PENGERING PAKAIAN DENGAN BANTUAN PAM HABA

(HEAT PUMP ASSISTED CLOTHES DRYER)

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ABSTRACT

A clothes drying in humid tropic is an energy intensive process. In densely built-up urban areas with many high rise apartments this is a more acute problem. Restricted air flow across the dense area, limited solar exposure and round the year humid climate make the drying process less effective.

In the present research, a Heat Pump Assisted Clothes Dryer was designed and developed to study the feasibility of drying clothes using waste heat of a condenser of a typical split type domestic air conditioner. Two modes of heat pump drying have been studied - the open system, and the close system. In the open system drying was done by condenser heat only whereas in the closed system the air was dehumidified by the evaporator prior to being heated by condenser heat. Three additional modes of drying were also tested to compare their relative performances vis a vis open and close system drying. These are heating by solar radiation, heating with electrical bulbs and electrical heating elements.

This investigation found that drying clothes in the open system heat pump drying mode is far better than the other modes. For experiment without solar exposure, it only took 45 minutes to dry 1.993 kg bone dry specimen clothes. It also has the highest drying rate of 0.724 kg/h compared to 0.117 kg/h for natural drying and 0.523 kg/h for close system heat pump drying. Time required for open system heat pump drying was only 16.36 % that of natural drying and 69.23 % that of close system heat pump drying. Supplementing the drying process by solar radiation improves the drying rate. The drying rate improves to 0.847 kg/h for open system heat pump, 0.316 kg/h for natural drying and 0.523 kg/h for close system heat pump drying. With solar flux, the drying time is only 35 minutes for open system heat pump drying, which is only 35 % of natural drying and 58.33 % of close system heat pump drying.

The results of the investigation show that heat pump assisted drying using condenser heat is a practical and economical option of utilising waste heat gainfully.

ABSTRAK

Pengeringan baju di iklim lembap merupakan proses intensif tenaga. Dalam kawasan bandar yang pesat dengan pembangunan rumah pangsa telah merumitkan proses ini. Kekurangan tiupan angin melalui kawasan pesat ini, pancaran suria yang terhad dan cuaca lembap sepanjang tahun telah menyebabkan proses pengeringan kurang efektif.

Dalam penyelidikan ini, sebuah Pengering Pakaian Dengan Bantuan Pam Haba telah direkabentuk dan dibangunkan untuk mengkaji kecekapan penggunaan haba buangan dari unit kondenser bagi sistem hawa dingin yang sedia ada. Terdapat 2 mod pengeringan pam haba yang dikaji, sistem terbuka dan sistem tertutup. Tiga mod pengeringan tambahan juga dikaji untuk membuat pembandingan relatif prestasi dengan sistem pengeringan terbuka dan tertutup. Antaranya ialah pendedahan kepada suria, pemanasan dengan lampu dan pemanasan dengan elemen pemanas.

Penyelidikan ini telah membuktikan bahawa pengeringan secara sistem terbuka pam haba jauh lebih baik daripada sistem pengeringan dan keadaan yang lain. Untuk eksperimen tanpa bantuan suria, ia hanya mengambil 45 minit untuk mengeringkan jisim pakaian kering seberat 1.993 kg dengan kadar pengeringan yang paling tinggi iaitu sebanyak 0.7244 kg/h berbandingkan dengan 0.1171 kg/h untuk pengeringan semulajadi dan 0.5231 kg/h untuk pengeringan secara sistem tertutup pam haba. Masa yang diperlukan untuk pengeringan secara sistem terbuka ini hanya 16.36 % dan 69.23 % daripada kaedah yang dinyatakan tadi. Kadar pengeringan ditingkatkan dengan bantuan suria. Kadar pengeringan untuk pengeringan sistem terbuka pam haba iaitu 0.8469 kg/h berbandingan dengan 0.3162 kg/h untuk pengeringan semulajadi dan 0.5225 kg/h pengeringan secara sistem tertutup pam haba. Dengan bantuan suria, masa untuk pengeringan bagi sistem terbuka ialah 35 minit, iaitu hanya 35% daripada pengeringan semulajadi dan 58.33 % daripada pengeringan secara sistem tertutup pam haba.

Keputusan daripada ujikaji ini telah menunjukkan bahawa pengering dengan bantuan pam haba yang menggunakan haba condenser adalah praktikal dan ekonomikal.

ACKNOWLEDGEMENT

I would like to take this opportunity to extend my most heartfelt gratitude to School of Mechanical Engineering, Universiti Sains Malaysia for giving me an opportunity to complete my final year project as part of the fulfilment for graduating in Bachelor of Mechanical Engineering.

Here, I have experienced the engineering working environment and industrial practice that impossible for me to gain in the theoretical bench. It also widened my sight and improved my knowledge through out the lessons. And yet it would certainly help me be more prepared for future.

I wish to tell out my utmost appreciation and thanks for my supervisor Associate Professor Ahmadul Ameen who had given me invaluable guidance, advice and support directly and indirectly with his patience and forgiveness throughout my final year project. I am greatly indebted to him for making a number of brilliant suggestions that improved my work.

Besides, I would like to say thank you to every technician working in the engineering workshop especially to Mr. Khomaruddin and Mr. Hamid, they also gave me invaluable guidance and kind support, working with them is really a great time and precious experience. Furthermore, I also like to thank Mr. Loo Siang Kooi, the proprietor of Wendy General Electrical, Refrigeration and Air-Conditioning Engineering for providing services and supply of equipments to my work.

Last but not least, my appreciation to my family and friends for the unfailing moral support throughout my work.

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1.0 INTRODUCTION

1.1 Introduction

In humid tropics, drying of clothes is becoming a difficult household chore. Moreover, the densely built-up urban areas with high rise apartments have added up to the problem. Restricted air flow across the dense area, limited solar exposure and round the year humid climate, hence make the drying process less effective (1).

The other mean of drying is to use the domestic electrical tumble dryer. Conventionally, drying is achieved by passing hot air into drying cambers and venting the humidified air, together with both sensible and latent heat, to the ambient (2). In a study done in 1997 by Energy Information Administration, UK(3), shows that among single family dwellings, electricity use for heating has taken 24% of the overall heating fuel and 86 % of the household own a clothes dryer. This expensive electrical dryer solution is not only not practical but in contra with the global concern for energy conservation and environment protection.

The criteria for evaluating the performance of the heat pump assisted clothes dryer were specific moisture extraction rate (SMER) and drying rate (4). The former indicate the effectiveness of the energy usage in the drying process in term of kg/kWh and the latter indicate the rate of amount of moisture removed in term of kg/h. Another parameter which is commonly used is specific energy consumption rate (SEC) in term of kWh/kg which can to be said as the inverse of SMER.

Heat pump dehumidifier dryers have been in widespread commercial use since the 1970's, particularly in the timber and food drying industries. But a limited study has been made for drying cloth or textile. Such studies were the feasibility of the an air heat pump cycle for tumble clothes dryer which offer up to 40% increase in energy efficiency(5), laboratory prototype laundry dryer equipped with CO_2 heat pump with different compressor modified from a commercial hot air laundry dryer which yield the SMER of 1.54 kg/kWh and 2.04 kg/kWh respectively(6) and another approach by using the heat pump assisted dryer with an opener mechanism in which wet wool was dried. SMER of the heat pump was 1.5 kg/kWh and 2.8 kg/kWh at bypass air and recirculation of air ratios of 20% and 80% respectively (7).

Although drying of clothes is a slow and problematic process that has been faced in the humid tropics, limited research has been done to solve this problem. Today, the installing and usage of air-conditioning system for domestic use is so common and its demand is progressively increasing. A heat pump is thermodynamically identical to a air-conditioner, but both satisfy contrasting human needs, the heat pump provides useful heat whereas air-conditioner are mainly provide cooling load for human comfort. This scope of project is to research the feasibility of utilizing the waste heat of air-conditioning system to dry clothes. In this case, then the users may enjoy the comfort air-conditioning room and on the other side having their clothes being dried by the waste heat rejected by the condenser without additional running cost.

Waste heat is another area of unutilized energy. In the present research, the designed and developed of a Heat Pump Assisted Clothes Dryer was to study the feasibility of drying clothes using waste heat of a condenser of a typical split type domestic air conditioner. Two modes of drying has been studied, in which the open system dries the clothes from the waste heat while cooling is provided to supply cool to a room and the close system dries the clothes from the waste heat and redirect the air back to the evaporator unit to dehumidify, then feed back to the condenser where the recycling of air take place. There are also 3 additional conditions of drying that are solar exposure, bulb heating and heat element heating. However, the former system is the first option as to achieve minimum cost and air-conditioning unit modification.

1.2 Objective

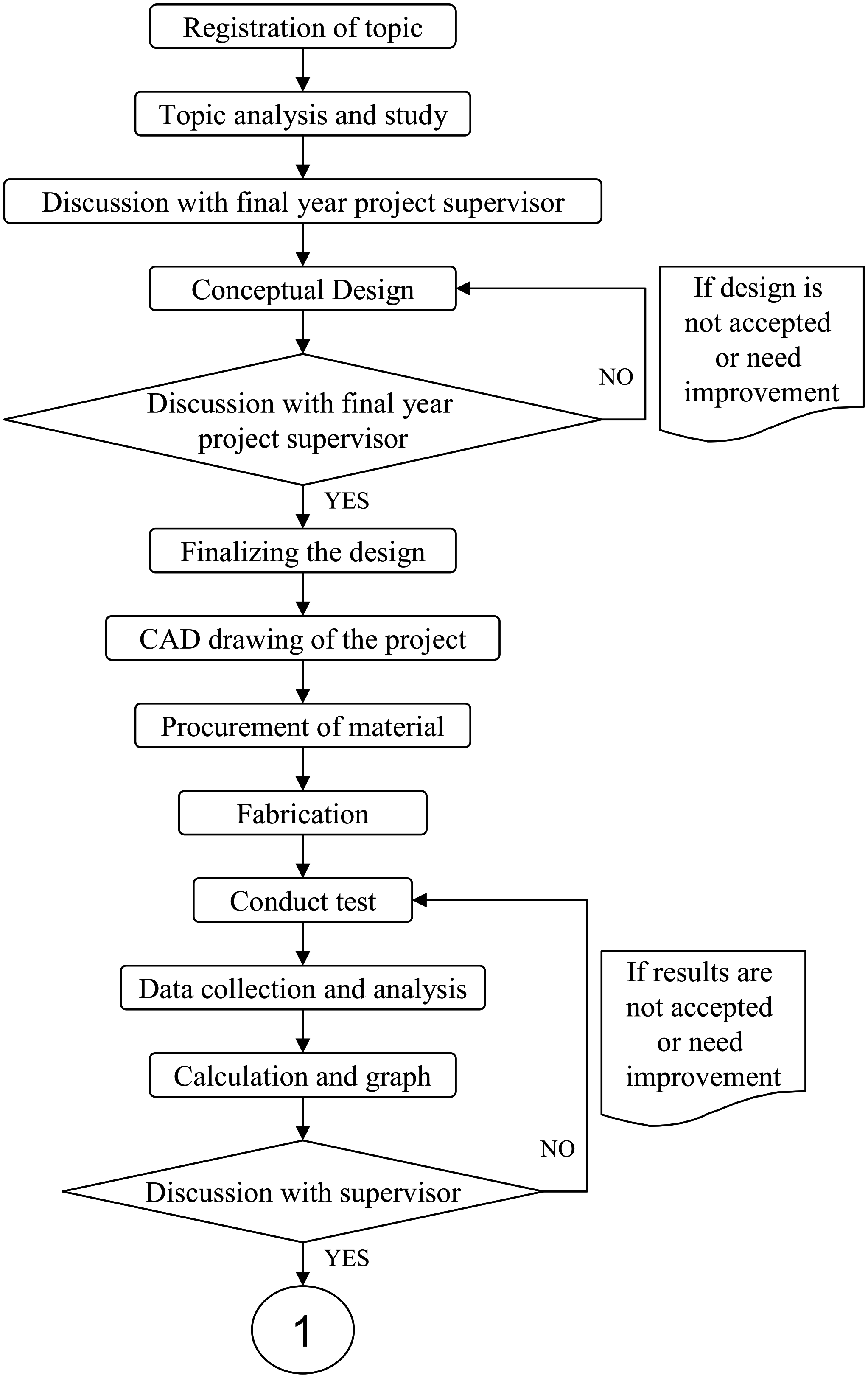
The project objectives are the following:

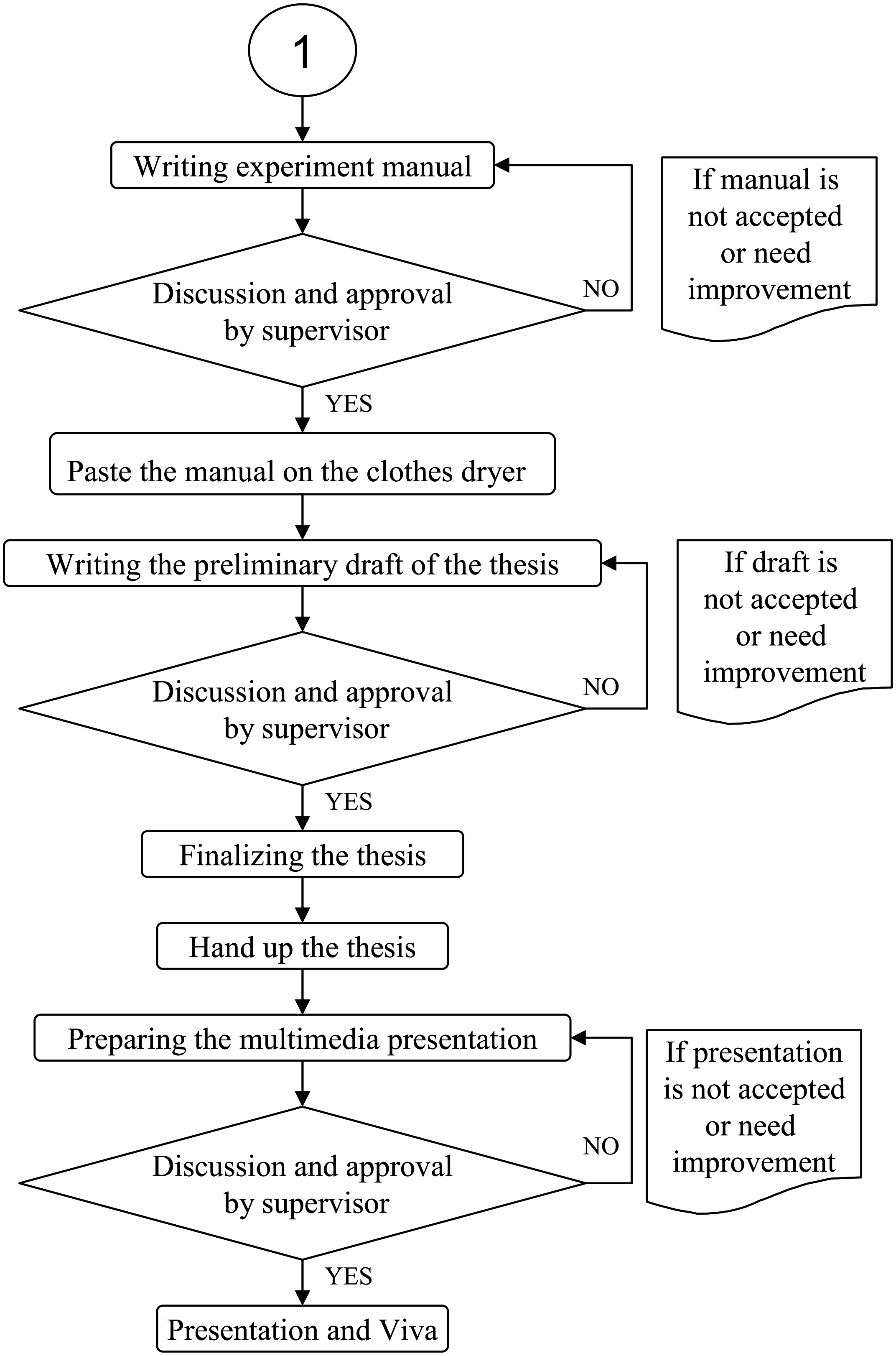
- To design a test rig in which experiments can be conducted to investigate the parameters of clothes drying.
- To fabricate the test bench with adequate instrumentation.
- To conduct experiments with a number of clothes/fabric specimens.
- To analyze the result of the test and ascertain drying rates under varying conditions.

1.3 Methodology

- Study and analysis of the final year project topic.
- Having discussion with supervisor and to work out a solution for the problem.
- Decide the schedule for the progress and to come out with a final design of the model for the heat pump assisted clothes dryer.
- Decide what material to use based on the cost and availability.
- Acquisition of materials
- Fabrication of test rig.
- Conduct drying tests with different type of textile/cloth specimens.
- Compare the results obtained with different systems and conditions.
- Write a report based on the study.

1.4 Final Year Project Process Flow Chart




1
Writing experiment manual
Discussion and approval by supervisor
NO
If manual is not accepted or need improvement
YES
Paste the manual on the clothes dryer
Writing the preliminary draft of the thesis
Discussion and approval by supervisor
NO
If draft is not accepted or need improvement
YES
Finalizing the thesis
Hand up the thesis
Preparing the multimedia presentation
Discussion and approval by supervisor
NO
If presentation is not accepted or need improvement
YES
Presentation and Viva

2.0 OVERVIEW

2.1 Principle of Drying

Air dehumidification can be achieved by means of three processes which are the sorption, air compression and refrigeration. The sorption process uses a desiccant material to soak up the moisture and subsequently the desiccant needed to be heated to evaporate the water it has collected to the atmosphere. Air compression process make use of the natural behaviour of air which when compressed, the absolute humidity of air reduces. It is then, cooled back to ambient temperature and expanded to ambient pressure. Refrigeration allows the air to be cooled below the dew point so that the water vapor condenses and runs off. Subsequently, the air has to be reheated to the desired ambient temperature (8).

A typical drying curve where drying rate is plotted against moisture content is shown in Figure 2.1(9), which contained the typical drying rate of:

A-B:	Initial Drying Rate
B-C:	Constant Drying Rate
C-D-E:	Falling Drying Rate

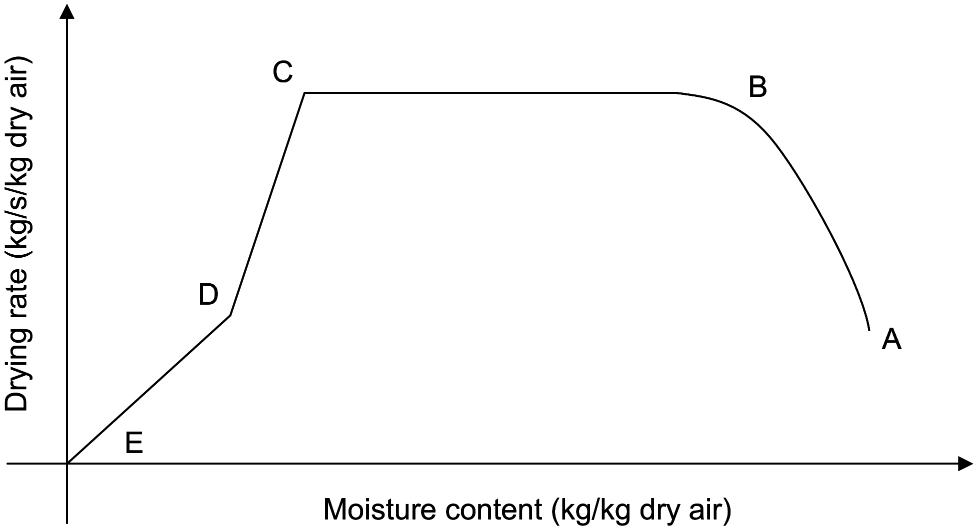


Figure 2.1: Typical drying rate curve

2.2 Factors Affecting Drying

The rate of clothes drying depends on several drying parameters. The parameters are the types of fabric, air velocity and circulation, surrounding air temperature, vapour pressure and relative humidity, moisture movement in fabric, and the supply of heat.

There are some types of fabric that are available in the market, such as cotton, polyester, jeans and nylon. The combinations of these types of fabric eventually generate a new form of fabric. The absorption of water molecules depends on the ratio of combination of the cotton, polyester, jeans and nylon. The degree of absorption of water molecules are in order of the following sequences:

- Jean
- Cotton
- Polyester
- Nylon

The higher the degree of absorption of water molecules means the lower degree of evaporation of water molecules. Similarly, higher the degree of absorption of water molecules means the lower degree of movement of water molecules.

Airflow does play an important role in drying similar to the influences of the external heat and mass transfer coefficients. The heat transfer coefficient is a function of the airflow rate, the thermal properties of the air and the geometry of the surface. The mass transfer coefficient is a function of the airflow rate and the diffusion coefficient. In short, air velocity is particularly relevant as higher the air flow rate the higher is the moisture extraction. Indirectly it will increase the moisture extraction rate and drying rate.

Besides that, the temperature of the air surrounding it has an effect to the rate of water evaporation from the fabric surface. With kiln drying, warm or hot air is passed over the clothes. At the beginning of the drying process, the temperature different between the air and the wet clothes will usually be large. Heat energy will flow from the high heat gradient to low heat gradient as in drying, the surrounding air to the clothes surface where it will raise the temperature of both the clothes and the water molecules within it. Water molecules in the clothes which gain enough energy to over come the energy of vaporization will then escape to the surrounding in the form of vapour, provided the surrounding air is not already saturated with moisture. As a result, a moisture content gradient exists between the inside to the outside of the fabric. The higher gradient of moisture content in the inner side of the clothes will then move to the lower gradient of moisture content as to the outer surface of the fabric. This phenomenon will then repeat itself as the moisture at the outer surface evaporated.

2.3 Kiln Drying

Kiln drying, uses higher temperature to increase the capacity of air to absorb moisture. An advantage of this is that less air needs to be heated and exhausted from the kiln. In addition to that, higher temperature allows more rapid drying of a timber load to uniform final moisture content. Among the most recent studies on the control of the drying process in drying kiln, the temperature drop across the load and the specimen temperature were the alternatives that presented the most promising results. The observation that the internal temperature of the wood increases as its moisture content decreases (10), suggests its use as a tool to indicate the end of drying period (11).

Figure 2.2 below shows a convective drying model for a non-hygroscopic material in which the wet and dry regions are separated by the moving evaporation front. In drying wet solids, simultaneous heat and mass transfer occur both inside the solids and at the boundary layer of the convective stream. This preliminary model accounts for the propagation of the evaporation front, and it is capable of predicting the moisture content and the temperature for the whole solid and as well as the partial vapour pressure in the drying region (9).

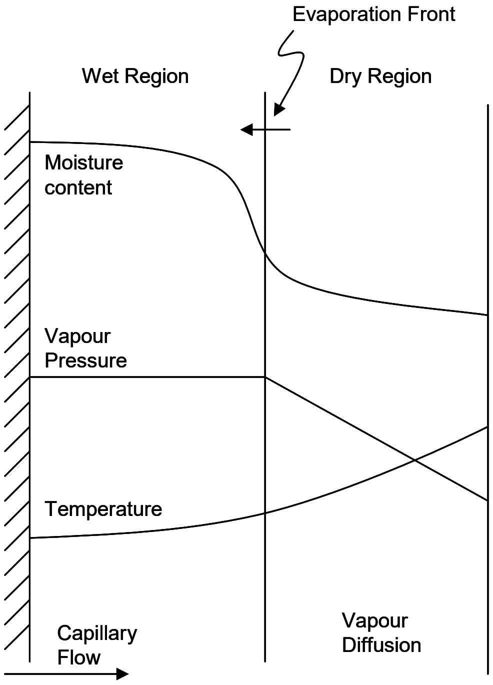


Figure 2.2: One Dimensional Model for Convective Drying Process

2.4 Tumble Clothes Dryer

A clothes dryer can be found in just about every house in the United States, and millions more of them are manufactured each year. They are very reliable, and very cheap to build (12). Clothes dryers have:

- A rotating tumbler that holds the clothes.
- An electric or gas powered heater that heats the air that is drawn through the clothes as they tumble, which in turn heats up the clothes and the water in them.
- An exhaust vents that passes out of the dryer and out of the house so that the water exits the dryer in the form of steam.

Warm and moist air leaves the dryer through a hole in the back, which is usually hooked up by a pipe to a vent on a house. Ambient air enters the body of the dryer through a large hole in the front of the dryer. It is then sucked past the heating element and into the tumbler. Then the hot air enters the door and is directed down through the lint screen. It passes through a duct in the front of the dryer and into the fan. The fan forces it into the duct leading out the back of the dryer, at which point it exits to the environment.

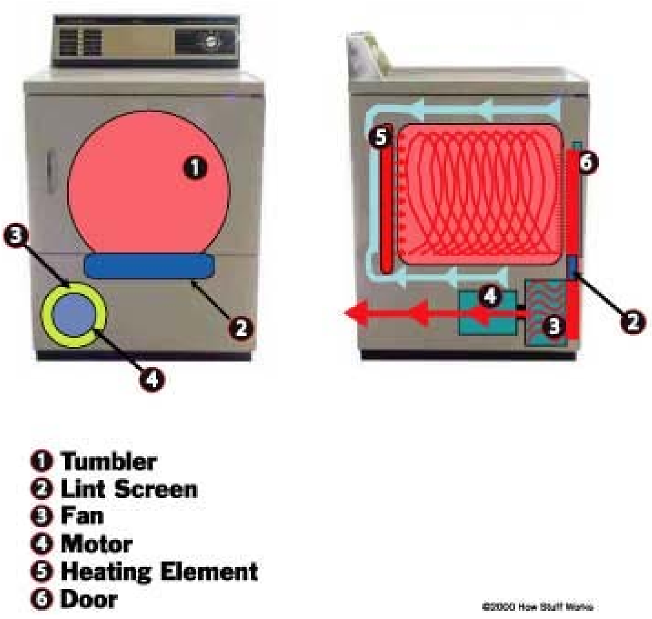


Figure 2.3: Tumble Dryer airflow diagram

3.0 HEAT PUMP

3.1 Heat Pump Cycle

The purpose of a refrigerator is to transfer heat from a cold chamber which is at a temperature lower than that of its surroundings. A temperature gradient is thus established from the surroundings to the chamber and heat will flow naturally in this direction. The heat flow can be resisted by insulating the chamber from the surroundings by the use of suitable insulating materials, but practical requirements and conditions make necessary a continuous means of transfer of heat from the chamber.

The nature of the problem suggests a means of refrigeration which consists of a cycle of processes with the same quantity of working fluid, called the refrigerant, in continuous circulation. If the refrigerant receives energy in the cold chamber at a temperature below that of the surroundings, then this energy must be rejected before the refrigerant can return to the cold chamber in its initial state. This energy rejection must be carried out at a temperature above that of the surroundings. The energy at rejection is of a higher quality, because of its higher temperature, than that received in the cold chamber. This energy can be used for heating purposes and refrigerating plants designed entirely for this purpose are called heat pumps.

The term `heat pump' is appropriate to the action of the plant since energy is transferred against the natural temperature gradient from a low-temperature to a higher one. It is analogous to the pumping of water from a low level to a higher one against the natural gradient of gravitational force. Both actions require an input of energy for their accomplishment. There is no difference in operation between a refrigerator and a heat pump. With the refrigerator the important quantity is the energy removed from the cold chamber called the refrigerating effect, and with the heat pump it is the energy to be rejected by the refrigerant for heating purposes. The machine can be used for both purposes and one particular domestic unit provides for the cooling of a larder and the heating of water (13).

Heat pump dryer (HPD) is co-existence of two engineering systems:- the heat pump and the dryer. Heat pump assisted-drying provides a controllable drying environment (temperature and humidity) for better products' quality at low energy consumption (cost). In a conventional hot air dryer, substantial energy (heat) loss is not avoidable as the process air at relative high temperature has to be vented off from the dryer.

The most widely used refrigerators and heat pumps are those which use a liquefiable vapour as the refrigerant. The evaporation and condensation processes take place when the fluid is receiving and rejecting the specific enthalpy of vaporization, and these are constant-temperature and constant-pressure processes. The cycle is one in which these two processes correspond to those of the reversed Carnot cycle for a vapour, and this enables the temperature range for a given duty to be kept low. The resistance to heat transfer during the change of state from liquid to vapour, or from vapour to liquid, is less than that for the refrigerant in the liquid or gaseous states. For a required rate of heat transfer the area of the surfaces required is less if this fact is utilized (13).

Heat pump drying is eventually based on the reversed Carnot cycle. The heat pump consists of the compressor, the condenser, the expansion valve and the evaporator connected in series to form a loop as shown in Figure 3.1. The Carnot cycle is simplified by replacing the expansion cylinder with a simple throttle valve. The process is highly irreversible so that the whole cycle becomes irreversible. Ideally, the compressor isentropically compresses the working fluid vapor from the low-pressure suction line to the high-pressure discharge line (process 1-2). Mechanical work is added into the working fluid hence increases its enthalpy. The compression is normally a polytropic process rather than isentropic one since the reversible adiabatic condition is not practically achievable. The superheated vapor rejects heat at the condenser and becomes a saturated or subcooled liquid (process 2-3) before isenthalpically expanding through the expansion valve (process 3-4). The low-pressure liquid vaporized in the evaporator (4-1) and in effect draws heat from the surrounding, normally ambient air.

The changes in the thermodynamics properties of the refrigerant throughout the cycle are indicated on the T-s diagram of Figure 3.2.

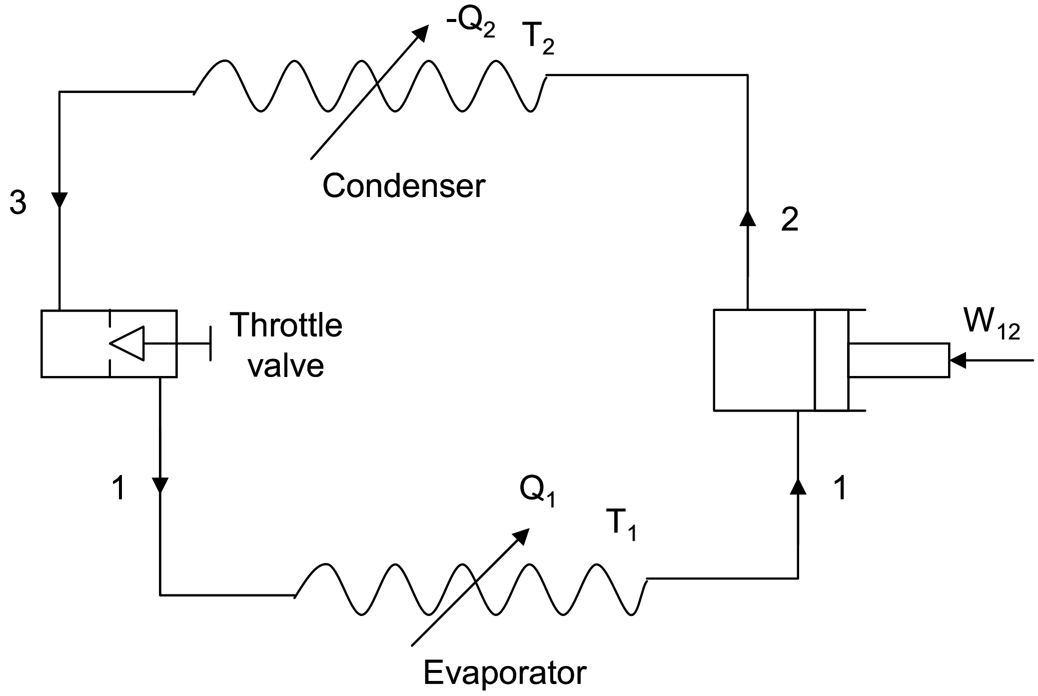


Figure 3.1: Schematic diagram of reversed cycle using a throttle valve

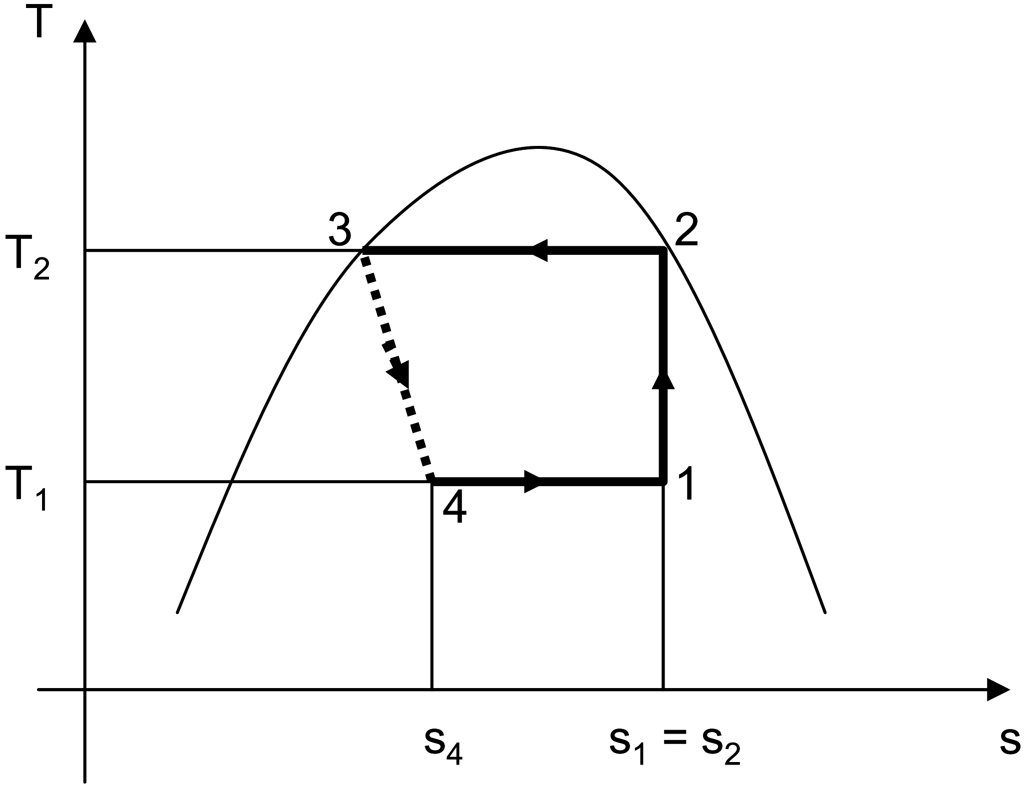


Figure 3.2: T-s diagram of reversed cycle using a throttle valve

A simple energy balance on the system shown gives

$$-Q_2 = Q_1 + W_{12}$$

where

$-Q_2$ = Heat rejected form the system
Q_1 = Heat supplied to the system from the surroundings
W_{12} = Power input

The heat pump performance is defines by the mean of coefficient of performance (COP) HP, which is given by:

$$\begin{aligned} COP_{HP} &= \frac{-Q_2}{W_{12}} \\ &= \frac{Q_1 + W_{12}}{W_{12}} \\ &= 1 + \frac{Q_{in}}{W_c} \end{aligned}$$

The coefficient of performance (COP) HP, may also defined in term of temperature, which is given by:

$$COP_{HP} = \frac{T_2}{T_2 - T_1}$$

From the equation above, it is clear show that the COP of the heat pump is always greater than 1. Therefore, a heat pump always produces more heat energy than work energy consumed, because there is a net gain of energy Q_1 transferred from the low temperature to the high temperature environment. In general, the heat pump COP is in the order of 3 to 5. Because of the ability to deliver the heat more than the work input, research and development of heat pumps have been aimed for energy conservation.

Beside the T-s diagram shown in figure 3.2, a more convenient method use to obtain the enthalpy value which can be directly read off instead of using calculation. The method concern is by using a chart known as pressure-enthalpy diagram as shown in the figure below. The points 1, 2, 3 and 4 represent the same positions in the cycle as they did in the previous figure, in addition a undercooling is shown.

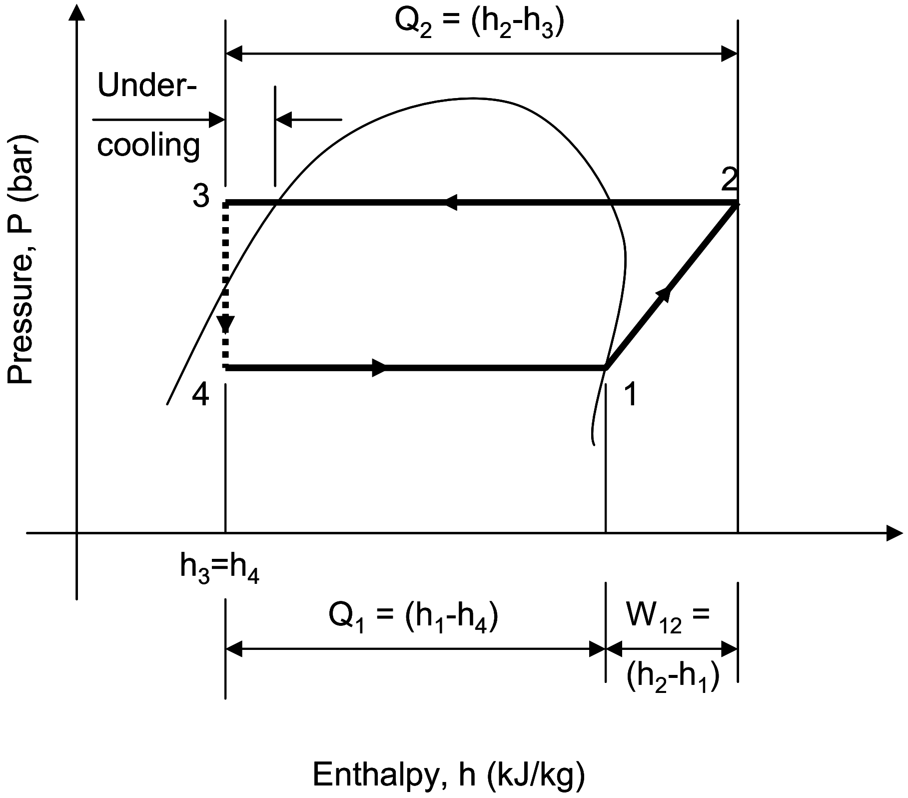


Figure 3.3: Pressure-enthalpy diagram for reversed cycle using a throttle valve

The following data and calculation can be obtained easily by using P-h diagram:

Heat rejected form the system, $Q_2 = h_2 - h_3$

Heat supplied to the system from the surroundings, $Q_1 = h_1 - h_4$

Power input, $W_{12} = h_2 - h_1$

$$COP_{HP} = \frac{-Q_2}{W_{12}} = \frac{Q_1 + W_{12}}{W_{12}} = \frac{h_2 - h_3}{h_2 - h_1}$$

In addition to the entire diagram mentioned earlier, another important chart which is the most convenient method to obtain specific humidity and percentage saturation are known as psychrometric chart. A skeleton of a psychometric chart is shown in appendix C. An ordinate erected at the known dry bulb temperature and the point of intersection between it and the diagonal line representing the known wet bulb temperature is found. The percentage of saturation is then found from the curve of constant percentage saturation which passes through this pint. The specific humidity is read off the ordinate scale in kilograms of vapour per kilogram of dry air. The enthalpy of the mixture in kilojoules per kilogram of dry air can be read off the diagonal scale of specific enthalpy. The zero specific enthalpy for the vapour is always taken at 0 °C. For the dry air the zero for specific enthalpy is taken at 0 °C [(14)].

Figure 3.4 shows the psychrometric chart of air circuit for drying with dehumidification (a-b-c-d-e-f) and without dehumidification (d-e-f). When the high humid air from the atmosphere is passed through the condenser coil (d-e), the air is heated up with reduction in relative humidity, this air is used for drying clothes at a constant enthalpy (e-f).

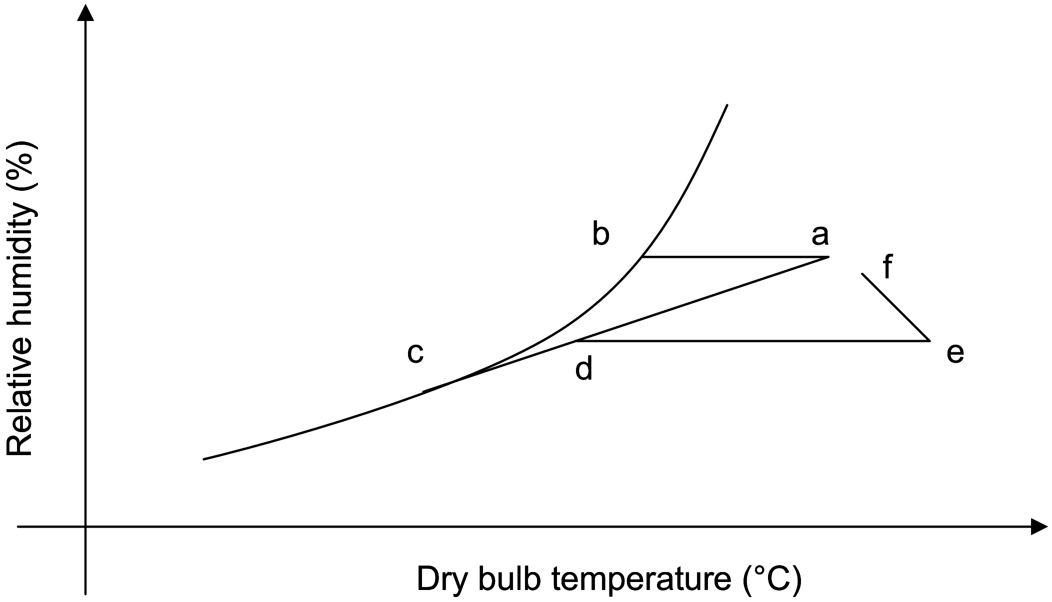


Figure 3.4: Psychometric chart for the dehumidifying process

3.2 Heat Pump Configuration

Heat pump dryers have a number of different configurations, depending on the placement of the heat pump evaporator. Figure 3.5 to 3.7 illustrate some of the options (Charters and Aye, 1993). Here the open-ended arrows represent airflows taken from, or being discharged to, the local environment and the dashed line indicates the klin boundary (15).

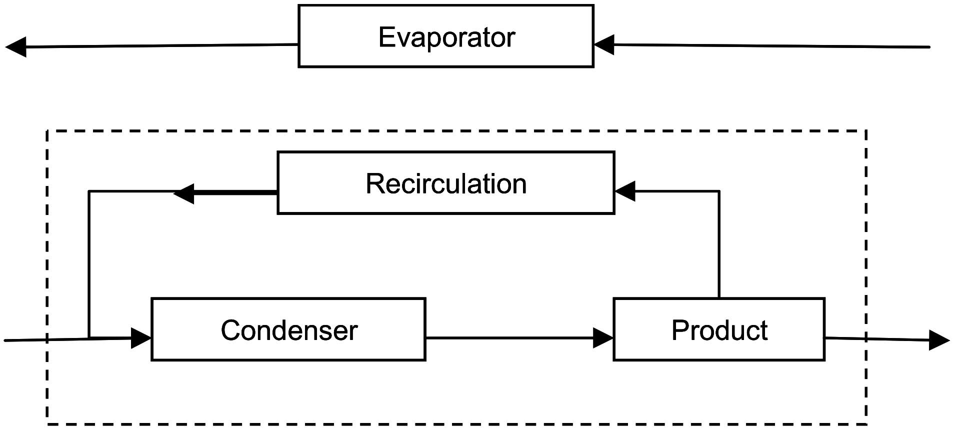


Figure 3.5: Atmospheric heat source heat pump drier

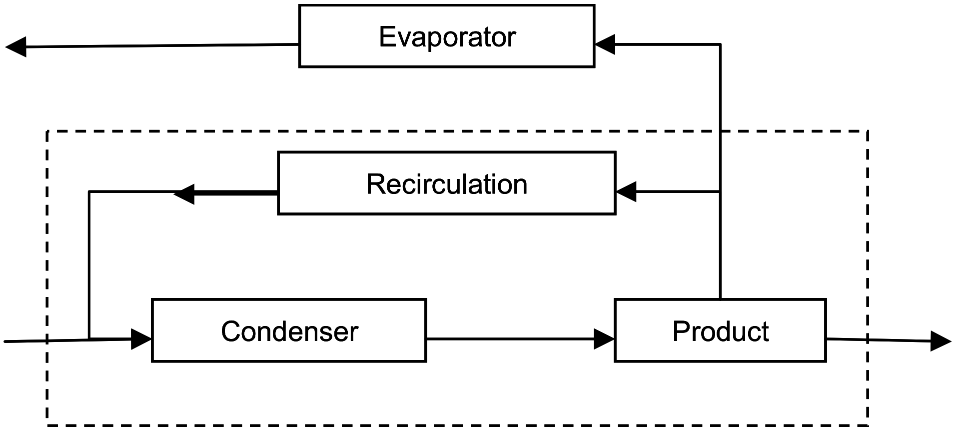


Figure 3.6: Open cycle heat pump drier with heat recovery

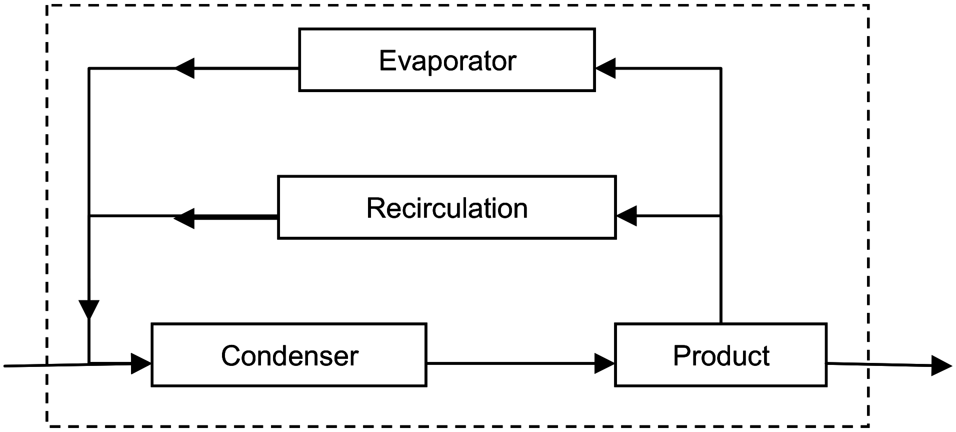


Figure 3.7: Schematic of a heat pump dehumidifier system uses air venting for temperature control

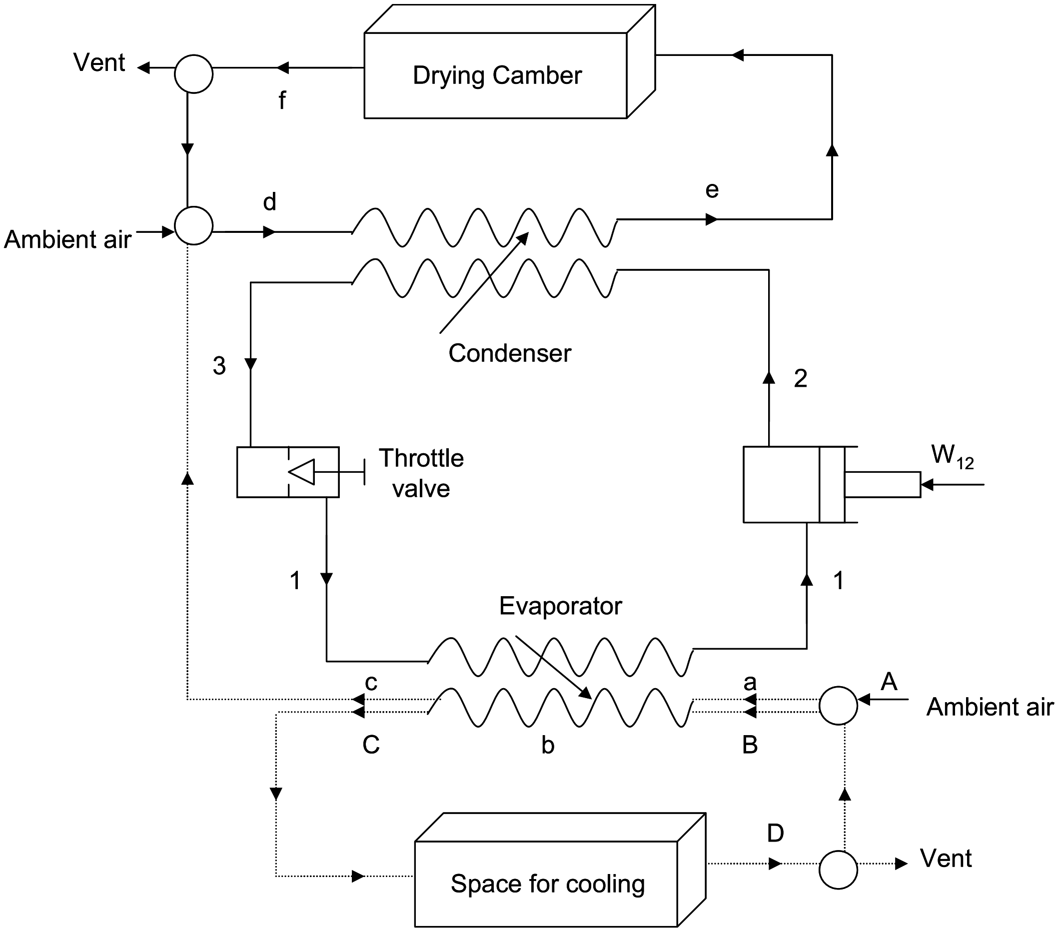


Figure 3.8: Configuration of a simple heat pump system for drying

3.3 Calculation

The purpose of this experiment was to find the moisture extraction rate of the clothes. This parameter defines the efficiency of the dryer. The loss in weight during drying indicates how much water was present in the clothes. The moisture extraction, moisture extraction rate, drying rate and percentage of moisture content can be calculated simply, as follows:

- Moisture extraction = initial weight – final weight

$$= \mathrm{w}_{\text{initial}} - \mathrm{w}_{\text{final}} \quad \text{(g)}$$

- Moisture extraction rate = $\dfrac{initial\ \ weight - final\ weight}{drying\ time}$

$$= \frac{w_{initial} - w_{final}}{t} \quad \text{(kg/h)}$$

- Drying rate = $\dfrac{moisture\ extraction\ rate}{weight\ of\ \ dry\ clothes}$

$$= \frac{w_{initial} - w_{final}}{t\ x\ weight\ of\ \ dry\ clothes}$$

(kg/s of moisture/kg of dry clothes)

- Percentage of moisture content = $\dfrac{weight\ of\ \ moisture}{weight\ of\ \ dry\ clothes} \times 100$

(kg of moisture/kg of dry clothes) (%)

The specific moisture extraction rate (SMER) defines the effectiveness of the energy used in the drying process. SMER value can be calculated by using the equation below.

$$\text{SMER} = \frac{moisture\ extracted}{total\ \ power\ consumption}$$

$$= \frac{w_{initial} - w_{final}}{P} \quad \text{(kg/kWh)}$$

Another parameter which is commonly used to determine the operation cost is the specific energy consumption rate (SEC) which can to be said as the inverse of SMER, is given by the equation below:

$$\text{SEC} = \frac{total\ \ power\ consumption}{moisture\ extracted}$$

$$= \frac{P}{w_{initial} - w_{final}} \quad \text{(kWh/kg)}$$

The performance of a heat pump also can be expressed in term of Coefficient of Performance (COP), which is defined by

$$COP_{Heatpump} = \frac{1}{1 - \dfrac{T_{Low}}{T_{High}}}$$

However, the pressure-enthalpy diagram is more convenient to use since the enthalpies required for the calculation can be read off directly.

Relative humidity (RH) of the ambient air can be read off directly by using the psychrometric chart in appendix C as the dry bulb and wet bulb temperature is known by means of thermocouples.

4.0 DESIGN AND FABRICATION OF EXPERIMENTAL FACILITY

4.1 Design of Test Rig

4.1.1 Introduction

The design and development of Heat Pump Assisted Clothes Dryer is to study the feasibility of drying clothes using waste heat of a condenser of a typical split type domestic air conditioner. Therefore, the clothes dryer are designed to operate under two modes, (i) in open system air dries the clothes from the waste heat while cooling is provided to supply cool to a room (like the conventional usage of air-conditioning) and (ii) in close system air dries the clothes from the waste heat and redirect the air back to the evaporator unit to dehumidify, then goes back to the condenser for further heating. Three additional modes of drying were carried out. These are drying by (i) solar heat, (ii) heating through bulbs and (iii) drying through heating by electrical element of 1000W.

The following factors were considered in the designing stage:

1. Economical of cost
2. Minimal modification of typical split type domestic air-conditioning
3. Feasibility of systems and conditions changes
4. Minimal weight for easy handling
5. Mobility
6. Easy to operate
7. Room for future improvement and development
8. Safety of operation
9. Practical in domestic use
10. Optimization of air flow
11. Easy to manufacture
12. Time constraint

4.1.2 Design of Heat Pump System

Since the design and development of Heat Pump Assisted Clothes Dryer is to study the feasibility of drying clothes using waste heat of a condenser of a typical split type domestic air conditioner, the components of the heat pump was not designed but sourced from those available commercially. Based on the popularity of 1 HP air-conditioning in urban area, mostly in installed in apartments, the 'YORK Wall Mounted Split Air-Conditioning' is chosen. The model for the indoor unit is YWM 10 F and the outdoor unit is YSL 10B. As stated in the product catalog, the 1 HP unit can achieve 10,000 Btu/hr which surpassing all the others in its category. This unit also boasts a high EER of 11.3%, 25% energy savings and the quietest sound level at 29 dBA.

Table 4.1 Specifications of the air-conditioning unit:

	Indoor unit	Outdoor unit
1. Nominal total cooling capacity	10,000 Btu/h	
2. Nominal sensible cooling capacity	6,800 Btu/h	
3. Power supply	220-240 V / 1 Ph / 50 Hz	
4. Running ampere	0.11 A	3.80 A
5. Input power	25 W	863 W
6. Evaporation coil	0.20 m^2 / 2/18 row/(fin/in)	
7. Condenser coil	0.32 m^2 / 1/18 row/(fin/in)	
8. Air volume	8.50 cmm	20.80 cmm
9. Fan Motor Speed	1180 rpm	790 rpm
10. Sound pressure level	36/32/29 dBA	48 dBA
11. Refrigerant	R-22	
12. Refrigerant discharge pipe size	6.35 mm	
13. Refrigerant suction pipe size	9.25 mm	
14. Condensate pipe size	16 mm	
15. Air filter	Anti fungus polypropylene honeycomb filter	
16. Compressor	Rotary hermatic	
17. Protection device	Overload protection	

Figure 4.1: Indoor unit of YORK air-conditioning, model YMW 10F

Figure 4.2: Outdoor unit of YORK air-conditioning, model YSL 10B

4.1.3 Design of Frame/Cabinet

The design of cabinet is the major design in this project as it serves a multi purpose functions. The first consideration is to fit the outdoor and indoor unit of the air-conditioning unit into the cabinet. The outdoor unit which is the condensing unit is to be located below the indoor unit which is the fan-coil unit, so that the refrigerant will flow back to the reserve tank when the unit is not in use. Therefore the condensing unit is placed at the bottom of the cabinet and the evaporator unit is placed at the top of the cabinet.

In order to have different modes of drying, the evaporator unit is fixed in an additional housing at the top back side of the unit. This housing space has 2 sliding doors to control the air flow direction in the system which one is situated on the top of the evaporator unit and the other is located at the bottom of the evaporator unit. A door is also needed to stop the intake air from the environment outside to the evaporator room when the close system is desired and vice versa.

At the bottom of the cabinet, where the condenser unit is located there is also a door serving the same function as the door in the evaporator. There is also a partition across the condenser to separate the outlet air of the condenser from mixing the inlet air which will drop the efficiency of the condenser and compressor. To eliminate the pressure drop of air as directed 90 degree up to the drying area, an arc metal sheet is installed so that is serve as a nozzle to increase the air velocity.

Optimization of the air flow to the drying area can be made by tilting the flipper on the partition at bottom of the drying area. A weighing machine holder is also design to hold the weighing machine and at the same time supporting the clothes hanging on the weighing machine. The weighing machine holder is placed on the top of the drying camber. An exhaust fan is installed to draw the drying area air to the atmosphere. This will help a smooth flow of air from the condenser thru the clothes and later removed by the exhaust fan.