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Analysis on the Effect of Thermal Performance with Various Load Patterns for Solar Hot Water Heating System

Byoung Gi Kim, Hwan Young Jang, Kyung-Taek Chung*, Jeong-Se Suh†**

Department of Mechanical Engineering, Gyeongsang National University, Jinju 660-701, Korea
2nd BK21(AMAEEP), Gyeongsang National University, Jinju 660-701, Korea
**School of Mechanical and Aerospace Engineering, ReCAPT, Gyeongsang National University, Jinju 660-701, Korea*

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ABSTRACT: The performance of a solar water heater incorporating evacuated tubes was evaluated using a transient simulation program, TRNSYS. Simulations were performed for 60 ℃ of hot water load temperature and for 280 liter of daily hot water volumes and three 400 liter of storage tank volumes. Three patterns of daily hot water consumption profile were used in the present study (morning, lunch and evening). The results show that the increase in solar fraction depends on the load profile, as well as the collector efficiency coefficient. Hot water draw profile has a large effect on the performance of the SDHWS, the morning load profile has the highest solar fraction. The annual solar fraction of the system, at the weather conditions of Jinju is approximately 84% at lunch load pattern, the 280 kg of load volume, 400 kg of tank volume and the 60 ℃ of load temperature.

Nomenclature

f	: solar fraction
F_R	: heat removal factor
Q_{solar}	: solar energy acquired [kJ]
Q_{load}	: hot water energy demand [kJ]
Q_{aux}	: auxiliary energy supplied to the system [kJ]
ΔT_{on}	: upper dead band temperature difference [℃]
ΔT_{off}	: lower dead band temperature difference [℃]
U_L	: heat loss coefficient of absorber [W/m^2 · ℃]

Greek symbols

α	: solar absorptance
τ	: solar transmittance

† Corresponding author
Tel.: +82-55-751-5312; fax: +82-55-757-5622
E-mail address: jssuh@gnu.ac.kr

1. Introduction

It is the water heating system which has the longest history and most economic efficiency in the solar energy application fields, and is now at the stage of its practical use. It is required to secure the its actual operational data over the long period of time and its load patterns in particular for the performance prediction and optimal design of the solar heating system which can stably operate.[1]

Although setting up the load patterns is absolutely important in order to grasp the exact performance and behaviors of the system, the detailed data on the load patterns meeting the purpose of use has not been ensured so far. The thermal performance of solar system depends on the pattern of heating load supplied to the hot shower. In this study, the typical simple pattern of heating load is applied to the active solar hot water system which has the auxiliary heater in series. The solar fraction of this system will be simulated using TRNSYS.

The daily heating load, which was used as the load pattern in the study, was regularly used for a year. In case of South Korea which has apparent four seasons, the heating load is differently applied for each season. Its application will not be considered in this study due to the lack of weather data.

Prior to the thermal performance analysis using TRNSYS, of course, the reliability on the simulation modeling should be guaranteed, and as various important input variables should be taken into account, it is desirable to input the optimal variable values fitting the relevant equipment. The input variables are as follows: such as thermal performance of solar collector, collector size, specification and performance of consisting factors in the solar water heating system, load conditions, meteorological conditions, etc.

2. Simulation model

Fig. 1 and Table 1 indicate the schematic diagram and analysis variables used in the study. The solar collector is a vacuum tube connected to the thermal storage tank of which shape is a vertical cylinder. The operation of circulation system is controlled by the valve device which responses to the temperature difference between solar collector and storage tank. The auxiliary tank is serially connected to the outlet of storage tank. For the stable operation of the solar collector, it was done to control on/off of the pump while sensing the temperatures of outlet and inlet of the

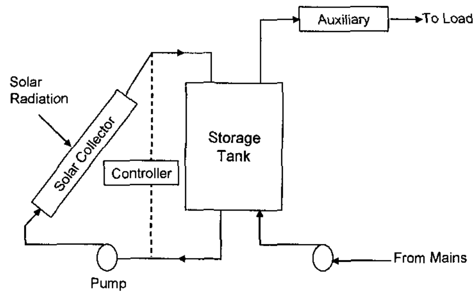

Fig. 1 Schematic diagram of solar system.

solar collector by using the controller. ΔT_{on} and ΔT_{off} of the controller were set as 10 ℃ and 5 ℃ respectively. The flow rate of pump was set as 72 kg/m^2 · hr based on the ASHRAE standard. As the temperature of hot water in the heater was set as 60 ℃, it was arranged to provide the wanted hot water with the auxiliary heater on the outside when the temperature in the upper part of the storage tank did not reach at 60 ℃.

As shown in Fig. 2, the weather data of Jinju issued from Korea Meteorological Administration in 2005[(2)] was used as input data for the solar collector. The stratified tank was used for the storage tank, and the number of node was set as three.[(3)] In order to maintain the stratification phenomenon, small amount of water was flowed in by setting the flow rate as 72 kg/m^2 · hr. The temperature of supplementary water is constant as 10 ℃.

The exact prediction on the load for hot water is required in order to appropriately decide the size of solar system, However, as the related data was insufficient, the concentrated load pattern was used as shown in Fig. 3 in this load pattern, the main load distributions were shown in the morning (05~09 o'clock), lunch (11~15 o'clock), and evening (15~21 o'clock). The daily hot water load capacity was set as 280 liters/day which was 70% of the storage tank capacity.

The solar fraction used in the study can be expressed by the following formula.

Table 1 System design parameters

Parameter		Specifications
Collector	Area	4 ㎡
	$F_R(\tau\alpha)$	0.7
	$F_R U_L$	3, 13, 23 kJ/hr · m^2 · K
	Slope	35°
Storage Tank	Type	Vertical cylinder
	Volume	400 ℓ
	Height	1 m
Controller	Type	Digital difference temperature control
	$\Delta T_{on}/\Delta T_{off}$	10/5 ℃
Auxiliary Heater	Set Tem.	60 ℃
	Capacity	10 kW
Pump	Capacity	72 kg/hr

$$f = \frac{Q_{load} - Q_{aux}}{Q_{load}} = \frac{Q_{solar}}{Q_{load}} \tag{1}$$

3. Results and analysis

3.1 Effect of load patterns

For the exact prediction on the system performance, modeling of load patterns becomes

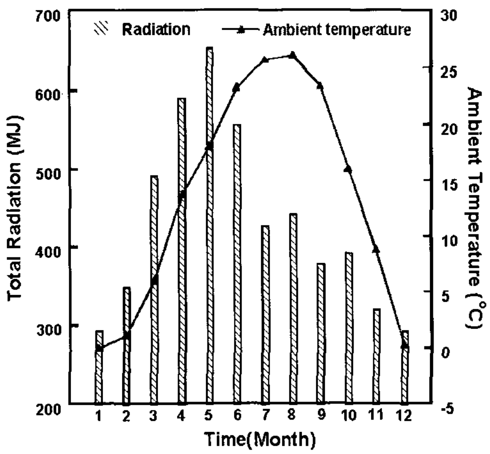

Fig. 2 Monthly weather data of Jinju in 2005.

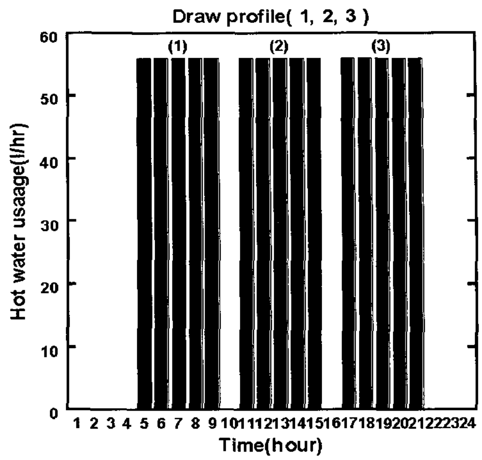

Fig. 3 Hot water consumption profile.

the very important factor. In the study, the annual solar faction corresponding to each load pattern was examined while dividing the concentrated load patterns into three times of morning, lunch, and evening. The daily hot water load was regularly used in 280 liters/day for one year, but the simulation in the study was performed while load for each season was not taken into account.

Fig. 4 indicates the solar fraction according to the load pattern as the term of acquired solar energy was $F_R(\tau\alpha)=0.7$, with the term of heat loss as $F_R U_L = 3$ kJ/hr · m^2 · K. In summer time, the solar fraction was indicated as high as almost 80%, and it was over 70% in winter as well. As the appropriate solar fraction is 60 ~80% in case of hot water based on the standard of ASHRAE, the result is remarkably of satisfaction.

For each pattern, the concentrated load pattern in morning indicated the lowest solar fraction compared to other ones in lunch and evening. Fig. 5, Fig. 6, and Fig. 7 indicate the solar energy allocated to hot water load, the total solar energy used as hot water load and auxiliary energy source through the solar fraction. Although similarly indicated in case of the concentrated load pattern in lunch and evening, the allocated solar energy was indicated as low,

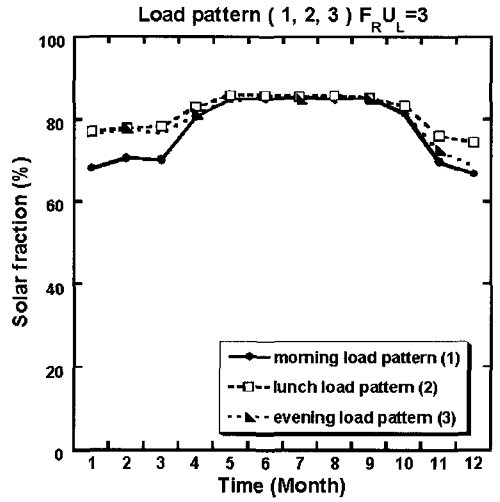

Fig. 4 Annual solar fraction for load patterns (1, 2, 3).

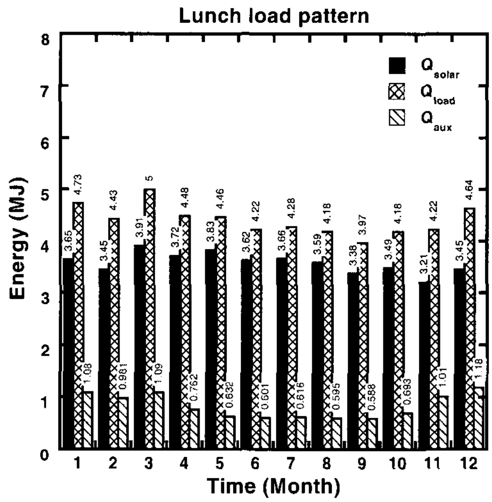

Fig. 6 Effect of load patterns(2) on acquired solar energy, load energy and auxiliary energy.

and the auxiliary energy was indicated as high in case of the concentrated load pattern in morning. As particularly in winter, the load was concentrated in morning time when the solar radiation was a little, and the solar collector did not set to operate normally yet, more auxiliary energy was used.

3.2 Effect of performance coefficient of solar collector

In order to figure out how the values of $F_R(\tau\alpha)$ and F_RU_L effected on thermal performance of system, it was conducted to ex-

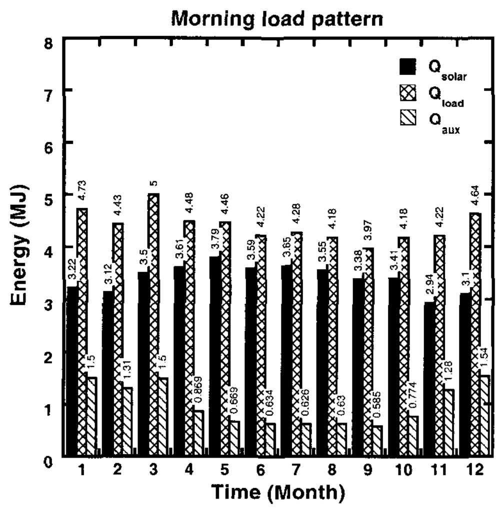

Fig. 5 Effect of load patterns(1) on acquired solar energy, load energy and auxiliary energy.

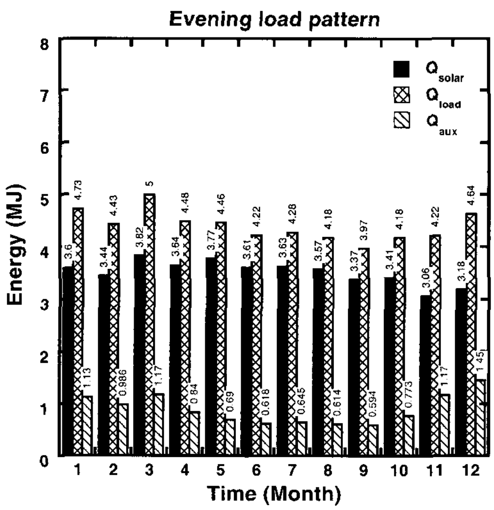

Fig. 7 Effect of load patterns(3) on acquired solar energy, load energy and auxiliary energy.

amine how the solar fraction changed while applying the different values of $F_R U_L$ by alternating 3, 13, 23 kJ/hr · m^2 · K. Especially, the simulation is performed 3 kJ/hr · m^2 · K for vacuum tube collector and 13, 23 kJ/hr · m^2 · K for plate collector, respectively.

Fig. 8 shows the graph indicating the solar fraction according to the value of $F_R U_L$, the term of heat loss as the concentrated load pattern appeared in morning(AM 5~9 o'clock). There was a tendency that as the value of heat loss term became larger, the solar fraction decreased relatively.

In case of the concentrated load pattern in morning, as the value of heat loss term became larger as in $F_R U_L$ = 3, 13, 23 kJ/hr · m^2 · K, the average of solar fraction was indicated as 77, 74, 68% respectively. Especially, the solar fraction was at the range of 58% and 52% respectively as the value of $F_R U_L$ was 13 kJ/hr · m^2 · K and 23 kJ/hr · m^2 · K in winter time from December to February.

Unlike this result, in case of the concentrated load patterns in lunch and evening as shown in Fig. 9, Fig. 10, there was a tendency that as the value of heat loss term became larger,

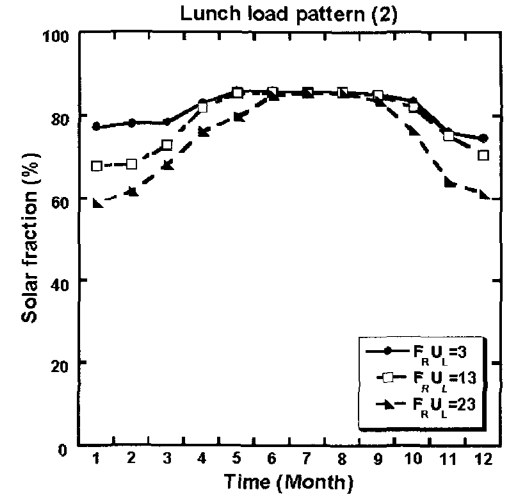

Fig. 9 Effect of $F_R U_L$ on solar fraction in morning load pattern(2).

the average of solar fraction was indicated at almost similar level of 79, 78, 73% respectively. The difference was 1-3% only.

In case of the concentrated pattern in morning during winter time from December to February, all the average of solar fraction was indicated as more than 60% even when the value of heat loss term was the largest as $F_R U_L$ = 23 kJ/hr · m^2 · K.

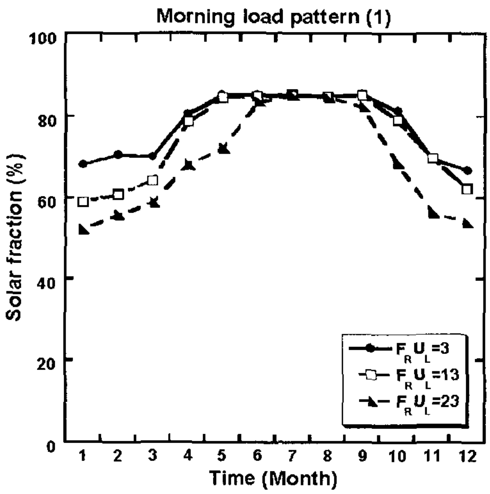

Fig. 8 Effect of $F_R U_L$ on solar fraction in morning load pattern(1).

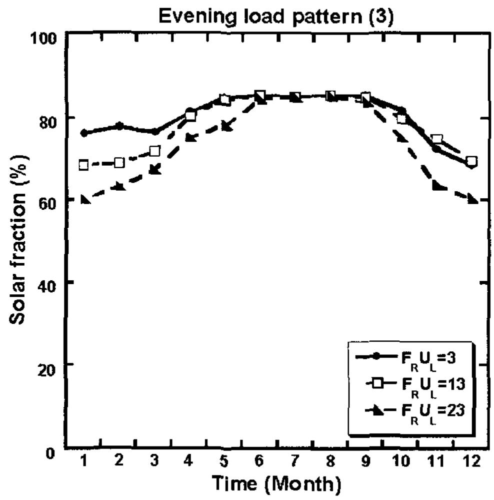

Fig. 10 Effect of $F_R U_L$ on solar fraction in morning load pattern(3).

This is because much of solar energy can be allocated as the load is to be concentrated in lunch and evening when the temperature of storage tank has been raisen enough.

4. Conclusions

In the study, the simulation was performed in order to figure out how the solar fraction changed according to the different load patterns and thermal performance coefficients of solar collector among various factors which can influence on thermal performance of the solar water heating system.

(1) Through the simulation, it was figured out that the thermal performance, namely, solar fraction of the vacuum tubular solar collector was effected by the concentrated load distributions(morning, lunch, evening), and performance coefficients.

(2) It was confirmed that the load distribution had much effects on thermal performance of the solar water heating system, and the solar fraction was indicated as relatively high as the concentrated load pattern in the storage tank of same capacity appeared in lunch time.

(3) In case of the concentrated load pattern in morning, it was impossible to enough utilize the temperature of storage tank, which caused much of auxiliary energy to be used, and the efficiency of system to be declined.

(4) As for the change of performance coefficients in the solar collector, the annual solar fraction reduced as the value of heat loss term became larger.

Acknowledgement

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