A Methodology of Optimal Design for Solar Heating and Cooling System Using Simulation Tool

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Abstract: ***Solar energy is one of the most important alternative energy sources which have been shown to meet high levels of heating and cooling demands in buildings. However, the efficiencies to satisfy these demands using solar energy significantly vary based on the characteristics of individual building. Therefore, this paper is focused on developing the methodology which can help to design optimal solar system for heating and cooling to be in cooperated within the existing buildings according to their load profiles. This research has established the Solar Heating and Cooling (SHC) system which is composed of collectors, absorption chiller, boiler and heat storage tank. Each component of SHC system is analyzed and made by means of Modelica Language and Pistache tool is verified the results. Sequential approximate optimization (SAO) and meta-models determined to 15 design parameters to optimize SHC system. Finally, total coefficient of performance (COP) of the entire SHC system is improved approximately 7.3% points compared to total COP of the base model of the SHC system.***

Keywords: ***SHC, Modelica(Object-oriented language for systems modeling), PISTACHE, SAO, DOE***

I. INTRODUCTION

The energy consumptions of building sectors are approximately 40% of the entire energy consumptions. The very low amounts of energy consumption in building sectors are called ‘nearly zero energy building’. Nearly zero energy building is achieving a high level of energy performance. The nearly zero is accomplished by renewable energy sources such as solar, geothermal, wind and fuel cell.

One of the crucial renewable energy sources is solar energy. Solar thermal energy is one of applicable solar energy system. Solar thermal system can deal with domestic hot water, heating and cooling for building by using cooling machine such as an absorption or adsorption chiller. As the application of cooling devices, this research established the base model of solar heating and cooling (SHC) system with absorption chiller into the specific building areas of Green Smart Innovation Center (GSIC) which is new research center made by Hyundai Engineering and Construction Company. The base model of SHC system is achieved by Modelica which is object-oriented language.

However, most SHC systems are not useable due to low efficiencies of the entire system and low prospections of economy. Therefore, the aim of this research is increasing total coefficient of performance (COP) of entire base model of SHC system with application of optimal parameters. To establishment of this aim, PISTACHE software is used to verify the values of results on SHC system. After accomplishment of the base model of SHC system, optimal design parameters of SHC system are attained by Sequential Approximate Optimization (SAO). Optimal design values apply into the base model of SHC system, and analyse the results through performance indicators.

Nomenclature

SHC	solar heating and cooling
COP	coefficient of performance
SAO	sequential approximate optimization
DOE	design of experiment
GSIC	green smart innovation center
IEA	international energy agency
Qsol	global irradiation on collector area [kWh]
Scoll	collector area [m^2]
Qsolm^2	Qsol / m^2 [kWh/year/m^2]
Rcoll	collector yield [-]
PSU	net solar productivity [kWh/ m^2]
Eaux.sol	solar auxiliary electricity consumption [kWh]
COPth	thermal absorption chiller COP [-]
TCOP	total SHC system COP [-]
H load	heating load [kWh]
C load	cooling load [kWh]
B.ratio	load of boiler / (Hload + Cload) [-]
Boi.G.H	boiler generation for heating [kWh]
Boi.G.C	boiler generation for cooling [kWh]
B.Gen.	Boi.G.H + Boil.G.C [kWh]
Room.Com	room consumption energy [kWh]

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II. Base model of SHC System Description

A. Indoor loads and outdoor circumstances of system

Targeted zone of solar heating and cooling system is a lobby of GSIC. This zone is located from second floor to fourth floor shown as Fig 1. This zone is applicable to use small capacity of absorption chiller based on the entire loads of this zone.

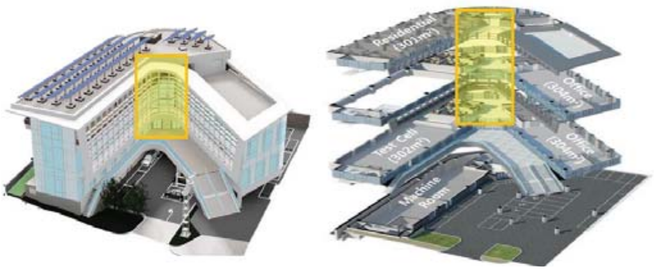

Fig 1. The lobby of GSIC

B. Indoor loads and outdoor circumstances of system

The heating and cooling loads of the indoor area which is a lobby of GSIC are gained by EnergyPlus software. The heating and cooling loads during a year are described in Fig 2. Also, the solar global radiation (Fig 3) is applied with calibrated data of Incheon and Suwon from Korean Weather Station.

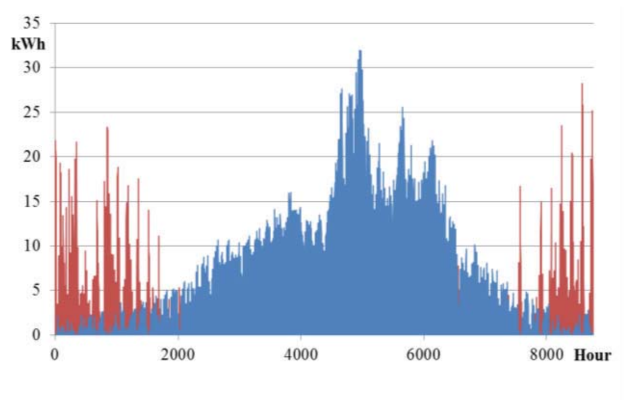

Fig 2. Indoor heating and cooling loads

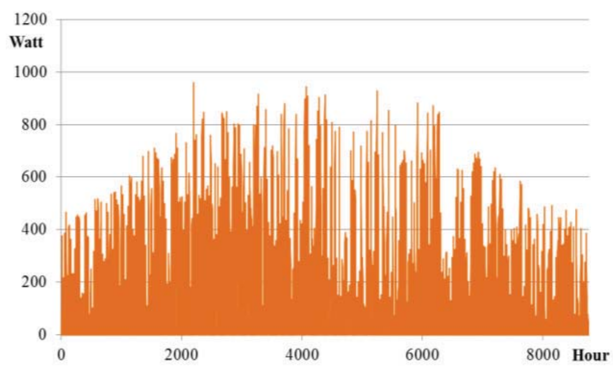

Fig 3. Yearly solar global radiation

C. System description

The SHC system applies the heat gained from the solar radiation into heating, cooling and domestic hot water. In case of heating and cooling, boiler is used to compensate heat when the heat of solar radiation is not enough to operate the system. SHC system is composed of solar collectors, heat exchangers, a thermal storage tank, a boiler, an absorption chiller, a cooling tower and the lobby of GSIC shown as Figure 4.

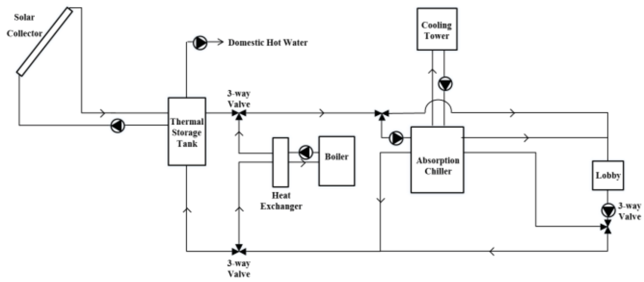

Fig 4. Components of the SHC system

D. Base model of SHC system with Modelica

Base model of SHC system is achieved by Modelica Language (Fig 5); some components of Buildings Library 1.5 developed by LBNL are applied. Other components which are not provided from Buildings Library 1.5 are developed and verified through this research. The developed components are an absorption chiller and vacuum tubes of solar collectors. The absorption chiller is developed from a reference of the product of YAZAKI Company. The solar collector is developed from a tubular type of vacuum tube made by SUNDA Company evaluated by ENI12975 and ASHRAE93. The detailed parameters of solar collector are provided from solar rating and certification (SRCC). This research also verifies same performances of 10RT absorption chiller of YAZAKI Company and same performances of the solar collector provided from SRCC.

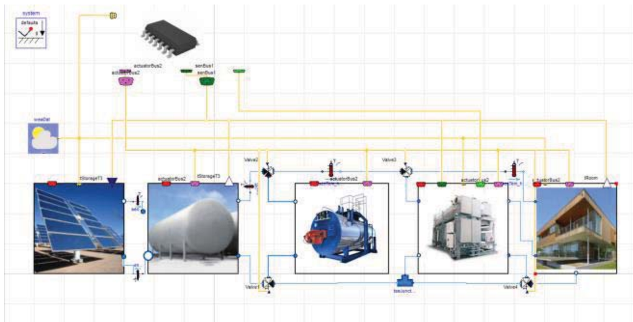

Fig 5. Base model of SHC system with Modelica

E. Verification by PISTACHE simulation

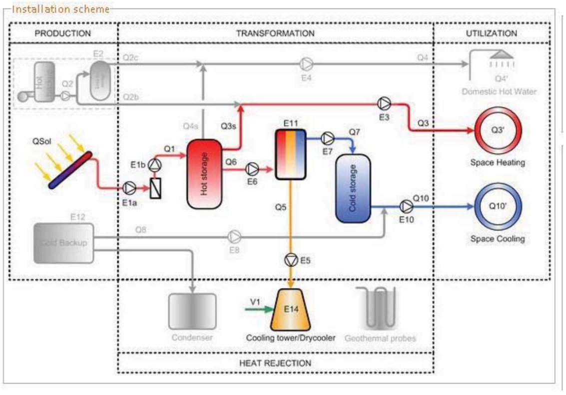

Fig 6. Schematic diagram for SHC system

Verification of the base model of SHC system with Modelica is accomplished by the PISTACHE tool. The PISTACHE tool is developed by results of the international energy agency (IEA) SHC Task 40. The design and simulation of SHC and domestic hot water system are simplified through PISTACHE tool. The PISTACHE tool can calculate monthly and annual energy loads of heating and cooling and domestic hot water yields. Fig 6 describes the schematic diagram for SHC system using PISTACHE. Constitutions of the SHC system in the PISTACHE tool are determined by Modelica. After simulation from PISTACHE, the base model made by Modelica software gets reasonable results of simulation shown as in Table 1.

Item	PISTACHE	Base Model
TCOP	0.157	0.164
Rcoll	0.26	0.48
Boiler ratio	0.68	0.56
COPth	0.54	0.68
Eaux sol	6765	2427

Table 1. Results of PISTACHE simulation

Ⅲ. OPTIMAL DESIGN PARAMETERS

A. Design Parameters

This research determines the specific parameters which are available for effects on results of optimization. The specific parameters are feasible to apply optimization of the entire SHC system. The design parameters are shown as Table 2.

No.	Component	Descriptioin	Initial Values	Range
1	Collector	Mass flow rates	1.6kg/s	0.8 – 2.4
2		Temperature differences between thermal storage tank and collector	5degC	3 – 10
3		Tilts of collector	45degC	15 – 60
4	Storage tank	Volume	1.2m^3	0.6 – 2.5
5	Boiler	Heating set temperature	58degC	53 – 65
6		Cooling set temperature	86.5 degC	80 – 95
7		Mass flow rates	2.4kg/s	0.5 – 3.5
8		Range of temperature at heating	7degC	3 – 10
9		Range of temperature at cooling	7degC	3 – 10
10	Cooling tower	Mass flow rates	5.2kg/s	2 – 7
11		Range of temperature at On/Off set	10degC	5 – 20
12		Reference temperature	35degC	33 – 40
13	Heating pump	Mass flow rate	1.52kg/s	1 – 3
14	Cooling pump	Mass flow rate	1.52kg/s	1 – 3
15	Boiler-Chiller	Mass flow rate	2.4kg/s	1 – 3

Table 2. Design parameters

B. Optimization Process

This research used to Sequential Approximate Optimization (SAO) process to optimize the parameters.

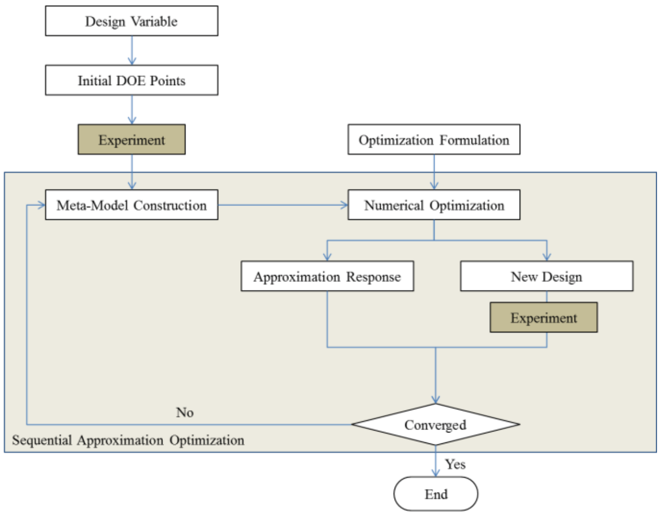

Fig 7. SAO process

As shown in Fig 7, Design of Experiment (DOE) is established to conduct experiment as selected design variables of SHC system. The objective function of optimization is shown as below.

$$Minimize\ \frac{1}{\alpha\, f(x)} + \gamma\, s(x)$$

$$f(x) = Maximize\left(\frac{RoomCom. - (Eaux.sol + Boil.G.H + COPth * Boil.G.C)}{Qsol\ * Scoll}\right)$$

After experiment of DOE method, the meta model is generated by performance objective of total COP of SHC system (TCOP). This research is determined to seventeen experiments based on fifteen design parameters. A type of the meta model is used as a radial distribution function which is an appropriate function type when a number of nonlinear design variables are existed.

C. *Optimal design parameters*

Design parameters of base model are referenced general optimal parameter values are attained by optimization process shown as Table 3.

	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Base Model	1.38	3.03	26.7	1.46	53	86.8	1.81	6.2
Optimal Model	1.15	4.74	15	1.5	53	80	0.9	4.83
	No.9	**No.10**	**No.11**	**No.12**	**No.13**	**No.14**	**No.15**	
Base Model	5.5	4.2	15	37.4	1.7	1.2	1	
Optimal Model	4.9	3.7	9.3	40	1	1	1	

Table 3.Parameters of base model and optimal model

As shown in Fig 8, entire design parameters are increased or same compared to design parameters of base model except of design parameter of No.2. The increasing value of No.2 means that temperature differences between thermal storage tank and collector are increasing. The increasing temperature differences give rise to decrease operation time of circulation pump and increase efficiency of the solar collector

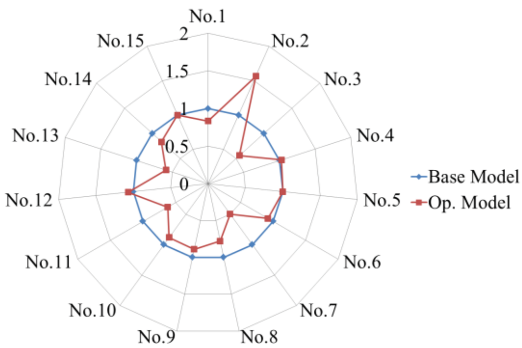

Fig 8. Comparison of design parameters

IV. Conclusion

The results of optimization process, this research gains that the values of TCOP are 44.5% (increased approximately 7.3% points compared to base model). The results of optimization in the entire solar heating and cooling system are essential elements to save energy and costs during the entire year not changing physical models. In near future, analysis of economy between normal SHC system and SHC system with optimal design parameters is needed.

Acknowledgement

The research of this paper is supported by Hyundai Engineering and Construction Company.

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Here are the examples of references format:

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