Development of a heat pump system with the heat source network model using solar, ground and air heat source

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Abstract
In this research, a heat pump system with a heat source network is suggested which utilizes outdoor air heat, solar heat and ground heat as heat source for cooling, heating, hot water and refrigerating. This paper describes the summary of the suggested system and the results of the annual energy simulation. The heating and cooling loads, the electric consumption and the COP were calculated by TRNSYS 16 and evaluated in the cases of different local conditions and different system compositions. In the results, the superiority of the suggested system has been quantitatively evaluated comparing with the conventional heat pump system using one heat source. Furthermore, it was more significant in cold climate, in which the heating COP was 64% up compared the air source heat pump system, than it in subtropical climate, 46% up.

Keywords: heat pump system, heat source, network model, solar heat, ground heat source

Introduction

Recently, heat pump systems using solar heat or ground heat as a heat source have got a lot of attention for the use of renewable energy. These kinds of systems can achieve more energy-saving than conventional air source heat pump systems by utilizing more efficient heat source.

However, the performance of each system has the limitation of efficiency due to its dependence on the condition of local climate, geology, system composition, etc. In order to achieve more efficient performance, it is necessary to develop a heat pump system which adopts various heat sources and optimizes them. O.Ozgener and A.Hepbasli[1] have conducted performance analysis of heat pump system using solar and ground heat source for heating, and suggested that the combined operation can be more efficient in Mediterranean and Aegean regions of Turkey through the experimental study [2]. Furthermore, superiority of the solar-assisted ground source heat pump system has been confirmed by a parameter study with exergetic modeling [3]. W.B.Yang et al.[4] also calculated the performance of a solar-ground source heat pump system on the condition of various design and operation by numerical simulation. K.Miyauchi et al. [5, 6] developed multi-source and multi-use heat pump (MMHP) system, which utilize air, ground and solar heat sources in heating, cooling and hot water, and estimated the system performance by experimental analysis. However, there are few researches which quantitatively estimate superiority by local characteristic and design tool considering life cycle cost of the system. In order to design and operate such multi-source heat pump systems efficiently, it is necessary to develop the optimal design tool which can be applied to various conditions. In this research, a heat pump system with the heat source network using solar, ground and air heat sources has been developed in order to achieve greater energy-saving and utilize various heat sources optimally in a building. This paper describes about the developed network model and parameter analysis with a heat source network model.

System Summary

Fig. 1 shows a conceptual diagram of the heat pump system with the heat source network model using solar, ground and air heat sources. The system has solar heat collector, air heat exchanger and ground heat exchanger as the equipment of heat source, which are linked by water-loop piping. More effective heat source is selected by a control valve considering with temperature of heat sources and the circulation water of the selected heat source is supplied to the heat pump. Moreover, a thermal storage tank can be additionally used depending on the conditions such as the operation schedule, heat exchange rate, temperature level, etc. In order to keep the annual balance of heat use, the system introduces the multiple uses including heating, cooling, refrigerating and hot water.

Simulation Model

In order to develop a heat source network model and conduct the parameter analysis through the application to the various conditions, a simulation model use TRNSYS 16 (Transient

Systems Simulation Program) with heating and cooling calculation of multi-zone in this research. The water-to-water heat pump model (Type504) is combined with solar collector module (Type73) and ground heat exchanger module (Type557), and meet heating and cooling loads of a building. Fig.2 shows the performance curve of the heat pump. More effective heat source, which is a heat source of lower temperature in cooling and that of higher in heating, is selected by control valve. Fig.3 indicates the control system of heat source. In this paper, air-source heat pump system is not connected to the heat source network model yet, but the performance of only air heat source is calculated in same condition by another model with air-source heat pump system model (Type665).

Calculation Summary

Fig.4 shows a building model (floor plan and elevation partly in section of base floor), the object of space heating and cooling, which is assumed to 8 story office building (total floor space 6,600m^2). External walls consist of wall board (0.012m), polystyrene (0.025m), common concrete (0.35m), cement mortar (0.02m) and tile (0.008m). Internal walls consist of cement mortar (0.02m), common concrete (0.15m) and cement mortar (0.02m). Furthermore, ceilings consist stone (0.012m), wall board (0.009m), common concrete (0.15m) and floor (0.003m). Table 1 presents the condition of building load in this calculation. Indoor heat gain from occupants sets to sensitive heat of 75W and latent heat of 75W (ISO7730). Table 2 shows the calculation conditions in all cases. In this calculation, it is assumed that the heat pump system with solar heat collector and ground heat exchanger supply heating and cooling to two office area of base floor. The assumed locations are Sapporo (annual average temperature 9.1^{o}C) and Kagoshima (annual average temperature 18.9^{o}C) in Japan. Case studies are conducted to find out the system performance in each case and to confirm the superiority of the system using the heat source network. The solar heat collector (SHC) has 0.7 of the efficiency factor of collector fin, 0.28 [W/m^{2}K] of the heat loss factor and 0.8 of the absorptance of absorber plate. Furthermore, the ground heat exchanger (GHX) is the bore-hole type (concrete grouting) with single U-tube (inner diameter 27mm, depth 100m, thermal conductivity 0.41 [W/mK]). The effective thermal conductivity of soil sets to 1.30W/mK.

Calculation Results

Fig.5 and Fig.6 show the calculation results of heating (13th Jan.) in Case1 and Case 7 which include the temperature of ground and solar heat source, the electric consumption (E.C.) of heat pump and COP (coefficient of performance) of heat pump. They are the results of each 20 minutes, and the results of the other time are interpolated. In Sapporo, as shown in Fig. 5, around noon when solar radiation is high, the system uses solar heat source but, ground heat source in most period. Consequently, the temperature of heat source and the COP of heat pump decreased in the end of operation, but the temperature of GHX became recovered after the operation stops. In the calculation of this period, average COP of heat pump with solar and ground heat source was 5.34, higher than that with only air heat source (2.17) and that with only ground heat source on same condition (4.58). However, in Kagoshima (Fig.6), even though the area of SHC sets to a half of Case 1, the higher temperature of heat source can be acquired due to higher solar radiation at Kagoshima (daily solar radiation 8.55[MJ/m^2]). Finally, the daily average COP with solar and ground heat source is 6.09, higher than that with only air heat source (2.78) and that with only ground heat source on same condition (5.61). Table 3 presents the results of parameter study. The average heating and cooling COP in all cases were calculated in respectively one month, heating from 5^{th} Jan. and cooling from 4^{th} Jul. In the results, the heating COP depends on both the area of SHC and the length of GHX, but the cooling COP depends on only the length of GHX due to lower temperature of ground heat source in summer. The COP of heating and cooling in Case 1, which has the largest SHC and the longest GHX, was higher than it in the other cases of Sapporo. Furthermore, the result of Cases 1 to 3 in which the length of GHX was changed, indicates that it affects on the cooling COP more significantly than the heating COP. Additionally, the difference of heating COP between Cases 3 and 5 (6.3%) was higher than that between Cases 1 and 4 (3.5%), because the length of GHX in Cases 3 and 5 was shorter than that in Cases 1 and 4, that means more dependent on the solar heat source. On the other hands, the COP of heating and cooling in Case 6 was higher than that in the other cases of Kagoshima. The COP of Kagoshima is higher in heating but lower in cooling than it of Sapporo because of higher solar radiation and annual temperature (ground temperature) in Kagoshima. Although Case 9 has a tenth area of SHC in Case 1, the heating COP of Case 9 is higher than it of Case 1. This indicates that it might be more efficient to install small SHC and balanced GHX in the location where solar radiation and annual temperature are high.

Conclusion

In this research, numerical simulation with a heat source network model has been conducted in order to estimate the superiority of the system using solar and ground heat source and develop the optimal design tool. In the results, the performance of the system has been calculated in various conditions, and it founds that the heating COP depends on both the area of SHC and the length of GHX, but the cooling COP depends on only the length of GHX. Furthermore, in the location where solar radiation and annual temperature are relatively high, it might be more efficient to install small SHC and balanced GHX. In the future, more detailed heat pump model which is suitable to the temperature level of solar and ground heat source will be developed by the specific of refrigerant and each device such as an evaporator, a compressor, condenser, etc. Moreover, this research will consider various operation methods such as the ground thermal storage, the use of storage tank and the application for hot water and refrigerating.

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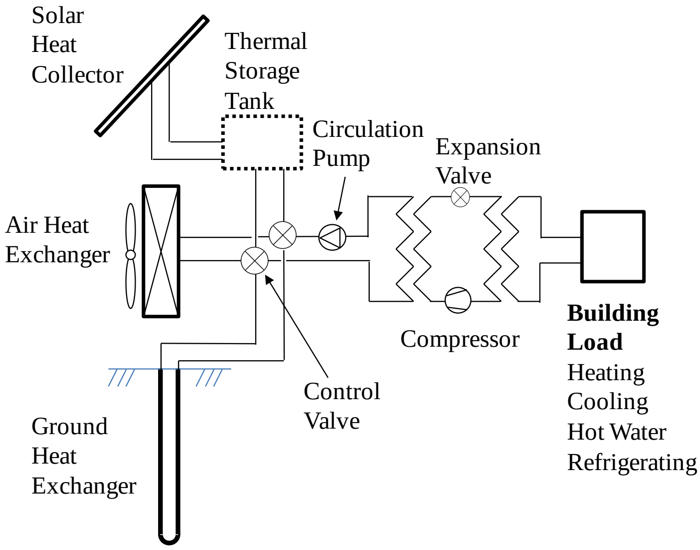

Fig. 1 Conceptual diagram of the heat pump system with heat source network model

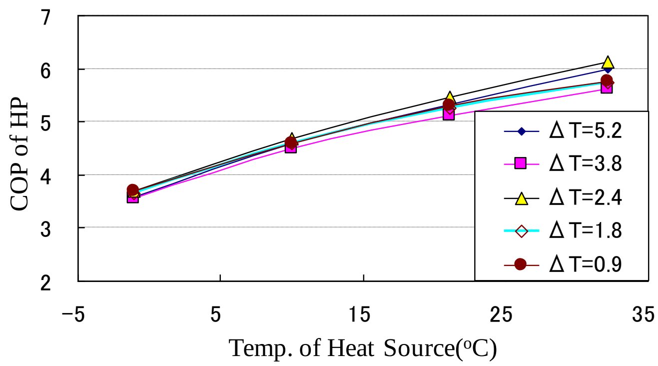

Fig. 2 The performance curve of a Heat pump

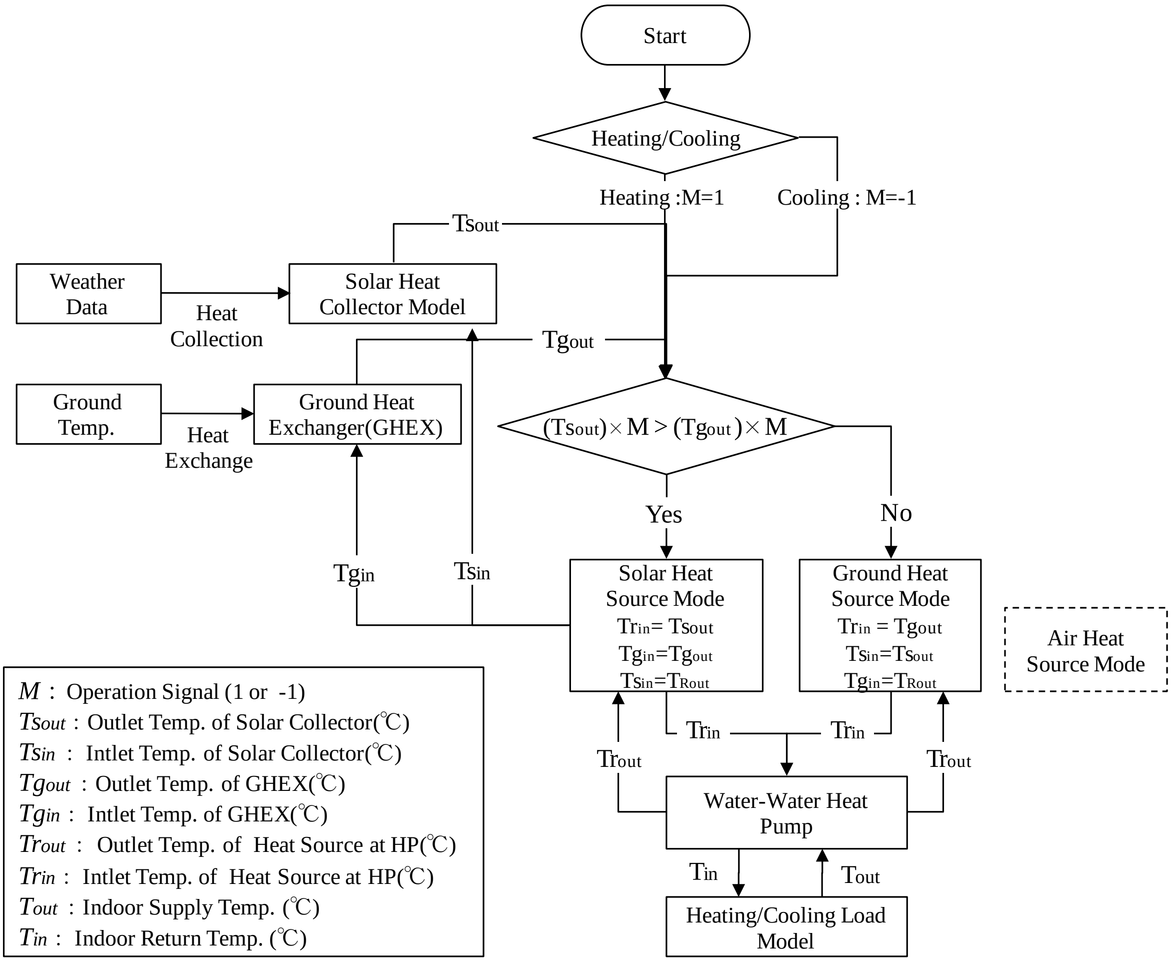

Fig. 3 The control system of heat source

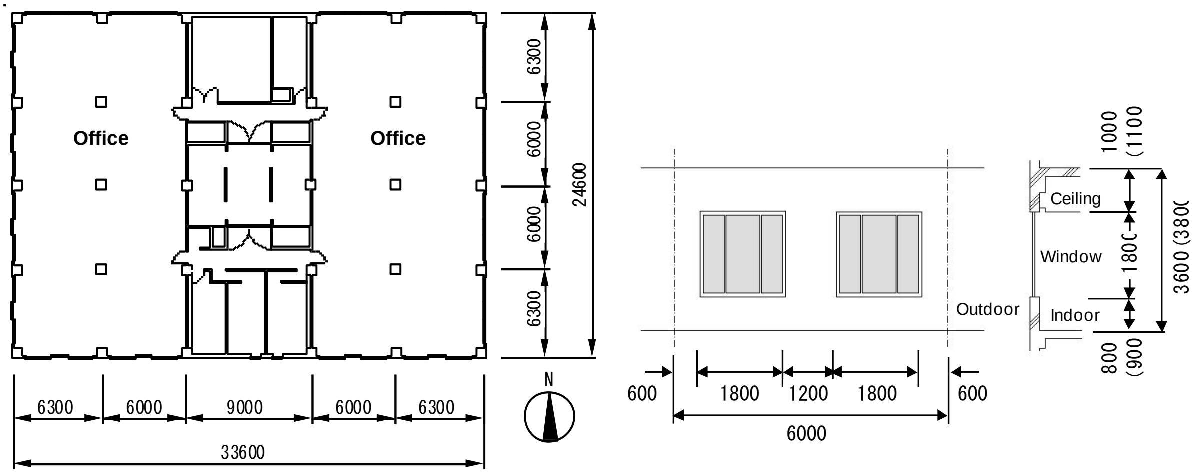

Fig. 4 Building model (floor plan and elevation partly in section of base floor)

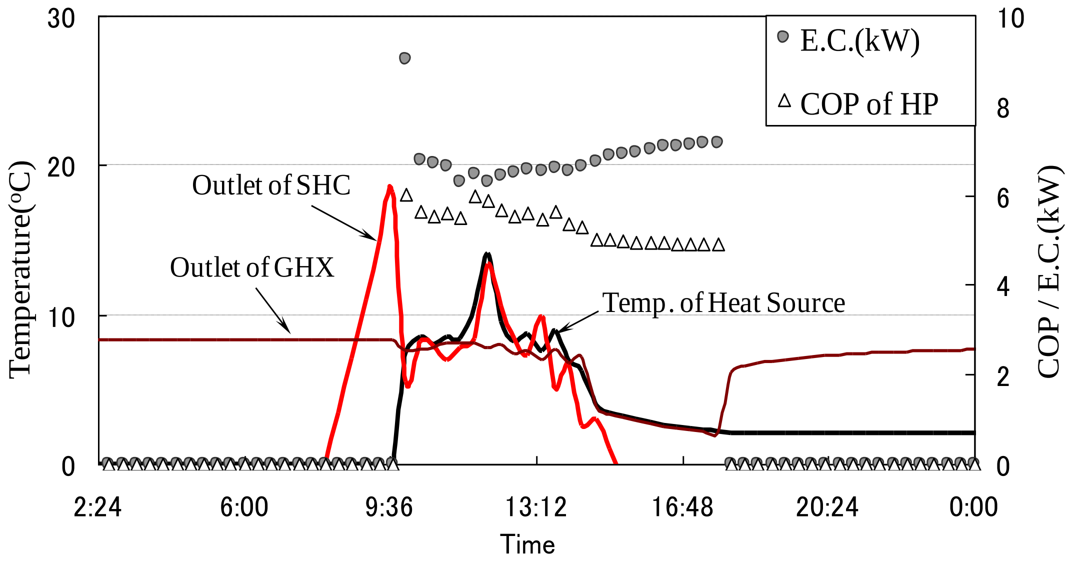

Fig. 5 Calculation result of heating (Sapporo, 13th Jan.)

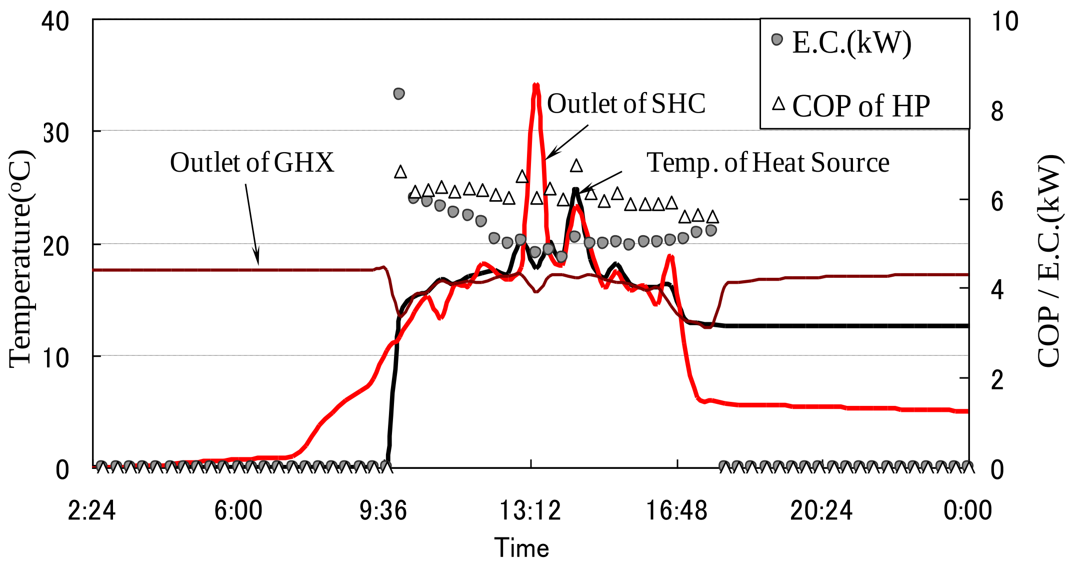

Fig. 6 Calculation result of heating (Kagoshima, 13th Jan.)

Table 1 Calculation Conditions

Location	Sapporo, Kagoshima (Meteonorm Data)
Design Temp. & Hum.	Summer 26°C, 50%, Winter 22°C, 50%
U-Value [W/m^2°C]	External Wall 0.71 Glass 5.72 Internal Wall 3.70 Ceiling/Floor 3.08
Operation Time	9 A.M.~6 P.M.
Artificial Lighting Equipment Density of Persons	20 W/m^2 10 W/m^2 0.20 person/m^2
Air Exchange Rate	1.2 Times/h

Table 2 Calculation Cases

Case	Location	Total Area of SHC [m^2]	Total Length of GHE [m]
Case1	Sapporo	100	500
Case2	Sapporo	100	300
Case3	Sapporo	100	100
Case4	Sapporo	50	500
Case5	Sapporo	50	100
Case6	Kagoshima	100	500
Case7	Kagoshima	50	500
Case8	Kagoshima	20	500
Case9	Kagoshima	10	500
Case10	Kagoshima	10	100

Table 3 Calculation Results

Case	Location	Heating COP	Cooling COP
Case1	Sapporo	5.45	4.17
Case2	Sapporo	5.32	3.33
Case3	Sapporo	5.12	2.93
Case4	Sapporo	5.26	4.17
Case5	Sapporo	4.80	2.92
Case6	Kagoshima	5.93	3.73
Case7	Kagoshima	5.82	3.73
Case8	Kagoshima	5.73	3.73
Case9	Kagoshima	5.72	3.73
Case10	Kagoshima	5.32	3.08