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Research Article

ENERGY CONSERVATION OF SMALL WATER TO WATER HEAT PUMP ASSISTED BY SOLAR COLLECTOR FOR RESIDENTIAL APPLICATION

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ABSTRACT:
Increase of heat pump utilization affected to higher energy consumption for all sections. In order to reduce energy consumption for heat pump, solar collector was selected to assist heating of water temperature due to solar radiation. This study focused on coefficient of performance (COP_t) and energy consumption of small water to water heat pump operated with solar collector for residential application. Firstly, solar collector was tested and followed by ASHRAE 93-77 then 70.5 % of efficiency was obtained. Secondary, small heat pump operated by R410a as refrigerant was experimented with 300 liters of water and followed by EN255-3 then 1.53 of COP_t and 7.02 kWh/D of average energy consumption were resulted. When small heat pump operated with solar collector to reach 50℃ of hot water, 1.77 kWh/D or 25.2% of average energy consumption was lower compared to operation only small heat pump. This study was concluded that small heat pump assisted by solar collector was applicable for energy conservation in residential application.

Keywords: *Heat pump, Solar collector, ASHRAE 93-77, EN255-3, COP*

1. INTRODUCTION

Nowadays, heat pump was applied widely in many sectors such as residential and industrial part. It was because of higher efficiency compared to hot water heated from fossil fuel. Heat pump has mainly potential in hospital and industries because 60% of factories use hot water in manufacturing process [1]. Heat pump was started to develop in 2002 following subsidy program from Ministry of Energy in Thailand due to high efficiency, low emission and energy conservation [2]. Load variations with seasonal conditions affected to COP_t of air to water heat pump was investigated by EN255-3 [3]. However, heat pump was high efficiency, increase of heat pump brought about high energy consumption. In order to reduce energy cost in heating system, hot water was applied in conventional air conditioner as an air-water heat pump and variation room temperature and hot water were investigated [4]. Recently, drain water heat recovery was analyzed and utilized to enhance the heat pump performance up to 400% [5]. Moreover, heat pipe technique was studied to apply with air-source heat pump which heating performance was varied under air temperature and outdoor air temperature to develop heat pump room heating system [6]. Multi-function solar heat pump system was also designed with maximum possible energy conservation for residential buildings [7]. Reduction of energy cost and higher *COP* of using R1233zd (E) was studied to assist heat pump with flexible solar collector [8]. Following many studies were used solar energy to enhance heat pump performance and reduce energy cost. Solar energy was studied and 18.2 MJ/m^2 per day of average solar irradiation was found in

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Thailand. This research reflected to class 11 of 14 regarding solar potential [9, 10]. As the above researches, solar energy has possible to operate with heat pump for energy conservation. Therefore, small heat pump applied with solar collector was selected to study energy conservation for residential application.

2. EXPERIMENTAL SETUP

A schematic diagram of solar collector efficiency setup is presented in Fig. 1. As the schematic diagram, solar collector in No.1 was inclined about 35 degree with plane to receive solar radiation (I). To find solar collector efficiency, 400 liters of water was fed in to system, temperature ambient air temperature (T_a) in No.2), input water temperature (T_i) in No.3, output water temperature (T_o) in No.4, tank water temperature (T_t) in No.5 and water flow rate ($\dot{m}$) in No.6 were measured. Then copper pipe length (L) and diameter (D) as the heat exchanger in small heat pump, was designed to obtain supplied water temperature, T_s=50 ºC. The designed small heat pump was experimented followed by EN255-3 to obtain COP_t and energy consumption. Figure 2 shows experimental apparatus for energy consumption and COP of small heat pump. 150 liters of input water at T_i=25 ºC was fed in to water tank, the small heat pump was cut off at T_t=50 ºC. This process was repeated to measure energy consumption (W_{et}). Moreover, hot water was tapped to supply until T_t<48 ºC, tapping water energy (Q_t) was analyzed. In order to apply heat pump with solar collector, 300 liters of water was fed in the tank with operation both small heat pump and solar collector (8 am - 4 pm) at T_t<48 ºC as shown in Fig. 3.

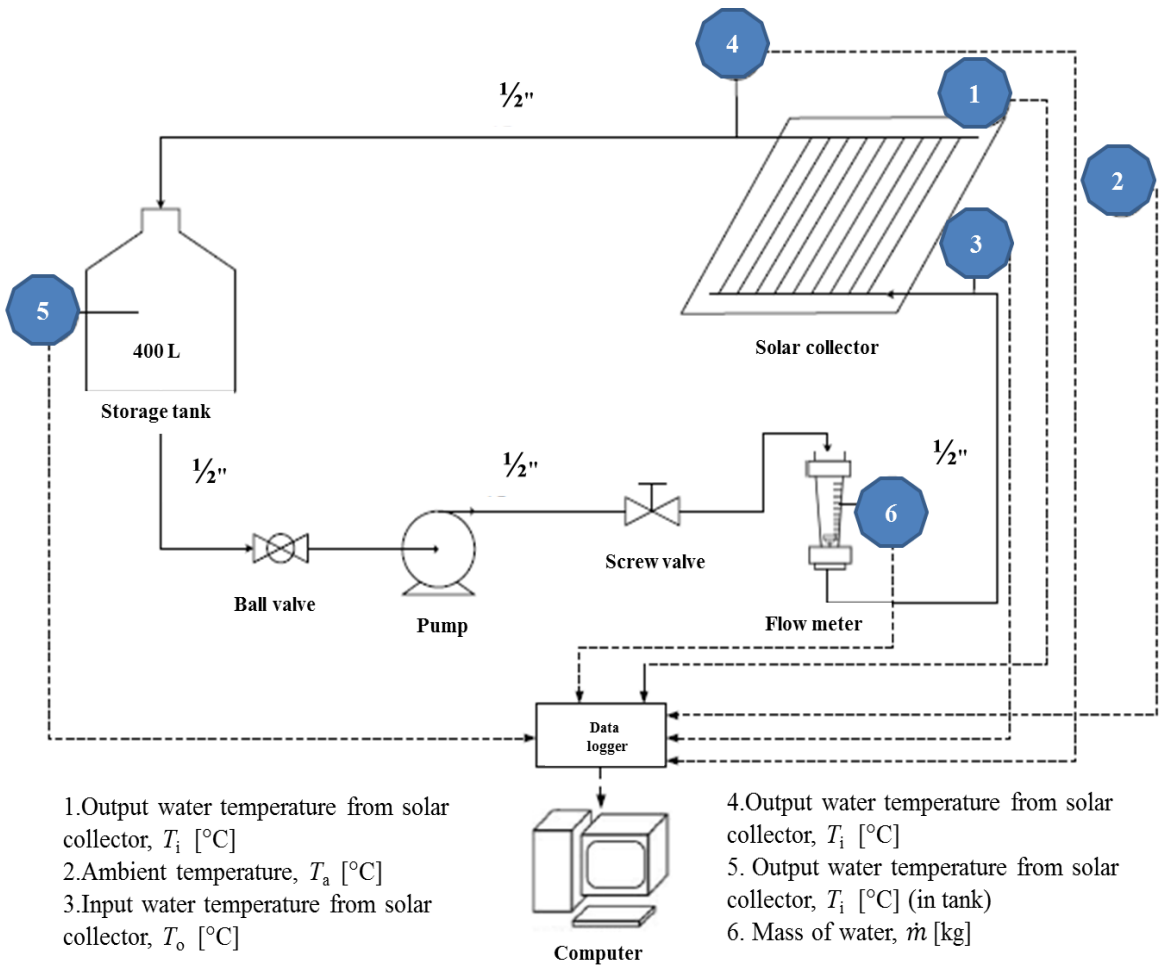

Fig. 1. Schematic diagram of solar collector efficiency setup.

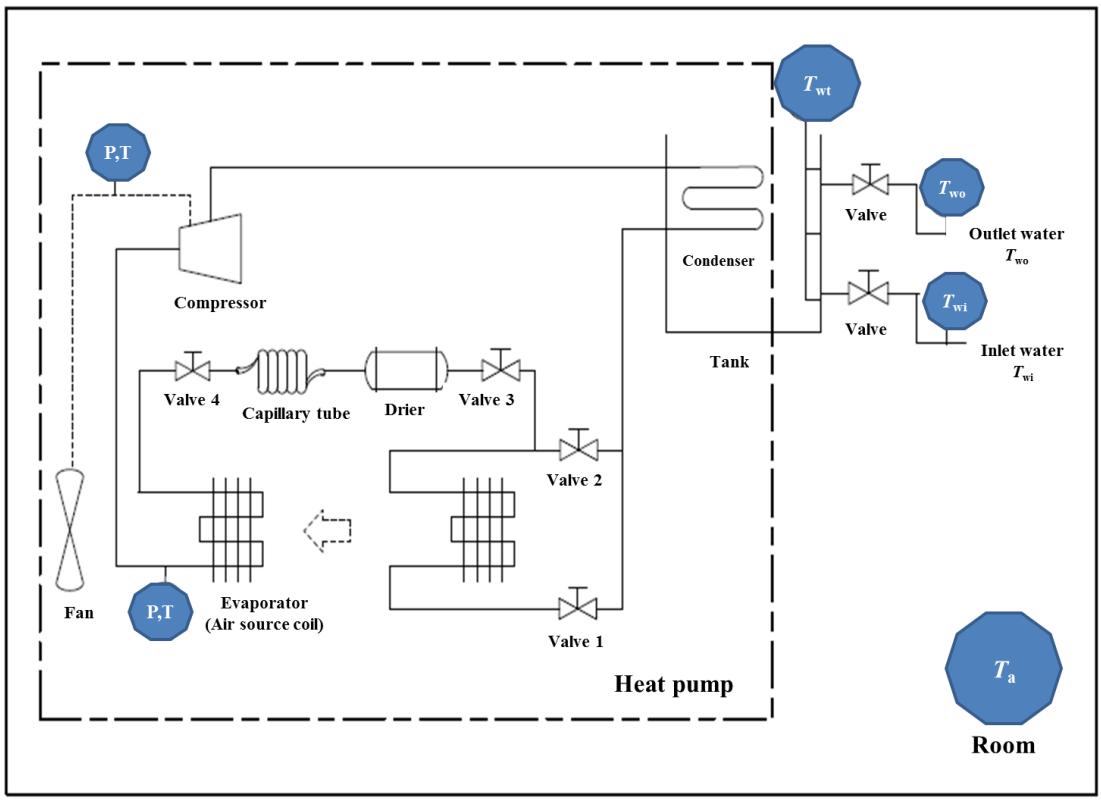

Fig. 2. Experimental apparatus for energy consumption and COP_t of small heat pump.

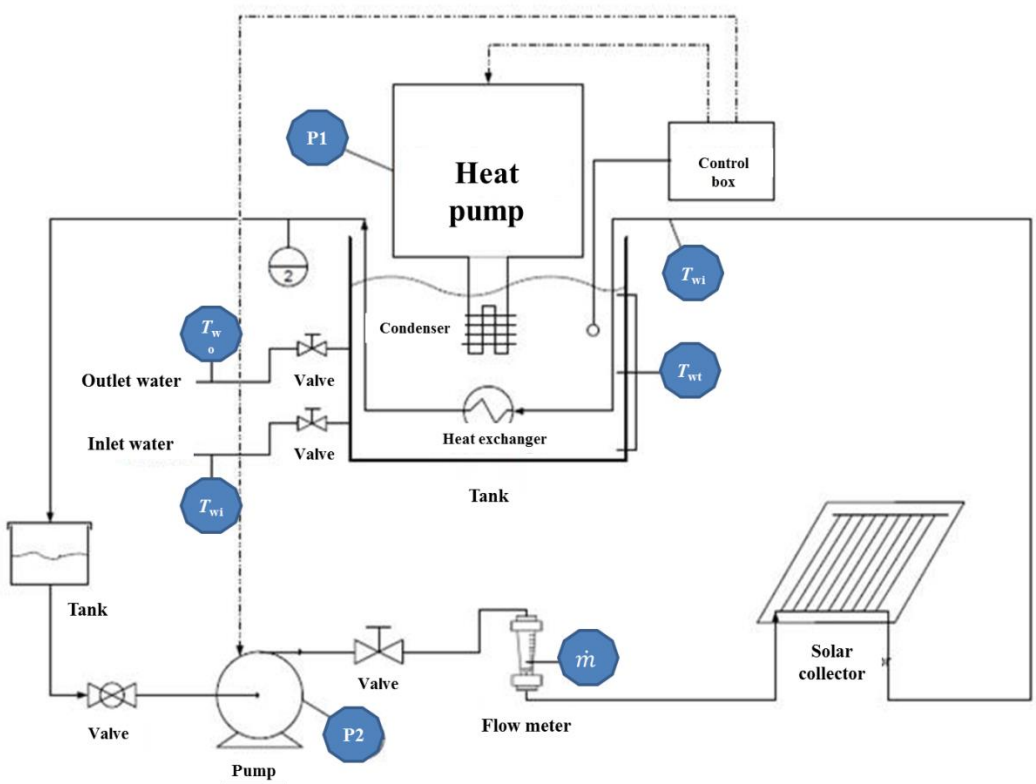

Fig. 3. Experimental apparatus for small heat pump operated with solar collector.

3. METHODOLOGY

The processes of this study consist of experiment and analysis for solar collector efficiency, *COP* and energy consumption of heat pump operated with and without solar collector. Firstly, solar collector was tested following by ASHRAE 93-77 thus mass of water, water output and input temperature recorded from solar collector, solar plate area, solar radiation and time were analyzed for solar collector efficiency according to Eq.(1). Regarding 18.2 MJ/m^2 per day of average solar radiation is referred in Thailand [8]-[9], thus solar radiation evaluated in this study during 10 hours per day is analyzed. When solar collector efficiency was known, small heat pump (1.1 kW) was designed to heat water as same as solar collector followed by Eq.(2).

$$\eta_c = \frac{m \cdot C_p \cdot (T_o - T_i)}{AI \cdot t} \times 100\% \tag{1}$$

$$Q = IA\eta_c \tag{2}$$

$$COP_t = \frac{Q_t}{W_{et} - P_{es} . t_t} \tag{3}$$

$$Q_t = \int_0^{t_t} \rho_{wo} \cdot Cp_w \cdot q_{wo} \cdot (T_{wo} - T_{wi}) dt \tag{4}$$

$$P_{es} = \frac{W_{es}}{t_s} \tag{5}$$

Moreover, *COP* of heat pump experiment was corresponding to European standard EN255-3 to obtain *COP* for tapping sanitary hot water (COP_t). Following European standard EN255-3shown in Fig. 4, there are five stages for standard experiment. Firstly, heating-up period is started from turned on heat pump until turned on thermostat (50ºC). Secondly, hot water is tapped equivalent to half of hot water storage tank, and reheated until the water temperature reach the setting point as the COP for tapping process COP_t. Thirdly, hot water is tapped until the hot water temperature below 40ºC which is called a determination of referenced hot water temperature. Fourthly, Outlet water temperature in storage tank is dropped to 5°C, heat pump is turned on to setting point and it is called 1 cycle which is determination of standby power input during standby period. Final stage is a determination of the maximum quantity of usable hot water in single tapping which hot water is tapped until the outlet water temperature below 40ºC after standby period. Corresponding to European standard EN255-3 [2], the determination of COP_t is calculated from measured of outlet water energy (Q_t), electrical energy input for tapping process (W_{et}), standby power input (P_{es}) and tapping time (t_t) following Eq.(3)-(5).

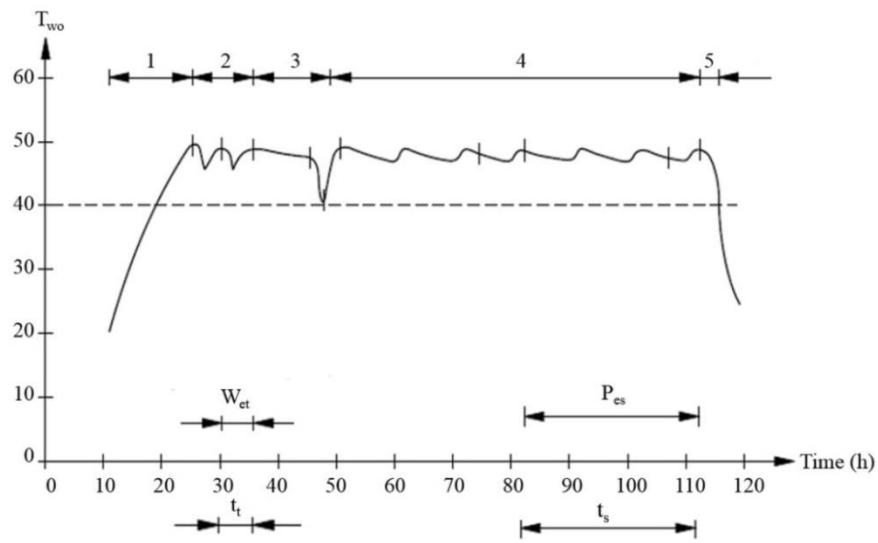

Fig.4. Operating cycle of heat pump based on European standard (EN255-3)[3].

4. RESULTS AND DISCUSSION

4.1 Solar collector efficiency

In order to apply solar collector with heat pump to assist for heating system, solar collector was experimented to obtain solar collector efficiency. Figure 1 shows solar collector efficiency setup followed by ASHRAE 97-33. The experiment was started from 2 liters of water flow on solar collector plate then solar radiation was recorded and analyzed to obtained solar efficiency accorded to Eq.(1). The recorded data shows relation between solar radiation and solar collector efficiency as illustrated in Fig. 5. When the obtained solar radiation increased, solar collector efficiency was higher. According to average solar radiation in Thailand, 505.6 W/m^2 of the average solar radiation was obtained and 70.5% of average of solar collector efficiency could be analyzed from Fig. 5. In addition, the obtained average solar collector efficiency could be calculated for received energy on solar collector plate by Eq.(2). Moreover, Fig. 6 shows that increase of ratio between temperature difference (T_i-T_a) and solar radiation affected to lower solar collector efficiency.

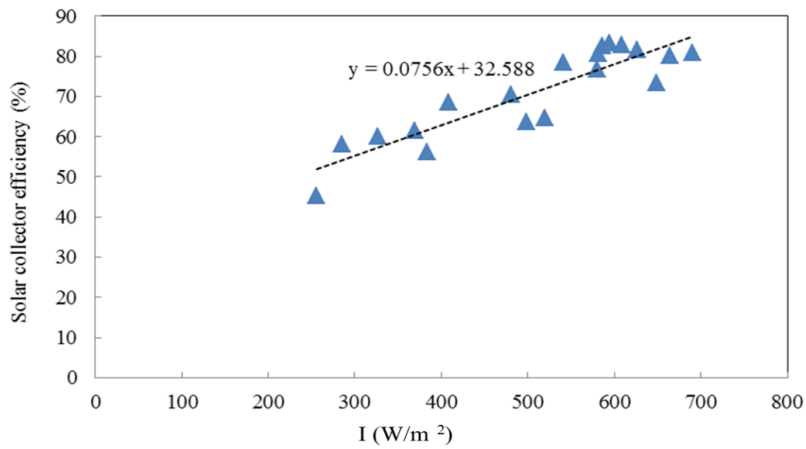

Fig. 5. Relation between solar radiation and solar collector efficiency.

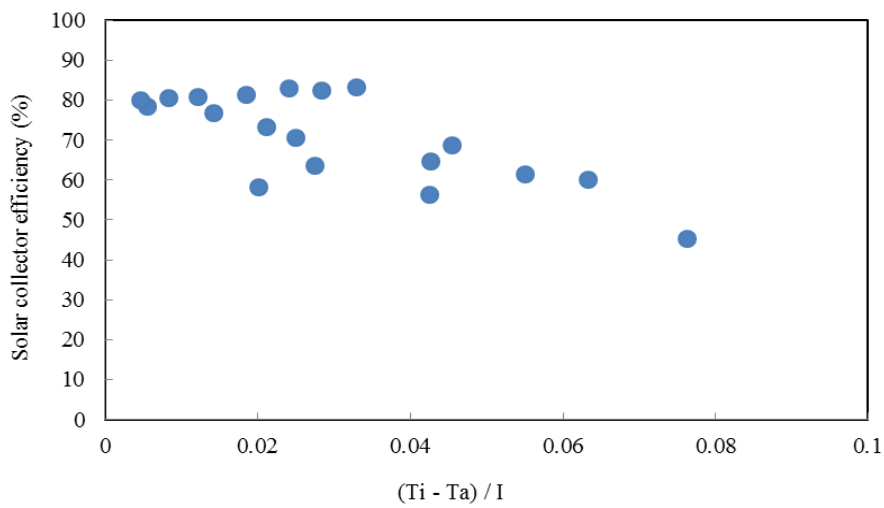

Fig. 6. Variation of (T_i-T_a) with solar radiation affected to solar collector efficiency.

4.2 COP_t of small heat pump

As the application of heat pump, COP_t of small heat pump was resulted corresponding to European standard EN255-3. Figure 7 illustrates operating cycle of small heat pump based on European standard (EN255-3). Following five stages of standard in Fig. 7, 1.53 of COP_t of small designed heat pump was resulted. Moreover, energy consumption of small heat pump was analyzed continuously for four days and 7.02 kWh of average energy consumption was obtained.

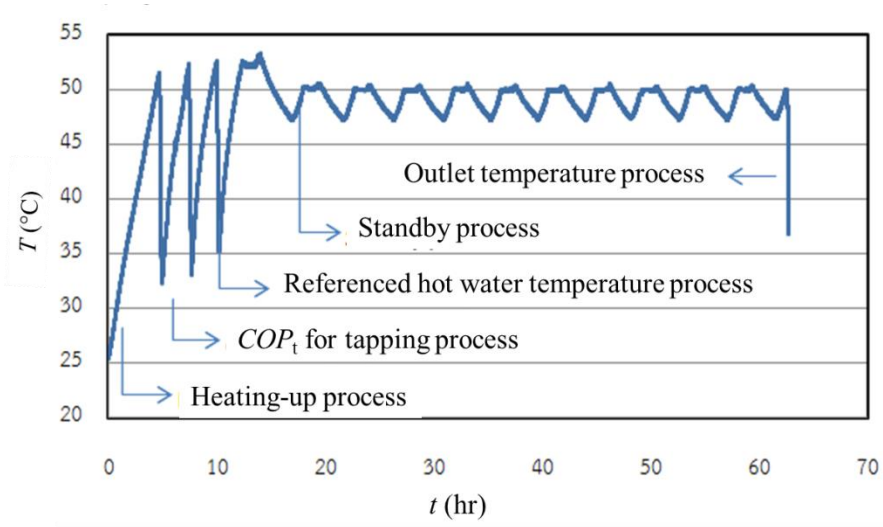

Fig. 7. Operating cycle of small heat pump based on European standard (EN255-3).

4.3 Small heat pump assisted by solar collector

When the small heat pump designed for heating water was experiment with solar collector, solar radiation, solar energy and energy consumption were analyzed as shown in Table. 1. Figure 8 shows lower solar energy and sol energy affected to higher energy consumption of system. The average solar energy and solar radiation for six day were recorded and 5.25 kWh/D of average energy consumption was resulted. As the results, 1.77 kWh/D or 25.21% of average energy consumption is lower compared to only small heat pump operation.

Table 1: Energy consumption of small heat pump assisted by solar collector.

Day	*Solar Energy*	*Solar radiation*	*Energy consumption*
	($MJ/m^2 \cdot D$)	*(W/m^2)*	*(kWh/D)*
1	*23.43*	*727.86*	*5.02*
2	*22.55*	*702.26*	*5.29*
3	*24.97*	*762.93*	*5.18*
4	*20.98*	*632.56*	*5.24*
5	*20.40*	*631.83*	*5.40*
6	*21.40*	*644.38*	*5.35*
Average	*22.29*	*683.64*	*5.25*

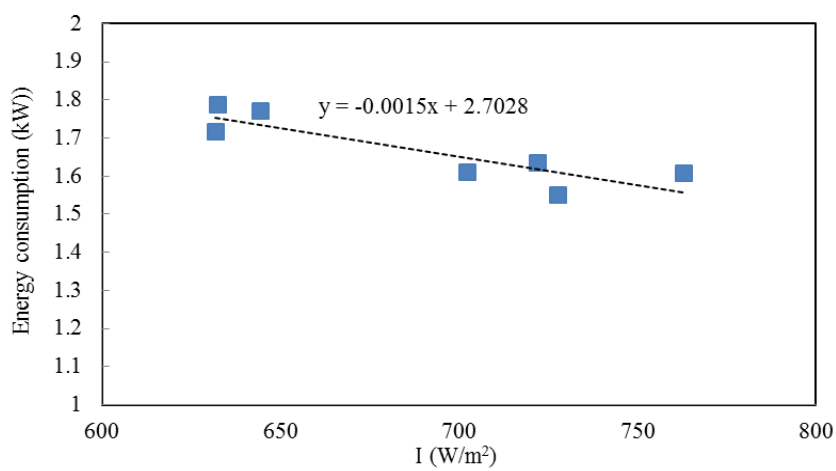

Fig. 8. Relation between solar radiation and energy consumption.

5. CONCLUSION

In order to reduce energy consumption for small heat pump, solar collector was applied to assist water heating system. This study focused on solar collector efficiency to design heat exchanger for small heat pump, energy consumption and COP of small heat pump and also energy consumption of small heat pump assisted by solar collector. Solar collector was tested according to ASHRAE 93-77 and 70.5 % of efficiency was obtained. The COP_t of designed small heat pump was investigated followed by EN255-3 and 1.53 of COP_t and 7.02 kWh/D of average energy consumption were resulted. In case of small heat pump operated with solar collector to heat up water temperature (50°C), 1.77 kWh/D or 25.2% of average energy consumption was lower compared to only small heat pump operation. It was concluded that small heat pump assisted by solar collector could be applied to achieve energy conservation in residential application.

NOMENCLATURE

A	Solar plate area, (m^2)
C_p	Specific heat of water, kJ·K/kg
COP_t	Coefficient of performance for tapping process
D	Day
I	Solar radiation, W/m^2
$\dot{m}$	Mass of water, kg
P	Power, kW
P_{es}	Standby power input, kW
Q_t	Outlet water energy, kJ
q_{wo}	Water tapping flow rate, m^3/s
t	Time, hr
t_s	Time of standby period, s
t_t	Time of tapping period, s
T_a	Ambient temperature, °C
T_i	Input water temperature from solar collector, °C
T_o	Output water temperature from solar collector, °C
T_{wi}	Inlet water temperature, °C
T_{wt}	Water temperature in tank, °C
T_{wo}	Outlet water temperature, °C
W_{et}	Electrical energy input for tapping process, kWh
ρ_{wo}	Density of outlet water at the flow meter, kg/m^3
η_c	Solar collector efficiency

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