ENERGY SAVING POTENTIAL OF COOPERATIVE OPERATION BETWEEN DISTRICT HEATING AND COOLING PLANT AND BUILDING HVAC SYSTEMS

Yoshitaka Uno[1], Reiko Kubara[1], Yoshiyuki Shimoda[1]

[1]Division of Sustainable Energy and Environmental Engineering,
Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

ABSTRACT

District heating and cooling (DHC) systems show a great potential to save energy. However, DHC has a number of problems related to other systems within a building; for example, decrease in the temperature difference between the supply and return water carrying cooling and heating energy affects efficiency. 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 at the same time. Using a simulation model, it is found that energy conservation measures at the demand side would decrease energy consumption by 5%.

INTRODUCTION

Recently, Japan has focused on area energy networks for mitigating global warming. District heating and cooling (DHC) is a promising energy-saving measure. However, DHC has a number of problems related to the other 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 building heating, ventilation, and air-conditioning (HVAC) systems (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 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). However, it is necessary to build a comprehensive model that includes building HVAC systems and heat source systems to verify the effects 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.

CLIMATE AGREEMENT

Goteborg Energi supervises and operates all equipment of the HVAC systems and guarantees to maintain the indoor temperature above an agreed temperature throughout the year. Many of the contracts are for long time periods, some as long as 10 years. Therefore:

- Effective energy saving measures can be chosen even when the pay-back time is long.
- The contract prevents customers from changing to other energy suppliers.

The customers pay a fixed price per year per square meter (Fig. 1). Usually, the price is lower than the sum of the maintenance and energy costs that existed before the contract. Fig. 2 shows the economic mechanism of the Climate Agreement. The company benefits from cost reductions due to the fixed rate per square meter. The cost reduction from energy conservation measures helps reduce the cost of heat production. Therefore, the energy company promotes energy conservation measures. The energy company and the environment have a win-win relationship due to the Climate Agreement. The benefits to the customers and the energy company from the Climate Agreement are described below.

Customer benefits

- Customers are not responsible for the difficult operation and maintenance of the heat source system.
- It is easy to estimate operating costs due to the fixed rate.

Energy company benefits

- It profits from its experience in operating and maintaining the heat source system.
- Energy conservation measures improve the heat production capacity. The company does not have to install new energy supply equipment as the number of the contracts increases.
- Energy conservation results in financial benefits to the company.
- The contract prevents customers from changing to other energy suppliers.

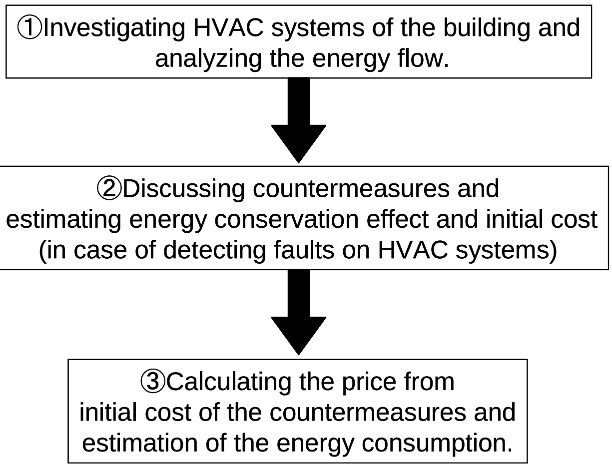

Figure 1 Flow chart for price setting

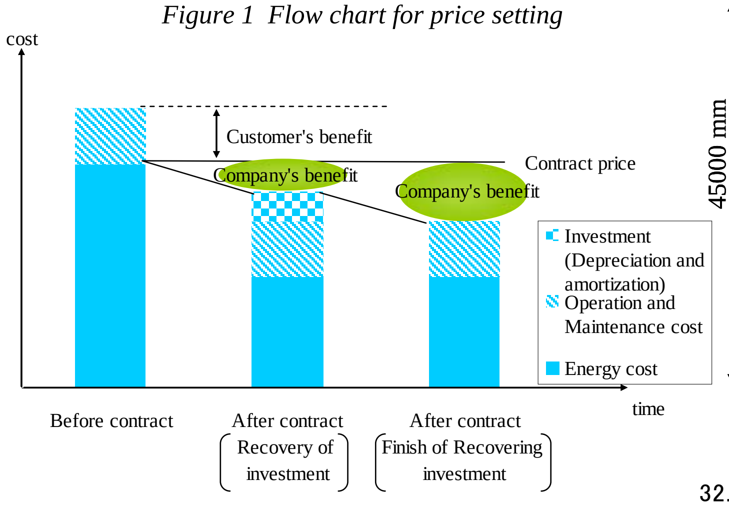

Figure 2
Economic mechanism of the Climate Agreement

SIMULATION OF HEATING AND COOLING LOADS OF A DHC PLANT

HVAC system simulation model

A HVAC system simulation model for buildings was built by using HVACSIM+(J), which is a dynamic simulation program for HVAC systems, and can simulate faults related to HVAC systems, such as decrease in the temperature difference between the supply and return chilled water. Another benefits using HVACSIM+(J) 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. 3, 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. 5, the HVAC systems for this floor were recreated in the simulation model. Fig. 4 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.

Table 1 Air conditioning equipment

AHU	Cooling capacity	47.7 kW
	Heating capacity	32.0 kW
	Supply air	8500 m^3/h
	Return air	7500 m^3/h
FCU1	Cooling capacity	7.7 kW
	Heating capacity	12.8 kW
	Supply air	1272 m^3/h
FCU2	Cooling capacity	5.5 kW
	Heating capacity	8.8 kW
	Supply air	930 m^3/h

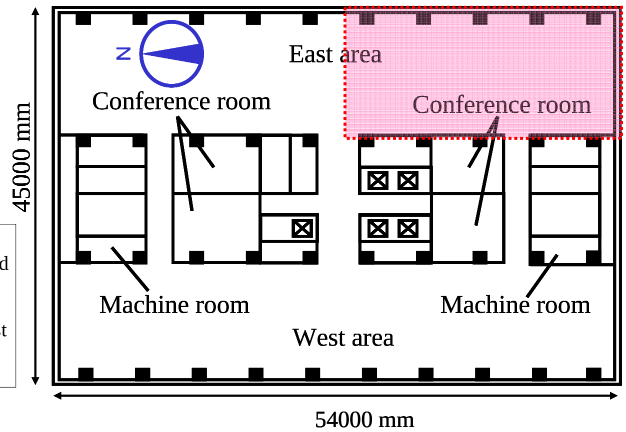

Figure 3 The area being modeled

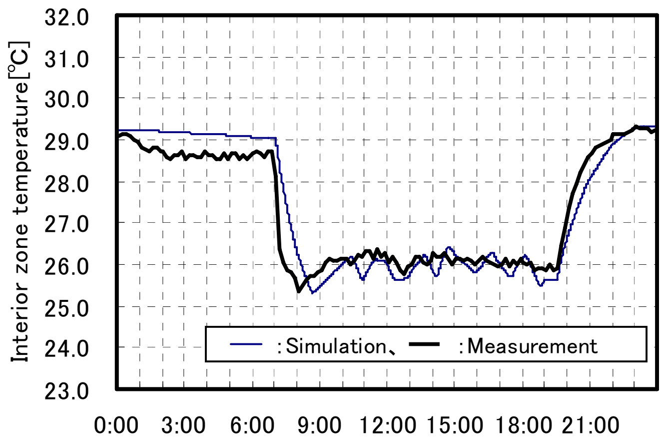

Figure 4
Comparison of interior average temperature

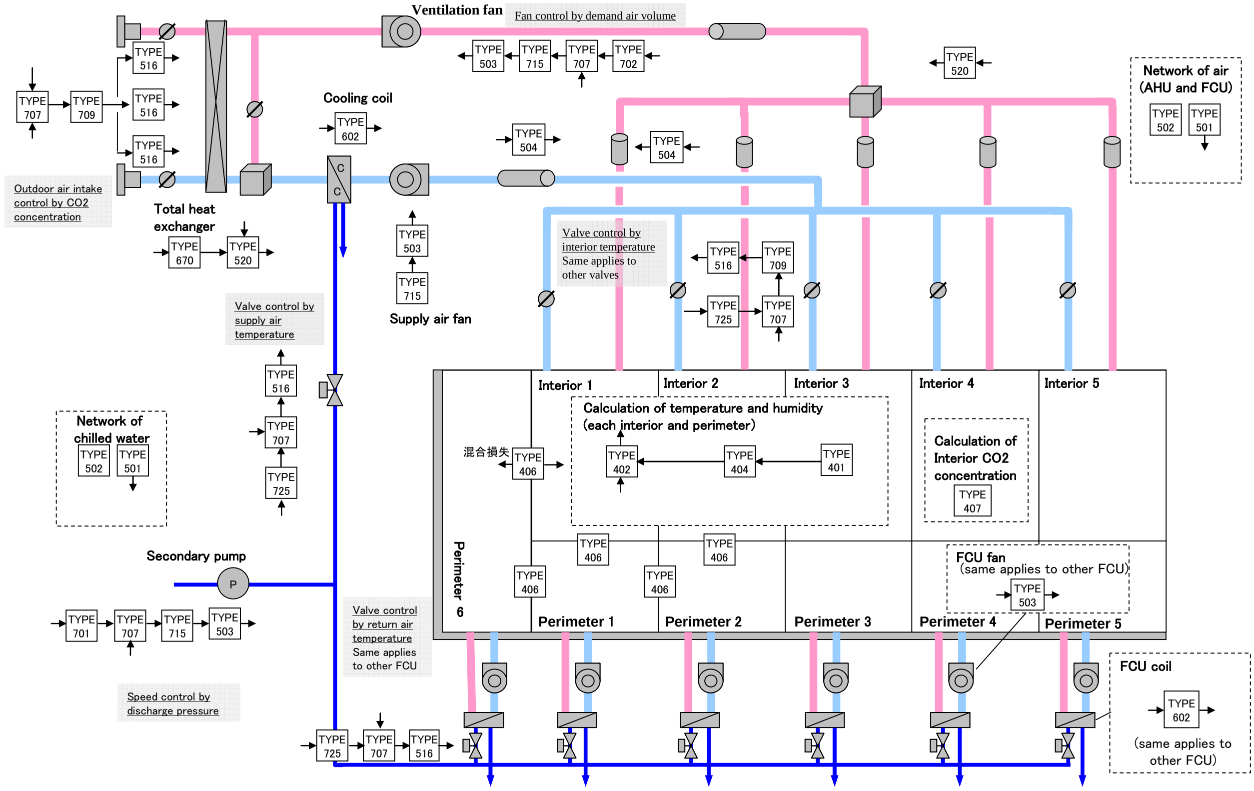

Figure 5 System configuration of HVAC systems on the model floor

Simulating the heating and cooling loads of a DHC plant

Assumed a mix of building types includes five office buildings (total floor area: 256,500 ㎡), one commercial building (35,749 ㎡), and one hotel (56,575 ㎡)—the area of the total site is 348,824 ㎡.

By investigation into the actual composition of building types and average number of buildings, the composition and number were decided. 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

Table 2 Behavioral pattern of occupants, operating hours of HVAC systems, and type and density of office equipment in each office building

<table>
<tr><th rowspan="2">Office</th><th rowspan="2">Day</th><th rowspan="2">Load type</th><th rowspan="2">Maximum load</th><th colspan="24">Hourly load pattern[%]</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th></tr>
<tr><td rowspan="4">1</td><td rowspan="24">Business day</td><td>Air conditioner</td><td>–</td><td colspan="8"></td><td colspan="14"></td><td colspan="2"></td></tr>
<tr><td>Lighting</td><td>19.3 W/㎡</td><td colspan="8"></td><td>80</td><td colspan="10">100</td><td>65</td><td>45</td><td>35</td><td>25</td><td>15</td></tr>
<tr><td>Occupancy</td><td>0.11 person/㎡</td><td colspan="8"></td><td>30</td><td colspan="3">100</td><td>50</td><td colspan="5">100</td><td>80</td><td>50</td><td>30</td><td>10</td><td>5</td><td></td></tr>
<tr><td>Equipement</td><td>14.08 W/㎡</td><td colspan="8">10</td><td>65</td><td colspan="3">90</td><td>85</td><td colspan="5">90</td><td>80</td><td>65</td><td>45</td><td>40</td><td>20</td><td>10</td></tr>
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<tr><td>Equipement</td><td>19.1 W/㎡</td><td colspan="8">10</td><td>60</td><td colspan="3">75</td><td>65</td><td colspan="5">75</td><td>70</td><td>65</td><td>60</td><td>55</td><td>50</td><td>10</td></tr>
<tr><td rowspan="4">3</td><td>Air conditioner</td><td>–</td><td colspan="8"></td><td colspan="14"></td><td colspan="2"></td></tr>
<tr><td>Lighting</td><td>19.3 W/㎡</td><td colspan="8"></td><td>80</td><td>90</td><td colspan="2">100</td><td colspan="2">90</td><td>100</td><td>90</td><td>100</td><td colspan="4">90</td><td colspan="2">80</td><td></td></tr>
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<tr><td rowspan="4">4</td><td>Air conditioner</td><td>–</td><td colspan="7"></td><td colspan="14"></td><td colspan="3"></td></tr>
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<tr><td rowspan="4">5</td><td>Air conditioner</td><td>–</td><td colspan="7"></td><td colspan="13"></td><td colspan="4"></td></tr>
<tr><td>Lighting</td><td>19.3 W/㎡</td><td colspan="7"></td><td>90</td><td colspan="10">95</td><td colspan="2">90</td><td colspan="4"></td></tr>
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<tr><td>Equipement</td><td>19.1 W/㎡</td><td colspan="7">10</td><td>55</td><td>80</td><td colspan="3">85</td><td>80</td><td>85</td><td colspan="3">80</td><td>65</td><td>55</td><td>50</td><td colspan="4">10</td></tr>
<tr><td rowspan="4">Base load thoughout the day</td><td>Air conditioner</td><td>–</td><td colspan="24"></td></tr>
<tr><td>Lighting</td><td>19.3 W/㎡</td><td colspan="24">100</td></tr>
<tr><td>Occupancy</td><td>0.09 person/㎡</td><td colspan="24">100</td></tr>
<tr><td>Equipement</td><td>17.3 W/㎡</td><td colspan="24">100</td></tr>
<tr><td rowspan="4">1～5</td><td rowspan="4">Holiday</td><td>Air conditioner</td><td>–</td><td colspan="24"></td></tr>
<tr><td>Lighting</td><td rowspan="3">Same to ”Business day”</td><td colspan="24"></td></tr>
<tr><td>Occupancy</td><td colspan="24"></td></tr>
<tr><td>Equipement</td><td colspan="24">10</td></tr>
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difference between office buildings results from changing behavioral patterns of the occupants, the operating hours of the HVAC systems, and the type and density of office equipment. Measured data from other studies was used for the hot water supply demand in office buildings and measured data from an existing DHC system was used for a commercial building and hotel.

As a result, the integrated DHC peak loads are 78.3 GJ/h for cooling and 40.7 GJ/h for heating. The cumulative patterns of heating and cooling loads of the DHC are shown in Fig. 6.

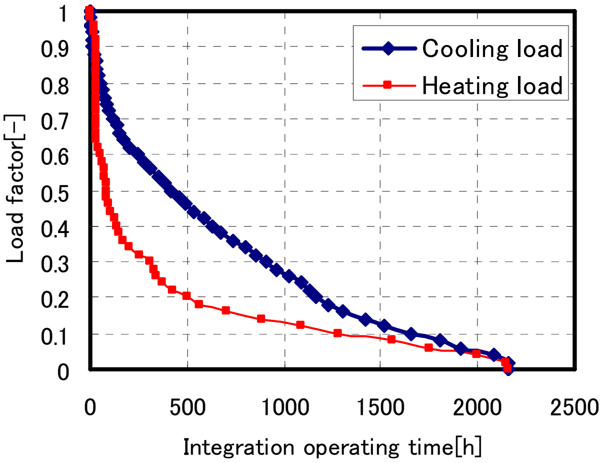

Figure 6
Patterns of DHC heating and cooling loads

DHC PLANT SIMULATION MODEL

In this study, an electric heat pump type plant was modeled. The plant consists of turbo refrigerator/heat pump, using heat storage tank and treated sewage water for cooling water as DHC system. Fig. 7 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. Table 3 lists the measured annual primary energy consumption in 2002 and the simulation result. The primary energy consumption is close between actual condition and simulation result.

Table 3
Comparison of actual annual primary energy consumption with simulation result

Consumption of electricity [GJ]		Actual condition		Simulation result		Differential
Chiller	Water source heat pump	158065	230979	159905	228498	−1.1%
	Heat recovery turbo chiller	68212		66710		
	Turbo chiller	4701		1883		
Accessories	Heat exchange pump	14396	55505	14268	56002	1.5%
	Other accessories	41108		41733		
Electric boiler			24968		24369	−2.4%
Sum total [GJ]			311452		308868	0.8%

POTENTIAL OF ENERGY SAVINGS BY COOPERATIVE OPERATION

Potential of energy conservation measures in buildings

Hereafter, the simulation results calculated using the loads simulated 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. On literature research, energy conservation measures as follows were listed; implementations of variable pump and fan, improvement of controls and correcting faults in HVAC system and changes of preset temperatures of air conditioners in buildings, etc. However in this paper, Case-A and Case-B as follows were evaluated because variable pump and fan are already

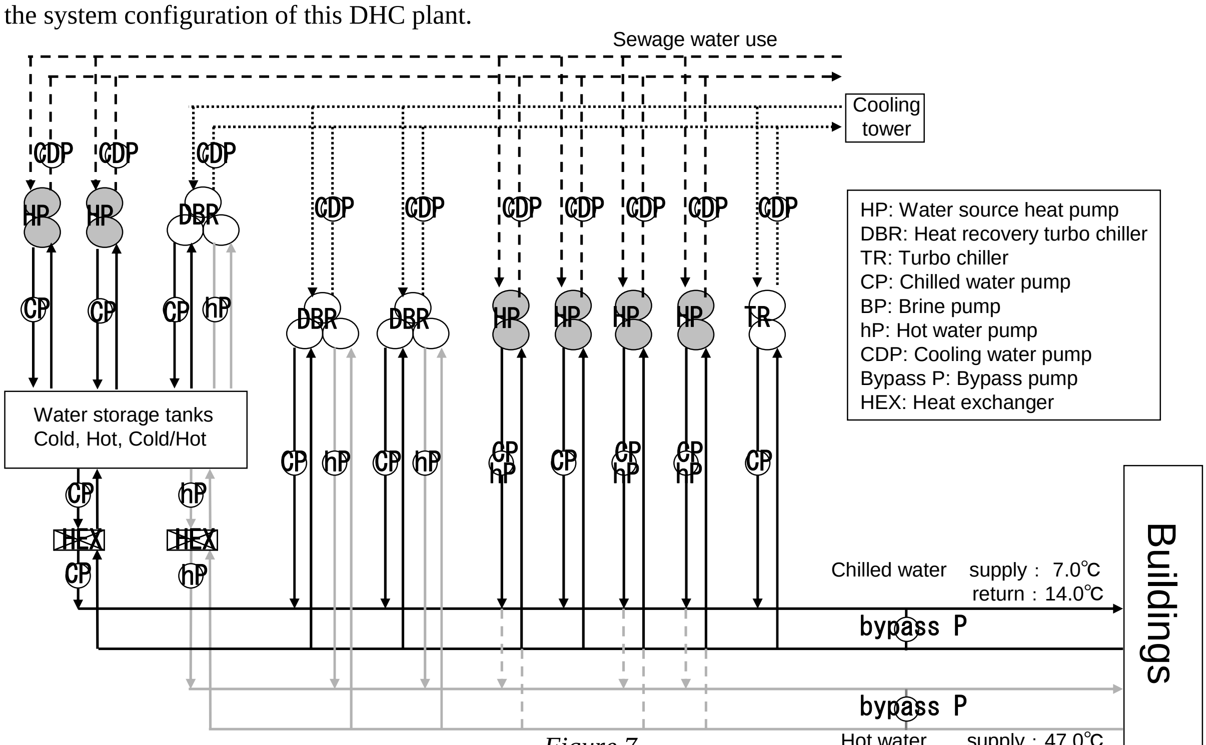

Figure 7
System configuration of model plant

implemented and other faults in HVAC system aren't figured out by investigation into the actual conditions.

Case-A: Preserve the temperature difference between the supply and return chilled water at a regulated value

The energy saving potential was evaluated by maintaining the temperature difference between the supply and return chilled water at a regulated value by modifying HVAC systems in buildings. In the following sections, the specific items involved are explained.

1. Change in the number of rows of coils in the AHU and FCU.

The number of rows of coils was changed from 8 to 10 in the AHU and from 4 to 5 in the FCU.

2. Increase in the flow rate of the FCU

The flow rate of FCU was increased from medium to high volume.

3. Improvement of the control valves

The precision of the control valves was improved. In particular, the minimum controlled variable was changed from 2 to 0.3%.

These measures resulted in a temperature difference between the supplied and the returned chilled water that was maintained as shown in Fig. 8; the annual primary energy consumption of the thermal system decreased, as shown in Fig. 10. Compared to the base case, the energy consumption of pump and fan in the building air conditioning system decreased by 1%. Maintaining a constant temperature difference between the supplied and the returned chilled water reduced the demand for chilled water, which should contribute to a reduction in energy consumption. The energy consumption in the heat source system is decreased by 3%. The reduction of the building heat demand should also contribute to the reduction of the energy consumption. In total, the energy consumption decreased by 2% in Case A.

Case B: Changes of preset temperatures of air conditioners in buildings

The preset temperatures of the building air conditioners were changed. In particular, the preset cooling temperature was changed from 26 to 28 degrees Celsius in summer, and the heating temperature was changed from 22 to 20 degrees Celsius in winter. These measures decreased the heating and cooling loads, as shown in Fig. 9, and the annual primary energy consumption in the total system decreased as shown in Fig. 10. For Case B, the energy consumption decreased by 5% compared to the base case and by 3% compared to Case A.

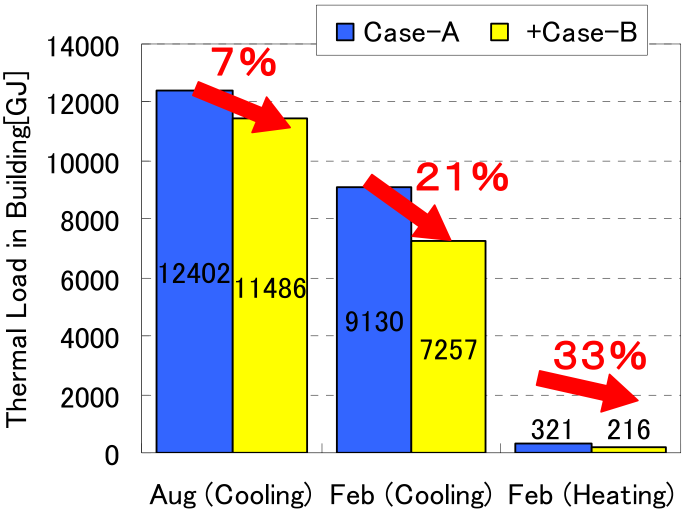

Figure 9
Energy change of loads by changing air conditioner preset temperatures

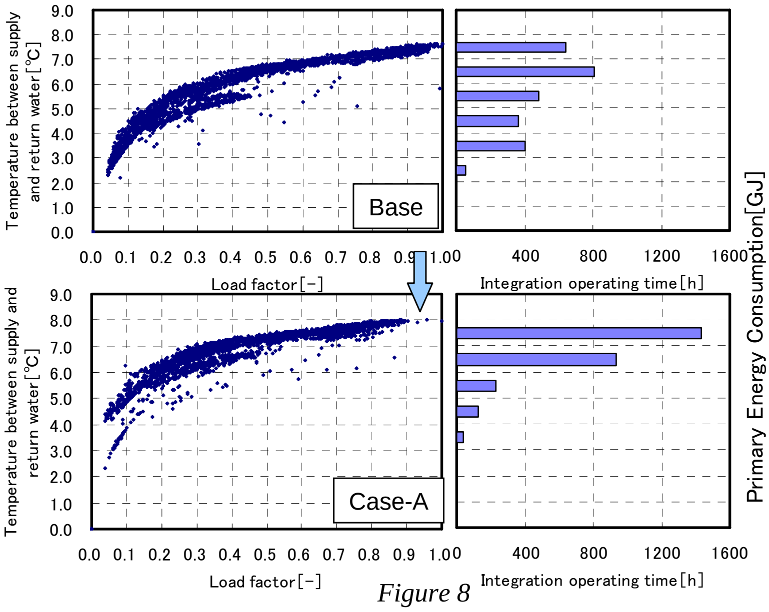

Figure 8
Temperature difference between the supply and return chilled water (Above: Base, Below: Case-A)

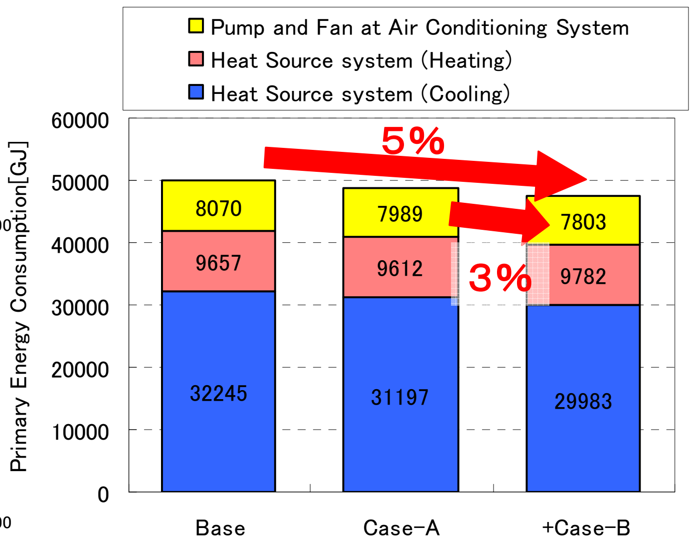

Figure 10
Change in total system use through conservation measures

Table 4 Electricity rate for DHC plant

Plant [yen/kW]		Rate
Base rate		1727.25
Metered rate	Peak load time	13.69
	Daytime	9.73
	Nighttime	7.61

※Peak load time: 10:00～17:00 in July, August and September (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

Table 5 Electricity rate for office buildings

Office [yen/kW]		Rate
Base rate		1685.25
Metered rate	Summer	12.08
	Other seasons	11.06

※Summer: July, August and September
※Other seasons: Expect for Summer

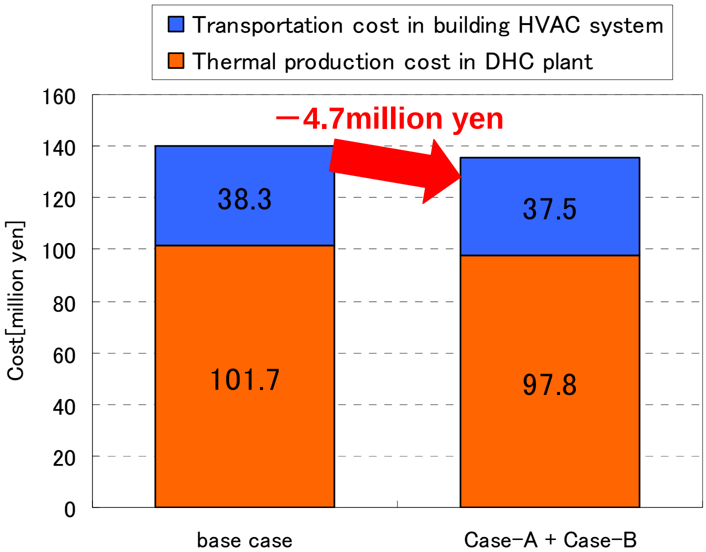

Figure 11
Cost reduction from using an energy service

Potential of operating cost reduction from building energy saving measures

When heat suppliers adopt the energy service 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. Table 4 shows the electricity rate for a DHC plant and Table 5 shows it for an office building. Cost calculations show that heat production cost is reduced by 3.9 million yen and the transportation cost in buildings is reduced by 0.8 million yen, as shown in Fig. 11. In total, the cost reduction is 4.7 million yen.

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, all building owners might not sign the contract and the climate can change. These risks can have a considerable affect 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.

Risk 1: The energy service contract ratio decreases

In previous sections, it was assumed that all building owners sign the energy service contract.

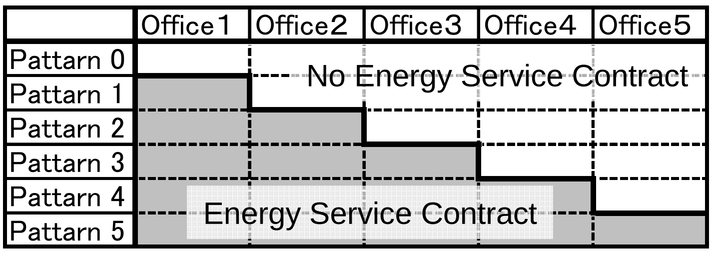

Figure 12 Patterns of contract ratios

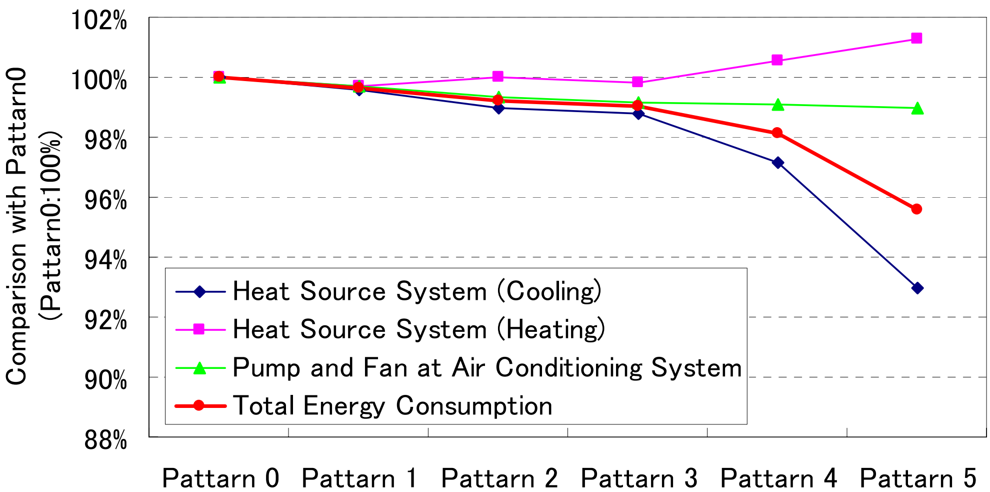

Figure 13 Change of energy conservation by patterns of contract ratio

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 preset 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. 12. As shown in Fig 13, the effects of the energy service decrease even if only one building owner does not agree to the contract. However, energy consumption in heat source system for heating increases as the contract ratio increases as shown in this figure. This is caused by decreases in operation time of heat recovery turbo chiller as cooling demand decreases.

Risk 2: 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. Will it still be profitable for owners and the DHC company? Changes in energy conservation were evaluated for an increase in outdoor temperature of 1 degree Celsius with fixed relative humidity. Fig. 14 shows the change of energy conservation resulting from this increase in outdoor temperature. The energy consumption increases by 4% compared to the actual climate. Thus, a temperature rise of 1 degree Celsius offsets the energy reduction from the energy saving measures. As explained in previous sections, the Climate Agreement contract usually covers a long time period, thus, this contract is susceptible to climate change by global warming and heat island effects. When energy suppliers plans this contract, they should consider this risk.

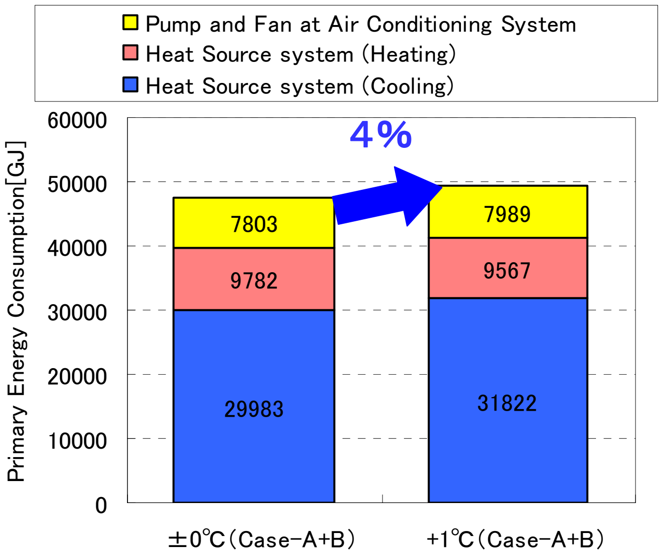

Figure 14
Change of energy conservation from a rise in outdoor temperature

Risk 3: No thermal insulation

It was estimated that the energy conservation from the energy service can be affected by thermal insulation performance, and thermal insulation performance varies with the building. In the above sections, thermal insulation material was installed in the buildings, however, it's estimated that quite a few buildings have no thermal insulation.

Thus, it was evaluated that change in energy conservation results from buildings with no thermal insulation materials. As shown in Fig. 15, this produces little change in energy conservation, however, if the outdoor temperature increases by 1 degree Celsius, with fixed relative humidity, the energy consumption of the air conditioning pump and fan increases by 16%. In office buildings in Japan, there is a demand for cooling throughout the year. Thus, when there are no thermal insulation materials, an outdoor temperature rise would greatly affect energy conservation. The energy consumption for heat source systems hardly changed. The reason seems to be that the energy conservation measures offset the increase in energy consumption from an outdoor temperature rise. Overall, the primary energy consumption increased by 3% compared to the base case and by 7% compared to energy service with the actual outdoor temperature. Thus, thermal insulation materials in target buildings are an important consideration when energy suppliers make an energy service contract.

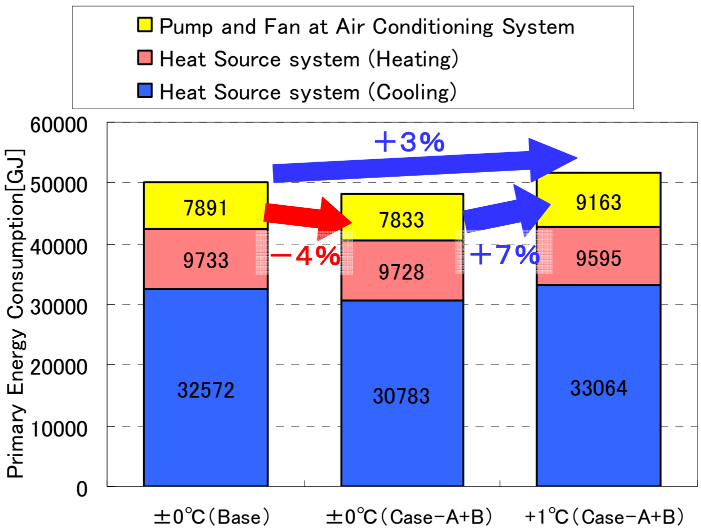

Figure 15
Energy change when there are no thermal insulation materials

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 2% when the temperature difference between the supply and return chilled water was maintained (Case A). Changing the preset indoor temperatures in buildings decreased the total primary energy consumption by 5%. 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 benefits of the energy service decrease even if only one building owner does not make the contract.
- The energy service contract is susceptible to the effect of climate change by global warming and heat island effects.
- The existence of thermal insulation material in target buildings has a great impact on the effectiveness of the energy service.

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 three points should be improved. First, much more buildings should be recreated 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. For example, in this case, variable pump and fan are implemented in HVAC system but in many buildings they aren't implemented. With recreating such saving measures, the energy service will make bigger impact on energy conservation. Finally, other risks related to the energy service have to be considered. Social factors such fluctuations in prices of fuel highly relates to the feasibility because long-term contract is one of characteristics of the energy service. By assessing such risks, the reliability of energy service could be strong.

ACKNOWLEGMENT

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