Integrated Energy Management System in Supermarket
Assuming Utilization of Exhaust Heat for Subcooling by PCM
to Achieve Sustainable Cities and Communities

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Summary
In this study, we focused on the way of waste heat utilization to subcooling into refrigerated cabinets by cold heat of PCM (Phase Change Material) in the case of supermarket fields. On this experiment, we installed a heat exchanger into after the condenser of the refrigerated cabinet to control the subcooling degree using the PCM cold storage tank. The cold heat capacity of PCM tank water for subcooling was set assuming that it was supplied by adsorption refrigerator which was driven by the exhaust heat from gas engine and solar energy absorber. As a result, we confirmed that the power consumption decreased in the case of the refrigerated cabinet with subcooling contributed to CO2 emission reduction. Result of this experiment, the utilization of exhaust heat for subcooling by PCM was effective for energy conservation on the summer and the intermediate season. We confirmed, on the other hand, that the effect of subcooling by PCM could be disappeared when it was below 16 degree Celsius of the outside temperature.

Keywords: Exhaust heat utilization, Refrigerated cabinet, Supermarket, Subcooling, PCM

1. Background and Purpose
Activities to reduce energy consumption have become increasingly important in recent years from the viewpoint of taking countermeasures against environmental problems such as global warming. The United Nations has set itself an objective of "Climate Action" as the thirteenth objective of the Sustainable Development Goals (SDGs) in Paris Agreement. Concept of an effective utilization of Energy Management Systems (xEMS) for commercial facilities with high energy consumption out of the concepts such as ‘Smart City technology’, ‘Realization of energy management technology based on Information Communication Technology (ICT)’ are highly required to achieve sustainable cities and communities.

The xEMS technology can be utilized in both cities and suburbs in consideration of not only "Climate Action" in SDGs, but also social problems such as hyper-aging society and depopulation in Japan. In suburbs, an idea of "Compact City" could be becoming popular to solve those problems (Fig. 1). 

In the previous research, we researched the possibility of mutual use of electricity and thermal energy, especially heat recovery, assuming a compact city in the suburbs with many business forms including Supermarket.

We constructed a 1/15 scale model to consider utilization Combined Heat and Power (CHP) assuming a complex of supermarket and restaurant in a compact city2) (Fig. 2).

Fig.1 Compact city concept

Fig.2 1/15 Scale model of supermarket and restaurant

In this study, we examined the possible countermeasures of energy conservation in supermarket facility, on the assumption that the waste heat from Combined Heat and Power (CHP) is converted to cold water by adsorption refrigerator. We focused on reducing the electricity consumption by extending the subcooling degree of the condenser in refrigerated cabinet since it was confirmed that refrigerated cabinet accounts for about 60% of the total electricity consumption of supermarket facilities in general.
The purpose of this study is to conduct experiments which focus on how much subcooling effect can be obtained by utilizing PCM (Phase change material) as cold heat storage material.

2. Approach

We constructed an indoor environment simulating a supermarket facility to conduct experiments within the environment using an actual refrigerated cabinet. We constructed an experimental apparatus for subcooling the refrigerant between the condenser outlet of the refrigerated cabinet and the expansion valve by installing a heat exchanger between the expansion valve and the condenser of the refrigeration cycle of the refrigerated cabinet.

The apparatus shows that the heat exchange is performed by cold water generated by the chiller, realizing subcooling of the refrigerant located after the condenser. In addition, the refrigerant used in this experiment is R404A which is widely used for refrigerated cabinet in general.

Fig.3 shows the system configuration of the experimental apparatus. Fig.4 shows the p-h diagram of the refrigeration cycle.

In this experiment, the energy saving effect of subcooling is confirmed by comparison of the power consumption of with and without PCM of the refrigerated cabinet.

This experiment was conducted to compare results measured during the summer, winter and intermediate season. Also, since the energy consumption of the refrigerated cabinet is greatly affected by the outside air temperature, we will grasp the relationship between the outside temperature and the effect of subcooling.

The experiment was scheduled to be conducted between 10:00 AM and 6:00 PM time period in which the actual supermarket facility is open for business and also the sun is out throughout the time period.

In the case of with PCM, we keep the tank temperature at 8°C after placing the PCM into the tank. Circulating the cooling water from 10:00 AM to conduct heat exchange with the condenser of the refrigeration cabinet by using the PCM thermal energy storage amount. In the case of without PCM, we fill the tank with cooling water of 8°C temperature. Circulating the cooling water from 10:00 AM to conduct heat exchange with the condenser of the refrigeration cabinet. In both cases, we circulate cooling water at 7.3 litter/min between the PCM tank and the heat exchanger (Fig. 5).

The purpose of this experiment is to conduct analysis with the results of comparison of energy consumption reduction rate to examine to what extent the subcooling effect PCM tank contributes to energy saving.
3. Comparison of Energy Consumption between With PCM or Without PCM

Figs. 6-8 are graphs summarizing the comparison of energy consumption of showcase throughout the year. The line graph has shown that there is no large difference in outside air temperature throughout the day. This is because days with stable weather conditions were selected for the measurements in order to ensure the subcooling effect is distinguishable with PCM or without PCM.

The bar graph has shown the energy-consumption reduction result of each season. The graph was used to examine the effect on the refrigerated showcase brought by subcooling effect of the refrigeration cycle.

The experimental results have shown that the summer season had the highest power consumption throughout the year. Also, comparison result of the performance of the refrigerated showcase under different conditions has shown that the amount of effect of energy consumption reduction amount with PCM was the highest in summer throughout the year to compare with normal operation.

In the case of intermediate season, it was about half of the energy consumption compared to summer. Compared to its normal operation, the result has shown that even though the power consumption with PCM is smaller than that in summer, it has shown the effect.

Also, the energy consumption is the smallest in winter throughout the year. The result has shown that there is almost no difference in energy consumption reduction with PCM or without PCM compared to its normal operation.

Table 1 summarizes the energy consumption reduction and the reduction rate of each subcooling experiment result for each season. The result of this experiment has proven that subcooling effect is the most effective in summer.
4. Relationship between Outside Air Temperature and Energy Consumption

Relationship between the outside air temperature and the energy consumption through the year was examined to clarify what extend it is based on the presence of the effects of the supercooling or not. The relationship-analitics condition of supercooling is based on installation with PCM because it was confirmed as highly performed in the energy consumption view point in summer season.

Fig. 11 illustrates a plot of energy consumption in the approximation formula as linear. $X = 15.84$ was obtained as the result when examined the intersection of two approximate lines.

Therefore, it can be considered that the energy conservation effect by subcooling using PCM disappears when the temperature is lower than approximately 16°C, at which time the subcooling effect of PCM disappears compare to its normal operation.

5. Conclusions

From the viewpoint of the effective energy consumption reduction, we have confirmed that the effect of subcooling by utilizing the PCM tank is highest in the summer throughout the year.

The experiment results have shown that the supercooling effect brought by PCM, in other words, the energy consumption reduction effect can be obtained when the outside air temperature is at 16 °C and over.

Therefore, throughout the year, the condition where the outside temperature is higher than 16 °C could be utilized as one of the index when considering the installation of PCM to the actual supermarket facility.

References


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