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Research on Energy Saving Calculation Combining Load of Air Conditioner and Load of Refrigerated Display Case in a Grocery store

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Abstract

In this study, the relationship between the enthalpy characteristics and the refrigeration characteristics of five typical refrigerated display cases in a grocery store were clarified by experiments. Based on the results, we devised a method to calculate the energy saving amount considering the interaction between the load of space conditioning and the load of refrigerated display case. Lower the store temperature by space-conditioning has the effect of reducing the total power consumption of refrigeration and space-conditioning, but it has been found that the store temperature needs to be lowered to 22 ℃ or below. Under the same store temperature and humidity conditions, the energy saving effect is greater at a low outside air temperature than at a high outside air temperature. It is important to control the space conditioning and shift the load of display cases to the load of space conditioning in early summer and early autumn.

Keywords: Grocery store, Space conditioning, Refrigerated display case, Energy saving

1. Introduction

From changes in Japan's final energy consumption, the overall increase rate from 1973 to 2013 was 1.2 times, but the increase in business divisions wahot.4 times, so that energy saving is required [1]. Manufacturers are actively developing energy-saving equipment for space-conditioning and lighting, which are typical energy-consuming equipment for business use. On the other hand, refrigeration equipment with a high energy consumption density is exposed to cost competition in the food store industry, so that energy-saving equipment is slow to spread. Therefore, it is important to save energy by devising operation and design.

From the advantage of easy to get products, many open display cases are installed in food stores. The open display case maintains the internal temperature with the air curtain, but from a part of the air curtain cold air in the refrigerator leaks from the display case and the surrounding air enters the display case. Leaked cold air stays in the lower part of the store, affects the air enthalpy in the store and worsens comfort. At the same time, air enthalpy entering display case affects the display case refrigeration load. For these reasons, the load of the open type display case interacts with the space conditioning load, making it difficult to consider energy saving.

There have been many reports on energy conservation in food stores [2]. Narumi created a prediction formula from the store's actual measurement data and calculated the energy saving effect when the display case type was changed or when the store's environmental temperature was changed [3]. Nakayama has reported the energy-saving effect of stores when the operation of space conditioning with high COP is increased by measuring food stores [4]. CFD analysis is effective to examine the effects of space conditioning and ventilation on store energy savings in detail [5], on the other hand the CFD analysis's cost is high, it is also important to develop the method that can be easily calculated.

In this report, the relationship between enthalpy characteristics and refrigeration characteristics of five typical refrigerated display cases in a grocery store was clarified through experiments. Based on the results, an

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energy saving calculation method was devised that takes into account the interaction between the space conditioning load and the refrigeration load. Using the devised method, the summer energy calculation was performed on a store model with a total floor of 2127m^2.

2. Outline of space conditioning and refrigeration energy calculation

Since display case power consumption is greatly affected by environmental enthalpy, it is important to adjust the enthalpy in the store by space conditioning and ventilation. Combining with space-conditioning load calculation and display case load calculation (refrigeration load regression formula), we calculated annual space-conditioning and display case power consumption at food stores. Figure 1 shows the calculation flow.

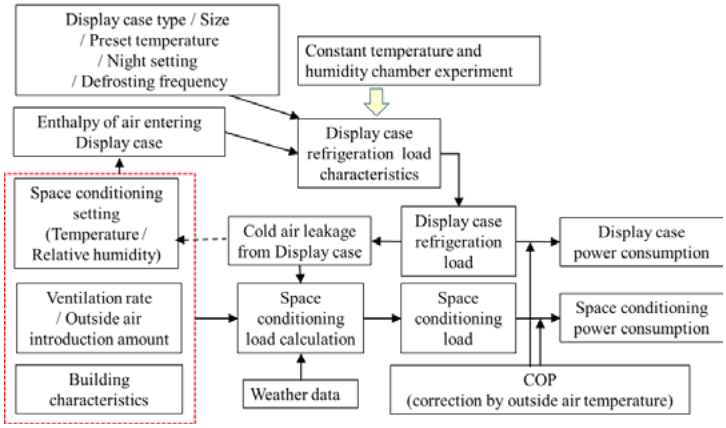


Fig.1. Calculation method of power consumption required for space conditioning and refrigeration

3. Energy consumption calculation for refrigeration

3.1. Energy consumption calculation for refrigeration

The display case refrigeration load characteristics were measured at constant temperature and humidity in the laboratory. There are two types of refrigerated temperature zones (multi-deck (MD (RE)) and semi-multi-deck (SMD (RE))) and three types of freezing temperature zones (multi-deck (MD (FR)) and flat tub (TUB (FR)) and glass door attachment (RI (FR))). Table 1 shows the outline of display case specifications, and Table 2 shows the specifications of refrigeration machines.

Table 1 Specification of the display cases refrigeration systems

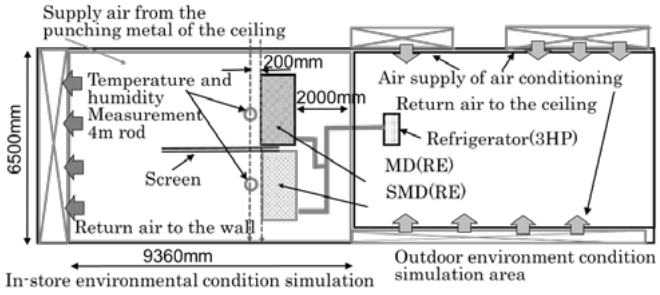
TYPE※1	MD(RE)	SMD(RE)	MD(FR)	TUB(FR)	RI(FR)
Operating Temperature (℃)	-2～2	-2～2	-20～-18	-20～-18	-20～-18
Effective Unobstructed Capacity(L)	1940	1477	1507	1180	1077
Outside Dimension(mm)	W 2440 H 1890 D1100	W 2440 H 1700 D1100	W 2440 H 1880 D1100	W2440 H810 D1810	W1430 H1905 D760
Required Refrigerating Capacity(kW)	2.22	3.04	3.75	1.84/1.47	0.6/0.5
Evaporating Temperature (℃)	-10	-10	-40	-40	-40
Defrosting Method	Off cycle	Off cycle	Heater	Heater	Heater

※1 MD(RE): an open refrigerated multi-deck display case SMD(RE): an open refrigerated semi multi-deck display case
MD(FR): a frozen multi-deck display case TUB(FR): a frozen tub display case
RI(FR): a frozen glass door reach-in display case

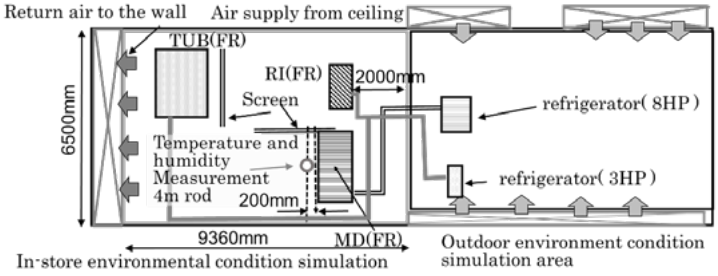
Table 2 Specification of refrigerator (Outdoor Environment: Temperature: 32 ºC Relative Humidity: 40%)

Items	refrigeration machine (3 HP)	efrigeration machine (8 HP
Working refrigerant	R410a	R410a
Evaporating Temperature (ºC)	-10	-40
Freezing capacity (kW)	7.77	6.70
Power consumption (kW)	3.5	6.5

MD (RE) and SMD (RE) were combined with a refrigeration machine (3HP), MD (FR) was combined with a refrigeration machine (8HP), and TUB (FR) and RI (FR) were combined with a refrigeration machine (3HP). The experimental equipment layout is shown in Figure 2, and the measurement items are shown in Table 3. For display case in the refrigerated temperature zone, the refrigeration load (total heat) was obtained from the sensible heat of the circulating air and the amount of drain discharged. For the freezing temperature zone display case, the refrigeration load was determined from the refrigerant enthalpy difference before and after the evaporator and the refrigerant flow rate.



(a) Experimental apparatus for refrigerated display case



(b) Experimental apparatus for frozen display case

MD(RE): an open refrigerated multi-deck display case
SMD(RE): an open refrigerated semi multi-deck display case MD(FR): a frozen multi-deck display case
TUB(FR): a frozen tub display case RI(FR): a frozen glass door reach-in display case

Fig.2 Layout of experimental equipment

Table 3 Measurement item and implementation method

Items	Measuring Location and method
Power consumption	Each device (refrigerator, case blower fan, Case lighting, heater)
Environmental measurement	Measurement 4m rod (8 points in temperature + 6 points in temperature and humidity)
Temperature and humidity Wind speed	Air curtain air supply and inlet (2 to 4 points for each display case air supply and inlet)
Refrigerant flow rate	Refrigerant piping for each display case
Weight of drain water	Continuous measurement of drain water of each display case

The experimental photograph of the multi-deck type is shown in Figure 3. Figure 4 shows the relationship between the display case refrigeration load at the time of stability and the enthalpy of the air entering the display case, obtained from experiments. If the enthalpy that enters the display case calculated from the enthalpy of the store air is input to these relational expressions, the refrigeration load of the display case can be calculated.

In order to correspond to the calculation for 24 hours, in addition to the steady load characteristics, the defrost time changed by the in-store air enthalpy, the load characteristics after defrost, and the load characteristics when installing the night cover in display case were also obtained from the experiment.

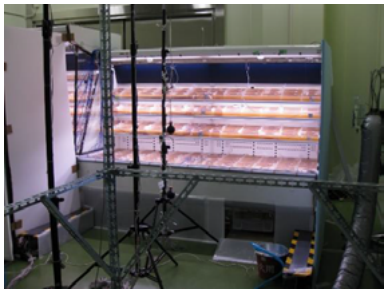
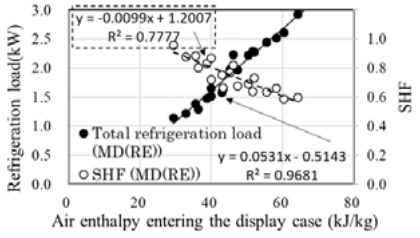
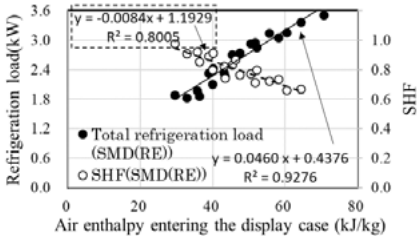


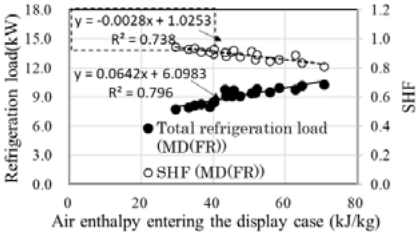
Fig.3 Experimental photo of the multi-deck display case



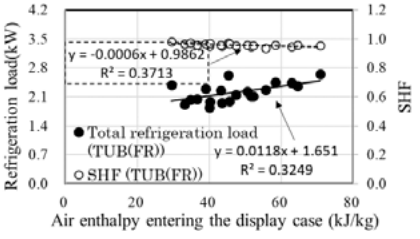
(a) MD(RE)



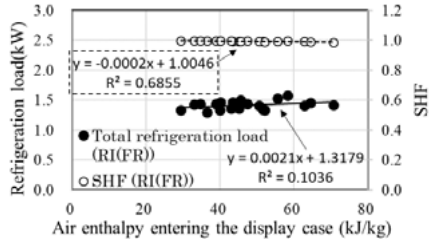
(b) SMD(RE)



(c) MD(FR)



(d) TUB(FR)



(e) RI(FR)

Fig.4 Relationship between refrigeration load, sensible heat factor and laboratory enthalpy

3.2. Calculation of power consumption for display case (refrigerator)

Various parameters are required to calculate the power consumption from the refrigeration load. In this study, (1) COP change due to evaporation temperature determined from display case preset temperature, (2) COP outside air temperature correction, and (3) refrigeration capacity decrease correction due to pipe length were formulated from manufacturer catalog values. In addition, a correction was made to increase the evaporation temperature when the display case load is small.

In order to confirm the validity of the calculation, the calculated value of the refrigerator power consumption was compared with the actual measurement value using the refrigeration load calculation and the refrigerator power consumption calculation method described above. The enthalpy of the store air which is used for the calculation, are the measured values on August 10, 2017. Table 4 shows the calculation conditions, and Figure 5 shows the calculation results. It was almost reproduced the load drop and the power consumption at night due to defrost.

Table 4 Display case load calculation conditions

Items	Calculation conditions
MDC(RE)	7℃ setting:18m / 0℃ setting:7.2m / -1℃ setting:9.6m
SMD(RE)	0℃ setting:9.6m / -1℃ setting:2.4m / -2℃ setting:9.6m / -2℃ setting:2.4m
Night setting	Setting to cover at night / Increase set temperature by 4 ° C
Defrosting times	4 times / day

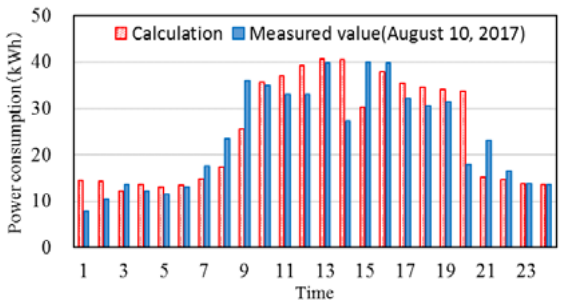


Fig. 5. Comparison of calculated and measured values for refrigerated power consumption

4. Energy consumption calculation for space conditioning

4.1. Outline of space conditioning load calculation

The space conditioning load is calculated by the building structure, ventilation, internal heat generation, indoor air temperature and humidity in the building as same. However, the space-conditioning of grocery stores is affected by the cold air leaking from the display case, so that the store temperature is not uniform. Although the horizontal temperature distribution does not become uniform depending on the arrangement of display case and the position of the entrance, we devised a calculation method that gives only the upper and lower temperature distribution with the horizontal temperature distribution being uniform.

First, the temperature and humidity near the ceiling were given, and the vertical temperature distribution was calculated. The building space conditioning load is calculated using the calculated vertical temperature distribution. Next, the intrusion enthalpy into the display case is calculated, and the refrigeration load is calculated using the enthalpy. The load obtained by subtracting the display case internal load (lighting and fan) from the refrigeration load becomes leakage cold, which reduces the building space conditioning load. The amount of heat obtained by subtracting the display case leakage cold air from the building space conditioning load is the net space conditioning load. A schematic diagram of the relationship between the vertical temperature distribution and the thermal load is shown in Figure 6. When the net space-conditioning load is negative, the temperature and humidity near the ceiling given first are lowered so that the net space-

conditioning load becomes zero. In this report, the food retail store shown in Table 5 was used as a model, and the load was calculated using a general-purpose load calculation program (BEST).

Table 5 Prerequisites for calculating space conditioning load

Items	Prerequisites	
Software	BEST program (Thermal load calculation function)	
Weather data	Extended AMEDAS (2010 edition) standard year Nagoya	
Sales floor area	2172m^2	
Floor height	5.6m（Ceiling height 4.0m）	
coefficient of overall heat transmission	Outer wall	1.26W/m^2・K
	Inner wall glass	4.27 W/m^2・K
	Inner wall	3.31 W/m^2・K
	Ceiling	0.73 W/m^2・K
Ventilation	Ventilation frequency 1 time / hour Gap Wind 0.1 times / hour	

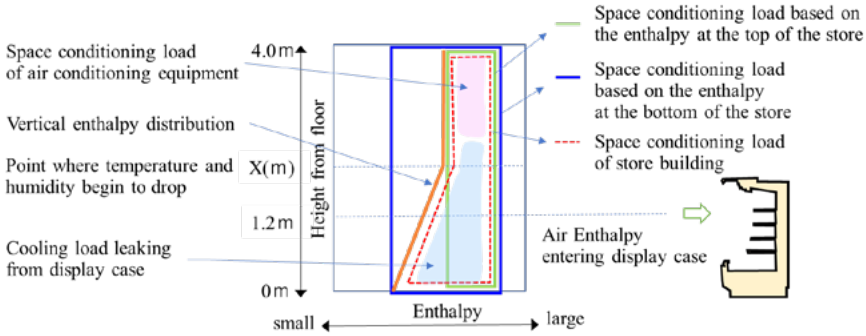


Fig. 6. Relationship between vertical temperature and humidity distribution, leakage heat from display case and space conditioning load

4.2. Determination method of vertical temperature and humidity distribution

The vertical temperature and humidity distribution were measured at the 24 points of the store in the November, where there was no space conditioning load. It is a grocery store with a sales floor area of 2172m^2 and a ceiling height of 4.0m. A floor plan view of the sore is shown in Figure 7. MD (RE) is installed on the wall of the store, and TUB (FR) and RI (FR) are installed. The average value of the measurement results is shown in Figure 8. Using the measurement results, it was assumed that the temperature and humidity would drop from FL + 2.0 m with a ceiling height of 4.0 m, and the space conditioning load calculation described above was performed. The building space conditioning load was 79 kW, and the cooling heat from display case was 70 kW, confirming that the two values were roughly balanced. In the subsequent calculations, it was assumed that temperature and humidity gradients occurred from FL + 2.0 m regardless of the season. The temperature / humidity gradient was calculated from the relationship between FL + 3.9m and FL + 1.2m obtained from annual measurement data.

4.3. Calculation method of space-conditioning power consumption

The calculation of power consumption required for space-conditioning was performed using a space-conditioning COP (outside air temperature correction only), assuming that no unprocessed load was generated and that all space-conditioning loads were processed by the space conditioner. It does not take into account the partial load characteristics resulting from the decrease in space conditioning load factor or the margin for space conditioning equipment. The rated COP is assumed to be 3.5 for cooling and 4.0 for heating.

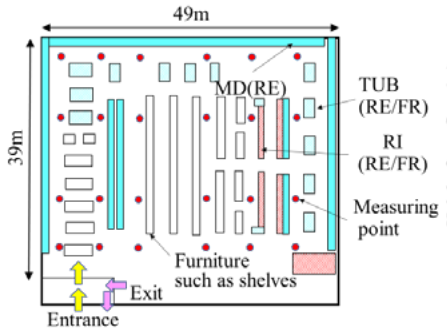


Fig. 7. Store floor plan and measurement points

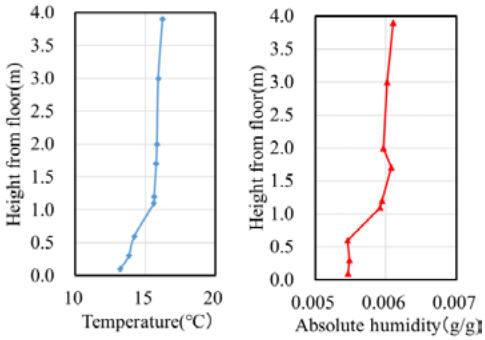


Fig. 8. Vertical distribution of average temperature and average absolute humidity

5. Calculation of power consumption for air conditioning and refrigeration energy

5.1. The validity evaluation of the calculation

The validity of the proposed energy calculation method was evaluated. For space conditioning and refrigeration energy, the results calculated using the standard weather data model (August 4) were compared with the measured data (August 10, 2017). As shown in Figures 9 and 10, the values and changes of space conditioning and refrigeration power consumption are well reproduced. Using this method, the energy saving effect by changing the space conditioning operation in summer was calculated.

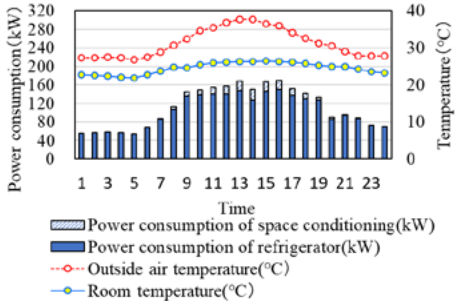


Fig. 9. Actual measurement (August 10, 2017)

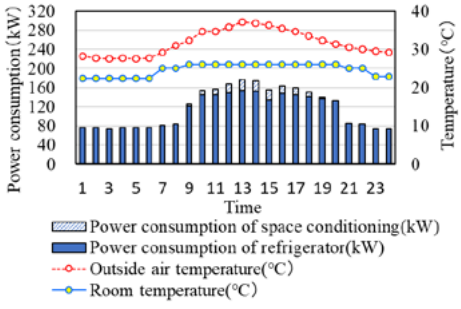


Fig. 10. Calculation (meteorological data August 4 Nagoya, Japan)

5.2. Calculation model and calculation cases

The space conditioning load calculation conditions are shown in Table 5 described above. Table 6 shows the display case conditions in the store. As shown in Table 7, there were 8 types of calculation cases. The weather model was a hot summer day (hot day: August 4) and a slightly cool day (cool day: September 25) in Nagoya, Japan. The space condition near each ceiling was set to 26 °C 60% to 20 °C 60%.

Table 6 Store display case conditions

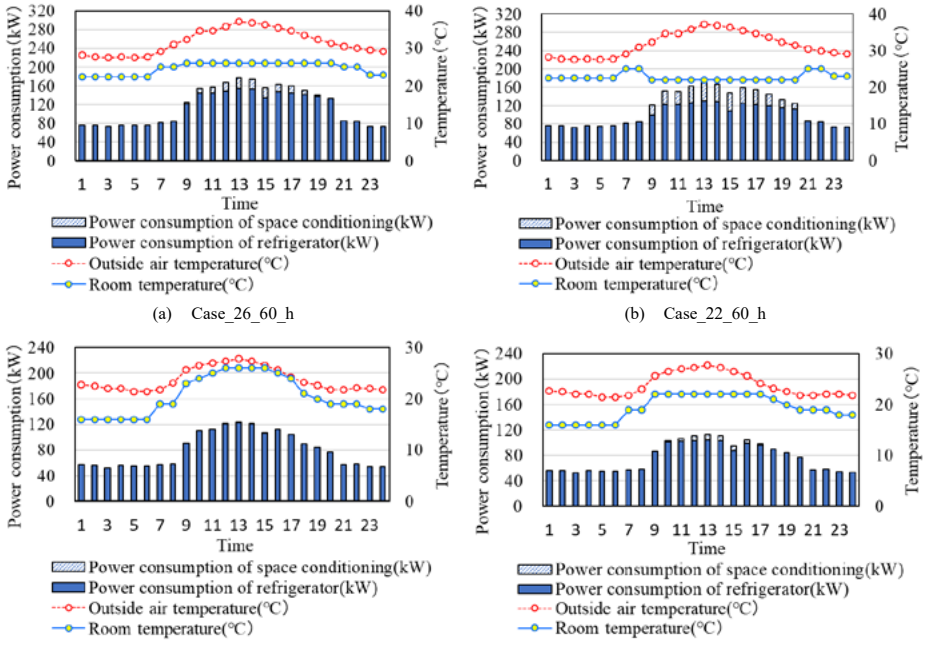
Items	Conditions
MD(RE)	3～9℃ setting:108m / -3～0℃ setting:50m
TUB(FR)	-3～0℃ setting:11m / -20℃ setting:14m
TUB(RE)	7℃ setting:43m
RI(FR)	-20℃ setting:33m
Night setting	Setting to cover at night / Increase set temperature by 4 ° C
Defrosting times	Refrigerated display case: 4 times / day Freezing zone display case: 2 times / day

5.3. Calculation results

Figure 11 shows the time changes for case_26_60 and case_22_60. Even on a hot day in summer, at 26 ° C near the ceiling, the display case leakage cold and the building space conditioning load balance, and there is almost no true space conditioning load. Under any conditions, increasing the space conditioning load decreases the total power consumption of refrigeration and space conditioning. The shape of the energy consumption curve, which is the sum of refrigeration and space conditioning, shows almost no change in any condition, indicating that the display case load has moved to the space conditioning. Japan's electricity charges are greatly affected by the annual peak power. For this reason, it is important to shift the display case load to the space conditioning load to suppress the peak of power consumption. Moreover, if the load shared by space conditioning increases, operation control for peak suppression can be performed by space conditioning instead of display case. This increases the ease of control.

Table 7 Calculation case

Case name	Temperature and humidity near the ceiling	Weather conditions (Extended AMEDAS)
Case_26_60_h	26℃ 60%	(2010 edition) standard year Nagoya August 4, 2006 Lowest Temperature : 27.6℃ Highest temperature : 37.2℃
Case_24_60_ h	24℃ 60%	
Case_22_60_h	22℃ 60%	
Case_20_60_h	20℃ 60%	
Case_26_60_c	26℃ 60%	(2010 edition) standard year Nagoya September 25, 2006 Lowest Temperature : 21.4℃ Highest temperature : 27.8℃
Case_24_60_c	24℃ 60%	
Case_22_60_c	22℃ 60%	
Case_20_60_c	20℃ 60%	



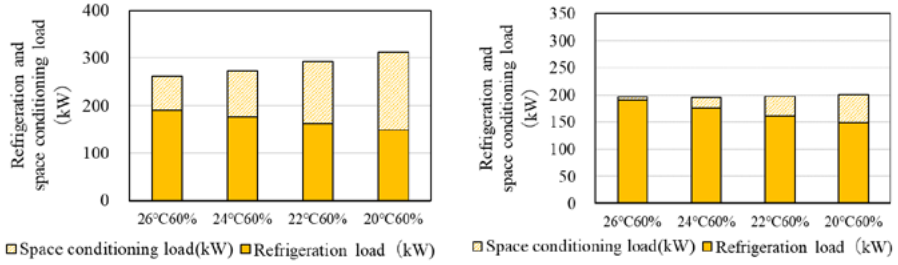
(a) Case_26_60_h (b) Case_22_60_h

(c) Case_26_60_c (d) Case_22_60_c

Fig. 11. 24-hour transition of power consumption for space conditioning and refrigeration

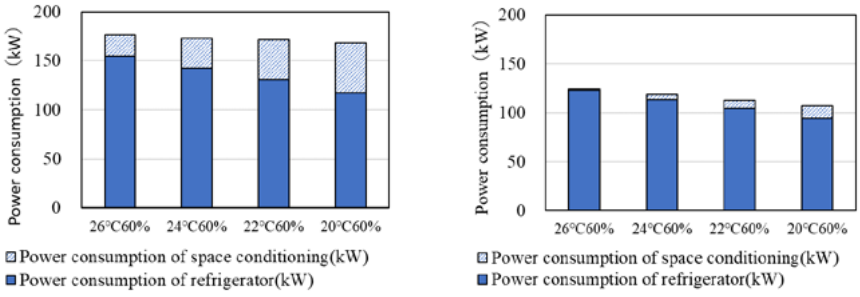
Take the time of 13:00 in each calculation case and compare in detail (Figures 12 and 13). As the temperature near the ceiling decreases, the rate at which the display case load shifts to the space conditioning load increases, and the energy consumption is suppressed by the difference between the display case and the

COP of the space conditioning. Energy savings due to the shift to display case load space conditioning are smaller in hot day where the temperature is high than in cool day where the temperature is low. The reason is that the COP of the space conditioner is more susceptible to the outside air temperature than the COP of the refrigerator, and the space conditioning load for controlling the store temperature and humidity is increased. Compare the amount of power saved each day in each case based on case_26_60 (Figure 14). Compared to hot day, the total power consumption of space conditioning and refrigeration in cool day decreases as the outside air temperature decreases, but the amount of energy saving increases compared to hot day. In grocery stores, the thermal environment has deteriorated due to cold air leakage from display case, so it is difficult to reduce significantly the space conditioning temperature in the store when the outside air temperature is high. However, if the outside air temperature decreases, the amount of clothes increases, so it is easier to reduce the store temperature than in midsummer. In order to save energy in the summer, it is important to control the space conditioning and shift the display case load to the space conditioning load in early summer and early autumn.



(a) Hot day (b) Cool day

Fig.12 Relationship between temperature and humidity near the ceiling, refrigeration load and space conditioning load



(c) Hot day (d) Cool day

Fig. 13. Relationship between temperature and humidity near the ceiling, refrigerated power consumption and space conditioning power consumption

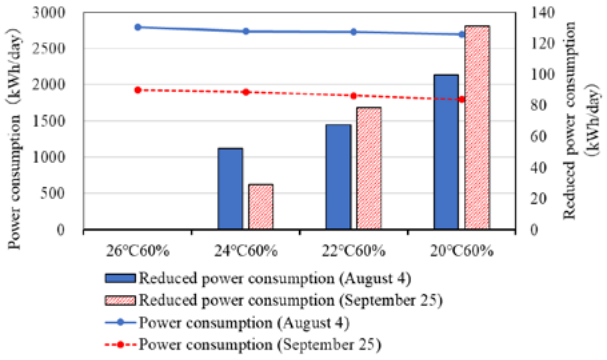


Fig. 14. Comparison of power saving of daily power consumption of refrigeration and space conditioning for each temperature and humidity near the ceiling

6. Conclusions

In this report, we proposed a method to give ingress air enthalpy to display case considering the vertical temperature and humidity distribution in the store. We changed the temperature and humidity in the store, and calculated the energy consumption in summer using a real store as a model. We investigated how changes in store temperature and humidity affect the relationship between space conditioning and display case load, and obtained the following knowledge. In the future, we proceed with consideration for the heating conditions.

1) If the temperature and humidity in the store are lowered by space conditioning, the total power consumption of refrigeration and space conditioning will be reduced.
2) It was found that the temperature inside the store decreased due to the cold leaked from the display case, and the space conditioner hardly operated under the condition of 26 °C near the ceiling. In order to save energy by operating space conditioning, it is necessary to greatly reduce the temperature to 22 °C or 20 °C.
3) Under the same store temperature and humidity conditions, the energy saving effect is greater at a low outside air temperature than at a high outside air temperature. Further, when the outside air temperature is low, it is easy to set the store temperature low, and energy saving can be expected. For this reason, it is important to use space conditioning well during the intermediate period such as early summer and early autumn.

Acknowledgements

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