Store Air Conditioning Solution to Save Storewide Labor and Energy

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ABSTRACT

In the supermarket and convenience store industries, there has been increasing demand to save labor and energy for store equipment. We have developed an in-store heat balance analysis tool that targets storewide heat load and airflow. The accuracy of heat balance calculation has been improved dramatically by performing analysis in consideration of store location conditions, size, equipment configuration, and layout. By using this tool, we found that the intrusion of outside air through the doors is responsible for a large percentage of the store's heat load. To reduce the air invasion, we developed a positive pressure control system that equalizes differential pressure inside and outside the store. We confirmed an energy savings effect of about 10% for stores that implement positive pressure control using our equipment for evaluating store performance.

1. Introduction

In the supermarket and convenience store industry, the demand for labor savings on in-store works and energy savings on store equipment has been significantly increasing in order to respond to intensified environmental regulations and labor shortages caused by the declining birthrate and aging population.

Fuji Electric has been committed to energy-saving solutions centered on equipment such as showcases. However, in an effort to increase sales, stores have been increasingly using cooling and heating equipment, and this has increased electricity usage per store. In order to save energy, it is important to have a comprehensive view that considers the heat balance relationship not only for single-unit equipment, but also for the entire store.

In this paper, we describe an air-conditioning solution for stores that aims to achieve storewide labor savings and energy savings by using an in-store heat balance analysis tool and positive pressure control system that prioritizes heat loads and in-store air flow from the perspective of the entire store.

2. Current Challenges and Development Aims

Actual stores differ with respect to various conditions such as location, size, store equipment configuration and customer volume. Likewise, there are various factors to consider in regard to increasing or decreasing power consumption, and as a result, approaches to energy savings also differ.

For example, the temperature distribution and airflow in stores are greatly influenced by the air conditioners and equipment layout. Therefore, simply introducing a system to control the entire store may not produce the desired effect.

Therefore, we have developed an analysis tool capable of analyzing the heat balance of the entire store through hot airflow analysis based on the layout of air conditioners and cooling and heating equipment in the store as well as the impact of airflow.

By using the analysis results, we build a positive pressure control system that controls the atmospheric pressure in the store to create a comfortable store environment while saving energy and reducing labor for cleaning of the entire store.

3. In-Store Heat Balance Analysis Tool

Figure 1 shows the configuration of the developed in-store heat balance analysis tool. The in-store heat balance analysis tool is composed of several units, including a user interface to input store conditions for calculation and display the results, a heat balance calculating unit that calculates the heat balance for the entire store seasonally and hourly, and a heat and airflow analysis unit that calculates the in-store temperature and humidity distribution required for the heat balance calculation.

The user interface and heat balance calculating unit use general-purpose spreadsheet software to ensure ease of use. The heat and airflow analysis unit uses general-purpose heat and airflow analysis software. The heat balance required for the design of the store is calculated by linking these two software applications together.

In order to study how to save storewide energy and optimize store layout using the simulation, it is important to first reproduce the actual conditions of the target store. Therefore, by using the in-store heat bal-

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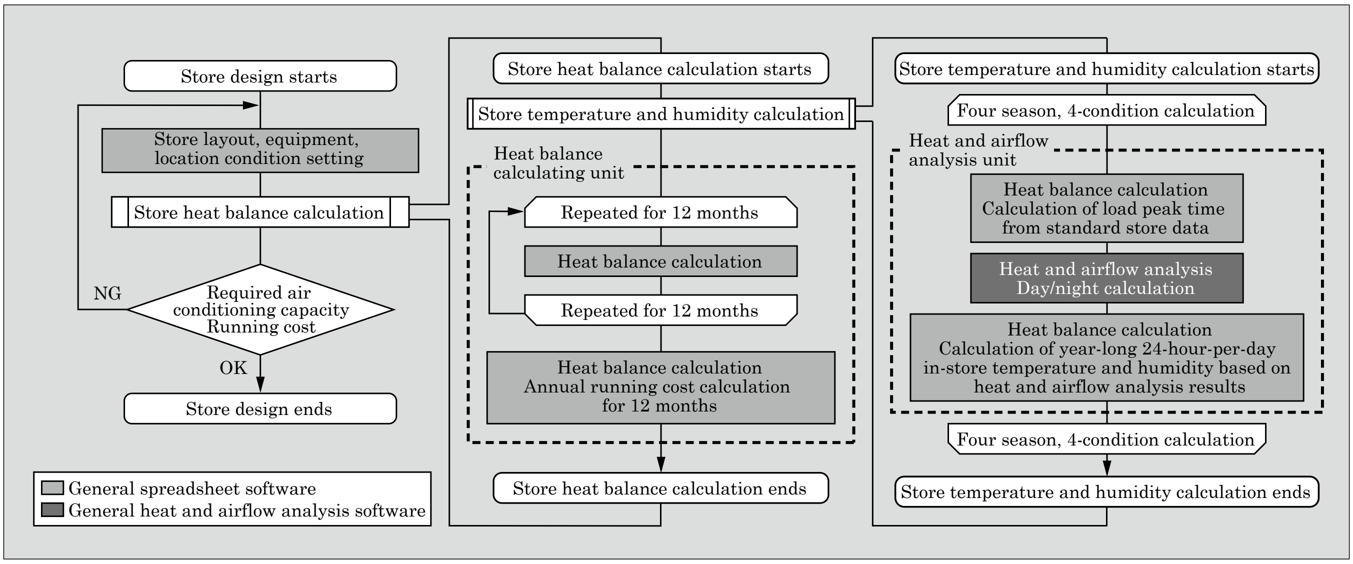

Fig.1 In-store heat balance analysis tool

ance analysis tool, users can consider various factors, such as the locational conditions and scale of the store, types and number of store equipment (equipment configuration), store layout and customer volume. As a result, it is now possible to analyze the in-store temperature distribution in detail and obtain a significantly more accurate heat balance calculation. This tool makes analysis more user friendly because it also enables users to visualize airflow inside the store.

In addition to equipment configuration and layout, other significant factors include changes in the outside environment due to the seasons and time slots. We therefore allow the tool to use various past test results to reflect changes in year-long environmental parameters, such as temperature and humidity, in the analysis.

3.1 Heat balance calculating unit

Figure 2 shows the parameters considered when calculating with the heat balance calculating unit. Stores are equipped with various types of equipment, such as cooking equipment including fryers, separate-type showcases, built-in showcases, air conditioners, and ventilation fans. With regard to heat loads, it is necessary to consider not only the heat generated by lighting, cooking and food warming devices, and the exhaust heat of built-in showcases, but also to take into account outside air intrusion from doors and ventilation fans, heat invasion from solar radiation and wall surfaces, as well as heat generated by the human body. These types of invading heat and heat sources are cooled using the cool air from air conditioners and showcases to maintain a heat balance.

Figure 3 shows heat balance calculation results. By entering information such as the types and number of store equipment and outside air conditions, it is possible to calculate the heat load, power consumption and running cost for each factor, including intrusion of outside air, solar radiation, and showcases, on an hourly basis 24 hours a day. If an annual power consumption were calculated from the seasonal averages, it would have a large error. The tool therefore calculates it on a one-month basis to provide accurate predictions.

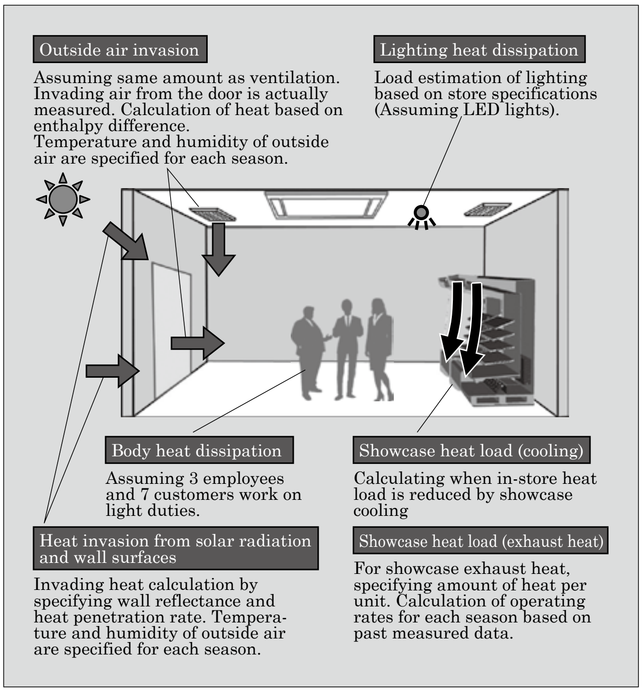

Fig.2 Parameters considered by the heat balance calculating unit

3.2 Store heat and airflow analysis unit

To improve the calculation accuracy of the in-store heat balance analysis tool, accurate temperature and humidity data are needed. Up until now, the accuracy of calculation results has been problematic because the actual temperature and humidity data of existing

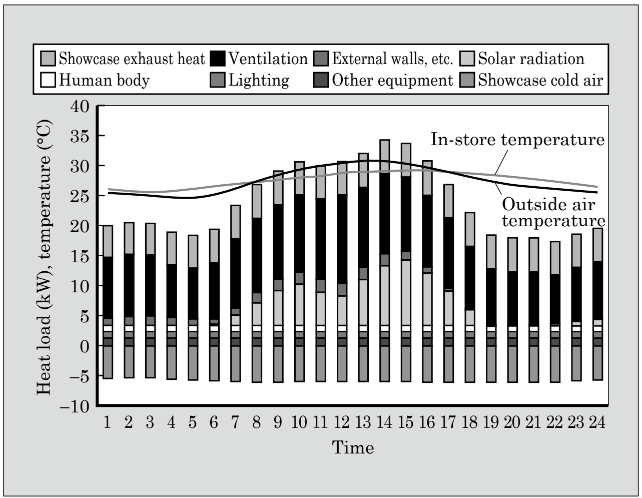

Fig.3 Heat balance calculation results

stores, which differ in store layout and parameters, as shown in Fig. 2, has been reused. Therefore, the heat and airflow analysis unit now uses general-purpose heat and airflow analysis software to accurately predict temperature and humidity.

Figure 4 shows the model used for the in-store heat and airflow analysis. The model reproduces the configuration for air conditioners, showcases, island gondolas, counters and ceiling ducts. It also reproduces the layout for eating areas, walk-in cases, storage rooms, restrooms, and office spaces. The natural convection, temperature and humidity of the internal air are also considered when performing analysis with the simulation. The influence of solar radiation, ground heat and heat generated by ceiling lighting fixtures is also considered, along with boundary conditions that include the air conditioner outlet air and intake air, air curtains of showcases, the generated heat of fixtures, and the cooling and ventilation of walk-in cases.

The cold air leakage of showcases and exhaust heat of built-in showcases have a great impact on the temperature and humidity inside a store. Therefore, we equipped this analysis tool with an equation that can calculate the amount of exhaust heat and cold air

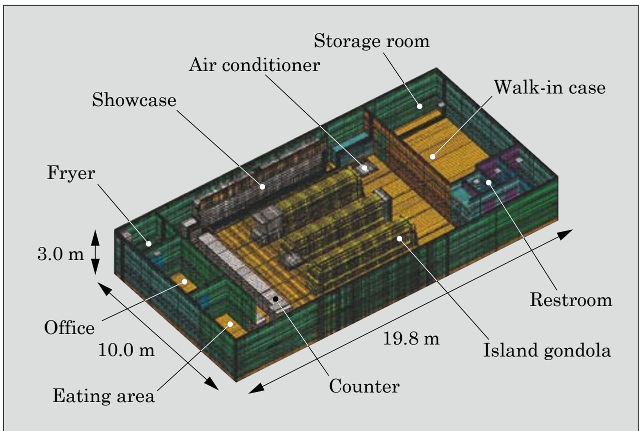

Fig.4 Heat and airflow analysis model

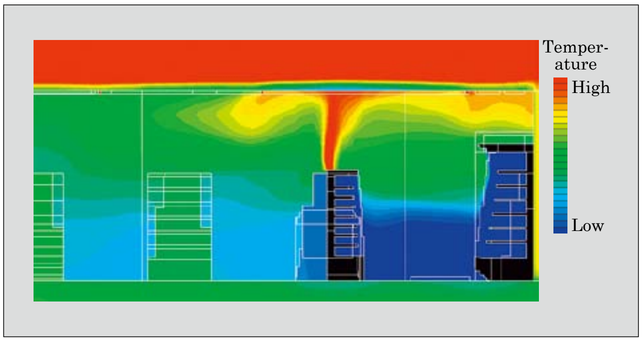

Fig.5 Temperature distribution based on heat and airflow analysis

Fig.6 Appearance of simulated store

by calculating the operating rate of the showcases according to the temperature and humidity inside the store. In addition, we compiled analysis models for showcases, island gondolas, and air conditioners into a library to accommodate seasonal conditions, equipment replacement, and layout changes. We also designed the tool so that it could respond quickly to customer requirements by taking into consideration operability, enabling simulations to be performed without a help of professional analyst.

Figure 5 shows the temperature distribution inside a store where summer-time heat and airflow analysis was performed. It was for the simulated store for experiment shown in Fig. 6. It recreated the ceiling temperature, built-in showcase exhaust heat and air curtain cold air leakage. We confirmed that the temperature distribution of the analysis and the actual in-store measurements were almost identical.

3.3 Power consumption calculation results

We first obtained the in-store temperature distribution using heat and airflow analysis and then inputting the results into the in-store heat balance analysis tool to calculate the amount of power consumption. Compared with conventional methods, this tool improves the accuracy of power consumption calculations and only has a margin of error of ±12% with respect to actual measurements (see Fig. 7).

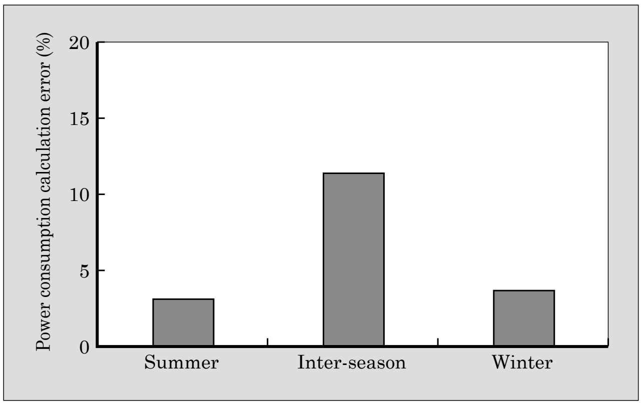

Fig.7 Calculation error in power consumption calculated with the in-store heat balance analysis tool

4. Positive Pressure Control System

4.1 System-based suppression of outside air invasion

We analyzed the heat balance of standard convenience stores by using the developed in-store heat balance analysis tool. As shown in Fig. 8, we learned that the invasion of outside air that enters from the automatic door at the entrance of the store occupies a large percentage of the store's heat load. Reducing the amount of invading outside air lead to prevent unclean air from entering the store, in turn, reduce the labor required to clean the store, and contribute to creating a comfortable store environment. Therefore, we studied technology for suppressing the invasion of outside air from the automatic doors.

In general, there is a large amount of ventilation needed to discharge fryer and restroom odors from a store. The air pressure in the store becomes lower (negative pressure) than that outside. As a result, outside air pours through the automatic door according to the differential pressure. We discovered that when the automatic door opens under a state of negative pressure, a large airflow is generated that invades through the door at a rate higher than that required to offset the pressure difference.

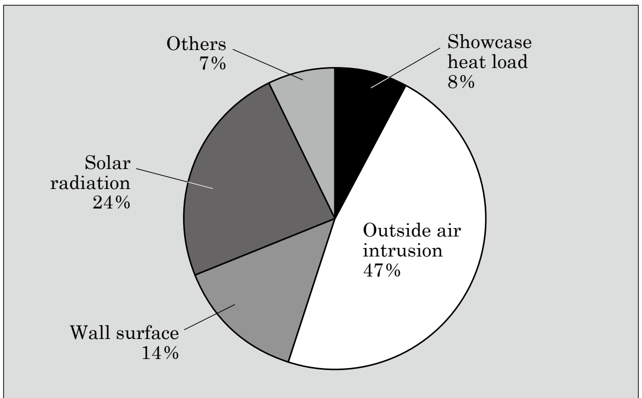

Fig.8 Heat load factor analysis results for air conditioning system

Therefore, we devised a positive pressure control system to keep the air pressure in the store higher than the outside air pressure (positive pressure). In operating rooms, sterilized rooms and food factories, positive pressure is implemented inside the room to prevent unclean air from entering the room. When applied to a store, excessive positive pressure will expel the temperature-controlled air from the inside of the store, increasing energy consumption. Therefore, it is necessary to attain an inexpensive "uniform pressure" controlled with high precision so that the differential pressure between the inside and outside of the store is as low as possible.

4.2 System configuration

In order to maintain a positive pressure inside the store, the system prevents the invasion of outside air by using a positive pressure fan to supply air inside the store from the supply inlet according to the pressure difference between the inside and outside of the store detected by the differential pressure sensor, as shown in Fig. 9.

The speed of the positive pressure fan is controlled according to the pressure difference between the inside and outside of the store by feedback control, thereby enabling high-precision control even in stores with different conditions. In addition, we designed the sensor structure to be insusceptible to outside air disturbances due to wind to improve precision in combination with filter signal processing.

Figure 10 shows an image visualizing the invasion of outside air from the doors. Positive pressure control, which suppresses the invasion of outside air from the door, prevents hot air from entering the temperature-controlled store in summer and cold air from entering in winter, thereby reducing air-conditioning loads.

In this system, the air supply fan is installed where it can avoid becoming heat load by preferentially expelling invading air from the store. In particular, we gave consideration to the layout of the air conditioners and ventilation of the store and installed air supply fans at locations where there is a large amount of air conditioning and ventilation such as between

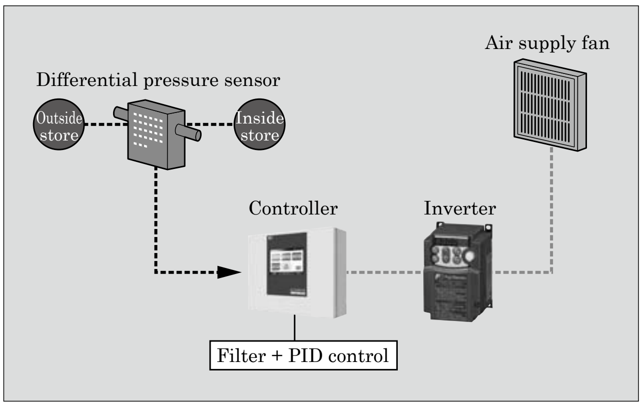

Fig.9 Positive pressure control system

Fig.10 Effect of reducing intrusion of outside air from doors

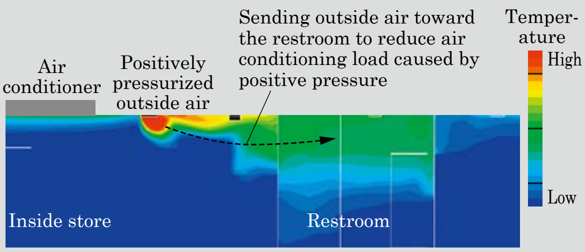

Fig.11 In-store temperature distribution at time of outside air intrusion

air conditioners and fryers or restrooms. Figure 11 shows the analysis results using the heat and air flow analysis simulation. The outside air used for creating positive pressure ventilates a fryer and restroom, contributing to reducing the impact on the air conditioners and lowering the building cost of a positive pressure system.

5. Facility for Evaluating Store Performance

A comprehensive performance evaluation through field testing takes about one year in consideration of the four seasons. Furthermore, it is necessary to consider differences in location and weather conditions. Fuji Electric operates the facility for evaluating store performance shown in Fig. 12. The actual store is reproduced in a huge temperature-controlled room where we simulate outside atmospheric conditions for the whole country for all four seasons day and night in order to verify the effect of energy savings.

By using the facility for evaluating store performance, we verified the effect of the positive pressure control system on energy-saving by reducing invading air from the door and on reducing the amount of dust in the air, which is an evaluation indicator of unclean air from the outside. We converted air conditioning load fluctuations in summer and winter into amounts of invading air. Similarly, we also determined the energy-saving rate from the air conditioning load fluctuations. We performed this verification on the assumption that the store inside was controlled at a positive pressure with almost no differential pressure between inside and outside the store, and the automatic entrance door was opened and closed once per minute.

Fig.12 Facility for evaluating store performance

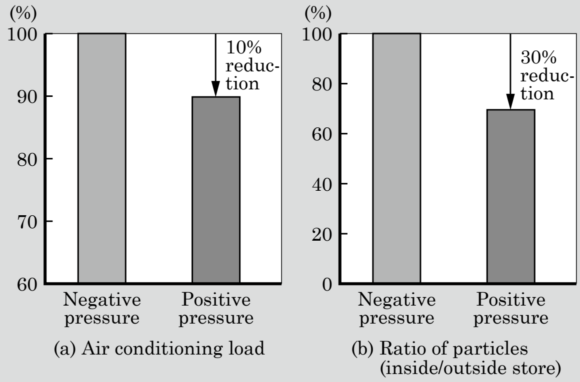

Fig.13 Results of effect verification

As shown in Fig. 13, we learned that stores utilizing positive pressure achieved an energy-savings of approximately 10% compared with negatively pressurized stores that do not implement positive pressure control. Furthermore, measuring the amount of the dust in the store with a particle counter, we verified that the stores utilizing positive pressure reduced the ratio of particles inside and outside the store by approximately 30% compared with negatively pressurized stores. In addition, we confirmed that the invading air volume and air conditioning energy-savings effect were consistent with the prediction results using the in-store heat balance analysis tool. This enabled us to verify the general calculation accuracy of the tool.

6. Postscript

In this paper, we described a store air conditioning solution for achieving storewide labor and energy savings.

There seems to be much value in achieving energy and labor savings from the viewpoint of the entire store, thus we plan to continue using our in-store heat balance analysis tool and facility for evaluating store performance through simulation of actual stores in order to contribute to further energy and labor savings. In the future, we also plan to expand the application to other stores such as supermarkets, in addition to convenience stores.

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