



Possibility of energy consumption control using consumer-side equipment

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Introduction (background)

- Since the Great East Japan Earthquake, power supply capacity has become a serious problem due to the shutdown of nuclear power plants. Under these circumstances, a negawatt trading market was established, and energy conservation and power saving measures, which position power reduction on the power consumer side as a new power source, have entered the implementation stage.
- The Paris Agreement, which was adopted as an international framework for global warming countermeasures after 2020, aims to reduce global greenhouse gas emissions as soon as possible, and to reduce them to virtually zero in the second half of this century. In order to achieve these goals, thorough energy conservation and conversion to non-fossil energy are necessary.
- Japan's long-term energy supply and demand outlook also aims to increase the proportion of variable renewable energy (VRE), such as solar power and wind power, whose output fluctuates. Therefore, it is necessary to fully consider the impact of VRE on the power system on the so-called demand side as well.

Introduction (content of today's talk)

- The following two cases will be described as examples of control of energy resources on the demand side in architecture (buildings).
- As a negawatt test, the target was an individual air conditioning system (Multi-Split Packaged Air Conditioner), and the demonstration was carried out with the goal of clarifying an air conditioning control method that can achieve energy consumption reduction and maximum power reduction while maintaining the indoor environment.
- As a countermeasure for surplus renewable energy, the results of simulations and demonstration tests in actual buildings to study measures to reduce the burden on the power grid by converting surplus electricity into heat using a heat pump and storing heat.

Control of demand-side heat pumps in PED

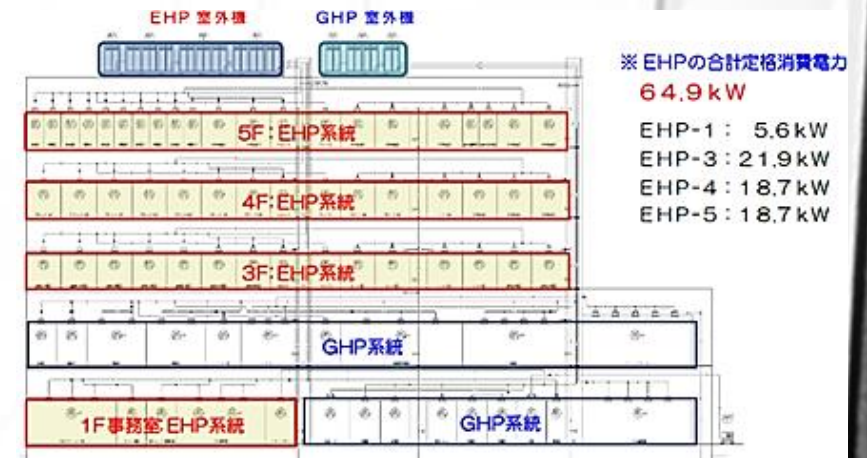
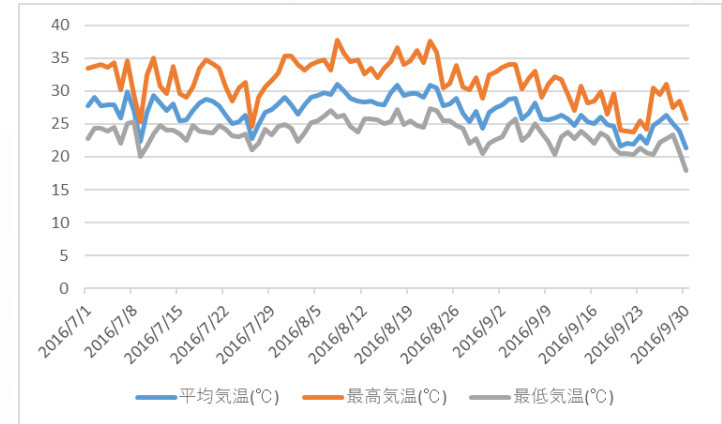
- One of the necessary elements of PED is the interrelationship between grids and buildings within a District.
- It is required to have demand response function and energy flexibility.
- Two researches introduced in this presentation are demonstration experiments of energy flexibility using heat pumps.

Power Conservation and Thermal Comfort of Individual Air Conditioning Systems

The electric driven Multi-Split Packaged Air Conditioner (EHP) of the target building was operated under the following two conditions.

Constant set temperature control The set temperature of each room is fixed at 26°C or 27°C, and air conditioning is operated continuously from 9:00 to 16:00.

Temperature shift control Raises the set temperature by 1°C or 2°C (1 hour) for the purpose of reducing power consumption.



Time							
9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
OST		CNT	OST	CNT	OST	CNT	Stop

OST : Operation at the cooling set temperature

CNT : Temperature shift control or Rhythm control

Power Conservation and Thermal Comfort of Individual Air Conditioning Systems

Evaluation index

■ Demand response effect (DR effect)

Based on the average power consumption (kW) for 30 minutes immediately before starting control.

Average power reduction (kW) for 10 minutes after starting control

Amount of electricity saved in one hour during control (kWh)

■ Recovery power (REC)

Defined as the power required to return the indoor environment changed by control to the original set temperature environment

Based on the average value (kW) of power consumption for 30 minutes immediately before performing control

Increased power (kW) against the reference value for 30 minutes after the end of control

■ Energy reduction effect

Evaluated by the amount of increase or decrease in EHP power consumption per day under temperature shift control, based on constant temperature control

■ indoor thermal comfort

PMV measurement values at representative rooms on each floor

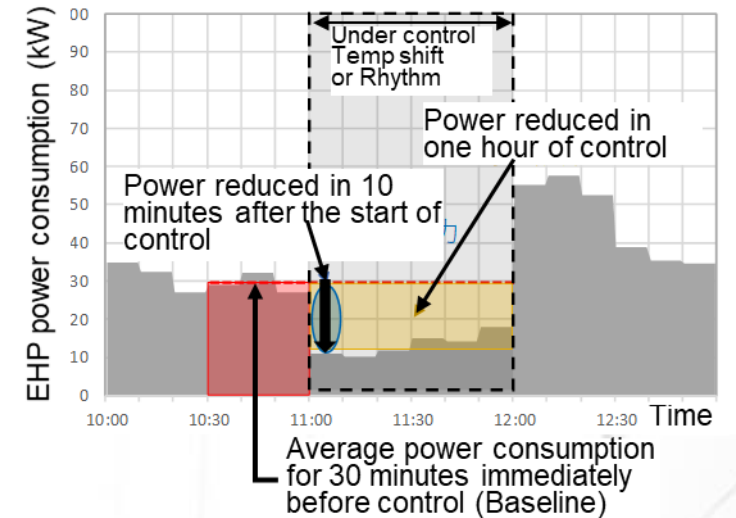


Figure 1. Effect of demand response

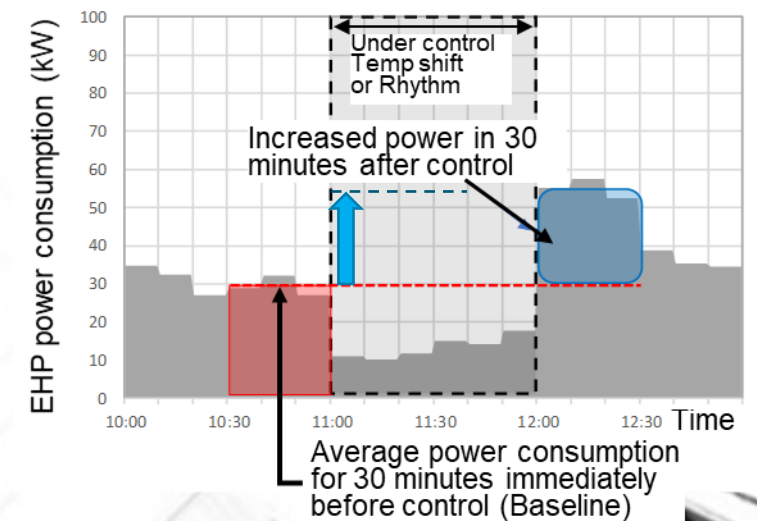


Figure 2. Recovery power

Power Conservation and Thermal Comfort of Individual Air Conditioning Systems

Test results (Demand response effect, Recovery power)

Temperature shift control (set temperature 26°C)

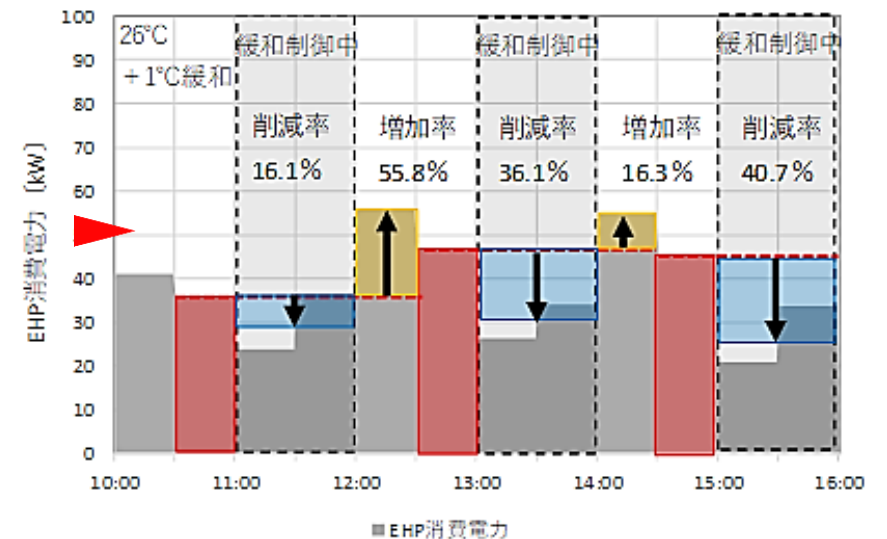
Demand response effect can be obtained, but recovery power is generated at the same time

The demand response effect (1 hour reduction rate) is 1.3 to 3.4 times greater when the set temperature is raised by 2°C compared to when the set temperature is raised by 1°C.

The recovery power is 1.4 to 2.7 times greater when the set temperature is raised by 2°C compared to when the set temperature is raised by 1°C.

	Demand Response Effect						Recovery power		
	Power reduced in 10 minutes after the start of control			Power reduced in one hour of control			Increased power in 30 minutes after control		
		KW	%		kWh	%		KW	%
Shift 1°C	11:00-11:10	-16.2	-45.1	11:00-12:00	-5.8	-16.1	12:00-12:30	20.1	55.8
	13:00-13:10	-22.8	-48.2	13:00-14:00	-17.1	-36.1	14:00-14:30	7.5	16.3
	15:00-15:10	-28.5	-62.1	15:00-16:00	-18.7	-40.7			
Shift 2°C	11:00-11:10	-18.2	-62.2	11:00-12:00	-16.0	-54.6	12:00-12:30	24.7	84.2
	13:00-13:10	-28.0	-77.2	13:00-14:00	-23.1	-64.3	14:00-14:30	15.5	44.7
	15:00-15:10	-23.7	-68.3	15:00-16:00	-23.9	-68.9			

26°C + 1°C



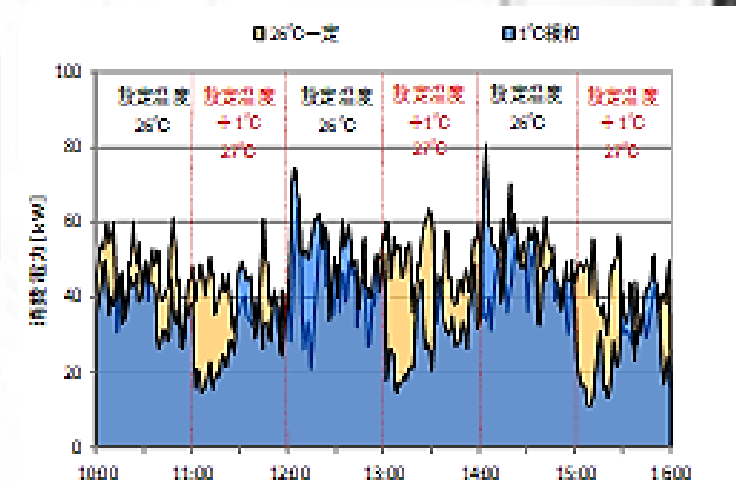
Power Conservation and Thermal Comfort of Individual Air Conditioning Systems

Test results (Energy reduction effect)

Compare the power consumption (kWh) when operating with the set temperature fixed at 26°C and the power consumption (kWh) when temperature shift control is performed.

Approximately 10 to 17% energy reduction effect can be obtained by performing temperature shift control

	Power consumption on the day of operation with temperature shift control (kWh)	Power consumption on the day when operating at the set temperature all day (kWh)	Reduction rate (%)
Shift 1°C	228.1	266.3	14.4
Shift 2°C	157.4	189.0	16.7
Fan mode	170.0	189.0	10.1



Power Conservation and Thermal Comfort of Individual Air Conditioning Systems

Test results (indoor thermal comfort: average value of PMV from 12:00 to 16:00)

- When the set temperature is raised from the set temperature of 27°C

Exceeding the comfort range $PMV < 0.5$

Control at a set temperature of 27°C causes discomfort

- When the set temperature is raised from the set temperature of 27°C

Temperature shift control (+2°C) slightly exceeds $PMV=0.5$

Other control methods have a PMV of 0.5 or less

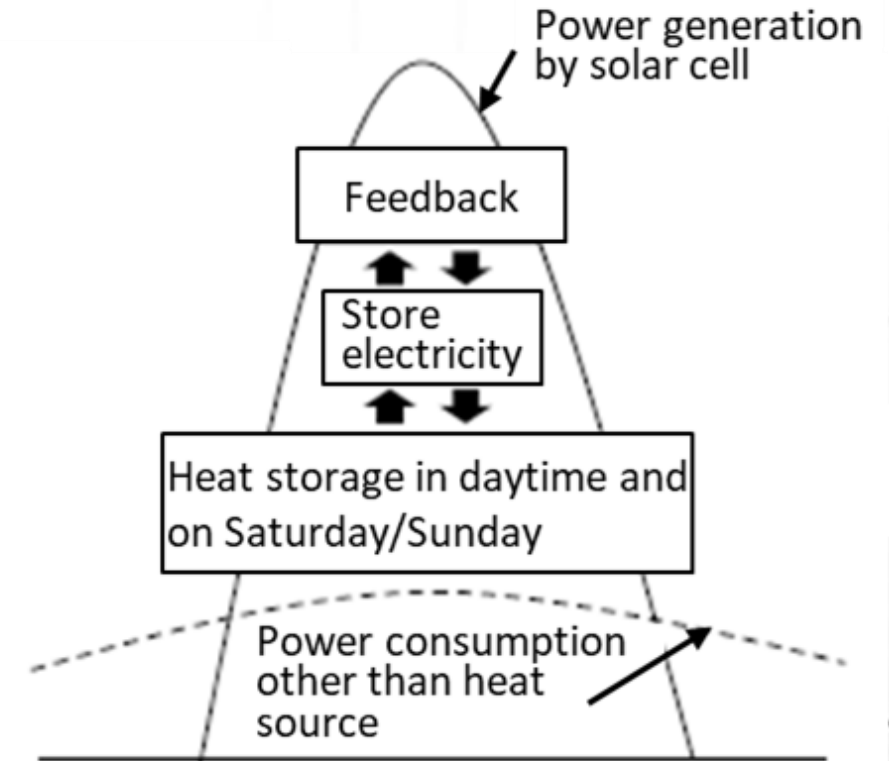
	cooling set point temperature	
	26°C	27°C
Shift 1°C	0.48	0.81
Shift 2°C	0.69	0.89

Self Demand Response : Control of reverse flow of surplus renewable power using heat pump and thermal storage

Overview of Control

If the amount of power generated by renewable power sources exceeds the amount of power used by sources other than heat sources, control is performed using the following procedure.

1. The surplus power is converted into heat using a heat pump and stored in a heat storage tank.
2. charge the battery
3. If there is more surplus power, reverse power flow to the grid



Self Demand Response : Control of reverse flow of surplus renewable power using heat pump and thermal storage

ZEB building targeted in this research

Use: office

Scale: 3rd floor above ground

Total floor area 5,535m²

Heat source equipment

Air-source heat pump chiller

Cooling capacity 57.2kW x 6 units

Thermal storage tank 430m³

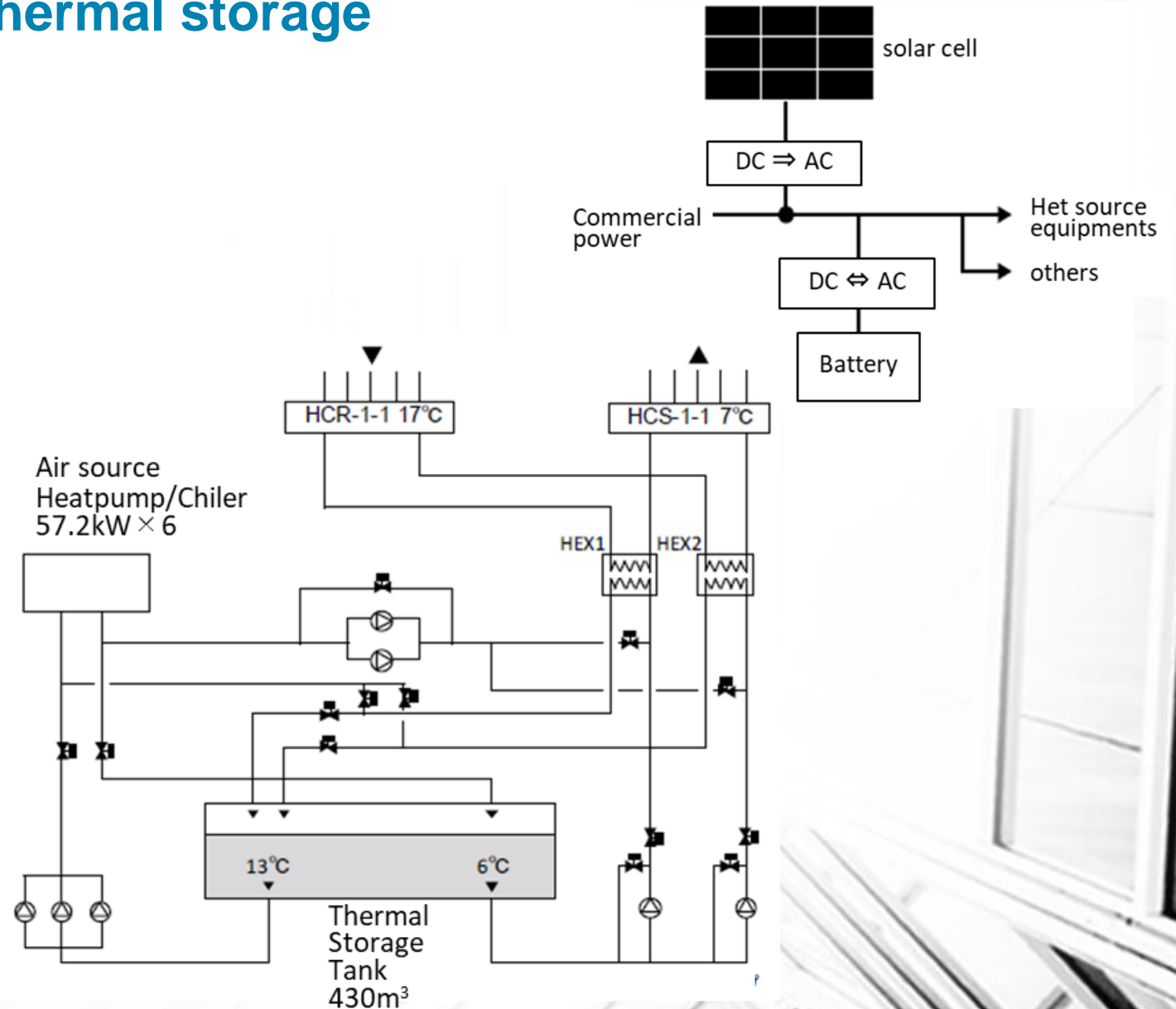
Air conditioning

Air conditioner (AHU)

Fan coil unit

Solar power generation equipment

700kW



Self Demand Response : Control of reverse flow of surplus renewable power using heat pump and thermal storage

Examination by simulation

Air-conditioning load and power consumption are based on actual measurements from July 28 to September 28, 2012 for the target building.

Heat storage and power storage operation shall be performed from 9:00 to 13:00.

- Countermeasures using heat storage (Case 2) can significantly reduce the peak value of the reverse flow rate
- Countermeasures using storage batteries (Cases 3-1 and 3-2) can reduce the total amount of reverse flow during the period, but cannot lower the peak value.
- In Case 4, which combines heat storage and electricity storage, both the total amount and the peak value can be reduced considerably.

		Case1	Case2	Case3-1	Case3-2	Case4
Thermal storage (430m ³) (heat loss 0.2%/h)		—	○	—	—	○
Battery [kWh] (Charging / discharging efficiency 72%)		—	—	100	750	750
Feedback	Total [kWh]	69,487	58,652	58,431	34,787	31,718
	Peak [kWh/h]	463	366	463	455	337
Amount of electricity purchased [kWh]		56,048	50,248	52,374	34,477	30,042
Self-consumption rate [%]		50	58	58	75	77
Power consumption [%]		124,922	129,957	132,303	138,050	136,685
Primary energy consumption [MJ]		-131,162	-82,025	-59,122	-3,031	-16,358
Percentage of energy loss [%]		—	4.0	5.9	10.5	9.4

Self Demand Response : Control of reverse flow of surplus renewable power using heat pump and thermal storage

Demonstration test (actual operation test)

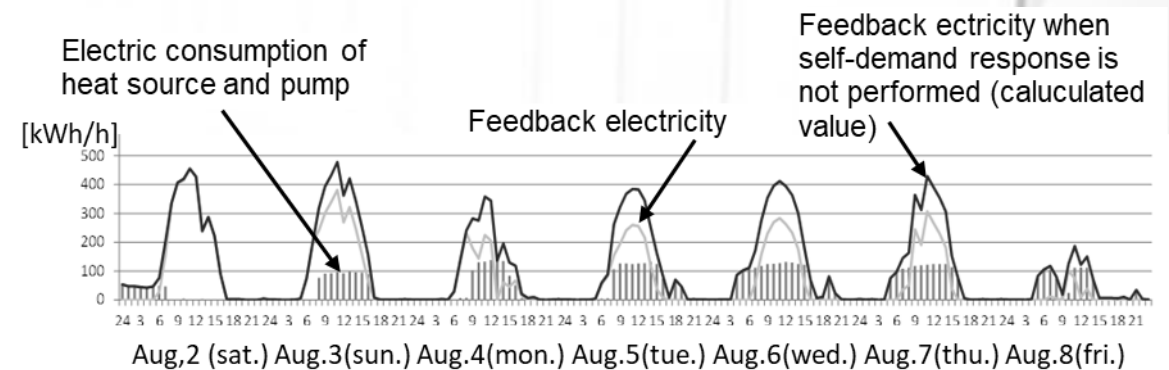
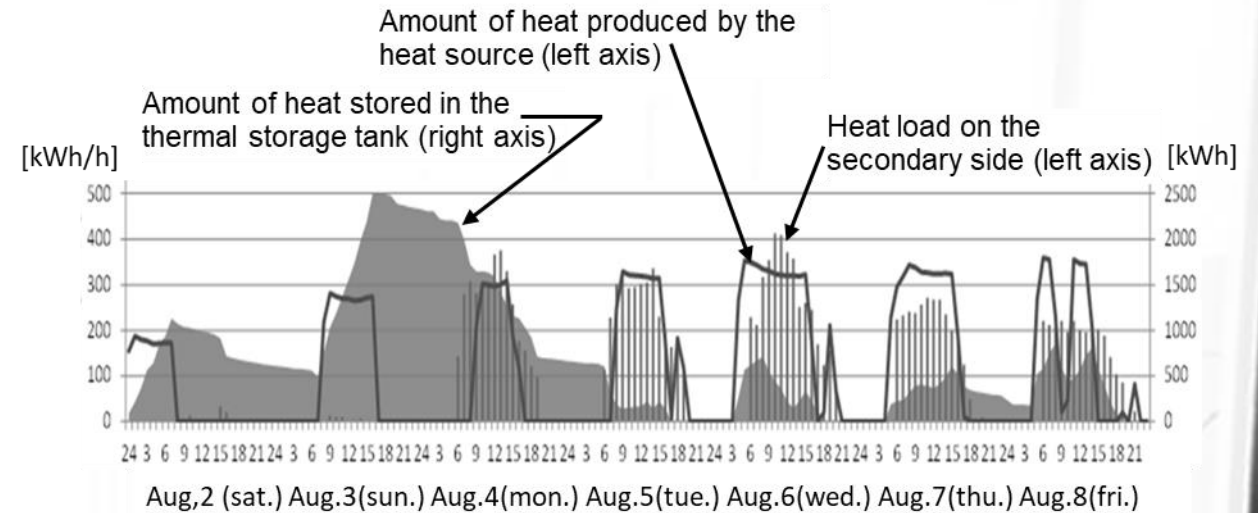
Heat storage by operating the heat source equipment using the power generated by the solar cell on Saturdays and Sundays when the power demand is low

During the daytime on weekdays, the heat is stored and released, and the heat stored on Saturdays and Sundays is all released at 18:00 on Tuesday.

After Tuesday, when heat dissipation was completed, the number of heat sources to be operated during the day was determined based on the next day's solar radiation amount forecast, and heat storage operation was performed at night to cope with the start-up operation in the morning.

Reverse power flow reduction effect

By operating the heat source equipment during the daytime on weekends and weekdays, we were able to reduce the reverse power flow peak by approximately 100 kWh/h.



in conclusion

- The possibility of controlling energy consumption on the consumer side is shown through demand response using individual distributed air conditioning systems, which are often used in buildings in recent years, and self-demand response, which controls surplus power generated by solar cells using heat pump and thermal storage tank.
- In addition, the authors are conducting research on how to reduce the reverse power flow and reduce the burden on the grid by using electric vehicles based on traffic behavior predictions.
- Towards a carbon-free society, it is necessary to appropriately consider the control of renewable energy from the perspective of self-help, mutual help, and public help.

Thank you for your attention