition. On the other hand, COP in the thinned-out operation with the optimized number of A.C. does not decrease until t_j = 18 °C and it is recognized that high COP is kept throughout the cooling season. Figure 11 shows the comparison of the primary energy consumption in the cooling season. As one can understand from the results of COP, the energy consumption is decreased with this optimizing operation in low temperature region. Although the cooling load is small in the low t_j region, the time of appearance of t_j is quite large in this region as found in Fig. 7. Therefore, improvement of COP in low t_j region by optimizing the number of operating A.C. according to t_j contributes to the energy-saving in the cooling season.

The results of COP and the primary energy consumption in the heating season are shown in Figs. 12 and 13, respectively. The histogram in Fig. 12 shows the total heating load at t_j in the heating season. Since the heating load in the present model store is far smaller than the cooling load, the optimization of the number of operating A.C. in the heating season is more effective than in the cooling season. COP with the optimized operation is increased over the whole outdoor air temperature region, and as a result the primary energy consumption is also decreased in the whole t_j region.

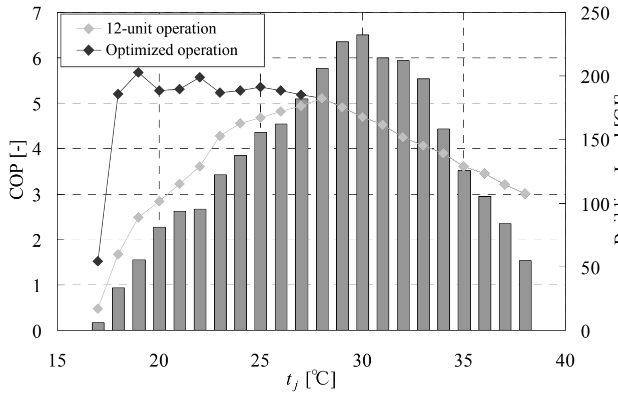


Figure 10: Comparison of cooling COP

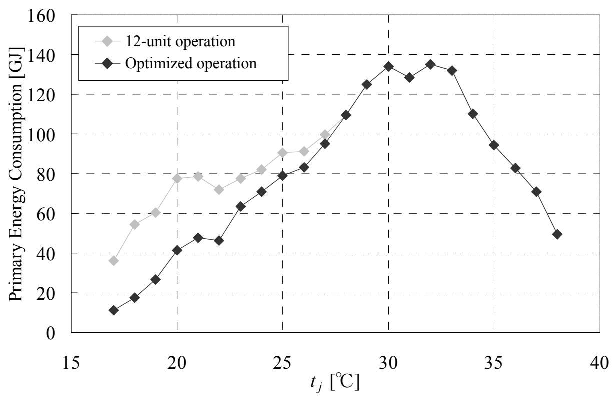


Figure 11: Comparison of primary energy consumptions in cooling season

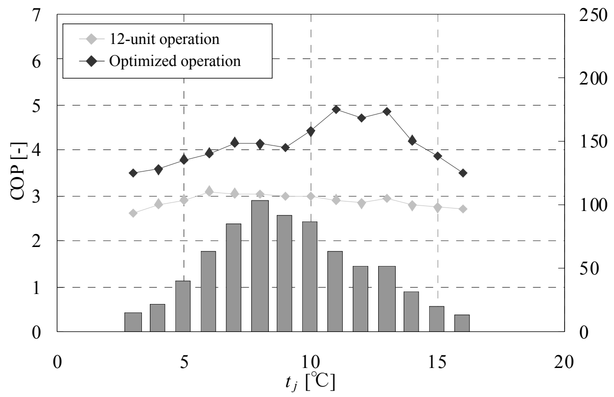


Figure 12: Comparison of heating COP

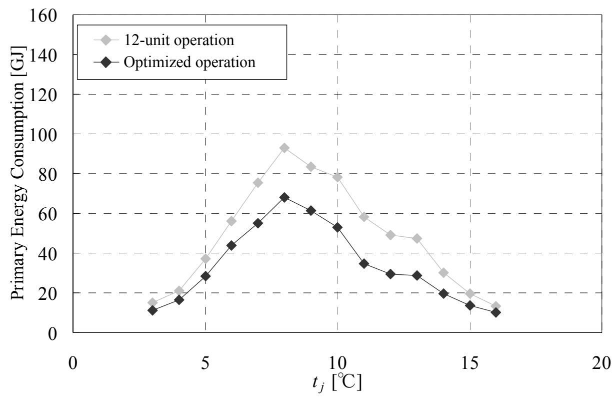


Figure 13: Comparison of primary energy consumptions in heating season

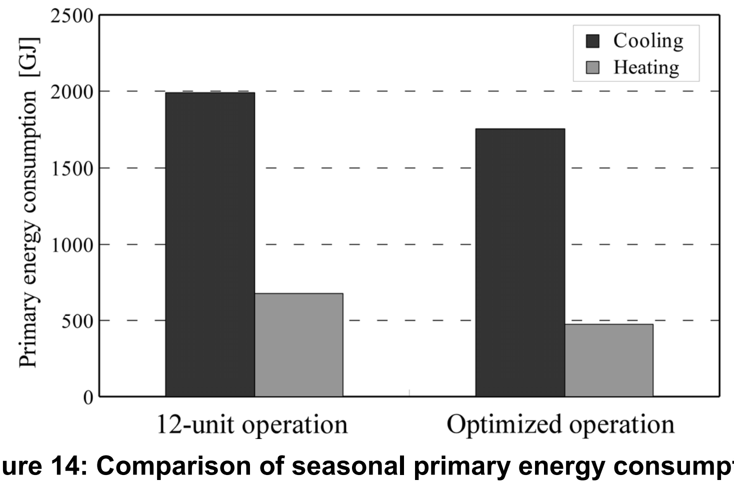


Figure 14: Comparison of seasonal primary energy consumptions

From the results shown so far, we have calculated the seasonal energy consumptions of the air-conditioners equipped in the model store and the results are shown in Fig. 14. In the cooling season, the energy consumption of A.C. can be reduced by 12 % by optimizing the number of operating A.C. according to t_j. In the heating season, the present energy-saving method is more effective and 30 % of energy can be saved with the proposed method. As shown in Fig. 7, in the present model store, the annual cooling load is about three times larger than the annual heating load. Therefore, it follows that the annual energy consumption of the air-conditioning can be decreased by 15 % with the energy-saving method proposed in this study.

7 CONCLUDING REMARKS

In this study, at first, we measured the annual variations of the indoor thermal loads in two mass merchandising detached stores dealing in clothing with floorages of about 6000 m^2. We measured outdoor air temperatures and electricity and/or gas consumptions of each air-conditioner equipped in these stores through a year. Then we calculated their indoor thermal loads based on the partial thermal load performance of air-conditioners equipped in them, on the assumption that the indoor thermal load was in equilibrium with the sum of capacities of operating air-conditioners. It was found that the cooling load arises from t_j = 16 °C - 18 °C and it increases linearly with the outdoor air temperature. The heating load also increases in proportion to the outdoor air temperature, but the annual cooling load is about three times larger than the annual heating load in these stores.

Next, on the basis of these indoor thermal loads of the stores and COP characteristics of the air-conditioners measured by the partial thermal load performance tests, we devised an energy-saving method of the air-conditioning in those mass merchandisers. This method is based on the optimization of the number of operating air-conditioners according to the outdoor air temperature and resulting indoor thermal load. It was confirmed that COP in low thermal load region is remarkably improved by this optimized operation of A.C. and high COP can be kept throughout a year. As a result, the energy consumption of A.C. can be reduced by 12 % in the cooling season and 30 % in the heating season, and the annual energy consumption of the air-conditioning can be decreased by 15 % with the energy-saving method proposed in this study.

8 REFERENCES

Architectural Institute of Japan 2005. “Expanded AMeDAS Weather Data,” Tokyo.

Hirota, M., Watanabe, C., Furukawa, M. and Nagamatsu, K. 2007. “Evaluation of Annual Performance of Multi-type Air-conditioners for Buildings - 1st report: Annual Energy Consumption of EHP,” *Trans. Japan Soc. Refrigeration & Air Conditioning Eng.*, Vol. 24, No. 4, pp. 303-314.

Japanese Standards Association 2006. JIS B 8616:2006 "Package air conditioners," Tokyo.

Nakayama, H., Watanabe, C., Sakuraba, I., Nagamatsu, K., Miyaoaka, Y., Ohashi, E. and Hirota, M. 2008. “A study on Energy Saving of Shop by Operational Change of Air-Conditioning System,” *Proc. Annual Meeting of Japan Soc. Refrigeration & Air Conditioning Eng.*, pp. 299-302.

Soc. Heating, Air-Conditioning & Sanitary Eng. Japan 2003. “Computer Aided Simulation for Cogeneration Assessment & Design III,” Tokyo, in CD-ROM.

Watanabe, C., Ohashi, E., Hirota, M., Nagamatsu, K. and Nakayama, H. 2009. “Evaluation of Annual Performance of Multi-Type Air-Conditioners for Buildings,” *J. Thermal Science Technology*, Vol.4, No.4, pp. 483-493.

Watanabe, C., Nagamatsu, K., Nakayama, H., Hirota, M. and Ohashi, E. 2008. “A New Test and Evaluation Method of Annual Energy Efficiency of Multiple Air-Conditioners for Buildings,” *Proc. 9th IEA Heat Pump Conf.*, Zürich, Switzerland, 3.19 in CD-ROM.