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THE STUDY OF AN OPTIMUM ON-OFF SCHEDULE OF A HEAT SOURCE FOR AN AIR CONDITIONING SYSTEM BY AHP

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Summary*:* *Generally, there are hot and chilled water generators, heat pumps, boilers and cogeneration machines, etc as energy facilities for building air conditioning systems. In this paper, we use air conditioning loads, energy cost and carbon emission as operational criteria of these facilities. And, this paper proposes AHP method for the choice of the optimum on-off states of energy facilities in each time step.*

1. Introduction

There are facilities that produce chilled water and hot water in many buildings. Cool air and warm air are produced with an air conditioner by using chilled water and hot water and do air conditioning in buildings. A cogeneration system has come to be used generally recently. It has an advantage such as being able to achieve the decrease of the energy cost compared with general equipment. But there is a disadvantage with high maintenance cost.

Generally, heat demand is equivalent to independent heat source equipment set up in the building and demand for electric energy is bought from an electric power company. Moreover, heat demand might be bought from DHC(District Heating and Cooling) in a large-scale building. In addition, a number of buildings where the cogeneration system is introduced have increased like the building taken up by this paper. Call energy facilities to fill demand for heat and electric energy in this paper.

The on-off states of energy facilities do an operation of each building almost decided by a season. From viewpoint of energy cost and carbon emission it is not necessarily the optimum choice the current use. Therefore, it can be said that it is very significant to derive choices of the optimum on-off states of energy facilities in each building.

The simplex method of the linear programming problem is a famous technique for deriving choices of optimum on-off states of energy facilities. This requests an optimum selection order in a reduction objects on an operation side under a condition of filling calorie and amount of electric power needed by the building. This is a method of requesting the optimum choice from the purpose under the condition of filling the demand for the heat and the electric energy. When the purpose is certainly single, the simplex method is very effective. But there is a weak point of difficult to say to be the best when purposes become two or more.

In this paper, I introduce AHP method for choices of the optimum on-off states of energy facilities in a season for air cooling.

2. A summary of equipment of energy facilities

There are hot and chilled water generators, heat pumps etc as energy facilities for general air conditioning. Heat is produced by these energy facilities. Electric energy is bought from the electric power company. On the other hand, the cogeneration system is generally driven for electricity oriented operation, and the control is hardly difficultly used as for heat oriented operation. In this case study, a supplementary energy facilities was not handled and it was assumed the one to think only about the main body. The input to the hot and chilled water generators and the prime movers is actually an electric energy and the city gases. Only the city gas that becomes a main is assumed.

3. Analysis by AHP

3.1 A summary of energy facilities of object building

The building subjected by this case study fills the heat demand and the demand for electric energy by purchase from the electric power company, three hot and chilled water generators and two cogeneration systems. The cooling capacity an hour, the power generation capacity an hour, the operation cost an hour, carbon emission as hour and the variable as alternatives is shown in Table-1. The cogeneration system adds the maintenance cost to the driving cost and calculates. Next, there is a characteristic that facilities other than the electric power company cannot be driven in the load that is less than a certain definite value. It is assumed to be 30% this time.

Table 1 The energy facilities list

Sign	Name	Cooling capacity [MJ/h]	Power generation capacity [kW]	Operation cost [Yen/h]	Carbon emission [kg-CO2/h]	Alternative
CGS-1	Cogeneration system-1	1,013	250	3,954	182	x_1
CGS-2	Cogeneration system-2	1,013	250	3,954	182	x_2
RH-1	Hot and chilled water generators-1	1,264	-	924	70	x_3
RH-2	Hot and chilled water generators-2	3,165	-	2,106	161	x_4
RH-3	Hot and chilled water generators-3	3,165	-	2,106	161	x_5
E	Purchase from the electric power company	-	1,250	22,250	473	x_6

3.2 Arrangement of criteria

Necessity for considers resolving problem to criteria as the first stage when the optimum choice is calculated by using AHP. First, the uppermost parts of the criteria are assumed to be an integrated purpose.
Next, it is decided from the relation to the element at an upper level at the level less than it. Finally, the variable is assumed to be alternatives.
The layered structure in the subject building was shown in Figure-1. The objective is a decision of the energy facilities choice order. The criteria that decide it are demands and reduction objects. Demand is a positive element because it should fill it. On the other hand, the reduction objects are negative element because minimizing it is a purpose. Alternatives of the demand and the reduction objects are the energy facilities. The weight of alternatives of the decision of the optimum choice can be calculated by dividing in the weight of alternatives that reduce the weight of alternatives of demand. First, the criterion of demand is set. Because it is an element to which the heat and the electric energy decide demand, the heat and the electric energy are put on the lower level of demand. The lower level becomes energy facilities that decide the heat and the electric energy. And, it becomes alternatives. Cost and carbon emission to be reduced the reduction objects similarly become the lower levels. And, the energy facilities become alternatives.

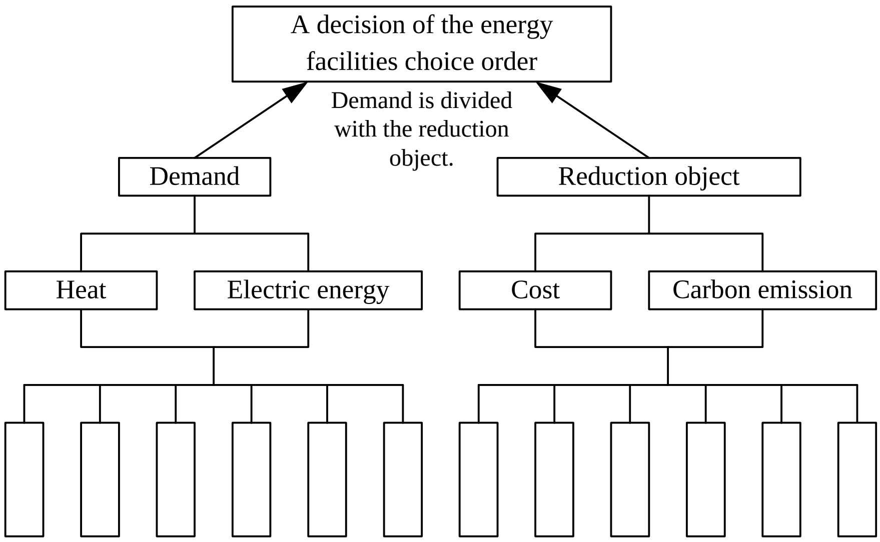

Figure 1 The layered structure

3.3 Weight putting

It is necessary to do the weight putting of each criterion. And, the operator must compare pairs between all criteria. There are 1(equal), 3(weakling), 5(strong), 7(very strong), and 9(absolute) as a standard of this pair comparison. It is necessary to compare pairs n(n-1)/two times for the operator if the number of comparison criteria is assumed to be n piece. The matrix obtained from this pair comparison is called a pair comparison matrix. Next, this becomes the weight of the criterion for the eigenvalue of the pair comparison matrix.
First, the pair comparison between the heat and the electric energy is calculated. The importance degree was assumed to be this level (equal:1) because the heat and the electric energy are filled in this case. However, it is possible to calculate in the consumption ratio of the heat and the electric energy. It was

assumed that cost was a little important (weakling:3) compared with the carbon emission in this example. Each pair comparison matrix becomes Table-2 and Table-3.

Table 2 Pair comparison matrix of the heat and the electric energy

	Heat	Electric energy
Heat	1	1
Electric energy	1	1

Table 3 Pair comparison matrix of the cost and the carbon emission

	Cost	Carbon emission
Cost	1	3
Carbon emission	1/3	1

Next, this is assumed to be weight for the eigenvalue of each pair comparison matrix. When the weight of the heat and the electric energy is assumed to be W_1, and the weight of the cost and the carbon emission is assumed to be W_2, They are shown as follows.

$$W_1=\begin{pmatrix}0.5\\0.5\end{pmatrix},\quad W_2=\begin{pmatrix}0.75\\0.25\end{pmatrix}$$

Each pairs of alternatives of demand and the reduction objects are compared. It is assumed to be weight that the eigenvalue is calculated for the pair comparison matrix. However, the value of the heat, the electric energy, cost, and the carbon emission has already been obtained from the energy facilities list in this case. Therefore, weight can be calculated by comparing and regularizing this value. When the element is a plural, weight to the element of alternatives is called an evaluation matrix. It is called the evaluation vector in case of 1 piece. When the evaluation matrix of the heat and the electric energy is assumed to be Y_1, and the evaluation matrix of the cost and the carbon emission is assumed to be Y_2, they are shown as follows.

$$Y_1=\begin{pmatrix}0.105 & 0.143\\0.105 & 0.143\\0.131 & 0\\0.329 & 0\\0.329 & 0\\0 & 0.714\end{pmatrix},\quad Y_2=\begin{pmatrix}0.112 & 0.148\\0.112 & 0.148\\0.026 & 0.057\\0.06 & 0.131\\0.06 & 0.131\\0.63 & 0.385\end{pmatrix}$$

Therefore, the evaluation vector of alternatives of the demand becomes the evaluation matrix of the heat and the electric energy (Y_1) multiply by the weight of the heat and the electric energy (W_1). The evaluation vector of alternatives of the reduction objects becomes the evaluation matrix of the cost and the carbon emission (Y_2) multiply by the weight of the cost and the carbon emission (W_2). When the evaluation vector of demand is assumed to be Z_1, and the evaluation vector of the reduction objects is assumed to be Z_2, they are shown as follows.

$$Z_1 = Y_1 W_1 = \begin{pmatrix} 0.105 & 0.143 \\ 0.105 & 0.143 \\ 0.132 & 0 \\ 0.329 & 0 \\ 0.329 & 0 \\ 0 & 0.714 \end{pmatrix} \begin{pmatrix} 0.5 \\ 0.5 \end{pmatrix} = \begin{pmatrix} 0.124 \\ 0.124 \\ 0.066 \\ 0.165 \\ 0.165 \\ 0.357 \end{pmatrix}$$

$$Z_2 = Y_2 W_2 = \begin{pmatrix} 0.112 & 0.148 \\ 0.112 & 0.148 \\ 0.026 & 0.057 \\ 0.06 & 0.131 \\ 0.06 & 0.131 \\ 0.63 & 0.385 \end{pmatrix} \begin{pmatrix} 0.75 \\ 0.25 \end{pmatrix} = \begin{pmatrix} 0.121 \\ 0.121 \\ 0.034 \\ 0.078 \\ 0.078 \\ 0.569 \end{pmatrix}$$

The demand is a positive factor, and reduction objects are a negative factor. Therefore, the weight of the overall alternatives is profitable according to the division of Z_1 with Z_2. When this is assumed to be A, it is shown as follows.

$$A = Z_1 / Z_2 = \begin{pmatrix} 0.124/0.121 \\ 0.124/0.121 \\ 0.066/0.034 \\ 0.165/0.078 \\ 0.165/0.078 \\ 0.357/0.569 \end{pmatrix} = \begin{pmatrix} 1.025 \\ 1.025 \\ 1.941 \\ 2.121 \\ 2.121 \\ 0.628 \end{pmatrix}$$

The priority value of the energy facilities is shown in Table-4. It only has to choose it from the energy facilities with higher the value.

Table 4 The priority value of the energy facilities

Ranking	Sign	Variable	Alternative
1	RH-2	x_4	2.121
1	RH-3	x_5	2.121
3	RH-1	x_3	1.941
4	CGS-1	x_1	1.025
4	CGS-2	x_2	1.025
6	E	x_6	0.628

4. Calculation of optimum ON-OFF schedule

When the transition of the heat and the electric energy during a day is given about the object building, the optimum choice is calculated in optimum selection order decided in Chapter 3
The transition of the heat and the electric energy on the representative day of summer is shown in Figure-2.

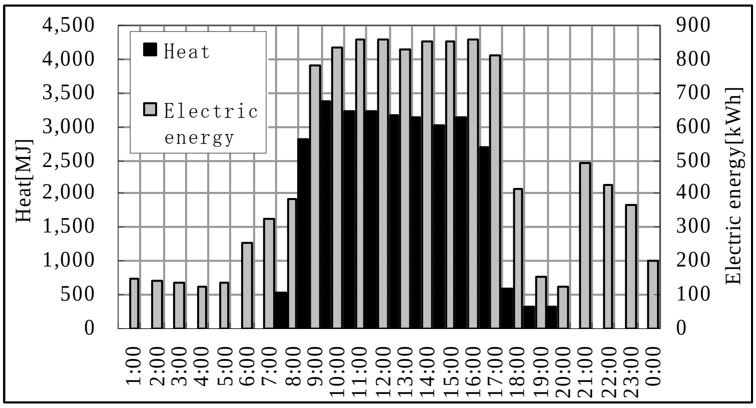

Figure 2 The transition of the heat and the electric energy on the representative day of summer

The optimal choice for each time is calculated. The optimal choice for 11:00 is calculated as an example. First, the first selection order chooses high RH-2.The heat is 3,219[MJ], and the electric energy is 860[kWh] at this time. The making heat is 3,165[MJ]. Therefore, the heat of the remainder is 54[MJ], and the electric energy of the remainder is 860[kWh]. Next, RH-3 that is the selection order of one below is chosen. The making heat is 6,330[MJ] in total. The heat of the remainder is lost, and the electric energy of the remainder becomes 860[kWh]. RH-1 that is the selection order of one below is chosen. But it is trivial to be going to use the electric power company that outputs only the amount of the electric energy because there is only an amount of the remainder electric energy. Therefore, the electric energy of the remainder (860[kWh]) will be bought in the electric power company. The demand for the heat and the electric energy could be filled. The heat of demand is 51% of the heat of the total of the energy facilities. Choosing RH-2, RH-3, and E is an optimum choice. This is shown in Table-5.

Table 5 Optimal choice in 11:00

Sign	Output ratio	Heat [MJ]	Electric energy [kWh]
CGS-1	0.00	0	0
CGS-2	0.00	0	0
RH-1	0.00	0	0
RH-2	0.51	1,610	0
RH-3	0.51	1,610	0
E	0.69	0	860

The output ratio when such an operation is done at all time is shown in Figure-3.

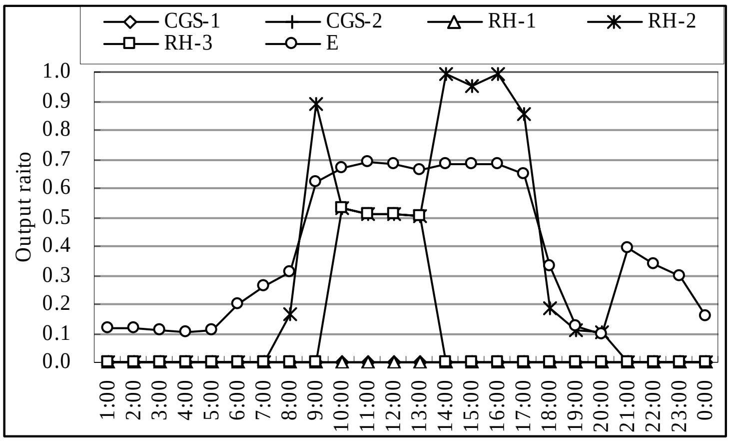

Figure 3 Output ratio of energy facilities

The heat is making with RH-2 and RH-3 and the electric energy is buying from the electric power company is an optimal choice as a result.

5. Conclusion

In this paper, the optimum selection order of the energy facilities was calculated by using AHP in consideration of each importance degree of two or more reduction objects. The stable supply and the cost decrease of the energy facilities were the prevailing purposes in the method of operating them. The control of the carbon emission has been needed from the viewpoint such as global warming recently. It came to operate them as you satisfied two or more reduction objects. The importance degree changes as reduced by operator's idea changes. And it is necessary to think about the selection order of energy facilities in consideration of it. In this case study, when the reduction object was assumed to be minimum cost and a minimum carbon emission, the optimum facilities was derived. Therefore, the operator obtains the optimum facilities in which my idea is reflected by expressing the importance degree of minimum cost and a minimum carbon emission numerically.

It is thought that it becomes one of the effective methods to choose the energy facilities from the viewpoint such as environmental problems in recent years.

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