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Research Article

INVESTIGATION OF LOAD VARIATIONS WITH SEASONAL CONDITIONS AFFECTED TO COEFFICIENT OF PERFORMANCE OF AIR TO WATER HEAT PUMP

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ABSTRACT:
Following EN255-3 standard, coefficient of performance for tapping process (COP_t) was defined. As the variation of temperature among different seasons, the load variations as outlet hot water temperature (T_{wo}) and the variation of temperature as ambient temperature (T_a) and air humidity from air to water heat pump (11 kW) were studied to obtain COP_t. The results showed increase of ambient temperature enhanced COP_t because lower electrical energy input (W_{et}) was induced by higher ambient temperature. Moreover, higher COP_t was affected by higher air humidity. The results were shown that decrease of outlet water temperature affected to higher electrical energy input and enhanced higher COP_t. This study could be concluded that ambient temperature was higher with lower outlet water temperature affected to lower electrical energy input for tapping process due to lower load of compressor. The overshot electrical energy input for tapping process was observed at specified ambient temperature for each outlet water temperature and it was resulted to diminish COP_t significantly.

Keywords: *Air to water heat pump, European standard EN255-3, Coefficient of Performance, Load variations, Seasonal conditions.*

1. INTRODUCTION

Air to water heat pump is a device that transfers heat energy from air source to water sink. Heat pump consists of four main components such as compressor, evaporator, condenser and expansion devices. Moreover, air to water heat pump is denoted as technology for producing hot water with higher energy efficiency. Nowadays, heat pumps are supported by Ministry of Energy in Thailand to apply widely because of high efficiency, decrease of emission and energy conservation. Regarding heat pump efficiency, the ratio between thermal energy and electrical energy as coefficient of performance (*COP*) was defined by heating process. Following European standard EN255-3 [2] which consists of heating-up period, hot water tapping period, determination of reference hot water temperature, standby and determination of the maximum quantity of usable hot water in single tapping. During hot water tapping period, there is tapped equivalent to 15.0 L/min of outlet water flow rate. Coefficient of performance for tapping process (COP_t) was defined the performance of heat pump [3]. Study of the seasonal performance rating of heat pump water heater was discovered that the range of ambient air temperature hot water temperature and humidity affected to *COP* [4]-[6]. However, *COP* obtained from previous study was analyzed by heating process which was not reflected to actual application. To investigate the performance of heat pump with actual utilization load, COP_t based on EN255-3 standard is analyzed for this study. As the variation of temperature among different seasons were

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effected to COP, it is necessary to investigate load variations such an outlet hot water temperature with ambient temperature and air humidity and from air to water heat pump.

2. Experimental Apparatus

Following Fig.1, schematic diagram was divided for three parts as inlet water part, condition control part and testing part. For inlet water part, inlet water was cooled by chiller and storage in cold water tank. The condition control part consists of evaporator, heater, centrifugal fan and humidifier. Testing part composes of hot water tank and air to water heat pump (11 kW). Testing part was also started from heated water which was stored into hot water tank. Moreover, thermostat was installed in hot water tank to control outlet water temperature.

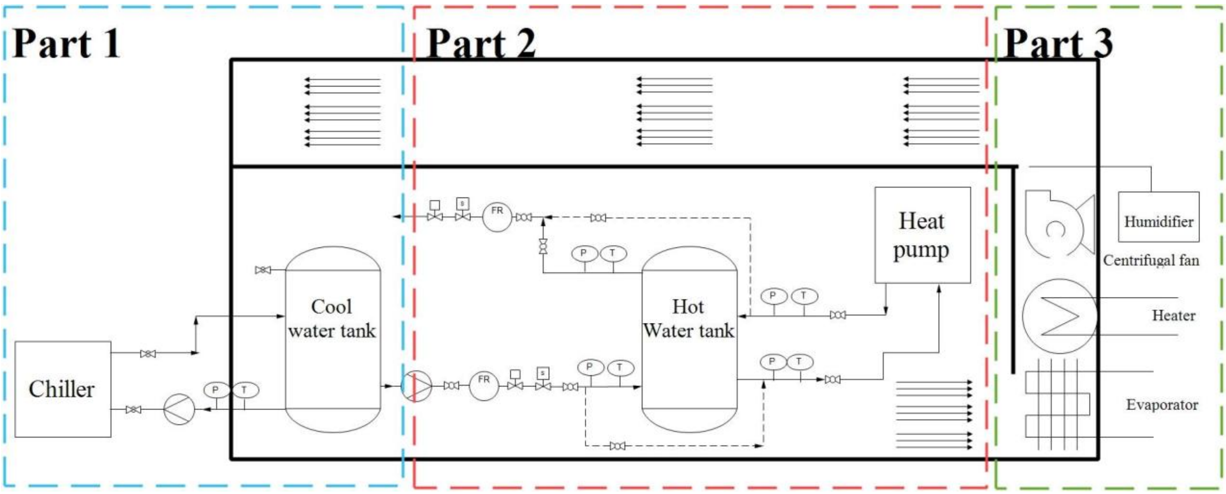

Fig. 1. Schematic diagram of experimental apparatus.

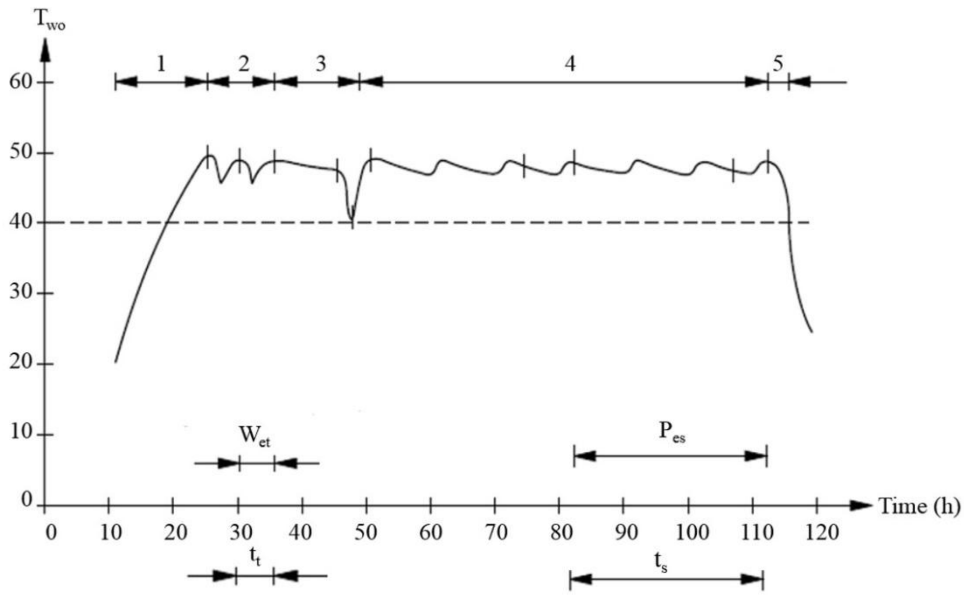

Fig. 2. Operating cycle of heat pump based on European standard (EN255-3).

3. METHODOLOGY

The experiment was operated based on EN255-3 standard which the load variations as outlet hot water temperature and the variation of temperature among different seasons as ambient temperature and air humidity from air to water heat pump were studied. The experimental conditions are adjusted at the range of ambient temperature between 18-34°C and *%RH*=50-80. The heat pump is set as inlet water temperature at 25°C and outlet water temperature interval between 40-55°C. The operating cycle of heat pump based on European standard EN255-3 is shown in Fig. 2. The first stage is heating-up period, which is started from turned on heat pump until turned on thermostat. The second stage is tapping process for determination of COP_t, which volume of hot water is tapped equivalent to half of nominal volume of hot water storage tank, reheated until the water temperature reach the setting point. The third stage is called a determination of reference hot water temperature which volume of hot water is tapped until the hot water temperature below 40ºC. The fourth stage is standby period, which is a determination of standby power input. To obtain standby power input, 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. The operating for number of cycles should not be operated less than 24 hours and at least 3 cycles. Final stage is a determination of the maximum quantity of usable hot water in single tapping, the volume of 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.(1).

$$COP_t = \frac{Q_t}{W_{et} - P_{es}.t_t} \tag{1}$$

Q_t is calculated from the density of outlet water at the flow meter, ρ_{wo}, the average specific heat at the constant pressure of the water interval between the outlet water temperature (T_{wo}) and the inlet water temperature (T_{wi}), water tapping flow rate (q_{wo}) and the different temperature between outlet water temperature and inlet water temperature following Eq.(2).

$$Q_t = \int_0^{t_t} \rho_{wo} \cdot Cp_w \cdot q_{wo} \cdot (T_{wo} - T_{wi})dt \tag{2}$$

P_{es}, is calculated from the electrical energy input (W_{es}) and the time of standby period (t_s) as shown in Eq.(3):

$$P_{es} = \frac{W_{es}}{t_s} \tag{3}$$

4. RESULTS AND DISCUSSION

4.1 Experimental results based on EN255-3 standard

The results show five stages of heat pump testing based on EN255-3 as heating-up period, hot water tapping period, determination of reference hot water temperature, standby and determination of the maximum quantity of usable hot water in single tapping. Figure 3 shows the time series of experimental results at T_a=18°C with %RH = 60%. Following EN255-3 standard, outlet water temperature flow rate of tapping hot water and power input (*P*) were analyzed as shown in Fig. 3. The results show 5 stages of operating cycle of heat pump experimented by EN255-3 standard. Firstly outlet water temperature was increased from 25°C -55°C which affected to higher power while almost constant water tapping flow rate was obtained for heating-up stage. Secondary, followed by EN255-3 standard, two times of water tapping and less 10% difference of obtained outlet water energy were experimented.

As the results, heat pump was operated when water was tapped and outlet water temperature decreases to 50 ^oC (setting point temperature). Following tapping process corresponding to the actual load, thus COP_t was calculated to evaluate performance of heat pump.

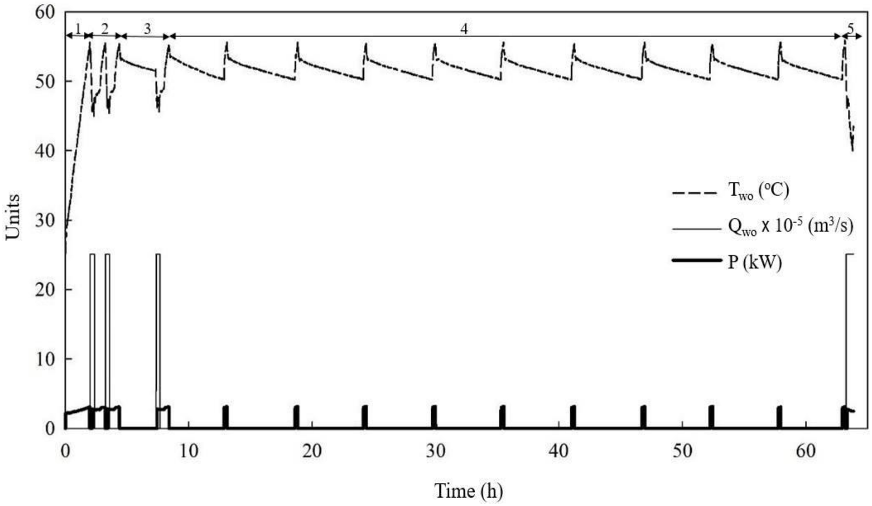

Fig. 3. Time series of experimental results at T_a=18^{o}C with %RH=60% based on EN255-3.

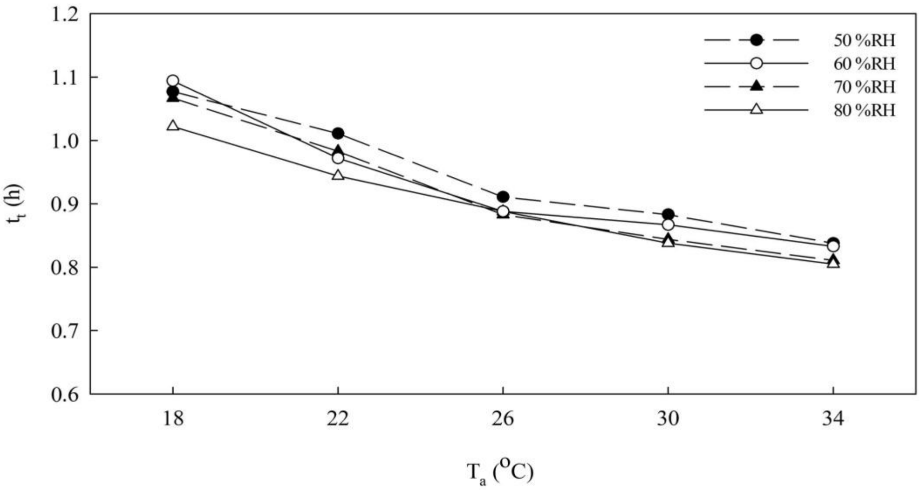

Fig. 4. Relations between T_a and tapping time (t_t) for %RH=50%, 60%, 70% and 80%.

4.2 Effects of ambient temperature (Ta) related with air humidity (%RH)

As the results based on EN255-3 as shown in Fig.3, tapping time, outlet water energy, electrical energy input for tapping process and COP_t were analyzed in Figs.4-6. To study the effects of load variations, ambient temperature were increased from 18 to 34^{o}C and air humidity was raised from 50% to 60%, 70% and 80%. Figure 4-6 shows increasing of ambient temperature brought about lower tapping time and electrical energy input, however outlet water energy were almost constant with ambient temperature variations. It was because of higher thermal energy caused by increase of ambient temperature which was absorbed by refrigerant in evaporator and affected to decrease of tapping time. Moreover, higher COP_t was slightly affected by higher air humidity due to the droplet deposition rate on evaporator increased with air humidity, which released latent heat was greater than sensible heat [7]. As the results, the increase of ambient temperature enhances COP_t due to increase of heat source induced higher COP_t followed by thermodynamics laws as shown in Fig. 7.

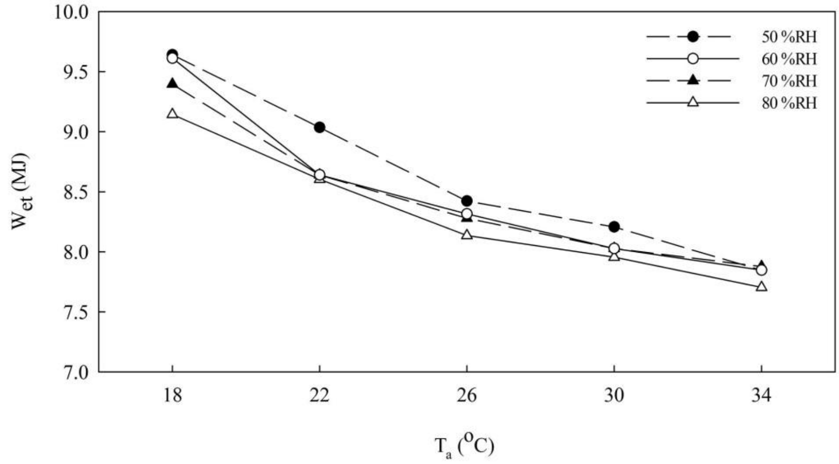

Fig. 5. Relations between T_a and W_{et} for %RH=50%, 60%, 70% and 80%.

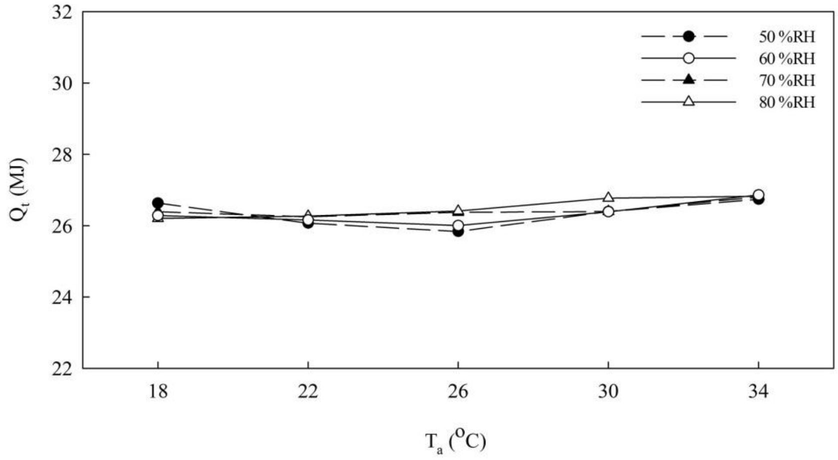

Fig. 6. Relations between T_a and hot water energy (Q_t) for %RH=50%, 60%, 70% and 80%.

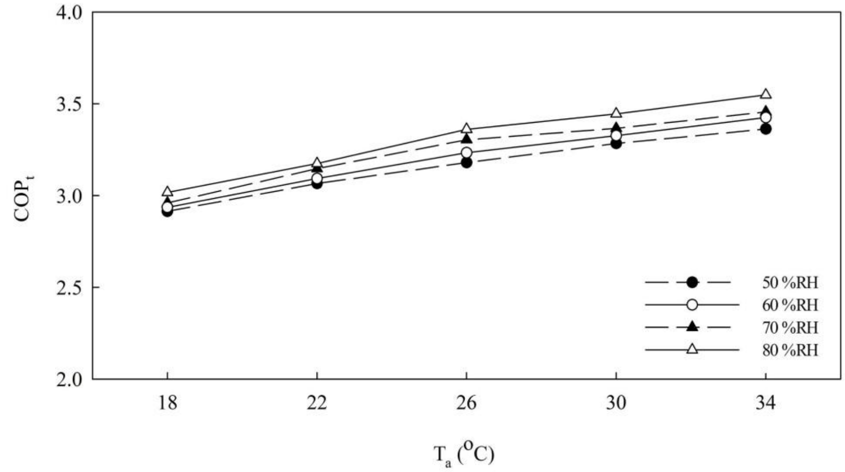

Fig. 7. Relations between Ta and COP_t for %RH=50%, 60%, 70% and 80%.

4.3 Effects of ambient temperature (Ta) related with outlet hot water temperature (Two)

Figure 8 shows relations between T_a and t_t for T_{wo} = 40°C, 43°C, 43°C, 49°C, 52°C and 55°C. As the above results, lower tapping time was induced by higher ambient temperature, moreover it was affected by lower outlet water temperature owing to decrease of required outlet water energy outlet water energy as in Fig. 9. Figure 10 shows relations between T_a and W_{et} for T_{wo} =40°C, 43°C, 46°C, 49°C, 52°C and 55°C. When ambient temperature was higher with lower outlet water temperature, Electrical energy input for tapping process is lower due to lower load of compressor. The overshot electrical energy input was observed at specified ambient temperature for each outlet water temperatures and resulted to diminish COP_t significantly as illustrated in Fig.11.

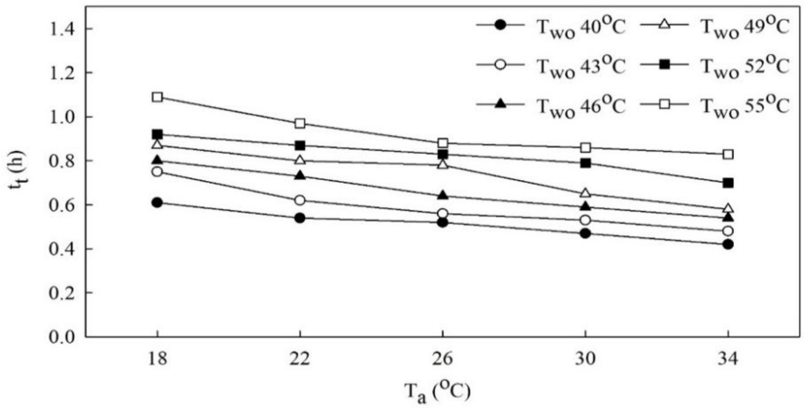

Fig. 8. Relations between T_a and t_t for Two =40, 43, 43, 49, 52 and 55°C.

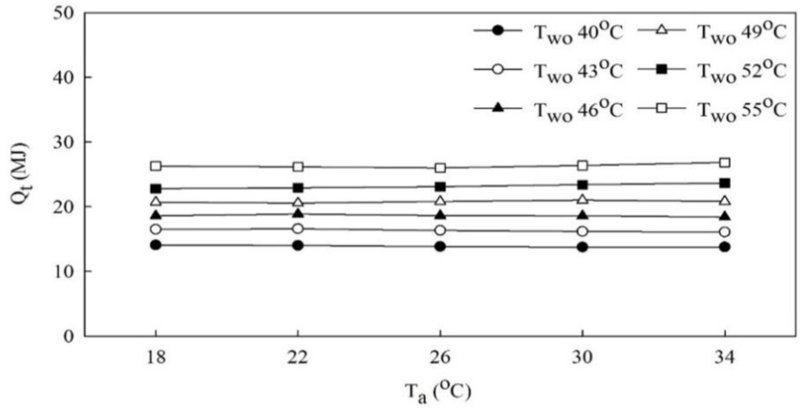

Fig. 9. Relations between T_a and Q_t for T_{wo} =40, 43, 43, 49, 52 and 55°C.

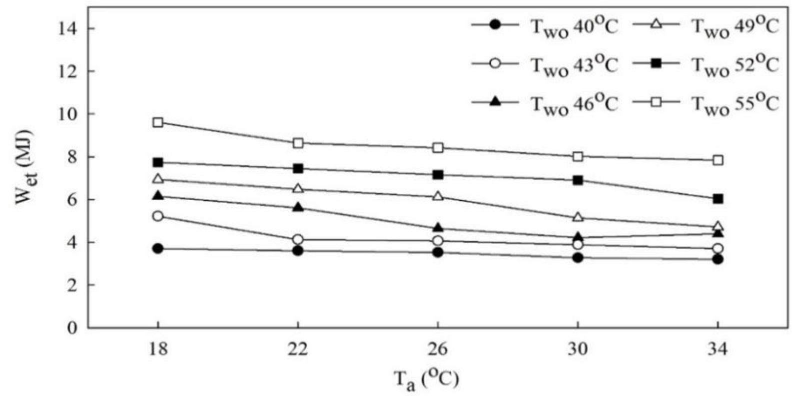

Fig. 10. Relations between T_a and W_{et} for T_{wo} =40, 43, 43, 49, 52 and 55°C.

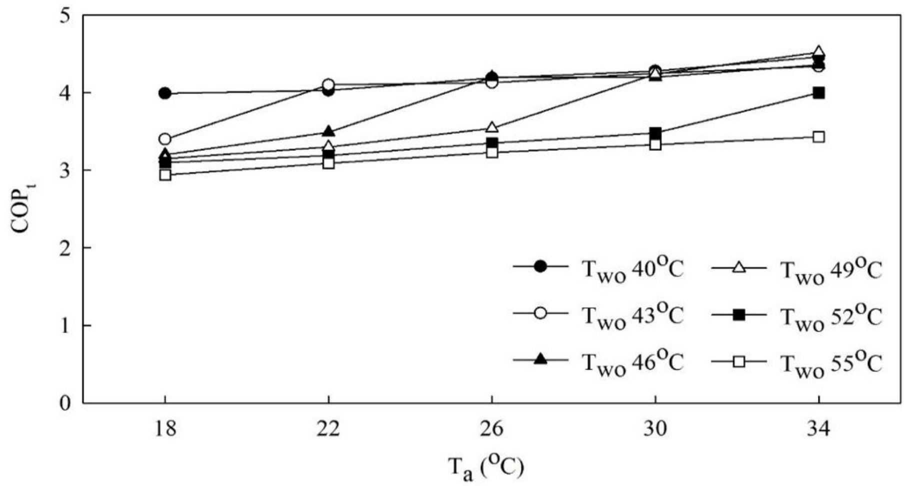

Fig. 11. Relations between T_a and COP_t for T_{wo} =40, 43, 43, 49, 52 and 55°C.

5. Conclusion

Following EN255-3 standard, coefficient of performance for tapping process (COP_t) was defined from performance of heat pump during tapping process. As the variation of temperature among different seasons, the load variations of ambient temperature, air humidity and outlet hot water temperature from air to water heat pump (11kW) were studied to obtain COP_t. This study focused on the effects of load variations from air to water heat pump by variation of T_a = 18 °C, 22 °C, 26 °C, 30 °C and 34°C. Moreover, the variation of ambient temperature was experimented with increase of T_{wo} = 40°C, 43 °C, 46 °C, 49 °C, 52 °C and 55 °C and %RH = 50%, 60%, 70% and 80%. The results showed increase of ambient temperature enhanced COP_t because lower electrical energy input was induced by higher ambient temperature. Moreover, higher COP_t was affected by higher air humidity owing to the droplet deposition rate on evaporator increased with air humidity, which released latent heat was greater than sensible heat [6]. The results were shown that decrease of outlet water temperature affected to higher electrical energy input and enhanced higher COP_t. This study could be concluded that higher ambient temperature, air humidity and lower outlet water temperature enhanced to higher COP_t. Especially, two significant parameters such as ambient temperature with specified outlet water temperature, the boundary of maximum COP_t = 3.99, 4.10, 4.20, 4.24 and 4.52 for T_a = 18°C, 22°C, 26°C, 30°C and 34°C for air to water heat pump was obtained.

6. Acknowledgement

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Nomenclature

COP_t	Coefficient of performance for tapping process
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_a	Ambient temperature, °C
T_{wi}	Inlet water temperature, °C
T_{wo}	Outlet water temperature, °C
t_s	Time of standby period, s
t_t	Time of tapping period, s

W_{et} Electrical energy input for tapping process, kWh
ρ_{wo} Density of outlet water at the flow meter, kg/m^3

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