DESIGN AND ANALYSIS OF CLOTH DRYER CABINET BY UTILIZING HEAT REJECTED FROM AIR CONDITIONING SYSTEM

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

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Dedicate to my beloved father, mother and my honour siblings

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First grateful to Allah SWT for making it possible for me to complete this project on time. It is a pleasure to acknowledge the help and support of everyone who concerned with this project. To my father, mother and siblings who have been so keen in helping and supporting me in the period of completing my final year project..

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Finally, my sincere thanks go to all my friends that help me especially for those who are under same supervisor with me. Thanks for all the coorperations.

ABSTRACT

Nowadays cabinet dryer is widely use, especially for those who are busy working. Besides that, most of the laundries today have a dryer. It is not just because it can run their operation all the time, but they also can prevent the risk to the cloths that might lost or get dirt. Cabinet dryer in the market nowadays is using electrical power as a source in generating heat. The other alternative in manipulation of heat being study to create a new cabinet dryer that make a benefit of waste. From the study, it found that split air conditioning system had waste heat that rejected from it condensing unit. The rejected heat had bad effect to the environment. This project is the study in manipulation of the heat rejected from air conditioning system to dry cloths inside a cabinet dryer. It cover the design of cabinet, investigation of the effectiveness and comparison to the several kind of other dryer. The comparison been made between natural drying and drying by commercial cabinet dryer According to the comparison, it shows that drying by heat rejected from condensing unit is better compares to the natural drying. But commercial dryer have a better drying rate compares to the cabinet dryer that manipulate the heat from condensing unit.From this project, it prove that the cabinet dryer utilizing heat rejected by air conditioning system is effective and worth even the performance is not good as commercial cabinet dryer, it is free and environmental friendly.

ABSTRAK

Kini cabinet pengering digunakan secara meluas terutamanya pada mereka yang sibuk bekerja. Selain itu, kebanyakan dobi kini juga menggunakan kabinet pengering. Ia bukan kerana cabinet pengering boleh berfungsi setiap masa, tapi dapat mengelakkan risiko kehilangan atau kekotoran pada baju semasa menjemur. Kabinet pengering di pasaran kini menggunakan kuasa elektrik untuk menjana haba. Sumber lain untuk memanipulasikan haba dikaji untuk mencipta sebuah cabinet pengering yang mendatangkan kebaikan daripada pembaziran. Dari kajian yang dijalankan mendapati bahawa system penghawa dingin melepaskan haba ke persekitaran melalui kondenser. Haba yang dilepaskan ini membahayakan persekitaran yang boleh menyebabkan pemanasan global. Projek ini bermatlamet untuk memanipulasikan haba yang dilepaskan itu untuk digunakan untuk mengeringkan baju melalui kabinet pengering. Ia meliputi reka bentuk kabinet, kajian mengenai keberkesanan dan perbandingan dengan proses pengeringan yang lain. Perbandingan ini dibuat dengan pengeringan semulajadi dan pengeringan menggunakan kabinet pengering yang sedia ada dipasaran. Melalui perbandingan ini dilihat pengeringan yang menggunakan haba dari kondenser lebih baik dari pengeringan semulajadi. Namun yang demikian, pengeringan menggunakan kabinet pengering dipasaran kini lebih baik berbanding kedua-dua pengeringan yang lain. Dari projek ini, ia membuktikan yang kabinet pengering yang menggunakan haba dari kondenser paling berbaloi kerata tiada kos diperlukan dalam masa yang sama mesra alam.

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LIST OF SYMBOLS

N_{CRDP} = drying rate in CRDP, kg/s m

N_{FRDP} = drying rate in FRDP, kg/s m

t_{CRDP} = duration of CRDP, min

t_{FRDP} = duration of FRDP, min

W_d = weight of dry material, g

A = area of a drying surface at which heat and mass transfer takes place, m

n = drying index (determined by experiments)

F = free moisture content, g/g

F_{cr} = critical free moisture content, g/g

t_{cr} = time of critical point, min

X = volume-average moisture content (dry basis), g/g

X_{cr} = critical moisture content, g/g

X_O = initial moisture content, g/g

X_E = equilibrium moisture content, g/g

X_{Ea} = equilibrium moisture content under the ambient condition, g/g

X_{Ed} = equilibrium moisture content under the drying environment, g/g

LIST OF ABBREVIATIONS

CRDP : Critical Rate Drying Process

FRDP : Falling Rate Drying Process

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In the modernization era nowadays, both man and women commute to work. Generally, working hours start from 8am until 5pm, which mean that the extra time from 24 hours per day left only 15 hours. Sadly, this extra time left start from evening until morning where the heat of sun is hard to be manipulated. Human can not avoid from daily job. Either it is personal job or in the workplace. Some of the jobs become routine. Everybody wear a cloth and it is important to keep it clean. Wash a cloths is like a routine and it is necessary that the washed cloths to be dry. For those who are busy commute to work, this routine is one of the challenges in daily life. As long as human have effort to upgrade the quality of lifestyle, the technology will always improve.

Technology has been created to help human job. To make it easy and solve problems that might be faced by human. So many appliances, devices and equipments have been use today, and the appliance which is been use to solve the problem is cabinet dryer. Cabinet dryer is such an appliance that been use to dry cloths or in other word is to remove moisture from cloths. Commercial dryer that widely use today use a heater as a heat supplier, where the electrical as a main power source to produce a heat, by transformation energy from electric to heat energy.

Nowadays cabinet dryer is widely use, especially for those who are busy working. This is because they can dry their cloths at night and also rainy day. Besides that, most of the laundries today have a dryer. It is not just because it can run their operation all the time, but they also can prevent the customers cloths from lost and also dirt, which is normal problems occur in natural drying when dry it to the sunlight which is open to the environment. There are risks by natural drying, it might be stolen, rain or the cloths become dirty by smoke and dust from air, and also fungi. More and more important, time needed to dry cloths with cabinet dryer is shorter. This can proven by the investigation that been made by Ahmadul Ameen and Saiful Bari between the natural dryer, commercial dryer and heat pump dryer. This benefit is really suitable for human nowadays, where always facing limited time per day. The other benefit for using the cabinet dryer is, save space. For example for those who live in flat or apartment, where the space to dry cloths is limited. By using cabinet dryer that come with many size and just need a small space this problem can be solve. For those countries that hard to manipulate heat from sun, dryer cabinet is necessary.

Even there are many benefit of using cabinet dryer it still has disadvantages. This is because of the cost to buy this appliance. For the commercial dryer nowadays, it follows by monthly electrical bills where the operation needs electrical power to generate heat. Maybe some people love to have cabinet dryer but because of the cost, most of them prefer the natural dryer where have no cost at all. In this era, the technology that can make human job easier, consideration on economic, ergonomic, and environmental friendly are also priority. To overcome these problems, the new type of cabinet dryer will be studied and will be discuss in this project.

1.2 PROBLEM STATEMENT

As being state in the project background, facing the monthly cost is the main problems in using a cabinet dryer. Base on the theory of drying, cabinet dryer need to supply heat to remove the moisture. To generate heat, commercial dryer today use heater that needs electric power, which meant there will be a monthly charge in our electric bill. To overcome this problem is to found other alternative to manipulate heat. The heat must be able for the drying period at the same time free.

A second problem is how to make the cabinet dryer is safe, ergonomic and environmental friendly. Even we have a free heat, the cabinet dryer should be able to perform the operation efficiently and marketable. This mean, the design of this appliance must be attractive and good performance.

Drying process involves two mechanisms. Energy has to be provided to change the water from liquid to vapor and air stream is needed to remove the vapor. According to the kinetic theory, temperature is the expression of the average energy of molecular motion. It means providing heat is necessary as the energy is to change the moisture shape to become vapor. Besides, air flow rate is also a very strong influence to drying rate. So much more water vapor is removed in a rapid air flow. The temperature doesn't change with wind speed but the evaporation rate does. Generally, natural drying has a wind that can ensure that the cloths will not stinky. Just same with the cabinet dryer where that need a mechanism that can ensure the cloth will dry without any bad effect. The air flow in the cabinet dryer must be considered at the same time the heat provided is also one of the main priorities. Hot air must flow through the cloths and directed out from the cabinet and the humid air must be reject from the cabinet dryer.

The studied of air conditioning system shown there are waste heat being rejected from the condenser to ambient air. This mean free heat is just being waste without any benefit. There is badness in releasing heat to the environment that will cause of global warming. This problem can overcome by manipulate the waste heat to flow into a cabinet dryer and remove the moisture from cloths. This heat will cost zero, which mean no monthly charge for using cabinet dryer. Cost for the air conditioning system usage can be separate to two functions which are also to dry cloths. This mean the cost that we spend is worth compared to the usage that only for air conditioning system without cabinet dryer.

1.3 PROJECT OBJECTIVES

There are several objectives regarding to the title of Design and Development of Cloth Dryer Cabinet by Utilizing Heat Rejected from Air conditioning System:

i. To design cloth dryer cabinet by utilizing heat rejected from air conditioning system.
ii. To analysis a cloth dryer cabinet by utilizing heat rejected from air conditioning system.

1.4 PROJECT SCOPES

Project scopes are very important to start this project. This is because, the objective is not enough to widely cover the project all about. The scopes for Design and Development of Cloth Dryer Cabinet by Utilizing Heat Rejected from Air conditioning System is:

i. Study about air conditioning system. The information of each part involve in air conditioning system. How it work, temperature and pressure involve in the air condensing unit should be notice.
ii. Study about the cloths drying process. It cover all the mechanism involve, calculation in determining the rate of drying and also all the factors that influence the process.
iii. Analyze the air flow into and outgoing the cabinet dryer. The air flow need to be simulated and how the flow influences the temperature inside the cabinet. The result of the of the flow simulation need to be interpret into heat distribution figure, where it can show the effectiveness of the design.

iv. Design an ergonomic, safe, economic and environmental friendly cabinet dryer. Several design need to be done and being evaluated to choose the best design base on it performance.

v. Testing and compared the drying process performance for natural drying and drying by heat waste from air conditioning system.

1.5 PROJECT FLOW CHART

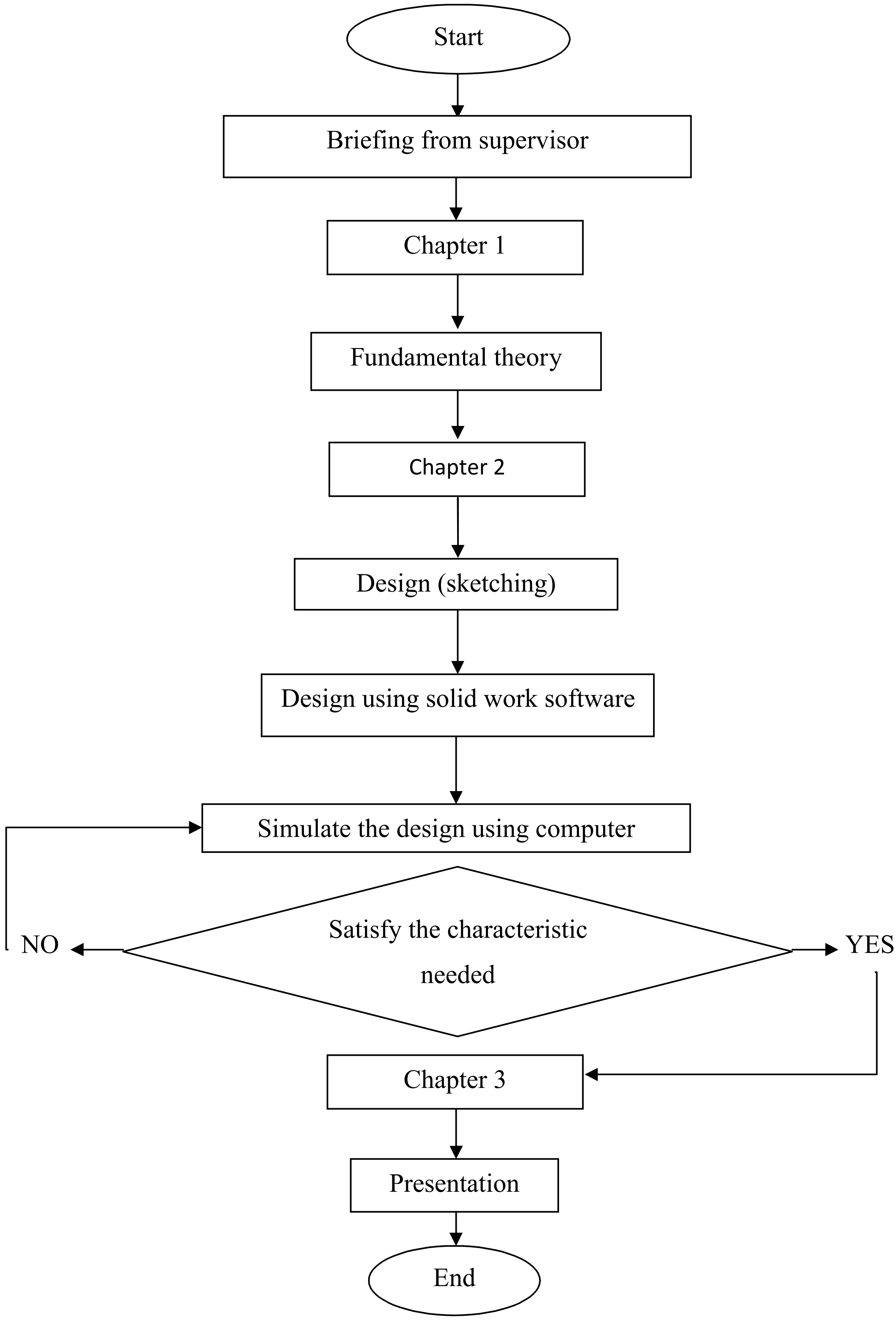

Figure 1.1: Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 SPIT SYSTEM AIRCONDITIONING SYSTEM

Most of people think that air conditioners lower the temperature in their homes simply by pumping cool air in. What is really happening is the warm air is being removed and cycled back in as cooler air. This cycle continues until your thermostat reaches the desired temperature. An air conditioner is basically a refrigerator without the insulated box. It uses the evaporation of a refrigerant, like Freon, to provide cooling. The mechanics of the Freon evaporation cycle are the same in a refrigerator as in an air conditioner. The compressor compresses cool gas, causing it to become hot, high-pressure gas (red in the diagram **Figure 2.1** below). This hot gas runs through a set of coils so it can dissipate its heat, and it condenses into a liquid. The liquid runs through an expansion valve, and in the process it evaporates to become cold, low-pressure gas (light blue in the diagram **Figure 2.1** below). This cold gas runs through a set of coils that allow the gas to absorb heat and cool down the air inside the building. The **Figure 2.1** shows the movement of the hot fluid and cool fluid inside the air conditioning system. The concepts of thermal balance make it possible to release and absorb heat. The physical property of the fluid inside air conditioning system which has very low melting point is one of the reasons for the functioning air conditioner. This is because this fluid is easily change it forms at the same time be able to absorb and releasing heat. Split air conditioning system which separate the system make it possible to be apply to work at the same time.

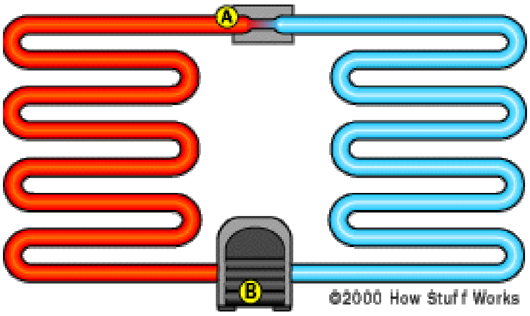

Figure 2.1: Diagram of a typical air conditioner (Danny Parker and John Sherwin 2004)

A split-system air conditioner as shows in the **Figure 2.2** splits the hot side from the cold side of the system. The cold side, consisting of the expansion valve and evaporator, live inside building. The hot side, lives outside the building known as the condensing unit as shows in the **Figure 2.3**. The major elements that exist in this unit are condenser and compressor. The condenser which is in high temperature will extract heat to have a balance heat with it surrounding. It is meaning that the high inlet temperature of condenser around 40 °C to 50°C will transfer heat to the environment and have a balance temperature to it ambient. This process is being help by the air blew of fan that existing in the condensing unit.

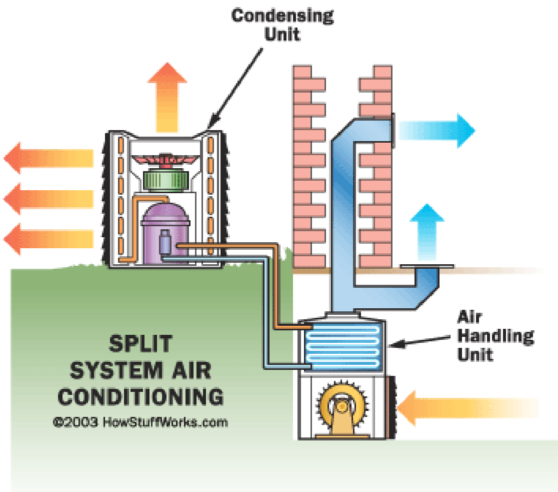

Figure 2.2: Split air conditioning system (Danny Parker and John Sherwin 2004)

Figure 2.3: Condensing unit (Danny Parker and John Sherwin 2004)

2.1.1 Evaporator

A device used to vaporize part or all of the solvent from a solution. Any of many devices in which liquid is changed to the vapor state by the addition of heat, for example, distiller, still, dryer, water purifier, or refrigeration system element where evaporation proceeds at low pressure and consequent low temperature. The solution containing the desired product is fed into the evaporator and passes a heat source. The applied heat converts the water in the solution into vapor. The most common medium consists of parallel tubes but others have plates or coils. Inside the evaporator, refrigerant is changing state from a liquid to a vapor, at a temperature that's about 15° to 20° below the desired final temperature of the space or product being cooled. The saturated gas enters the evaporator where it is changed to a cool dry gas. **Figure 2.4** shows one of the evaporator uses for air conditioning system nowadays.

Figure 2.4: Evaporator (Danny Parker and John Sherwin 2004)

2.1.2 Condenser

Condenser is a device or unit used to condense vapor into liquid typically by cooling it. For air conditioning system the condenser changes the refrigerant from a high temperature gas to a warm temperature liquid. Condensers are used in power plants to condense exhaust steam from turbines and in refrigeration plants to condense refrigerant vapors, such as ammonia and Freon. The petroleum and chemical industries use condensers for hydrocarbons and other chemical vapors. In distillation, a condenser transforms vapors to liquid. All condensers work by removing heat from the gas or vapor. In some, the gas passes through a long tube of heat-conductive metal, such as copper (usually arranged in a coil or other compact shape), and heat escapes into the surrounding air. Inlet temperature of condenser for conditioning system is about 40°C to 50°C and the outlet temperature is around 30°C which is same to the ambient temperature. **Figure 2.5** shows the example of condenser use for air conditioning system nowadays.

Figure 2.5: Condenser (Danny Parker and John Sherwin 2004)

2.1.3 Expansion Valve

A thermostatic expansion valve is a component in air conditioning systems that control the amount of superheat at the outlet of the condenser. The expansion valve meters the proper amount of refrigerant into the evaporator. The expansion valve takes the high pressure liquid and changes it to a low pressure cold saturated gas. This is accomplished by use of a temperature sensing bulb filled with a similar gas as in the system that causes the valve to open against the spring pressure in the valve body as the temperature on the bulb increases. When temperatures in the evaporator decrease so does the pressure in the bulb and therefore on the spring causing the valve to close. A thermostatic expansion valve is a key element to refrigeration cycle where the cycle that makes air conditioning, or air cooling, possible. Figure 2.6 shows example of expansion valve.

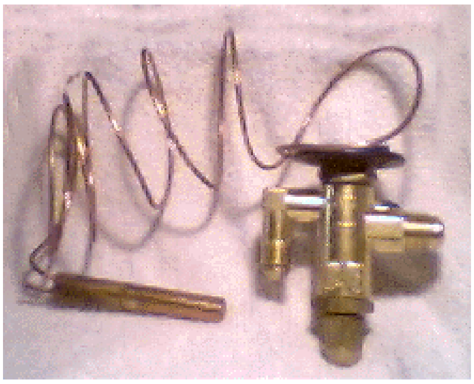

Figure 2.6: Expansion valve (Danny Parker and John Sherwin 2004)

2.1.4 Compressor

Compressor is a machine that increases the pressure of a gas. The pressure of the fluid is increased by reducing the fluid specific volume during passage of the fluid through the compressor. When compared with centrifugal or axial-flow fans on the basis of discharge pressure, compressors are generally classed as high-pressure and fans as low-pressure machines. Compressors are used to increase the pressure of a wide variety of gases and vapors for a multitude of purposes. A common application is the air compressor used to supply high-pressure air for conveying, paint spraying, tire inflating, cleaning, pneumatic tools, and rock drills. The air conditioning compressor is used to compress the gas formed in the evaporator. Compressor will compress the gas and sent out of the compressor as a high temperature, high pressure, superheated gas. **Figure 2.7** shows an example for compressor.

Figure 2.7: Compressor (Danny Parker and John Sherwin 2004)

2.2 DRYING PROCESS

The kinetics of the clothes-drying process inside the dryer involves continuous variation in the values of the temperature and moisture content with respect to time. Assumptions are necessary for successful modeling of various processes occurring inside the dryer. The assumptions are:

- The thermo-physical properties the fabric materials are uniform throughout the volume occupied.
- Dispersion of moisture content within the fabric material is homogenous.
- Instantaneous distribution of moisture within the working fluid is uniform.
- The temperature of the fabric material and the wet-bulb temperature of the working fluid are the same.
- Instantaneous temperature distribution within the bulk of the fabric material is uniform.
- Transfer of moisture from the fabric material to the working fluid takes place inside a cylindrical enclosure, where the material is placed.
- The cylindrical enclosure and the material being dried may be static or in motion; both cases are considered.

- The hot fluid with low moisture-content enters from one of the axial direction and leaves from another.
- For the model implementation purpose, all thermo-physical properties of the working fluid are considered to be the same as those of air.

A complete drying process can generally be divided into three periods namely a pre-heat period, constant-rate drying period (CRDP) and a falling-rate drying period (FRDP). Normally, clothes are mechanically dried (spin) before subjecting to thermal drying. Thus, a pre-heat period will not exist since the initial surface temperature is ready for constant-rate drying, therefore, only the modeling of a CRDP and a FRDP has been considered.

$$N_{CRDP} = \frac{(\qquad)}{}$$

Equation above is used to determine the drying rate in a CRDP. After determining the drying rate in a CRDP, its duration can be calculated by the following equation:

$$t_{CRDP} = t_{cr} = \frac{}{}(X_o - X_{cr})$$

.

After determining the drying rate in a CRDP, we now need to calculate the drying rate in FRDP. The equation below is to determine the drying rate in FRDP.

$$N_{FRDP} = N_{CRDP} \frac{E}{E}$$

After determining the drying rate in FRDP its duration can be calculated by the equation below:

$$t_{FRDP} = \frac{}{(\quad)}[F^{(\quad)} - Fcr^{(\quad)}]$$

2.3 AIR FLOW THEORY

Flow of air or any other fluid is caused by a pressure differential between two points. Flow will originate from an area of high energy, or pressure, and proceed to area(s) of lower energy or pressure.

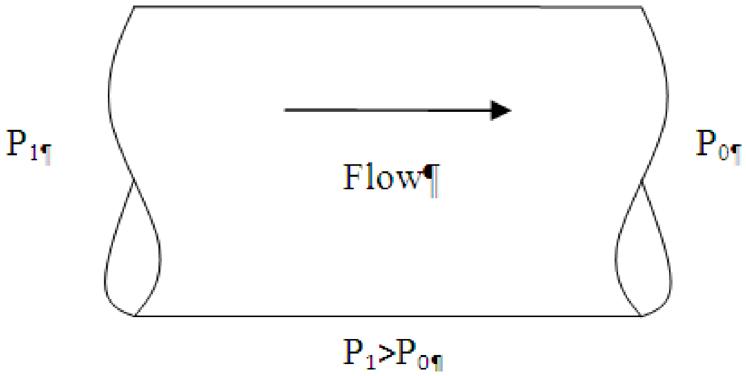

Figure 2.8: Conservation of momentum

Duct air moves shows by the **Figure 2.8** according to three fundamental laws of physics: conservation of mass, conservation of energy, and conservation of momentum.

Conservation of mass simply states that an air mass is neither created nor destroyed. From this principle it follows that the amount of air mass coming into a junction in a ductwork system is equal to the amount of air mass leaving the junction, or the sum of air masses at each junction is equal to zero. In most cases the air in a duct is assumed to be incompressible, an assumption that overlooks the change of air density that occurs as a result of pressure loss and flow in the ductwork. In ductwork, the law of conservation of mass means a duct size can be recalculated for a new air velocity using the simple equation:

$V_2 = (V_1 * A_1)/A_2$

The law of energy conservation states that energy cannot disappear; it is only converted from one form to another. This is the basis of one of the main expression of aerodynamics, the Bernoulli equation. Bernoulli's equation in its simple form shows that, for an elemental flow stream, the difference in total pressures between any two points in a duct is equal to the pressure loss between these points, or:

(Pressure loss)1-2 = (Total pressure)1 - (Total pressure)2

Conservation of momentum is based on Newton's law that a body will maintain its state of rest or uniform motion unless compelled by another force to change that state. This law is useful to explain flow behavior in a duct system's fitting.

2.3.1 Types of Flow

Laminar Flow

Flow parallel to a boundary layer. In HVAC system the plenum is a duct.

Turbulent Flow

Turbulent flow is perpendicular and near to the center of duct and parallel and near to the outer edges of duct. Most HVAC applications fall in the transition range between laminar and turbulent flow.

2.3.2 Types of Pressure Losses or Resistance to Flow

Pressure loss in ductwork has three components, frictional losses along duct walls and dynamic losses in fittings and component losses in duct-mounted equipment. Component pressure due to physical items with known pressure drops, such as hoods, filters, louvers or dampers.

Dynamic Pressure

Dynamic losses are the result of changes in direction and velocity of air flow. Dynamic losses occur whenever an air stream makes turns, diverges, converges, narrows, widens, enters, exits, or passes dampers, gates, orifices, coils, filters, or sound attenuators. Velocity profiles are reorganized at these places by the development of vortexes that cause the transformation of mechanical energy into heat. The disturbance of the velocity profile starts at some distance before the air reaches a fitting. The straightening of a flow stream ends some distance after the air passes the fitting. This distance is usually assumed to be no shorter then six duct diameters for a straight duct. Dynamic losses are proportional to dynamic pressure and can be calculated using the equation:

Dynamic loss = (Local loss coefficient) * (Dynamic pressure)

Where the local loss coefficient, known as a C-coefficient, represents flow disturbances for particular fittings or for duct-mounted equipment as a function of their type and ratio of dimensions. Coefficients can be found in the ASHRAE Fittings diagrams. A local loss coefficient can be related to different velocities. It is important to know which part of the velocity profile is relevant. The relevant part of the velocity profile is usually the highest velocity in a narrow part of a fitting cross section or a straight/branch section in a junction.

Frictional Pressure

Frictional losses in duct sections are result from air viscosity and momentum exchange among particles moving with different velocities. These losses also contribute negligible losses or gains in air systems unless there are extremely long duct runs or there are significant sections using flex duct.

2.3.3 System Effect

There are some variable which is effect the air flow. The **Table 2.1** below shows the system effect table that been consider in investigation of flow inside duct.

Table 2.1: System effect table

Distance between Riser and Elbow	System Effect Coefficient (K)
2 feet	1.75
3 feet	1.5
4 feet	1.3
5 feet	1.2

2.4 HEAT PUMP THEORY BASE ON DRYING PROCESS

The possibility of using a vapor compression refrigeration cycle for both spaces cooling and drying of clothes is considered and the system is referred to an integrated heat pump system (IHPS). A line diagram of the IHPS is shown in **Figure 2.9** below, which shows the air circuit for space cooling (B–C–D), the alternative circuit for drying (d–e–f) and the refrigerant circuit (1–2–3–4). A p–h diagram of the refrigerant circuit (1–2–3–4) is shown in figure shows that the theoretical energy available for heating or drying is (h2–h3), for space cooling is (h4–h1) and the work energy input to the compressor is (h2–h1).

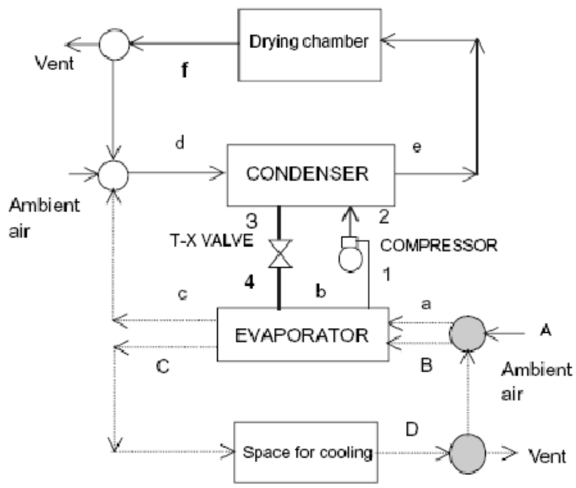

Figure 2.9: Modular configuration of the simple IHPS for drying (Ahmadul Ameen and Saiful Bari 2003)

Figure 2.10 below shows the psychometric chart of the air circuits for drying with dehumidification (a–b–c–d–e–f) and without dehumidification (d–e–f). In the present investigation, only drying without dehumidification is considered. When the humid air from the atmosphere is passed through the condenser coil (d–e), the air is heated with a reduction in relative humidity. This air is used for drying clothes at constant enthalpy. A typical drying curve as shows in **Figure 2.11**, where the drying rate (kg/s) is plotted against moisture content is shown in the figure, which has an initial heating stage (A–B), unhindered or constant drying period (B–C), or hindered drying or falling rate drying period (C–D–E).

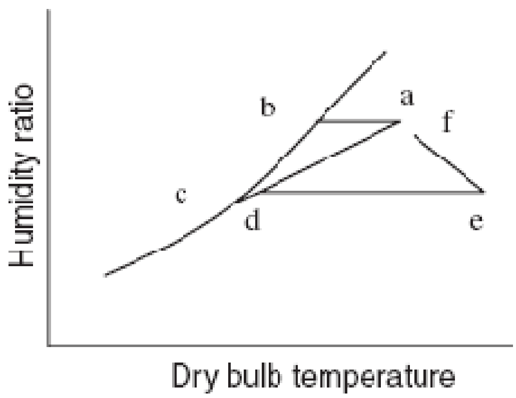

Figure 2.10: Psychometric chart for drying air circuit (Ahmadul Ameen and Saiful Bari 2003)

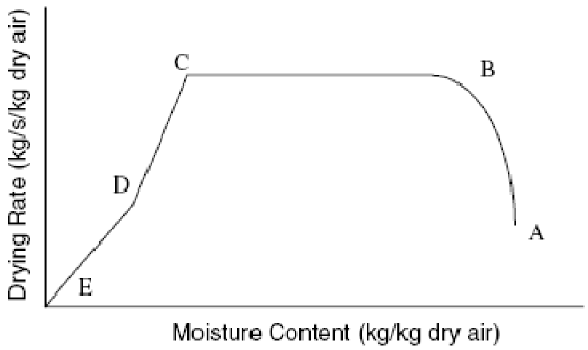

Figure 2.11: Typical drying rate curve (Ahmadul Ameen and Saiful Bari 2003)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology of this project can be described as design of experiment. In this chapter, the process of design selection and the description of the experiment will be elaborated.

The experiment is to investigate the effectiveness of dryer cabinet by utilizing heat rejected from air conditioning system. The experiment is to study two case of drying. First case is natural drying and the second case is drying by condensing unit of air conditioning system. For this experiment, the manipulation variable will be the mechanism of drying.

3.2 FLOW CHART TECHNOLOGY

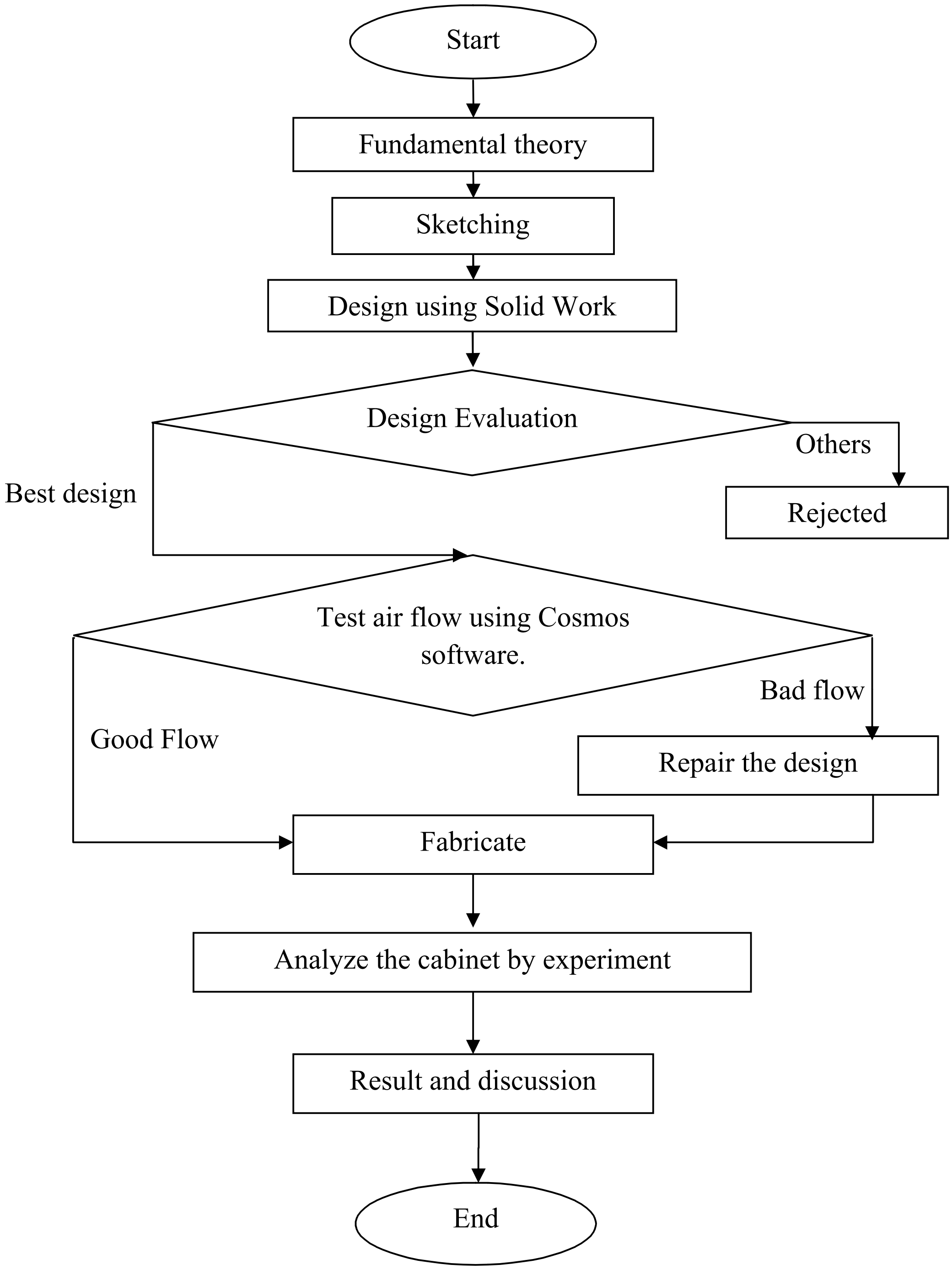

Figure 3.1: Methodology flow chart

3.3 DESIGN SELECTION

Design selection is one of the important things for this project. This is because the effectiveness of the cabinet dryer is also depending on the air flow inside the cabinet dryer which is depend on it design. For the best performance design, the design should consider several aspects such aspect the position of the air inlet and air outlet, the size for the outlet and inlet hole, the heat distribution and how to direct hot air to the wet cloth. These three elements are to make sure the cabinet dryer is in the optimum performance.

Other than performance, the design also should consider the other criteria such as safety, economic, ergonomic and attractive. This criterion is to make sure this product is marketable and have high demand from the user. Besides, the design also needs to consider the way in building it, either it is complicated to fabricate or not.

3.3.1 First Design

There are two legs to support this cabinet to stand. Compared to the other design, these designs need a smaller amount of material, but it is complicated to build it. This cabinet stability is lower compared to the other design. From the front view in the **Figure 3.3**, we can see that this design have lack of space for drying. Besides that, it is hard to hang a cloth because small size of the door. The circle hole at the back side of the cabinet is for the hot air flow from condensing unit. The position is at the bottom side because of the characteristic of air which is low density will flow to the upper side by itself. This design was shape like this to help it flow smoothly from the inlet to the outlet.

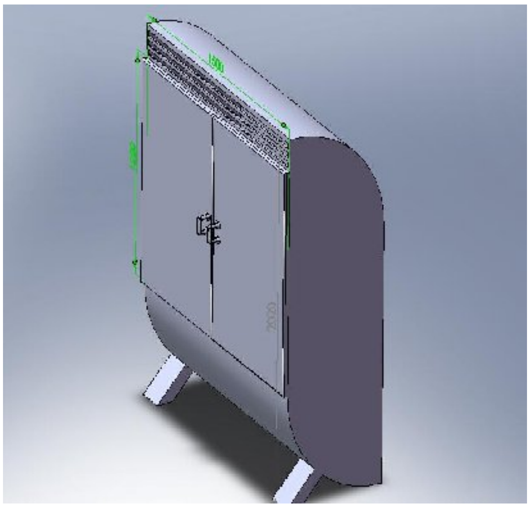

Figure 3.2: Isometric view of first design

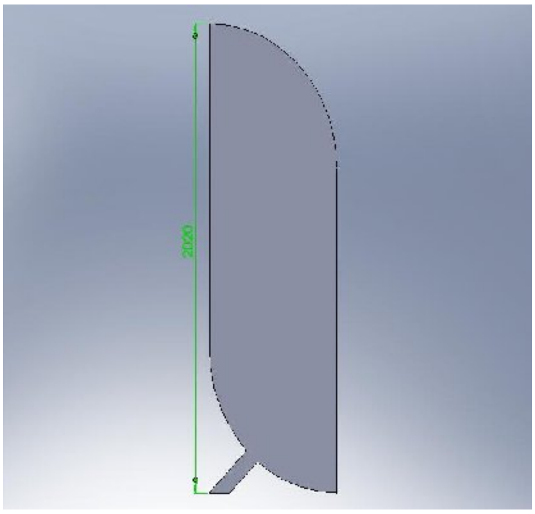

Figure 3.3: Side view of first design

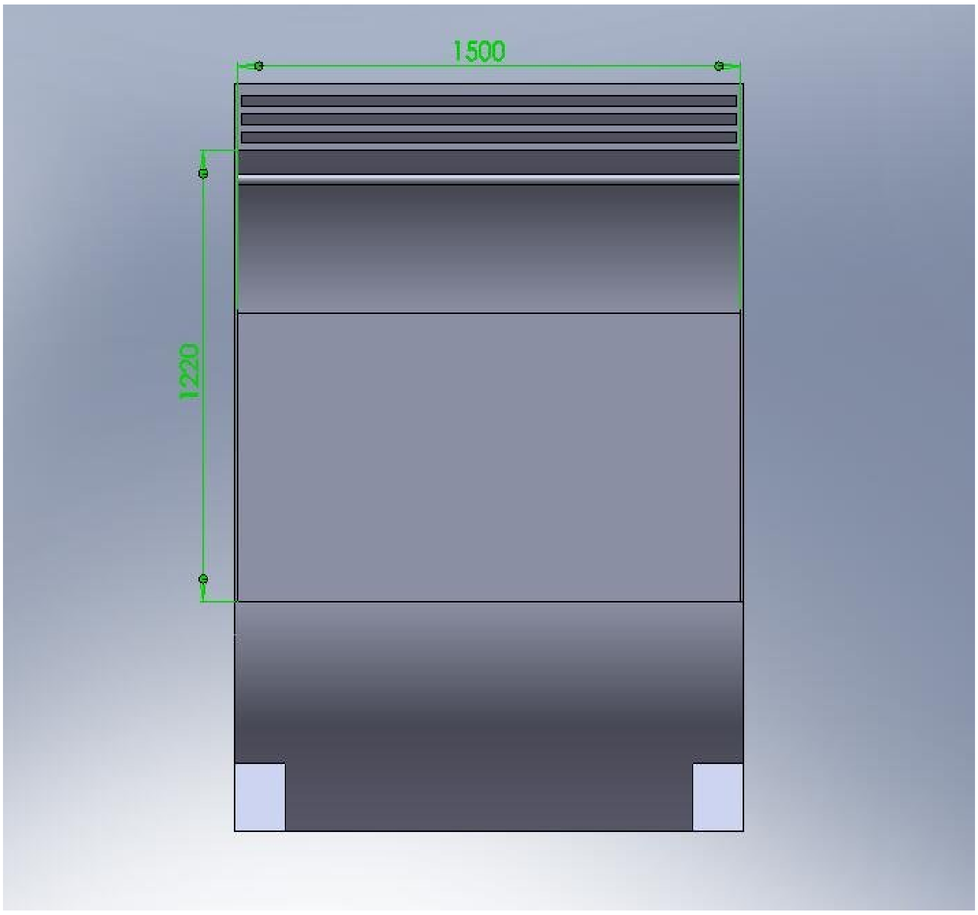

Figure 3.4: Front view of first design

3.3.2 – Second Design

This design as shows in **Figure 3.5** is simple and easy to use like ordinary cabinet. Amount of material use are greater compared to the first design. The shape of this design not really helps the air flow inside the cabinet. From the front view in the **Figure 3.7** we can see that the space to hang the close is bigger than the first design. This cabinet design use air director as shows in **Figure 3.6** function to guide the air flow to the upper side, through the cloth and directed to the air outlet. At the back and side surface, of the cabinet it have a hole for air inlet. Just like first design, the hole for air inlet being place at the back surface on the bottom side.

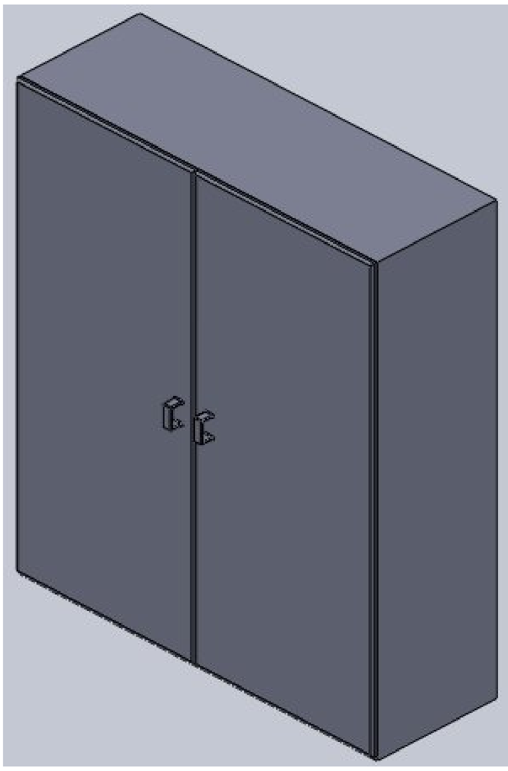

Figure 3.5: Isometric vief of second design

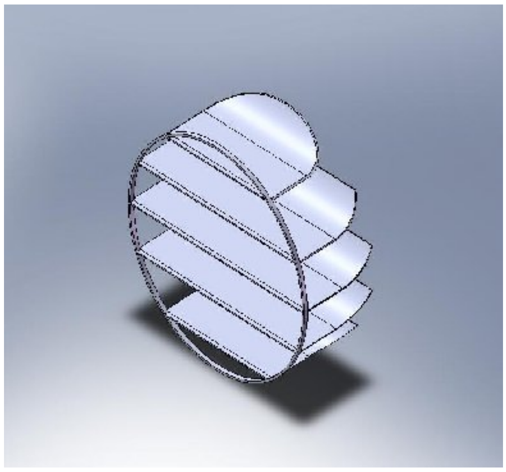

Figure 3.6: Air director

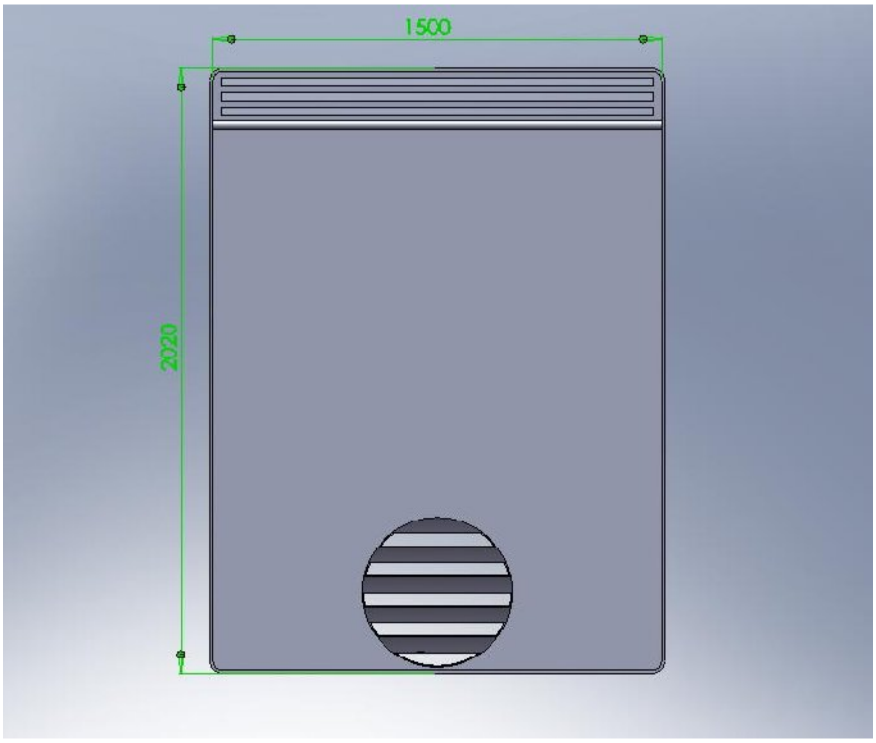

Figure 3.7: Front view of the second design

3.3.3 Third Design

This design is simple as shows in **Figure 3.8** and easy to use like ordinary cabinet. Amount of material use are greatest compared to all design. The shape of this design not really helps the air flow inside the cabinet. From the front view in the **Figure 3.10** we can see that the space to hang the close is bigger than the first design. At the back surface, of the cabinet it has a hole for air outlet. Just like first and second design the hole for air inlet being place at the back surface on the bottom side. The mechanism to flow air in this cabinet design is by using stabilizer as shows in **Figure 3.9**. This method is the best compared to the others because it not just helps the flow, but also distribute the air equally inside the cabinet.

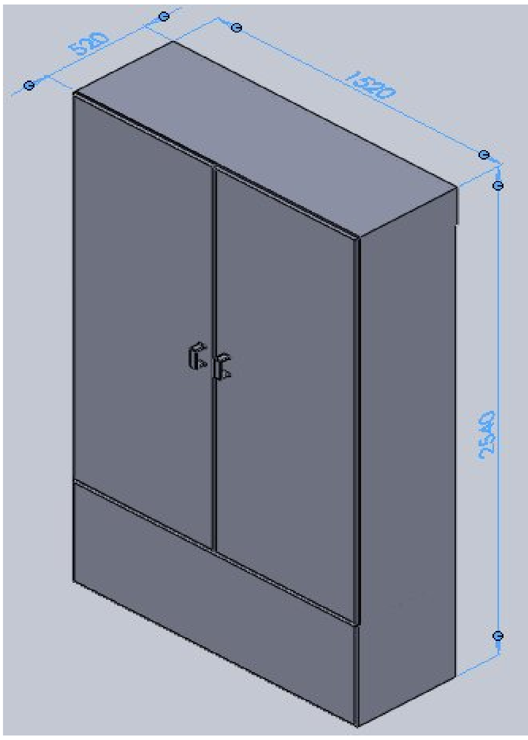

Figure3.8: Isometric view of third design

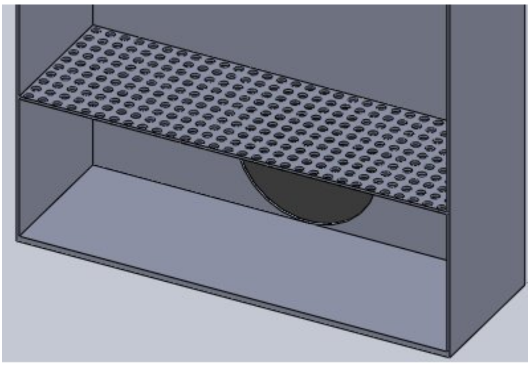

Figure 3.9: Stabilizer

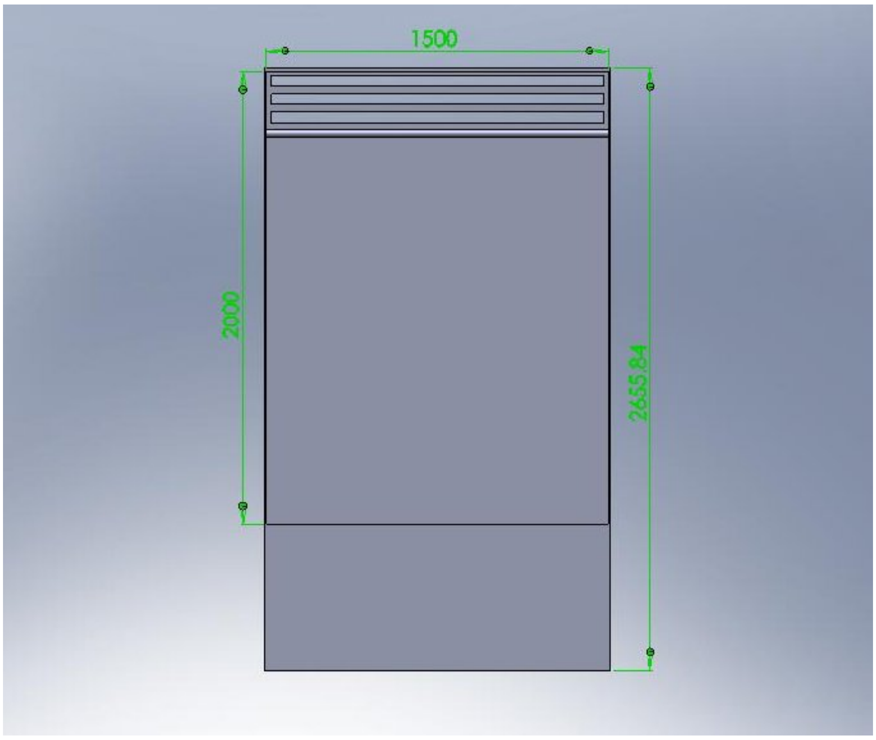

Figure 3.10: Front view of third design

3.4 DESIGN EVALUATION

All the design above will be evaluate base on the several aspect. Each aspect had a different priority and will be valued by point . The aspect that will be considered is:

Performance: For cabinet performance, the best evaluation is by experiment or may use Cosmos flow simulation to simulate the air flow pattern inside the cabinet. For this evaluation we can compared the mechanism use to flow air in the cabinet. This aspect will be evaluate differ from the others because of the performance of cabinet is very important for this task.
Bad = -1
Average = 0
Good = 1

Stability: From the design we can generally analyze the stability of the cabinet. How the cabinet maintain to stand.
Not Stable = -1
Average = 0
Stable = 1

Appearance: The appearance been evaluate from the design either attract or not.
Bad = -1
Average = 0
Good = 1

Complexity: This aspect is estimated either the design is easy to fabricate or not.
Simple = -1
Average = 0
Complex = 1

Size: Size of cabinet also needs to be consider, either the installation need a big space or not.

Large = -1

Average = 0

Small = 1

Easy to use: from the design, this aspect can be compared by the size of door and space to hang the cloth.

Difficult = -1

Average = 0

Easy = 1

Table 3.1: Table design evaluation

Aspect \ Design	**Reference**	**First Design**	**Second Design**	**Third Design**
Economic	0	1	0	0
Stability	0	-1	0	0
Appearance	0	1	0	0
Complexity	0	-1	0	0
Size	0	-1	1	1
Suitable	0	1	1	1
Ergonomic	0	-1	1	1
Total	0	-1	3	3

From the evaluated table, second and third design got a highest point. Those design will be simulate by Cosmos flow simulation, where the result of the air flow pattern and heat distribution need to be considered.

3.5 EXPERIMENT SETUP

Experiment for the drying by condensing unit being run by hanging the wet cloth in front of the big condensing unit of air conditioning system. It is to make cure all the hot air blow from air condensing unit is equally distribute to all surface of the material tested. Beside that, the experiment needs to be running at night. It is to minimize the eror on the result, where it will not affected by sunlight or heat from sum. Even it not precisely accurate compare to drying it the cabinet, we can assume that this experiment will get the best result to interpret the drying process in cabinet dryer utilizing heat rejected from air conditioning system.

For the natural drying, we need to hang it inside the building. As we refer to the problem statement which is consider those people who are hard to dry cloth under the daylight. In other word the comparison is between indoor natural drying ang drying by utilizing heat rejected from air conditioning system.

3.4.1 Experiment Procedure

Experiment procedure for drying process in the cabinet dryer.

1. Weight the fabric before it being wash and record it.
2. Wash the fabric by washing machine and spin.
3. Weight the fabric again and record it.
4. Hanged a wet fabric in front of big condensing unit of air condition system
5. Weight the hanging fabric every 30 minutes until the fabric not change it weight.
6. Record all the data in the table below.
7. Plot a graph of moisture remove versus time. Assume that the final weight after drying process is the weight without moisture. As the weight change, the difference value of the final weight and the weight recorded is equal to a moisture remove in every 30 minutes.

Experiment procedure for natural drying process.

1. Weight the fabric before it being wash and record it.
2. Wash the fabric by washing machine and spin.
3. Weight the fabric again and record it.

4. Hanged a wet fabric inside room.
5. Weight the hanging fabric every 30 minutes until the fabric not change it weight.
6. Record all the data in the table below.
7. Plot a graph of moisture remove versus time. Assume that the final after drying process is the weight without moisture. As the weight change, the difference value of the final weight and the weight recorded is equal to a moisture remove in every 30 minutes.

CHAPTER 4

RESULT AND DISCUSSION

4.1 AIR FLOW SIMULATION

Proceeding to the flow simulation, actual data is for the condensing unit is very important. It is compulsory to measure the velocity and temperature that blow from condensing unit. This variable will be the input for Cosmos Flow simulation. **Figure 4.1** and **Figure 4.2** is an example of condensing unit.

4.1.1 Reading Data

Figure 4.1: A condensing unit of split air conditioning system

Figure 4.2: Heat blow from one condensing unit will be use to dry clothes

For the simulation part, airflow modeling been utilized by using COSMOS Flow Simulation. Simulation objective is to choose the best design from two types of cabinet dryer design, which is second design and third design. The chosen is base on the performance of the cabinet dryer. The simulation is to simulate the air flow from the inlet to the outlet hole and temperature distribution inside the dryer. The way of the flow inside the dryer not need to be too fast at the same time must be equivalent distribution of heat.

Figure 4.3: Anemometer

Figure 4.4: Sensor to measure temperature and velocity

According to the air flow simulation, two variable needs to complete the simulation, which is temperature and the velocity from the condensing unit. Anemometer as the **Figure 4.3** and **Figure 4.4** above being uses to read the data required for the simulation. It is difficult to get the exact reading because of the difference value of data for different point of position. To get the accurate data several point position of the data reading being done as **Figure 4.5** below. Random distribution of the yellow point shows the position where the data is taken. There are 16 readings been record for temperature and he velocity. The average of the data been calculated and it insert in the COSMOS flow simulation input data.

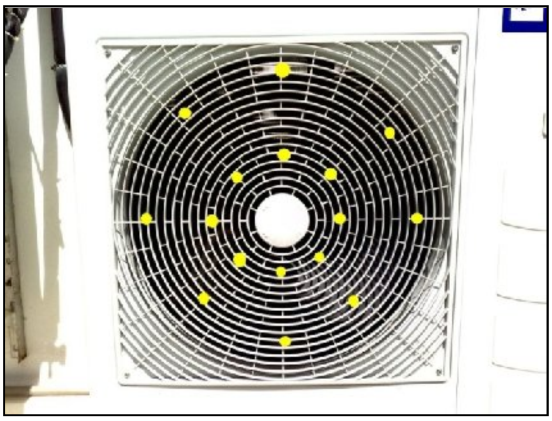

Figure 4.5: Random yellow dot shown the point where temperature and velocity being measured

Table 4.1: Velocity and temperature air flow

Number	Temperature,˚C	Velocity, m/s
1	43.9	7.8
2	43.8	8.7
3	43.5	8.8
4	43.3	10.4
5	42.8	5.6
6	42.2	10.3
7	44.4	10.3
8	45.3	8.0
9	43.8	8.3
10	42.6	8.4
11	42.5	8.1
12	45.8	7.2
13	41.1	6.8
14	43.3	6.0
15	42.4	7.0
16	42.1	7.8

Average temperature = $\frac{\Sigma}{\quad}$

= 43.3 m/s

Average velocity = $\frac{\Sigma}{\quad}$

=8.09375

4.1.2 Simulation by Cosmos Floworks Software

Step in the process of declaration of input data in the Cosmos Flowork software is like figure above. **Figure 4.6** showed the selection of the fluid to be simulate. Air being select as the fluid use for simulation according to the air that blow from condenser. **Figure 4.7** indicate the way inserting value of temperature as the input. **Figure 4.8** is the declaration of boundary condition. The first boundary condition is inlet velocity, which is inserting the value of velocity of air flow from condenser and the inlet hole is selected. Second boundary condition being setup is static pressure where outlet hole is selected. Final boundary condition is is real wall which indicate all surface that cannot through it. All the cabinet surface is selected for this condition.

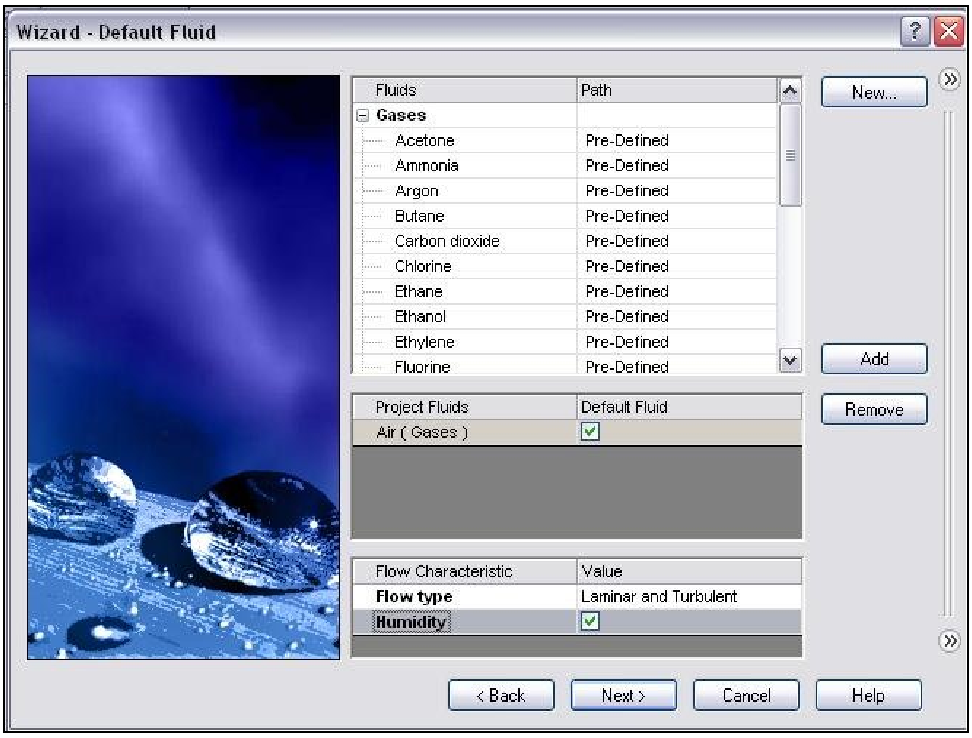

Figure 4.6: Choosing air as a type of flow

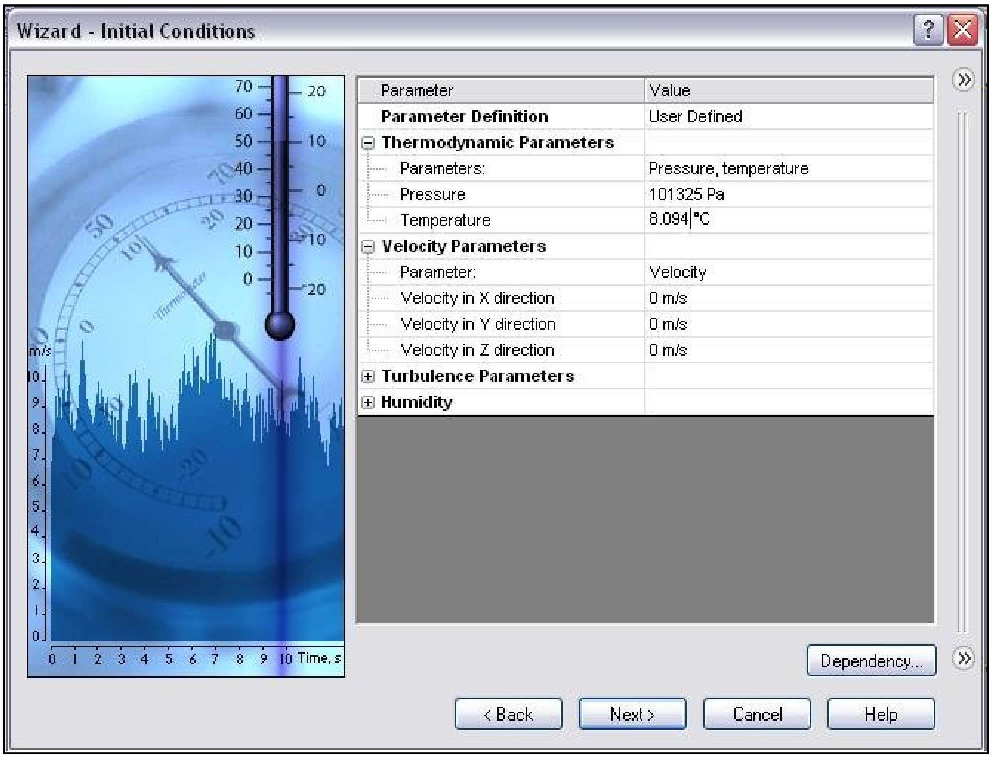

Figure 4.7: Insert the temperature value

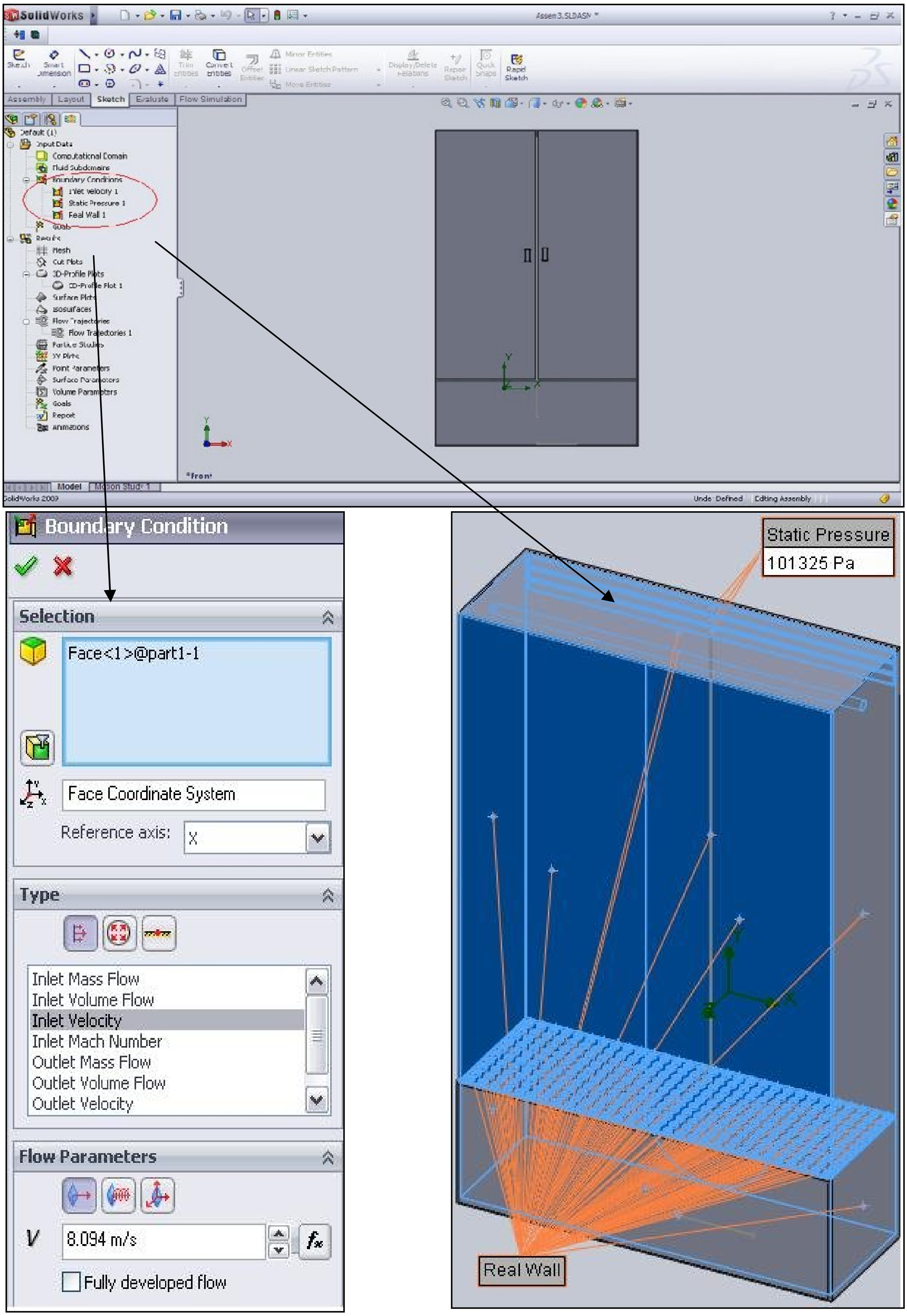

Figure 4.8: The input of the velocity of the air flow

4.1.3 Simulation Result, Show the Air Flow Pattern In the Cabinet

The **Figure 4.9** and **Figure 4.10** below show the simulation of the air flow pattern inside the cabinet. The lines represent the air flow and the color of the line indicate the temperature of the air flow.

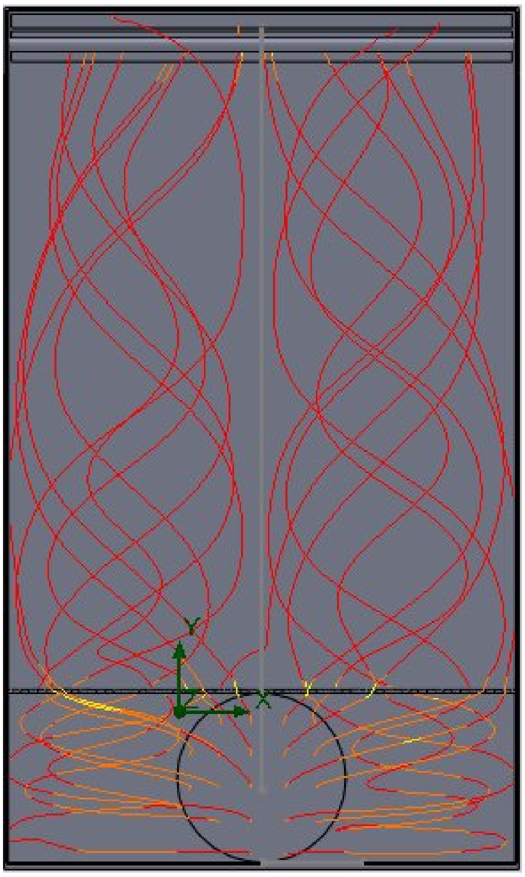

Figure 4.9: Air flow pattern for third design

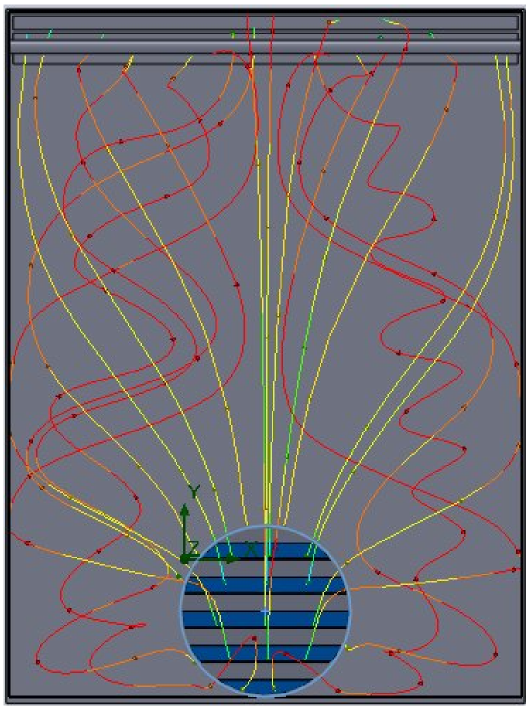

Figure 4.10: Air flow pattern for second design

Most of the line simulate inside the third design as showed in the **Figure 4.9** is in the red colored which is shown that it is in a maximum temperature. The airflow pattern is also randomly distributed. Besides, all the lines not directly flow to the outlet hole which means the hot air that flow inside the cabinet will flow through the cabinet is space for some period. It compared to the airflow pattern inside the second cabinet in the **Figure 4.10**. Air flow that represented by the line not in the red colored which shown that it is not in a maximum temperature. The airflow pattern randomly distributed but some of the lines directly flow to the outlet hole which might waste the hot air that flow inside the cabinet.

4.1.4 Simulation Result, Distribution of Heat In the Cabinet

The Figure 4.11 and Figure 4.12 below showed the distribution of heat inside cabinet dryer. The colors indicate the temperature as shown by the indicator at the right side of each cabinet design. From the figure we can analyze the temperature at any point inside the cabinet and assume the heat distribution base on the temperature value.

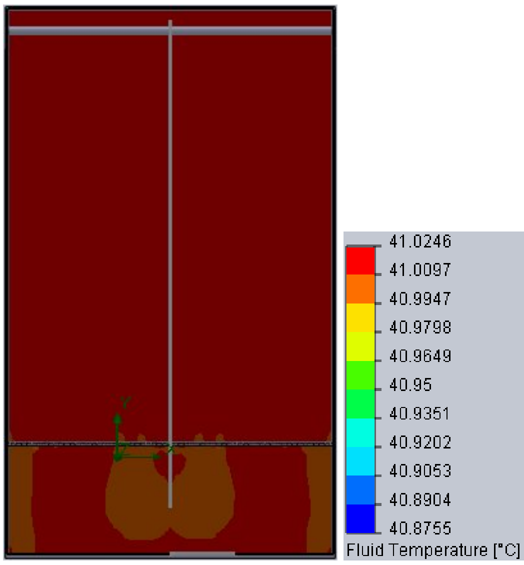

Figure 4.11: Distribution heat for third design

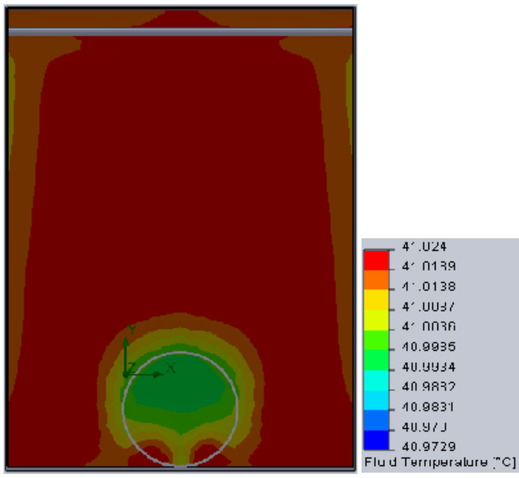

Figure 4.12: Distribution heat of second design

As being mention from the text above, the color indicates the temperature, the indicator can show the temperature value for each color. Third design as shown in the **Figure 4.12** showed that maximum temperature that represented by the red colored is fulfill the drying space. It concludes that heat is equally distributed inside the cabinet. Compared to the second design as showed in the **Figure 4.11** the maximum temperature that represented by the red colored shows not fulfill the drying space for the cabinet. Besides that, the highest temperature inside the cabinet for the second design and third design is different, where the third design has greater of the maximum temperature compared to the second design. The distribution of heat in the both design above is one of way to determine the performance and the effectiveness of the cabinet dryer design. Even the heat distribution does not show the exact performance, but it can prove that all point in the drying space been supplied by maximum heat that indicate by highest the temperature. From the simulation, third design got a better performance compared to the second design.

4.1.5 Simulation Result, Graph Temperature versus Length of Cabinet

The length is start from the inlet hole to outlet hole, which is a represent the below part to the top part of the cabinet.

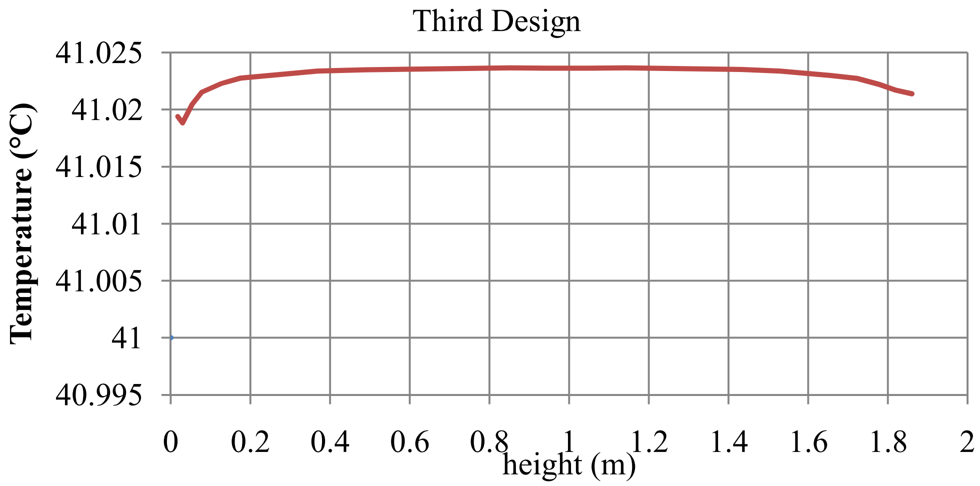

Figure 4.13: Graph temperature versus height of cabinet of the third design

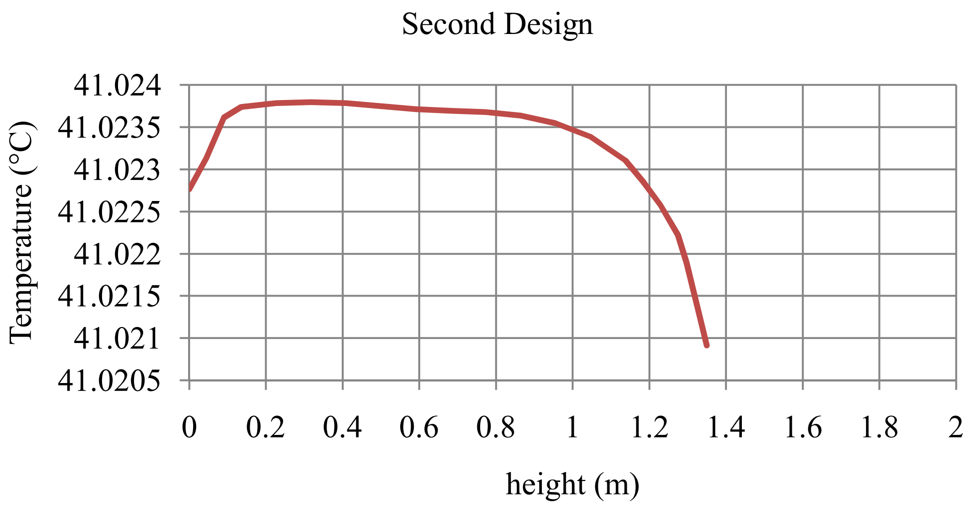

Figure 4.14: Graph temperature versus height of cabinet of the second design

The Figure 4.13 and Figure 4.14 show graph temperature value versus height of the cabinet dryer. It is clearly shown by the graph that the third design had maintain it temperature from the below part of the cabinet to the upper space of the cabinet. It shows that the cloth which is being dry in the cabinet might receive constant heat for each area for the cloth.

4.2 EXPERIMENT SETUP

The experiment data recorded to the Table 4.2 and Table 4.3 below. From that table result below, the graph of moisture remove versus time is plotted for both experiment of natural drying and drying by cabinet dryer utilizing heat rejected from air conditioning system. From the experiment, we assume that the final weight of the drying process is a dry weight where there is no moisture content. The experiment stops when the measured data of weight is repeated or increase. This is because of the moisture having fully removed from cloths.

Table 4.2: Table result of weight and moisture remove during drying process

Time, t (s)	Cabinet dryer utilizing heat from air conditioning system		Natural drying	
	Weight, (g)	Moisture remove, (g)	Weight, (g)	Moisture remove, (g)
0	2477	0	2613	0
30	2085	448	2506	107
60	1903	574	2399	214
90	1774	703	2291	322
120	1694	783	2211	402
150	1695	782	2129	522
180			2057	556
210			1996	617
240			1942	671
270			1890	723
300			1843	770
330			1792	821
360			1743	870
390			1717	896
420			1686	927
			1686	927

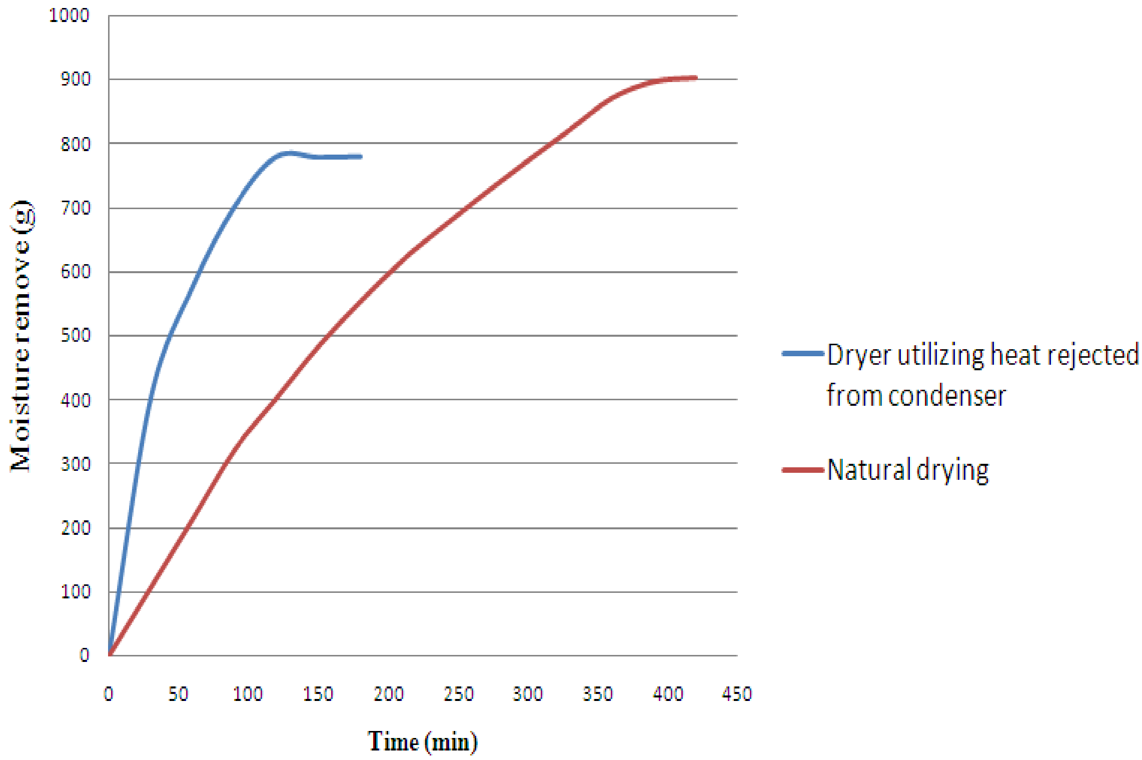

Figure 4.15: Graph moisture removes versus time

In determining the drying rate and period time for each process, the weight of the cloths in all stage must be measured. Weight before and after wash is recorded. Then the final weight after the drying process is finish also recorded. That value is use in the calculation in determining the drying rate for the drying by heat rejected from air conditioning system and natural drying. The different value of final weight and thr weight before wash is because of the different environment humidity and the content of the cloth itself which might have dirt on it.

Table 4.3: Weight recorded before wash, after wash and final weight of drying process

Case \ Mass	Weight before wash (g)	Weight after wash (g)	Final weight (g)
Cabinet Drying Process	1749	2477	1694
Natural Drying Process	1693	2613	1686

4.3 DRYING RATE

4.3.1 Calculation

NOMECLATURE

N_{CRDP} = drying rate in CRDP, kg/s m

N_{FRDP} = drying rate in FRDP, kg/s m

t_{CRDP} = duration of CRDP, min

t_{FRDP} = duration of FRDP, min

W_d = weight of dry material, g

A = area of a drying surface at which heat and mass transfer takes place, m

n = drying index (determined by experiments)

F = free moisture content, g/g

F_{cr} = critical free moisture content, g/g

t_{cr} = time of critical point, min

X = volume-average moisture content (dry basis), g/g

X_{cr} = critical moisture content, g/g

X_O = initial moisture content, g/g

X_E = equilibrium moisture content, g/g

X_{Ea} = equilibrium moisture content under the ambient condition, g/g

X_{Ed} = equilibrium moisture content under the drying environment, g/g

A complete drying process can generally be divided into three periods namely a pre-heat period, constant-rate drying period (CRDP) and a falling-rate drying period (FRDP). Normally, clothes are mechanically dried (spin) before subjecting to thermal drying. Thus, a pre-heat period will not exist since the initial surface temperature is ready for constant-rate drying, therefore, only the modeling of a CRDP and a FRDP has been considered.

$$N_{CRDP} = \frac{(\qquad)}{\qquad}$$

Equation above is used to determine the drying rate in a CRDP. After determining the drying rate in a CRDP, its duration can be calculated by the following equation:

$t_{CRDP} = t_{cr} = \frac{}{}(X_o - X_{cr})$

.

After determining the drying rate in a CRDP, we now need to calculate the drying rate in FRDP. The equation below is to determine the drying rate in FRDP.

$N_{FRDP} = N_{CRDP} \frac{E}{E}$

After determining the drying rate in FRDP its duration can be calculated by the equation below:

$t_{FRDP} = \frac{}{(\quad)} \frac{}{} [F(\quad) - Fcr(\quad)]$

Dryer utilizing heat from air conditioning system

$X = \frac{-}{} + \frac{}{} /2$

$= 0.247$ g/g

$Xo = \frac{}{}$

$= 0.403$ g/g

$X_E = 0$ g/g

$X_{Ed} = 0$ g/g

$X_{Ea} = \frac{}{}$

$= 0.032$ g/g

$X_{cr} = \frac{}{}$

$= 0.264$ g/g

$t_{cr} = 30$ min

$n = 0.8$

$A = 2.13 \times 0.63$

$= 1.342$ m

$F = X_{Ea} - X_{Ed}$

$= 0.032 - 0$

$= 0.032$ g/g

$F_{cr} = X_{cr} - X_{Ed}$

$= 0.264 - 0$

$= 0.264$ g/g

$N_{CRDP} = \frac{(\quad)}{\quad}$

$= \frac{(\,.\quad .\,)}{(\,.\,)(\quad)}$

$= 5.849 \quad /$

$t_{CRDP} = t_{cr} = 30$ min

$N_{FRDP} = N_{CRDP} \frac{\quad}{\quad}$

$= 5.849 \frac{.}{.}$

$= 5.205$ g/s

$t_{FRDP} = \frac{\quad}{(\quad)} \frac{\quad}{\quad} [\,{}^{(\quad)} - {}^{(\quad)}]$

$= \frac{\quad}{(\,.\,)(\,.\,)} \frac{.}{.} [0.032^{(\,.\,)} - 0.264^{(\,.\,)}]$

$= 98.755$ min

Total time = 30 + 98.755

= 128.755 min

Natural Drying.

X = /2

= 0.253 g/g

Xo =

= 0.490 g/g

X_E = 0 g/g

X_{Ed} =

=0.016 g/g

X_{Ea} = 0 g/g

X_{cr} =

= 0.260 g/g

t_{cr} = 150 min

n = 0.8

A = 1.342

$F = X_{Ea} - X_{Ed}$

= 0 – (-0.016)

= 0.016 g/g

$F_{cr} = X_{cr} - X_{Ed}$

= 0.260 – (-0.043)

= 0.303 g/g

$N_{CRDP} = \frac{(\quad)}{\quad}$

$= \frac{(\ .\quad\quad .\quad)}{(\ .\quad)(\quad)}$

= 1.926 g/s

$t_{CRDP} = t_{cr} =$ 130 min

$N_{FRDP} = N_{CRDP} \frac{\quad}{\quad}$

$= 1.926 \frac{.}{.}$

= 1.884 g/s

$t_{FRDP} = \frac{\quad}{(\quad)} \frac{\quad}{\quad} [\ ^{(\quad)} - \ ^{(\quad)}]$

$= \frac{\quad}{(\ .\quad)(\quad .\ )} \frac{.}{.} [0.016^{(\ .\ )} - 0.303^{(\ .\ )}]$

= 439.459 min

Total time = 130+ 439.459

= 569.459 min

Commercial dryer

X = 0.508 g/g

X_o = 0.857 g/g

X_E = 0 g/g

X_{Ed} = 0 g/g

X_{Ea} = 0.056 g/g

X_{cr} = 0.656 g/g

$t_{cr} = 21$ min

$n = 0.8$

$A = 6.050$

$F = X_{Ea} - X_{Ed}$

$= 0.056 - 0$

$= 0.056$ g/g

$F_{cr} = X_{cr} - X_{Ed}$

$= 0.656 - 0$

$= 0.656$ g/g

$N_{CRDP} = \frac{(\quad)}{\quad}$

$= \frac{(\;.\qquad .\;)}{(\;.\quad)(\quad)}$

$= 19.301$ g/s

$t_{CRDP} = t_{cr} = 21$ min

$N_{FRDP} = N_{CRDP} \frac{\quad}{\quad}$

$= 19.301 \frac{.}{.}$

$= 15.731$ g/s

$t_{FRDP} = \frac{\quad}{(\quad)} \frac{\quad}{\quad} [\,^{(\quad)} - \,^{(\quad)}]$

$= \frac{\quad}{(\;.\quad)(\quad .\;)} \frac{.}{.} [0.056^{(\;.\;)} - 0.656^{(\;.\;)}]$

$= 81.849$ min

Total time $= 21.000 + 81.849$

$= 102.849$ min

4.3.2 Comparison Result of experiment

Table 4.4: Comparison result from the experiment

Type	Commercial dryer [3]	Natural drying	Dryer by utilizing heat rejected from air conditioning system
N_{CRDP} (/)	19.301	1.926	5.849
t_{CRDP} (min)	21.000	130.00	30.000
N_{FRDP} (/)	15.371	1.884	5.205
t_{FRDP} (min)	81.849	439.459	98.757
t_{total} (min)	102.849	569.459	128.775

4.4 DISCUSSIONS

In the present research, drying of clothes takes about 128.775 min by the dryer that utilizing heat rejected from air conditioning system, compares with 102.849 min required by the commercial dryer and about 569.459 min for indoors natural drying. The drying rate for the test configuration in CRDP is 5.849(g/s m) and FRDP 5.205 (g/s m)compared to indoor natural drying which is in CRDP 1.926(g/s m) and in FRDP is 1.884(g/s m). For drying by a commercial dryer, drying rate in CRDP 19.301(g/s m) and in FRDP is 15.371(g/s m). The present investigation shows that by using condenser waste heat, clothes can be dried under a controlled environment in a shorter time compared to the natural drying and with marginal additional energy cost. The energy consumption was nil against commercial dryer. More and more important, waste heat which has a bad effect to environment is being manipulated to get a benefit.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the result of simulation, cabinet dryer by using stabilizer shows a good distribution of heat. Its means that the third design is most suitable design compared to others. From the experiment, drying using heat waste from air conditioner to dry cloth takes about 128.775 min compares with 102.849 min required by the commercial dryer and about 569.459 min for indoors natural drying. The present investigation shows that by using condenser waste heat, clothes can be dried under a controlled environment in a shorter time compared to the natural drying and with marginal additional energy cost. The energy consumption was nil against commercial dryer. More and more important, waste heat which has a bad effect to environment is being manipulated to get benefit. Drying and subsequent storing of clothes in such a drying chamber has another advantage of eliminating fungi.

5.1 RECOMMENDATION

1. Optimizing the size of outlet hole.
2. Ascertaining the optimum position of the partition around the condensing unit for directing hot air towards the hung clothes before leaving the chamber.
3. Ensuring fastest drying using an exhaust fan on top of the drying cabinet with air velocity inside cabinet.

4. All the surfaces of the enclosure are transparent to maximize the quantity of sunlight absorption, to provide enough heat retention via the “greenhouse effect” also to permit the visual inspection of the clothes.
5. Study the effect which might occur if the cabinet dryer utilize the heat from conditioner.
6. Improve the simulation which needs to simulate with the cloth hanging inside the cabinet to get a better design.
7. Create a piping system that portable for any position of condensing unit that can direct the air flow into the cabinet.

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