A Design Optimization for Primary HVAC Systems in Buildings Using Genetic Algorithm

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ABSTRACT
A number of specialists have been studied a method to introduce high-performance equipment and to apply a renewable energy source in order to increase energy efficiency and to reduce energy consumption. To achieve high energy saving, the best combination of energy system and operation schedules must be planned. This is because energy consumption of energy system is highly dependent on the equipment capacity and operational conditions. As a result, type of equipment and capacity changes the actual energy efficiency in buildings. Consequently, a new design method should be presented to ensure effectiveness, primary HVAC system design in buildings. For this purpose, a numerical optimization-based selection approach has been proposed to find at the best solution for a given application in the primary HVAC system. This study presented a new method to use a genetic algorithm for the optimum design of a primary system. Using the equipment load factor and size as variables, this study conducted optimization to minimize primary energy use. The considered equipment were represented by the cooling source, the turbo-refrigerator, the absorption-refrigerator, and the heat pump, and were organized with 2 units per heat source after considering number of devices(unit). The boiler and the heat pump were considered as heat sources, and the equipment was organized with 2 units per heat source. According to the result of the optimization using the genetic algorithm, this design method has led to a potential energy reduction of 10%-18%. Therefore, it was found that energy reduction could be introduced, and equipment efficiency increased.

KEYWORDS
Optimal Design, Genetic Algorithms, Primary HVAC system, Chromosomes, Equipment efficiency

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INTRODUCTION

Today's global economic developments have been unfolding at a rapid speed. As a result, energy consumption is exponentially increasing. Meanwhile, the limited resources of fossil fuels and the greenhouse gas problem they cause call for reduced energy consumption, which is in contrast to the demands of today's economy. Many types of efficient HVAC equipment have been recently developed in the field of building energy. However, the use of these devices does not always guarantee reduced use of energy. This is because the energy consumption of the building is exhibited in various patterns, based on the combination of equipment that was simultaneously used, and the operational pattern of the equipment. Accordingly, energy reduction is achieved when appropriate equipment is operated with optimum HVAC systems. However, the operational schedules and the type of HVAC equipment with restricted information during the planning stage of HVAC system cause optimization problems on vast combinations. Such problems cannot be resolved without finding the best combination with a computerized calculation of the combination of all cases. Some studies have examined the optimization of energy systems through linear optimization in order to solve these problems. However, the input of energy system and output of the equipment are greatly affected by the partial load of the equipment without having a linear relationship, thus, there is a need for an improved optimization methodology to solve non-linear problems. In this context, this study intends to propose a methodology concerning the optimum design of HVAC systems that searches the combination of equipment that uses the least amount of primary energy. In this study, representation the method on Apply the genetic algorithm (GA) to deal with combinatorial optimization problems.

LITERATURE REVIEW

This section is included to allow the resolution of complex problems that were not resolved previously, with the development of the computer industry, and is said to be a result of increased interest in the field of building energy. There have been many studies undertaken by previous researchers. Huang (1997) has performed optimization on heating, air-ventilation, and HVAC control problems by using GA, and Ryozo Ooka (2008) has proposed an optimum design method for a HVAC equipment by using GA, and concluded that an optimum solution could be found. Sanchez (2010) has conducted a study that determined the size of combined systems that simultaneously considered the existing system that used fossil fuel and renewable energy system through particle swam optimization. Omar Hafez (2012) has proposed a method for designing a combined system with the smallest development costs, and the net-present value through LCC and optimization functions, and has deduced that the simultaneous use of renewable energy and a diesel engine is effective.

Many existing studies have been conducted mainly with interest on optimum control; however, recent studies mainly displayed concentrated tendencies on combined HVAC system that combined renewable energy and conventional energy system. The study of Ryozo Ooka (2008) considered various aspects, including the operational schedule of the equipment and the use of optimized algorithms during the design phase of the heat source. However, the simultaneous use of equipment is restricted to four, and it does not substantially consider the operational pattern of the equipment, such as air-conditioning, heating, and hot-water heat sources.

OPTIMAL DESIGN METHODS

Figure 1 displays the flow of the optimized design methodology proposed by this study. The procedure in obtaining the solution for optimum designing is as follows.

1) Selection of the capacity of equipment
2) Selection of the operational schedule of the selected equipment
3) Evaluation of the objective function: Calculation of the amount of energy consumption by using the equipment performance curve
4) Execution of the genetic algorithm: Setting of variables through the execution of genetic algorithms

The type of HVAC system and the line-up of the equipment selected in the first process is shown in Table 1. The HVAC system proposed in Table 1 displays the generally used systems of turbo refrigerator, absorption refrigerator, heat pump, boiler, with two types of equipment consisting of each heat source considering the number of devices (units).

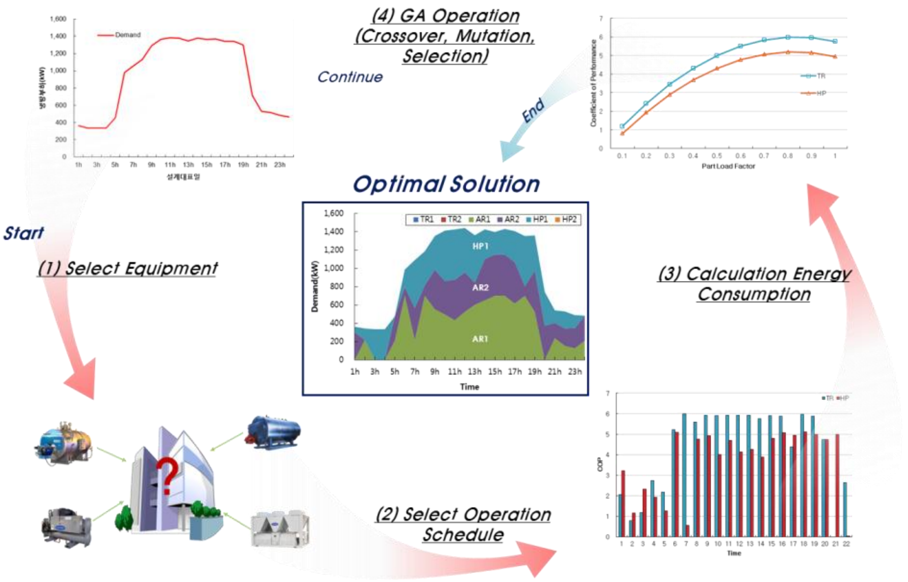

Figure 1 *Schematic Diagram of Optimization*

The second process involves the selection of the operational schedule of the selected equipment. As shown in Table 1, the operational schedule of the equipment is categorized into 01:00 to 24:00 of the selected date, and the sum of the output of the equipment at each hour of the date has been determined to explore cooling and heating load demanded by the building. The third and fourth processes have to do with optimization by using genetic algorithms, and must simultaneously consider the equipment type and the applied operational schedule. The evolutionary process of mutation, cross-breeding, and selection of the chromosome developed in this process are applied, and optimization of the determined value of each variable is conducted.

Table 1 *Matrix of Optimal Design Plan (Sizing/Operation)*

Category		Time serise Load Factor[1~24]																							
Capacity[kW]	Type	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	24h
0, 500, 700, 1200, 1800	TR1	$T1_{F1}$	$T1_{F2}$	$T1_{F3}$	$T1_{F4}$	$T1_{F5}$	$T1_{F6}$	$T1_{F7}$	$T1_{F8}$	$T1_{F9}$	$T1_{F10}$	$T1_{F11}$	$T1_{F12}$	$T1_{F13}$	$T1_{F14}$	$T1_{F15}$	$T1_{F16}$	$T1_{F17}$	$T1_{F18}$	$T1_{F19}$	$T1_{F20}$	$T1_{F21}$	$T1_{F22}$	$T1_{F23}$	$T1_{F24}$
	TR2	$T2_{F1}$	$T2_{F2}$	$T2_{F3}$	$T2_{F4}$	$T2_{F5}$	$T2_{F6}$	$T2_{F7}$	$T2_{F8}$	$T2_{F9}$	$T2_{F10}$	$T2_{F11}$	$T2_{F12}$	$T2_{F13}$	$T2_{F14}$	$T2_{F15}$	$T2_{F16}$	$T2_{F17}$	$T2_{F18}$	$T2_{F19}$	$T2_{F20}$	$T2_{F21}$	$T2_{F22}$	$T2_{F23}$	$T2_{F24}$
0, 105, 320, 620, 1200	AR1	$A1_{F1}$	$A1_{F2}$	$A1_{F3}$	$A1_{F4}$	$A1_{F5}$	$A1_{F6}$	$A1_{F7}$	$A1_{F8}$	$A1_{F9}$	$A1_{F10}$	$A1_{F11}$	$A1_{F12}$	$A1_{F13}$	$A1_{F14}$	$A1_{F15}$	$A1_{F16}$	$A1_{F17}$	$A1_{F18}$	$A1_{F19}$	$A1_{F20}$	$A1_{F21}$	$A1_{F22}$	$A1_{F23}$	$A1_{F24}$
	AR2	$A2_{F1}$	$A2_{F2}$	$A2_{F3}$	$A2_{F4}$	$A2_{F5}$	$A2_{F6}$	$A2_{F7}$	$A2_{F8}$	$A2_{F9}$	$A2_{F10}$	$A2_{F11}$	$A2_{F12}$	$A2_{F13}$	$A2_{F14}$	$A2_{F15}$	$A2_{F16}$	$A2_{F17}$	$A2_{F18}$	$A2_{F19}$	$A2_{F20}$	$A2_{F21}$	$A2_{F22}$	$A2_{F23}$	$A2_{F24}$
0, 170, 300, 350, 550	HP1	$H1_{F1}$	$H1_{F2}$	$H1_{F3}$	$H1_{F4}$	$H1_{F5}$	$H1_{F6}$	$H1_{F7}$	$H1_{F8}$	$H1_{F9}$	$H1_{F10}$	$H1_{F11}$	$H1_{F12}$	$H1_{F13}$	$H1_{F14}$	$H1_{F15}$	$H1_{F16}$	$H1_{F17}$	$H1_{F18}$	$H1_{F19}$	$H1_{F20}$	$H1_{F21}$	$H1_{F22}$	$H1_{F23}$	$H1_{F24}$
	HP2	$H2_{F1}$	$H2_{F2}$	$H2_{F3}$	$H2_{F4}$	$H2_{F5}$	$H2_{F6}$	$H2_{F7}$	$H2_{F8}$	$H2_{F9}$	$H2_{F10}$	$H2_{F11}$	$H2_{F12}$	$H2_{F13}$	$H2_{F14}$	$H2_{F15}$	$H2_{F16}$	$H2_{F17}$	$H2_{F18}$	$H2_{F19}$	$H2_{F20}$	$H2_{F21}$	$H2_{F22}$	$H2_{F23}$	$H2_{F24}$
0, 500, 700, 1200, 1500	GB1	$G1_{F1}$	$G1_{F2}$	$G1_{F3}$	$G1_{F4}$	$G1_{F5}$	$G1_{F6}$	$G1_{F7}$	$G1_{F8}$	$G1_{F9}$	$G1_{F10}$	$G1_{F11}$	$G1_{F12}$	$G1_{F13}$	$G1_{F14}$	$G1_{F15}$	$G1_{F16}$	$G1_{F17}$	$G1_{F18}$	$G1_{F19}$	$G1_{F20}$	$G1_{F21}$	$G1_{F22}$	$G1_{F23}$	$G1_{F24}$
	GB2	GA_{F1}	GA_{F2}	GA_{F3}	GA_{F4}	GA_{F5}	GA_{F6}	GA_{F7}	GA_{F8}	GA_{F9}	GA_{F10}	GA_{F11}	GA_{F12}	GA_{F13}	GA_{F14}	GA_{F15}	GA_{F16}	GA_{F17}	GA_{F18}	GA_{F19}	GA_{F20}	GA_{F21}	GA_{F22}	GA_{F23}	GA_{F24}
Demand=Supply		Building Load																							

INPUT DATA

This study requires many types of data in the equipment energy calculation process. The equipment performance curve used to calculate energy consumption, and cooling and heating load of building data is need to energy calculation.

The building load data used for this study was collected in an office building among benchmark buildings for EnergyPlus, as published by the DOE. The load profile of the building is calculated by EnergyPlus model in condition of heating and cooling design-day. Simulation model was changed to weather conditions and U-value suitable for Korean. Figure 2 displays the COP data of the equipment and cooling and heating load profiles of the study. Here, TR represents the turbo refrigerator, HP, the heat pump, and AR, the absorption refrigerator. The input and output energy produced during the operation of each equipment is considered as non-linear functions. TR operates at its highest efficiency when the load rate is between 0.8 and 0.9, and HP operates at its highest efficiency when running at a condition of 0.8. AR displays the best efficiency when the load rate is between 0.4 and 0.7. The amount of energy consumption on the load rate was calculated by using the performance data of equipment.

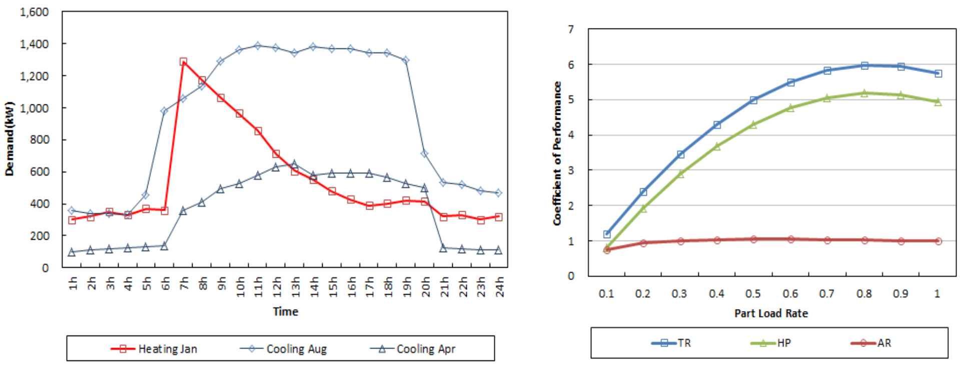

Figure 2 *Demand Profile / Equipment Data*

OBJECT FUNCTION AND CONSTRAINTS

The purpose of this study is to select the combination of devices and operational schedule that use the least amount of energy. Thus, the objective function that minimizes the energy consumption has been used. The used energy source is divided into gas and electricity, thus, the objective function that minimizes primary energy use has been applied by converting each energy source into primary energy. The equipment that uses electric energy translated into 48% generating efficiency of electricity and 4% transmission loss. The amount of energy consumption changes to a non-linear form based on the given load by using the performance curve of the equipment. Constraints have been set to satisfy all heating and cooling loads of the building, when the cooling and heating production of the equipment become more than the load of the building at each hour. Furthermore, the safety factor of the energy system has been considered, setting the maximum load of the capacity of all equipment at more than 110%.

RESULT

Table 2 *Optimization Result*

	Optimal Design	Conventional Design
Cooling Equipment	TR1: 12,00kW HP1: 170kW HP2: 170kW	TR1: 500kW TR2: 1,200kW
Summer Design day (Energy Use/day)	21,433kWh	23,994kWh
Midterm Design day (Energy Use/day)	12,763kWh	10,805kWh
Heating Equipment	GB1: 500kW, GB2: 500kW HP1: 170kW, HP2: 170kW	GB1: 700kW GB2: 700kW
Winter Design day (Energy Use/day)	11,929kWh	13,627kWh

Table 2 shows the size and type of equipment that were selected through optimization. A 1,200 kW turbo refrigerator and a 170 kW heat pump were selected as the heating equipment that displayed the most efficient operation through capacity optimization. The equipment for cooling has a total capacity of 1,540 kW, which is 115% of the maximum load of 1,380 kW. Two 700 kW turbo refrigerators can be considered, however, efficient operation is achieved at 1,120 kW, which is 80% of the selected 1,400 kW, thus, 1,200kW is analyzed to be more beneficial after considering the load of this building that is operated at 1,000 kW.

The results have been compared by selecting the equipment with the conventional design for a relative comparison of the optimum results. The equipment selected as the resolution included 500 kW and 1,200 kW turbo refrigerators, which have been considered in order to respond to the base load and peak load. Figure 3 shows the operational results according to the design-day in the summer. In comparison with the energy consumption of the equipment designed with the conventional design method (left) at 23,994 kW, the energy consumption of the optimized heat source (right) is 21,433 kW, displaying an approximate energy reduced operation of 12%.

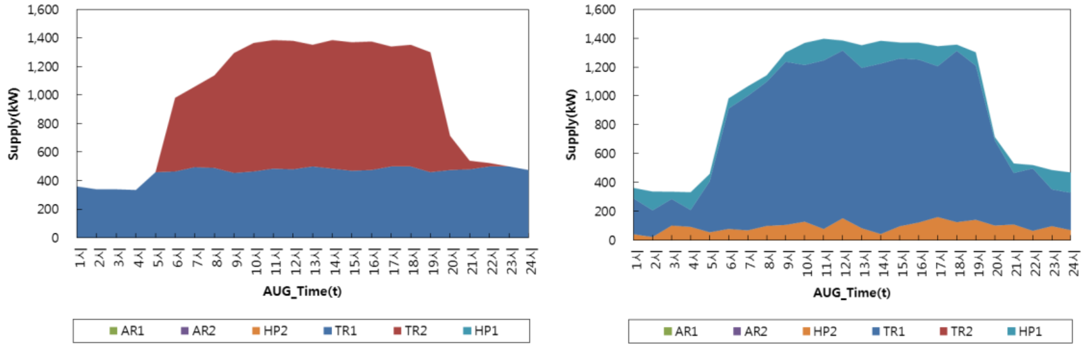

Figure 3 *Optimal Result of Cooling (August)*

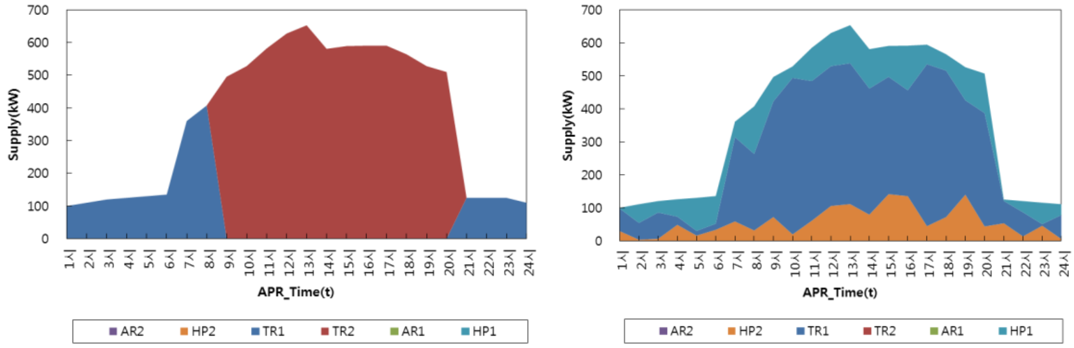

Figure 4 *Optimal Result of Cooling (April)*

Figure 4 shows the operational schedule in April, as the representative date of the intermediary season. Compared to the representative date in the summer, the representative date in the intermediary season has been operating as partial load. The conventional design method of operating two turbo refrigerators consumes 12,763 kW of primary energy. However, the optimized method that uses two heat pumps consumes 10,805 kW of primary energy, this result indicate that design method has the possibility of an 18% relative potential energy reduction.

Figure 5 displays the heating operation results of the representative date in the winter, which show 14% less consumed energy with the optimum design that simultaneously used 2 heat pumps and 2 boilers than the conventional method that uses two boilers.

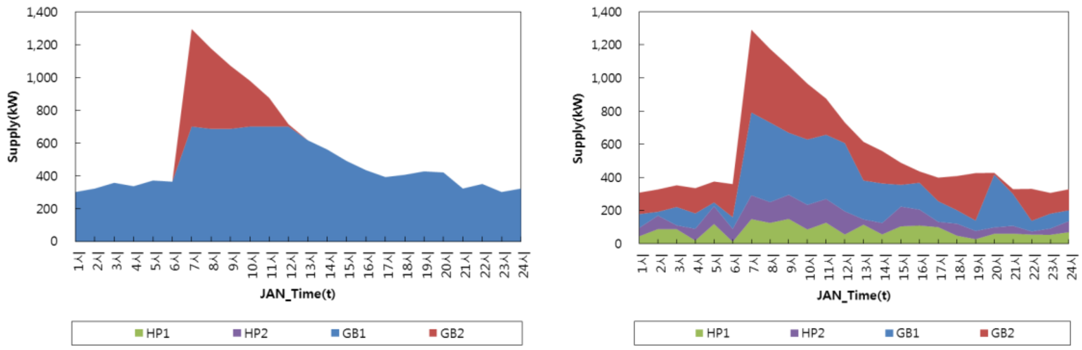

Figure 5 *Optimal Result of Heating (January)*

DISCUSSION

The HVAC system of the building has the potential to operate with high efficiency, based on the demand properties of the building. Accordingly, a quantitative optimum design method has been proposed through this study so that equipment can be operated with high efficiency can be selected, and so that the equipment can be divided under a suitable standard. However, this study was developed to respond to the load of the building by using the load of the equipment. This study does not consider other HVAC systems, such as the supply fan, cooling tower, and pump, so different results can occurs this point. Furthermore, additional studies on various equipment type, such as the absorption heat and refrigerator, and renewable energy system, and other HVAC systems must be conducted.

CONCLUSION

This study has proposed an optimum design method that simultaneously considers the capacity and the operational schedule method of the HVAC system. The most energy-efficient combination of HVAC system has been selected by evaluating which combination of equipment consume the least amount of energy when the most effective operational method is applied. The COP curve that suits the type of equipment has been used to calculate the energy and non-linear properties reflected on the partial load. The results of calculating the energy consumption of the building on the representative days in the summer, winter, and intermediary seasons through this design method have led to a potential energy reduction of 10%-18%. Thus, the method proposed by this study is expected to provide an effective solution through quantitative analysis in situations that examine various types of HVAC system with restricted information in the early stages of the design.

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