# ENERGY CONSERVATION OF COMMERCIAL REFRIGERATED CABINETS INSUPERMARKETS –FOCUSING ON THE INFLUENCE OF SUBCOOLING AFTER CONDENSER OF CABINETS-

*Rei Hamamoto, MEng(Mechanical Engineering), Waseda University, 3-4-1 Okubo,Shinjuku-ku, Tokyo, Japan*
*Saori Tajima, MEng(Mechanical Engineering), Waseda University, 3-4-1 Okubo,Shinjuku-ku, Tokyo, Japan*
*Tatsuya Shikano, MEng(Mechanical Engineering), Waseda University, 3-4-1 Okubo,Shinjuku-ku, Tokyo, Japan*
*Sang-chul Bae, Waseda University Environmental Research Institute, 1011 Nishitomida, Honjo-shi, Saitama, 367-0035, Japan*
*Masafumi Katsuta Prof. (Mechanical Engineering), Waseda University, 3-4-1 Okubo,Shinjuku-ku, Tokyo, Japan*

**Abstract:** In this research, in order to realize the energy conservation in supermarkets, we focused on saving electricity consumption of commercial refrigerated cabinets. At first, thermal environment and electricity consumption for air conditioners, lightings, commercial cabinets, and hot water supplying system were measured all day long in each season in real store. As a result, commercial refrigerated cabinets occupied the largest ratio of the all electricity consumption and it accounted for 60-85%. Therefore energy conservation of the commercial refrigerated cabinets had large effect on energy conservation of supermarket.

From the experimental data, a sub cooling after the condenser of commercial refrigerated cabinets was considered to have positive effect on electricity consumption of commercial refrigerated cabinets. So 1/15 scale (133m$^2$) substantiative store were used for validate the effect. From the experimental results, the electricity consumption of commercial refrigerated cabinet was reduced by 10-50%. In addition, the effect was large at the high outside air temperature region.

**Key Words: commercial refrigerated cabinet, desiccant system, electricity consumption, sub cooling, energy conservation**

## 1 INTRODUCTION

Energy management system (EMS) such as HEMS and BEMS attracts many people's attention. EMS controls air conditioner, lighting, hot water supplying system, ventilator, and other electric system's energy consumption by using couple of sensors. This system contributes to the saving energy by taking account of the information of energy consumption apparatus, and energy supplying systems. Therefore the system can supply the energy from the appropriate supplying system automatically.

In Japanese industry, consumer sector's energy consumption increased 2.7 times from 1973, therefore it is very important to conserve energy in consumer sector. Supermarkets consume the most energy in consumer sector, and also the supermarkets don't have well developed energy conservation measures. The introduction of EMS can have a lot effect on the energy conservation, because there are many supermarkets have chain stores and one EMS can be applied in those stores.

From these backgrounds mentioned above, in order to realize the energy conservation in supermarkets, we focused on saving electricity consumption of commercial refrigerated cabinets. Shiraishi K et al. reported commercial refrigerated cabinets and refrigerator occupied the largest ratio of the electricity consumption of supermarkets which was up to more than 60% during the store time. Therefore commercial refrigerated cabinets' electricity consumption was measured in real store. Then strongly correlated parameter was researched. To investigate the accuracy of the real store data, commercial refrigerated cabinets in 1/15 scale substantiative store was measured.

## 2 REAL STORE DATA

### 2.1 The Information about Supermarket

In order to research about the supermarkets' electricity consumption and energy conservation measures, we investigated the middle-scale supermarket (3458m$^2$) in Gunma prefecture in each season. Gunma Prefecture locates 100km northeast from Tokyo. This store opened in November 2010. So it is quite new store and it has remote observing system which can gain the electricity consumption data for each device from the internet. This store's store time is 10:00~20:30. And also this store has chain store development in Kanto, Kansai, and Chubu regions which are middle part of Japan.

Figure 1 shows the thermometers and hygrometers map of the real store, and also Tables 1 and 2 shows the explanation of measurement equipment. Commercial refrigerated cabinets in this store have the condensing unit at the outside of store.

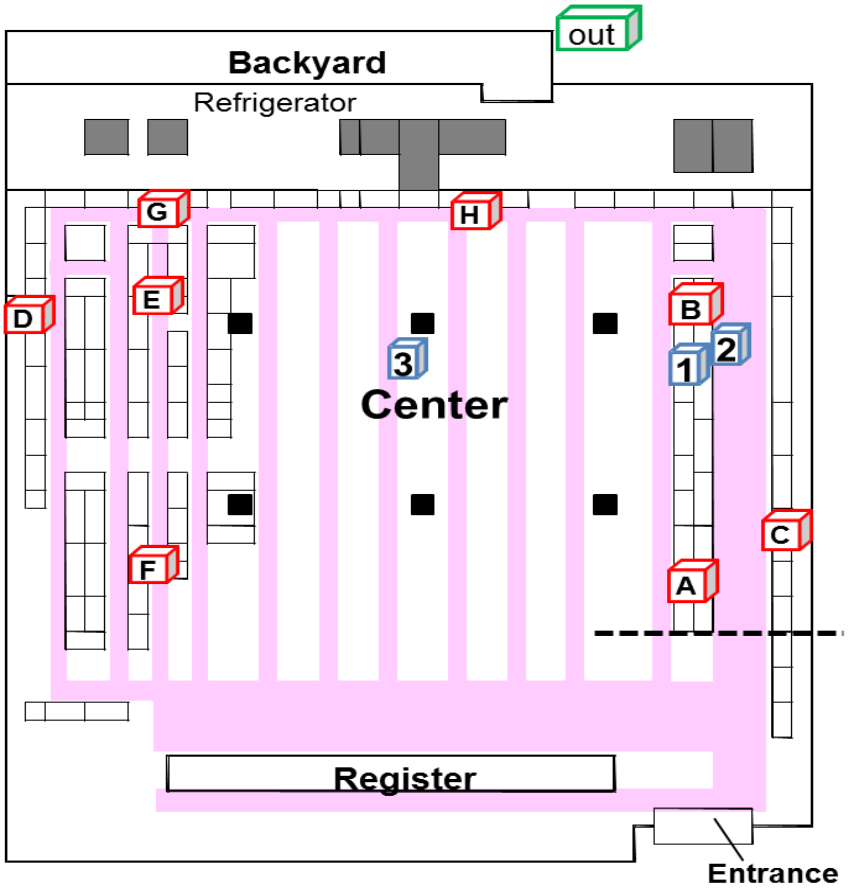



**Figure 1: Thermometers and Hygrometers Map**

**Table 1: Measurement Term of Equipment written in Map**

| Equipment Number | Measurement parameter | Measurement Term |
|---|---|---|
| A~H | Temperature, Humidity | All Year Round |
| Out | | July 25th~July 31st<br>October26th~November1st<br>December4th~December10th |
| 1~3 | | |

**Table 2: Measurement Place of Equipment written in Map**

| Equipment Number | Measurement Place | Measurement Height m |
|---|---|---|
| A~H | Top of the Commercial refrigerated cabinet | 2 |
| Out | Outside of the Store | 1.5 |
| 1 | Top of the Commercial refrigerated cabinet | 2 |
| 2 | Downward of the Commercial refrigerated cabinet | 0.3 |
| 3 | Center of the Store | 1.5 |

The boxes (□) written in Figure1 shows the commercial refrigerated cabinets in the store. The equipment named A~H is the measurement equipment which data can gain from remote observing system. This data can be obtained all year round. On the other hand, the boxes named 1~3 and Out were the measurement equipment set during the term written in Table1. This equipment was set to research the commercial refrigerated cabinet area and center area in detail for each season. This equipment measures temperature and humidity for each 15 minutes.

### 2.2 Results and Analysis

#### 2.2.1 Electricity consumption about all equipment

Figures 2 to 4 show the electricity consumption of all equipment in the store each season. Others include backyard, plug socket, kitchen, and hot water supplying system power.

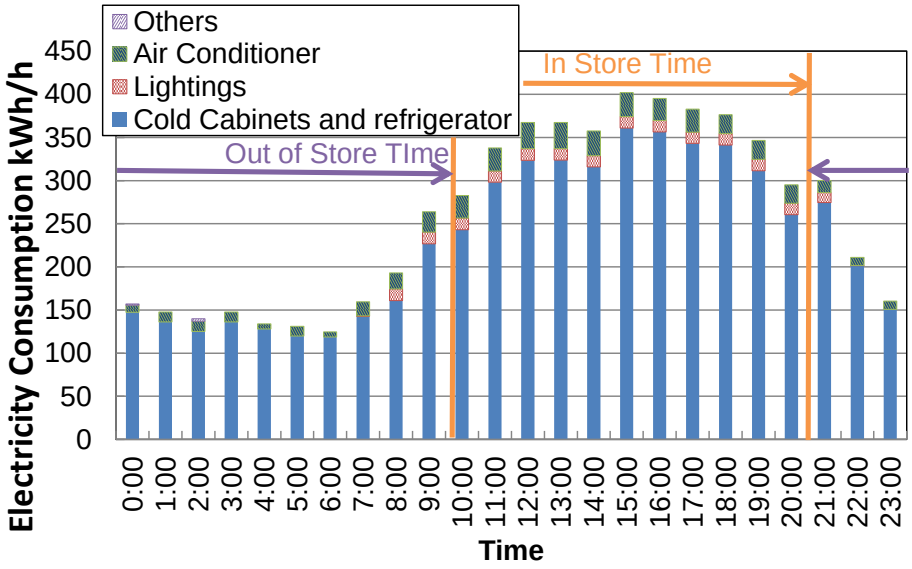



**Figure 2: Electricity Consumption of All Equipment (Summer)**

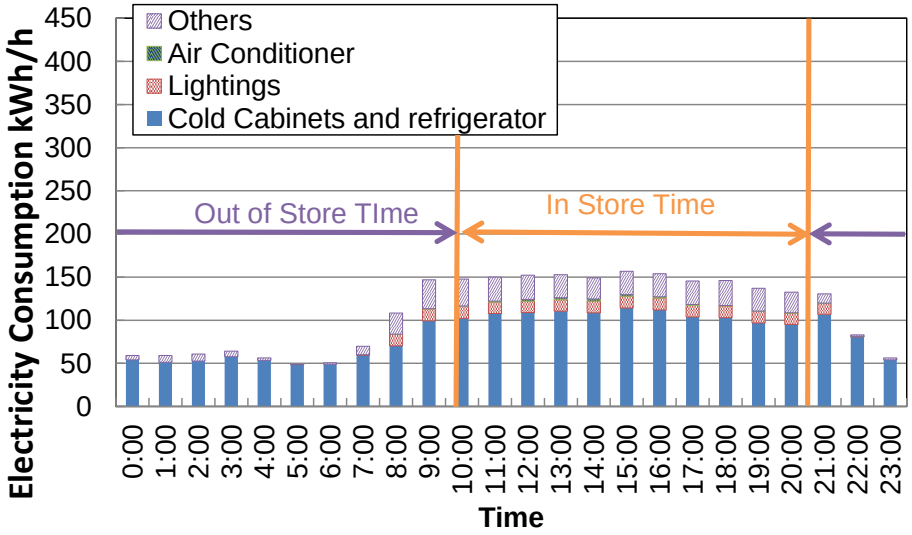



**Figure 3: Electricity Consumption of All Equipment (Intermediate Season)**

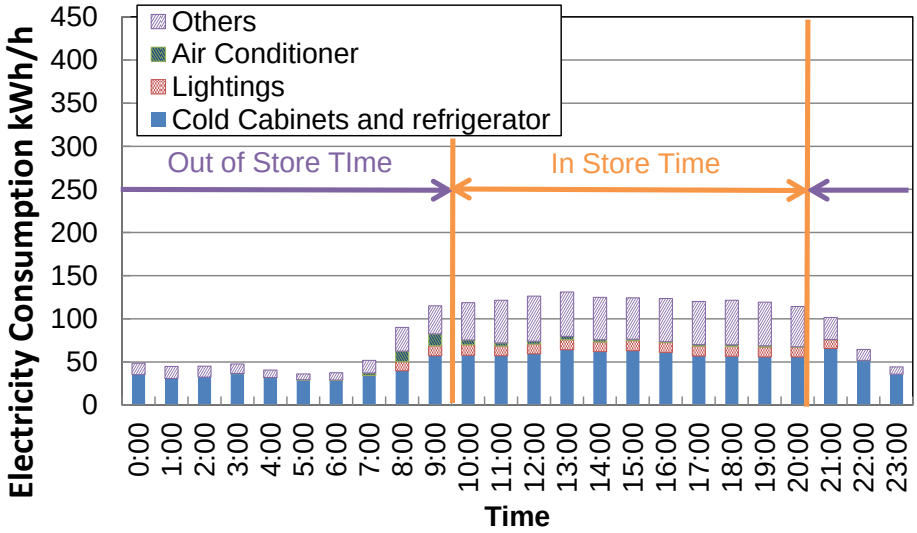
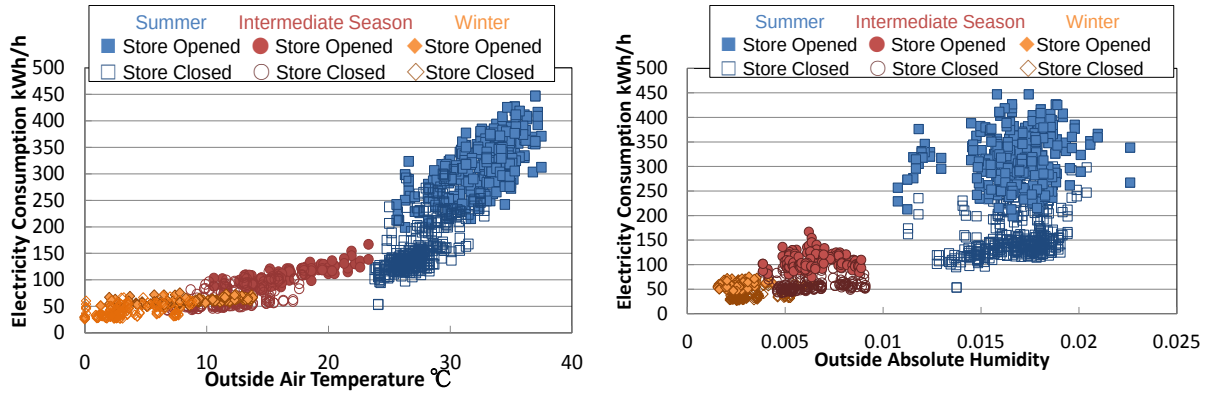



**Figure 4: Electricity Consumption of All Equipment (Winter)**

From Figures 2 to 4, the most part of electricity consumption was occupied by cold cabinets and refrigerator. It accounts for approximately 85% in summer, 80% in intermediate season, and 60 % in winter. It is obvious that cold cabinets and refrigerator are the most important equipment for saving energy in supermarket. In addition the electricity consumption of cold cabinets and refrigerator was up to 350kWh/h in summer 15:00.

### 2.2.2 Correlation with thermal environment and electricity consumption

The electricity consumption of cold cabinets and refrigerator with outside of store's thermal environment is shown in Figure 5. The plots are categorized by season and store hour. The electricity consumption has difference when store is open or not because the night covers which can save the cold air in the cold cabinets are settled to save electricity consumption.

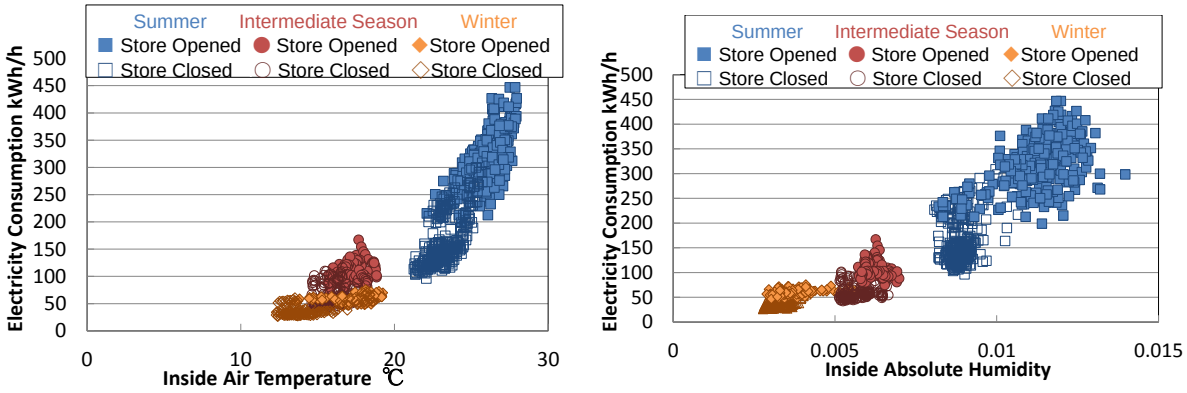



(a) Outside Air Temperature (b) Outside Absolute Humidity

**Figure 5: Electricity Consumption with Thermal Environment (Outside of Store)**

The electricity consumption of cold cabinets and refrigerator with outside air temperature is shown in Figure 5 (a). From Figure 5 (a), electricity consumption had strongly correlated with outside air temperature. The electricity consumption increased as the outside air temperature increased. This trend was more obvious in summer than other seasons. On the other hand, Figure 5 (b) shows the electricity consumption with outside absolute humidity. The electricity consumption was not correlated with absolute humidity as air temperature.

The electricity consumption of cold cabinets and refrigerator with Inside thermal environment is shown in Figure 6.




(a) Inside Air Temperature (b) Inside Absolute Humidity

**Figure 6: Electricity Consumption with Thermal Environment (Inside of Store)**

The electricity consumption with inside air temperature is shown in Figure 6 (a). The electricity consumption was weakly correlated with inside air temperature because the intermediate season and winter plots were almost same temperature but the electricity consumption was different. The electricity consumption with inside absolute humidity is shown in Figure 6 (b). The electricity consumption increased as the inside absolute humidity increased.

As shown in Figures 5 and 6, the electricity consumption was correlated with outside air temperature and inside absolute humidity. In this research, we focused on the outside air temperature, because it strongly correlated with the electricity consumption. So making sub cooling after the condenser of cold cabinets was considered to have effect on electricity

consumption. To investigate the influence of sub cooling, 1/15 scale substantiative store were used. The detail and results are written in next chapter.

## 3 1/15 SCALE SUBSTANTIATIVE STORE DATA

### 3.1 The Outline of Substantiative Store

To investigate the effect of sub cooling in summer, 1/15 scale substantiative store were used. Photographs of the main apparatus in substantiative store and simplified diagram of it are shown in Figure 7.

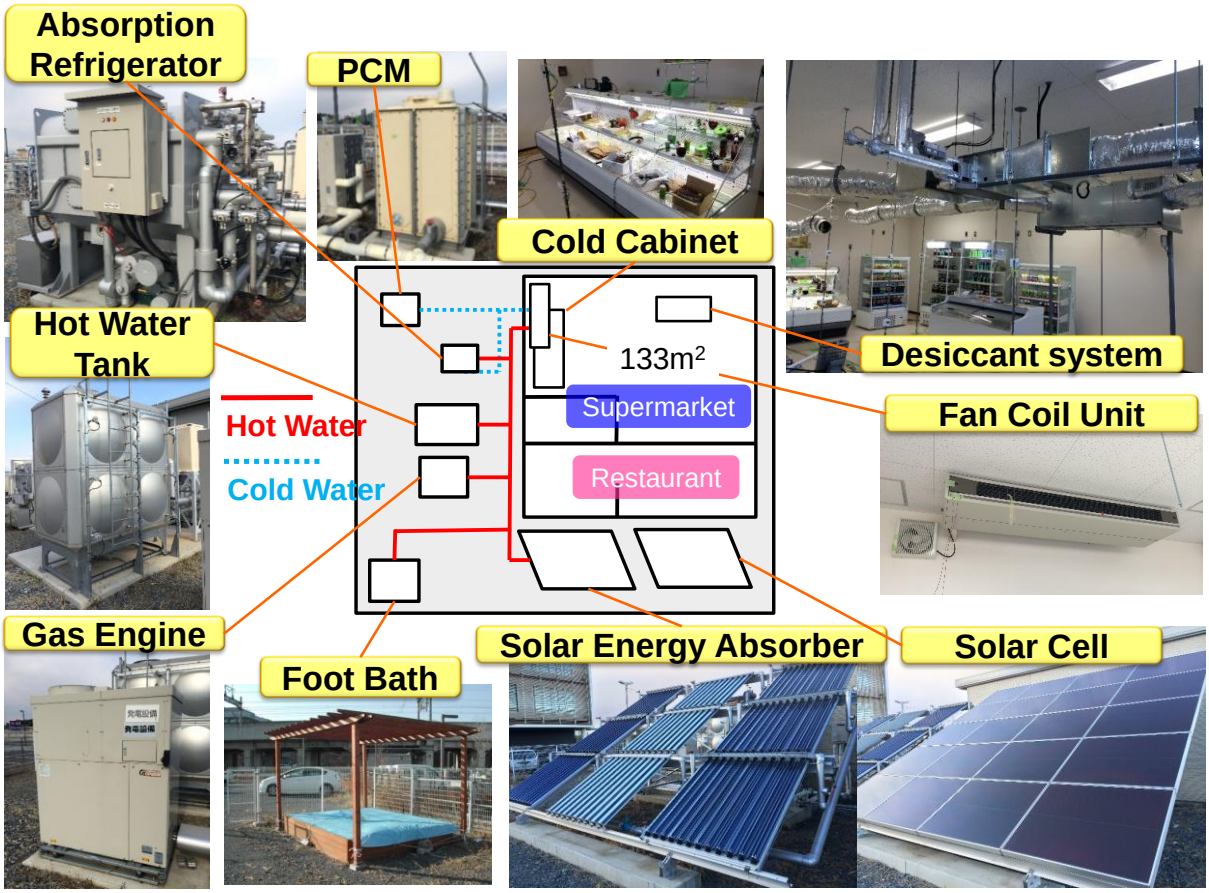



**Figure 7: All Systems of 1/15 Substantiative Store**

This store has gas engine which can use not only electricity but also exhaust heat to supply hot water. In addition this store has solar cell and solar energy absorber to use renewable energy for reducing $CO_2$. Absorption Refrigerator can make the hot water into cold water by using exhaust heat from gas engine or solar cell. The temperature of water can be maintained with 7°C by using PCM.

To make the substantiative store's thermal environment to that of real store, heat pump air conditioner and desiccant system were used. The thermal environment of substantiative store is shown in Table3

**Table 3: Thermal Environment of Substantiative Store**

| | Thermal Environment 1 | Thermal Environment 2 |
|---|---|---|
| Temperature | 25°C | 28°C |
| Humidity | 50% | 40% |

### 3.2 Sub Cooling Experiment

Experimental apparatus of sub cooling experiment is shown in Figure 8.

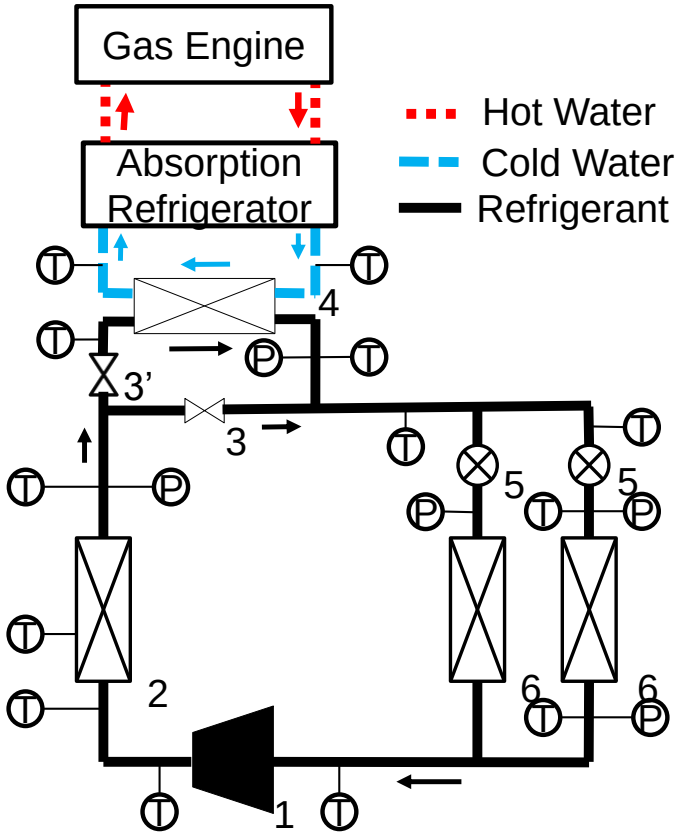



**Figure 8: Experimental Apparatus of Sub Cooling Experiment**

Compressor 1 was used to refrigerant (R404A) to make a refrigerating cycle. For fundamental data without sub cooling, the refrigerant passed through the valve 3 after the condenser 2. On the other hand for sub cooling experiment, the refrigerant passed through valve 3' and sub cooling was made at heat exchanger 4. Cold water for sub cooling is made by absorption refrigerator using exhaust heat of gas engine. For both without sub cooling and sub cooling experiment, refrigerant went through the expansion valve 5 and evaporator 6.

The effect of sub cooling can be examined by next equations. Without sub cooling, COP can be defined by using next equation (1)

$$COP = (h_{eva}-h_{exp})/(h_{com}-h_{eva}) \quad (1)$$

$h_{eva}$: enthalpy after evaporator
$h_{com}$: enthalpy after compressor
$h_{con}$: enthalpy after condenser
$h_{exp}$: enthalpy after expansion valve (isenthalpic expansion)

On the other hand, the COP with sub cooling can be defined by using next equation (2)

$$COP = (h_{eva}-h_{exp}')/(h_{com}-h_{eva}) \quad (2)$$

$h_{exp'}$: enthalpy after expansion valve with sub cooling (isenthalpic expansion)

COP can be made higher by sub cooling effect, because the numerator of equation (2) got $(h_{exp}'-h_{exp})$ higher than equation (1).

### 3.2 Results and Analysis

The results of sub cooling experiment on July 30th and 31st 2013 are shown in Figure 10. These two days were chosen because the temperature of these two days had similar thermal environment and it was proper to compare.

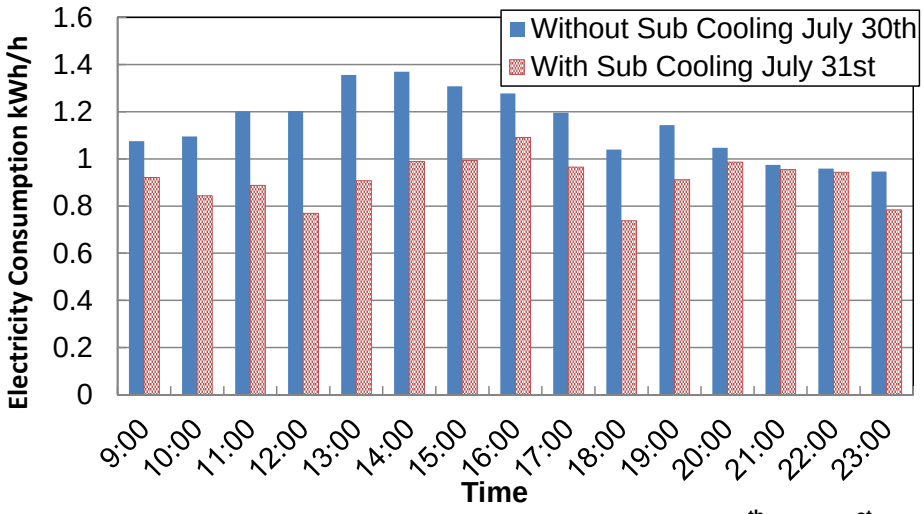
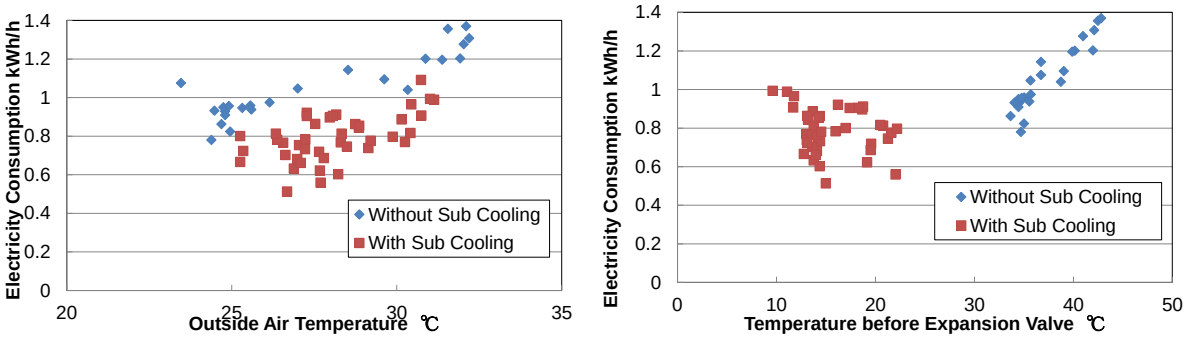



**Figure 9: Results of Sub Cooling Experiment on July 30th and 31st**

The electricity consumption of the cold cabinet was reduced more than 25 % in the daytime. On the other hand, the electricity consumption was reduced only 5 ~ 10%. It is obvious to consider that the sub cooling have large effect on the daytime. In addition, the night time, cold cabinet do not need sub cooling so only the night cover are needed.

The electricity consumption of cold cabinet with outside air temperature, and with temperature before expansion valve is shown in Figure 10. These data were obtained in daytime.




(a) Outside Air Temperature (b) Temperature before Expansion Valve

**Figure 10: Results of Sub Cooling Experiment**

Electricity consumption was reduced by 10~50% with sub cooling from figure 10 (a). As the outside air temperature decreases, the effect of sub cooling decreased. The effect was obvious from 27~30°C, but the effect was not so obvious at 25°C. And also the temperature before the expansion valve had correlation with the electricity consumption from Figure 10(b). The electricity consumption was reduced by making the temperature before expansion valve into 10~20°C. However, the electricity consumption didn't change in between 10~20°C. Therefore 20°C was the better temperature than 10°C for the temperature before expansion valve, because it used smaller power.

## 4 CONCLUSIONS

The electricity consumption of cold cabinets and refrigerator accounted for more than 60% of that of all electric systems such as air conditioner, lighting, backyard, plug socket, kitchen, hot water supplying system and cold cabinets from the real store data. In addition, it accounted for 85% during the summer. Analyzing the data of real store, the outside temperature and the inside absolute humidity was correlated with the electricity consumption. So we focused on making sub cooling before the expansion valve of cold cabinet in substantiative store because the outside temperature had strongly correlated with electricity consumption.

The electricity consumption was reduced largely by the sub cooling experiment using the cold water which was made by absorption refrigerator using the exhaust heat of gas engine, especially when the outside temperature was high region like 27~30°C. As the outside air temperature decreases, the effect of sub cooling got smaller. And also the temperature before the expansion valve had correlation with electricity consumption. The temperature of it was better in 20°C than 10°C by the experiment.

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