OPTIMAL SIMULATION OF DISTRIBUTED GENERATION SYSTEM FOR CO_2-REDUCTION IN SUPERMARKET AND RESTAURANT FOCUSING ON THE USAGE OF EXHAUST HEAT

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Abstract: Since the nuclear disaster caused by the Great East Japan Earthquake (2011), Japanese energy system has been expected to prioritize safety and trustworthiness. Now, distributed power systems are considered as one solution, but utilizing exhaust heat is an important task to be solved.
The purpose of this study is building a simulation model to harness the exhaust of commercial buildings. We obtained two types of data: one is data of 1/15 scale model of supermarket and restaurant standing next to each other with distributed power supply system, the other is real world data of the two buildings.
Results showed cold cabinets, whose electricity was affected by difference in temperature of outside and inside, consumed most of energy in supermarket. While air conditioning, affected by difference in air enthalpy of outside and inside, consumed most of energy in restaurant.
According to our simulation with gas engine, PV panel, PCM, thermal storage, FCU and commercial refrigerated cabinets in scale model, we could reduce 27% of CO_2 emission and 25% of running cost by selecting equipment.

Key Words: distributed energy supply, thermal energy management, CO_2 reduction, exhaust heat, commercial buildings

1 INTRODUCTION

Nowadays many companies have started to consider Business Continuity Plans (BCP); BCP is a plan for the company to continue their business if there are rival competitors or natural disasters making the power grid out. Especially the natural disaster is serious problem all over the world. After a huge earthquake in Japan 2011, the importance of BCP which companies think has become 1.34 times more than that occurred in north Japan (Hamaguchi 2012). To be more prepared for these emergencies, most of large companies have private power generators, but for middle and small scale companies, it is difficult to invest a number of money on emergency which rarely occurs.

To improve the BCP of middle and small scale companies such as commercial buildings distributed power supply system will be one of great solutions (Hirai 2005). For this system, we should consider the CO_2 emission, because the electricity from grid power generates less CO_2 than distributed power system. Considering less emission of CO_2, utilizing exhaust heat is key point for the system (Wakabayashi 2010). Distributed power suppliers generate a great number of exhaust heat, therefore we need to investigate good ways to utilize this exhaust heat replacing electricity (Nakamaru 2008).

This paper describes and analyzes a simulation which focuses on heat utilization for selecting machines of distributed power supply system installed in restaurant and supermarket. These two commercial buildings both consume a large amount of thermal energy: restaurant needs hot heat and supermarket needs cold heat (Washizu 1999). In this simulation, we took into account not only the demand of buildings based on time but also temperature of stored heat level. To make our simulation accurate, we conducted two types of measurements: one was real commercial buildings energy and the other was data of 1/15 scale model of the buildings.

2 METHOD

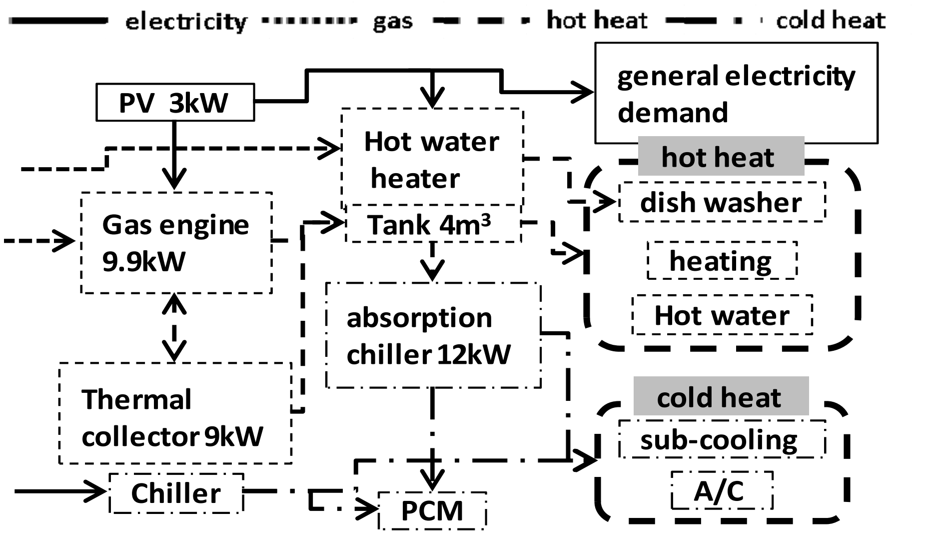
In method section and result and discussion section, we presented three parts:
Step 1: Using the calculation results of energy consumption per unit from previous study (Ojima 2004), we constructed 1/15 scale model building and distributed power system. At this scale model building, we obtained the data with operating power supply machines for each use according to the step 2, real world data.

Step 2: We needed actual pattern of energy consumption for operating machines, so that we measured by seasonal and time zone.

Step 3: we built heat simulation to optimize CO_2 emission using above two data and previous studies. The purpose of this simulation is to select distributed power system.

2.1 Step 1: Scale Model Buildings

At this scale model building, we use heat energy replacing electricity such as dishwasher's preheating and Fan Coil Unit (FCU) which is a substitution of a/c. Then, we put the data how much we can substitute electricity, into our heat simulation. In figure 1, it shows the general view of the 1/15 scale model building, PV, gas engine and thermal collector are energy supply machines



Explanations: PV – photo voltaic generation, PCM – phase changing materials storage of cold heat, sub-cooling =to have sub-cooling on a condenser of an outdoor unit of a cold cabinet

2.2 Step 2: Real World Data of Buildings

2.2.1 Restaurant

We measured electricity and thermal environment for each one week in summer, autumn, and winter in 2012. The restaurant of subject is an Italian middle scale restaurant in suburb of Tokyo. In table 1 explains the restaurant measuring details below 2.2.2.

2.2.2 Supermarket

We measured electricity and thermal environment for one week in summer, autumn, and winter. The supermarket of subject is a middle scale supermarket in Gumma prefecture in Kanto. This supermarket is relatively new, and they put great importance on saving electricity. Table 1, 2 shows details of the measurements of restaurant and supermarket, measuring points for electricity, and points of thermal environment in the supermarket. (RH* stands for relative humidity, and EcoCute** stands for CO_2 heat pump water heaters.)

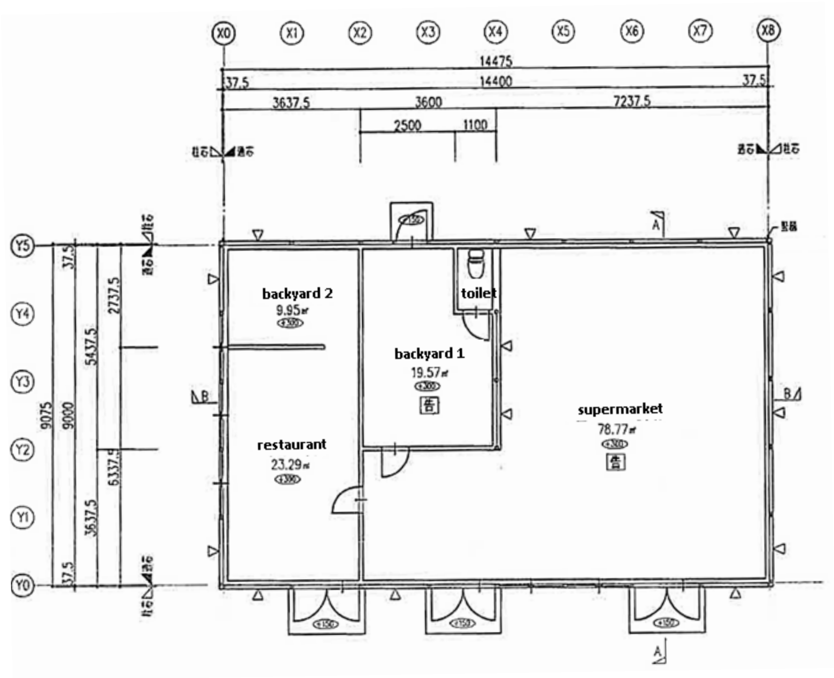


Table 1 Details of restaurant and supermarket measurements

Location/ size	Restaurant	Supermarket
	Koganei city, Tokyo, Japan/ middle size	Isesaki city, Gumma / standard
Area of floor	312 ㎡ two stories	3458.6 ㎡ one story building
Opening time	AM11:00~AM1:00	AM10:00~PM20:30
Objectives	To get data of energy consumption pattern and availability for replacing electricity to heat energy	To get data of energy consumption pattern and availability for replacing electricity to heat energy
Period	Summer：14th Aug ~ 23th Aug Autumn： 16th Oct ~21th Oct Winter ： 12th Dec ~ 21th Dec	summer：16th Aug ～ 28th Aug autumn ：27th Oct~ 8th Nov winter ：3th Decr~17th Dec
Measurement items	(logging each average data of every 30 minutes)	(logging each average data of every 30 minutes)

Table 2 Measuring points for electricity in the restaurant

	restaurant		supermarket	
	types	usage of electricity	types	usage of electricity
power board	main	a/c in kitchen	main	a/c outdoor unit
	brunch	dishwasher	main	feed/exhaust fan
	brunch	air conditioner	main	background
	main	a/c outdoor unit, feed/exhaust fan	brunch	stove, frier
			main	lighting of sales area
lighting panel	main	lighting	main	plugs
	main	plug, microwave	brunch	EcoCute** 1
	main	background	brunch	EcoCute** 2
			all cold cabinets (remote supervision)	

	restaurant		supermarket		
items	points	objective	items	points	objective
Temp., RH*, air flow	a/c outdoor unit	outdoor unit temp. and energy consumption	Temp., RH, air flow	a/c outdoor unit	outdoor unit temp. and a/c energy consumption
Temp., RH	a/c of customer area	for calculation of a/c load of customer area	Temp., RH	inside center	temp. and RH of inside
	customer area center	temp. and RH of customer area		cold cabinet	the way cooling around aisle of cold cabinets
	center of kitchen	temp. and RH of kitchen		cold area~ a/c distribution	relationship between a/c and cold cabinet
	distribution between stove~ a/c	relationship between a/c and stove	Temp	inside cold cabinet	RH distribution of cold cabinet

2.3 Step 3: Heat Simulation

Figure 3 explains the way we divided the electricity data into five groups, then they were assembled into four groups by energy usage: electricity, air heating, air cooling, and hot water. We focused on the heat usage substituting electricity.

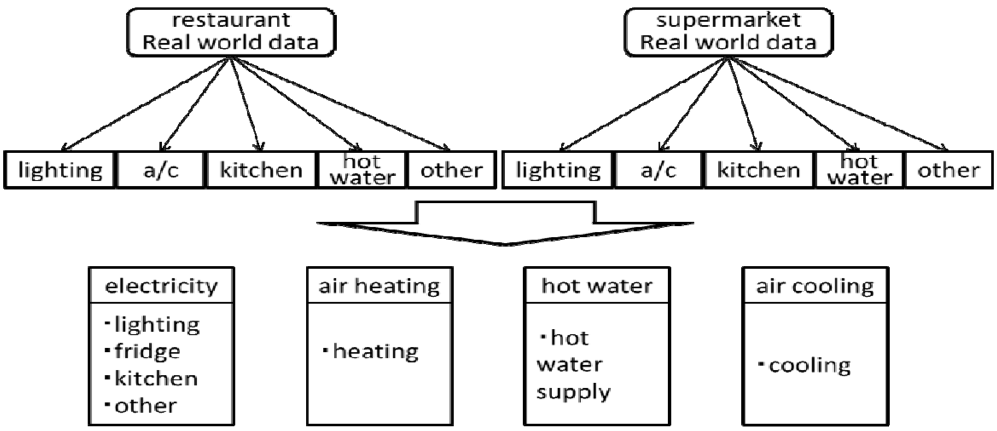


Figure 4 shows three flows of the simulation. In (a) general flow, the calculation is conducted for each one hour. Real world data of restaurant and supermarket are put into first, then the heat are generated depends on the electricity demand. After heat such as hot water and FCU heating are supplied, if there is excess exhaust heat, it can be used for subcooling more by making higher degree of subcooling. When there is not enough amount of exhaust heat, the heat is compensated by electricity. All of our calculations of the simulation were done for one day by one hour.

In (b), it explains a flow of total electricity consumption. When this demand is under the rated output of the gas engine (GE), that of the demand is generated. On the other hand, when the demand is over the rated output, both of the GE and grid power are used. Then, the total CO_2 emission is obtained.

In (c), it explains its heat energy flow. Considering not only the amount but temperature (temp.) level in hot water tank is an important point. The GE safety system allowed hot water from the GE exhaust under 80 °C. As for the usage of heat, when temperature is above the tap water, the tank water is used for preheating of dishwasher and when from 65~80 °C, hot water is converted into cold energy for sub-cooling or FCU cooling. This system did not have a battery, so the GE cannot be operated with the rated output.

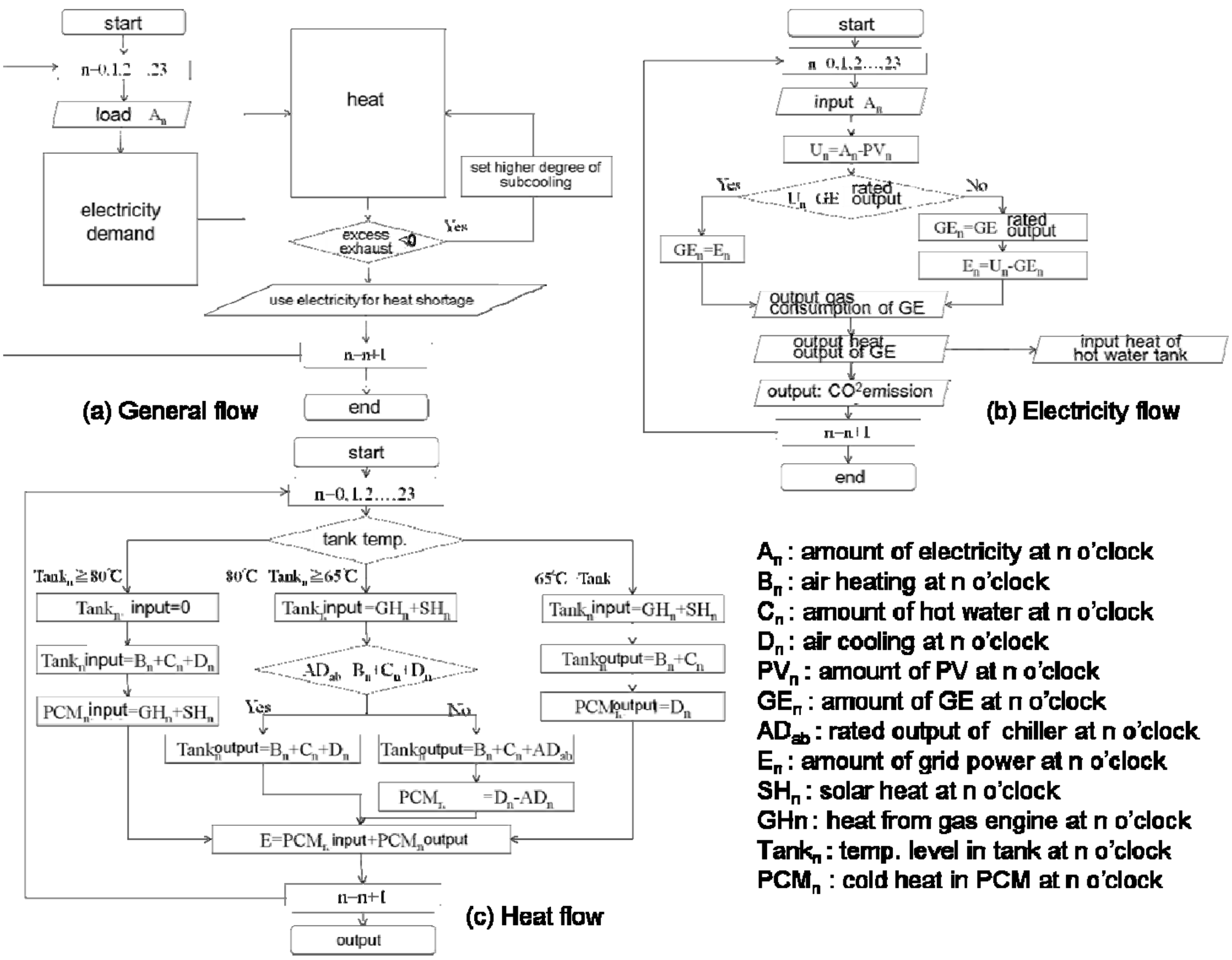


Figure 4: Three flows of simulation

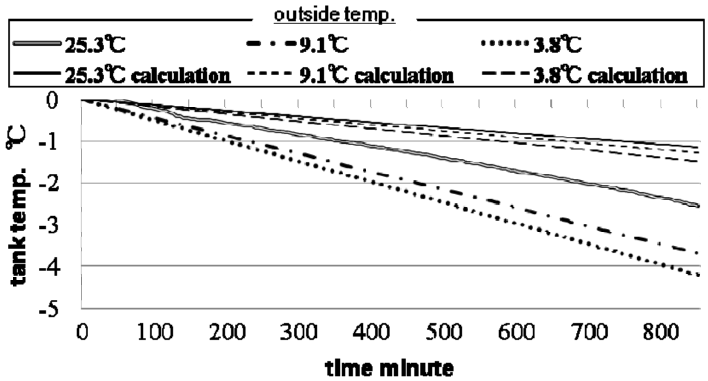
3 RESULTS AND DISCUSSION
3.1 Step 1: Scale Model Buildings
3.1.1 GE operation with renewable energy in distributed power system

We ensured the manufacturer data about the GE when operating with other energy supplying machines such as PV and solar heat. Comparing surveyed data and manufacturer data in each season, although there was a little difference, the GE mainly works as manufacturer data. When temperature of hot water tank is over 80°C, heat exhaust cannot be obtained because of its refrigeration system. Therefore, to consider the temperature of hot water tank is important.

3.1.2 Lowering a temperature of the hot water tank

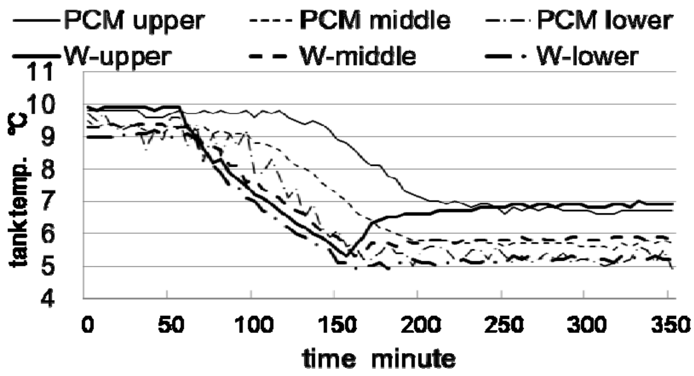
Lowering a temperature of the hot water tank depends on the outside temperature. So, we investigated how it differed in three seasons, and also measured the temperatures at different levels in the tank. We applied these data into the simulation.

First, results of theoretical calculation and surveyed are shown for three outside temperatures In figure 5. All surveyed data were lower than that of calculation. One if the reasons was that the calculation did not consider the holes inserting thermocouples. Even in summer, the temperature was lowered by 2~4 °C in 10 hours, thus taking this effect into consideration is important. Secondly, the temperature difference within the hot water tank was investigated. The height of the tank is 2m, and measured levels were 0.1, 1.1, 1.8m. From the results, 1 °C difference in temperature occurred in 12 hours. Therefore, this error range should be applied when GE stops for a while.



3.1.3 Storage and radiation of thermal energy in PCM

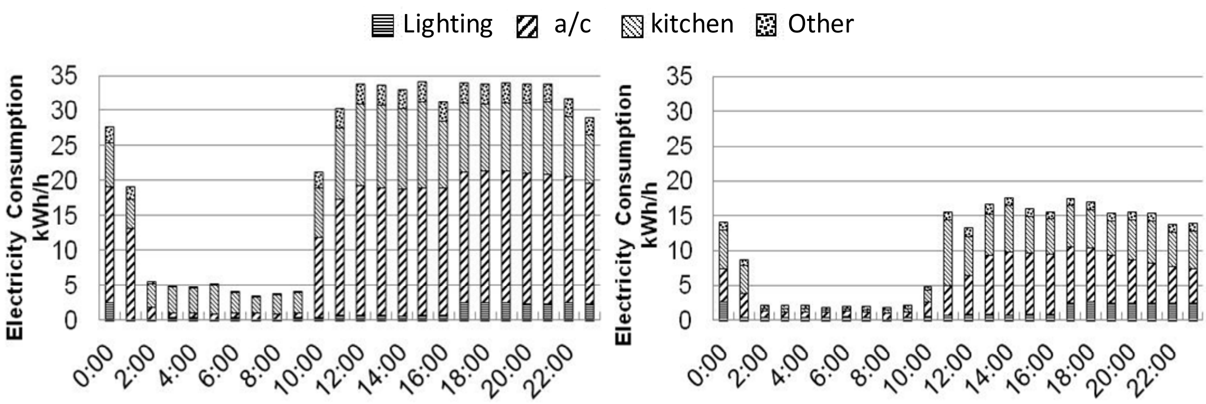
PCM can store a certain temperature of thermal energy, and that cold heat radiates from PCM when we need it. This time, we investigated the period of storing and radiating time in order to ensure the availability of PCM as cold thermal energy storage. In figure 6, it shows the thermal storing process. There were six measuring points : water temperature and PCM temperature for each three levels, the purpose of measuring water was to see heat transfer between PCM and water. At first, tank temperature was 9~10 °C; after the phase changed, the temperature kept around 7 °C with the flow was 1.12 L/sec. Storing took just two and half hours, it would be useful thermal storage. The second investigation was to ensure the thermal radiation process. Tank temperature was 7 °C, PCM is solid phase, we measured it rose up to 20°C with the flow was 0.41 L/sec. Cold thermal energy from PCM was used for FCU cooling, this FCU heat demand was continuously still. That would be the reason the tank temperature increased constantly.



3.2 Step 2: Real World Data of Buildings

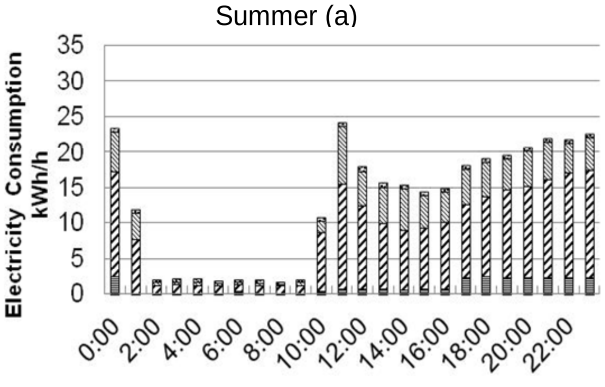
3.2.1 Restaurant

In figure 7, it showed electricity consumption of the restaurant for three seasons.



Summer (a)

Autumn (b)



Lighting

because of availacility of measuring, we set all of lighting demands for three seasons as the same amount.

Winter (c)

Figure 7: Electricity consumption of restaurant

At the restaurant, the consumption greatly differed on opening or not. Main demand in summer non-open time, was kitchen. This is because large size refrigerators consumed a lot. Throughout the year, a/c consumed 54% of total electricity. Kitchen needs a large amount of ventilation and thus was affected well by outside air. On the contrary, lighting consumed only 10% of total electricity, That is to say, it can save small amount of electricity when changing to LED lights. When substituting this a/c demand for exhaust heat, heat pump COP and converting cold heat have to be considered. COP of Heat pump is 3.5, so heat is needed 7 times as much as electricity. Moreover COP of absorption chiller is 0.4, so to obtain cold heat needs 2.5 times quantity of hot heat.

From the standpoint of enthalpy, we found the relationship between a/c consumption and difference in enthalpy of inside and outside. In summer, there was big difference in enthalpy between customer seating and outside, and kitchen enthalpy was mostly the same with outside. Then, this difference is assumed to have a great influence on a/c consumption. Supporting this suggestion, we investigated the relationship between the difference in enthalpy and a/c electricity consumption. When the difference at customer seating is bigger than 20 kJ/kg, a/c consumption soared to 6~8 kWh/h. In kitchen, there is a similar result. Hence installing desiccant humidity control system should be effective when outside temperature is high. That desiccant system needs hot water and cold water, so the effectiveness of using heat is key point in the simulation.

3.2.2 Supermarket

In figure 8, it showed electricity consumption of the supermarket for three seasons.

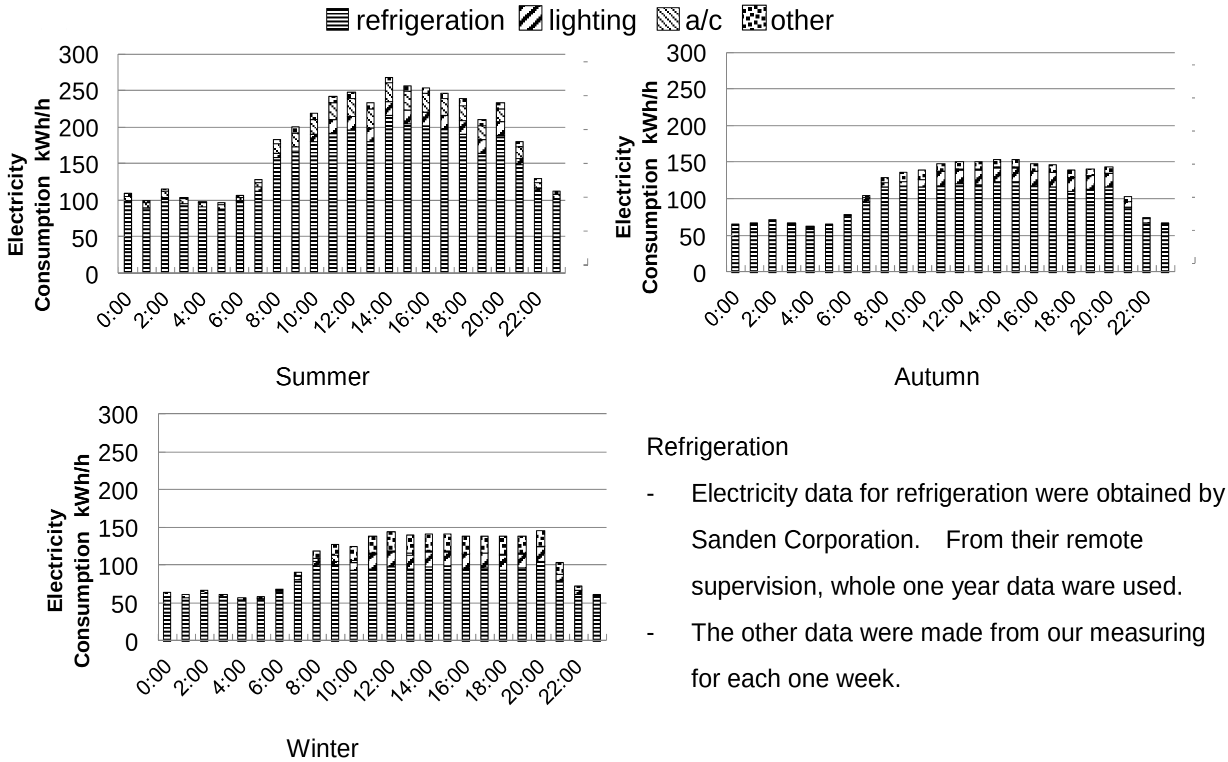


Figure 8: Electricity consumption of supermarket

For the supermarket, the demand of electricity was stable especially in autumn and winter. This is because there is demand for refrigeration 24 hour, and that demand occupies 80%, 70%, and 60% of total in summer, in autumn, and in winter. For non-opening time, that refrigeration demand decreased to 80%, because a cover is attached to a cold cabinet after closing the building. From the refrigerant cold cabinet, a large amount of cold air came out of case, that is the reason why the a/c consumption was very small. The setting temperature of air heating is low in winter because of the cold air leaking. Likewise, lighting consumed 6% of total in summer, 15% in autumn and winter, It can also save small amount of electricity when changing to LED lights.

From this results, we focused on the biggest consumption, refrigeration electricity consumption in summer. Investigation of the relationship between refrigeration consumption and four parameters are conducted following as; outside temperature, outside humidity, outside enthalpy, and inside and outside difference in temperature. Then, inside and outside difference in temperature had the best relationship. On a high temperature day, the load to compressor in outside unit of refrigerant becomes large. Therefore, it is effective to apply cold water to a refrigerant in order to make the temperature of sub cooling bigger after being condensed. This makes the refrigeration capacity bigger. In simulation, we included the effect of subcooling by calculation.

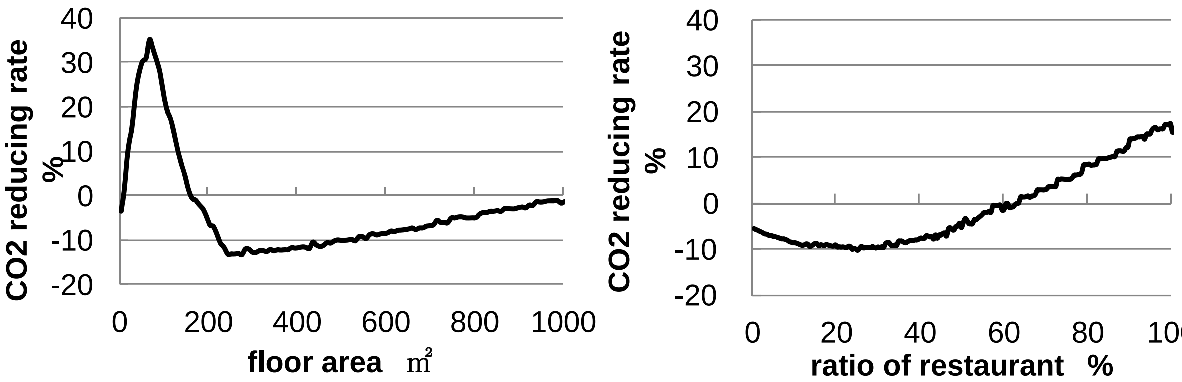
In terms of sub cooling with applying cold water, we installed the facilities to investigate the effect of using heat energy such as measuring apparatus for refrigerant cold cabinet electricity and heat exchanger for cold water and the refrigerant. But after installing the facilities, we could done investigation of sub cooling only in winter season. In winter, temperature outside is generally colder than that of refrigerant. Thus, it was not needed to use cold water in winter. Above these reasons, the effect of subcooling was suggested that COP of a cold cabinet becomes 1.5% higher as the sub cooling becomes 1℃ bigger. This suggestion was made by a cold cabinet manufacturer. For next study, we will investigate this effect with real machines.

3.3 Step 3: Heat Simulation

3.3.1 Relationship between the floor area and CO_2 emission and floor ratio without selling electricity

Here are the results of floor area and CO_2 emission. First, this model was simulated with the same machines installed in the scale model building, then by changing total floor area. In figure (a), at the current floor area which is 133 m^2, CO_2 emission increased 10%. In the optimum scale model which is 276 m^2, CO_2 emission decreased 12%. Secondly, the result was about changing the floor area ratio of supermarket and restaurant with fixed the floor area which is 276 m^2.

It is obvious that the floor area has huge impact on CO_2 emission. This is because of GE surveyed data which GE needs many pumps to utilize hot water. That is reason the efficiency was bad when GE operated at low load. To illustrate the heat usage, when the floor area became large, all exhaust heat was used for hot water usage. There was not exhaust heat for sub cooling at the model. In figure (b), the optimum ratio was that restaurant was 37%, and CO_2 emission decreased 14%. The current restaurant ratio was 33%, so the current ratio is close to the optimum.



(a) (b)

Figure 9: floor area and CO2 emission

3.3.2 Simulation model with selling electricity

To select capacity of PV generation, we conducted the simulation that the electricity can be sold according to a subsidy in Japan which a eco-town in North Kyusyu area adopted. The subsidy for renewable energy was When the electricity can be sold, GE can operate at a rated output. This is a big difference between 3.3.1 and 3.3.2 result. Table 4 shows buying electricity or gas prices depending on time period and selling electricity price of PV generation. In this simulation, these data were used for calculating optimum cost.

Table 4: Energy prices of buying and selling for simulation

period	time range	electricity price (cent/kWh)	item	electricity price (cent/kWh)
daytime	10:00~17:00	22.7	gas charge	109.0
living time	8:00~10:00, 17:00~22:00	26.8	selling price of PV	19.4
night	22:00~8:00	5.7		

When selling PV generation, the electricity simulation flow written in figure 4 (b) changed as following. PV generation is used for the building itself unless there is more PV electricity generation than the electricity demand which is subtracted GE rated output. According to this follow, we conducted the calculation with the parameters were GE rated output and PV capacity, and CO_2 reduction rate or running cost. As for CO_2 reduction rate, the biggest 9.9 kW rated output GE is the best, and as for running cost, the smallest 1.65kW rated output GE is the cheapest. In addition, installation of PV more than 20 kW have constant effect of reducing the amount of CO_2, since the total electricity demand of the building is less than 20 kW.

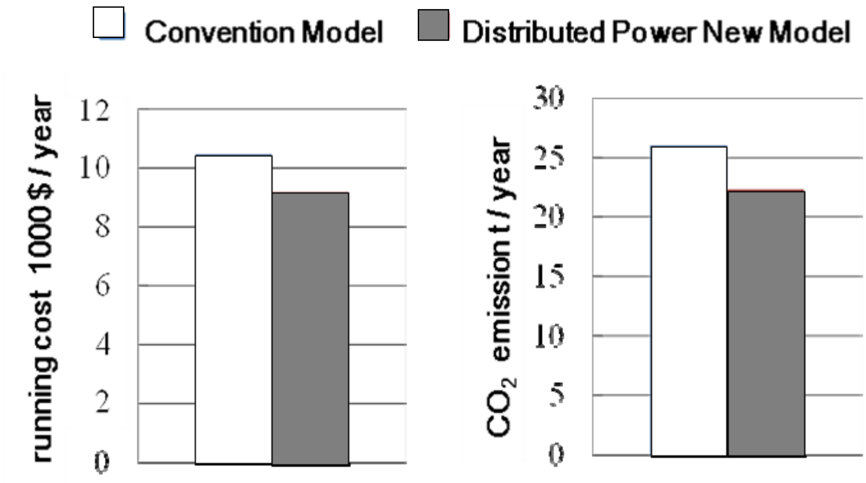
3.3.3 Optimum selection of distributed power supply by the simulation

From above 3.3.1 and 3.3.2 results, we concluded the optimum selection of distributed power supply system and machine capacity in table 5. There are two purposes to optimize; one is CO_2 reduction rate, and the other is about running cost. In summary, figure 10 shows the amount of running cost and CO_2 emission in total. The distributed power new model can reduce 25% of running cost and 27% of CO_2 emission.

The main purpose of our paper is CO_2 reduction for commercial building by installing distributed power supply system. However, additional suggestion about focusing money is provided here. With regard to the running cost, it included the effect of installing PV generation. If the model does not install any PV generation, the amount of running cost is reduced 12% and CO_2 reduction is 14%. Comparing the running cost with and without PV, it can be reduced 1,000 dollar in the model with PV. On the contrary, PV generation cost a lot. At the current Japanese subsidy, PV initial cost should be 5,500 dollar/kWh. Then, the initial cost becomes 55,000 dollar if there installs 10kW PV. Therefore, PV generation would not be a good machines to install in this model.

Table 5: optimum distributed power system

supply machines	GE	below 3.3 kW
	PV rated output	5.5~16 kW
	solar thermal collector	10 kW
heat storages	PCM storage	60MJ (8kW for max. cold heat)
	hot water tank	4 m^3
heat applying apparatus	absorption chiller	10 kW
	sub cooling apparatus	degree of sub cooling is 10°C in summer, 5°C in autumn
	FCU	21kW (for cooling max.)



running cost CO$_2$ reduction

Figure 10: result of optimising

4 CONCLUSION

In summary, first, we obtained the operation data at small scale model building, and applied that data with calculation into the simulation focusing on heat utilization. Secondly, energy consumption pattern of each usage in restaurant and supermarket were measured in three type season; summer, autumn, and winter. Then, it was found that electricity consumption of air conditioning in restaurant and that of refrigeration in supermarket have been influenced greatly by the enthalpy and difference in temperature inside and outside. Lastly, based on actual surveyed data, we built a simulation to optimize CO_2 emission and running cost. Using this simulation, the distributed power new model can reduce 27% of CO_2 emission and 25% of running cost.

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