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Performance of Heat Pipe with Different Working Fluid on Harvesting Wasted Heat Energy at Air Cooled Split Unit

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ABSTRACT

These days, life would not be comfortable without air conditioning which leads to high power consumption due to air conditioning and subsequently increases the carbon footprint. In this research, verification was done on the capability of increasing superheat to improve the performance of the air-cooled split unit and the effect of power consumed by the air conditioning system. The superheat was increased by the heat harvested from the condensing unit of the air-cooled split unit by using a heat pipe. The heat pipe was charged with water, R134a, and R600a with a 100% filling ratio and 90° and 70° inclination angles. K-Type thermocouples, pressure gauges, and power meter were used in data collection. According to data analysis, water with a 90° inclination angle of heat pipe showed the best performance compared to other fluids because of its ability to increase superheat by approximately 32% compared to R600a which increased only approximately 6.5% compared to normal conventional air conditioning. However, it demonstrated that a rise in the superheat at the suction line and a rise in the Coefficient of Performance cannot guarantee a fall in energy usage. This was due to an increase of superheat by the water heat pipe at 90° angle inclination indicating approximately a 28.8% increase in power consumption.

1. Introduction

Air Conditioning (AC) system play a vital role in facilitating the cooling of many essential infrastructure, including residential dwellings, commercial establishments, medical facilities, data centers, laboratories, and other pivotal structures that contribute significantly to our economy and daily operations. The use of AC, once considered as luxurious amenity, has now become an essential necessity, accounting for substantial proportion of total energy usage, as stated by Bernama [1], reaching up to 48%. Increased electricity use for AC systems can contribute to the release of greenhouse gases, hence exacerbating climate change and global warming [2-4]. In addition, the dissipation of heat to the surrounding environment from condenser part of Outdoor Unit (ODU) of AC system can also have impact on global warming and the phenomenon of urban heat island. The

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heat release also indicates the presence of energy inefficiency [5,6]. Efforts have been made to harness and reuse dissipated waste heat energy to mitigate the excessive energy consumption associated with AC systems.

1.1 AC System and Superheat

The core components of the AC cycle are the compressor, condenser, expansion valve, and evaporator. The compressor is the significant component that utilizes the most energy. As a result, the compressor efficiency is determined by the input current and energy extracted. The compressor compresses the refrigerant until it reaches a superheated state at high pressure and high temperature to start the AC cycle. Once within the condenser coils of the air-cooling unit, the liquid condenses. As the temperature and pressure drop, the fluid enters the expansion valve, where it turns into liquid and goes into the evaporator. Heat exchange occurs between the refrigerant within the evaporator coil and the air within the space that being conditioned. The heat exchange process result in an elevation of both the temperature and enthalpy of the refrigerant, ultimately leading it to attain a superheated state before it returns to compressor via suction line [7,8].

The superheat value is determined by subtracting the saturation temperature from the actual temperature. The saturation temperature is derived from the data collected during the pressure conversion process, which involves measuring the temperature. Superheat is the result of subjecting refrigerant to prolonged heating under a constant pressure beyond its saturated steam limit. The superheat value is determined by subtracting the saturation temperature from the actual temperature[9].

1.2 Renewable Energy

The rapid economic expansion experiences in Malaysia has resulted in a significant surge in energy consumption, namely in the domain of electrical energy utilised by both commercial and residential structures [10,11]. Numerous studies have been conducted by researchers to investigate strategies for addressing the environmental impacts of AC, particularly in relation to greenhouse gas emissions, global warming, and the urban heat island phenomenon. A study conducted by Al-Fahham *et al.,* [10] involved the utilisation of Heat Pipe Heat Exchanger (HPHE) to regulate the subcooling of refrigerant after the condenser section of a window AC system, as well as the superheating of the refrigerant prior to its suction into the compressor. The HPHE copper shell consists of two distinct components. The upper section of the copper shell comprises the evaporated working fluid, which is prepared to heat up the refrigerant in the suction line. This refrigerant flows through the copper shell via a capillary tube. The working fluid undergoes condensation during the heat exchange process occurring between the refrigerant in the suction line and the working fluid located at the upper section of the copper shell. The subcooling of the system is influenced by the immersion of the capillary tube, which carries high-temperature liquid refrigerant from the condenser, into the working fluid located in the lower section of the copper shell. Based on Eidan *et al.,* [12] findings, it has been observed that the utilisation of HPHE to elevate subcooling levels can lead to a notable enhancement in refrigeration capacity, ranging from 5% to 7.5%. Furthermore, an increase in mass flow rate ranging from 6.5% to 10% resulted in a corresponding decrease in power consumption ranging from 2% to 5%. The findings align with the research findings of Al-fahham *et al.,* [10].

In the year 2020, Vinson Chua [13,14] successfully developed a hybrid AC system through the utilisation of evacuated thermosyphon heat pipe technology. The energy which was gathered was subsequently reused to facilitate the process of superheating the refrigerant within the system, causing its transformation from gas with low pressure and low temperature to gas with high pressure and high temperature. The research findings indicated that the utilisation of hybrid AC systems can result in energy savings of up to 55%.

Nevertheless, research conducted by Ardita *et al.,* [9] has shown differences in their findings, indicating that an increase in superheat results in a corresponding rise in power consumption ranging from 0.03% to 0.1%.

1.3 Heat Pipes

Heat pipes are commonly employed to enhance the recovery and utilization of thermal energy. Heat pipes, recognized as a highly efficient passive devise for thermal energy transfer, were capable of transferring energy with minimum temperature disparity [12,15–17]. Heat pipes operated as a closed-loop system that used a working fluid undergoing phase transition. The three divisions into which they were categorized are evaporation, condensation, and the adiabatic zone [15,18, 19]. The efficacy of heat pipes as devices capable of functioning throughout a broad spectrum of temperature variations and aiding in energy conservation has been established by several studies involving AC.

There are various aspects that can potentially impact the functioning of a heat pipe. The performance of the system may be influenced by several factors, including the selection of the working fluid, the angle of inclination, and the filling ratio (FR) of the working fluid. The disparity can impact the dry out effect and quantity of heat absorption and transfer by the working fluid [20–22].

There were inconsistencies in the findings on the influence of superheating changes on energy savings and performance of the system, with varying conclusions regarding whether such changes have a beneficial or negative effect. There were variances in the outcomes of prior study about the optimal working fluid and angle of inclination that yield the most efficient performance of a heat pipe and the suitable working fluid and angle inclination of the new innovated heat pipe need to be discovered. Therefore, the objective of this study is to investigate the potential impact of changes in superheat on the efficiency of air conditioning systems. The regulation of superheat variation is contingent upon the selection of distinct working fluid and the adjustment of the inclination angle of a heat pipe. Throughout the course of this study, the efficacy of the innovative heat pipe technology in energy harvesting was examined. Additionally, the impact of altering the superheat on the air conditioning system was confirmed by the collection and analysis of data.

2. Methodology

The primary aim of this study is to validate the influence of hybrid air conditioner superheat increase on the operational performance and energy consumption of AC systems. Superheat was adjusted by altering the angle of inclination of the heat pipe and the type of working fluid employed. Figure 1 illustrates how the heat discharged was transferred to the heat pipe between the evaporator and the compressor suction to control the system's superheat.

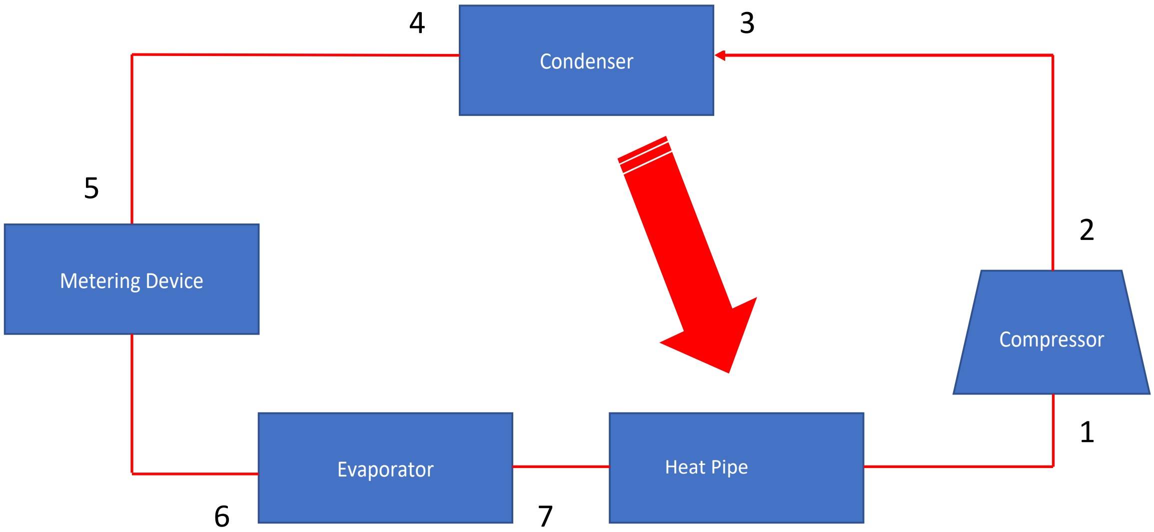


Fig. 1. Schematic diagram of hybrid air conditioner by using heat pipe to harvest the heat dissipated at condensing unit

The working fluid and angle of inclination are the variable features of the heat pipe. In this research, the working fluids selected for study included R134a, water and R600a, each having a FR of 100%. The selection of these working fluid types was based on their extensive use in heating pipes and their exceptional thermal efficiency in diverse HVAC applications. The experiment was divided into two primary portions, with the initial section focusing on the analysis of conventional refrigerant cycles in commercial AC. A total of six test sets were undertaken in order to investigate the efficacy of the AC system utilizing a heat pipe that was loaded with different types of working fluid. Additionally, two inclination angles, specifically 90 deg and 70 deg, were considered throughout the experimentation process. Table 1 presents a comprehensive list of parameters that were included in the scope of this investigation.

Table 1
List of experimental set up components and parameters

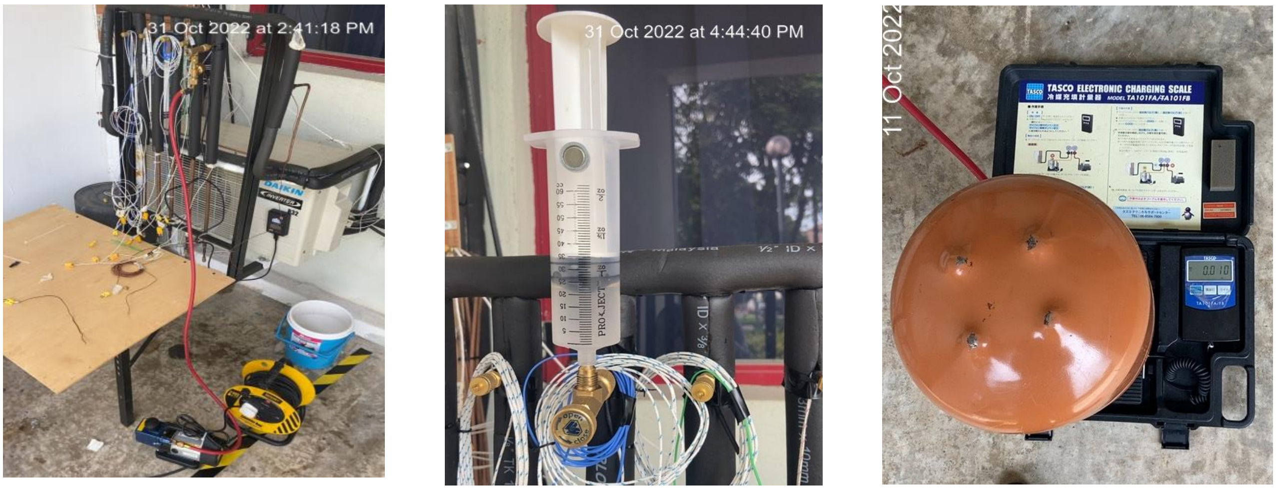
Part	Specification	Value
Air Cooled Split Unit (ACSU)	• Cooling capacity • Indoor design condition • Outdoor condition • Refrigerant	• 1 HP • 16 °C ± 5 °C , 65% ± 5% • 35 °C ± 5 °C , 55% ± 5% • R32
Heat pipe	• Type of heat pipe • Working fluid used • Temperature change along the heat pipe	• Copper Heat Pipe • R134a, R600a and Water • 33 °C ± 5 °C , 60% ± 5%

Table 2 lists the instrument used and the parameters to comply. The working fluid was charged with the specified amount as indicated in Table 2.

Table 2
List of equipment and parameters to control

Syringe 	a) Syringe properties - Min: I ml - Max: 60 ml - Accuracy: 1 ml b) Volume of water: 316 ml ± 1 ml
Refrigerant charging scale 	a) Refrigerant charging scale - Accuracy : 5 g b) Mass of R134a : 595 g ± 5 g c) Mass of R600a : 375 g ± 5 g

The process of vacuuming the heat pipe to achieve a relative vacuum pressure of 500 micron typically required a minimum of 30 minutes using a vacuum pump as illustrated in Figure 2a. Two discrete methodologies were employed for inserting the working fluid into the heat pipe. Method shown in Figure 2b involved the utilization of a syringe for injecting water, with careful monitoring of the volume to ensure the filling ratio was 100%. The second shown in Figure 2c approach involved implementing a weight-based system for R134a and R600a.



a) b) c)

Fig. 2. a) Vacuum procedure for working fluid charging work b) Charging method by volume using a syringe c) Charging method by using the weight the of working fluid

The experimental setup continued with the collection of pressure, temperature change, and power consumption data. Changes in temperature across the AC system were detected using a type K thermocouple and data logger, as depicted in Figures 3a and 3b. The measurement of pressure changes inside the system was conducted by employing a custom-made pressure gauge, as depicted in Figure 3c. Also, Figure 3d illustrates the utilization of a plug-in power meter to monitor the power consumption of the system.

a) b) c) d)

Fig. 3. a) K-Type thermocouple, b) Data logger, c) Pressure gauge, d) Plug in power meter

The data were collected 3 times per day to observe the changes of the system performance. The collected data was tabulated and presented in Table 3 and Table 4.

3. Results

3.1 Refrigerant Cycle in Conventional AC System and Modifies Hybrid AC with Heat Pipe

Table 3 shows the obtained data referring to the angle inclination of the heat pipe at 70^0, while Table 4 displays the collected data for the angle of inclination of the heat pipe at 90^0. Reading number 1 signified the system's performance in the morning, whereas reading number 2 was obtained throughout the afternoon. Data for reading number 3 was gathered during the evening.

Table 3
Reading for 70° angle of inclination of heat pipe

Heat pipe	**Conventional air conditioning**			**100% FR water**			**100% FR R134a**			**100% FR R600a**		
Set of reading	1	2	3	1	2	3	1	2	3	1	2	3
Pressure												
Point 1	143	140	141	155	155	150	149	149	150	145	148	148
Point 2	409	425	421	400	402	406	436	417	452	420	421	410
Point 3	409	420	419	395	399	401	435	421	449	419	420	402
Point 4	409	410	411	389	390	399	430	405	440	410	415	398
Point 5	409	410	411	389	389	399	429	400	439	409	410	392
Point 6	170	160	160	169	170	170	189	170	191	169	175	170
Point 7	150	142	140	145	146	146	160	152	163	147	150	145
Temperature												
Point 1	12.5	11	12.5	15	14.7	15.2	14.4	14	15.6	13	13.5	13.5
Point 2	84.5	85	85	77.6	78.5	77.3	82.5	82	85	83.5	84	83
Point 3	77.6	79	76.5	80	80	80	82	81.3	81	80.5	80.2	81.3
Point 4	33.0	33	34	29	26	28	33	30	33	32	33	32
Point 5	27.7	18.3	17	27	28.5	29	33	28.5	30	27.5	28.4	28.2
Point 6	13.6	12.5	12.1	14.3	15	15.6	17.3	15.4	17.8	14.3	15.5	15.5
Point 7	11	10	10.7	12.6	10.8	11	13.5	12	15	11	12	12

Table 4
Reading for 90° angle of inclination of heat pipe

Heat pipe	**Conventional air conditioning**			**100% FR water**			**100% FR R134a**			**100% FR R600a**		
Set of reading	1	2	3	1	2	3	1	2	3	1	2	3
Pressure												
Point 1	143	140	141	155	155	150	151	151	152	150	150	150
Point 2	409	425	421	388	381	408	440	452	448	405	419	415
Point 3	409	420	419	382	379	401	439	450	442	400	411	410
Point 4	409	410	411	380	375	396	430	444	440	395	409	405
Point 5	409	410	411	375	370	390	430	444	432	390	402	410
Point 6	170	160	160	162	160	172	183	197	195	160	165	160
Point 7	150	142	140	140	140	142	160	170	167	140	142	141
Temperature												
Point 1	12.5	11	12.5	15.5	15.2	15.5	14.6	14.2	15.8	14.1	13.7	12.8
Point 2	84.5	85	85	76.2	76.4	77.4	82	83	83	82.4	83.5	82.5
Point 3	77.6	79	76.5	78	78	79	84.4	81.5	80.5	83.3	80	79
Point 4	33.0	33	34	26	26.2	28	30	32.6	33	31	32	30
Point 5	27.7	18.3	17	28	27	28	33.3	31	30	28	28	27.1
Point 6	13.6	12.5	12.1	13.8	13.5	15.6	17.4	19	17.5	14	14.1	13.5
Point 7	11	10	10.7	10	10	11.9	13.6	14.6	16.1	11	10	9.4

The thermodynamic analysis was conducted through the comparison of the normal AC with the modified AC. The pressure and temperature collected were used to obtain the enthalpy change throughout the system by using Microsoft Excel Add-In and Pressure-Enthalpy (P-H) diagram.

Figure 4 presents the Pressure-Enthalpy (P-H) diagram illustrating the refrigerant cycle. At the initial stage, the compressor received superheated refrigerant at a low pressure. During the compression process, the pressure of the refrigerant increased until it reached point 2. Pressure drop occurred as the refrigerant exited the compressor and underwent further condensation until it reached the point 4. Upon the refrigerant's entry into the metering device, a pressure decrease occurred at constant enthalpy between points 4, 5 and 6. When a result of the phase change of the refrigerant, a further fall in pressure occurred when it underwent the process of moving through the evaporator, specifically from points 5 and 6 to point 1. The pressure differential between point 5 and 6 to point 1 exhibited a lesser magnitude compared to the pressure differential between point 5 and point 1. The observed phenomenon was attributed to the heating of the suction line after the heating of the heat pipe. The presence of heat pipe did indeed impact both the pressure drop and the superheating of the AC.

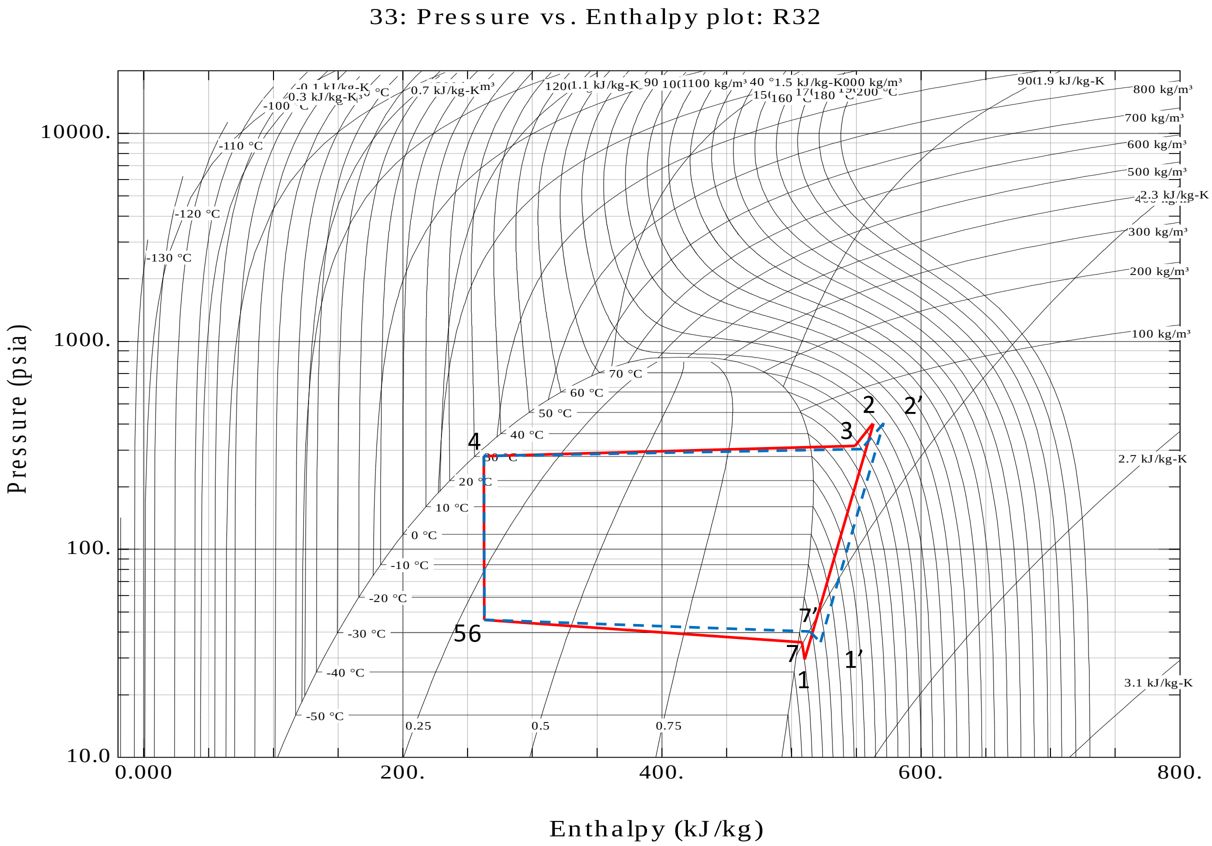


Fig. 4. Refrigerant cycle of AC in P-H diagram with and without heat pipe

The calculation of enthalpy was carried out using the temperature and pressure values obtained from the data. To evaluate the operational efficiency of the AC system, further calculations were conducted utilizing the enthalpy.

The evaluation of a system's performance involved the calculation of the refrigerant effect, denoted as $\mathrm{Q_e}$. The determination of the refrigerant's enthalpy was based on the difference between the enthalpy of the refrigerant vapor as it exited the evaporator and the enthalpy of the liquid refrigerant after it has passed through the expansion valve. The equation for determining the refrigerant effect in a typical conventional AC system was presented as Eq. (1), whereas Eq. (2) represents the computation for an AC system including a heat pipe.

$$Q_{e,ACSU} = h_6 - h_1 \quad (1)$$
$$Q_{e,ACSU+heat\ pipe} = h_6 - h_1 \quad (2)$$

In order to assess the energy transformations occurring within the compressor and evaluate its efficiency, the calculation of compressor work done has been performed for conventional AC systems using Eq. (3) and modified AC systems including heat pipe technology using Eq. (4). The enthalpy utilized in the calculation was acquired from the REFPRO database.

$$w_{comp,ACSU} = h_2 - h_1 \quad (3)$$
$$w_{comp,ACSU+heat\ pipe} = h_2 - h_{1'} \quad (4)$$

The Coefficient of Performance, COP has been calculated to assess the overall performance of the AC system. The determination of COP involved the application of the ratio between the

Refrigerant Effect and Work Done by Compressor. Both conventional AC Eq. (5) and modified AC with heat pipe Eq. (6) utilized the same formula.

$$COP_{ACSU} = \frac{Refrigerant\ Effect, Q_e}{Work\ Done\ By\ Compressor, W_{COMP}} = \frac{h_6 - h_1}{h_2 - h_1} \quad (5)$$

$$COP_{ACSU+heat\ pipe} = \frac{Refrigerant\ Effect, Q_e}{Work\ Done\ By\ Compressor, W_{COMP}} = \frac{h_6 - h_1}{h_2 - h_1} \quad (6)$$

The calculation of superheat as shown in Eq. (7) was performed to determine the quantity of heat extracted from a heat pipe, which affected the thermodynamic cycle of the AC system. The saturated temperature of the refrigerant was obtained from the Daikin R32 handbook [23].

$$Superheat = Suction\ Temperature - Saturated\ Suction\ temperature \quad (7)$$

The calculated data of daily reading were represented in graphs, with Figure 5 illustrating the changes of system superheat, and Figure 6, depicts changes of COP of the system. Figure 5 illustrates the decrease in superheat levels observed at reading number 2 (afternoon). This phenomenon was attributed to the reduced activity or occupy within the air-conditioned environment around lunchtime, leading to a decline in the refrigerant effect and subsequently reducing the quantity of heat extracted from the condenser unit of the AC system. The refrigerant effect exhibited a direct relationship with COP, indicating that variations in superheat similarly followed a similar pattern as COP. Both graphs demonstrate that water with heat pipe angle inclination of 90° exhibited the greatest rise in superheat and coefficient of performance (COP).

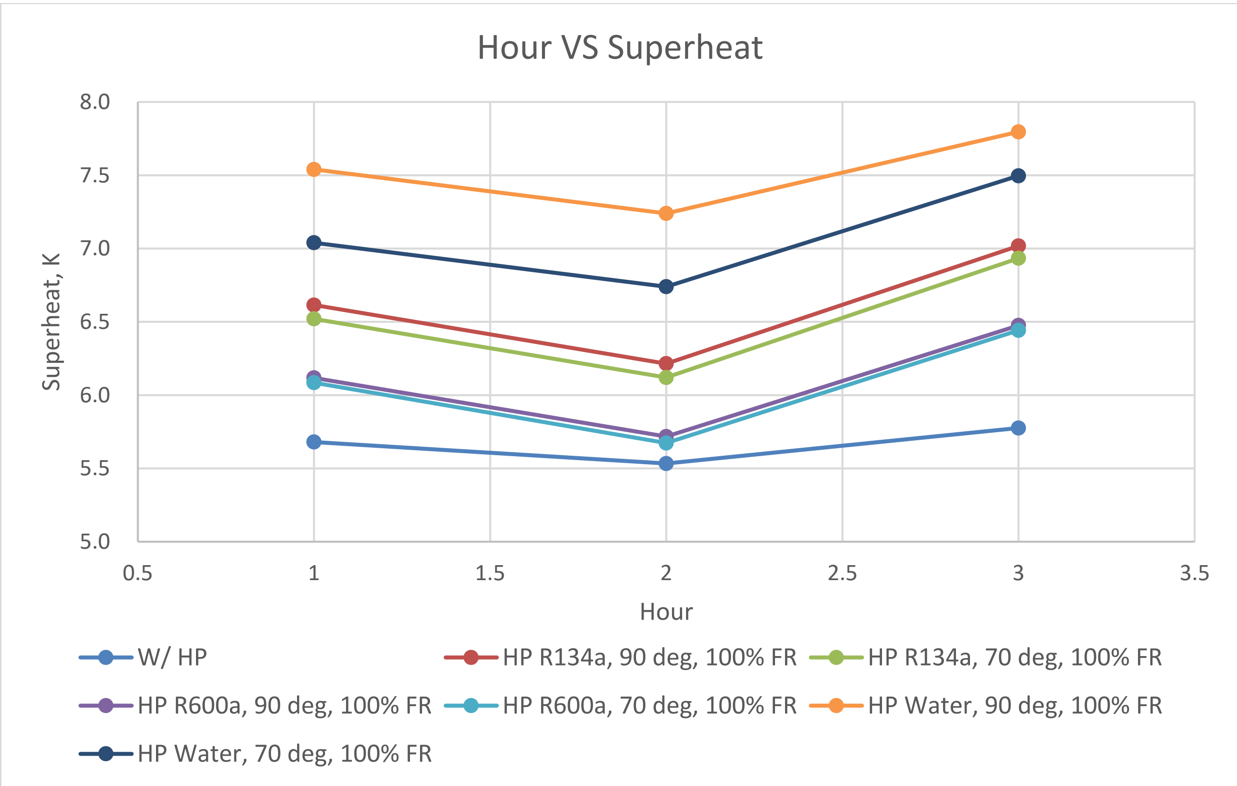


Fig. 5. Changes of superheat through out a day at different condition

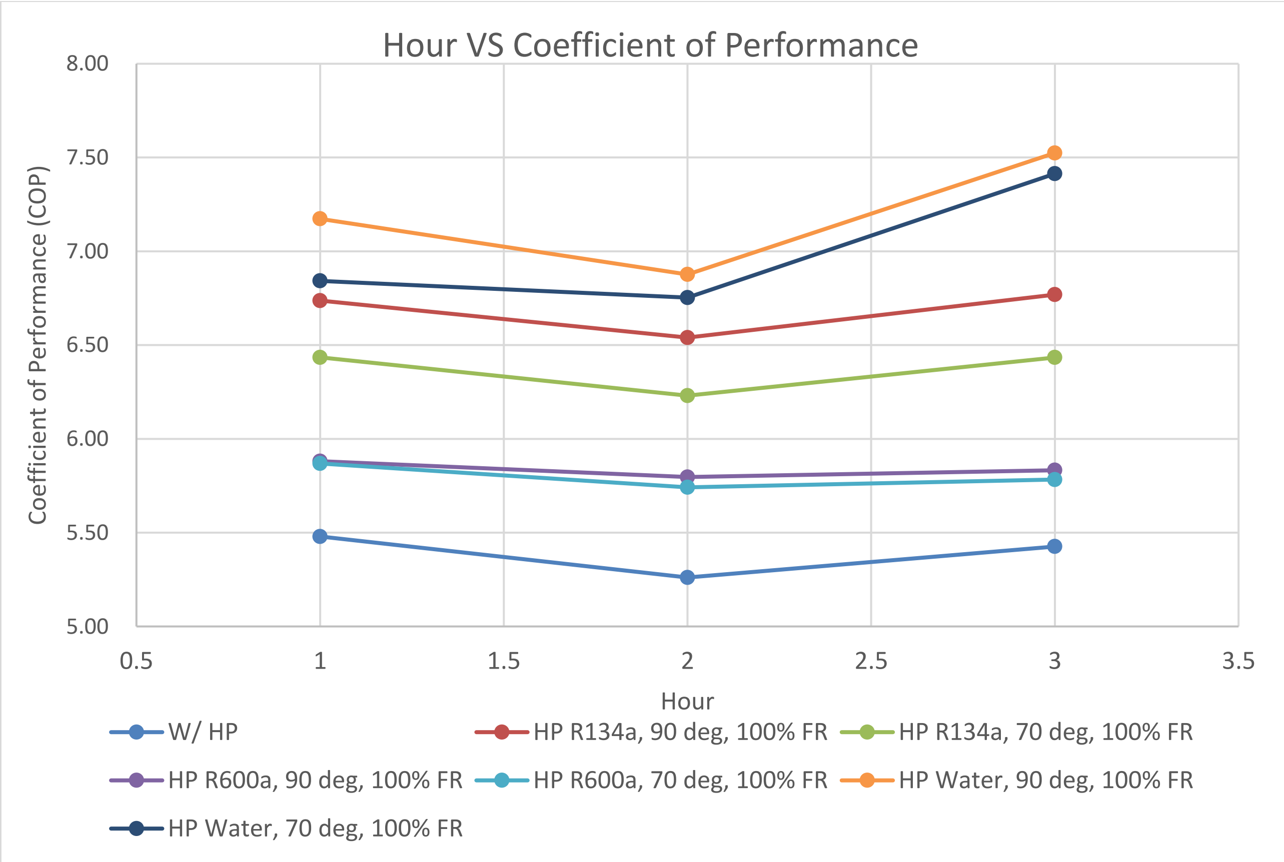


Fig. 6. Changes of superheat throughout a day under different conditions

3.2 Working Fluid and Performance of AC

Table 5 shows that the average superheat for a conventional AC system was recorded to be 5.7K which was 6.5% lower than R600a at 70° angle of inclination. Followed by R134a at 70° with superheat 6.37K and R134a at 90° with superheat 6.62K and R134a at 90° with superheat 6.62K. Water at 90° showed the best performance of 7.53K (32% higher than normal conventional AC).

3.3 Superheat and Power Consumption

The power usage of conventional AC units was 0.825 kW. The average superheat for conventional AC system was 5.7 K. The increase of superheat when water was used as the working fluid showed the highest power consumed by the AC. The findings of this study demonstrated the increase of the instantaneous power consumption recorded as the superheat increased which align with Ardita *et al.,* [9] findings but different from findings by Qi [24].

Table 5
Average of superheat, refrigerant effect, work done by compressor and power consumption

	Superheat	Refrigerant effect, kJ/kg	Work Done by compressor	Coefficient of performance, COP	Power consumption, kW
ACSU W/O HP	5.70	262.13	48.66	5.39	0.825
R134a HP 90 deg, 100%FR	6.62	266.23	39.85	6.68	0.840
R134a, HP 70 deg, 100%FR	6.37	266.18	41.82	6.37	0.855
R600a, HP 90 deg, 100%FR	6.10	266.57	45.67	5.84	0.864
R600a, HP 70 deg, 100%FR	6.07	264.43	45.61	5.80	0.862
Water, HP 90 deg, 100%FR	7.53	276.5	38.51	7.19	0.897
Water, HP 70 deg, 100%FR	7.03	274.56	39.21	7.00	0.888

3.4 Superheat and Heat Pipe

Figure 7 exhibits the process of increase in superheat when the heat pipe was combined with AC system. This observation showed the influence of heat pipe absorption on the AC system. The transfer of heat from the heat pipe to the suction line was facilitated by the assembly tube-in-tube of the heat pipe header and the suction line as shown in Figure 7.

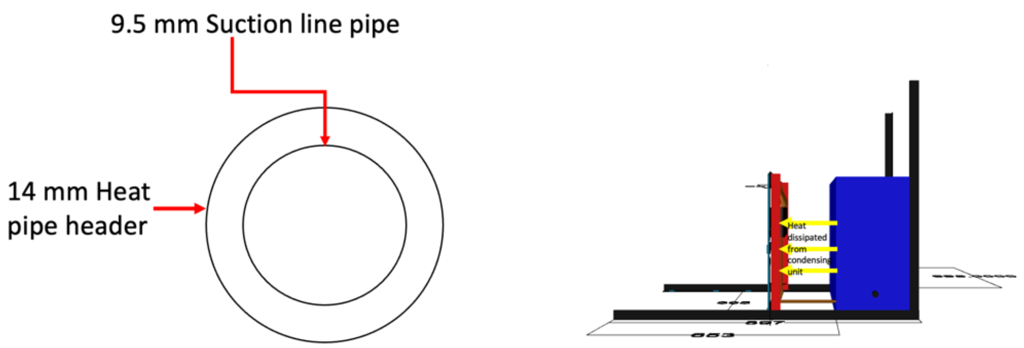


Fig. 7 Tube-in-tube assembly of the suction line and heat pipe header and assembly of the heat pipe and AC system

There was no substantial difference between the 90° and 70° inclination angles for R134a and R600a. The superheat of R134a exhibited 3.92% rise when the inclination was changed from 70° to 90°. The pattern exhibited similarities to R600a, however with a reduced superheat gap between 70° and 90°. The most significant difference between temperatures of 70° and 90° was observed in the context of water, where the 90° angle of inclination was 7.11% higher than the 70° angle of inclination.

4. Conclusions

In this experimental study, the optimal working fluid has been established to be water compared to R600a and R134a. The usage of the new innovated heat pipe proves that it is able to harvest the heat dissipates from the condenser part of AC and the tube-in-tube assembly to assist the heat transfer from the working fluid to refrigerant has maximised the heat pipe performance. Superheat exhibits a positive correlation with both the refrigerant effect and the COP where the refrigerant effect and COP is directly proportional to the superheat increase. Nonetheless, it concurrently leads to an escalation in the power consumption of the system. The energy harvesting of the heat pipe is minimally affected by the inclination angle as the working is filled to a 100% FR, preventing it from drying out. For future research purposes, it is suggested that researchers investigate the impact of increasing subcooling on power consumption. This is because an increase in subcooling also has the potential to enhance the refrigerant effect and the coefficient of performance (COP) of AC systems.

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