

ENERGY SAVING BY COOPERATIVE OPERATION BETWEEN DISTRICT HEATING AND COOLING PLANT AND BUILDING HVAC SYSTEM

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ABSTRACT

District heating and cooling (DHC) systems show a great potential for energy saving. However, a number of problems related to heating, ventilation, and air conditioning (HVAC) systems within a building resulted in an increase in energy consumption. The main reason is that the DHC plant and the building air conditioning systems are operated separately. This study proposes a new energy service in which the operator of the DHC plant controls air conditioning systems in the buildings simultaneously. Using a simulation model, it is found that energy conservation measures at the demand side would decrease energy consumption by 23.9%.

INTRODUCTION

Recently, Japan has promoted district level energy networks as one of the government's measures for mitigating global warming. DHC is a promising energy-saving measure. However, DHC has a number of problems related to the HVAC systems within a building; for example, decrease in the temperature difference between the supply and return water because of inadequate design and the operation of air handling unit and fan coil unit (Matsuo et al., 2006). In addition, not all commercially available energy saving measures have been installed in buildings, and building system operators have not operated them effectively. The main reason for these problems is that the DHC plant and air conditioning systems of buildings are designed and operated separately.

Servicizing is expected to be an effective solution to these problems (White et al., 1999). Servicizing refers to selling a service offered by a product rather than the product itself. In the case of a heat supply business, it means selling thermal comfort in a room rather than a certain number of MJ of heat. Goteborg Energi, in Sweden, offers a Climate Agreement, which delivers an agreed room temperature at a fixed price per square meter (Nagota et al., 2006). The agreement covers both the energy supply and the operation and maintenance of the HVAC systems in the building. In this case, the heat source plant and building HVAC systems can be operated by the heat supplier simultaneously.

A DHC plant simulation model has been developed, and its accuracy improved by simulation parameters derived from data measured with existing heat source systems (Shimoda et al., 2008 and Nagota et al., 2008). A comprehensive model that includes building HVAC systems and heat source systems also has been developed to verify the effects of a Climate Agreement (Uno et al., 2009). However, it is necessary to introduce much more energy conservation measures and verify the energy saving potential of a Climate Agreement.

In this paper, the potential of cooperative operation of the heat source plant and building HVAC systems in a DHC system for energy saving is estimated. To reveal the energy savings, two simulation models were used—one to model the building HVAC systems and the other a DHC plant.

SIMULATION OF HEATING AND COOLING LOADS OF A DHC PLANT

HVAC system simulation model

A HVAC system simulation model for buildings was built with Building Energy Simulation Tool (BEST) program, which is a dynamic simulation program that calculates annual energy consumption of a building and includes HVAC, telecommunications and all other building loads (Kohri et al., 2010). The program also can simulate faults related to HVAC systems, such as decrease in the temperature difference between the supply and return chilled water. The other benefits using BEST are that HVAC systems in Japan can be recreated and it can be applicable in various buildings because of its module architecture. First, to confirm the accuracy of the simulation model, an existing building was modeled and simulation results were compared to measured data. As shown in Fig. 2, the modeled area is the south and east area on the seventh floor of an office building; Data on the area was measured for three months starting in July 2005. The air conditioning equipment for this floor is shown in Table 1. As shown in Fig. 1, the HVAC systems for this floor were recreated in the simulation model. Fig.3 compares the simulated and measured interior average temperatures. The difference between the measured data and the simulation result is small, which verifies the accuracy of the model.

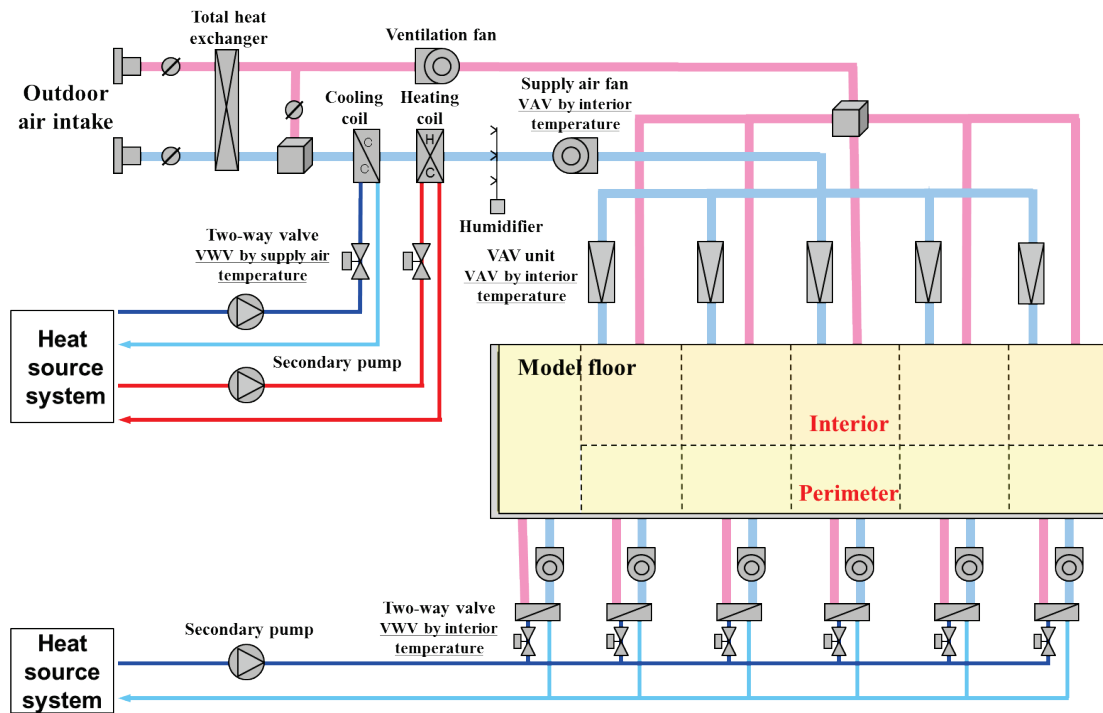


Figure 1 Air conditioning equipment

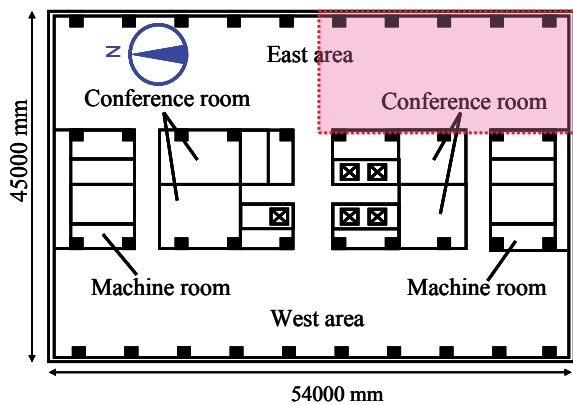


Figure 2 The area being modeled

Table 1 Air conditioning equipment

AHU (air handling unit)	Cooling capacity	47.7 kW
	Heating capacity	32.0 kW
	Supply air	8500 m ³ /h
	Return air	7500 m ³ /h
FCU 1 (fan coil unit)	Cooling capacity	7.7 kW
	Heating capacity	12.8 kW
	Supply air	1272 m ³ /h
FCU 2	Cooling capacity	5.5 kW
	Heating capacity	8.8 kW
	Supply air	930 m ³ /h

Simulating the heating and cooling loads of a DHC plant

The DHC plant supplies an assumed mix of building types includes five office buildings and a commercial building.

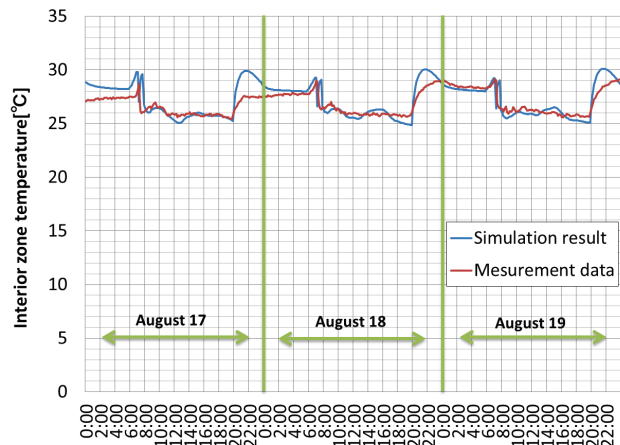


Figure 3 Comparison of interior average temperature

The composition and number were decided by investigation into the actual composition of building types and average number of buildings. The air conditioning load in the office buildings was calculated with the HVAC system simulation model in the previous section. As shown in Table 2, the load difference between office buildings results from changing behavioural patterns of the occupants, the operating hours of the HVAC systems, and the type and density of office equipment. In addition, hot water supply demand is not included because the assumed DHC plant is electric driven heat pump type and on-site water heaters are assumed to be used in buildings.

As a result, the integrated DHC peak loads are 134.6 GJ/h for cooling and 40.9 GJ/h for heating. The cumulative patterns of heating and cooling loads of the DHC are shown in Fig. 4.

Table 2 Behavioral pattern of occupants, operating hours of HVAC systems, and type and density of equipment

Building use	Day	Load type	Maximum load	Hourly load pattern[%]																											
				0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23				
Office	1	Business day	Air conditioner																												
			Lighting	19.3 W/m ²	0	80	100																66	45	34	23	14				
			Occupancy	0.11 person/m ²	0	30	100	50	100																80	50	30	10	5	0	
	2	Business day	Equipment	14.08 W/m ²	12	64	88	85	88																82	63	44	38	18	12	
			Air conditioner																												
			Lighting	19.3 W/m ²	0	90																80								0	
	3	Business day	Occupancy	0.17 person/m ²	0	29	50	53	35	50	49	53	56	47	33	26	16	8	0												
			Equipment	19.1 W/m ²	10	60	75	65	75																70	65	60	55	50	10	
			Air conditioner																												
	4	Business day	Lighting	19.3 W/m ²	0	90																80								0	
			Occupancy	0.21 person/m ²	0	45																35	45	40	20	15	13	11	0		
			Equipment	12 W/m ²	15	42	75	100	67	100	92	92																58	42	33	25
	5	Business day	Air conditioner																												
			Lighting	19.3 W/m ²	0	77	100	77	100																77	64	54	13	0		
			Occupancy	0.23 person/m ²	0	45	70	50	70	60	60																25	10	5	3	0
	1 - 5	Holiday	Equipment	14 W/m ²	14	93	100	93	100																93	57	36	29	14		
			Air conditioner																												
			Lighting		0																										
	Data center		Occupancy	"Same to Business day"	0																										
			Equipment		10 (Office 2 and 3) 12 (Office 1) 14 (Office 5) 15 (Office 4)																										
Air conditioner																															
Commercial	Monday to Friday	Equipment	150 W/m ²	100																											
		Air conditioner																													
		Lighting	35 W/m ²	0	30	65	100																65	30	0						
	Store	Holiday	Occupancy	0.50 person/m ²	0	8	15	23																8	0						
			Equipment	10 W/m ²	0	30	65	100																65	30	0					
			Air conditioner																												
	Special day		Lighting	35 W/m ²	0	30	65	100																65	30	0					
			Occupancy	0.50 person/m ²	0	8	38	75																38	8	0					
			Equipment	10 W/m ²	0	30	65	100																65	30	0					
	Restaurant		Air conditioner																												
			Lighting	35 W/m ²	0	100																50	100								0
			Occupancy	0.50 person/m ²	0	40																80	40	80							

* Special day: January 1 and 2

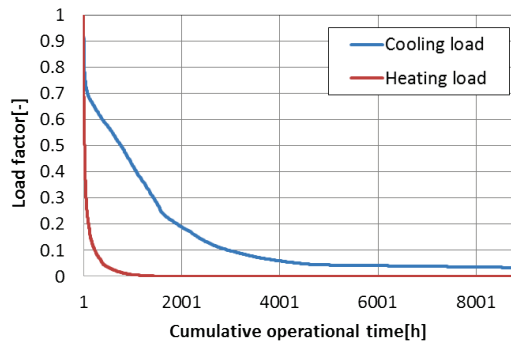


Figure 4 Patterns of DHC heating and cooling loads

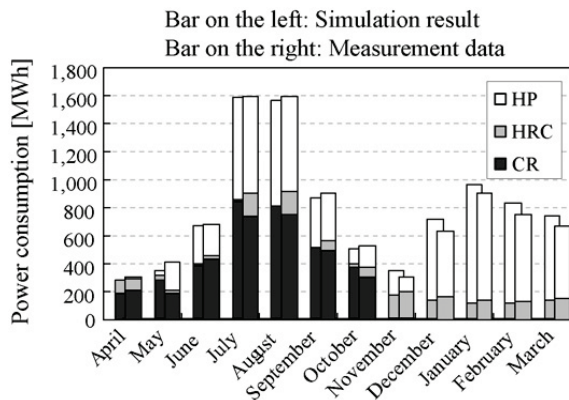


Figure 5 A comparison of the monthly power consumption of the chillers and heat pumps between the simulation result and measurement data

DHC PLANT SIMULATION MODEL

In this study, an existing electric driven heat pump type plant was modelled. The plant consists of electric-driven chillers/heat pumps and thermal storage tanks. Fig. 6 shows the system configuration of this DHC plant.

For simulating this plant, a simulation model was built. The simulation model can consider the faults related to DHC such as decrease in the temperature difference between the supply and return chilled water. Fig. 5 shows a comparison of the monthly power consumption of the chillers and heat pumps between the simulation result and measurement data. The power consumption is close between actual condition and simulation result.

POTENTIAL OF ENERGY SAVINGS BY COOPERATIVE OPERATION

Hereafter, the results of DHC and building simulation obtained from the heating/cooling loads calculated in the previous sections are used as a base case. The potential of energy conservation measures was evaluated by comparing their results with the base case results. There are two types of energy conservation measures. One is resolving problems expanding energy consumption and impairing energy efficiency, which occur during design and operation. The other is introducing additional energy

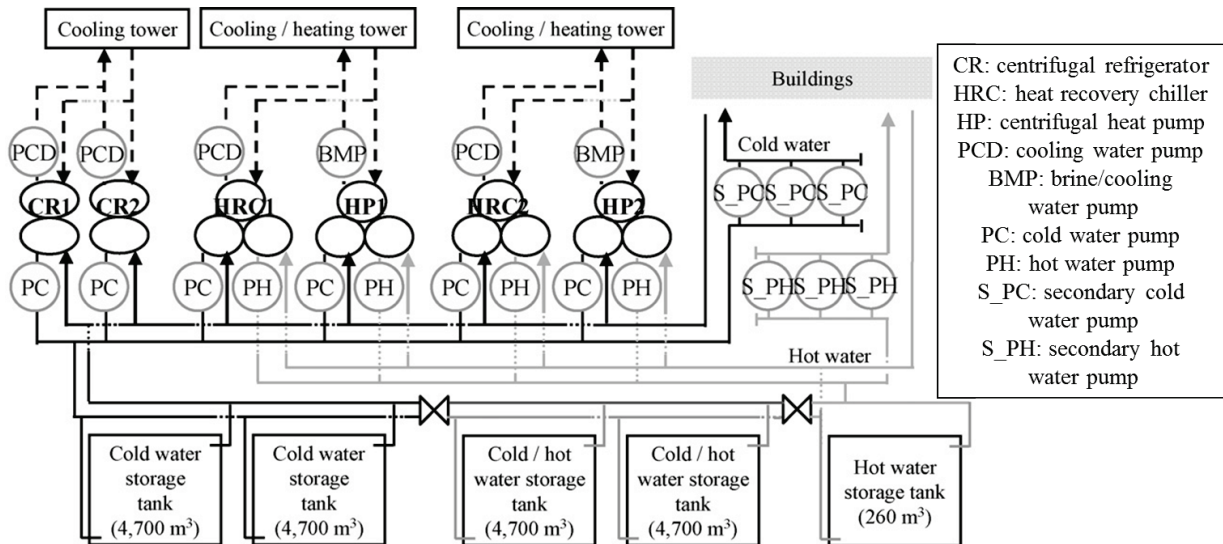


Figure 6 System configuration of model plant

conservation measures to reduce heating/cooling load, such as cooling with outside air. In following sections, each energy saving measure which is introduced in this paper is categorized in the above two types and discussed separately.

Resolving problems which occur during design and operation on building HVAC system

On existing building HVAC systems, inadequate design and operation have big effects on their performance. From the points of economical advantage and energy conservation, it is important to resolve problems impairing energy efficiency and expanding energy consumption. We first verify the energy saving potential by resolving these problems.

Case-A: Decrease in the temperature difference between the supply and return chilled water

The energy saving potential was evaluated by recreating decreases in the temperature difference between the supply and return chilled water at a regulated value by setting expected faults in building HVAC systems. In the following, the specific faults involved are explained.

1. Low supply air temperature set-point

In the base case, supply air temperature set-point is 16°C in cooling and 32 °C in heating. In this case, air temperature set-point is assumed to be changed to 13 °C in cooling and 35 °C in heating in order to achieve the set-point quickly and save fan power of air-conditioner.

2. High flow rate of water than design value

With an ideal design of valves and pumps, supply chilled water flow rate is at a regulated value. In this case, 120% of designed water flow rate is supplied with problems in designing valves and pumps.

3. Inadequate design value in PI controllers

To achieve the targets continuously, PI controllers are installed in building HVAC systems. It is clear that parameters in the controllers have big impact on

Table 3 P values changes of PI controllers(Office)

	AHU(VWV)		FCU(VWV)	
	Cooling	Heating	Cooling	Heating
Before	0.02	0.01	0.35	0.6
After	0.05	0.04	1.6	1.5

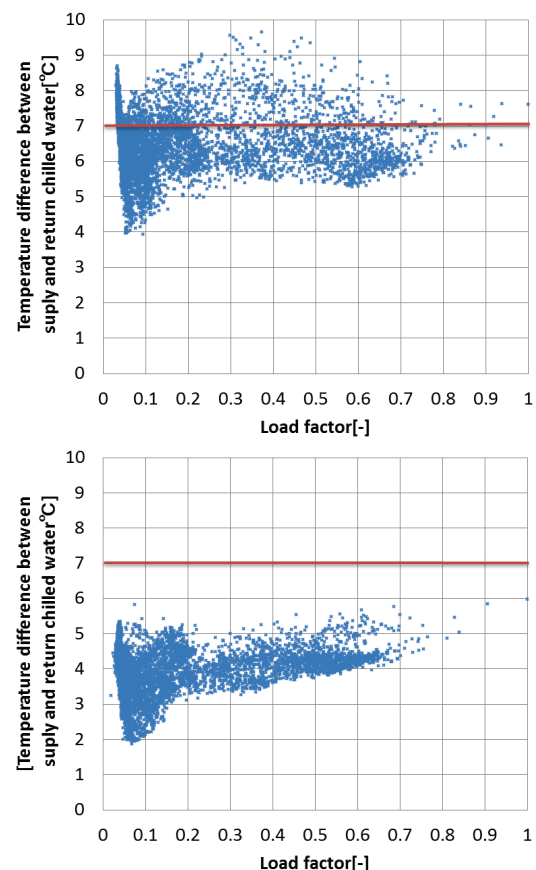


Figure 7 Temperature difference between the supply and return chilled water (Above: Base, Below: Case-A)

whether control system works well. In this case, parameters are changed as shown in Table 3 in order to recreate improper control system.

Fig. 7 shows the temperature differences. As shown in Fig. 8, total energy consumption of DHC plant and

building HVAC systems is reduced by 7.8% with resolving the decrease in the temperature.

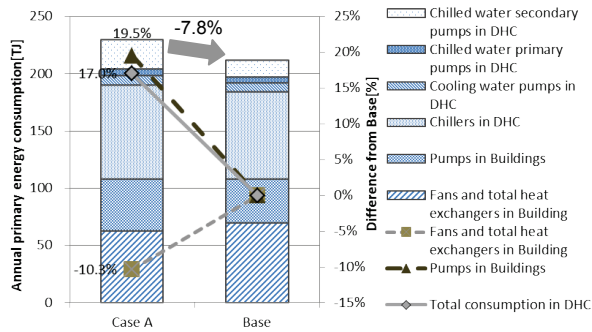


Figure 8 Annual primary energy consumption change (Case-A)

Case-B: Annual operation of total heat exchanger

Total heat exchanger leads to large energy saving. To produce the expected effect, it is required to bypass the heat exchanger when the outdoor air is cooler than the room air in cooling, and hotter in heating. In this case, a situation that the heat exchanger is operated annually is recreated to clarify the energy saving potential by the adequate operation above.

Fig. 9 shows total energy consumption is saved by 6.5% in case the heat exchanger is bypassed properly.

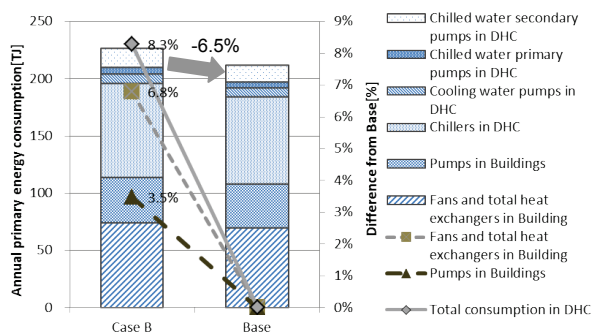


Figure 9 Annual primary energy consumption change (Case-B)

Introducing additional energy conservation measures on building HVAC system

Case-C: Cooling with outside air

It is a promising energy conservation measure to intake outside air into the room directly by bypassing total heat exchanger when the outside air temperature is lower than the inside in cooling. In this case, the energy saving potential was evaluated by cooling with the outside air with the condition as shown in Table 4.

Table 4 The condition cooling with outdoor air

		The condition cooling with outside air
Office/	Summer	10°C ≤ Outdoor temperature ≤ 25°C
Commercial	Others	10°C ≤ Outdoor temperature ≤ 24°C
Data center		10°C ≤ Outdoor temperature ≤ 23°C

Fig. 10 shows total energy consumption is increased by 1.4% in Case-C. This result indicates that the power increase of fans went over the energy saving by cooling with the outside air. To achieve energy conservation, detailed planning is required before introducing cooling with outdoor air.

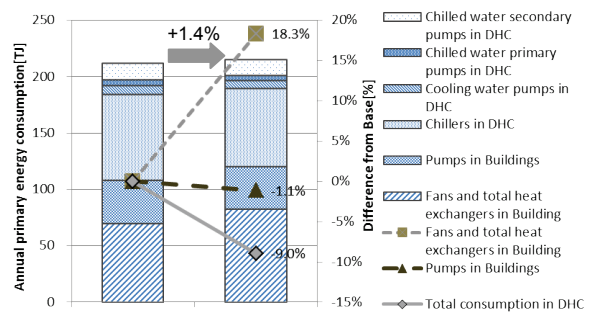


Figure 10 Annual primary energy consumption change (Case-C)

Case-D: Proper design in the volume of intake outdoor air

The volume of intake air is decided with the designed density of occupants. However, the actual maximum density is lower than the designed as shown in Table 2. In this case, the energy saving potential was evaluated in case the volume of intake air is set with the actual maximum density as shown in Table 5.

Table 5 The volume of intake outdoor air

[m ³ /h]	Office 2	Office 3	Office 4	Office 5	Store	Restaurant
Before	2907	1539	3591	3933	8550	8550
After	1628	1154	1616	2753	6413	6840

Fig. 11 shows total energy consumption doesn't change in Case-D. It is because the energy saving in heating might be equal with the energy loss in cooling. To enhance the effect, CO₂-based demand controlled ventilation might be effective.

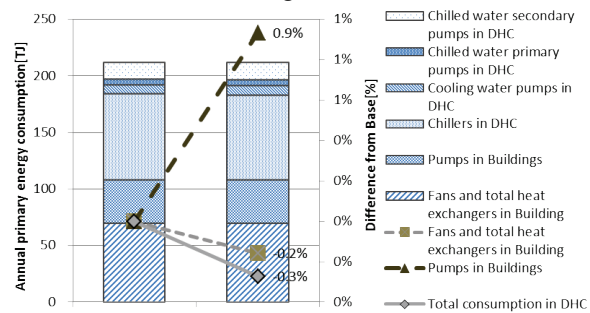


Figure 11 Annual primary energy consumption change (Case-D)

Case-E: Easing preset temperatures of air conditioners in buildings

To mitigate global warming, easing preset temperatures of building air conditioners is proposed recently. In this case, the energy saving potential was evaluated by changing the preset temperatures from 25 and 26 to 28 °C in cooling, and from 22 to 20 °C in heating.

Fig. 12 shows total energy consumption is reduced by 10.9% in Case-E.

With resolving Case-A and Case-B, and introduction of Case-C, Case-D and Case-E, the total energy consumption is reduced by 23.9% in total as shown Fig. 13. It shows that high energy conservation is achieved by introducing the energy service which this paper proposes.

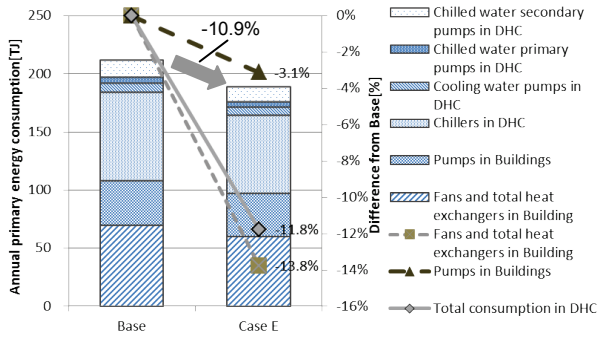


Figure 12 Annual primary energy consumption change (Case-E)

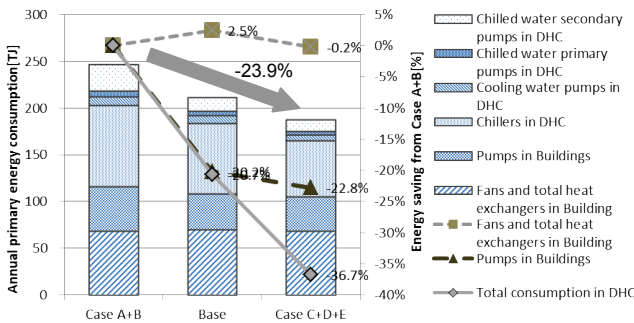


Figure 13 Annual primary energy consumption change (all Cases)

Operating cost reduction from building energy saving measures

When heat suppliers adopt the energy service as this paper suggests, it must be determined whether the energy saving measures provide a profit. Thus, the operating cost reductions were evaluated for Case-A and Case-B, Base case and Case-C, Case-D and Case-E. Table 6 shows the electricity rate for buildings and Table 7 shows it for a DHC plant. Cost calculations show the cost is reduced by 6.6% in buildings, by 18.8% in the DHC plant, and by 12.8% in total with resolving Case-A and Case-B and introduction of Case-C, Case-D and Case-E as shown in Fig. 14.

Table 6 Electricity rate for building

Building HVAC systems	Base rate	Metered rate
	[JPY/kWh month]	[JPY/kWh]
Summer	1638	13.75
Other seasons		12.65

※Summer : Jul. August and September

※Other seasons : Except for Summer

Table 7 Electricity rate for DHC plant

Plant	Base rate	Metered rate	
	[JPY/kWh month]	[JPY/kWh]	
Peak load time	1585.5	13.96	
Daytime		Summer	13.38
		Other seasons	12.28
Nighttime		9.02	

※Peak load time : 13:00~17:00 in summer (Except for Sunday and national holiday)

Daytime : 8:00~22:00

(Except for Sunday, national holiday and Peak load time)

Nighttime: Except for Peak load time and Daytime

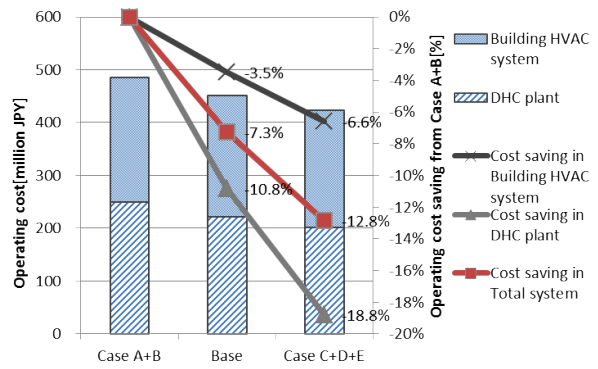


Figure 14 Operating cost reduction

RISK ASSESSMENT FOR ASSUMED VARIABLE FACTORS

In previous sections, it was assumed that all building owners agree to an energy service contract with the DHC company and the climate does not change during the entire contract period. However, not all building owners might sign the contract and the climate might be change. These risks can have a considerable effect on the potential energy conservation from energy saving measures.

Thus, a case was assumed that the DHC company offers the building owners the energy saving measures outlined in the previous section as an energy service, and assessed the risks for the assumed variable factors.

The energy service contract ratio decreases

In previous sections, it was assumed that all building owners sign the energy service contract. However, the energy service contract ratio can decrease, because the energy service includes risks that might disturb the comfort of building occupants, such as changes in the pre-set temperatures.

Thus, changes in energy conservation were evaluated when the energy service contract ratio decreases. Assumed changes of the contract ratio are shown in Fig. 16. As shown in Fig 15, the effects of the energy service increase linearly as the contract ratio increase. Therefore, the more the contract ratio increase, the more energy saving effects it brings.

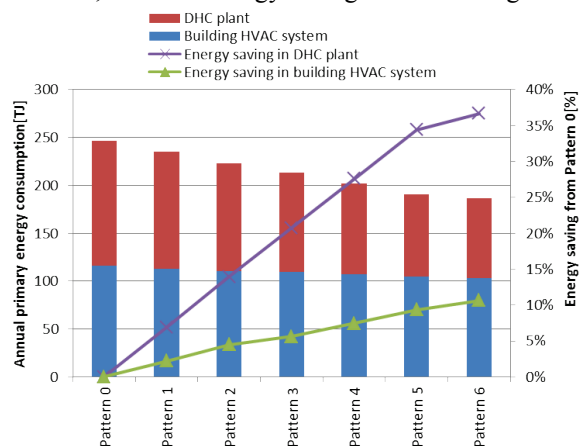


Figure 15 Change of energy conservation by patterns of contract ratio

	Office1	Office2	Office3	Office4	Office5	Commercial
Pattern 0						
Pattern 1				No Energy		
Pattern 2				Service		
Pattern 3				Contract		
Pattern 4						
Pattern 5		Energy Service				
Pattern 6		Contract				

Figure 16 Patterns of contract ratios

Increase in outdoor temperature

It is important to evaluate whether energy conservation from an energy service is maintained if there are climate changes from global warming and heat island effects. In addition, the service still should be profitable for owners and the DHC company. Changes in energy conservation were evaluated for an increase in outdoor temperature of 1 °C with fixed relative humidity. Fig. 17 shows the change of energy conservation resulting from this increase in outdoor temperature. The energy consumption increases by 3.1% compared to the actual climate. Thus, a temperature rise of 1 °C detracts little from the energy saving effects. However, it is necessary to bring stability to the business that energy suppliers consider this risk in planning energy prices.

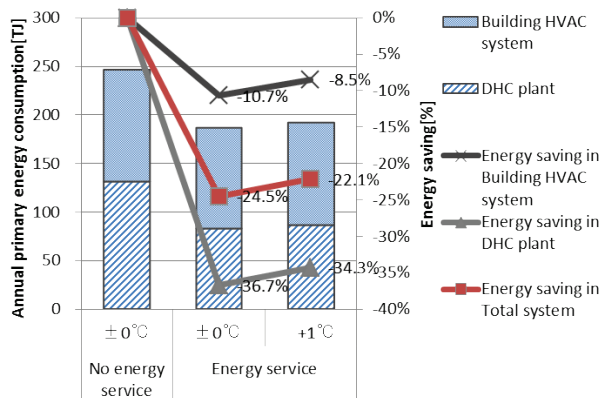


Figure 17 Change of energy conservation from a rise in outdoor temperature

Global warming tax enforcement

To tackle with global warming, many countries adopt environment and carbon taxes. In Japan too, an environmental tax to counter global warming was decided to introduce in 2011. In this paper, an increase in operating cost was estimated with the CO₂ exhaust rate (0.324 kg-CO₂ per kWh) and the tax rate (300 JPY per CO₂ tonnes). As shown in Fig. 18, the increase in operating cost does not go over 1%. Thus, the present tax does not have a considerable effect on profitability of the business. However, tax-based pricing model is required to bring stability to the business, because the tax rates might increase in the future.

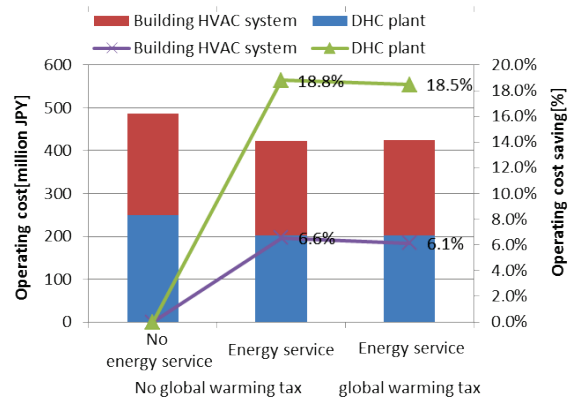


Figure 18 Change of operating cost from enforcement of global warming tax

Rise in the price of fossil oil

Recently, fossil oil prices have had a trend in rise although the prices temporally downed from global recession. As International Energy Agency (IEA) estimates in its report, this trend is assumed to continue in the future.

The power companies in Japan will introduce flexible pricing model based on a price of fossil oils. In this case, an increase in operating cost was evaluated by soaring fossil oil prices in the future. The additional price rates by rising in price of fossil oils were calculated in case the prices soared at 150% of their base prices, although the companies already abolished this limit in 2009. The additional price rates are shown in Table 8 and added to the rates in Table 6 and Table 7. As shown in Fig. 19, the operating cost increases by 14.8% compared to present fossil oil price with the energy service, by 2.2% compared to present fossil oil price without the energy service. Thus, it is strongly required to introduce a pricing model such as the above example in Japan in order to bring stability to the business.

Table 8 Additional electricity rate from soaring fossil oil prices

	Additional metered rate [JPY/kWh]
DHC plant	3.89
Building HVAC system	3.96

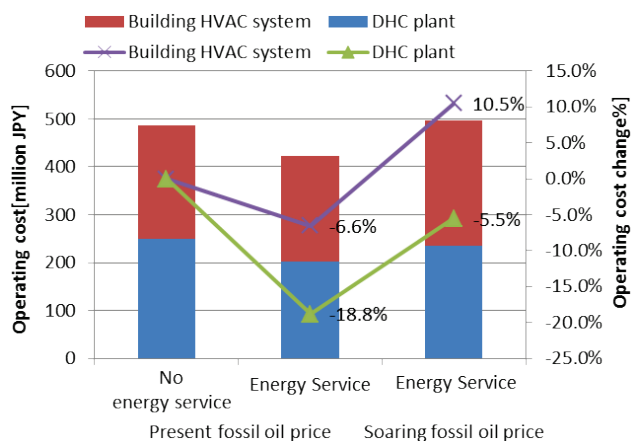


Figure 19 Change of operating cost by soaring fossil oil price

CONCLUSION

The potential of energy savings by cooperative operation of the heat source plant and building HVAC systems in a DHC system is estimated. Simulation results show that total primary energy consumption decreased 23.9% when the problems which occur during design and operation on building HVAC systems were resolved (Case-A and Case-B), and the additional energy conservation measures were introduced (Case-C, Case-D and Case-E). On the other hand, several risks related to the energy service were assessed and it was found that three significant points must be considered when a heat supplier adopts the suggested energy service.

- The more the energy service contract ratio increase, the more energy saving effects it brings.
- Pricing models based on the effect of climate change by global warming and heat island effects, and the environmental tax to combat global warming are should be introduced.
- Pricing model based on prices of fossil oils must be adopted to bring stability to the energy service business.

Thus, the details of the energy service contract should be structured with these risk assessments in mind.

For increasing the feasibility of the energy service, in two points should be improved. First, much more buildings should be simulated in HVAC system simulation model. In this paper, a popular building was recreated; however, there are various types of building actually. By improving this point, the simulation results could be more general. Second, a lot of energy saving measures must be chosen. Especially, problems that occur during design and operation on building HVAC systems should be recreated and resolved more. From the aspect of business, such cost-effective energy saving measures are welcome. With recreating such saving measures, the energy service will make bigger impact on energy conservation.

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