STUDY ON OPTIMAL ENERGY SYSTEM DESIGN FOR APARTMENT HOUSE USING GENETIC ALGORITHMS

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ABSTRACT

The purpose of this study is to propose an optimal design method for the energy system in apartment house using a genetic algorithm and to examine the possibility for the energy conservation of a designed energy system. The energy demand for cooling and heating in apartment house is determined by using TRNSYS. By a modified genetic algorithm called multi-island genetic algorithm, the optimal running pattern of building equipment systems is decided to minimize the energy consumption. An optimal design method for the energy system of the apartment house was proposed using both genetic algorithm and data of cooling/heating demand load simulated by TRNSY. The results show that this proposed method is significantly capable of determining optimal system design for saving energy in apartment house.

INTRODUCTION

Recently, environmental issues such as an energy problem, a heat island, a global warming and carbon dioxide emissions have become a concern in the world. In the case of energy problems, it is essential to consider measures for effective energy consumption and develop an alternative energy because natural resources are in danger of running out.

In East Asian where densely populated cities located, the amount of energy consumption used in buildings shows a tendency to have increased (Yuasa Y et al., 2007 and Kim Y, 2005). It has been reported that energy consumption in residential sector in Tokyo and Seoul particularly is increasing because it is likely that many large-sized and high-rise apartment buildings are constructed in cities (Agency for Natural Resources and Energy, 2007). In order to save energy for residential sector, it is important to design optimal energy system for such apartment buildings.

The genetic algorithm (GA) is widely used as the method for designing an architectural environmental design (Chen H et al., 2008 and Ooka R et al. 2008). Studies on optimizing energy systems of commercial buildings have also been carried out by using the optimal design method (Ooka R et al. 2008, Ono E et al., 2007 and Wang F et al. 2007).

In this research, authors propose an optimal design method for the energy system of the apartment house located in Tokyo using GA and examine the possibility for the energy conservation of a designed energy system. In this method, firstly, the cooling and heating energy demanded in apartment house is simulated by using TRNSYS. By a modified genetic algorithm called multi-island genetic algorithm (MIGA) (Ooka R et al., 2008 and Kayo G et al., 2008), the optimal running pattern of building equipment systems, which is considered the type and number of equipment, capacity size, are determined to minimize the energy consumption.

METHODS

The flow chart for designing an optimal energy system is shown in Figure 1. TRNSYS, which is simulation software analyzing a heat transfer and an energy demand in the multi-zone, is utilized in this study in order to calculate the energy demand for cooling and heating of an objective building (Yau Y, 2008 and Farraj F, 2008). And then an optimal operation pattern and machinery combination to minimize a primary energy consumption are suggested using the MIGA, which includes input conditions such as machinery data, GA parameters and demand data. In this research, MIGA is adapted to select machinery combination which needs enormous calculation practice (Ooka R et al., 2008 and Kayo G et al., 2008). MIGA is superior to avoid

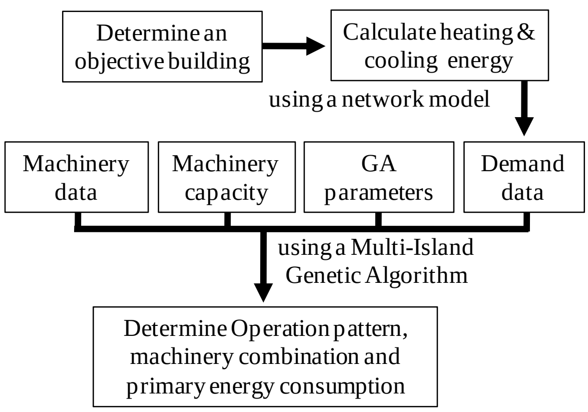
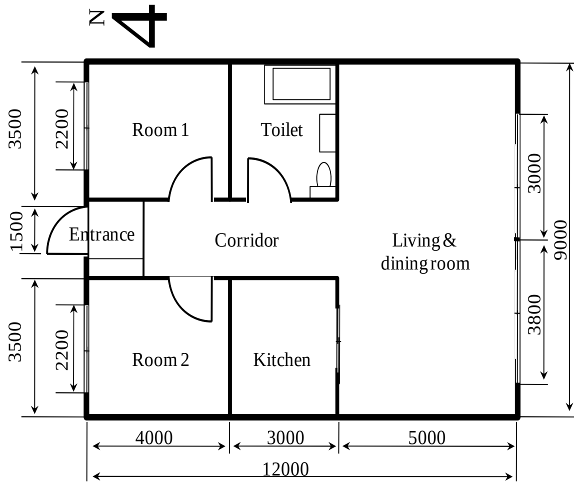


Figure 1 flow chart for designing an optimal energy system



* Height of ceiling: 2.4 m
* Floor area
  Room 1: 14 m^2, Room 2: 16 m^2, Toilet: 10.5 m^2,
  Kitchen: 12 m^2, Living room: 45 m^2, Corridor: 10.5 m^2
* Window area
  Room 1: 3.96 m^2, Room 2: 3.96 m^2, Toilet: 10.5 m^2,
  Living room: (5.4+6.84) m^2
* Door area
  Room 1: 1.8 m^2, Room 2: 1.8 m^2, Toilet: 1.8 m^2,
  Kitchen: 4 m^2, Entrance: 1.8 m^2

Figure 2 one representative family model [mm]

Table 1 Properties of building materials and input data

Building materials	Heat transfer Coefficient (U-value) [W/m^{2}K]	Location
Outer wall for energy saving	0.385	External wall
Partition wall	3.583	Internal wall
Wooden door	2.591	Door at room
Metal door	2.411	Door at entrance
Ceiling material for energy saving	0.294	Ceiling
Flooring material for energy saving	0.403	Floor
One story glass	5.800	Window

converging partial optimal solution that is easy to occur in Simple GA. MIGA is one of the optimal method of parallel distribution. MIGA performs calculation among islands, which divide population into some island (sub-population). Exchanging of the individual information called "migration" among each island regularly evades the outbreak of the partially optimization every several generations once. To search the optimal operation plan of machineries, the outputs of machinery are calculated by all investigation. for 11 ways of output is divided into 11 steps, every 10% from 0% to 100%.

Objective building and loads

The high-rise apartment building located in Tokyo is selected as an objective building and is composed of ninety families. In order to analyze the applicability of the design method, one representative family selected is modelled using TRNSYS 16 as shown in Figure 2. TRNSYS Type 56, which is one of the

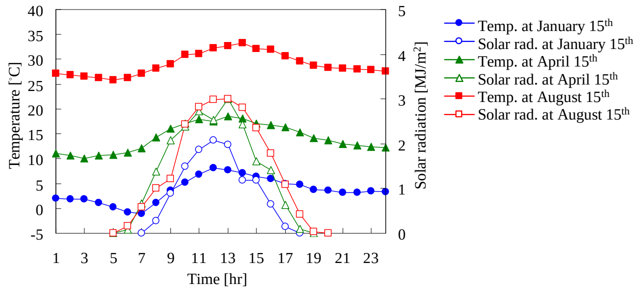
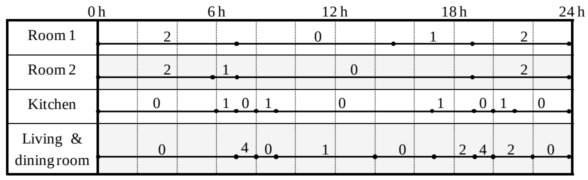
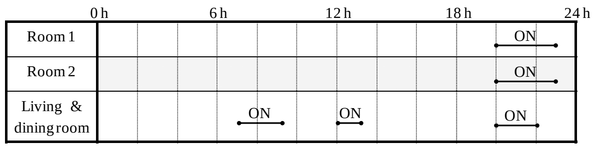


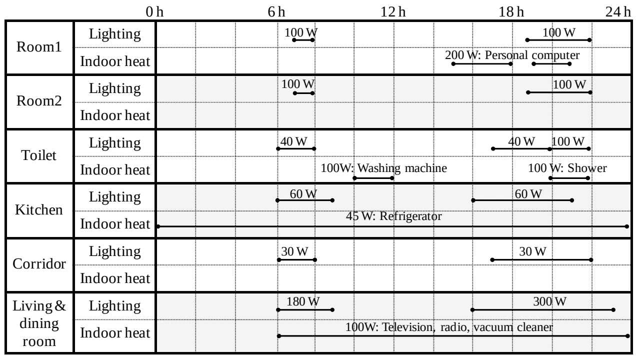
Figure 3 ambient temperatures and solar radiations



a) *Resident*



b) Heating and cooling system



c) Lighting and heat emitted from electric appliances
Figure 4 Schedule

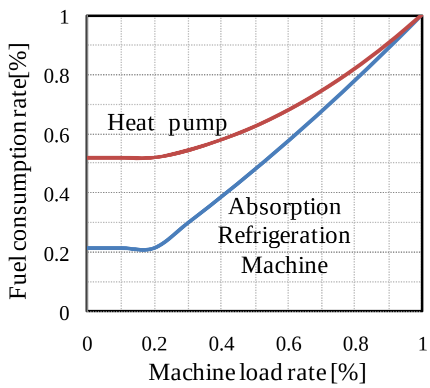


Figure 5 Machinery performance for fuel consumption

components to simulate building thermal behaviour and deals with the thermal balance of the multi-zone, is used. The building model of Type 56 is non-geometrical balance model with one air node per zone. Thermal properties of building materials and input data are shown in Table 1.

Climate descriptions

The Meteorological data observed form Automated Meteorological Data Acquisition System (AMeDAS) of Tokyo, i.e., wind direction and speed, air temperature, humidity and sunshine duration, are used. 0.5 h^{-1} of infiltration air exchange by natural ventilation is assumed. Figure 3 shows ambient temperatures and solar radiations for spring, summer and winter representative day. The representative family house model includes two rooms, a living room, a kitchen, a toilet and a corridor. A family is composed of father, mother and two children. Heating and cooling systems are operated by a fixed schedule; heating temperature of 20 ºC and cooling temperature of 28 ºC are controlled.

A resident pattern, lighting and the heat emitted from electric appliances also are controlled. Figure 4 describes schedules of resident, lighting, internal heat gain, heating and cooling systems.

Optimal design of energy system using GA

The GA definition, the chromosome coding and the energy system modelling reported by Ooka R et al. (2008) have application to this study.

The performance curve of machinery for absorption refrigeration machine (AR) and heat pump system (HP) are described in Figure 5. Machinery efficiency is defined as fuel consumption rate for machinery performance. The characteristic curve of fuel consumption rate becomes non-linear function of the machine load rate. The machinery data referred to a manufacturer catalogue value and the value of the machinery database of the CEC/AC calculation program "BECS/CEC/AC for Windows" published by Institute for Building Environment and Energy Conservation (IBEC) based on energy saving method.

Tables 2 and 3 show the selection range of each variables and machine line-up. Two ARs for supplying cooling heat and two HPs for supplying cooling and hot heat are introduced in this study. The variables are not continuous, but step change machinery line-up. Basically, kilowatt (kW) is used as an unit in the calculation model. The machinery which can provide both cooling heat and hot heat, are used other unit, United States Refrigerating ton (USRT) such as AR or Hosre Power (hp) such as HP. In the calculation, USRT or hp is converted to kw of necessary supply.

The objective is mineralization of primary energy consumption. It doesn't include initial energy, just only running energy.

In this study, MIGA parameters are used as shown in Table 4 and the relationship between number of generation and GA result are examined. (Komamura K et al., 2007).

Table 2 Machinery capacity

System	Unit	0	1	2	3	4	5
AR	USRT	0	30	40	50	-	-
HP	hp	0	8	10	13	16	20

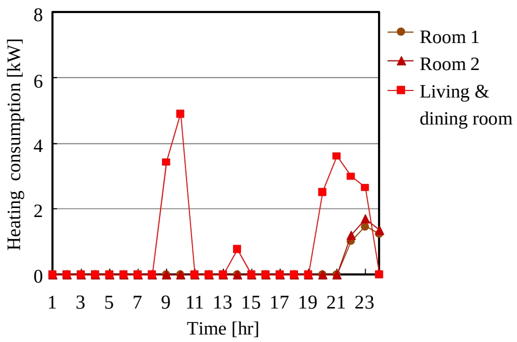
Table 3 Machinery line-up

	COP		Input		Output	
	C	H	Gas	Elec.	C	H
AR	1.1	0.8	●		●	●
HP	1.4	1.4		●	●	●

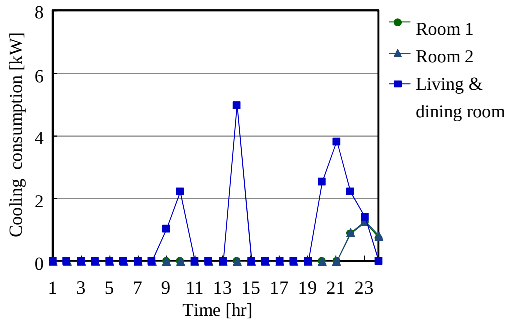
C: Cooling, H: Heating
COP: Coefficient of performance
(= Output / Input)

Table 4 GA parameters

Size of sub-population	50
Number of islands	4
Population size	200
Number of generations	50
Total individual size	10000
Rate of crossover	1.0
Rate of mutation	0.07
Rate of migration	0.5



a) Winter (January 15th)



b) Summer (August 30th)

Figure 6 Seasonal energy consumption

RESULTS

Demand data

Heating and cooling energy consumptions of 24 hours on a representative day of each season simulated by TRNSY are shown in Figure 6. Heating and cooling in January 15th of winter and August 30th of summer were consumed maximally, respectively.

Any heating or cooling energy was not consumed in middle season. In winter, heating systems were operated in the morning and evening, the length of person's stay in house and then heating energy consumption was maximal. In summer, cooling systems were operated in the afternoon influenced by radiation and cooling energy consumption is significantly increased.

Optimal design and operation of energy system

Table 5 shows the machinery combination to operate optimally the energy system. Only one HP of 8 hp (horse power) was selected to supply cooling and hot heat because maximum cooling and heating consumptions among 24-hour by calculated TRNSYS were both under 6 kW as shown in Figure 6.

The optimum operations of heating and cooling supply in winter and summer are shown in Figure 7. In winter, only one HP of 8 hp, which has maximum capacity of 25.2 kW for supplying hot heat, was operated to supply hot heat and it was shown that the capacity of HP satisfied to heating demand by changing of output rate of HP. In summer, one HP of 8 hp, which has maximum capacity of 22.4 kW for supplying cooling heat, was also operated to supply cooling heat. Annual primary energy consumption estimated by the results of daily representative data on each season was 42616.2 MJ/yr.

CONCLUSION

In this study, an optimal design method for the energy system of the apartment house was proposed using both GA and data of cooling/heating demand load simulated by TRNSY. We also examined the possibility for the energy conservation of a designed energy system.

The heating and cooling energy consumption in one representative family of an objective model had a peak load while someone stays in house and heating and cooling systems are operated. Cooling and hot heat supply in one representative family were satisfied by being operated only one HP of 8 hp because heating and cooling load of winter and summer were under 6 kW, respectively.

This proposed method is significantly capable of determining optimal system design for saving energy in apartment house. It has been confirmed that energy for equipment systems in apartment house can be saved by using operation plan of building equipment systems.

In order to validate the accuracy of results analyzed in this study, the relationship between parameter setting and its calculation precision should be also examined. We will perform a sensitivity analysis using GA parameters such as a population size, an island number and a generation number, etc in the future.

Table 5 Results of machinery combination

Cooling heat supply				Hot heat supply	
AR 1 [USRT]	AR 2 [USRT]	HP 1 [hp]	HP 2 [hp]	HP 1 [hp]	HP 2 [hp]
0	0	0	0	0	0
30	30	8	8	8	8
40	40	10	10	10	10
50	50	13	13	13	13
-	-	16	16	16	16
-	-	20	20	20	20

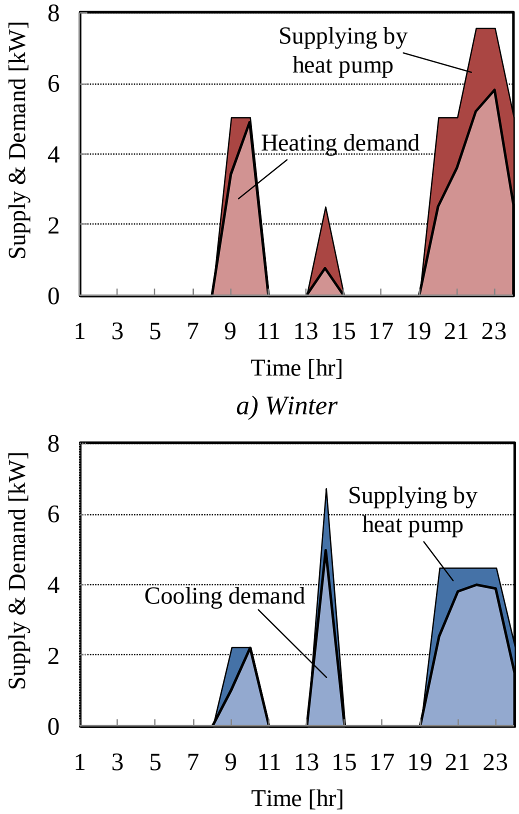


Figure 7 Operation of cooling and heating supply

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