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Experimental Investigations on the Performance of a Water Heater using Waste Heat from an Air Conditioning System

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Abstract

Energy is one of the basic requirements for the existence and development of human life. The focus is now shifting to energy conservation due to the problems associated with conventional energy sources. This project introduces a novel water heater product that can achieve the multi-functions with improved energy performance. This paper deals with experimental investigations on the performance of a water heater, which uses waste heat from a 1.5 tonne air conditioner. Thus incorporation of a water heater in the outdoor unit of a split-type air-conditioner would result in simultaneous room space cooling and water heating. The experimental results showed that the water heater is capable of producing 88 litres of hot water in one hour of time with a temperature of 52°C. It is seen that up to 37°C of hot water temperature, COP of the waste heat recovery system is more than the COP of conventional air conditioner. But after 37°C, with the increase in hot water temperature, the COP of the waste heat recovery system decreases and becomes less than the COP of conventional air conditioner.

Keywords: COP, Water Heater, Waste Heat Recovery, 1.5 Tonne Air Conditioner

1. Introduction

Waste heat from an air conditioning system can be used to heat domestic water. An enormous amount of waste heat is rejected from the air conditioner's condenser to the atmosphere. This waste heat can be recovered and utilized it to heat water, which could reduce water-heating costs. Shaowei Wang et al[1] have experimentally studied a split air conditioner with a new hybrid equipment of energy storage and water heater all year round (ACWES). Abu-Mulaweh et al[2] have analyzed the design and performance of a thermo siphon heat recovery system which recovers heat rejected from an air conditioner and it is described by presenting some experimental test data. Heat recovery from an air conditioner by thermosiphon is attractive because it eliminates the need for a circulating pump. Results indicate that the design of the thermosiphon heat recovery system was a success. The study has shown that such a system is technically feasible and economically viable. Di Liu et al[3] have developed a looped separate heat pipe as waste heat recovery facility for the air-conditioning exhaust system in this work. An experiment was implemented to validate the simulated results. The numerical predictions compare favorably with experimental results. Huimin Jiang et al[4] have carried out an experimental study on the waste heat recovery from the condenser of an air conditioner which experimentally studies a modified air conditioner that operates in the space-cooling and water-heating mode. Mostafa et al[5] have carried out a experimental investigation on heat pipe heat exchangers which are used in heat recovery applications to cool the incoming fresh air in air conditioning applications.

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Techarungpaisan et al[6] have simulated a model on to predict the performance of a small split type air conditioner with integrated water heater. The mathematical model consists of sub models of system components such as evaporator, condenser, compressor, capillary tube, receiver and water heater. It was found that the experimental and simulation results are in good agreement. Guangcai Gong et al[7] have carried out a experimental work on a new heat recovery technique for an air-conditioning/heat-pump (AC/HP) system. Hua Chen et al[8] have carried out an experimental investigation on a split type air conditioner with air cooled condenser and water cooled condenser at different conditions of indoor and outdoor temperatures. From the experimental testing results, it can be seen that Coefficient of Performance (COP) of the air conditioner with water cooled condenser is 14.7% more than that of air conditioner with air cooled condenser. Yi Xiaowen et al[9] have carried out a experimental investigation on the performance of a air-conditioner with water cooled condenser which consists of a helical heat exchanger of tube in- tube type. Ming Liu Jiang et al[10] have studied performance of air conditioner in which waste heat is recovered from the condenser. From the experimental testing results, it can be seen at the start of the heat recovery process, the condensing heat recovery has a negative effect on the cooling capacity. Experimental investigations were carried out to investigate the performance of air conditioning systems in which waste eat is recovered by using a water cooled condenser[11,12]. From the experimental testing results, it is clear that the Coefficient of Performance (COP) initially increased, but the temperature of water affects the COP of the system significantly, which works as air-water heat pump. Therefore, the aim of this paper is to present the outcomes on waste heat recovery from an air conditioning system.

2. Constructional Details and Test Procedure of the Experimental Set-up

The experimental set-up mainly consists of a 1.5 tonne air conditioner with a reciprocating compressor, evaporator, air cooled condenser, water cooled condenser, compressor, water tank. The overall experimental set-up is shown in Figure 1 as a block diagram.

A water cooled condenser recovers waste heat from the system also functions as a heat pump. The whole experimental set-up used for the experimental study is shown in Figure 2. In the present experimental investigation, refrigerant R-22 is used as a refrigerant for the system. Suction pressure, temperature, discharge pressure and temperature of the refrigerant of the system with air cooled and water cooled condenser is measured by pressure gauges and temperature sensors which are fitted at both the ends of the compressor as shown in Figure 3. Power consumption by the compressor is found by using an energy meter. Regarding the water cooled condenser, it consists of copper tube coils which are immersed in the hot water tank. The water tank is made of mild steel. The dimensions of the water tank were chosen based on the dimensions of condenser. As shown in Figure 4, the condenser is submerged in the water tank. The tank is of length 50 cm, height 65 cm, width 30 cm and capacity 88 litres.

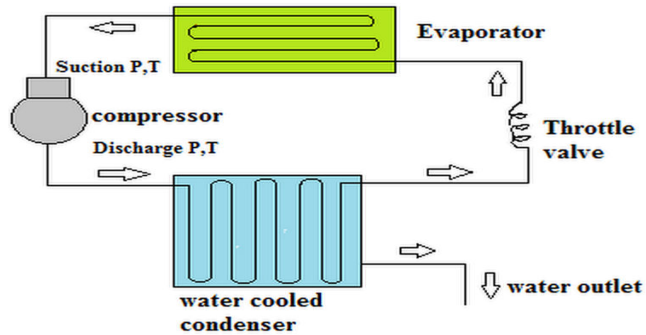

Figure 1. Block diagram.

Evaporator is placed in the room. Room temperature is kept at 22, 24 and 26 degree Celsius. The suction pressures, temperatures, discharge pressures, temperatures at the compressor inlet and outlet for the different conditions of indoor temperature are noted. The temperature at the condenser outlet is also noted to calculate the heat rejected in the condenser for the same conditions. The power consumption by the compressor is determined by the wattmeter by noting the number of revolutions from it. For every 5 minutes readings are noted experimentally from the system. The power consumption and COP of the system with air cooled condenser and water cooled condenser is determined by adopting the above procedure separately for the systems with air cooled condenser water cooled condenser respectively. The COPs of the both the systems determined were compared. The initial and final temperatures of the water in the tank were noted. Thus the rate in which the water is heated is calculated for three different conditions of indoor temperature. The influence of water temperature on the COP of the system was also

Figure 2. Experimental set up.

Figure 3. Compressor fitted with pressure gauges and temperature knobs.

Figure 4. Condenser submerged in water tank.

investigated. The above procedure is first done for air cooled condenser and then it is repeated for the water cooled condenser after fitting the water tank. The following are the formulae used for performance evaluation,

- Mass Flow rate of refrigerant, m_r = Capacity in kW/ $(h_1 - h_4)$ (1)
- Refrigeration Effect (Re) = $(h_1 - h_4)$ (2)
- Compressor work (W) = $m_r \times (h_2 - h_1)$ (3)
- Heat rejected in the Condenser = $m_r \times (h_2 - h_3)$ (4)
- Power consumption by the compressor

  $$(W) = \frac{300 \times n}{3600 \times t} \quad (5)$$

  Where,
  n = number of revolutions of compressor,
  t = time taken for n revolutions in seconds.
- Coefficient of Performance, (COP) = $(h_1 - h_4)/(h_2 - h_1)$ (6)

  Where,
  h_1 = Enthalpy at the beginning of compression in kJ/kg,
  h_2 = Enthalpy at the end of compression in kJ/kg,
  h_3 = Enthalpy at the beginning of the expansion in kJ/kg,
  h_4 = Enthalpy at the end of expansion in kJ/kg.

By using the above formulae, the COP, power consumption of the system with air cooled condenser and water cooled condenser is found out.

- Heat transfer in the tank, $Q = m\, C_p\, (T_2 - T_1)$ (7)

  Where,
  m = mass flow rate of water in kg/sec,
  C_p = specific heat capacity of water in kJ/kg K,
  T_2 = final temperature of water in degree Celsius,
  T_1 = initial temperature of water in degree Celsius.

3. Results and Discussion

From the Figure 5, it is clear that for room temperatures of 26°C, 24°C, 22°C COP of the system decreases gradually with the increase in room temperature. The COP of the system is higher for a room temperature of 26°C than for 24°C and 22°C. The COP of the system is higher for a higher room temperature when compared with lower room temperature. With the decrease in room temperature, the COP of the water cooled condenser decreases.

From the Figure 6, it can be seen that the COP of the water cooled condenser with a hot water temperature of 33°C is higher than the COP of the water cooled with a hot water temperature of 37°C. When the room temperature increases the COP for both air cooled and water condenser increases. Up to 37°C of hot water temperature, the COP of the water cooled condenser is more than the COP of the air cooled condenser.

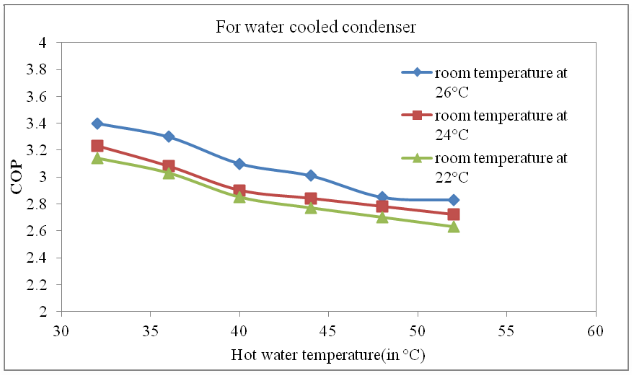

Figure 5. Comparison of COP for water cooled condenser at different room and hot water temperatures.

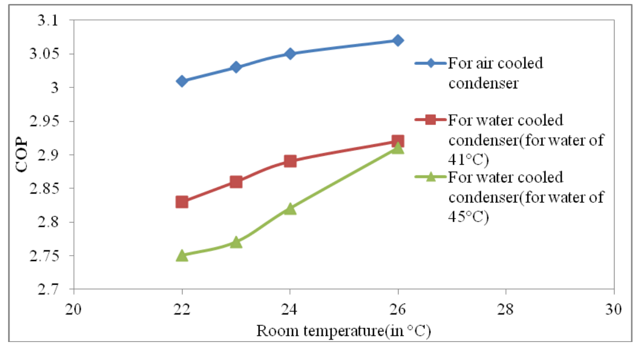

Figure 7. Comparison of COP for air cooled condenser and water cooled condenser (at 41°C and 45°C of water temperature).

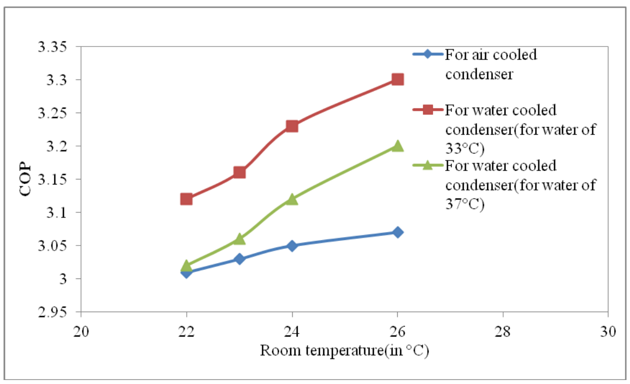

Figure 6. Comparison of COP for air cooled condenser and water cooled condenser (at 33°C&37°C of water temperature)

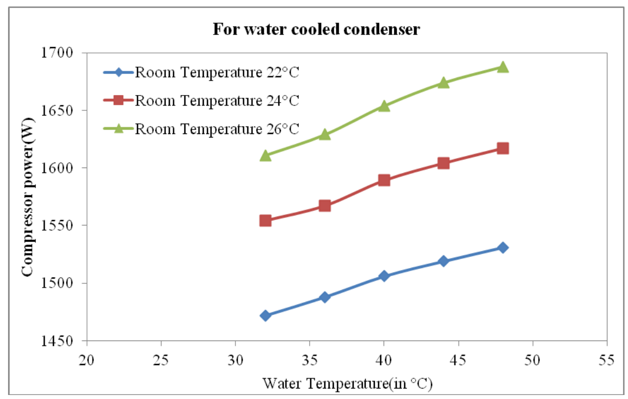

Figure 8. Comparison of compressor power for different room temperatures.

From the Figure 7, it is observed that the COP of the water cooled condenser with a hot water temperature of 45°C is higher than the COP of the water cooled with a hot water temperature of 41°C. When the room temperature increases the COP for both air cooled and water condenser increases. After 37°C of hot water temperature the COP of water cooled condenser decreases gradually than that of air cooled condenser due to improper condensation of refrigerant. The COP of water cooled condenser decreases with the increase in hot water temperature.

From the Figure 8, it can be seen that the compressor power for room temperature of 26°C is higher than that for room temperatures of 24°C and 22°C. With the increase in room temperature and hot water temperature the compressor power consumption of system with the water cooled condenser increases. For higher room temperatures the work done by compressor is high, so the power consumption of the compressor is high for high room temperature. The compressor power increases with the increase in water temperature.

From the Figure 9, it is clear that the heat rejected from the water cooled condenser is maximum for a room temperature of 22°C when compared with other room temperatures of 24°C and 26°C. For a lower room temperature, the amount of the heat to be removed from the room is high when compared to higher room temperatures. Due to this reason, a large amount of heat is rejected from the water cooled condenser for a lower room temperature. So, the heat rejected from the water cooled condenser increases with the decrease in room temperature. The water temperature increases with the increase in the heat rejected from the condenser.

From Figure 10, it is observed that the time taken for heating of water is less for a lower room temperature of 22°C, when compared to higher room temperatures of 24°C, 26°C. This is due to the reason that, a large amount of heat is rejected from the water cooled condenser for

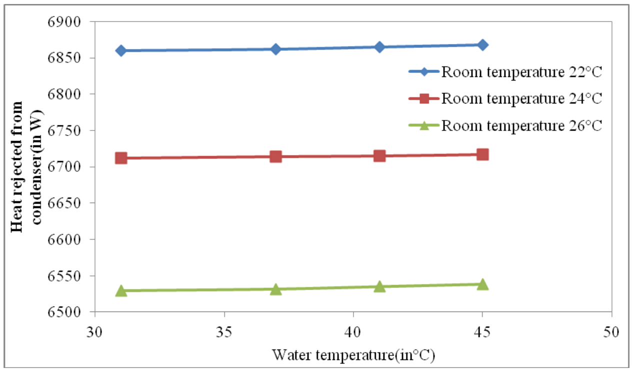

Figure 9. Comparison of the condenser heat rejected for different water and room temperatures.

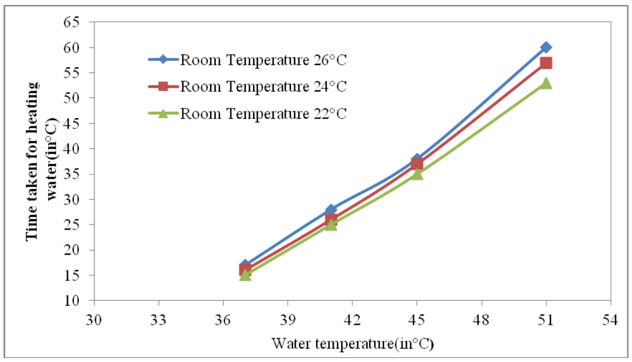

Figure 10. Comparison of the time taken for heating water for different room and water temperatures.

a lower room temperature of 22°C, when compared to higher room temperatures. So the rate of heating of water occurs at a faster rate for a lower room temperature than for higher room temperatures. The water temperature increases with the increase in time. It is seen that with the increase in room temperature the rate of heating of water decreases due to the decrease in the heat rejected from the water cooled condenser.

From the Figure 11, it is seen that the heat transfer in the water tank is maximum for a room temperature of 22°C than for room temperatures of 24°C and 26°C. This is due to the reason that the heat rejected from the condenser is maximum for a room temperature of 22°C when compared with other room temperatures.

The rate of heating of water occurs at a faster rate for a lower room temperature than for higher room temperatures. The heat transfer in the water tank increases with the increase in time. With the increase in room temperature the heat transfer in the water tank decreases due to the decrease in the heat rejected from the condenser.

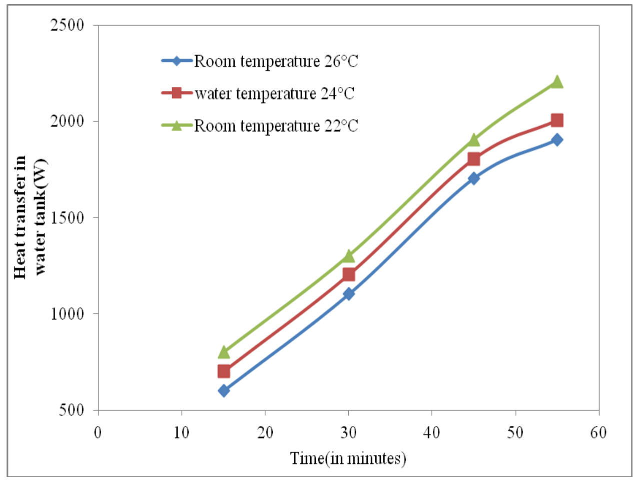

Figure 11. Comparison of the heat transfer in water tank for different room temperatures

4. Conclusion

During the experimental investigation on the performance of the water heater using waste heat recovery from a 1.5 tonne air conditioning system, the results showed that the water heater is capable of producing 88 litres of hot water in one hour of time with a temperature of 52°C. The COP of air conditioner with water cooled condenser is more than the COP of air conditioner with air cooled condenser till the water in the tank attains a temperature of 37°C. But after 37°C of temperature of hot water, due to improper condensation of refrigerant the COP of the system with water cooled condenser decreases and becomes less than the COP of air conditioner with air cooled condenser. The COP of the system with water cooled condenser decreases with the increase in temperature of the water in tank. The power consumption of air conditioner with water cooled condenser is less than that of the air conditioner with air cooled condenser till the water in the tank attains a temperature of 37°C. After 37°C of temperature of hot water, the power consumption of air conditioner with water cooled condenser increases than that of the air conditioner with air cooled condenser. The rate in which the water is heated is maximum for minimum room temperature due to maximum heat rejection from the condenser at that condition. This water heater could also eliminate the need for a separate water heater and there by a enormous energy can be saved. By using this device, energy efficiency can be improved by cutting the costs for heating water.

5. References

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