THE EXPERIMENTAL STUDY OF THAILAND SEASONAL COEFFICIENT OF PERFORMANCE OF HEAT PUMP WATER HEATER

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ABSTRACT In recent years, the use of heat pump water heater (HPWH) is progressively increasing in Thailand. The HPWH is denoted as technology for producing hot water with higher energy efficiency than conventional technology. The energy of performance called coefficient of performance (COP) of HPWH that is affected from the change of climatic. There are three climate conditions in Thailand, i.e. winter, rainy and summer. Thus the COP is absolutely different from each condition. The experimental study of Thailand seasonal coefficient of performance of HPWH was based on European standard EN255-3 under Thailand climate conditions. Testing conditions of surrounding air temperature and relative humidity (%RH) were adjusted at the range between 18-34 ^oC and 50-80 %RH respectively. The hot water temperature was set at 55 ^oC. The cold water inlet temperature was set at 25 ^oC. The analysis was determined both heating-up and hot water tapping periods. The COP of heating-up period (COP_h) is defined as the ratio between energy supplied to the hot water and electrical energy input. The COP of hot water tapping period (COP_t) is defined as the ratio between hot water energy output and electrical energy input during hot water tapping periods. In order to investigate the variation of COP_h and COP_t, the measurement of energy consumption, surrounding air temperature, %RH, and hot water temperature setting in storage tank were required. The COP_h and COP_t were obviously changed due to the effect of Thailand climatic changes. The results have shown that COP_h and COP_t were increased because of the effect of rising in surrounding air temperature and %RH. The COP_h was in the range of 3.32 to 4.85 and the COP_t was in between 2.91 and 3.54. The COP_h of summer, winter, and rainy season were 4.34, 4.04, and 4.14, respectively. The COP_t of summer, winter, and rainy season were 3.37, 3.30, and 3.36, respectively.

1. INTRODUCTION

Heat pump is a device which is commonly used to obtain both heating and cooling with vapor-compression cycles. Operation in the heating mode is simply an air conditioner operating in reverse. Heat pump water heater (HPWH) is extensively used to produce hot water in hospitality and indusial sector in Thailand. The energy of performance called coefficient of performance (COP) of HPWH in Thailand was based on European standard (EN255-3) under Thailand climate conditions because of using hot water in Thailand as tapping of EN255-3. There are three climate conditions in Thailand. The surrounding air temperature of 30 ^oC (70%RH), 26 ^oC (70%RH), and 26 ^oC (80%RH) are represented a wide range of practical summer, winter, and rainy conditions in Thailand, respectively. The COP is absolutely different from each condition. Study of the seasonal performance rating of HPWH was discovered the range of surrounding air temperature and humidity ratios lead to transform of COP (G.L. Morrison et al., 2003). The range of surrounding air temperature and humidity ratio are insignificant parameter. Moreover, a range of hot water temperature was led to the conversion of COP (J.J. Guo et al., 2010). Consequently, the experimental study of Thailand seasonal coefficient of performance of HPWH was significant.

2. EXPERIMENT

2.1 Experimental apparatus

A schematic diagram of the experimental apparatus is shown in Fig. 1. The HPWH with external condenser is rated heating capacity 11 kW. It consists of a compressor, condenser, expansion valve, evaporator and 520L of hot water storage tank. The refrigerant R-417A in the evaporator extracts heat from the air then the refrigerant releases heat to water in storage tank at condenser.

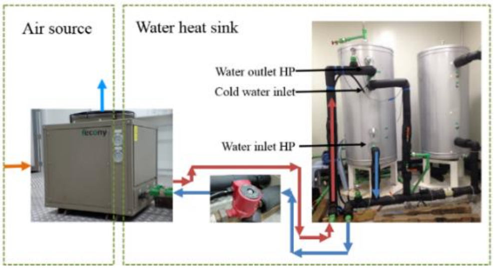

Fig. 1. Schematic diagram of the experimental apparatus

2.2 Experimental with measuring points

A schematic diagram of the experimental apparatus with measuring points is shown in Fig 2, which is composed of a 520L of hot water storage tank with temperature sensors measured hot water temperature at the top, middle and bottom level as represented by T1, T2, and T3, respectively. Hot water tapping temperature (θ_{wh}) and cool water inlet temperature (θ_{wc}) are measured at T4 and T7. Moreover, water incoming and outgoing heat pump is measured at T5 and T6. The hot water temperature is controlled by thermostat ($T_{thermostat}$). When the temperature of water is reached to hot water temperature set point, thermostat shuts off. The power meter is used to measure the power consumption of compressor and circulate pump.

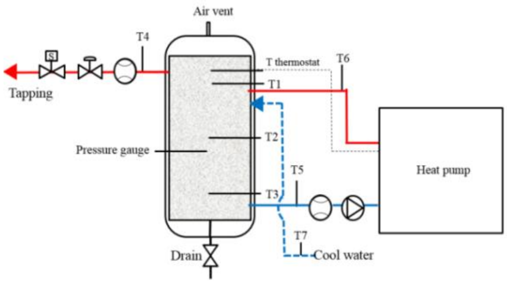

Fig. 2. Schematic diagram of the experimental with measuring points

2.3 Experimental procedure and data reduction

In this study, experimental conditions of surrounding air temperature and %RH are adjusted at the range between 18-34 °C and 50-80 %RH, respectively. The hot water temperature is set at 55 °C and the cold water inlet temperature is set at 25 °C. In addition, the hot water temperature setting in storage tank at 40, 43, 46, 49, 52, and 55 °C are investigated in the event that the range of surrounding air temperature is in between 18-34 °C and 60 %RH.

The method of test is based on European standard (EN255-3) which consists of 5 principal stages in Fig. 3. At the first stage, heating-up period is started from switched on the heat pump until shutting off when hot water thermostat situated in storage tank. The COP heating-up period (COP_h) is determined at this stage. In the second stage, a determination of the COP for heating sanitary water is called COP of hot water tapping (COP_t). Volume of hot water is tapped equivalent to half of nominal volume of hot water storage tank and reheated until the water temperature reach the setting point, which called hot water tapping period. Third stage called, a determination of reference hot water temperature is the volume of hot water is tapped until the hot water temperature falled below 40 °C. Forth stage, a determination of standby power input is period of operating for a number of full cycles that should not be less than 24 hours. Final stage called, a determination of the maximum quantity of usable hot water in single tapping, the volume of hot water is tapped until the hot water temperature falls below 40 °C after standby period.

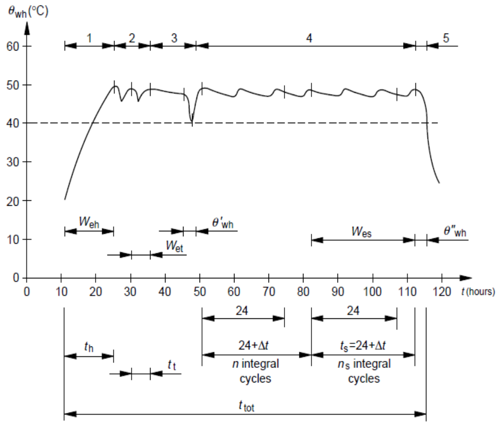

Fig. 3. European standard (EN255-3)

In this study, the first, the second and the fourth stages are investigated for determination COP_h and COP_t. The COP_h is calculated in the following equations:

$$COP_h = \frac{Q_h}{W_{eh}} \tag{1}$$

The heating-up energy, W_{eh}, is determined in heating-up period. The energy to heat 520L of hot water from 25 °C to temperature in storage tank output is energy supplied to the hot water, Q_h.

The COP_t is calculated from measured of hot water energy output, O_t and electrical energy input of HPWH, W_{et}, in hot water tapping and reheating time, t_t, as

$$COP_t = \frac{Q_t}{W_{et} - P_{es} \cdot t_t} \tag{2}$$

Q_t is calculated from the density of hot water at the flowmeter, ρ_{wh}, the average specific heat at the constant pressure of the water in the temperature interval between the hot water tapping, θ_{wh} and the cold water inlet, θ_{wc}, the tapping flow rate, q_{wh}, and the different temperature between θ_{wh} and θ_{wc} in the following equation:

$$Q_t = \int_0^{t_t} \rho_{wh} \cdot Cp_w \cdot q_{wh} \cdot (\theta_{wh} - \theta_{wc})dt \tag{3}$$

Standby effective power input, P_{es}, is calculated from the electrical energy input, W_{es}, and the time of standby period, t_s, according to

$$P_{es} = \frac{W_{es}}{t_s} \tag{4}$$

3. RESULT AND DISCUSSION

3.1 COP with surrounding air temperature

Variations of COP according to surrounding air temperature in heating and tapping period are shown in Fig 4 and 5, respectively. The results show that COP_h and COP_t increase with increasing surrounding air temperature, because an increase in enthalpy change is affected from a rise of air source temperature. So heat capacity is obviously evaporated to refrigerant and abundantly releasing it to water sink. The COP_h is during 3.32 to 4.85 and the COP_t is during 2.91 to 3.54.

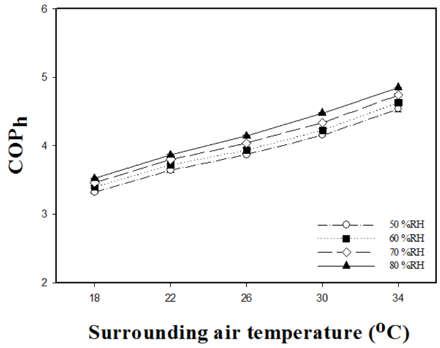

Fig. 4. The variation of COP_h with respected to surrounding air temperature.

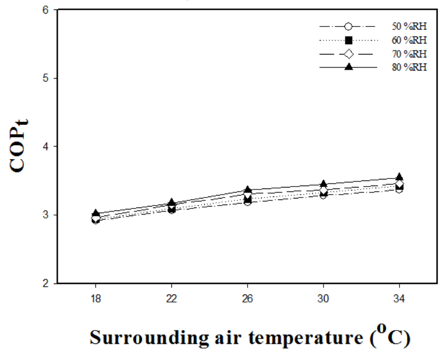

Fig. 5. The variation of COP_t with respected to surrounding air temperature.

3.2 COP with %Relative humidity

The results show that COP_h and COP_t are increased with increasing %RH as shown in Fig 6 and 7. Due to the droplet deposition rate on evaporator increased with %RH, which resulted in more release of latent heat greater than sensible heat (Bo Xu et al., 2015). Therefore, the heat capacity is abundantly absorbed and released to water heat sink.

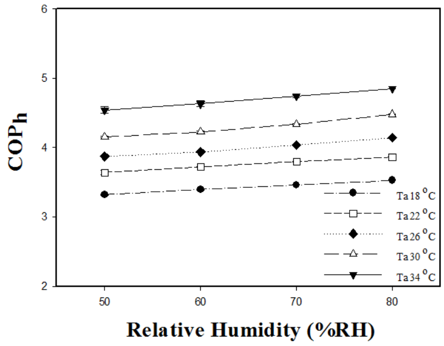

Fig. 6. The variations of COP_h with respected to %RH.

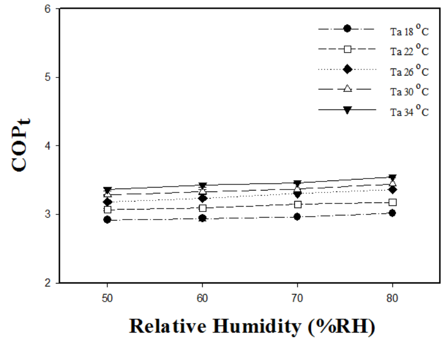

Fig. 7. The variations of COP_t with respected to %RH.

3.3 Variations of COP according to hot water temperature setting in storage tank

Variations of COP according to hot water temperature setting in heating are shown in Fig 8. The result shows that COP_h is decreased with increasing hot water temperature setting in storage tank due to higher water temperature setting effected the increasing of power consumption as shown in Fig. 9. It shows occurring when compressor have to compress refrigerant to high change in pressure and temperature for releasing to water.

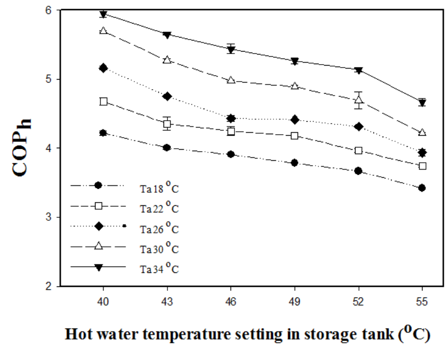

Fig. 8. Variations of COP_h according to hot water temperature setting.

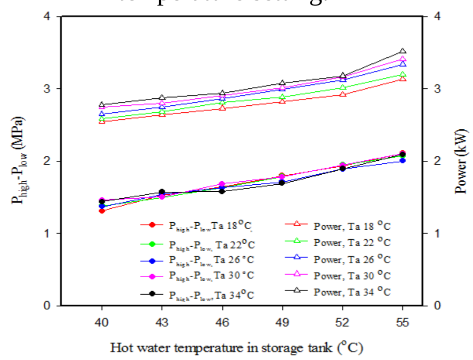

Fig. 9. Variations of change in pressure and power according to hot water temperature setting.

Variations of COP according to hot water temperature setting in tapping are shown in Fig 10. The result shows that COP_t of each surrounding air temperature at 60 %RH is decreased when hot water temperature setting more temperature than dropping point, which higher surrounding air temperature has a high dropping point. Because heat transfer of refrigerant and water is declined, so it causes overshoot of energy consumption as shown in Fig. 11.

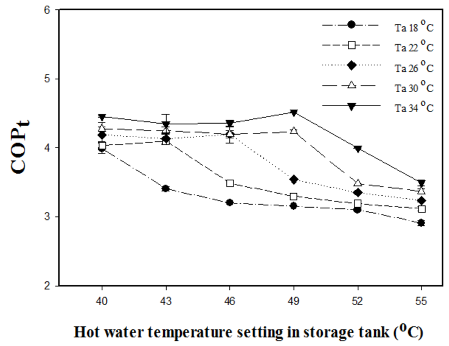

Fig. 10. Variations of COP_t according to hot water temperature setting.

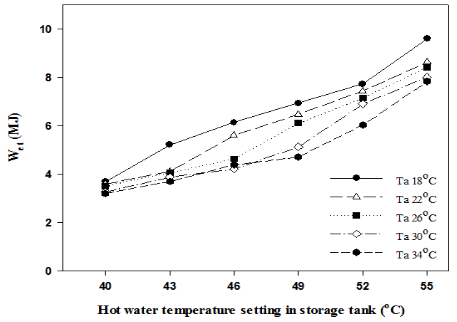

Fig. 11. Variations of energy consumption according to hot water temperature setting in tapping period.

3.4 Thailand seasonal coefficient of performance

Thailand Seasonal coefficient of performance is shown in Fig 12. Table 1 shows both COP_h and COP_t of HPWH for each condition in Thailand. The surrounding air temperature and %RH are determined to represent a wide range of practical three climate conditions of Thailand, which is defined by Thai Meteorological Department (TMD).

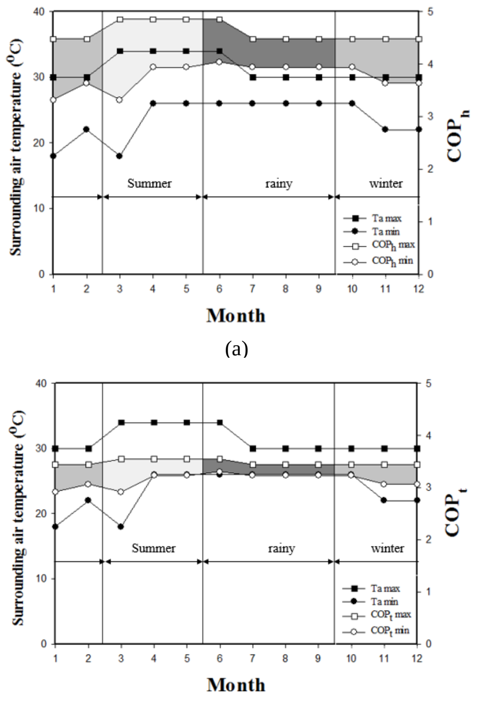

Fig. 13. Thailand Seasonal coefficient of performance

Table 1 COP_h and COP_t for Thailand Seasonal.

Season	condition	COP_h	COP_t
summer	30°C (70%RH)	4.34	3.37
winter	26°C (70%RH)	4.04	3.30
rainy	26°C (80%RH)	4.14	3.36

4. CONCLUSION

The COP_h and COP_t of HPWH are increased with increasing surrounding air temperature and %RH because evaporator profusely absorbs energy from environment to water. The COP trends to linearly increase. Therefore, prediction of COP is possible for climate change.

The COP_h is decreased with increasing hot water temperature setting because of the effect of power consumption. A variation of COP_t according to hot water temperature setting is implied optimization for working. However, optimization operation depends on the operating conditions and testing device.

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