effect when the capacity of the heat source equipment are made smaller. In this report, simulation models of three air-conditioning units renovated by an ESCO business were constructed. The effect of the cases where the capacity of the heat source equipment are made smaller in accordance with the load (the effects of down-sizing) is quantitatively analyzed.

2. Outline of Targeted System

The charts of the targeted systems are shown in Fig. 1 and the list of heat source equipment is shown in Table 1. The targeted systems are from a medical institute in Yamaguchi Prefecture (Building A), a commercial institute in Hokkaido (Building B) and an additional commercial institute in Hokkaido (Building C). In building A, two refrigerating machines and a heat exchanger are installed. In the cooling period, R2 (water cooling screw chiller) is operated, and when cooling is lacking, R1 (air source heat pump chiller) is also operated. In the heating period, R1 is preferentially operated and when heating is lacking, the heat is supplied through HEX1 (heat exchanger) from boiler system. In building B, four refrigerating machines and two heat exchangers are installed. In the cooling period, the refrigerating machines are operated in the order of R2(H)(air source heat pump chiller), R2(S)(water cooling screw chiller), R1(S)(water cooling screw chiller) and R1(H)(absorption refrigerating machine). In the heating period, R2(H) is preferentially operated, and the heat is supplied through HEX1 (heat exchanger) from the district heating and cooling (DHC). In building C, two refrigerating machines are installed and an all year round cooling is implemented. R2 (turbo refrigerating machine) is preferentially operated, and when cooling is lacking, R1 (absorption refrigerating machine) is operated.

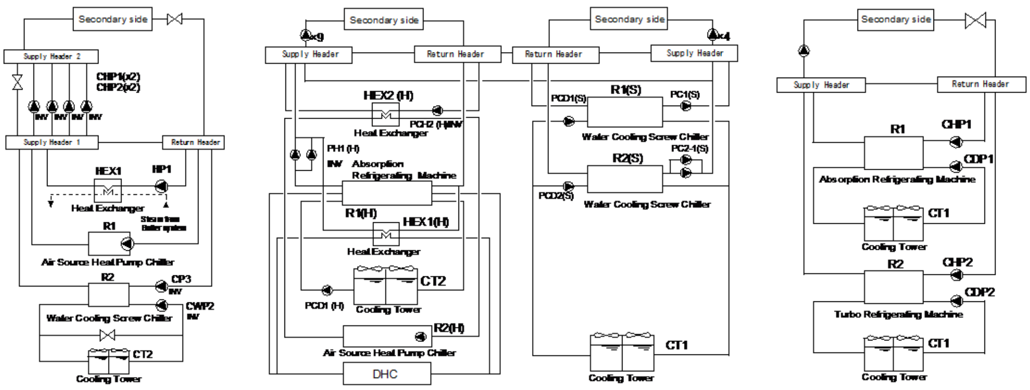


Fig. 1. *Targeted System (Building A , Building B , Building C)*

Table 1. *The list of heat source equipment*

Building	equipment	Type	Rated capacity [kW]
Building A	R1	Air Source Heat Pump Chiller	1,168 / 1,188 (Cooling / Heating)
	R2	Water Cooling Screw Chiller	1,200
	HEX1	Heat Exchanger	-
Building B	R1(S)	Water Cooling Screw Chiller	1,440
	R1(H)	Absorption Refrigerating Machine	2,356
	R2(S)	Water Cooling Screw Chiller	1,440
	R2(H)	Air Source Heat Pump Chiller	1,111 / 651 (Cooling / Heating)
	HEX1	Heat Exchanger	4,035
	HEX2	Heat Exchanger	1,073
Building C	R1	Absorption Refrigerating Machine	2,461
	R2	Turbo Refrigerating Machine	2,812

2

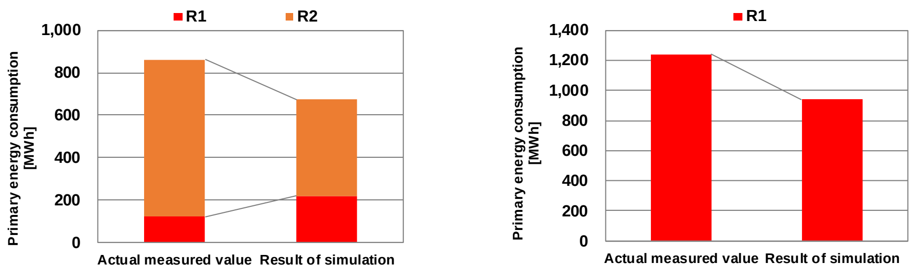
3. Air-conditioning Simulation Models

3.1 Outline of Model

The model was to be input with the secondary side load and the primary side system was constructed. The calculation time interval was one minute. When the actual measured data of the load were not recorded at one-minute intervals, one-minute data were created by a proportional complement. Meteorological data measured at each targeted building were used. When they were not measured at the institute, they were substituted with the data measured at the nearest meteorological observatory. The date of the heat source equipment and pumps, which partial load characteristics were not known, were substituted with the characteristics of the equipment with the same capacity.

3.2 Accuracy Verification

The accuracy verification of a calculation model was implemented using the actual measured values of building A. The integrated energy consumption in building A is shown in Fig. 2. The error in the cooling period was 20%. As the cause of error, because, according to the actual measured data, the secondary side heat load amount was larger than the primary side processing heat, the measurement errors were considered to be included. Because the secondary side heat load amount is the input data, the error of calculation result of energy consumption becomes large. In addition, it is pointed out that because the characteristics of the refrigerating machine were substituted and manual controls were implemented in the actual operation, it was impossible to replicate all control logics on the calculation model. The error in the heating period was 25%. It is considered that the error occurred for the same reasons as those in the cooling period.



a) Cooling Period *b) Heating Period*

Fig. 2. *The integrated energy consumption*

The errors occurred between the actual measured values and calculation results. This was due to problems with the measuring accuracy of the actual measured values and the characteristics of the equipment were substituted. However, the characteristics of the equipment substituted were from actual equipment. Therefore, the comparisons among the simulations are considered to adequately realize the effects of downsizing. The comparisons of the calculation results by simulations were implemented and discussed.

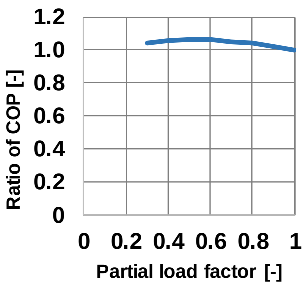
3

4. Effects of Downsizing

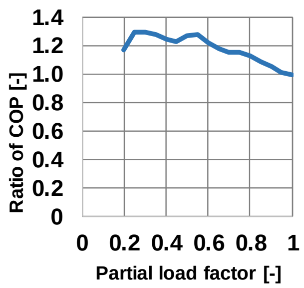
The contents of discussion on the targeting facilities are shown in Table 2. The discussions on the three buildings in the cooling period were implemented. The partial load characteristics of the refrigerating machines used in the discussions are shown in Fig. 3. The results shown in this research were not the effect of ESCO business but, in fact, the effects of downsizing and not the comparison between before and after the renewal.

Table 2. *Case setting*

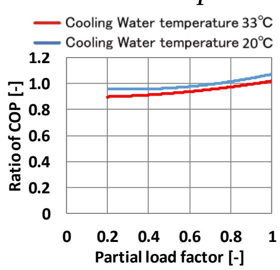
Case			Constitution of system	Contents of changing	Multiple units control
Building A	caseA1	100	R1：Air Source Heat Pump Chiller (INV) R2：Water Cooling Screw Chiller (INV)	R1：100% R2：100%	-
		R1-80		R1： 80% R2：100%	-
		R2-80		R1：100% R2： 80%	-
	caseA2	100	R1：Air Source Heat Pump Chiller (INV) R2：Turbo Refrigerating Machine	R1：100% R2：100%	-
		R1-80		R1： 80% R2：100%	-
		R2-80		R1：100% R2： 80%	-
	caseA3	100	R1：Turbo Refrigerating Machine R2：Turbo Refrigerating Machine	R1：100% R2：100%	-
		90		R1： 90% R2： 90%	-
		80		R1： 80% R2： 80%	-
	caseA4	100	R1：Turbo Refrigerating Machine (INV) R2：Turbo Refrigerating Machine (INV)	R1：100% R2：100%	-
		90		R1： 90% R2： 90%	-
		80		R1： 80% R2： 80%	-
Building B	caseB1	100	R1(S)：Water Cooling Screw Chiller(INV) R1(H)：Absorption Refrigerating Machine R2(S)：Water Cooling Screw Chiller(INV) R2(H)：Air Source Heat Pump Chiller(INV)	R1(S)：100% R1(H)：100% R2(S)：100% R2(H)：100%	-
		120		R1(S)：120% R1(H)：120% R2(S)：120% R2(H)：120%	- -
		110		R1(S)：110% R1(H)：110% R2(S)：110% R2(H)：110%	- -
		90		R1(S)： 90% R1(H)： 90% R2(S)： 90% R2(H)： 90%	- -
		80		R1(S)： 80% R1(H)： 80% R2(S)： 80% R2(H)： 80%	- -
	caseB2	100		R1(S)：100% R1(H)：100% R2(S)：100% R2(H)：100%	-
		1			changing
		2		R1(S)： 90% R1(H)： 50% R2(S)： 90% R2(H)： 90%	changing
	caseB3	100	R1(S)：Turbo Refrigerating Machine R1(H)：Turbo Refrigerating Machine R2(S)：Turbo Refrigerating Machine R2(H)：Air Source Heat Pump Chiller (INV)	R1(S)：100% R1(H)：100% R2(S)：100% R2(H)：100%	-
		1			changing
		2		R1(S)： 90% R1(H)： 50% R2(S)： 90% R2(H)： 90%	changing
Building C	caseC1	100	R1：Absorption Refrigerating Machine R2：Turbo Refrigerating Machine	R1：100% R2：100%	-
		120		R1：120% R2：120%	-
		110		R1：110% R2：110%	-
		90		R1： 90% R2： 90%	-
		80		R1： 80% R2： 80%	-
	caseC2	100	R1：Turbo Refrigerating Machine R2：Turbo Refrigerating Machine	R1：100% R2：100%	-
		120		R1：120% R2：120%	-
		110		R1：110% R2：110%	-
		90		R1： 90% R2： 90%	-
		80		R1： 80% R2： 80%	-



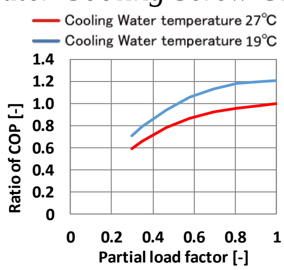
a) Air Source Heat Pump Chiller



b) Water Cooling Screw Chiller



c) Absorption Refrigerating Machine



d) Turbo Refrigerating Machine

Fig. 3. *The partial load characteristics of the refrigerating machines*

4.1 Building A

The performances of the heat source equipment introduced to building A have a

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leeway of 40% for the maximum load in the cooling period. In caseA1, the energy consumption when the current system was downsized was calculated. In caseA2, the combination of heat source equipment was considered and the effects of downsizing when the inverter equipment and constant speed equipment were combined were calculated. In caseA3 and caseA4, the case of the combination between the inverter equipment and the case of the combination between the constant speed equipment were calculated. The reason why these cases were calculated is that it was presumed that the effects of downsizing changes depending on the characteristics of the heat source equipment. Downsizing is considered to be effective in the system in which constant speed equipment is used, in particular. The ratio of heat load integrated value by load range is shown in Fig. 4 and the integrated value of the energy consumption by each cases discussed is shown in Fig. 5. In Fig. 4, the heat load is integrated by load range and its ratio to the total load is obtained. In the system of building A, COP of R2 is high compared with R1, and both R1 and R2 are effective under a low load. In the system where inverter equipment are used as seen above, the effects of downsizing are less likely to be obtained (caseA1). In the case where R2 was replaced with constant speed turbo refrigerating machine and the equipment that was preferentially operated (R2: turbo refrigerating machine) was downsized, 2.6% of the energy conservation effect was obtained (caseA2-R2-80). It was confirmed that the equipment with low partial load efficiency can easily obtain the effects of downsizing. However, if the equipment that is operated as the second one is low-efficient, the effect of downsizing lowers because the operation time of the equipment increases. When the equipment with similar characteristics were combined, in the case of the constant speed equipment 4.5% of the energy conservation effect was obtained, and in the case of inverter equipment 4% of energy conservation effect was obtained (caseA3, caseA4). The reason why the similar effect could be obtained in an inverter equipment as a constant speed equipment is that the higher the partial load characteristics is when temperature of cooling water is high, the more the inverter equipment becomes effective, which is the same as the case of the constant speed equipment.

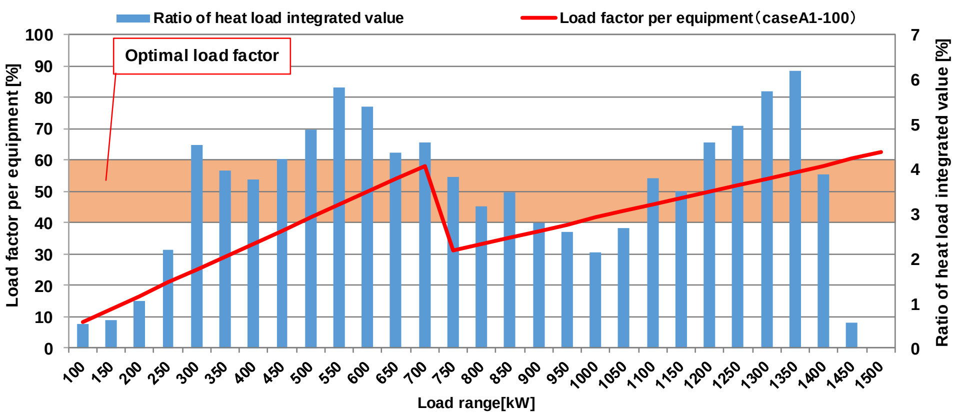

***Fig. 4.** The ratio of heat load integrated value by load range*

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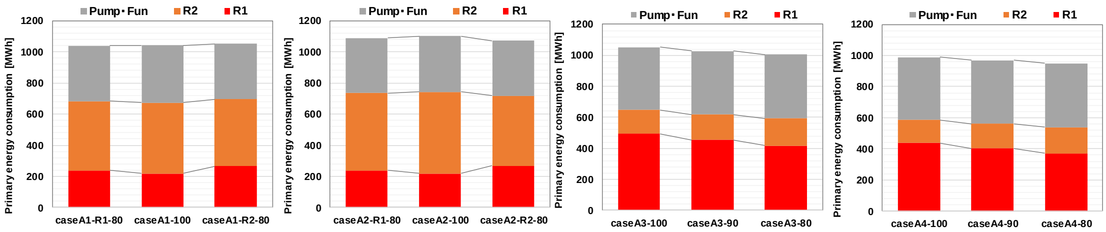

a) case A1 b) case A2 c) case A3 d) case A4

Fig. 5. *The integrated value of the energy consumption by each cases*

4.2 Building B

The performances of the heat source equipment introduced into building B have a leeway of 25% for the maximum load in the cooling period. In caseB1, the equipment capacity of the current system were changed. In caseB2, the equipment capacity were changed in the case where the multiple units control was incorporated. In caseB3, a system was constructed with the constant speed equipment and multiple units control was incorporated. The ratio of heat load integrated value by load range is shown in Fig. 6, and the integrated value of energy consumption by each case discussed is shown in Fig. 7. If the current system is downsized, because the operation time of an inefficient 4th equipment (R1 (H): absorption refrigerating machine) increases, the energy consumption also increase. In caseB2, where the multiple units control was incorporated, the threshold value was set so that the load factor per equipment becomes optimal around the load range from 1800kW-2000kW where the frequency of heat load is high. By the multiple units control being incorporated, an energy conservation of 2% was obtained (caseB2-1). In caseB1, no effect of downsizing was obtained, in caseB2-2 where the multiple units control was incorporated, an energy saving effect was obtained. However, if the equipment capacity from the first one to the third one are made smaller, the operating time of the heat source equipment of the inefficient fourth one becomes longer, so that the downsizing effect is small. In order to produce the effect of downsizing in the system where there are a number of heat source equipment, it is more effective to operate the equipment under the optimal partial load factor by the multiple units control being incorporated. In caseB3 where a system was constructed with the constant speed equipment and the multiple units control being incorporated, a threshold value was set so that the load factor per equipment became optimal around the load range of 2000kW-300kW where the frequency of heat load is high. By the multiple units control being incorporated, an energy conservation effect of 7.3% (caseB3-1) was obtained, and by downsizing, an energy conservation effect of 8% (caseB3-2) was obtained. If the efficiency of the fourth heat source equipment is the same as other ones, even if the operation time of the fourth equipment increases, the effect is obtained.

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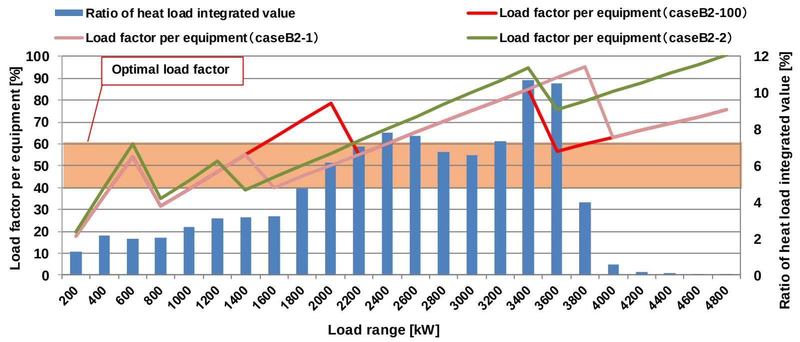
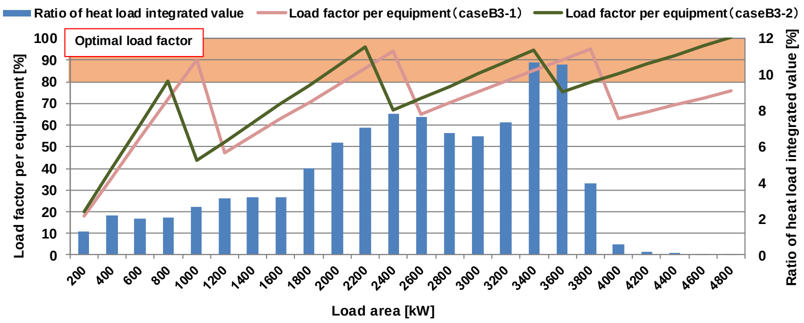
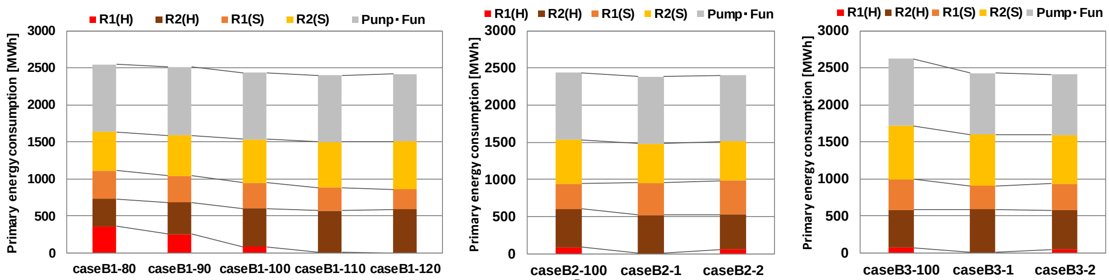


a) . case B2



b) . case B3

Fig. 6. *The ratio of heat load integrated value by load range*



a) . case B1 b) . case B2 c) . case B3

Fig. 7. *The integrated value of the energy consumption by each cases*

4.3 Building C

The performances of the heat source equipment introduced to building C have a leeway of approximately 40% in the cooling period. In caseC1, the equipment capacity of the current system were changed. In caseC2, a system was constructed with the same constant speed equipment and the equipment capacity were changed. The integrated value of energy consumption by each case discussed is shown in Fig. 8. When the current system was changed, the energy conservation of 6.7% was achieved at the maximum (caseC1-80). However, it was found that too much downsizing cannot obtain a good energy conservation effect, because it increases the operation time of the ineffective equipment (R1: absorption refrigerating machine) (caseC1-70). When the second equipment was changed to efficient one, and the equipment capacity were changed, a maximum energy conservation effect of 8.8% was achieved (caseC2-80).

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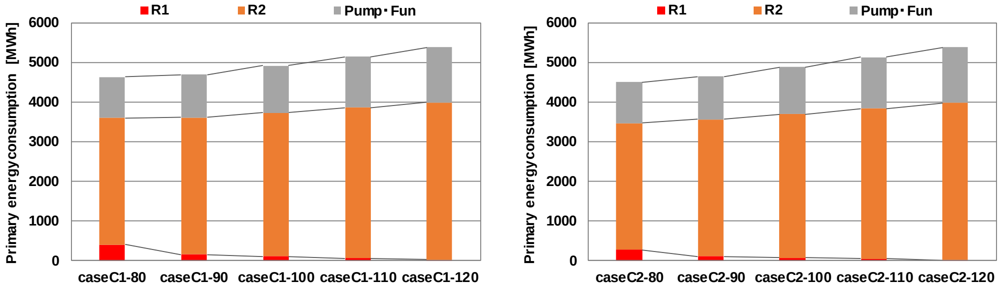

a) . case C1 *b) . case C2*

Fig. 8. *The integrated value of the energy consumption by each cases*

5. Conclusion

In this research, discussions were held about downsizing heat source equipment by introducing equipment with smaller contents than the original ones at the time of renewal. In the discussions, this time, energy conservation of approximately 9% at the most were achieved by downsizing. The system can sufficiently be affected by downsizing to facilities that have fewer numbers of heat source equipment, or employing constant speed equipment where the partial load efficiency is low. In the case where the efficiency of the heat source instrument corresponding to the peak load (the instrument that operates at the end of the multiple units control) is inferior to other equipment, the effect of downsizing decreases. It is necessary to discuss the effect of energy conservation by downsizing as well as by control methods of the heat source equipment. It is also required to discuss methods of determining the contents and unit numbers of the heat source equipment by analyzing load patterns in accordance with the results of research.

Acknowledgements

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