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Performance of Low Power Electric Energy Clothes Dryers for Households

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Abstract

One of the problems faced by middle to lower economic class people in big cities is drying clothes, both in the dry season and in the rainy season. Artificial clothes drying equipment is needed that can replace the role of solar energy. The purpose of this study was to determine the performance of electric energy clothes dryers and the length of time needed to dry clothes on a household scale. The clothes dryer works by using a heat-pump based on the vapor-compression cycle. The total power of the heat pump is 200 watt. The working fluid of the heat-pump is R134a. The working fluid used to dry clothes is air, using a closed airflow system. The research was carried out experimentally by varying the amount of clothes in the drying chamber. The clothes dryer performance (COP) of the heat pump is 7.94. Drying time for 15, 25 and 40 clothes respectively for 210 minutes, 330 minutes and 450 minutes.

Keywords: Dryer, Performance, Clothes, Heat Pump, Vapor Compression Cycle

1. Introduction

The process of drying clothes is the process of eliminating water in clothes. The process of drying clothes is done after the clothes are washed and the water is squeezed out. Squeezing clothes can be done by hand or by using a washing machine, then clothes can be dried by the evaporation process. The process of evaporation of water on clothes can be done in various ways, such as: aerating, drying in the sun, passing hot air, passing hot and dry air. After the clothes are dry, the clothes are ironed, in addition to smoothing the clothes, it is also to kill the germs that are on the clothes.

Volume 5, Issue 1, pages 39-54
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Once tidied up, the clothes are stored in the wardrobe. When the clothes will be worn, the clothes are taken and put on.

The main process in drying clothes is the evaporation of water contained in clothes. The evaporation process is the process of changing the water phase from the liquid phase to the water vapor phase. During the evaporation process, water is transferred from the clothes to the air. The evaporation process requires heat. The heat of vaporization is taken from the air. The air temperature will decrease and the water content in the air will increase. The specific humidity of the air increases. This process is known as the cooling and humidifying process. The drying process is influenced by several air conditions, such as: air temperature, air humidity and air flow [1]

Drying by drying is natural drying. Drying with the help of drying equipment, called artificial drying. Combined drying is drying with solar-energy and other-energy drying equipment. Energy sources for drying equipment can come from waste fuel energy or biomass (husk, straw, corn cobs, sawdust, and coconut-fiber), LPG, CNG, or electricity. Research with the help of drying equipment has been carried out by several researchers. Saptariana, et al dry the traditional rengginang food made from sticky rice using an LPG drying oven [2]. Doddy Purwadianto and Petrus Kanisius Purwadi dried corn chips using an electric energy drying oven [3]. Petrus Kanisius Purwadi drying clothes using an electric energy drying oven [4]. Wibowo Kusbandono, Petrus Kanisius Purwadi and A. Prasetyadi drying wooden planks in an electric energy drying oven [5,6]. Adhi Prasnowo dries potato chips using an electric energy oven [7]. Tri Mulyanto and Supriyono dry the chili using an electric oven and solar energy [8]. Dian Morfi Nasution et al, Sari Farah Dina, et al, dry cocoa beans using solar energy and electrical energy [9,10]. Efriwandy Simbolon et al dried cloves in an oven burning coconut waste [11].

Disadvantages of the process of drying clothes by drying in the sun are: long and depending on the weather. Drying with an LPG-fired oven can be done at any time (morning, afternoon and evening) and does not depend on the weather (can be done during the dry season, or during the rainy season). Drying with LPG ovens can be done indoors and can dry quickly. Disadvantages of drying with an oven: impractical or complicated, less safe because it has the potential for fires, wastes energy, is not environmentally friendly because it creates exhaust gas pollution, and the environment is not clean.

In big cities, many middle-class people find it difficult to dry clothes naturally, because they do not have a large outdoor yard in their house. The solution that can be given is to make artificial clothes drying equipment using a heat pump that has low electric power. The heat pump works on the basis of the vapor-compression cycle. With a heat pump, you can get the dry and hot air needed to dry clothes. No electric heating elements are used in the drying process. Electricity is only used to drive the compressor and fan. Air drying is carried out by the evaporator while air heating is carried out by the condenser. The evaporator and condenser are the main components of the heat pump, apart from the compressor and capillary tube. The drying time is not a problem if the dryer is only for household use (not for doing business). With the use of a heat pump, the process of drying clothes can be abandoned. Safe, because the potential for the heat pump to pose a minor hazard. Clothes drying can be done indoors, and can be done at any time, regardless of the weather, safe and comfortable.

Research on drying clothes involving heat pumps has been carried out by: Pradeep Bansal, Amar Mohabir, William Miller [12], Ward TeGrotenhuis, Andrew Butterfield, Dustin Caldwell, Alexander Crook, Austin Winkelman [13]. In addition to being able to be used at any time, the use of a heat pump produces high performance, is practical and environmentally friendly. Another study using heat pumps to dry clothes was carried out by Purwadi, PK using 800 watts of electric power, as well as that carried out by Cakra, et al, using 1 PK of electric power [14]. Research conducted by Gordon, et al, uses a lower electric power of 0.5 PK [15]. For people of middle economic class, a clothes dryer that is suitable for household use is a dryer that uses a heat-pump with low electric power. In this study, the energy needed to drive the heat pump is 200 watt.

a. Heat pump

The clothes dryer used in this study uses a heat pump based on a vapor compression cycle. The working fluid in the heat pump is called refrigerant or freon. Requirements for the use of refrigerants must be safe and environmentally friendly so

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Volume 5, Issue 1, pages 39-54
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as not to damage the ozone layer. The vapor compression cycle is usually used in refrigeration engines [16]. The ideal vapor compression cycle is composed of several main processes: the compression process, the desuperheating process, the condensation process, the pressure reduction process and the evaporation process. To improve engine performance, additional processes can be added to the standard vapor compression cycle, namely superheating and subcooling processes. The heat pump has main components: compressor, condenser, capillary and evaporator. The compressor functions for the compression process, the condenser for desuperheating and refrigerant condensation processes, the pipe-capillary functions to reduce pressure and the evaporator functions for the evaporation process. Fig. 1 presents a series of main components of a heat pump.

Fig. 2 presents the vapor-compression cycle on the P-h diagram. In the condenser, a process of releasing heat occurs when the refrigerant undergoes a process of desuperheating and condensation, and in the evaporator, absorption of heat from the environment occurs when the refrigerant undergoes a boiling process. In the heat pump there is an energy balance. The energy entered into the heat-pump (which is absorbed by the evaporator) plus the energy used to drive the heat-pump (which is used to drive the compressor) equals the energy released by the heat-pump (energy released by the condenser to the environment).

When the vapor compression cycle machine is running, refrigerant successively flows from the compressor, condenser, capillary-pipe, evaporator, and then flows to the compressor again. As long as there is electricity, the vapor-compression cycle in the heat-pump continues continuously. The function of the compressor is to increase the refrigerant pressure at a fixed entropy value (isentropy), from low pressure P_1 to high pressure P_2. The work done by the compressor per unit mass of refrigerant is expressed by W_{in}. In addition to experiencing an increase in pressure, the refrigerant temperature increases so that the gas condition changes from saturated gas to superheated gas. Exiting the compressor, refrigerant enters the condenser. The condenser's job is to dissipate heat into the surrounding air. There are two processes that refrigerants undergo, the desuperheating process and the condensation process. When removing heat in the desuperheating process, the refrigerant temperature decreases. The condition of the refrigerant gas changes from superheated gas to saturated gas at high pressure P_2. The process continues with the condensation process. The condensation process in the condenser takes place at constant pressure and constant temperature. The refrigerant phase changes from a saturated gas phase to a saturated liquid. If desired, the refrigerant phase can be made in the superfluid state. In this case, a sub-cooling process is required. The amount of heat that is discharged by the condenser into the ambient air is expressed by Q_{out}. Exiting the condenser, the refrigerant flows into the capillary-pipe. Before flowing into the capillary-pipe, the refrigerant flows through the filter, to undergo a process of filtering impurities. When the refrigerant flows into the capillary tube, the refrigerant pressure drops until it reaches low pressure P_2, and the refrigerant temperature also drops. This process takes place at a constant refrigerant enthalpy. The pressure drop in the refrigerant is caused by friction between the inner surface of the capillary-pipe and the flowing refrigerant. Because the diameter of the capillary tube is quite small, the pressure drop that occurs is quite large. Some of the refrigerant changes phase to vapor. The refrigerant then enters the evaporator, and the refrigerant absorbs heat from the surrounding air to be used to change the refrigerant phase from a liquid and gas mixture to a saturated gas.

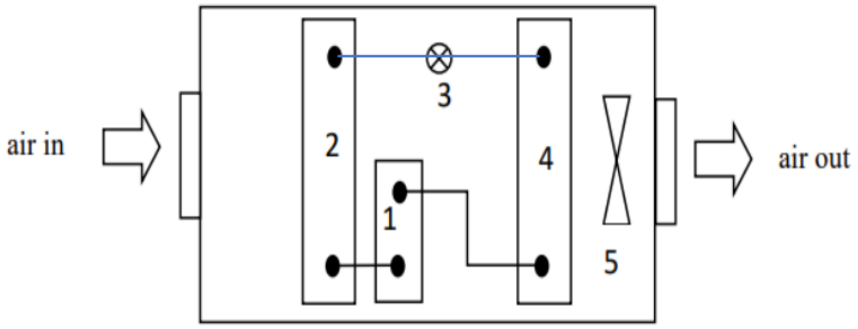

Figure 1. Series of main components in a heat pump

Description in Fig. 1:

1 compressor
2 evaporator
3 capillary pipe
4 condenser
5 fan

Fig. 1 besides presenting a series of main components in a heat pump, also presents the direction of air flow when passing through the heat pump. The air entering the heat pump is first passed through the evaporator and lastly through the condenser. After passing through the condenser, the air is removed from the heat pump. The air released by the heat pump is then fed into the clothes drying room. The air entering the evaporator is air that has dried the clothes in the drying chamber.

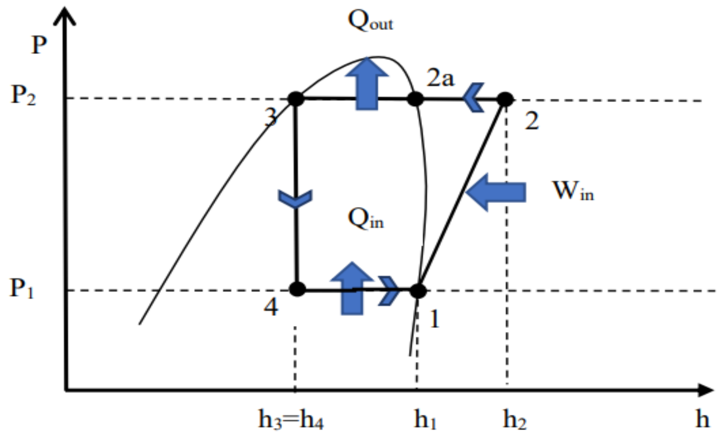

Figure 2. Vapor compression cycle on a Mollier diagram, without superheating and subcooling

The ratio of useful energy to the energy required to drive a vapor-compression cycle engine is called performance. In this case, the useful energies are Qin and Qout. The performance or coefficient of performance or COP of the clothes drying oven is calculated using Equation (1).

$$COP = \frac{(Q_{in}+Q_{out})}{W_{in}} . \tag{1}$$

In Equation (1),

$$Q_{in} = h_1 - h_4 \tag{2}$$

$$Q_{out} = h_2 - h_3 \tag{3}$$

$$W_{in} = h_2 - h_1 \tag{4}$$

In Equations (2), (3) and (4), h_1 represents the enthalpy of refrigerant before it enters the compressor, h_2 represents the enthalpy of refrigerant when it leaves the compressor,

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h_3 is the enthalpy of refrigerant when it enters the capillary-pipe and h4 is the enthalpy of refrigerant when it enters the evaporator.

b. Clothes Dryer

Fig. 3 presents a schematic of a clothes dryer using a heat-pump. The refrigerant used in the heat pump is R-134a. The fluid used to dry clothes is dry and hot enough. The air flow used in the drying process is a closed air cycle. No airflow is introduced into the drying chamber or removed from the clothes drying chamber. To obtain dry and hot enough air, air is circulated through a heat-pump by passing air through finned pipes from the evaporator and condenser components. Air can flow, because of the fan inside the heat pump. Dry and hot enough air then flows through the entire surface of the clothes which are hung on hangers in the clothes drying room. After the air has passed through the clothing, the air temperature will drop but the air humidity will increase. The air is then flowed repeatedly to the evaporator again. The air cycle is repeated until dry clothes are obtained with the desired degree of dryness.

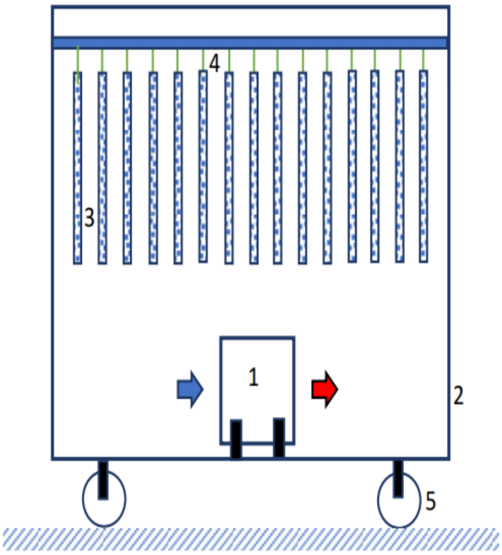

Figure 3. Schematic of a clothes dryer using a heat pump

Description in Fig. 3.

1	Heat pump	4	*Hanger*
2	Drying chamber	5	Drying chamber wheels
3	Clothes		

2. Research Methodology

The research was conducted experimentally. At the time of the study, the heat pump was placed in the clothes drying chamber. The size of the drying chamber is 1.1 m long, 1.1 m wide and 1.15 m high. The drying chamber is made of wood with a thickness of 8 mm. In the drying chamber there are a number of clothes hanging on hangers. The arrangement of the clothes is shown in Fig. 3. The total electric power used by the heat pump is 200 watts. The evaporator used in the heat pump is of the finned-pipe type, with the pipe material being made of copper and the fins of aluminum material. The condenser used is also of the finned pipe type, with pipes made of copper and fins made of aluminum. The capillaries are made of copper, having a diameter of 0.026 inches. The research was conducted by varying the number of clothes used in the drying room: (a) 15 clothes, (b) 25 clothes and (c) 40 clothes. During the drying process the clothes drying chamber is tightly closed. There is no inflow of air and no outflow of air. The clothes that are dried are in the form of t-shirts made of cotton, with size XL.

3. Results and Discussion

Fig. 4 presents the vapor compression cycle in the P-h diagram R-134a of a heat pump used in a clothes dryer. The delineation can be obtained using the absolute pressures P_1 and P_2. The absolute pressure P_1 is the working pressure of the evaporator and the absolute pressure P_2 is the working pressure of the condenser. The P_1 and P_2 values are based on the measuring working pressure plus the outside air pressure. A vapor compression cycle is described assuming no superheating and no subcooling. From the vapor compression cycle, it can be seen that the working temperature of the evaporator (T_{evap}), the working temperature of the condenser (T_{kond}), the enthalpy values h_1, h_2, h_3, and h_4 are presented in Table 1. However, the enthalpy values h_1, h_3 and h_4 are presented in Table 1, taken from the table of the properties of refrigerant R-134a in order to obtain accurate data. By knowing the enthalpy value, the Qin, Qout, Win and COP of the heat pump can be calculated, the results of which are presented in Table 2. The working temperature of the evaporator is the boiling temperature of the refrigerant in the evaporator at low pressure P_1 and the working temperature of the condenser is the temperature of the refrigerant condensing in the condenser at high pressure P_2.

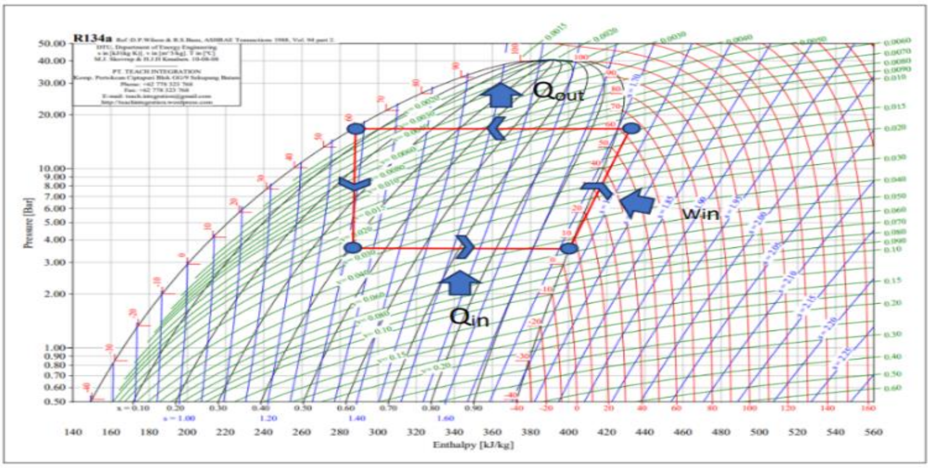

Figure 4. Heat pump vapor compression cycle in diagram P-h, R-134a

Table 1. Research data for the characteristics of a vapor compression cycle based heat pump used in clothes dryers, with 15, 25 and 40 clothes

Researched machine	P_1 (bar)	P_2 (bar)	T_{evap} (°C)	T_{kond} (°C)	h_1 (kJ/kg)	h_2 (kJ/kg)	h_3 (kJ/kg)	h_4 (kJ/kg)
Heat pump	3,496	16,813	5	60	400,07	432,55	287,39	287,39

Table 2. Characteristics of heat pumps for drying 15, 25 and 40 clothes

Researched machine	P_1 (bar)	P_2 (bar)	Q_{in} (kJ/kg)	Q_{out} (kJ/kg)	W_{in} (kJ/kg)	COP
Heat pump	3,496	16,813	112,68	145,16	32,48	7,94

Table 3. Air conditions in the drying process

<table>
<tr><th rowspan="2">Amount of clothes</th><th>Average air temperature before entering the evaporator, (°C)</th><th>Average air temperature out of the condenser (°C)</th></tr>
<tr><th>$T_{db,A}$</th><th>$T_{db,D}$</th></tr>
<tr><td>15 clothes</td><td rowspan="3">38,6</td><td rowspan="3">53,87</td></tr>
<tr><td>25 clothes</td></tr>
<tr><td>40 clothes</td></tr>
</table>

Table 4. Length of time for drying clothes

No	Amount of clothes	Initial total mass wet clothes (kg)	Final total mass dry clothes (kg)	Mass of wet clothes-mass of dry clothes (kg)	drying time (menit)
1	15	3,94	2,55	3,94-2,55 = 1,39	210
2	25	6,57	3, 96	6,57-3,96 = 2,61	330
3	40	10,51	6,51	10,51-6,51= 4,00	450

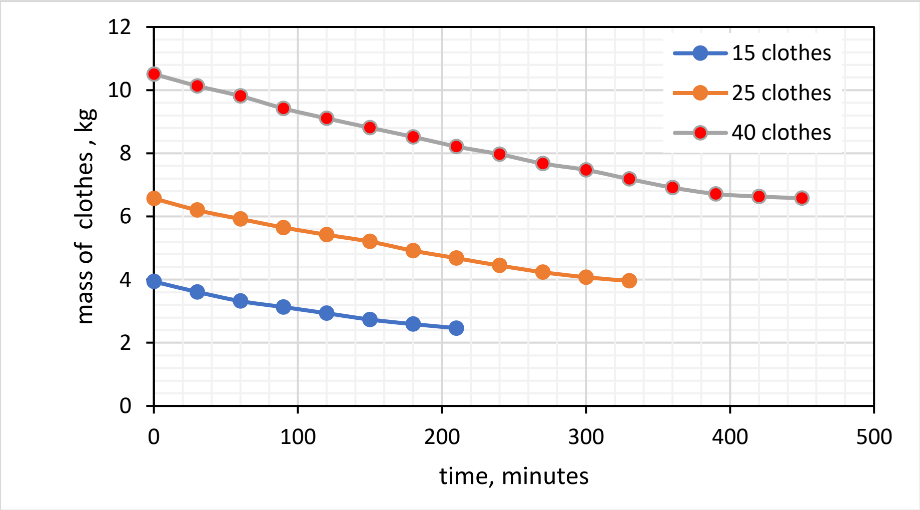

Figure 5. The total mass of clothes over time during the drying process.

When drying clothes, air flows by repeated air-cycles in the dryer. The air cycle consists of 4 processes: air cooling (sensible cooling), air cooling process accompanied by condensation of water vapor (cooling and dehumidifying), air heating (sensible heating) and cooling accompanied by an increase in specific humidity (evaporative cooling). The cooling and cooling and dehumidifying processes occur when air passes through the evaporator, the heating process occurs when air passes through the condenser, and the evaporative cooling process occurs when air is drying the clothes.

In the sensible cooling process, the process takes place in the evaporator. Dry-ball air temperature and wet-ball air temperature decrease. The sensible cooling process runs with a fixed humidity-specific value. Before the air undergoes the sensible cooling process, the air condition is at point A which has a dry bulb air temperature $T_{db,A}$ and a wet bulb air temperature with $T_{wb,A}$. At the end of the process, the air condition is at point B, with dry-ball air temperature expressed by $T_{db,B}$ which is lower than $T_{db,A}$ and wet-ball air temperature by $T_{wb,B}$ which is also lower than $T_{db,B}$. The results showed that at the end of the sensible cooling process, the dry-bulb air temperature and wet-ball air temperature had the same values $T_{db,B}$ = $T_{db,B}$ and had a relative humidity (RH) value of 100%. Thus the RH of the air has increased until it reaches 100% RH. In the sensible cooling process, heat is released from the air, and the heat released by the air is absorbed by the evaporator to be used to boil some of the refrigerant flowing in the evaporator pipes.

In the process of cooling the air which is accompanied by condensation of water vapor from the air (cooling and dehumidifying), the process takes place at a constant relative humidity of 100%, but the dry bulb air temperature and wet bulb air temperature decrease. This process can occur because the working temperature of the evaporator (T_{evap}) is much lower than the temperature of the condensation of water vapor in the air. This causes in this process the condensation of water vapor from the air. The water content in the air decreases. A specific moisture reduction process occurs. When the air temperature leaves the evaporator, the dry bulb air temperature is expressed by $T_{db,\ C}$ and the wet bulb air temperature is expressed by $T_{db,\ C}$. The condition of the air coming out of the evaporator can be said to be dry. Even though it has an RH of 100%, the water content in the air is low. In this process, air releases heat, because in the phase change process from water vapor to the liquid phase (condensation) it always releases heat. The heat released by the air is also used to boil some of the refrigerant flowing in the evaporator pipes or is used to change the phase from a liquid and gaseous refrigerant mixture to a saturated gas.

The total amount of heat absorbed by the evaporator from the air in the sensible cooling process and in the cooling and dehumidifying process, the refrigerant mass unit is expressed in Q_{in}. The process of heat absorption in the evaporator through the surface of the fins installed on the evaporator pipes and through the outer surface of the evaporator pipes. In order for the heat absorption process through the fins and the pipe surface to run quickly, the fin material is selected from aluminum and the pipe material is selected from copper. Both of these materials have relatively high thermal conductivity values and affordable selling prices. A fan is installed near the evaporator to increase the speed of the air flow. By increasing the air speed, it will increase the value of the convection heat transfer coefficient. The higher the value of the convection heat transfer coefficient, the greater the rate of heat transfer that occurs from the air fluid to the refrigerant flowing in the evaporator.

Coming out of the evaporator, air is passed through the condenser. When it passes through the condenser, the process of heating the air occurs. In this process, the process runs at a fixed specific humidity. The temperature of the dry bulb air and the wet bulb air temperature rising from the evaporator increases, from $T_{db,C}$ and $T_{wb,C}$ to $T_{db,D}$ and $T_{wb,D}$. The air temperature rises because the working temperature of the condenser is higher than the air temperature. There is a flow of heat from the refrigerant flowing in the condenser into the air. Refrigerant can release heat, because the refrigerant in the condenser experiences a decrease in temperature from superheated gas to saturated gas (desuperheating process), and undergoes a phase change from a saturated gas phase to a saturated liquid phase (condensation process). The condenser releases heat into the air through the fins on the pipes and through the outer surface of the condenser pipes. Inside the condenser finned pipes, there is a process of decreasing temperature and the process of refrigerant condensing which releases heat

In the evaporative cooling process the dry bulb air temperature ($T_{db,D}$) decreases, while the wet bulb air temperature remains ($T_{wb,D}$). In an ideal process, the process runs at a fixed enthalpy value. The evaporative cooling process occurs when the air coming out of the condenser passes through clothes that are hung on hangers in the drying chamber. When air passes through the clothes, the water in the wet clothes evaporates, and the water moves from the clothes into the air. Clothes dry. The water phase changes from the liquid phase to the water vapor phase. In the process of changing the phase from the liquid phase to the water vapor phase, it requires heat, and the heat is taken from the air that passes through the clothes. Hence the dry bulb air temperature decreases. The amount of sensible heat provided by air is equal to the amount of latent heat used for the process of evaporating water from clothes. In this process there is an addition of water content in the air, then the specific humidity of the air increases.

From Table 4, it appears that the length of time for drying clothes depends on the amount of clothes being dried or depending on the mass of clothes to be dried. The more clothes or the larger the mass of clothes to be dried, the longer the drying time will be. This is because the more clothes or the greater the mass of clothes that are dried, the more water has to be evaporated from the clothes. The degree of dryness obtained on clothing is evenly distributed for all clothing and in all clothing positions. Everything dries evenly like solar energy drying does. From Table 4 it can be seen that the average temperature before passing through the evaporator is 38.6^{o}C and the air temperature leaving the condenser is an average of 53.87^{o}C.

Some of the advantages of using a clothes dryer using a vapor compression cycle-based heat pump are: practical, safe and comfortable, environmentally friendly, can be used anytime and anywhere. The potential for fire is small, as there is no fire, oxygen and fuel. Oven work does not make noise and does not cause hot air conditions outside the oven. The environment is kept clean. Because it uses electrical energy, the clothes dryer is easy to operate and doesn't bother the user. The use of dryers does not pollute the environment, because there is no combustion process that produces exhaust gases. The dryer can work regardless of the weather. Can be done during the dry season or rainy season, morning, afternoon, evening or night, indoors or outdoors.

4. Conclusion

The conclusions of this study are (a) electrical energy clothes dryer using a vapor compression cycle-based heat pump has a performance (COP) of 7.94 (b) the time needed for a clothes dryer using a heat pump to dry 15 clothes, 25 clothes and 40 clothes respectively takes 210 minutes, 330 minutes and 450 minutes.

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