Energy-Saving Measures for Stores

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ABSTRACT

Retail outlets such as convenience stores have been further required to save energy. Meanwhile, store comfortability is also need. Fuji Electric's store environment analysis using an index called predicted mean vote (PMV) suggested the effectiveness of controlling the temperature setting of air conditioners during the summer. We have also developed an outdoor air intake system to reduce the load on showcases by using cold outdoor air during the winter. The results of using thermal fluid analysis software showed that the system can reduce the power consumption of showcases installed in typical stores by 1.84 kWh.

1. Introduction

In order to respond to the growing social demand to combat global warming, the convenience store industry is working on various energy-saving measures. In this regard, individual stores are being required to further reduce power consumption. Although it is conceivable to reduce air conditioning as an energy-saving measure in stores, it is not easy to implement in practice because of concerns that the resulting loss of comfort in the store may affect the number of customers and sales. Fuji Electric has been contributing to reducing power consumption in stores by pursuing higher efficiency in individual pieces of equipment such as showcases and developing positive pressure control systems that improve air conditioning efficiency. In order to further contribute to energy saving, we have begun to work toward comprehensive energy saving that reduces the power consumption of the entire store, taking into account of even comfort, rather than optimizing individual equipment and systems.

In this paper, we will describe measures to achieve both energy saving and comfort from the viewpoint of the entire store, focusing on operational methods for showcases, positive pressure control systems,[1] air conditioners, ventilation systems, and other equipment.

2. Energy-Saving Issues at Stores

Figure 1 shows the percentage of electricity consumed by typical store equipment. More than 70% of the total is occupied by air conditioning, refrigerated and freezer equipment, and heating and warming equipment, where Fuji Electric can contribute to energy saving. We have been improving the efficiency of showcases, which are refrigerated and freezer equipment with high power consumption, reducing their power consumption to the same level as that of heating and warming equipment. Furthermore, we have developed positive pressure control systems that improve the operating efficiency of air conditioning equipment by maintaining the air pressure inside the store at a pressure slightly higher than the air pressure outside the store. As shown in Fig. 1, the difference in the ratio of power consumption at present is 25% for refrigerated and freezer equipment, 26% for heating and warming equipment, and 20% for air conditioning equipment.

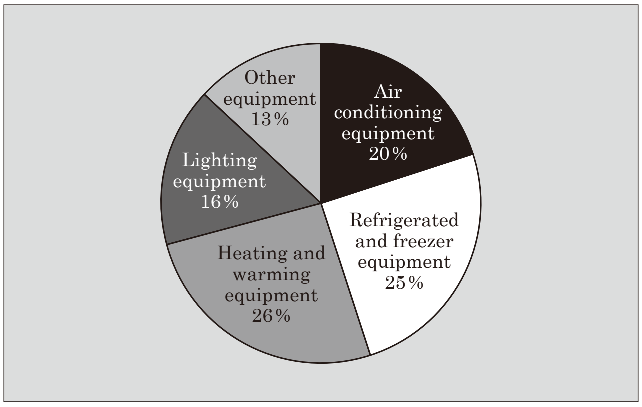

Fig.1 Percentage of power consumption by equipment

Although optimization of individual equipment has been pursued until now as described above, pieces of thermal equipment interact with each other in power consumption. To further save energy, the operating conditions of these equipment and systems thus must be coordinated so that they optimize the entire store.

In order to reduce the power consumption of the entire store, it is necessary to visualize the overall heat balance. We investigated the heat balance of an

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Fig.2 Appearance of the simulated experimental store

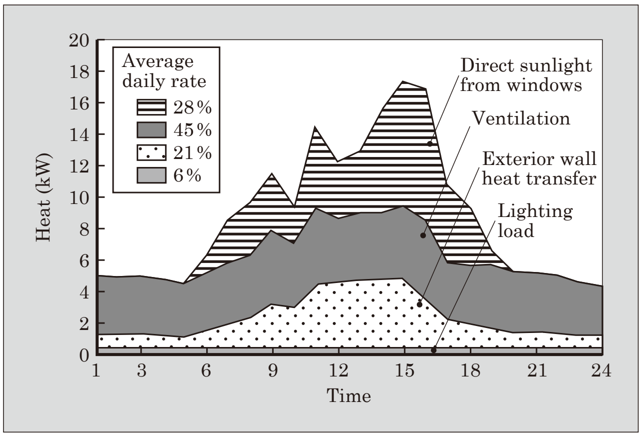

Fig.3 Percentage of heat entering stores

actual store using a simulated experimental store set up on the premises of Fuji Electric's Mie Factory, as shown in Fig. 2. Figure 3 shows a time-series graph of the amount of heat entering the store on a single day in June. We can see that the amount of heat entering the store varies more than threefold between night and day. Furthermore, the amount of heat entering the store varies not only on a daily basis, but also on a seasonal basis. It is necessary to consider energy-saving measures in response to such changes in the external environment.

3. Considerations to Achieve Both Energy Saving and Comfort

3.1 Modeling the entire store

The overall power consumption of the store and the comfort of the inside of the store are greatly affected by the external environment, such as the season and the weather. The simulated store shown in Fig. 2 is located outdoors, its external influences cannot be controlled, making it difficult to systematically demonstrate the effect of the energy-saving measures in the simulated store. Therefore, we decided to model the entire store and utilize simulation. Figure 4 shows the model used for in-store analysis. The model had air conditioning units, showcases, and magazine shelves,

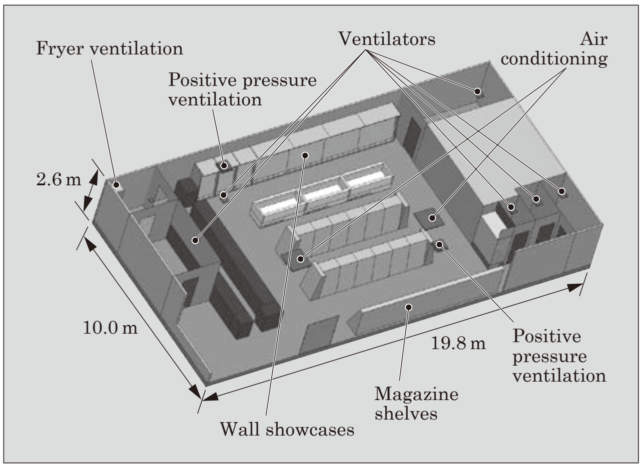

Fig.4 Model used for in-store analysis

which were arranged in the same way as in the simulated store in Fig. 2. The model can be modified in settings, such as air conditioning settings, the amount of ventilation for the positive pressure control system, and even the number of air conditioning units in operation. As for external environmental factors, the outside temperature and solar radiation can be changed and analyzed.

3.2 Comfort evaluation index PMV

In order to study the compatibility of energy saving and comfort, it is necessary to introduce a comfort evaluation index. This study therefore uses an index called the Predicted Mean Vote (PMV). PMV was published based on the comfort equation derived by Fanger[(2)] and became an international standard in 1994. PMV is distinctive in that it uses the thermal sensation, rather than sensible temperature, as the index. It is calculated by adding the four environmental factors that determine the thermal sensation [air temperature (°C), relative humidity (%), wind speed (m/s), and thermal radiation (°C)] to the two human factors [metabolic rate (met) and amount of clothing (clo)]. The PMV rating scale is based on the predicted percentage of dissatisfied (PPD), which indicates the percentage of people who are dissatisfied or uncomfortable with the thermal environment. Table 1 shows PPD and PMV for the thermal sensation. In terms of the PMV index, PMV

Table 1 PPD and PMV for sensation of warmth and coolness

Thermal sensation	Predicted percentage of dissatisfied (PPD) (%)	Predicted mean vote (PMV)
Hot	99	+3
Warm	75	+2
Slightly warm	25	+1
Neutral	5	±0
Slightly cool	25	−1
Cool	75	−2
Cold	99	−3

= 0 is considered neutral, and PMV = ±3 is considered unpleasant by as many as 99% of people.

3.3 Analysis-based correlation evaluation of energy saving and comfort

(1) Analysis conditions

We performed analysis using the model described in Section 3.1 and thermo-fluid analysis software. Factor assignment was performed using the design of experiment method for the analysis conditions to determine the impact of each factor. Table 2 shows the conditions of the analysis parameters. Here, the air conditioning blowout angle is specified as 0° when blowing horizontally with the ceiling, and the number of air conditioners is normally specified as two independently operated air conditioners. Reference values are also listed for control factors. For the human factors of the PMV calculation, the clothing of outdoor visitors was assumed, with 0.6 clo as the amount of clothing representing typical clothing in summer, and 2.0 clo representing clothing in the winter. The metabolic rate was set to 1.4 met, which represents standing posture in both summer and winter. To evaluate energy savings and PMV, we used sensitivity analysis to determine the effect of each factor on total power consumption (energy efficiency), which represents the sum of air conditioning, ventilation, and refrigerated equipment, as well as on PMV (comfort), which represents the average of space in the store. By doing this, we examined how to control energy saving.

Table 2 Conditions of analysis parameters

	Factor	Analysis conditions (criteria)
Control factors	Air conditioning temperature setting (°C)	22, 25, 28 (Reference: 25)
Environmental factors	Air conditioning blowout airflow (m^3/h)	1,200, 1,620, 1,800 (Reference: 1,620)
	Air conditioning blowout angle (°)	20, 40, 60 (Reference: Swing)
	Qty. of air conditioners in operation	1, 2 (Reference: 2)
	Positive pressure ventilation rate (m^3/h)	1,000, 1,400, 1,800 (Reference: Automatic)
	Outdoor air temperature (°C)	Summer: 28, 32, 36 Winter: 0, 5, 10
	Sunlight	Without sunlight; shading; and with sunlight

(2) Analysis results

Figure 5 shows the results of total power consumption and PMV sensitivity analysis under summer conditions, and Fig. 6 shows the results of total power consumption and PMV sensitivity analysis under winter conditions. The left vertical axis and the black plot represent the total power consumption, with smaller values being preferable. The right vertical axis and gray plot is PMV, with values close to zero being pref-

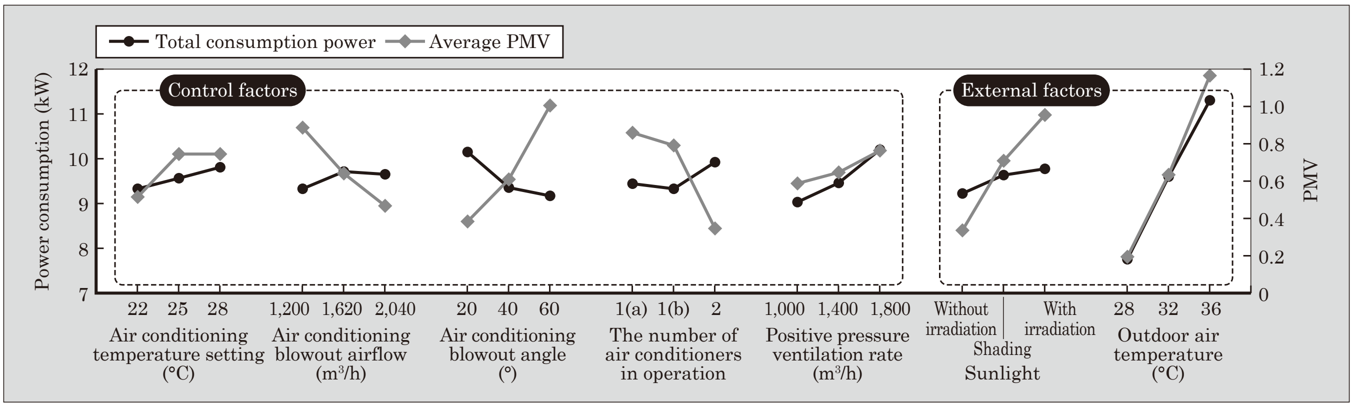

Fig.5 Sensitivity analysis results of summer total power consumption and PMV

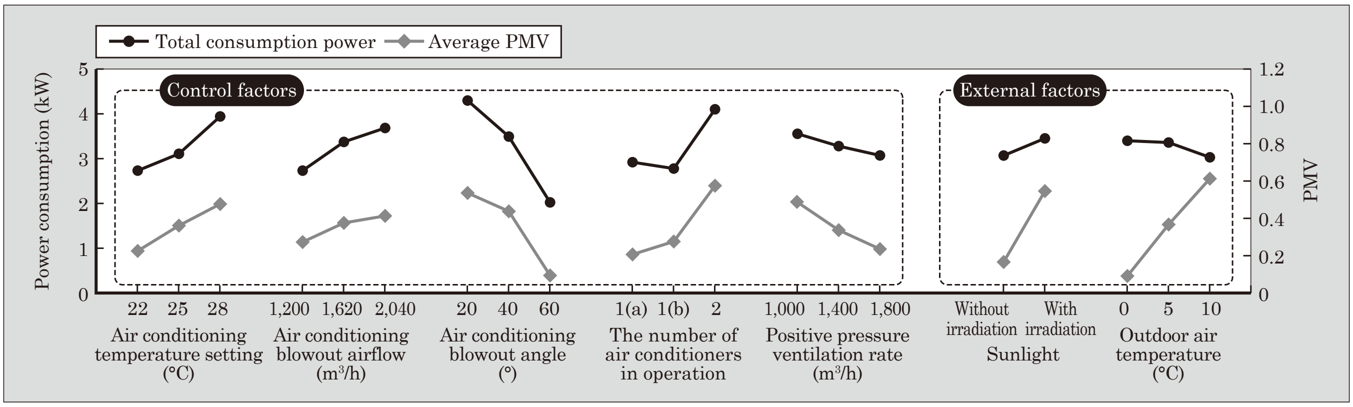

Fig.6 Sensitivity analysis results of winter total power consumption and PMV

erable.

Under summer conditions, by focusing on the air conditioning blowout angle as a control factor, we found that the larger the blowout angle, the smaller the power consumption and larger the PMV, indicating that it is difficult to achieve both energy saving and comfort. Due to the large slope of the PMV, we found that maintaining a small air conditioning blowout angle was effective in improving comfort. We also discovered that trends in power consumption and PMV were the same at the set air conditioning temperature and positive pressure ventilation rate, indicating that both energy saving and comfort can be achieved. Both power consumption and PMV can be reduced by lowering the set air conditioning temperature, in contrast to the generally recognized trend to save energy by raising the set air conditioning temperature. We believe this is because showcases consume more power than air conditioners in stores, and lowering the air conditioning temperature setting improves the power consumption of refrigeratied equipment, resulting in lower overall power consumption.

Under winter conditions, we found that the control factors showed the same trend in power consumption and PMV, indicating that energy saving and comfort are highly compatible. In terms of the positive pressure ventilation rate, the more ventilation is increased, the more energy is saved. We think the reason for this is that, similar to summer, the temperature around the showcases drops due to the outdoor air, reducing the power consumption of refrigerated equipment.

Since this analysis assumes that there will be outdoor visitors, we can expect differences in PMV among store clerks and visitors who use various modes of transportation. We plan to verify this in the future.

3.4 Proposed measures to balance energy saving and comfort in winter

Analysis of summer conditions showed that lowering the temperature around showcases was effective in reducing overall store power consumption. Therefore, as a measure to save energy in winter, we examined the use of an outdoor air intake system as a way to effectively use cold outdoor air through ventilation. Figure 7 shows an overview of the outdoor air intake system. By allowing cold outdoor air to blow downward from above the showcase during the winter months, we expect the air curtains to be less warmed by contact with the air inside the store, resulting in less energy required to cool the air supplied to the air curtains.

The energy saving effect of the outdoor air intake system was calculated using thermo-fluid analysis software. Figure 8 shows the power consumption for a single three-foot-long showcase relative to the airflow rate. We calculated the heat load on the showcase by setting the outdoor air temperature to 5°C and varying the airflow rate of the outdoor air, and then calculated the amount of power consumed for a single showcase. We found that power consumption decreases as the blowout airflow rate of the outdoor air intake increases. Figure 6 shows that a positive pressure ventilation rate of 1,800 m^3/h, which is the maximum airflow rate, can reduce power consumption by 0.23 kWh compared with the rate of 0 m^3/h. Although the configuration of showcases varies depending on the type of store, power consumption can be reduced by 1.84 kWh for a 24-foot-long unit installed in a standard store.

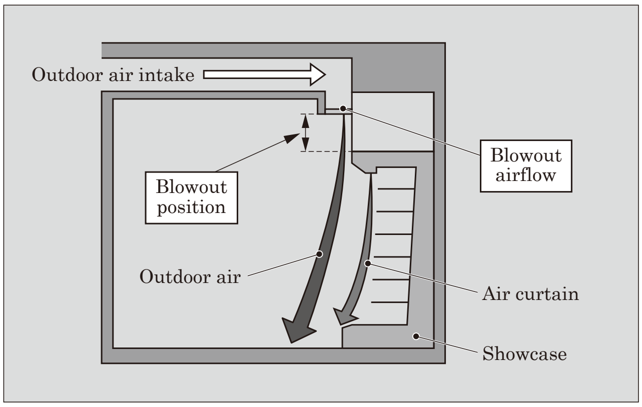

Fig.7 Overview of the outdoor air intake system

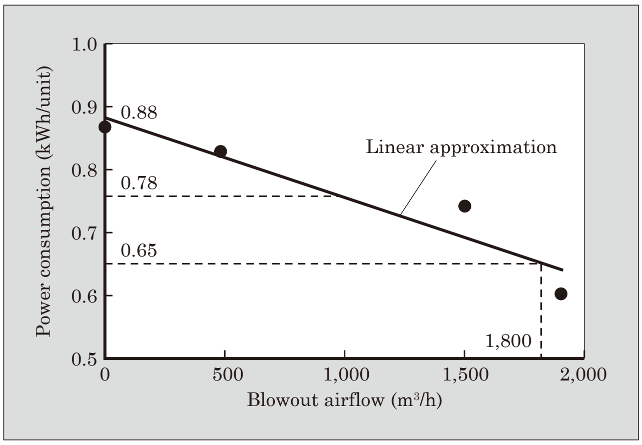

Fig.8 Power consumption for a single three-foot-long showcase relative to the airflow rate

4. Postscript

This paper described energy-saving measures for stores. In addition to clarifying the effect of air conditioning and ventilation on comfort and energy saving, we found that it is possible to achieve both energy saving and comfort by effectively adjusting the air conditioning temperature in the summer and utilizing outdoor air in the winter. In the future, we plan to verify the findings of these analyses through long-term evaluations in a simulated experimental store, and establish energy-saving design guidelines for convenience stores that take comfort into account.

References

(1) Terawaki, H. et al. Store Air Conditioning Solution to

Save Storewide Labor and Energy. FUJI ELECTRIC REVIEW. 2019, vol.65, no.1, p.33-38.
(2) P.O.Fanger, Thermal comfort, Danish Technical Press,1970.

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