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ORIGINAL ARTICLE

Performance of air source air conditioning water heater using trombone coil dummy condenser with different diameter and pipe length

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ABSTRACT – The Air Source Air Conditioning Water Heater (ASACWH) performance as an energy source to heat water in the tank using dummy condenser type of trombone coil with different diameter and pipe length without hot water circulation has been investigated. The diameter and length of the dummy condenser pipe are intensely affected by ACWH performance. In this study, cooling capacity, Coefficient of Performance (COP), compressor power and room temperature were evaluated in three types of trombone coil (6.4 mm coil diameter with a length of 7.9 m, 6.4 mm coil diameter with a length of 5.3 m, and 9.5 mm coil diameter with a length of 5.3 m) with different cooling load variation. This study used cooling load with a variation of 0 W, 1000 W, 2000 W, and 3000 W without hot water circulation in the simulation room. It was found that the ASACWH using a pipe with a coil diameter of 6.4 mm and length of 7.9 m performed the highest cooling capacity and COP, and produced more comfortable room temperature than the other two pipes. The results indicated that when the cooling load icreased from 0 W to 3000 W, the compressor power increased by 11.3%, 6.3%, and 9.3%, using the 6.4 mm coil diameter with 7.9 m length, 6.4mm diameter of the coil with 5.3m length and 9.5mm coil diameter with 5.3m length, respectively.

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KEYWORDS
Dummy condenser;
air conditioning;
cooling capacity;
trombone coil;
COP.

INTRODUCTION

In a hotter climate, the air conditioning water heater with air source has better performance than using electricity for heating water [1]. Various technology innovations have been developed to improve the energy efficiency of heating water for various hot water needs, including water source air conditioning water heater (ASACWH) [2–5]. The electrical energy consumption using an electric resistance water heater is about three times higher than ASACWH, so the use of ASACWH was more efficient, energy-saving and environmentally friendly with natural refrigerant that including evaporative cooling [6–10]. The performance of the ASACWH system was influenced by the cooling load, the surrounding temperature, hot water temperature in use, refrigerants, system structure including refrigerant pipe diameter and length, etc. [11–15].

J. Zhang et al. [16] reported the experimental research and optimization of air source heat pump water heater. The results showed the Coefficient of Performance (COP) improvement. L. Zhang et al. [17] published a review on vapor compression air source heat pump system advances that widely applied in cold regions due to its simplicity of structure system and low cost in operation. Willem [18] presented a review of the residential heat pump water heaters system performance and energy efficiency. It showed that heat pump water heater was operated in the COP around 1.8-2.5 and some potential technological updates could increase COP around 2.9-5.5.

Sparn et al. [19] published an evaluation of the integrated heat pump water heater performance for residential use. Air source air conditioning water heater (ASACWH) in residential is the current technology system that gives low-cost operation systems with energy savings compared to other water heating systems in residential. ASACWH provides high COP (the ratio of useful heating energy to the electrical energy input required). Water heaters based on electric resistance have COP of almost 1.0, lower than ASCWH that provides COP 2.0. ASACWH is an old concept that was developed in the 1950s and recently was develops as an integrated system ASACWH for heating or cooling. Generally, ASACWH was very efficient and low-cost electrical consumption, with performance increasing in warmer conditions or tropical areas.

A. Amirirad et al. [20] reported that air source heat pump water heater (ASHPWH) was a relatively new addition device for providing hot water with high efficiency. The ASHPWH system has achieved significant revenue for mild to warm climate regions, in which the heating or space is minimal or non-existent. The results showed that summer cooling decreased and winter heating increased in homes with indoor use of ASHPWH units. However, the net effect reached 21.3% reduction in total home electricity consumption (room heating, cooling, and heating of water). This research provided accurate predictions of ASHPWH performance for applications throughout the year in Canada's residential

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house. A previous study by the authors had presented the performance of split air conditioner with and without trombone coil condenser as air conditioning water heater [5].

The objective of this work is to investigate the performance of ASACWH using dummy condenser type of trombone coil (copper tube) with different diameters and lengths without hot water circulation. The method used in this work is a comparative experimental method on three types of trombone coil as dummy condensers using copper type. The three types of trombone coil are type A using 6.4 mm diameter of a coil with a length of 7.9m, type B using 6.4mm diameter of coil with length of 5.3m and type C using 9.5mm diameter of coil with length of 5.3m. The significance of this work is to find out which type from three types of trombone coil provides better performance. In this work, the performance of ASACWH such as cooling capacity, coefficient of performance (COP), compressor power and room temperature were evaluated in three types of trombone coil with different cooling load variations.

METHODOLOGY

The method used in this research was experimental by comparing ASACWH performance between three types of trombone coil: type A (6.4mm diameter of coil with length of 7.9m), type B (6.4mm diameter of coil with length of 5.3m), type C (9.5mm diameter of coil with length of 5.3m). This trombone coil was employed as a dummy condenser for heating water in a 50 L water tank. The schematic of experimental apparatus unit as shown in Figure 1 [5] was designed and fabricated in Maintenance Laboratory Department of Mechanical Engineering, University of Riau by using one unit of split type air conditioning that has a cooling capacity of 2.6 kW and R-22 refrigerant as working fluid with compressor power was 0.67 kW. The optimum charge in order to achieve high performance of ASACWH was 500 gram of R-22.

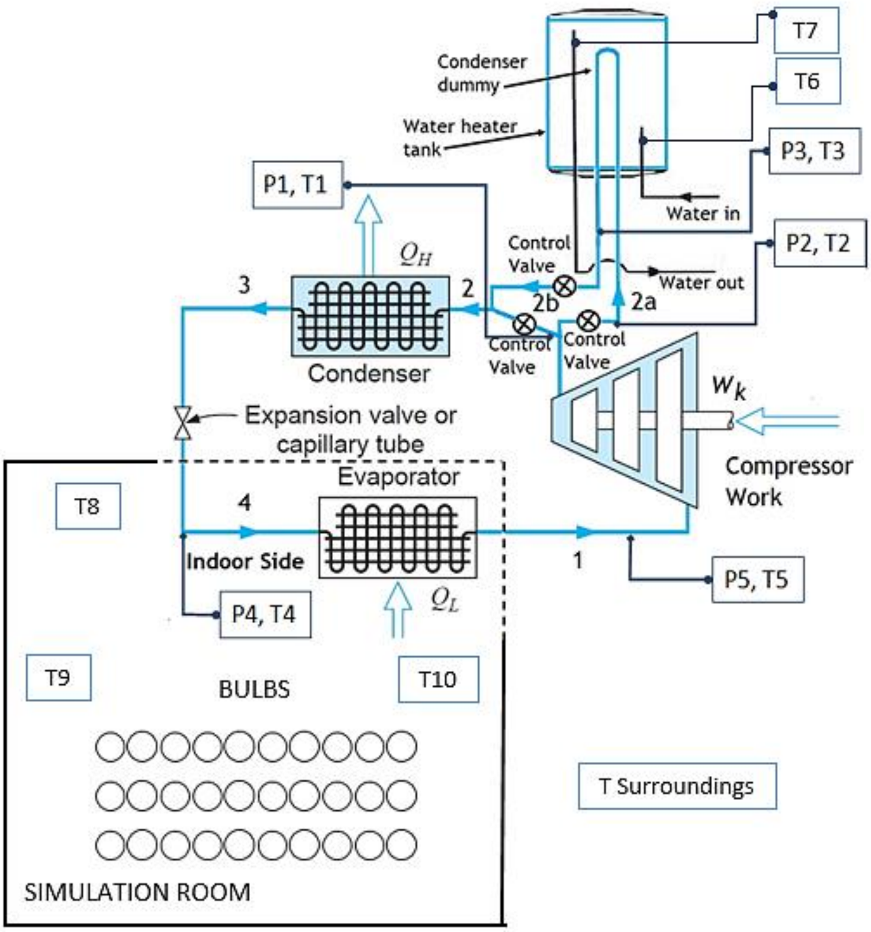


Figure 1. Schematic diagram of Air Source Air Conditioning Water Heater (ASACWH) with simulation room at various cooling loads [5].

The legend of data recording in each test was as follows:

1. Compressor Outlet Temperature (T1)
2. Dummy Condenser Inlet Temperature (T2)
3. Dummy Condenser Outlet Temperature (T3)
4. Evaporator Inlet Temperature (T4)
5. Evaporator Outlet Temperature (T5)

6. Water Inlet Temperature (T6)
7. Water Outlet Temperature (T7)
8. Test Room Temperature (T8)
9. Test Room Temperature (T9)
10. Test Room Temperature (T10)
11. Surrounding Temperature (TSurroundings)
12. Compressor Outlet Pressure (P1)
13. Dummy Condenser Inlet Pressure (P2)
14. Dummy Condenser Outlet Pressure (P3)
15. Evaporator Inlet Pressure (P4)
16. Evaporator Outlet Pressure (P5)
17. Electric Current of Compressor (I)
18. Electric Voltage (V)

Figure 2 shows the ASACWH test facility apparatus used in this work; it appears the simulation test room, main condenser (outdoor unit) and water heater tank (dummy condenser). The ASACWH test facility apparatus are consisting of [21]:

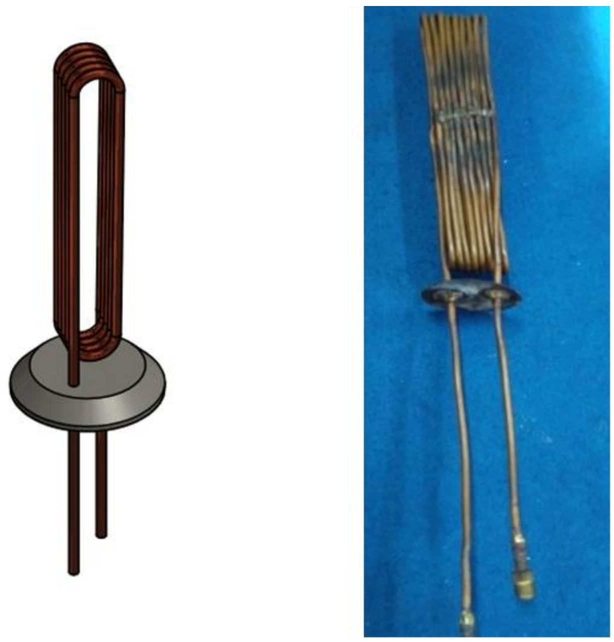
1. Water tank with trombone coil as dummy condenser water heater.
2. Refrigerant pressure gauge.
3. Hot water control valve.
4. Refrigerant tube main system.
5. Compressor.
6. Main Condenser.
7. Evaporator line tube.
8. Simulation room (control cooling load).

The variation of the cooling load of 0W, 1000W, 2000W and 3000W was used in this study to evaluate ASACWH performance with three different types of coil. The performance calculations were performed using the data reduction in principles of thermodynamics [22] and the thermodynamic properties of the refrigerant were evaluated using the software called REFPROP ver. 8.

Figure 2. Air Source Air Conditioning Water Heater (ASACWH) test apparatus [21].

The measurement devices that used for data captured in this study were analogue pressure gauge for refrigerant pressure (accuracy ±5 psi for high pressure and ±1 psi for low pressure), digital thermometer (accuracy ±0,1°C), thermocouple K type temperature sensor with TC-08 data acquisition module (accuracy 0.2% ± 0.5°C and has a resolution of better than 0.1°C), ampere-meter for electric current (accuracy ± 2.0% and 3 digits), voltmeter (accuracy ± 1.0% and 3 digits), digital weight scale for a refrigerant mass charge (accuracy ±10 gram) [5]. The test data were recorded continuously for 120 minutes with 5 minutes intervals.

Figure 3 shows the trombone coil as dummy condenser for water heater used in this study in three different types of diameter and length of copper tube. Figure 3(a) shows the CAD model of trombone coil [23] and Figure 3(b) shows the actual product of trombone coil which is manufactured in Maintenance Laboratory Department of Mechanical Engineering, University of Riau [24].



(a) CAD model (b) actual product

Figure 3. Trombone coil as dummy condenser: (a) CAD model [23] and (b) actual product [24].

The coefficient of performance (COP) of Air source air conditioning water heater (ASACWH) can be expressed as Eq. (1):

$$COP_C = \frac{CoolingEffect}{WorkInput} = \frac{Q_L}{W_k} \tag{1}$$

where, Q_L is the energy absorbed in the experimental room as cooling effect and W_k is the compressor power input. The COP of ASACWH, including room cooling and water heating (AC combined water heating) can be expressed as Eq. (2):

$$COP_{C+wh} = \frac{CoolingEffect + HeatingEffectofCoil}{WorkInput} = \frac{Q_L + Q_{coil}}{W_k} \tag{2}$$

where, Q_{coil} is the energy released in the water heating as the heating effect of the coil. The compressor power (W_k) can be calculated from the following Eq. (3):

$$W_k = \eta_m V.I.\cos\phi \tag{3}$$

where, η_m is electric motor efficiency, V, I and $cos\Phi$ are the electric voltage, electric current, and power factor, respectively.

RESULTS AND DISCUSSION

This study was carried out on ASACWH through the loading of different cooling loads in a simulation room without hot water circulation. The cooling load variations in the simulation room were 0 W, 1000 W, 2000 W, and 3000 W respectively. The set data was recorded of each test for three types of trombone coil every 5 min for 120 min; then, they were compared to get the best performance. The three different coil types are type A (6.4mm diameter of coil with length of 7.9m), type B (6.4mm diameter of coil with length of 5.3m), type C (9.5mm diameter of coil with length of 5.3m).

Figure 4 shows the effect of increasing the cooling load of 0W, 1000W, 2000W, and 3000W on the ASACWH system on the compressor power requirement in three different coil types. The compressor power on ASACWH with 6.4mm diameter of the coil with a length of 7.9m, 6.4mm diameter of the coil with a length of 5.3m and 9.5mm diameter of the coil with a length of 5.3m were around 699W- 782W (increased up to 11.3 %), around 646W-686W (increased to 6.3%) and around 665W-727W (increased up to 9.3%) respectively. The compressor power increased with increasing of the cooling load as shown in Figure 4, where the compressor power in three different types of coil compared to cooling load just in little difference or not significantly different values. While trombone coil with 6.4mm diameter with length 5.3m provides the lowest compressor power compared to other coils due to an increase of compressor power around 6.3%.

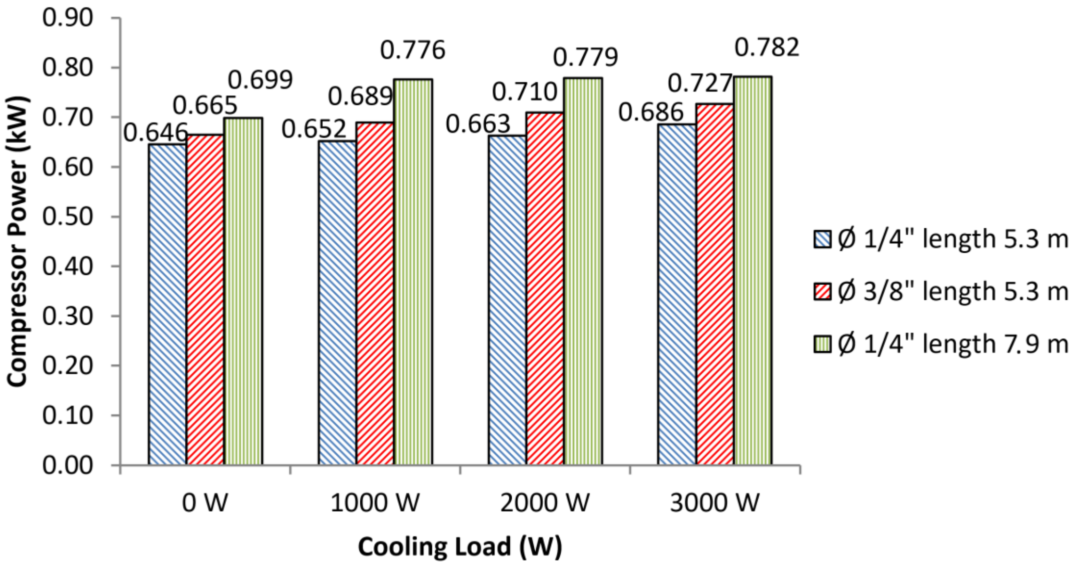


Figure 4. Compressor power at various cooling loads in different diameter and length of copper pipe trombone coil.

Figure 5 shows the cooling capacity on the ASACWH system for three different coil types at various cooling loads. The cooling capacity on ASACWH with 6.4mm diameter of the coil with a length of 7.9m, 6.4mm diameter of the coil with a length of 5.3m and 9.5mm diameter of the coil with a length of 5.3m were around 3.39kW- 4.47W (increased up to 24.1%), around 2.98kW-3.23kW (increased to 8.4%) and around 3.54kW-4.1kW (increased up to 15.8%) respectively, as shown in Figure 5. The cooling capacity was obtained from the mass flow rate of refrigerant (kg/s) with the refrigeration effect (kJ/kg) or cooling capacity.

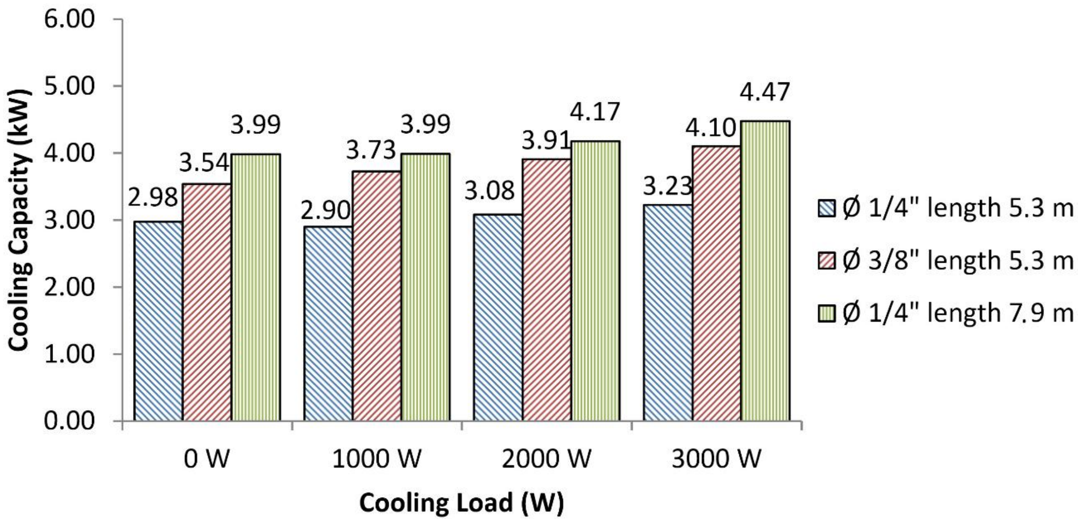


Figure 5. Cooling capacity at various cooling loads in different diameter and length of copper pipe trombone coil.

The cooling capacity increased with the increasing of cooling load. This is due to the increase of compressor power to maintain the performance of the vapour compression system as shown in Figure 4. Figure 5 shows the trombone coil with 6.4mm diameter with length 7.9m provides the highest cooling capacity compared to other coils due to an increase of cooling capacity around 24.1% as cooling load function from low to high.

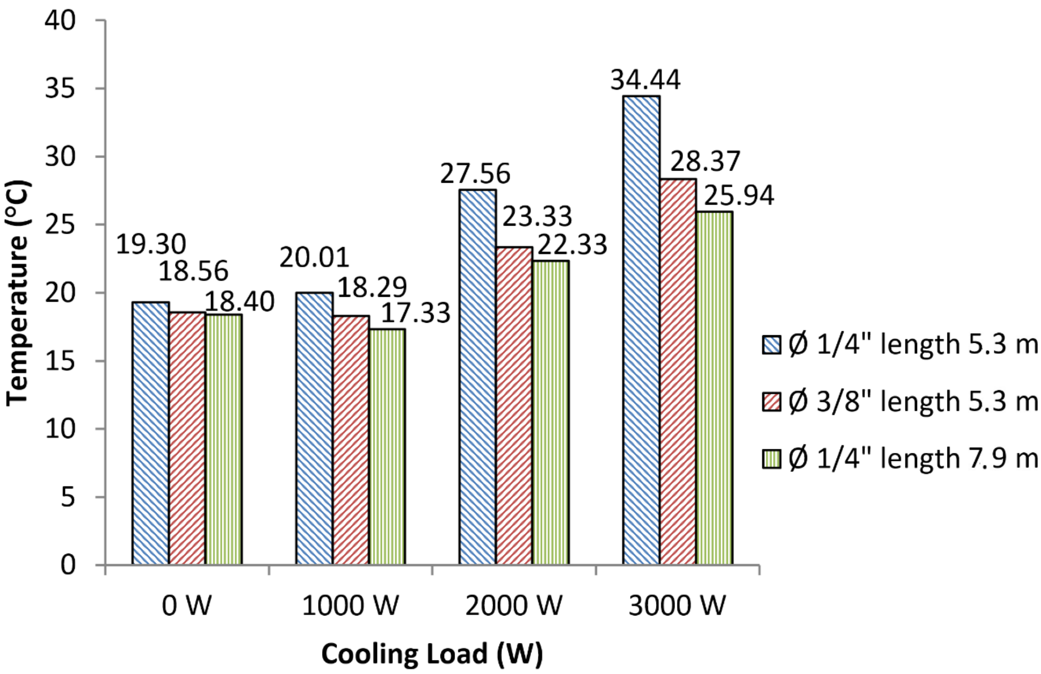


Figure 6. Room temperature at various cooling loads in different diameter and length of copper pipe trombone coil.

Figure 6 shows the room temperature in the simulation room on the ASACWH system for three different coil types at various cooling loads. The temperature change under the no-load condition and 1000W cooling load tend to be the same in narrow temperature range around 0.9ºC-2.7ºC, while in cooling load 2000W and 3000W, there was a significant temperature change in wide temperature range around 5.3ºC-8.5ºC. The highest cooling capacity was achieved with coil pipe diameter 6.4mm with 7.9 m length than the other types (Figure 5), where will affect the achievement of room temperature.

The achievement of room temperature with coil pipe diameter 6.4mm with 7.9 m was lower than other pipe types (pipe diameter 6.4mm with 5.3m in length and diameter 9.5mm, 5.3m length) as shown in Figure 6. The higher cooling load variation from 0 W, 1000 W, 2000 W and 3000 W, the higher the room temperature difference in each load where the type of coil pipe with diameter 6.4mm in 7.9m length gave the lowest temperature achievement compared to the other pipes types, both in conditions without cooling load (0W) and with a cooling load of 1000W, 2000W and 3000W.

Figure 7 shows the hot water temperature in a hot water tank without circulation on ASACWH system for three different coil types (6.4mm diameter of the coil with a length of 7.9m, 6.4mm diameter of the coil with the length of 5.3m and 9.5mm diameter of the coil with the length of 5.3m) as a function of the cooling load from 0W, 1000W, 2000W and 3000W.

The highest water temperature achieved by ASACWH with a 6.4mm diameter of the copper coil with a length of 7.9m is 48.34 ˚C lower than the water temperature of 9.5mm diameter of the copper coil with a length of 5.3m which is 64.33˚C and higher than the temperature of the 6.4mm diameter of copper pipe with a length of 5.3m, which is 47.30˚C as shown in Figure 7. This is due to 6.4mm diameter of copper pipe with a length of 7.9m (the same surface area with 9.5mm diameter of copper pipe with 5.3m length) has a larger surface contact area with water than 6.4mm diameter of copper pipe with a length of 5.3m. Whereas the 6.4mm diameter of copper pipe with 7.9m length has a smaller surface contact area with water than the 9.5mm diameter of copper pipe with a 5.3m length.

The temperature comparison of refrigerant as working fluid at suction and discharge of compressor for 6.4mm diameter of copper pipe with length 7.9m, 6.4mm diameter with 5.3m length, and 9.5mm diameter with 5.3m length, respectively due to cooling load variation are shown in Figure 8. The refrigerant temperature at suction and discharge of compressor were also influenced by the diameter of the copper pipe. The suction temperature of the compressor from ASACWH system for 6.4mm diameter of copper pipe with length 7.9m, 6.4mm diameter with 5.3m length, and 9.5mm diameter with 5.3m length were 15.4°C - 17.4°C, 16.3°C - 20.8°C and 14.2°C -17.3°C respectively. The discharge temperature of the compressor from ASACWH system for 6.4mm diameter of copper pipe with length 7.9m, 6.4mm diameter with 5.3m length, and 9.5mm diameter with 5.3m length are 48.12°C - 60.97°C, 104.18°C -105.45 °C and 79.53°C -80.59 °C respectively.

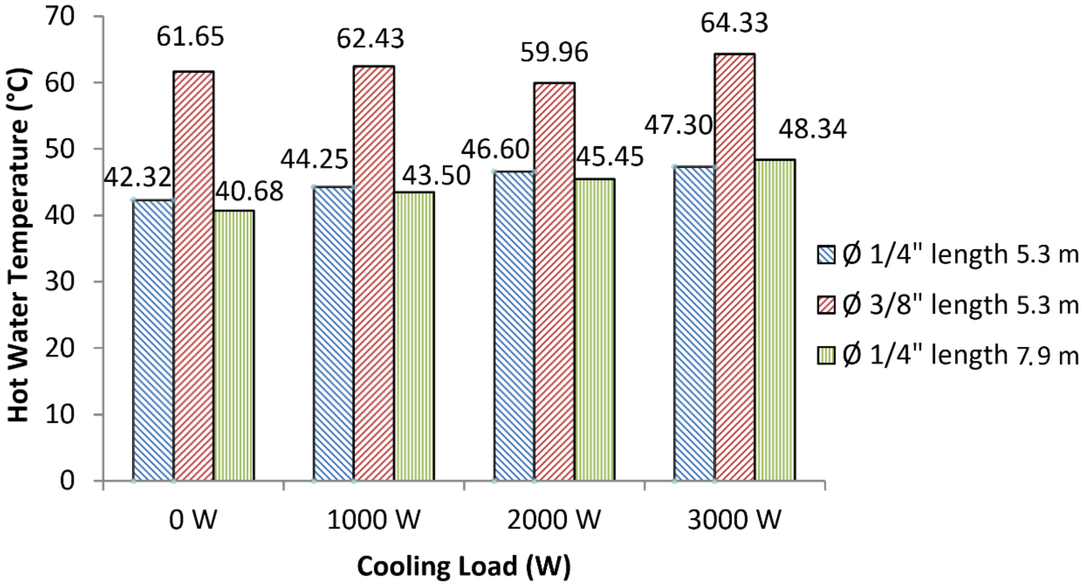


Figure 7. Hot water temperature as a function of cooling load in different diameter and length of trombone coil.

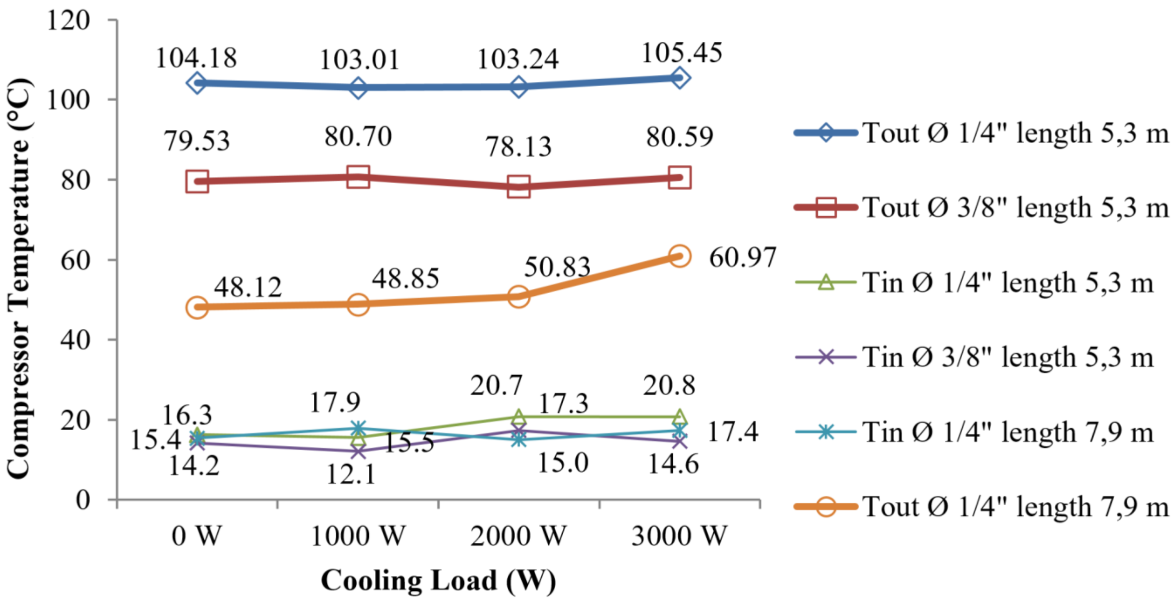


Figure 8. The comparison of suction and discharge temperature of the compressor due to the cooling load in different diameter and length of copper pipe trombone coil.

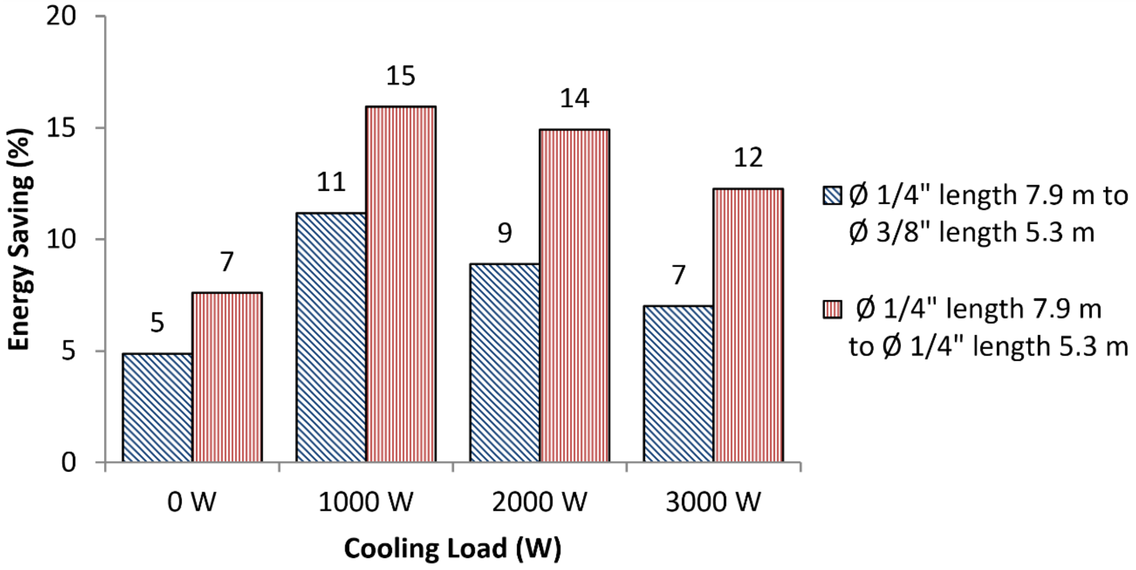


Figure 9. Energy-saving of the compressor in ASACWH at various cooling loads in different diameter and length of copper pipe trombone coil.

Figure 9 shows the energy saving of compressor in ASACWH at various cooling loads for 6.4mm diameter 7.9m length to 9.5mm diameter 5.3m length and 6.4mm diameter 7.9m length to 6.4mm diameter 5.3m length of copper pipe trombone coil. Compressor power was calculated to determine energy saving (energy saving) on the use of each copper pipe trombone coil with different diameter and length. The use of copper pipe with 6.4mm diameter 7.9m length compared with 6.4mm diameter 5.3m length was resulted in energy savings with a percentage of 7%-15%. The use of copper pipe with 6.4mm diameter 5.3m length compared with 9.5mm diameter with length 5.3m was resulted in energy saving 5%-11% as shown in Figure 9.

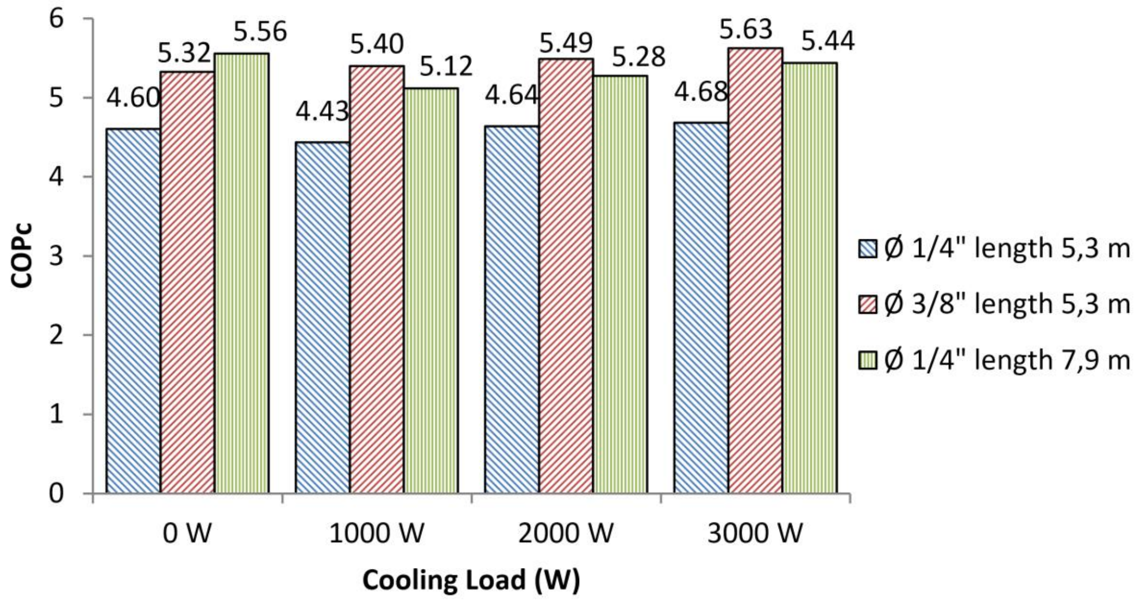


Figure 10. The COPc (COP cooling) in ASACWH at various cooling loads in different diameter and length of copper pipe trombone coil.

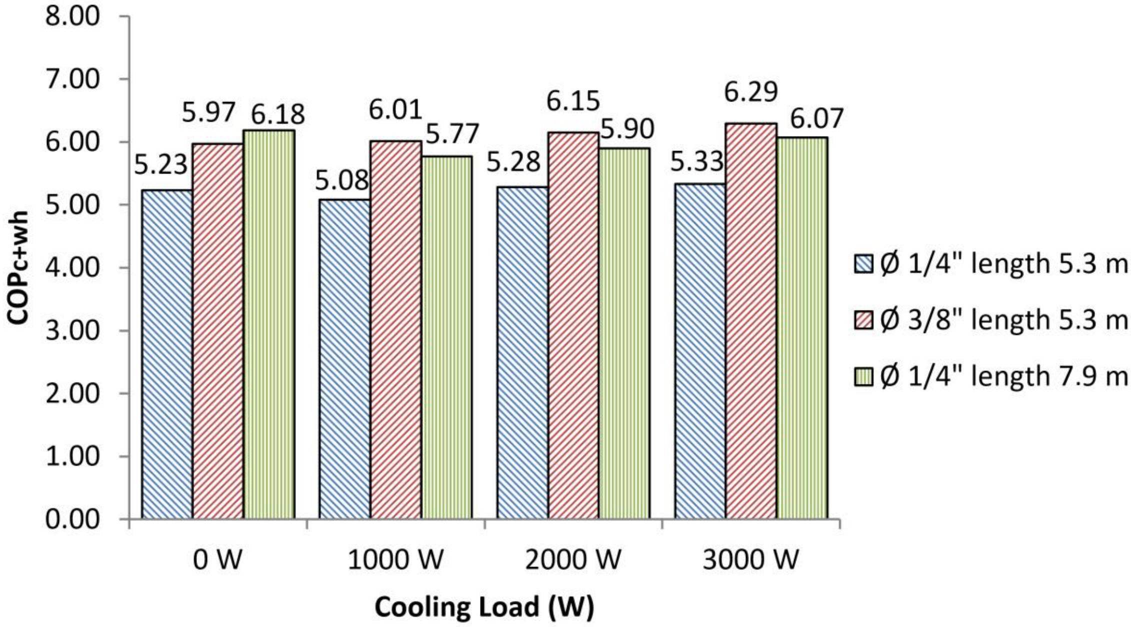


Figure 11. The COPc+wh (COP cooling and heating of water) in ASACWH at various cooling loads in different diameter and length of copper pipe trombone coil.

Figure 10 shows COPc (Coefficient of performance in cooling) without hot water circulation on ASACWH system for three different coil types (6.4mm diameter of the coil with length of 7.9m, 6.4mm diameter of the coil with length of 5.3m and 9.5mm diameter of the coil with length of 5.3m) at various cooling load from 0W, 1000W, 2000W and 3000W. Then Figure 11 shows COPc+wh (Coefficient of performance in cooling and heating water) without hot water circulation on ASACWH system for three different coil types (6.4mm diameter of the coil with length of 7.9m, 6.4mm diameter of the coil with length of 5.3m and 9.5mm diameter of the coil with length of 5.3m) at various cooling load from 0W, 1000W, 2000W and 3000W.

The increase of cooling capacity using 6.4mm diameter of the coil with 7.9m length against 6.4mm diameter of the coil with 5.3m length affect the COPc value (COP cooling) and COPc+wh value (COP cooling and heating of water). While the increase of cooling capacity using a 6.4mm diameter of the coil with 7.9m length against 9.5mm diameter of the coil with 5.3m length affects the COPc value (COP cooling) and COPc+wh value (COP cooling and heating of water). According to the experimental results, with the increasing of the cooling load, the COPc and COPc+wh values also increasing too.

The value of COPc using 6.4mm diameter of the coil with 7.9m length in testing without hot water circulation around 5.12-5.44 (increase up to 5.82%), while the value of COPc using the diameter of the coil with 5.3m length around 4.45-4.69 (increase up to 5.4%) and COPc using 9.5mm diameter of the coil with 5.3m length around 5.32-5.63 (increase up to 5.8%). The value of COPc+wh using 6.4mm diameter of the coil with 7.9m length, it is obtained around 5.77-6.07 (increase up to 5.1%), while COPc+wh 6.4mm diameter of the coil with 5.3m length, it is obtained around 5.23-5.33 (increase up to 4.9%). Then the value of COPc+wh using 3/8″ diameter of a coil with 5.3m length, it is obtained around 5.97-6.29 (increase up to 5.4%) as shown in Figure 10 and Figure 11.

The value of the COPc and COPc+wh depends on the size of the copper pipe trombone coil diameter used in the ASACWH system, as shown in Figure 10 and Figure 11 respectively. The result shows that the bigger of the copper pipe diameter, the higher of COPC value and COPC + WH value and the length of copper pipe has no significant effect.

CONCLUSIONS

The experimental study to investigate the performance of air source air conditioning water heater (ASACWH) using trombone coil dummy condenser with different diameter and pipe length without hot water circulation was reported. According to the experimental results, it can be concluded that the effect of increasing cooling load (0W, 1000W, 2000W, and 3000W), using 1/4" diameter of the coil with 7.9m length, 6.4mm diameter of the coil with 5.3m length and 9.5mm diameter of the coil with 5.3m length, the compressor power increased by 11.3%, 6.3% and 9.3%, respectively. The results show that the higher cooling load, the compressor's power is higher too, where the cooling capacity and COP were also increasing. This is because heat absorption is greater when the cooling load rises so that the cooling capacity and the COP increase too. The room temperature on the use of 6.4mm diameter of the coil with 7.9m length is more convenient than the use of 6.4mm diameter of the coil with 5.3m length and 9.5mm diameter of the coil with 5.3m length. The use of 9.5mm diameter of the coil with 7.9m length gives better cooling capacity, COP and cooler room temperature (18.56ºC, 18.29ºC, 22.2ºC and 25.94ºC) compared to 6.4mmdiameter of the coil with 5.3 m length and 9.5mm diameter of the coil with 5.3m length.

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