# A Research on the Thermal Daily Performance of Hybrid Solar Collector with Fin-and-Tube Heat Exchanger in Winter

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**Abstract.** A hybrid solar collector, in this study, means the flat plate solar collector that has fin-and-tube heat exchanger beneath absorbing plate. It was focused on the combination with heat pump system. Solar thermal energy obtained from the collector can be used as a heat source of evaporator of heat pump, and the C.O.P. (coefficient of performance) of heat pump can be increased because of the increment of evaporating temperature. In case of this hybrid solar collector, different with traditional collector, it can get a thermal energy from ambient air for heating circulated water when the solar radiation is not enough. Hence, the collector can supply thermal energy to evaporator of heat pump using heated water by ambient air or solar energy selectively depending on the weather. So, in this study, thermal performance of this collector on daily operation was investigated with various flow rate of water experimentally for confirming how much solar energy can be obtained by this collector in winter. As a result, maximum thermal efficiency was shown from 55% to 62% enough to make hot water according to mass flow rate even the fin-and-tube heat exchanger was installed beneath absorbing plate instead of insulator of traditional flat plate solar collector and it was increased with increment of flow rate. But the overall heat loss coefficient also increased similar with thermal efficiency and from those efficiency curves, it was confirmed that the optimal operating condition need to be investigated in the further study before applying to heat pump system.

**Keywords:** Solar thermal energy · Solar assisted heat pump · Heat pump · Flat plate solar collector · Fin-and-tube heat exchanger

**Nomenclature**

$\dot{Q}$ Useful heat gain [W]
$\dot{m}$ Mass flow rate [kg/s]
T Temperature [$^{o}$C]
$C_p$ Specific heat of heating medium [kJ/kgK]


V.H. Duy et al. (eds.), *AETA 2017 - Recent Advances in Electrical Engineering and Related Sciences: Theory and Application*, Lecture Notes in Electrical Engineering 465,
https://doi.org/10.1007/978-3-319-69814-4_92

G Intensity of solar radiation [$W/m^2$]
$A_c$ Absorbing area of collector [$m^2$]
$F_R$ Heat removal factor [-]
$F_R$ Overall heat loss coefficient [$W/m^2K$]

**Greek Symbols**

$\eta$ Thermal efficiency of solar collector [-]
$\tau$ Transmission coefficient of glazing [-]
$\alpha$ Absorption coefficient of plate [-]

**Subscripts**

*w* Water
O Outlet
*I* Inlet
*amb* Ambient air

## 1 Introduction

Many researches about solar assisted heat pump using solar collector have been conducted as a part of the effort to increase use of solar thermal energy [1–3]. In the solar assisted heat pump system, solar thermal energy can be used as a heat source of evaporator of heat pump. Thus the C.O.P. (coefficient of performance) of heat pump can be increased with increment of evaporating temperature. In addition, thermal efficiency of collector also can be increased because of the lower operating temperature than traditional collecting system. But these systems are hard to work when the solar radiation is not enough such as cloudy, rainy day and at night.

Thus, the hybrid solar collector that can heat circulated water of the collector using not only solar energy but also ambient air has been developed [4–6]. This collector is flat plate solar collector that has fin-and-tube heat exchanger beneath absorbing plate, and consequently it can get a thermal energy from ambient air for heating circulated water like outdoor unit of heat pump system. So, the heated water by ambient air can be used as a heat source of evaporator of heat pump even the solar radiation is not enough. However, the lower thermal efficiency than traditional flat plate solar collector can be predicted since the hybrid solar collector has fin-and-tube exchanger under absorbing plate instead of insulator different with traditional collector.

Thus, the thermal efficiency of hybrid solar collector is need to be known for designing solar assisted heat pump system integrated with this collector and because of this, in this study, thermal efficiency of the collector was investigated experimentally on daily operation with various flow rate of water in winter. And also this study aims to establish base data of the collector before combing with heat pump system.

# 2 Experimental Apparatus and Method

## 2.1 Experimental Apparatus

Figure 1 shows the exploded view of hybrid solar collector for experiment. This collector is composed of glass cover, absorbing plate, fin-tube heat exchanger, case and two air channel for inlet and outlet air. Fin-and-tube heat exchanger is installed under absorbing plate. Thus the thermal energy can be obtained from incident solar radiation or ambient air depend on the weather for heating circulated water in collector.

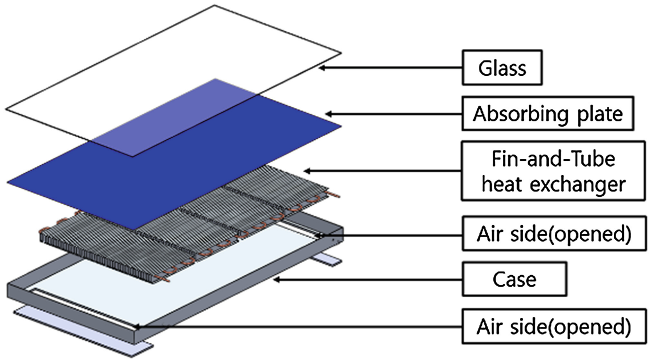


**Fig. 1.** Exploded view of hybrid solar collector

Actual view of experimental apparatus is shown in Fig. 2. Components of solar collecting system for experiment are hybrid solar collector, thermal storage tank, pyranometer and water pump. Hybrid solar collector has a 1.65 $m^2$ absorbing area and it was installed with 30° of horizontal angle with azimuth 171° at the Campus of University of Pukyong National University in Busan(at 36°6.98′N and 129°5.39′E). The pyranometer(model MS-410) was used to monitor the incident solar radiation on collector surface and the capacity of thermal storage tank was 80 L.

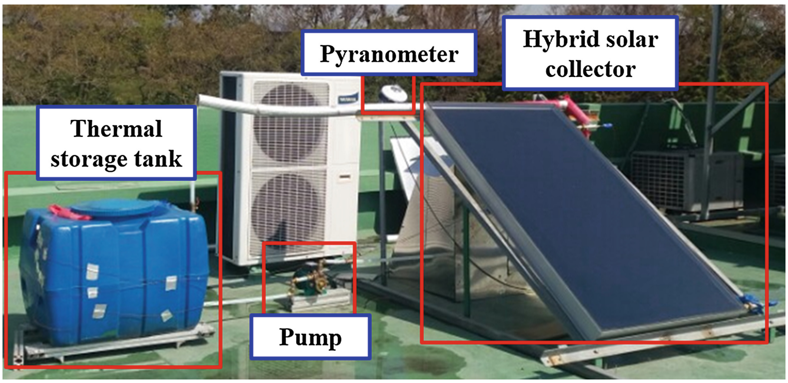


**Fig. 2.** Actual view of experimental apparatus

## 2.2 Experimental Method

Experiment for confirming thermal efficiency of the collector was carried out from 10:30 to 17:00 with constant flow rate of water at clear day in winter. Flow rate of water was 4, 6 and 8 L/min respectively for each day. Solar radiation was acquired by pyranometer and ambient air temperature, water temperature in thermal storage tank, inlet and outlet water temperature were measured by T-typ thermocouple. All of data were recorded by a data acquisition at an interval of 60 s and more detail experimental conditions are given in Table 1.

**Table 1.** Experimental conditions

| Parameter | | Value |
|---|---|---|
| Location | | Campus of University of Pukyong National University 36°6.98′N and 129°5.39′E |
| Install direction | | Installation angle 30°, Azimuth angle 171° |
| Time (hh:mm) | | 10:30–17:30 |
| Collector size | Length (mm) | 1800 |
| | Width (mm) | 980 |
| | Height (mm) | 110 |
| Absorbing area ($m^2$) | | 1.65 |
| Flow rate of water (L/min) | | 4, 6, 8 |
| Capacity of thermal storage tank (L) | | 80 |

Heat gain of water was obtained by Eq. (1) with experimentally acquired data:

$$\dot{Q}_w = \dot{m}_w C_{p,w} \left( T_{w,o} - T_{w,i} \right) \tag{1}$$

Thermal efficiency of a collector is defined as ratio of the useful thermal energy to the total incident solar radiation and it can be expressed as Eq. (2):

$$\eta = \frac{\dot{Q}_w}{GA_c} = \frac{\dot{m}_w C_{p,w} \left( T_{w,o} - T_{w,i} \right)}{GA_c} \tag{2}$$

At this time, thermal efficiency can be expressed in a different form by Hottel-Whillier-Bliss equation as shown in Eq. (3):

$$\eta = \frac{\dot{Q}_w}{GA_c} = F_R \tau \alpha - F_R U_L \frac{\left( T_{w,\mathrm{i}} - T_{amb} \right)}{G} \tag{3}$$

In this study, heat gain of water and thermal efficiency were calculated by Eqs. (1) and (2) and maximum thermal efficiency and overall heat loss coefficient were confirmed by Eq. (3) using experimentally acquired data and obtained thermal efficiency.

## 3 Results and Discussion

Figure 3 shows change of temperature on daily operation of hybrid solar collector when the flow rate of water was 4 L/min. Water temperature was increased with incident of solar radiation and it was heated until 31 °C enough to use as a heat source of heat pump system. Temperature difference between inlet and outlet water was shown 2.9 °C when the water began to heated and it was decreased continuously with the increment of inlet temperature of water.

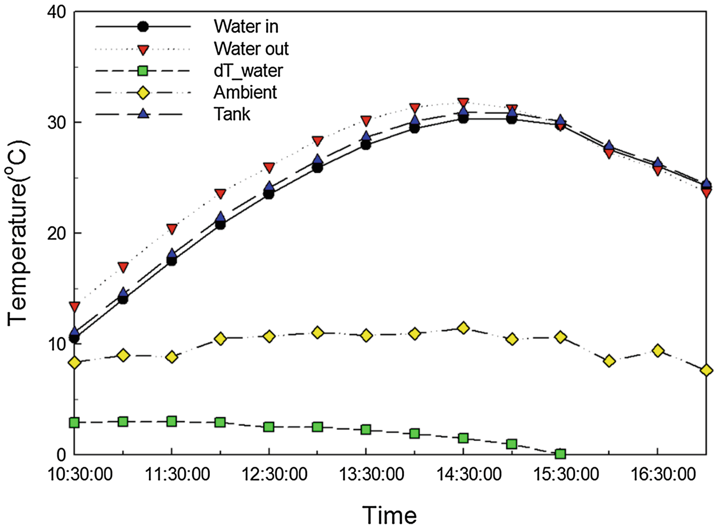


**Fig. 3.** Temperature change of each measured point on daily operation ($\dot{m}_w = 4\,\mathrm{L/min}$)

Figure 4 shows temperature change of each measured point when the flow rate of water was 6 L/min. Water temperature was increased until 33 °C from 11 °C and the temperature difference between inlet and outlet water was shown maximum 1.9 °C when the water started to heated lower than the temperature difference on 4 L/min because of high velocity of water in liquid tube and circulated water was not heated more after 16:00 due to the high inlet water temperature and low solar intensity.

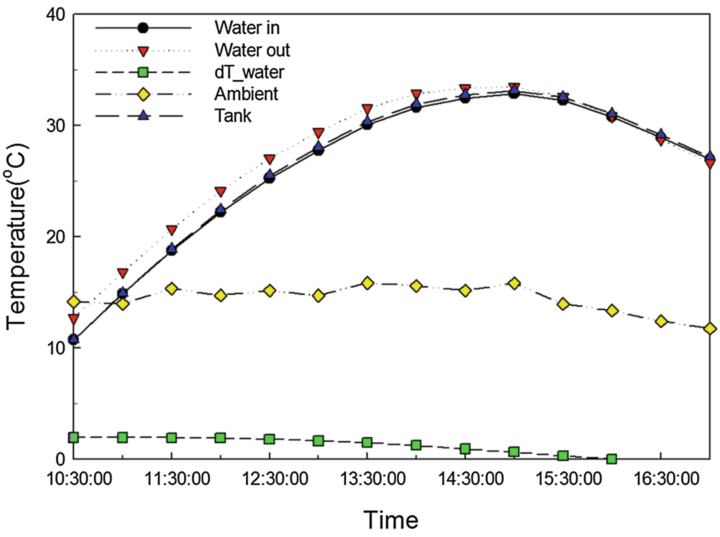


**Fig. 4.** Temperature change of each measured point on daily operation ($\dot{m}_w = 6\,\mathrm{L/min}$)

Temperature change of each measured point on the flow rate of water of 8 L/min was shown in Fig. 5. Water temperature was reached to 29 °C from 5 °C and temperature difference between inlet and outlet water was shown maximum 1.7 °C lower than that of 4 L/min and 6 L/min because of higher velocity of water in the liquid tube. Circulating water was not heated after 16:00 p.m. similar with other cases because of the high inlet water temperature and low solar intensity. It means that incident solar radiation on the surface of the collector after 16:00 was not changed to useful energy.

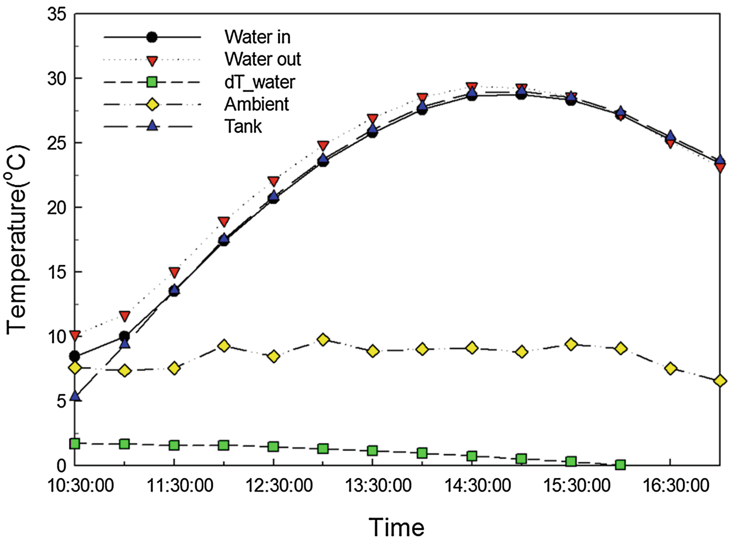


**Fig. 5.** Temperature change of each measured point on daily operation ($\dot{m}_w = 8\,\mathrm{L/min}$)

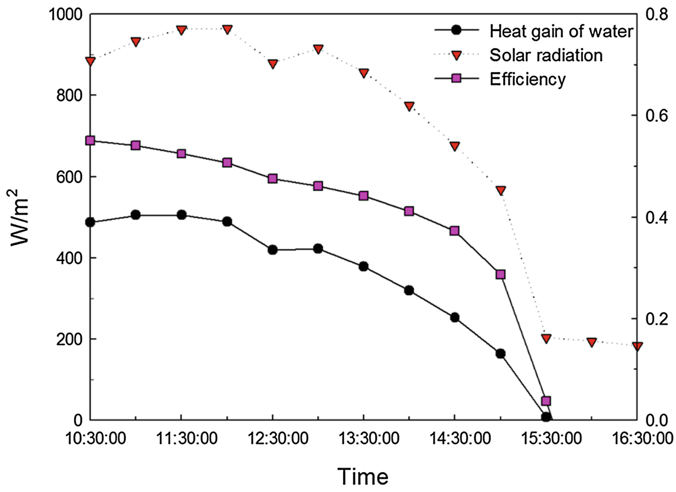


**Fig. 6.** Heat gain of water and thermal efficiency of the collector on daily operation ($\dot{m}_w = 4\,\text{L/min}$)

Figure 6 shows heat gain of water and thermal efficiency of the collector on daily operation when the flow rate of water was 4 L/min. Heat gain and thermal efficiency was shown maximum values of 505 W/m$^2$ and 55% when the water began to heated. Because of the installation of fin-and-tube heat exchanger under absorbing plate, lower values than traditional flat plate solar collector were confirmed but enough to use for heat pump system. And these values were decreased with increment of inlet water temperature and decrement of solar intensity.

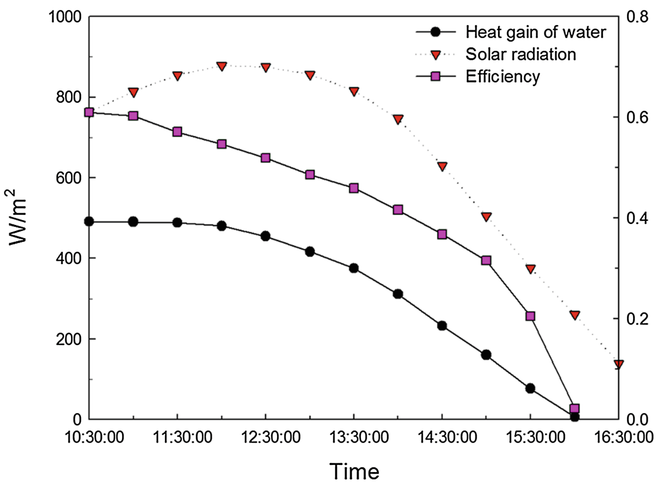


**Fig. 7.** Heat gain of water and thermal efficiency of the collector on daily operation ($\dot{m}_w = 6\,\text{L/min}$)

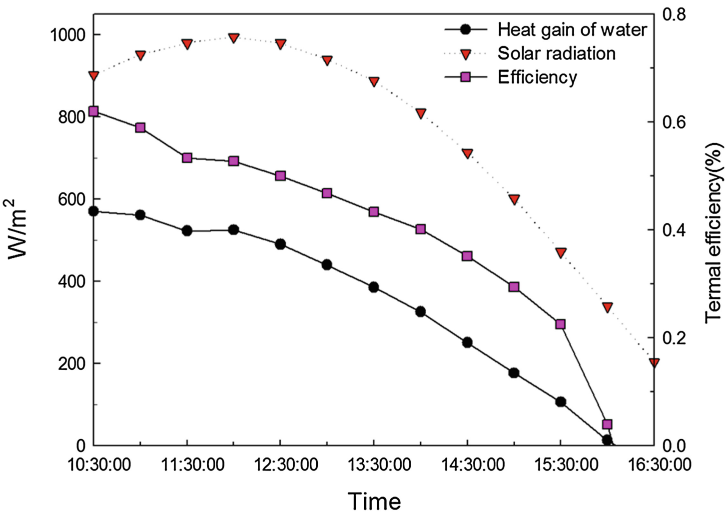


**Fig. 8.** Heat gain of water and thermal efficiency of the collector on daily operation ($\dot{m}_w = 8\,\text{L/min}$)

Heat gain of water and thermal efficiency were shown in Figs. 7 and 8 when the flow rate of water was 6 L/min and 8 L/min respectively. Heat gain and thermal efficiency were shown maximum values of 491 W/m$^2$ with 61% and 570 W/m$^2$ with 62% on the 6 L/min and 8 L/min. Increase of thermal efficiency was confirmed because heat transfer coefficient in inner tube increased when the velocity of water increase. These values were also decreased with increment of inlet water temperature and decrement of solar intensity similar with 4 L/min.

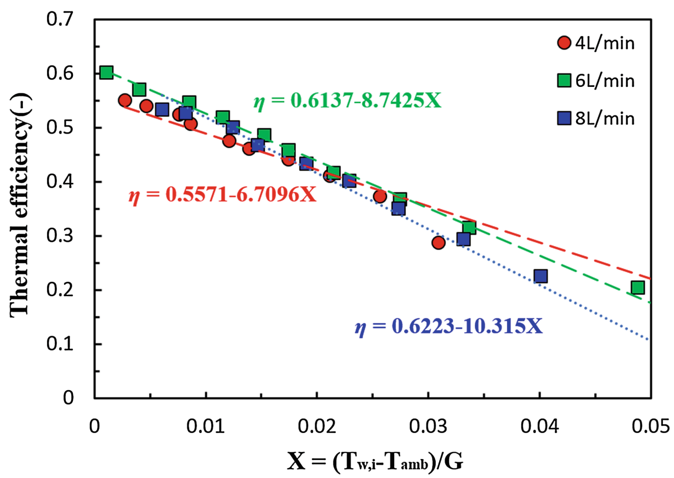


**Fig. 9.** Thermal efficiency of hybrid solar collector with respect to flow rate of water

Figure 9 shows the thermal efficiency curve of hybrid solar collector with respect to flow rate of water based on inlet water temperature, ambient air temperature and solar radiation. Maximum thermal efficiency was shown 55%, 61% and 62% water on the 4 L/min, 6 L/min and 8 L/min respectively enough to make hot. In addition, maximum thermal efficiency was increased with increment of flow rate of water because the higher maximum thermal efficiency can be resulted from higher heat transfer coefficient in tube caused by higher velocity of water. From these results, it was confirmed that thermal efficiency of hybrid solar collect is enough to make a hot water by self and it was not so much lower than traditional flat plate solar collector considering installation of fin-and-tube heat exchanger instead of insulator of traditional collector. And also, it was expected that the hybrid solar collector can supply more thermal energy to heat pump system than traditional collector because it also can get a thermal energy from ambient air as well as solar radiation.

But the overall heat loss coefficient was increased with increment of flow rate of water because heat transfer from water in tube to ambient air is increased with increment of heat transfer coefficient in tube when the water temperature is higher than the air. It means that maximum thermal efficiency of collector on the specific operation conditions such as inlet water temperature, ambient air temperature and solar radiation is changed. Thus the optimal operation conditions need to be confirmed as a further study for combining with heat pump.

## 4 Conclusion

In this study, thermal performance of hybrid solar collector that has fin-and-tube heat exchanger was investigated on daily operation with various flow rate of water in winter condition. As a result, water temperature in thermal storage tank with the capacity of 80 L was increased about 20 °C than initial temperature and maximum thermal efficiency was shown from 55% to 62% according to flow rate of water.

These temperature and efficiency are enough to supply thermal energy to heat pump system and it was not so much lower than traditional flat plate solar collector considering installation of fin-and-tube heat exchanger in hybrid solar collector instead of insulator of ordinary flat plate solar collector. Also energy utilization of the hybrid solar collector is expected to higher than traditional collector for supply thermal energy to evaporator of heat pump system because it can take a thermal energy from ambient air as well as solar radiation.

But different efficiency and overall heat loss coefficient were confirmed according to the flow rate of water and maximum efficiency on the specific operation conditions such as inlet water temperature, ambient air temperature and solar intensity were changed by flow rate of water. Thus, the optimal operating conditions need to be confirmed as a further study for maintaining maximum thermal efficiency when the collector combine with heat pump system.

**Acknowledgments.** This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20153030081190).

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