

Long-term Performance Simulation of a Solar Space Heating & Cooling System

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ABSTRACT: The purpose of this study is to present the simulation results and an overview of the performance assessment of a solar heating & cooling system by means of the 200 m² evacuated tubular solar collector. The simulation was carried out using the thermal simulation code TRNSYS with new model of a single-effect LiBr/H₂O absorption chillers developed by this study. The calculation was performed for yearly long-term thermal performance and for the capacity of the solar storage tank and the cold storage tank as the parametric variables.

As a result, it was anticipated that the yearly mean system efficiency is 46.7% and the solar fraction for the space heating, the space cooling and hot water are about 84.4 %, 41.7% and 72.4%, respectively.

Keywords: 1-effect LiBr/H₂O absorption chillers, TRNSYS simulation, Space heating & cooling system, Demonstration study, Evacuated tubular solar collector

1. INTRODUCTION

Solar cooling system driven by surplus energy in summer was gradually increased the potential of solar market to maximize yearly round-use for solar thermal and prevent from overheating for solar thermal system as well as to decrease the demand of electricity and peak-cut and to reduce the emission of CO₂. Task 25 of IEA-SHC [1] was investigated the study for penetration of the market of the solar cooling system from 1999 to 2002.

The present representatively commercialized solar cooling technology was popularized the 1-effect LiBr/H₂O absorption chillers with evacuated tubular solar collector or compound parabolic concentrating (CPC) collector. The energy

needed the generator of absorption chillers was supplied by solar system instead of waste heat or gas boiler.

General speaking, the COP of 1-effect absorption chillers is lower than that of 2-effect absorption chillers but the 1-effect absorption chillers was suitable to solar cooling system because the supply temperature of generator was low; the cost of installation, operation and maintenance of the system was also low.

Various researchers presented recently modelling and simulation studies of solar cooling system.

Florides et al.[2, 3] analyzed the performance and the economics for solar cooling system installing a residential house in Cyprus. The system comprises a 15m²

CPC collector and a 18kW 1-effect absorption chillers.

Assilzadeh et al. [4] presented the optimized simulation for solar cooling system with a 3.5kW LiBr/H₂O absorption chillers and a 35m² evacuated tube solar collectors in subtropical climate of Malaysia.

Syed et al. [5] also accomplished the demonstration test for the solar cooling system with a 35kW 1-effect absorption chillers and a 49.9m² flat-plate solar collector. They suggested the operating characteristics for solar absorption chillers in Madrid.

Zambrano et al. [6] developed the analytical model of a 35kW 1-effect absorption chillers linking with a 151m² flat-plate solar collector and was investigated its feasibility through the demonstration test.

But as considered the climate condition of Korea, because the design of solar cooling system reflecting only cooling load was impossible, the optimum scheme considering the load of hot water and space heating in design the solar cooling system necessarily requires.

Therefore in the present study, the simulation for long-term thermal performance of the firstly demonstrated the solar heating and cooling system to cope with solar hot water, the heating and cooling loads of the conditioning space in the building was carried out. TRNSYS was used to develop and analyze of a simulation model, and the yearly dynamic characteristics with several design parameters was analyzed.

2. Modelling of the absorption chillers

The model of 1-effect absorption chillers examined in this study was estimated COP of chillers based on WFC-SC10 model of YAZAKI. [7]

The cooling capacity of the evaporator and the power of the generator expressed as the function of the inlet temperature of condenser(T_C) and the inlet temperature of

the generator(T_G) can be calculated as (1) and (2);

① Cooling capacity, Q_{eva} (kW)

$$Q_{eva} = a_0 + a_1 T_C + a_2 \cdot T_C^2 + a_3 \cdot T_G + a_4 \cdot T_G^2 + a_5 \cdot T_C \cdot T_G \quad (1)$$

Where,

$$a_0 = -1.53493599E + 2, a_1 = -4.41505761E - 1,$$

$$a_2 = -8.46744027E - 2, a_3 = 4.41538092,$$

$$a_4 = -2.44999997E - 2, a_5 = 3.06507266E - 2$$

② Cooling capacity, P_{gen} (kW)

$$P_{gen} = b_0 + b_1 T_C + b_2 \cdot T_C^2 + b_3 \cdot T_G + b_4 \cdot T_G^2 + b_5 \cdot T_C \cdot T_G \quad (2)$$

Where,

$$b_0 = 1.64353709E + 2, b_1 = -9.66883729,$$

$$b_2 = 4.66795615E - 2, b_3 = -1.74685730E - 1,$$

$$b_4 = 4.91071428E - 3, b_5 = 4.29452485E - 2$$

Therefore, the COP of the chillers was functioned the inlet temperature of the condenser and the inlet temperature of the generator can be calculated as (3);

$$COP = \frac{Q_{eva}}{P_{gen}} \quad (3)$$

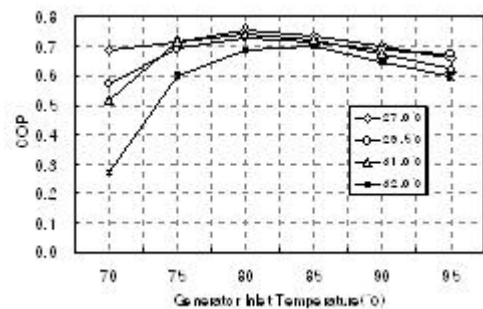


Fig. 1 COP of the absorption chillers

Fig. 1 represents its performance curve of absorption chillers. When the inlet temperatures of the generator and the condenser maintains 88°C and 31°C respectively, the net cooling capacity is 35kW and COP is 0.7.

3. Modelling of the system

3.1 Candidate building

The building installed the solar system in this study was the cultural centre building that was a three story building located in Gwang-ju and was built in 2000. (Fig. 2) The building was composed of library, performance hall, health club and several cultural facility, and had a constant hot water loads and a big thermal characteristic of space heating and cooling loads.



Fig. 2 Photo of a candidate building

The schematic diagram of the third floor is shown as Fig. 3. Library floor of the building is shown to be rectangular shape comprised of three reading rooms, one book storage room and rest area including stairs. Here the solar thermal driven air conditioning space is to be the reading rooms 1 and 2 which are on the third floor of the building. Maximum occupants for reading room 1 and 2 are 168 and 132 respectively, and daily average occupant is about 120-150.

All input data, which is architectural structure, internal thermal loads, daily averaged occupant, daily hot water use, was grasped through the-spot probe.[9]

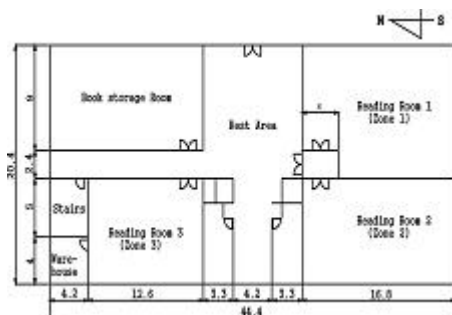


Fig. 3 Schematic of library floor

3.2 Configuration of the system

Fig. 4 showed schematic diagram of a solar system. This system consist of evacuated tubular solar collector, heat exchanger, absorption chillers, auxiliary boiler, solar storage tank, hot water tank, cold storage tank, circulation pump and packaged air conditioner.

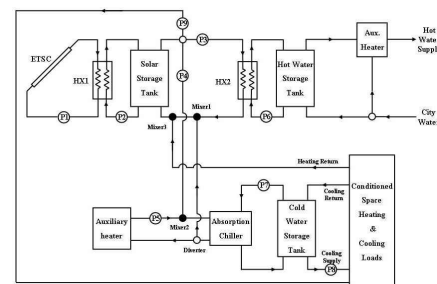


Fig. 4 Schematic diagram of the solar system

Table I: Specification of the system

Items	Components	Specification
Building	Area(reading 1)	182 m ²
	Area(reading 2)	151 m ²
	Height of room	2.4m
Absorption chillers	Cooling capacity	35.2kW
	COP	0.7
Packaged air-conditioner	Cooling capacity	35kW
Auxiliary boiler	Capacity	50000kW
	Setting temperature	90°C
Heat exchanger	Solar HTX efficiency	85%
	Cooling HTX efficiency	85%
Solar collector	Aperture area	200 m ²
	Inclined/azimuth angle	23°/0°
	$FR(\tau\alpha)$	0.7295
	$F_R U_L$	0.72W/m ² °C
Storage tank	Solar tank	6 m ²
	Hot water tank	3 m ²
	Cold tank	1 m ²
Temperature controller	Temp. for space heating	22°C
	Temp. for space cooling	26°C
Solar control system	Control method	Temp. diff.
	Start, ΔT_{on}	8°C
	Stop, ΔT_{off}	3°C

The collected energy from evacuated tubular solar collector stored a solar storage tank, and the stored energy directly supplied to AHU for space heating or generator of absorption chillers for space cooling, and also supplied for hot water in case of surplus energy.

Also, the space heating and cooling system in the reading rooms was designed to make possible by auxiliary source, if the supply energy by solar system according to weather condition was insufficient.

The specification of the detailed system is given as Table 1.

3.3 Simulation model

In this study, simulation for performance analysis for the solar system was used TRNSYS. [8]

The main components of TRNSYS used simulation summarized as Table 2.

The component of the building energy described the operation of system along loads in real time adopted the temperature level control in 'type 56' that is the analytical model of multi-zone building.

The component of the absorption chillers used 'type 810' developed in this study base on the described theoretical analysis in 'modeling of absorption chillers'.

Meanwhile, the component of the room control used 'type 8' that the 1-stage control of room temperature enforced by the solar heating and cooling system, and the 2-stage control of room temperature, if the supply energy is insufficient, enforced by auxiliary boiler.

Table II: Component of TRNSYS

Items	Components
Building energy	MULTI-ZONE BUILDING, Type 56
Chillers	1-effect LiBr/H ₂ O absorption chillers, Type 810
Room temp. control	Three stage room thermostat, Type 8

4. Results and discussion

In this study, yearly thermal performance of the solar system was analyzed the measured weather data from Kwang-ju meteorological station in 2006. Table 3 showed the supply temperature control of hot water from the solar storage tank for application. The system operation takes precedence of the supply for space heating and space cooling use in summer and winter, exclusive of spring and fall.

Table III: Temperature control for application

Items		Control value
Minimum supply temp for space heating		45 °C
Hot Water	Winter (January ~ March, December)	60 °C and over
	Spring, fall	Pre-heating
	Summer (June ~ September)	93 °C and over
Supply temperature rang for space cooling		78 ~ 93 °C

4.1 Long-term thermal performance

Table 4 represents the acquired energy from solar system and the supply energy for applications. The yearly total acquired energy was 555.2GJ, and the yearly averaged efficiency of the system showed 46.7%.

Table IV: Monthly analyzed result of solar system (unit : GJ)

month	Inclined radiation	Total acquired energy	System eff. (%)	Supply energy		
				Space heating	Hot water	Space cooling
1	85.5	41.9	49.0	20.4	21.5	0.0
2	91.0	44.5	48.9	18.8	25.7	0.0
3	125.1	60.1	48.0	11.2	48.9	0.0
4	105.0	51.1	48.6	0.8	50.2	0.0
5	111.1	55.2	49.7	0.0	55.2	0.0
6	112.7	46.8	41.5	0.0	15.6	31.2
7	71.9	31.6	44.0	0.0	3.7	28.0
8	112.0	51.4	45.9	0.0	12.2	39.2
9	104.7	43.0	41.1	0.0	17.3	25.7
10	117.5	56.3	47.9	0.0	56.3	0.0
11	84.3	42.4	50.3	3.8	38.6	0.0
12	67.0	30.9	46.2	16.1	14.8	0.0
sum	1188.0	555.2	46.7	71.1	360.1	124.0

The reason why the system efficiency of summer is lower than that of winter was showed that the higher-setting supply temperature of storage tank for the generator of absorption chillers relatively make the efficiency of collector decrease.

The use pattern of the yearly acquired solar energy showed 12.8% of space heating, 22.3% of space cooling and 64.9% of hot water.

Also, if the energy consumption for application classified in summer and winter, the winter season exclusive of April supplied 37.5% for space heating and 62.5% for hot water, the summer season supplied 71.8% for space cooling and 28.2% for solar hot water of the total acquired energy from sun. The reason why the supply energy of solar hot water was relatively much in spite of taking precedence of the supply of space heating and space cooling in control of operation showed that the surplus energy, that the temperature range for space heating and cooling was strayed, was supplied for hot water.

Therefore, to increase yearly round-use of solar system in design of solar heating and cooling necessarily have to prepare the load of hot water for use of surplus energy during the period of heating and cooling.

Table V: Solar fraction for application

Application			fraction
space heating	yearly heating load		84.3GJ
	supply energy from sun		71.1GJ
	solar fraction		84.4%
hot water	yearly hot water load		479.2GJ
	supply energy from sun		360.1GJ
	solar fraction		72.4%
space cooling	yearly cooling load		211.1GJ
	absorption chillers	solar system	88.0GJ
		auxiliary	57.1GJ
	packaged air-conditioner		66.0GJ
	solar fraction		41.7%

The solar fractions for application are as shown in table 5. The solar fraction for space heating and hot water in the present

system was 84.4% and 72.4% respectively, and was analyzed the appropriate system indicating ASHRAE.

And, the supply energy of absorption chillers by solar energy was 88GJ, the solar fraction for space cooling was predicted 41.7% compared to yearly cooling load. On the other hand, the operation of the packaged air-conditioner in spite of continuously operating of absorption chillers with the auxiliary boiler was implied that the capacity of absorption chillers was small compare to maximum cooling load.

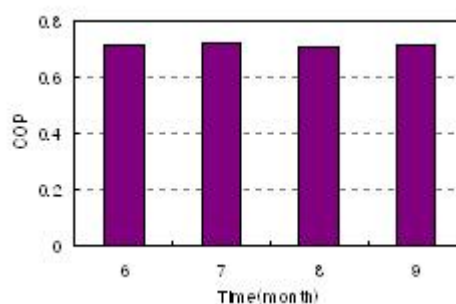


Fig. 3 Monthly averaged COP of chillers

Fig. 5 showed the monthly averaged COP of absorption chillers, there were scarcely showed the monthly difference of performance. The yearly averaged COP showed 0.71 satisfying results compared to 0.7 of COP in standard operating condition. ($T_C=31^\circ\text{C}$ and $T_G=88^\circ\text{C}$)

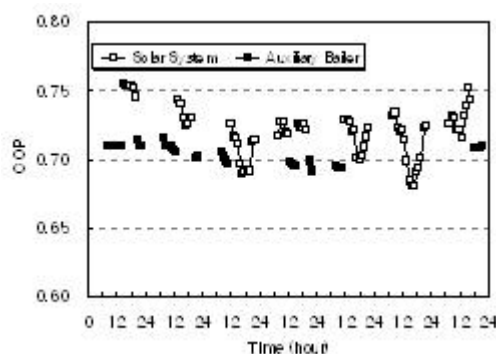


Fig. 6 Hourly average COP of chillers

Fig. 6 showed the hourly averaged COP of absorption chillers during 1 week from 19th, August to 25th August.

The absorption chillers were operated by auxiliary boiler at morning and night along the temperature of the solar storage tank and the load. The absorption chillers were continuously operated by the solar system at sunny day. The COP operated by auxiliary boiler was lower than that of solar system, but showed a nearly constant performance of approximately 0.7.

4.2 Parametric study of storage tank

In the present study, the capacity of the solar storage tank and the cold storage tank as the parametric variables of system was investigated.

Table 6 showed the supply energy for application along the capacity of solar storage tank, and Fig. 7 showed the increase and decrease rates of the supply energy base on a 6m³ solar storage tank. The total supply energy was known a little increase expanding the capacity of the solar storage tank. As considered the distribution of application, the supply energy of space heating and cooling was increased, but that of hot water showed the trend of decrease. In case of a small capacity of storage tank, the supply energy of space heating and cooling was relatively decreased because the surplus energy increasing the temperature of solar storage tank was supplied for hot water.

Table VI : supply energy for application along to capacity of storage tank

capacity (m ³)	application(GJ)			
	space heating	hot water	space cooling	total supply energy
4	66.2	372.3	109.3	547.8
6	71.1	360.1	124.0	555.2
8	74.2	353.0	131.3	558.5
10	75.2	344.5	139.9	559.6
12	76.3	343.8	146.3	566.4
14	77.3	344.1	152.4	573.9
16	77.7	347.6	156.0	581.3
18	78.6	349.1	158.5	586.3
20	78.8	346.8	160.1	585.7

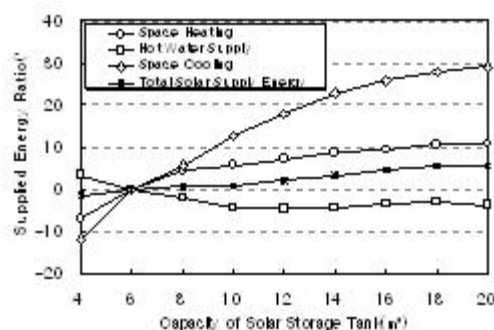


Fig. 7 supplied energy ratio along the capacity of solar storage tank

In general design handbook of solar storage tank, the capacity of solar storage tank vs. collector area showed 50 - 100kg/m². The 30kg/m² solar storage tank was a little smaller in this study. That was the reason considering the load of slab of building and the mechanical room on slab.

Fig. 8 showed the distribution of the supply energy for cooling along changes of the capacity of the cold storage tank. When the capacity of the cold storage tank compared 1m³ with 6m³, the increase of the supply energy showed less than 2%, and was not affected.

In order to improve the solar fraction for space cooling, the change of the capacity of the solar storage tank was more effective.

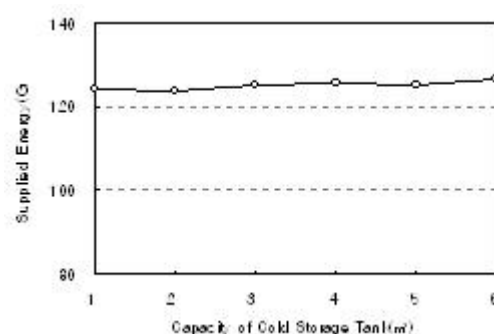


Fig. 8 supplied energy along the capacity of cold storage tank

5. CONCLUSION

In the present study, the simulation for the demonstrated solar cooling system to cover the load of hot water, space heating and cooling on the conditioned space at cultural

centre building located in Gwangju Korea was carried out.

The modeling and simulation of the system comprising of a 35kW absorption chillers and a 200m² evacuated tubular solar collectors is performed with TRNSYS program. The yearly thermal performance with 2 design parameters was analyzed. The main results summarized are as follows;

1) The yearly averaged efficiency for the solar system was analyzed 46.7%, and the yearly total acquired energy from sun showed 555.2GJ.

The use pattern of the yearly acquired solar energy showed 12.8% of space heating, 22.3% of space cooling and 64.9% of hot water.

2) The winter season supplied 37.5% for space heating and 62.5% for hot water, and the summer season supplied 71.8% for space cooling and 28.2% for hot water from the total acquired solar energy.

3) The COP of the normal operation showed 0.7 from Yazaki's catalogue, but on the other hand, the COP of operation was analyzed 0.71 in this study.

4) As the capacity of the solar storage tank and the cold storage tank for parametric variables of system was considered, as the capacity of the solar storage tank increase, as the supply energy of cooling and hot water increase and the efficiency of system improve, but the capacity of the cold storage tank was not affected the efficiency of system.

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