UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: **DESIGN AND ANALYSIS OF A CLOTH DRYING MACHINE BY USING HEAT WASTE**

SESI PENGAJIAN: 2011/2012

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DESIGN AND ANALYSIS OF A CLOTH DRYING MACHINE BY USING HEAT WASTE

HAZIRATUL NAJIHAH BINTI OTHMAN

Report submitted in fulfillment of the requirements
for the award of the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Design and Analysis of a Cloth Drying Machine by using Heat Waste" is written by Haziratul Najihah Binti Othman. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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Date :

DEDICATION

TO MY LOVING MOTHER, RAMNAH BINTI MARLAN AND MY CARING FATHER, OTHMAN BIN SIDIK WHO ARE ALWAYS WITH MY DREAM.

" I am the lukiest daughter in the universe because I have you all in my life."

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All praise and honor be to Allah S.W.T, the Lord of the Universe, Who has given the writer His blessing to accomplish the writing of the final year project.

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In doing her bachelor degree, she was also helped by many people who could not be completely mentioned here, especially her friend who are under the same supervisor with her. She was really indebted to them all.

Her heartfelt thanks go to her parents for their endless love, taking her as she is and having faith in her, even when they do not always know what she is doing; faith is never something that can be underestimated.

As a famous saying goes, "Nobody's perfect," the writer knows very well that this project needs many improvements. The writer would like to accept any constructive criticisms and suggestions from any parts. Last but not least, it is hoped that this work will be useful for the readers who want to apply clothes dryer machine in daily activities. For all of them, this project is humbly bought.

ABSTRACT

This project was to study the clothes dryer machine by using heat waste. There are many cabinet dryer is widely used today as an alternative to natural clothes drying, especially for those who are busy working from morning until evening, having limited time and for the residents in urban areas. Nowadays cabinet dryer already offered in the market, but its use electrical power as a heat. Therefore in this project, heat waste will be used as an alternative to electrical heat source. The objectives of the project is to design and analyze cloth drying machine by using heat waste and to analyze performance of the drying machine. The heat waste was taken from the air conditioning. Detail drawing was developed from all concepts. In this project, Pugh Concept has been used to make evaluation of all concepts to decide final concept for further development. In order to obtain a good performance for the chosen concept, performance of drying machine using the concept has been analyzed in air flow simulation using Computational Fluid Dynamic analysis by using Solidwork Flow Simulation. The result was tested and compared with indoor natural drying and outdoor natural drying. The result from experiments show that the maximum drying rate is from the heat utilizing from air conditioning. While the result from the simulation shows that the concept B is chosen as the better performance in the simulation of the distribution of heat and,also for the airflow of temperature and velocity. As the conclusions, the concept B is chosen as the final design. The final design has been considered with all the criteria needed. Therefore, utilizing heat waste from air conditioning can be used as one of the sustainable energy resources. Anyway, future effort is required to improve the concept and to provide verification using more experimental data example like to improve the simulation by simulating the design with the cloth hanging inside the cabinet to get accurate data for better design.

ABSTRAK

Projek ini adalah untuk mengkaji mesin pengering pakaian dengan menggunakan sisa haba. Terdapat banyak kabinet pengering pakaian digunakan secara meluas hari ini sebagai alternatif pengering pakaian, terutamanya bagi mereka yang sibuk bekerja dari pagi sehingga petang, yang mempunyai masa yang terhad dan untuk kediaman di kawasan Bandar. Pada masa kini pengering kabinet telah ditawarkan dalam pasaran, tetapi ia menggunakan kuasa elektrik sebagai haba. Oleh itu dalam projek ini, sisa haba akan digunakan sebagai alternatif kepada sumber haba eletrik. Objektif projek ini adalah untuk merekabentuk dan menganalisis kabinet pengering pakaian dengan menggunakan sisa haba dan menganalisa prestasi kabinet pengering pakaian itu. Sisa haba diambil dari penghawa dingin. Lukisan terperinci telah dihasilkan dari semua konsep. Dalam projek ini, Konsep Pugh telah digunakan untuk membuat penilaian terhadap semua konsep reka bentuk untuk memutuskan konsep akhir yang diperlukan untuk kajian seterusnya. Dalam usaha untuk mendapatkan prestasi lebih baik bagi reka bentuk yang dipilih, konsep akhir itu akan dianalisis dalam aspek aliran udara menggunakan Komputasi Dinamik Bendalir analisis dengan menggunakan perisian Simulasi Aliran Solidwork. Hasilnya telah diuji dan dibandingkan dengan pengeringan semulajadi di bahagian luar dan dalam rumah. Hasil daripada beberapa kajian menunjukkan kadar maksimum pengeringan adalah dengan menggunakan haba dari penyaman udara. Manakala hasil daripada simulasi menunjukkan reka bentuk B dipilih menjadi reka bentuk yang lebih baik dari reka bentuk yang lain dalam simulasi agihan haba, dan juga aliran udara suhu dan halaju. Kesimpulannya, reka bentuk B telah dipilih sebagai reka bentuk akhir. Reka bentuk ini telah dipertimbangkan dengan kesemua criteria yang diperlukan. Oleh itu, sisa haba dari penghawa dingin boleh digunakan sebagai salah satu sumber tenaga yang berterusan. Bagaimanapun, usaha yang berterusan diperlukan untuk memperbaiki konsep dan untuk menyediakan pengesahan menggunakan lebih banyak data experiment contohnya seperti memperbaiki simulasi dengan mensimulasikan reka bentuk dengan kain tergantung di dalam kabinet unntuk mendapatkan data yang tepat untuk mendapatkan reka bentuk yang lebih baik.

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LIST OF SYMBOLS

N_{CRDP}	Drying rate in CRDP, kg/s m^2
N_{FRDP}	Drying rate in FRDP, kg/s m^2
t_{CRDP}	Duration of CRDP, s
t_{FRDP}	Duration of FRDP, s
W_d	Weight of dry material, kg
A	Area of a drying surface at which heat and mass transfer takes place, m^2
η	Drying index (determined by experiments)
F	Free moisture content, kg/kg
F_{cr}	Critical free moisture content, kg/kg
t_{cr}	Time of critical point, s
X	Volume-average moisture content (dry basis), kg/kg
X_{cr}	Critical moisture content, kg/kg
X_O	Initial moisture content, kg/kg
X_E	Equilibrium moisture content, kg/kg
X_{EA}	Equilibrium moisture content under the ambient condition, kg/kg
COP_c	Coefficient of performance
W_{in}	Work energy input of compressor, kJ/kg
Q_L	Cooling capacity, kJ/kg
$\dot{m}_{air}$	Mass flow rate of air, kg/s

LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamic
IHPS	Integrated Heat Pump System
COP	Coefficient of Performance
CRDP	Critical Rate Drying Period
FRDP	Falling Rate Drying Period
SEC	Specific Energy Consumption
SMER	Specific Moisture Extraction Rate

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Formerly, drying clothes usually use natural way by using the energy from the sunlight and the wind, but nowadays the technology is plentifully developed upward and the clothes dryers that use the electric energy or other energy come to use extensively, especially in the urban area (Suntivarakorn et al., 2009) where limited sunlight (cloudy days) and restricted air flow for house types such as high rise condominiums and apartments, natural drying is prohibited in some housing areas for aesthetic reasons and conventional domestic electric dryers are too expensive and inefficient (Mahlia et al., 2010).

Decreasing energy losses and heat recovery are important research topics, nowadays. Many cabinet dryers widely use, especially those who are busy working. Besides that, most of laundries today have their own dryer cabinet. It is not just because to run their operation at all the time, but they also can prevent the risk to the cloths that might lose or dirty. Cabinet dryer on the market nowadays is using electrical power as a source in generating heat. The other alternative of heat source that can be used for drying machine is heat waste.

Heat waste is the capture of energy contained in fluids or gases that would otherwise be lost from a facility. Heat sources may include heat pumps, chillers, steam condensate lines, hot air associated with kitchen and laundry facilities, power-generation equipment (such as micro turbines or fuel cells), and wastewater drain lines. There are two basic requirements for heat waste;

i. Heat waste demand must be great enough to justify equipment and maintenance costs.
ii. The heat waste temperature must be high enough to serve as a useful heat source.

Large facilities such as hospitals and military bases often have the perfect mix of heat waste and demand for clothes dryer to effectively use heat waste recovery for clothes dryers. Also large quantities of hot flues are generated from boilers, kilns, oven and furnaces. If some of the heat waste could be recovered then a considerable amount of primary fuel could be saved. However, the limited sources for the study is only heat waste from the residential such as wood, kitchen stove, natural gas, residential refrigerators and air conditioning. The study will continue with the heat waste from residential and adopting the following measures as outlined in this study.

1.2 PROBLEM STATEMENT

Design and analyze the clothes dryer machine using heat waste normally include an exploration on starting and growing a study about the clothes dryer machine and heat waste. The elements that need to be considered are evaluating heat waste, and developing new products and parcel of most designs and analyze clothes dryer machine. The design must be considerate on the economic, ergonomic and environmentally friendly. There are also must be energy efficient and less power consumption.

Currently, power consumption becomes an important issue addressed by our government. They focused more on energy efficient and less power consumption. Therefore, the use of electric cloth dryer can be replaced by utilizing other heat source such as heat waste. The relationship between energy efficiency and less power consumption has attracted a lot of interest given. It will focus on energy saving features in the residential as well as in industrial and commercial sectors. Energy efficiency standards has been implemented as a voluntary basis since 2005.

The increase in energy prices is a reality for Malaysian, but also for many other countries all over the world. Switching to energy saving solutions is the answer for reducing costs and the impacts of the energy sector on the environment. There are also to improve competitiveness of products and services in the global market. Efforts are being made to activate promote the utilization of renewable energy resources. Further applications of new energy sources are planned for the immediate future. Heat waste technologies will be developed with emphasis on utilizing cost effective methods as well as strengthening of the cabinet.

The heat waste means free heat is just being wasted without any benefit. There is badness in releasing heat to the environment that will cause of global warming. This problem can overcome by manipulating the heat waste to flow into a cabinet dryer and remove the moisture from cloths. The heat will cost zero, which mean no energy efficient and less power consumption.

1.3 OBJECTIVES OF STUDY

For the purpose of the study, two objectives have been set up to guide the research. They are as follows;

i. To design and analyze cloth drying machine by utilizing heat waste.
ii. To analyze performance of the drying machine.

1.4 SCOPE OF STUDY

In scaling the cloth dryer machine to a correct extent, the study of concept of drying machine (cabinet) that can be utilized waste heat in its operation has been focused on residents. The design of the drying machine must be analyzed using Computational Fluid

Dynamic (CFD) software. In order to achieve the main objective there are some guide that must be followed as listed below.

i. Literature.

- The literature is including doing the research about the Clothes Dryer Machine. The dryer concept to dry the cloth using the entire heat source. Heat source for the residents. The sources are the journal from ezproxy.ump.edu.my, and search from the internet.

ii. Concept development and concept evaluation.

- There are four (4) design concepts that had been developed. Before analyzing using CFD software, some criteria had been considered first. After that, the final concept will come out from the analysis tools.
- Detail drawing was developed from all concepts using solidwork. The project feature will be easy to understand and also used for the next steps of the project.
- The final concept was chosen using Pugh concept based on the concept criteria. Some of the criteria are ergonomic, safe, economic and environmental friendly cabinet dryer.

iii. Experiment of natural drying.

- There are three experiments that were conducted to obtain the drying rate which is outdoor natural drying, indoor natural drying and drying using air conditioning heat waste.
- The outdoor natural drying was taken outside the building without the roof top in midday only.
- The indoor natural drying was taken inside the building of the hall or any room inside the building with the fan on. It was conducted in midday and night.

- The drying using air conditioning heat waste was taken in front of the outlet air conditioning and was conducted inside a box that is interpreted as drying process on cabinet dryer. It was conducted at night.
- All the clothes must be spin first before drying process.

iv. Analysis.

- The analysis contains the air flow through the cabinet dryer which to determine how the flow influences the temperature inside the cabinet.
- The result then was tested and compared with the other dryer especially natural drying.

1.5 SIGNIFICANCE OF STUDY

The significant of study would provide new design that more ergonomic, safe, economic and environmental friendly cabinet dryer to the residents. In most high rise flats, tall building, restrictions communities, it is very time consuming operation because of the year round humid climate, limited sun rays and restricted air flow.

1.6 PROJECT FLOW CHART

Figure 1.1 shows the flow chart for this project. The project starts with finding literature review, then sketching the design, design using solidwork and analysis the project by using CFD analysis and Pugh concept to determine the performance of the design. The project also was analyzed by using the experiment to get the drying rate.

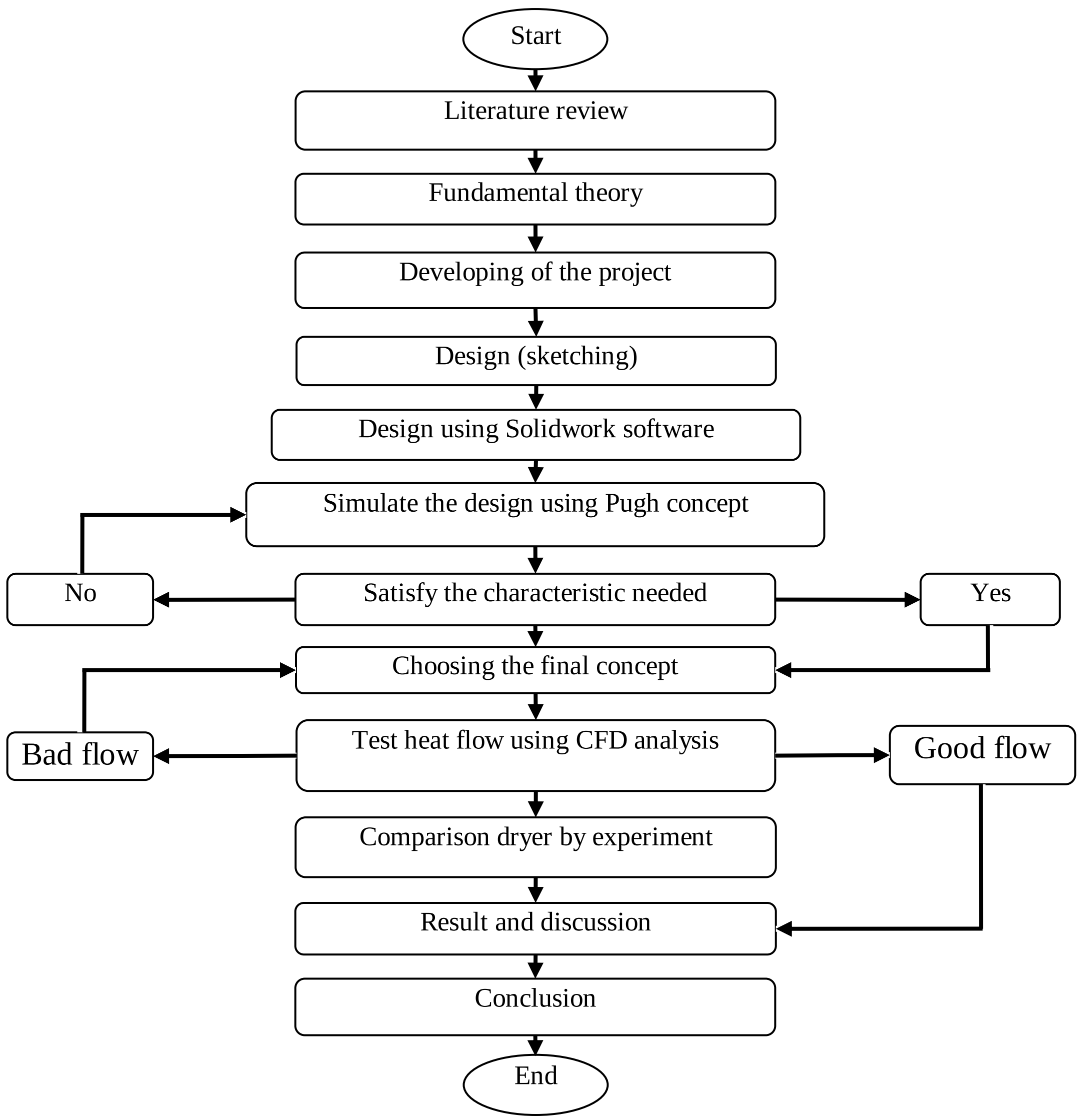


Figure 1.1: Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides background cloth dryer machine research previously done, heat waste source for residents and finding that leads to the existence of this study. Furthermore, the chapter presents theoretical frameworks that built the conceptual foundation for the study and guide the research design and methodology.

2.2 CLOTH DRYER MACHINE

A clothes dryer or tumble dryer is a household appliance that is used to remove the moisture from a load of clothing and other textiles, generally shortly after they are cleaned in a washing machine.

Of course, one of the cheapest means of drying clothes uses no appliance what-so-ever. The simple clothes line and clothes pins cost hardly anything. Using the heat of the sun and drying power of breezes, clothes lines are making a comeback in many backyards. Some homeowners associations and cities, however, have local convenient, codes and restrictions that restrict the use of clotheslines in planning communities.

Woodford (Woodford, 2010) had investigated the process cloths dry. The process is evaporation which turning the liquid water in clothes into a vapor and getting rid of it. In the washing machine usually for shortest and simplest setting with only a half load of washing, the water used is about 20 liters (5 gallons). Most of that water is spun out at high speed and then drained away, but even the most efficient machines leaves a significant amount of wetness lingering in clothes.

The easiest way to form energy to dry wet clothes is to heat it up. The molecules in a liquid are closer and more tightly bound together, move more slowly, and have less energy than the molecules in a gas. So it needs to put a small amount of energy to make the liquid molecules break apart, escape from the bulk of the liquid and form a vapor.

Figure 2.1 calls as a phase diagram which is a simple way of showing how a particular substance will be a solid, liquid or gas depending on the temperature and pressure. At high temperatures, the water is going to be gassed (steam) unless the pressure is high too. At low temperatures, the water is generally going to be ice, unless the pressure is low. So from the Figure 2.1, the solid ice can be heated to make it become a water vapor (gas).

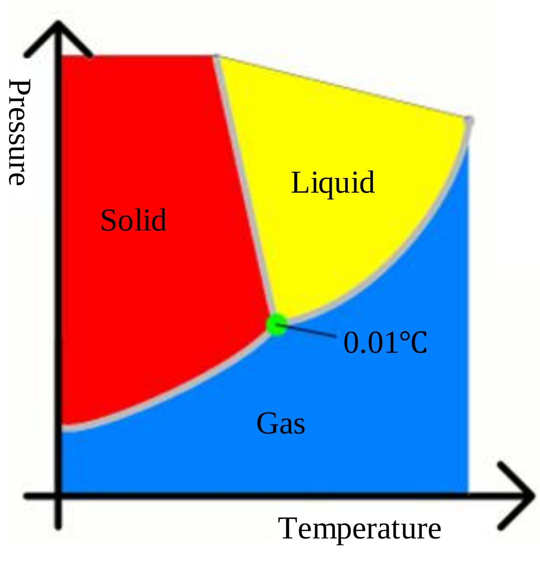


Figure 2.1: Phase diagram

Source: Woodford (2010)

Another investigation by Woodford is about the transpiration. The transpiration is when the plants lose the water by the wind blows. For example, when the wind blows past trees, the water evaporates from their leaves and turns into cool water vapor that dissipates in the air. In clothes drying, blowing air past wet things mean the water will evaporate more quickly and can make the water completely removed from the air around it.

So there are three things favoring the evaporation of water from wet clothes;

i. High temperatures – to increase the number of molecules that can turn from liquid to vapor.
ii. Air movements – to carry water away and prevent the air near clothes from becoming saturated with vapor.
iii. Low humidity – to make the evaporation continue steadily and water molecules won't return to clothes from the air.

Moreover for now, there are two types of clothes dryer machine prototype. First, microwave clothes dryers which work on the same principle as a microwave oven. Instead of passing warm air over the clothes, microwaves directly evaporate all water present in the laundry. Microwave clothes dryers use about 17 to 25 % less energy and dry clothes about 25 % faster than conventional electric air dryers. To avoid the problems with metal objects, prototypes switch to electric resistance heaters when the clothes are almost dry. These new dryers cost from $ 30 to $ 395 more than conventional models available on the market.

Second, heat pump dryers which use a refrigerant cycle to dehumidify the recapture heat from the exhausted air, which is then recycled through the dryer. Heat-pump dryers look like conventional dryers but require only 100 to 120 V power and can be installed anywhere in the house. These units may save 60 % of the energy required to dry clothes conventionally, but may cost $ 300 more than a new gas dryer. They are currently in a prototype stage for residential applications.

Therefore as the study is to design and analysis clothes dryer machine using heat waste, the heat pump dryer can be used as a subject in the study.

2.3 HEAT WASTE FROM RESIDENT

Heat waste is heat generated in a process by way of fuel combustion or chemical reaction, which is the “dumped” into the environment and not reused for useful and economic purposes. The essential fact is not the amount of the heat, but rather its “value”. The mechanism to recover the unused heat depends on the temperature of the waste heat gases and the economics involved.

2.3.1 Types of Heat Waste Recovery from Residential

This section describes the best source of heat waste from a resident that can be used to recover waste heat to design the clothes dryer machine.

i. Wood

Wood is locally available renewable energy source that has widely varying costs and quality. Wood needs a lot of processing (cutting, splitting, hauling) requiring specialized equipment (saws, splitters, trucks) and human energy to use it. Wood is a steady heat source but it is not suitable to the weather in Malaysia and hardly to build at home. In extreme cases, home insurance may be very limited or nonexistent because heating with wood not commercially in this country.

ii. Kitchen Stove

Kitchen stove is a kitchen appliance designed for the purpose of cooking food. Kitchen stove relies on the application of direct heat for the cooking process and may also contain an oven, used for baking. After cooking the heat will go waste. So heat waste can be used for another application like the cloth dryer machine but kitchen stove heat waste hard to take because the heat waste is very low.

iii. Natural Gas

A natural gas that can be found suitable for this is a geothermal energy. The geologists have estimated that there's about 42 million megawatts that trapped inside the earth, which is equivalent to the energy made by 25 000 large power plants. So the geothermal can be generated to form a heat pump to dry the clothes but unfortunately there is no supplier of geothermal gas in Malaysia.

iv. Residential refrigerators

Refrigerators are nominally "on" at all times, though they load varies slightly throughout the day. However, refrigerators are somewhat self-regulating (for example, to accommodate the significant fouling of condenser tubes which is expected in many household environments), care must be taken so that water cooling does not, in fact, deteriorate the cooling capacity of the refrigerator or detract from its reliability. Robert et al., (Robert et al., 1996) has found out that if the system designed to couple a residential refrigerator with water cooled condenser/pre-heater, the experimental system was able to increase heat temperature by about 30 ℃ in 5 days. For the clothes drying it maybe take long time to dry. So the residential refrigerators not suitable to use as a waste heat to dry the clothes.

v. Air conditioning

Air conditioning is used seasonally and intermittently. Suntivarakorn et al., also had done a research through air conditioning that the resident usually used are split-type air conditioner which the air is used to carry away heat rejected from its air-cooled condenser and is therefore heated so that its temperature may be increased by up to 10 °C. This presents an opportunity to reuse the heated air exiting from an air-cooled split type air conditioner for clothes drying in residential building. Furthermore, the research has successful with the results shown the experiment can be effective, for its reasonably short drying duration and high energy efficiency during air conditioning season. Moreover, the result is also revealed that the drying chamber with auxiliary fan is working and drying rate is higher than the drying chamber without auxiliary fan.

2.3.2 Summary of Heat Waste

From the research, the sources of heat waste from residents have come to a conclusion. Table 2.1 shows the evaluation form for heat waste from residential. From the table, there are 5 sources which are wood, kitchen stove, natural gas, residential refrigerators and air conditioning. The evaluators have decided to focus on 4 subject which is heat waste, time, strength and suitable in this country of Malaysia. The results show the higher total of this evaluation is air conditioning. So the experiment will proceed with the waste heat from air conditioning.

Table 2.1: Heat waste evaluation of residential

Subject	Wood	Kitchen Stove	Natural Gas	Residential Refrigerators	Air Conditioning
Heat Waste	4	1	4	3	4
Time	4	1	4	1	4
Strength	2	4	1	4	4
Suitable	1	4	1	4	3
Total	**11**	**10**	**10**	**12**	**15**

Evaluation rate 1 - Very Poor, 2 - Poor, 3 - Good, 4 - Excellent

2.4 AIR CONDITIONING SYSTEM

Air conditioning is used to cool products or a building environment. The air conditioning system transfers heat from a cooler low-energy reservoir to a warmer high-energy reservoir that is shown in Figure 2.2.

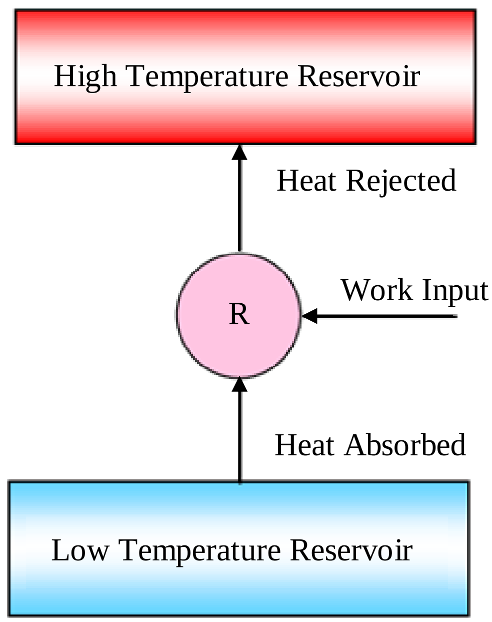


Figure 2.2: Schematic representation of air conditioning system

Source: Electrical Energy Equipment

i. Air conditioning processes

Air conditioning process include simple heating (raising the temperature), simple cooling (lowering the temperature), humidifying (adding moisture), and dehumidifying (removing moisture). Sometimes two or more of these processes are needed to bring the air to desired temperature and humidity level.

The various air conditioning processes are illustrated on the Psychrometric Chart in Figure 2.3. The simple heating and cooling processes appear as horizontal lines on the figure since the moisture content of the air remains constant during the processes. Air is commonly heated and humidified in winter and cooled and dehumidified in summer. These processes noticeably appearing in the Figure 2.3 shown below.

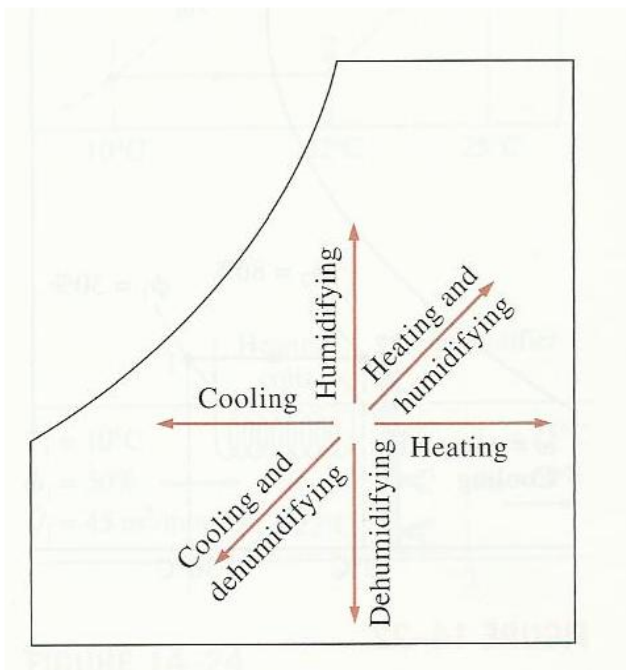


Figure 2.3: Various air conditioning processes

Source: Yunus and Michael (2007)

ii. Simple cooling and heating

Many residential heating systems consist of a stove, a heat pump, or an electric resistance heater. The air in these systems is heated by circulating it through a duct that contains the tubing for the hot gases or the electric resistance wires, as shown in Figure 2.4. The amount of moisture in the air remains constant during this process since no moisture is added to or removed from the air. That is, the specific humidity of the air remains constant during a heating (or cooling) process with no humidification or dehumidification. Such a heating process proceeds in the direction of increasing dry-bulb temperature following a line of constant specific humidity in the Figure 2.3, which appears as a horizontal line.

Notice that the relative humidity of air decreases during a heating process even if the specific humidity remains constant. This is because the relative humidity is the ratio of the moisture content of the moisture capacity of air at the same temperature, and moisture capacity increases with temperature. Therefore, the relative humidity of heated air may be well below comfortable levels, causing dry skin, respiratory difficulties, and an increase in static electricity.

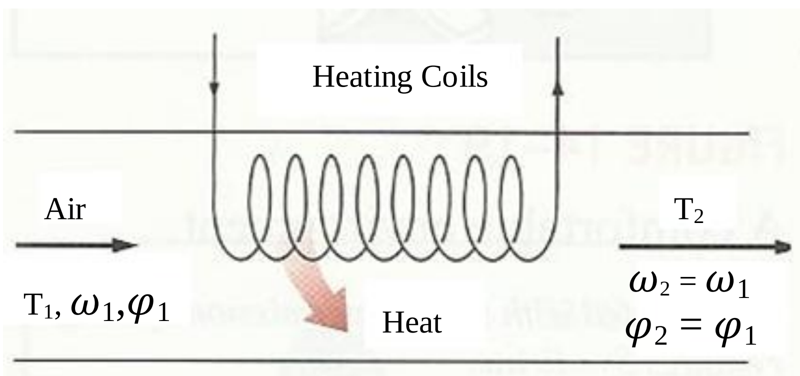


Figure 2.4: During simple heating, specific humidity remains constant, but relative humidity decreases

Source: Yunus and Michael (2007)

A cooling process at constant specific humidity is similar to the heating process discussed above, except the dry-bulb temperature decreases and the relative humidity increases during a process, as shown in Figure 2.5. Cooling can be accomplished by passing the air over some coils through which a refrigerant or chilled water flows.

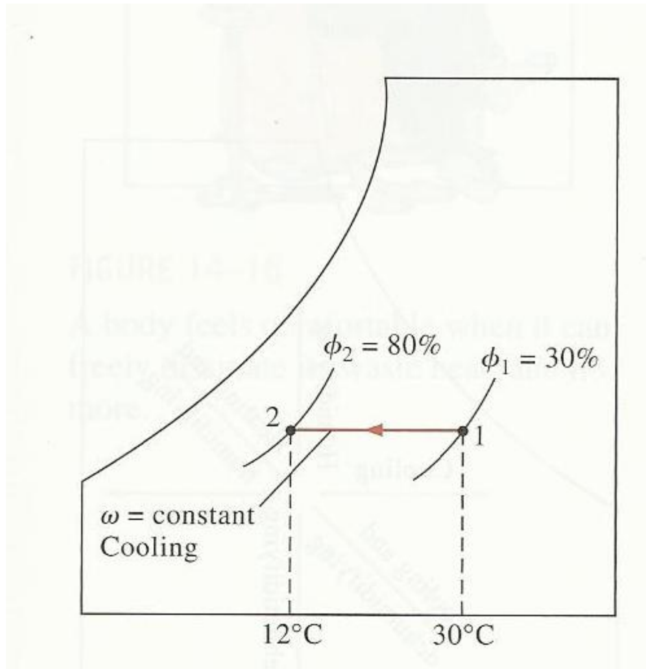


Figure 2.5: During simple cooling, specific humidity remains constant, but relative humidity increases

Source: Yunus and Michael (2007)

2.5 DRYING CONCEPT

The drying concept for the study was developed from all the types of drying of clothes. The types of dryer are discussed below;

i. Natural dryer

Natural dryer is wonderful in warm weather, when fabrics can dry quickly in the breeze and warm sunlight. There are traditional long lines which can be installed with rope and a set of hooks. There is free-of-charge, uses no energy and ecofriendly clothes dryer. Woodford also has investigated the best conditions for natural dryer;

- Warm and windy days when the humidity is relatively low.
- To lessen wrinkles, give each item a good shake and once it is pinned to the line, give the bottom corners a good tug to pull out more wrinkles.
- To prevent fading from the sun, place your clothesline in a breezy shaded area.
- For faster drying, hang clothes separately with room between them and fully stretched out, using as many pins as needed to prevent sagging.

ii. Natural Gas dryer

Natural gas clothes dryer work by moving warm air through the clothes inside. The dry usually use a gas burner to create heat to flow through the clothes. The capacities of the dryer are up to 70 % more powerful than most electric clothes dryers reducing cycle times. The gas dryer usually may cost a little more to buy than an electric dryer, but it will be paid back quickly in energy savings.

Nowadays, as an energy conservation feature, gas dryer does not use a continuously burning pilot light to ignite the gas burner. It has been replaced by electronic ignition systems. The main part of the dryer is a rotating drum. The dry, heated air from a natural gas burner flows through the clothes as the drum tosses them through the air. The moist air coming off the clothes is then exhausted through a lint filter to the cut-doors and replaced by warmer air.

Following the description explain the feature of natural gas dryers;

- Automatic shutdown – older dryers use a set of time clock for drying cycle but newest use a moisture sensor. The moisture sensor is the most sensitive kind, but may add a little cost of the dryer. The temperature sensor reduces energy costs by about 10 % but the moisture sensor can save up to 15 %.

- Exhausting - the end of the exhaust should be located so that the wet air coming out doesn't harm the area around it. The natural dryer should use the straightest, shortest duct pipe for exhausting. Rigid, metal duct piping traps the least amount of lint and lets the air flow freely.
- A drying rack that fits into the drum to provide flat drying for special items, such as tennis shoes or stuffed toys, that shouldn't be tumbled.

iii. Spin dryer

This machine simply spins their drums faster than a typical washer could in order to extract additional water from the load. The machine may remove more water in two minutes than a heated tumbler dryer can in twenty, thus saving significant amounts of time and energy. Although spinning alone will not completely dry clothing, this additional step saves a worthwhile amount of time and energy for large laundry operations (Kharulnizam, 2008).

iv. Heat pumps dryer

Ameen and Bari (Ameen and Bari, 2003) have investigated the heat pump unit is where the air returning from the drying chamber is dehumidified by the evaporator of the heat pump unit followed by heating of the air by the condenser heat. The dehumidified and heated air is then returned to the drying chamber, which is theoretically more efficient than a conventional dryer.

In other side, the hot, humid air from the tumbler passed through a heat pump where the cold side condenses the water vapor into either a drain pipe or a collection tank and the hot side reheats the air. In this way not only does the dryer avoid the need for ducting, but it also conserves much of its heat within the dryer instead of exhausting it into the surroundings. Heat pump dryers can therefore use less than half the energy required by either condensation or traditional dryers (Kharulnizam, 2008).

The heat pump is a high-efficiency heater, it consumes a small amount of high-quality energy to realize heat transfer from low-temperature to high temperature. The heat pump dryer in this paper precisely takes advantage of the characteristic of heat pump (Xinping and Pengyang, 2011). The structure and working principle are shown in Figure 2.6.

In the system, heat pump cycle and air cycle are connected at the evaporator and condenser to precede heat transfer. In the heat pump cycle, the compressor consumes a certain amount of electric energy to drive the refrigerant flow. It makes the refrigerant can absorb heat at evaporator at a lower temperature. Merged with the compressor's energy consumption, the heat was transferred to the condenser where the air is heated.

Xinping and Pengyang also had investigated in the heat pump cycle, the heat absorbed by the evaporator is less than release by a condenser, in order to maintain the balance of the system; an assistant heat exchanger was set before the evaporator. The heat dissipating capacity approximately equals to the compressor's power dissipation. The cooling medium can be water or air. Even if use air as the cooling medium, its influence of the indoor environment is small because of the release is small also.

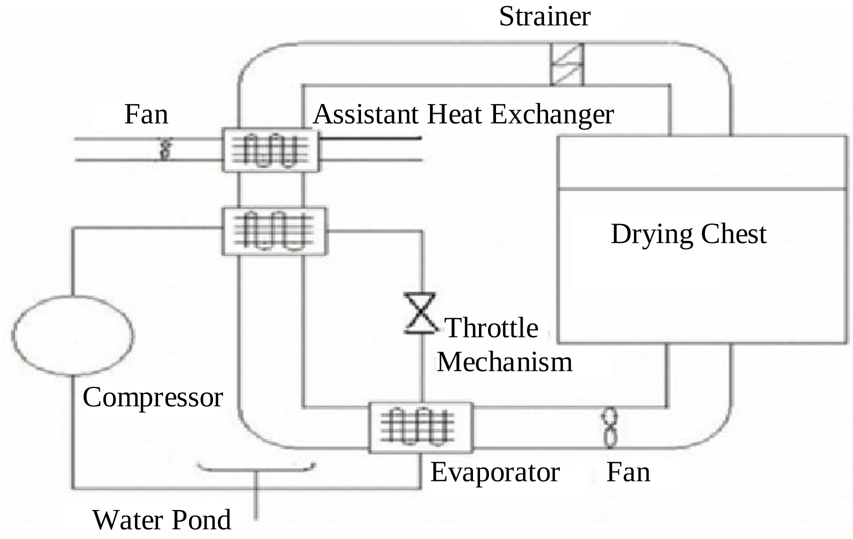


Figure 2.6: The frame and principle of heat pump dryer

Source: Xinping and Pengyang (2011)

v. Condensation dryer

The condensation dryer pass heated air through the load. However, instead of exhausting this air, the dryer uses a heat exchanger to cool the air and condense the water vapor into either a drain pipe or a collection tank. Afterwards, this air runs through the loop again. The heat exchanger typically uses ambient air as its coolant, therefore the heat produced by the dryer will go into the immediate surroundings instead of the outside, increasing the room temperature slightly. In some designs, cold water is used in the heat exchanger, eliminating this heating, but requiring increased water usage (Kharulnizam, 2008).

Condensation dryer is now popular on the market, and its basic working principle is shown in Figure 2.7.

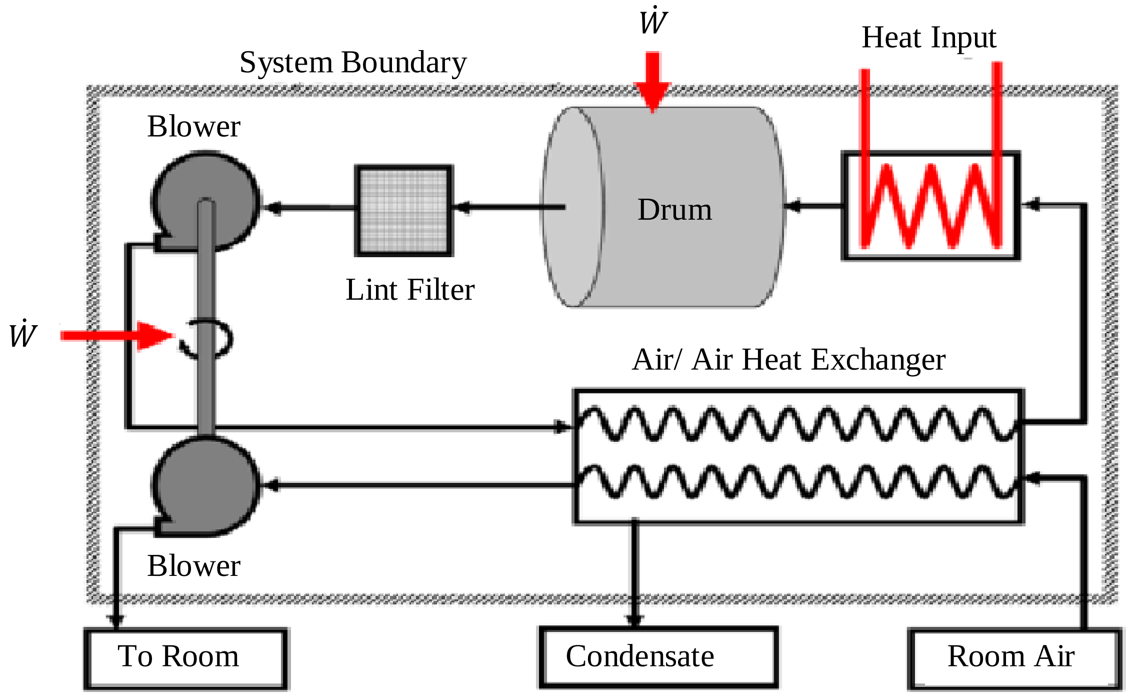


Figure 2.7: Condenser dryer flow schematic

Source: Bing and Deng (2008)

The air circulation in condensing dryer is closed. In the heat exchanger, the high temperature and humidity air comes from the dryer cylinder is cooled by indoor air or water, and the moisture condensates and is eliminated. If using indoor air to cool, the humidity in the room will be impervious. If using tap-water to cool, both the temperature and humidity in the room will be impervious. So, the superiority of condensing dryer is that there is less or even no pollution to the indoor environment when we use it without setting up vent discharge duct, what's more, compared with traditional dryer, the energy consumption of condensing dryer is less, even so, the energy consumption of condensing dryer is still high. At present, the air circulation heat pump dryer is proposed, it is based on the reverse cycle of Brayton cycle, but it needs to discharge a lot of heat and it does not suit for household uses (Cochran et al., 2009).

From the research, the drying concepts have come to a conclusion. Based on the types of drying concept that have been reviewed in Literature, the experiment has been proceed with the following condition.

i. Natural dryer as one of the conditions to conduct the experiment smoothly, which is the experiment, will compare the performance of the drying clothes in outdoor natural drying, indoor natural drying and drying using air conditioner heat waste.
ii. Spin dryer as assumption to the experiment where all the clothes must be spin first before conduct the experiment.
iii. The experiment will use heat pump system as one of the drying concepts which is suitable for the air conditioner because if turned an air conditioner backwards, it could pump heat from the outside into inside and heat pump is a special type of air conditioner that uses valves to control the flow of heat.

2.6 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 2.8 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).

Figure 2.9 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 2.10, 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) (Farid, 2009).

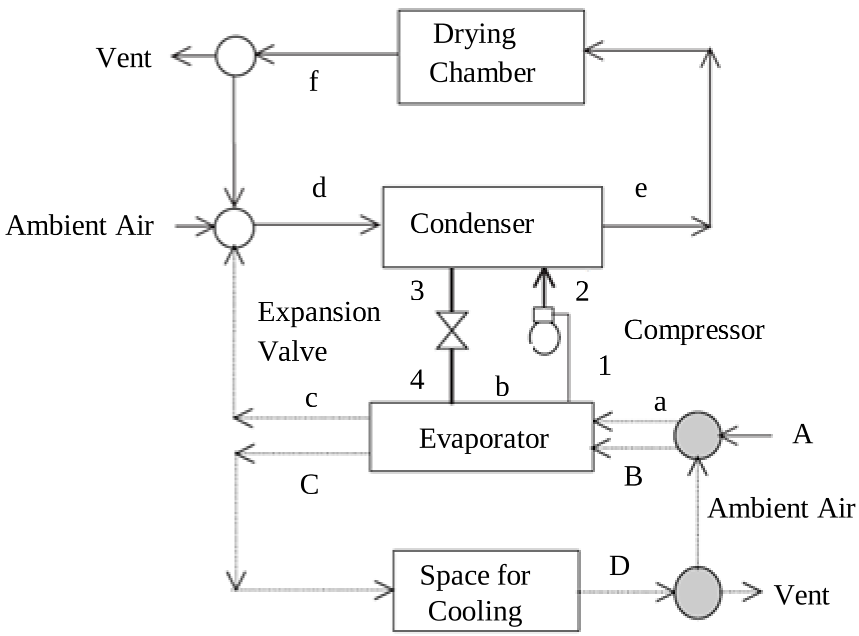


Figure 2.8: Modular configuration of the simple IHPS for drying

Source: Ameen and Bari (2003)

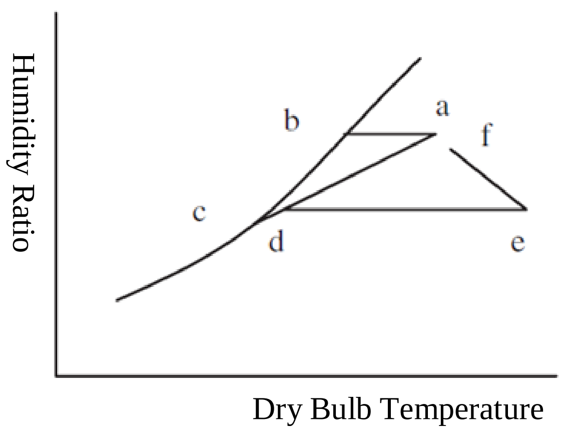


Figure 2.9: Psychometric chart for drying air circuit

Source: Ameen and Bari (2003)

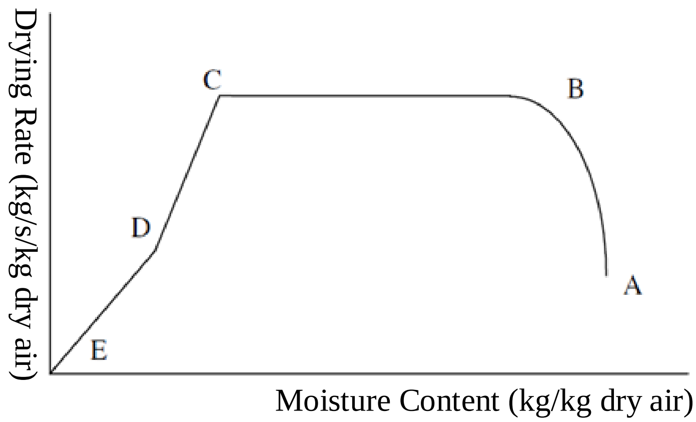


Figure 2.10: Typical drying rate curve

Source: Ameen and Bari (2003)

2.7 BASIC ANALYSIS AND MODELING ASSUMPTIONS

Yadav and Moon (Yadav and Moon, 2008) had conducted an approach of various processes occurring inside a cloth dryer. 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. The mean integral values for these variables can be derived by solving the relevant different-equations for the transfer of moisture and heat in the capillary-porous material. However, to use these solutions, the values for the transport coefficients must be known. As the coefficients of moisture and heat transfer vary with time, the associated system of governing differential equations is non-linear and difficult to solve. The assumptions are;

- The thermo-physical properties the fabric material is 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 bulb 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 of 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.

2.7.1 Theoretical Consideration

In this study, the possibility of using the vapor compression refrigeration cycle for both space cooling and drying clothes are considered. A *P-H* diagram of the refrigerant circuit (1-2-3-4) is shown in Figure 2.11.

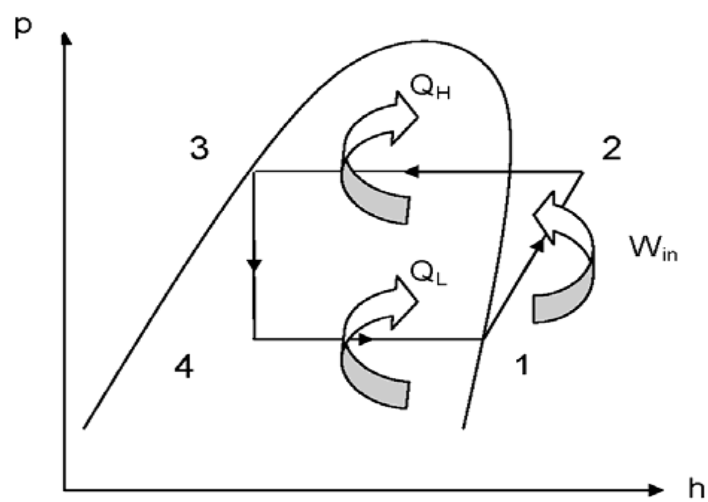


Figure 2.11: Pressure vs. enthalpy diagram of the refrigerant circuit

Source: Mahlia et al., (2010)

Thus, using this diagram, the performance of a clothes dryer machine is by the ratio of cooling capacity and power consumption and is referred to as Coefficient of Performance (COP_c) which can be calculated by the following equation;

$$COP_c = \frac{Cooling\ Capacity}{Power\ Consumption} = \frac{Q_L}{Win} \tag{2.1}$$

The work energy input to the compressor equation is;

$$W_{in} = (h_2 - h_1) \tag{2.2}$$

While, the Q_L from the diagram can be calculated by the equation below;

$$Q_L = (h_4 - h_1) \tag{2.3}$$

And also the Q_L can be calculated using this equation;

$$\dot{Q}_L = \dot{m}_{air}\ Cp_{air}\ (T_{out} - T_{in}) \tag{2.4}$$

Where, amount of mass flow rate of air can be defined by using this equation. The amount of mass flow rate is define same with the other concepts design.

$$\dot{m}_{air} = A\ \rho\ \nu \tag{2.5}$$

With,

$\dot{m}_{air}$ = mass of the air (kg/s)

A = room area, (m^2)

ρ = air density, 1.225 (kg/m^3)

ν = air flow velocity, (m/s)

2.7.2 Mathematical Model for Drying (CRDP and FRDP)

According to Yunus and Michael (Yunus and Michael, 2007), 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.

The modeling of a CRDP start with the initial moisture content where the initial moisture was measured and divide it with the final weight. The equation is shown below;

$$X_o = \frac{(weight\ of\ spin\ dried\ cloths - final\ weight)}{final\ weight}\ kg/kg \qquad (2.6)$$

Then, find the critical moisture content with the equation below;

$$X_{cr} = \frac{(moisture\ content\ with\ the\ time\ critical)}{final\ weight}\ kg/kg \qquad (2.7)$$

Thus, based on the equation above, the drying rate in a CRDP equation can be determined;

$$N_{CRDP} = \frac{(Xo - Xcr)\,Wd}{A\,t_{cr}}\ kg/s\ m^2 \qquad (2.8)$$

With,

N_{CRDP} = drying rate in CRDP, (kg/s m^2)

W_d = weight of dry material, (kg)

A = area of a drying surface at which heat and mass transfer takes place, (m^2)

t_{cr} = time of critical point

So, after determining the drying rate in a CRDP, the drying rate in FRDP can be determined by the equation below. Each drying material has its own specific drying index. So for this equation, the specific drying index is 0.8.

$$N_{FRDP} = N_{CRDP} \left(\frac{X - X_E}{X_{cr} - X_E}\right)^n \quad kg/s\ m^2 \tag{2.9}$$

With, volume-average moisture content (dry-basis) is calculated by the equation;

$$X = \left(\frac{(weight\ before\ wash - final\ weight)}{final\ weight}\right) + X_0 \quad kg/kg \tag{2.10}$$

And the equilibrium moisture content equation is defined as zero because the clothes are assuming in constant weight based on the weight of spin dried clothes. Therefore, after determining the drying rate, its duration can be calculated. The duration from the initial point to any drying instant within the CRDP can be determined by the following equation;

$$T_{CRDP} = t_{cr} = \frac{Wd}{A} \frac{1}{N_{CRDP}} (Xo - Xcr) \tag{2.11}$$

Where, duration time for CRDP is equal to the time critical. Meanwhile, for the duration time for FRDP, first, the free moisture content must be defined. The equation is;

$$F = X_{EA} - X_E \tag{2.12}$$

With,

$$X_{EA} = \left(\frac{(weight\ before\ wash - final\ weight)}{final\ weight}\right) \quad kg/kg \tag{2.13}$$

Then find the critical free moisture content by using this equation;

$$F_{cr} = X_{cr} - X_E \tag{2.14}$$

Thus, the duration time for FRDP is;

$$T_{FRDP} = \frac{Wd}{A\,(1-n)} \frac{Fcr^{n}}{N_{CRDP}} \left[F^{(1-n)} - Fcr^{(1-n)}\right] \tag{2.15}$$

2.7.3 Performance of a Heat Pump Dryer

There are two most important with respect to the performance of the heat pump dryer are (i) Specific energy consumption (SEC) rate in *kWh/kg*, defined as the ratio of the energy consumed (*kWh*) per kg of moisture removed and (ii) Specific moisture extraction rate (SMER) in *kg/kWh* defined as the moisture removed per unit *kWh* of energy consumption. It may be noted that SMER is the inverse of the SEC, and the drying efficiency is highest when SMER is maximized (Ameen and Bari, 2003).

During this investigation, the heat waste that is used has to be considered as free energy or energy saving compared to an alternate process of drying using direct electric power or other methods. *X* is the moisture removed, which can be calculated from the weight difference of clothes before and after drying. SMER is a characteristic to indicate the effectiveness of energy use in the drying process. SMER is calculated by the following equation:

$$SMER = \frac{X}{[\dot{m}air\ Cpair\ (Tout - Tin) x\ Win]} \tag{2.16}$$

Where,

X	= moisture removed, (kg)
$\dot{m}_{air}$	= mass of the air (kg/s)
Cp_{air}	= constant pressure specific heat, (1.005 kJ/kg. K)
T_{out}	= air temperature leaving the evaporator, (^{o}C)
T_{in}	= air temperature entering the evaporator, (^{o}C)
W_{in}	= power consumption, (kWh)

The drying rate can be calculated by the following equation;

$$DR = \frac{X}{DT} \tag{2.17}$$

Where,

DR	= drying rate, (kg/h)
DT	= drying time, (h)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The literature review indicates a need to further explore and extend the research in design and analyze the clothes dryer machine. This chapter will present the concept of the clothes dryer machine and the study will conduct in three conditions which are in outdoor natural drying, indoor natural drying and drying using air conditioner heat waste. Specifically, this chapter discusses the developing and conceptual models of the design, analyze of the design, feature for design, and material selection for the design.

3.2 DESIGN OF THE STUDY

The design of the study will be facing the problem as stated in the problem statement in Chapter 1. The problems are focused on energy efficient and less power consumption. The relationship between energy efficiency and less power consumption has attracted a lot of interest given. Further applications of new energy sources are planned for the immediate future. Heat waste technologies will be developed with emphasis on utilizing cost effective methods as well as strengthening of the cabinet. The design criteria are ergonomic, safe, economic and environmental friendly cabinet dryer. Several designs need to be done and being evaluated to choose the best design base on its performance.

3.3 METHODOLOGY FLOW CHART

Figure 3.1 shows the methodology flow chart. The project starts with concept development, then sketching the design, design using solidwork and analysis the project by using Computational Fluid Dynamic (CFD) analysis and Pugh concept to determine the performance of the design. The project also was analyzed by using the experiment to get the drying rate.

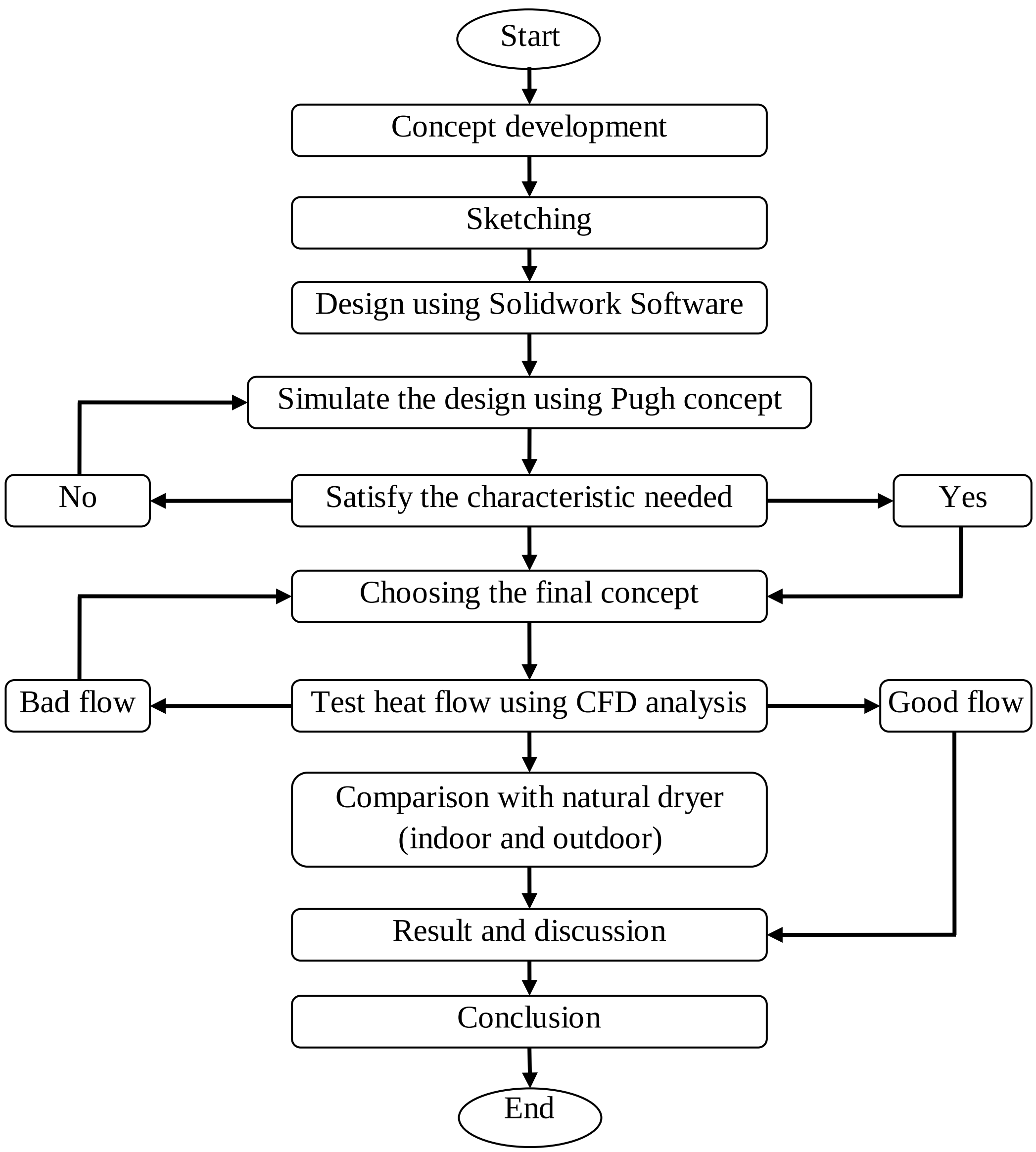


Figure 3.1: Methodology flow chart

3.4 DESIGN CONCEPT

From the research, the design concept will proceed with the entire conclusion that comes from the literature review. The conclusion will include the assumption, theory and condition to design the clothes dryer. Before starting to design there are three important things to know which is how to evaporate water from wet clothes. The three important things are high temperatures (to increase the number of molecules that can turn from liquid to vapor), air movements (to carry water away and prevent the air near clothes from becoming saturated with vapor) and low humidity (to make the evaporation continue steadily and water molecules would not return to clothes from the air).

Furthermore, the feature and condition must take note before start sketching design concept. The conditions are shown below;

i. The experiment will use heat pump system as one of the drying concepts which is suitable for the air conditioner because if turned an air conditioner backwards, it could pump heat from the outside into inside and heat pump is a special type of air conditioner that uses valves to control the flow of heat.

ii. The clothes will hang separately with room between them and fully stretched out, using as many pins as needed to prevent sagging for faster drying. The natural flow of the heat is from below to the top because warm air will rise and cool air will sink.

iii. The concept criteria such as drying clothes, stability, installation size, safety, appearance, economical, ergonomic, environmental friendliness, complexity, and specialty.

iv. The stabilizer was needed to make the flow of the heat not dispersed, run smoothly and distribute air equally inside the cabinet.

3.5 SKETCHING DESIGN

After the concept of design, the research proceeds with the sketching of design to make an illustration of by the design that will build using Solidwork software. The designs are presented in Figure 3.2.

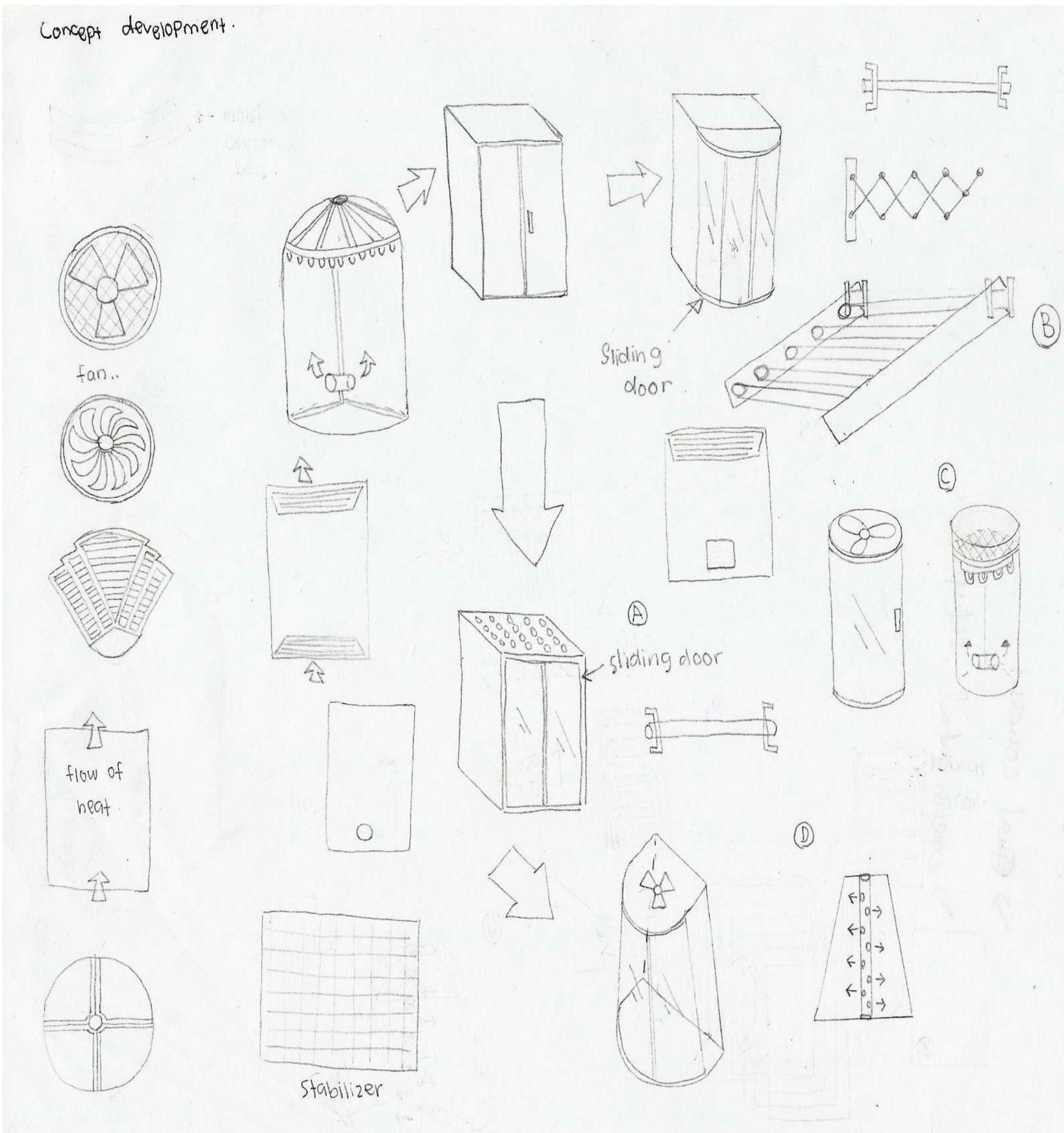


Figure 3.2: Concept development for concept A, B, C and D

3.6 CONCEPT SELECTION

Concept Selection is one of the most critical decision-making in a product development. The goal is to expend the least amount of resources on deciding which concepts have the highest potential for becoming a quality product. The difficulty is to choose the best concept with very limited knowledge and data on which to base the selection.

After careful screening of brainstorming which has generated hundred of ideas, many whimsical or outlandish at sketching design, all the concept will be going on further development and detail drawing using Solidwork to make it clear for concept selection.

3.6.1 Concept A

Figure 3.3 and 3.4 shows the design is simple and easy to use like ordinary cabinet. Amount of material used are average from the other design. The shape of this design is not really helping the air flow because the space inside is rectangular. So the flow will not contribute equally to all space. At the back surface, the cabinet has only a hole for air inlet. The flow of heat will go up and out at the top of the design. The top of the design has a hole for heat outlet. The mechanism to overcome the flowing air in this design is by using a stabilizer.

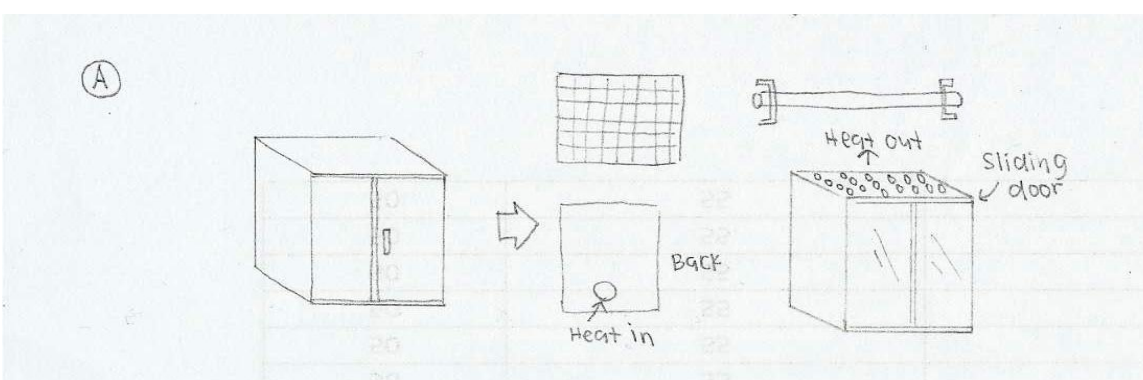


Figure 3.3: Sketching idea for concept A

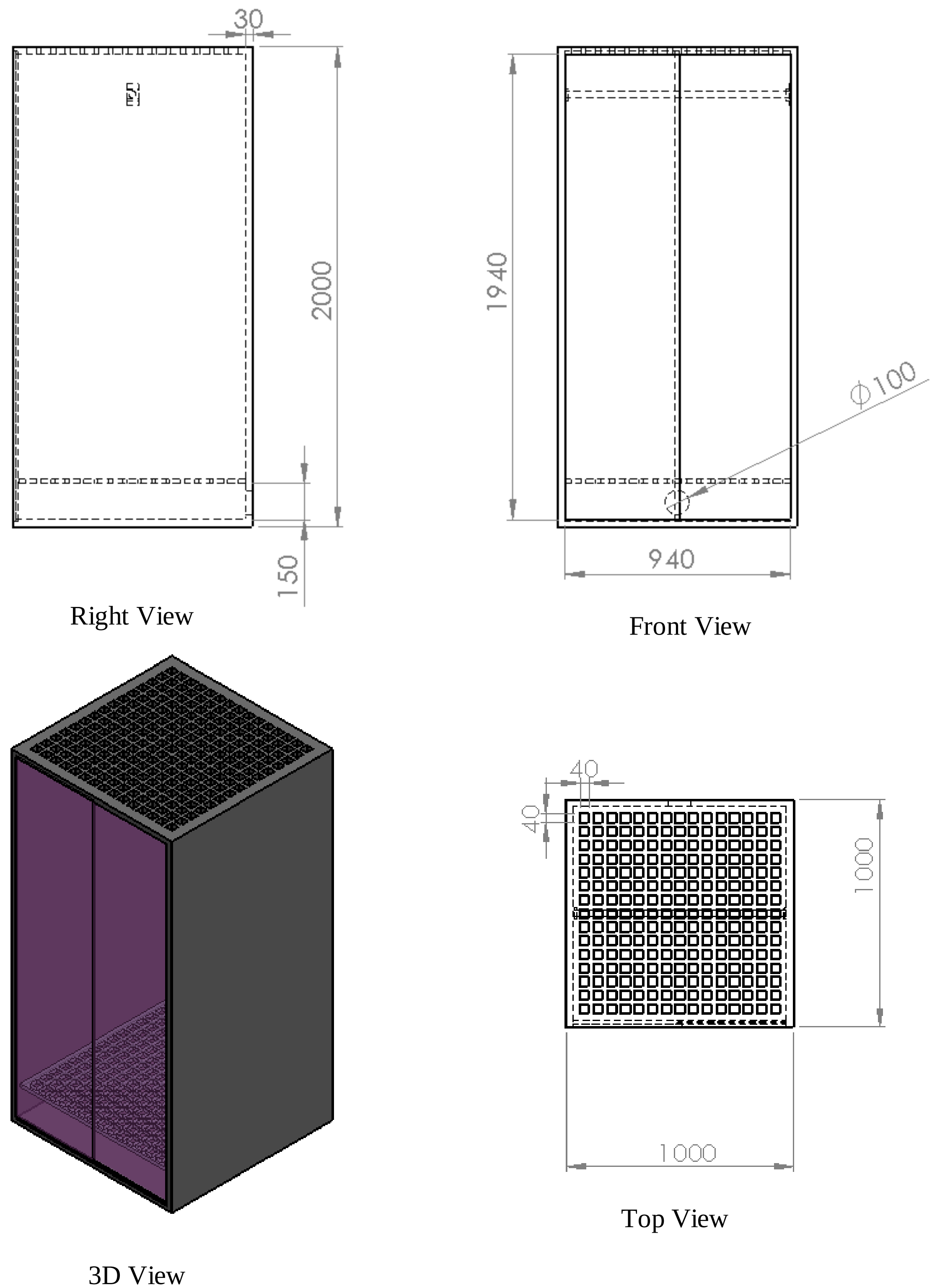


Figure 3.4: Technical drawing for concept A

3.6.2 Concept B

Figure 3.5 and 3.6 shows the design is simple and easy to use like ordinary cabinet but in a semicircle and rectangle shape. Furthermore, the design has many features inside such as flexible hanger that can put as many clothes to dry. The user also can dry shoes or shocks inside. Because the design has many features inside, the amount of material use is greatest compared to all design and the design more complicated to build. The shape of this design is not really helping the air flow inside the cabinet because the space inside is bigger than the other design. At the back surface, the cabinet has a hole for air outlet and air inlet. The mechanism to overcome the flowing air in this design is by using a stabilizer.

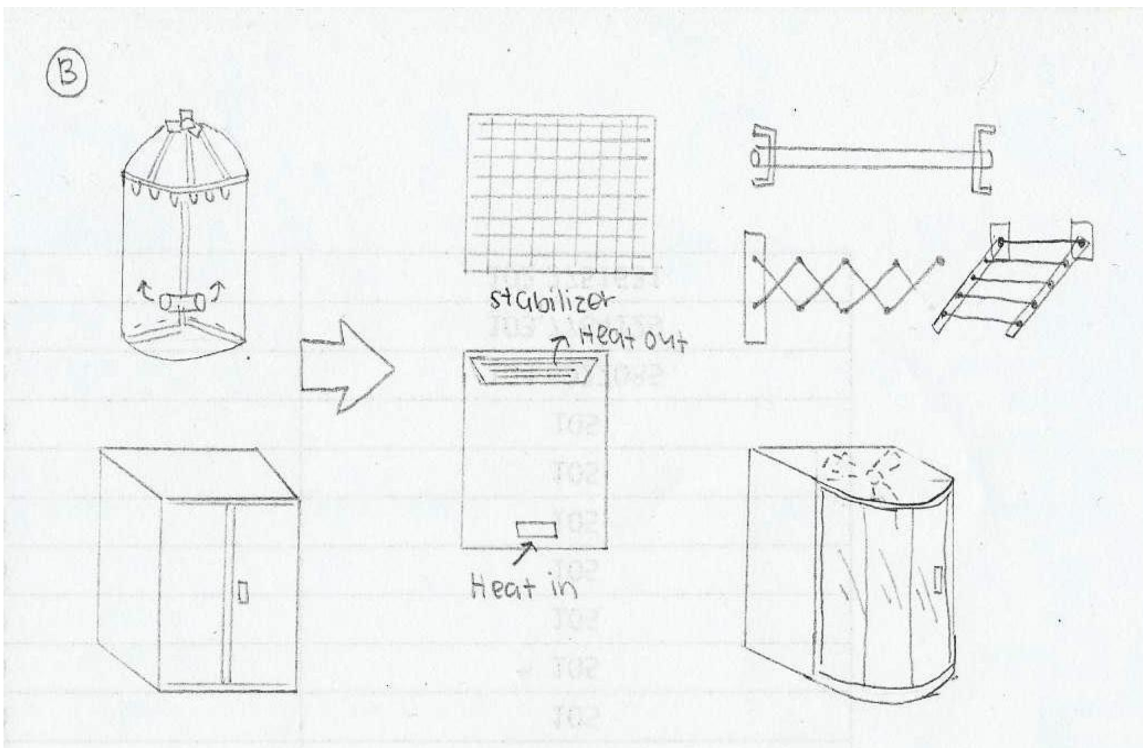


Figure 3.5: Sketching idea for concept B

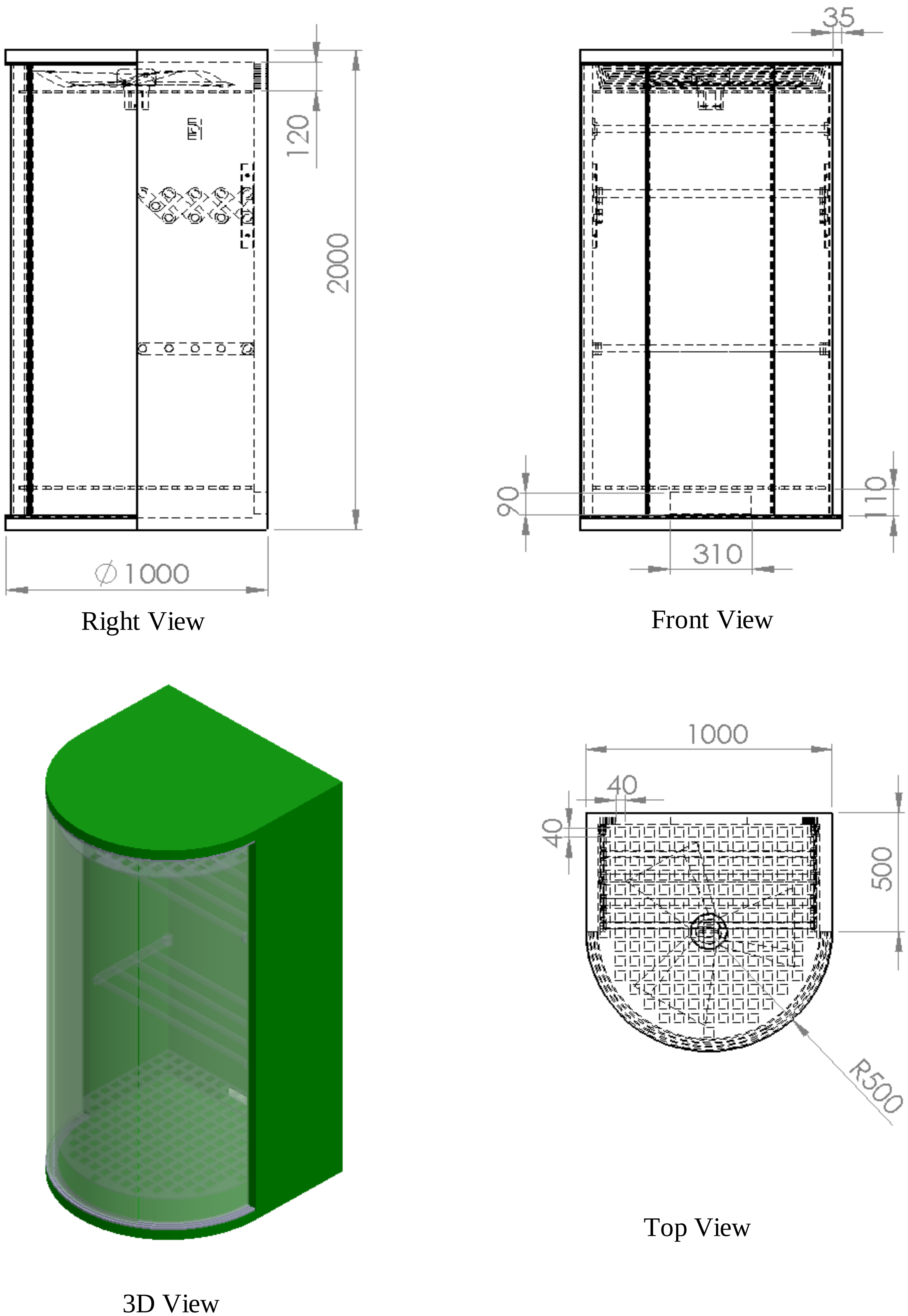


Figure 3.6: Technical drawing for concept B

3.6.3 Concept C

Figure 3.7 and 3.8 shows the design is simple and easy to use like ordinary cabinet but in a round shape. The shape round make the design have lack of space for drying but it much more clothes can dry compare to design concepts A. The design needs a small amount of material and easy to build. Besides that, when the drying processes in operation the fan is not safe to the user because the fan outlet is designed with open space. The two circular holes from the pipe place in the center of the cabinet is for the hot air flow from condensing unit. The position is on the bottom side because of the characteristic of air which is low density will flow to the upper side by itself. This design was shaped like this to help it flow smoothly from the inlet to the outlet without using a stabilizer.

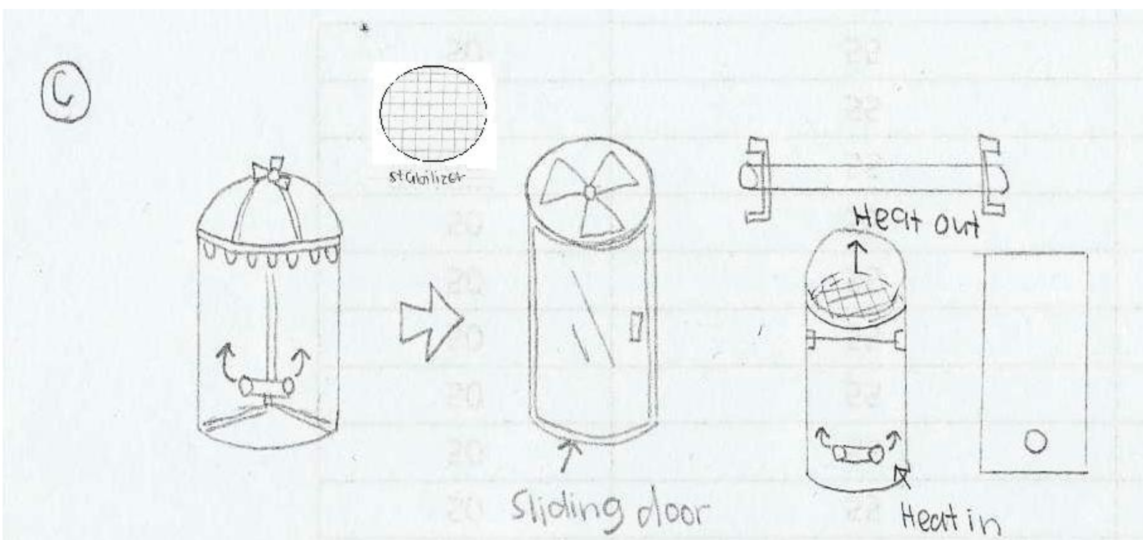
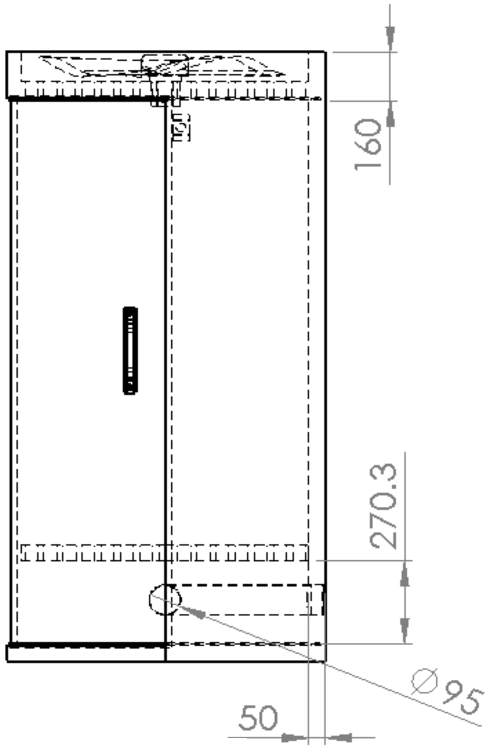
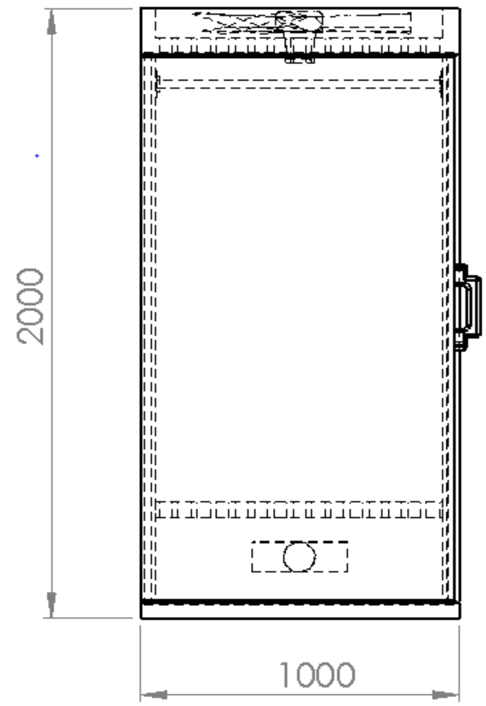


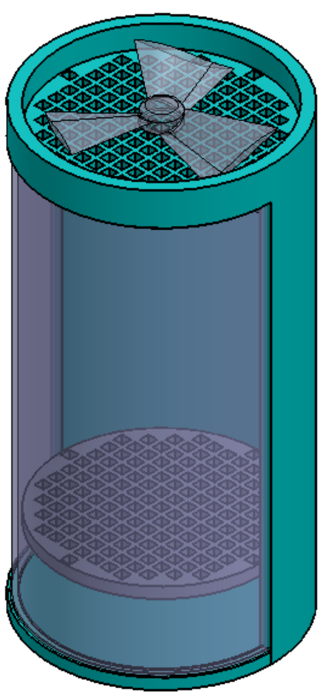
Figure 3.7: Sketching idea for concept C



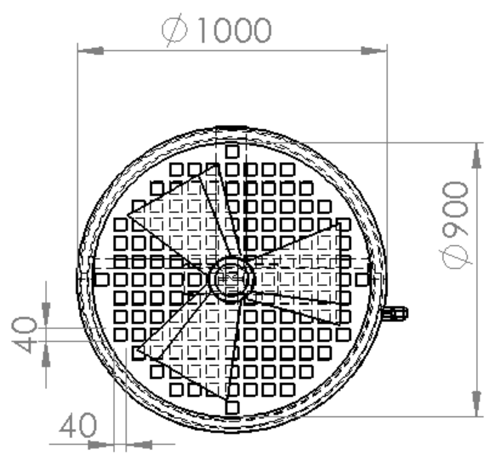
Right View



Front View



3D View



Top View

Figure 3.8: Technical drawing for concept C

3.6.4 Concept D

The design shape is from smaller to larger at the bottom. Therefore the design needs more space to install in the resident. The design also needs a small amount of material, but it is averagely complicated to build. The design stability is higher than the other design because of the area at the bottom is larger than the area at the top. Figure 3.9 and 3.10 show that this design have lack of space for drying because of the space in the design are smaller than other design but with the space left around, the user can dry the smaller things like shoes and shocks. As same as design concept C, when the drying processes in operation the fan is not safe to the user because the fan outlet is designed with open space and please be caution of the heat flow in.

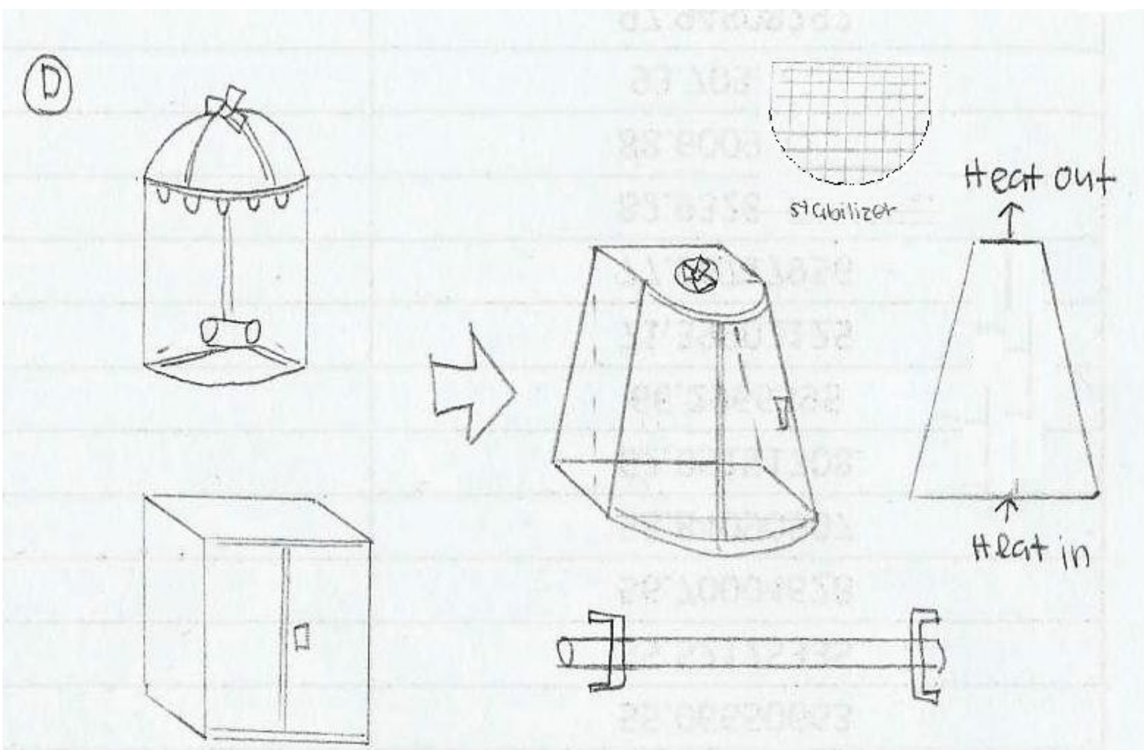


Figure 3.9: Sketching idea for concept D

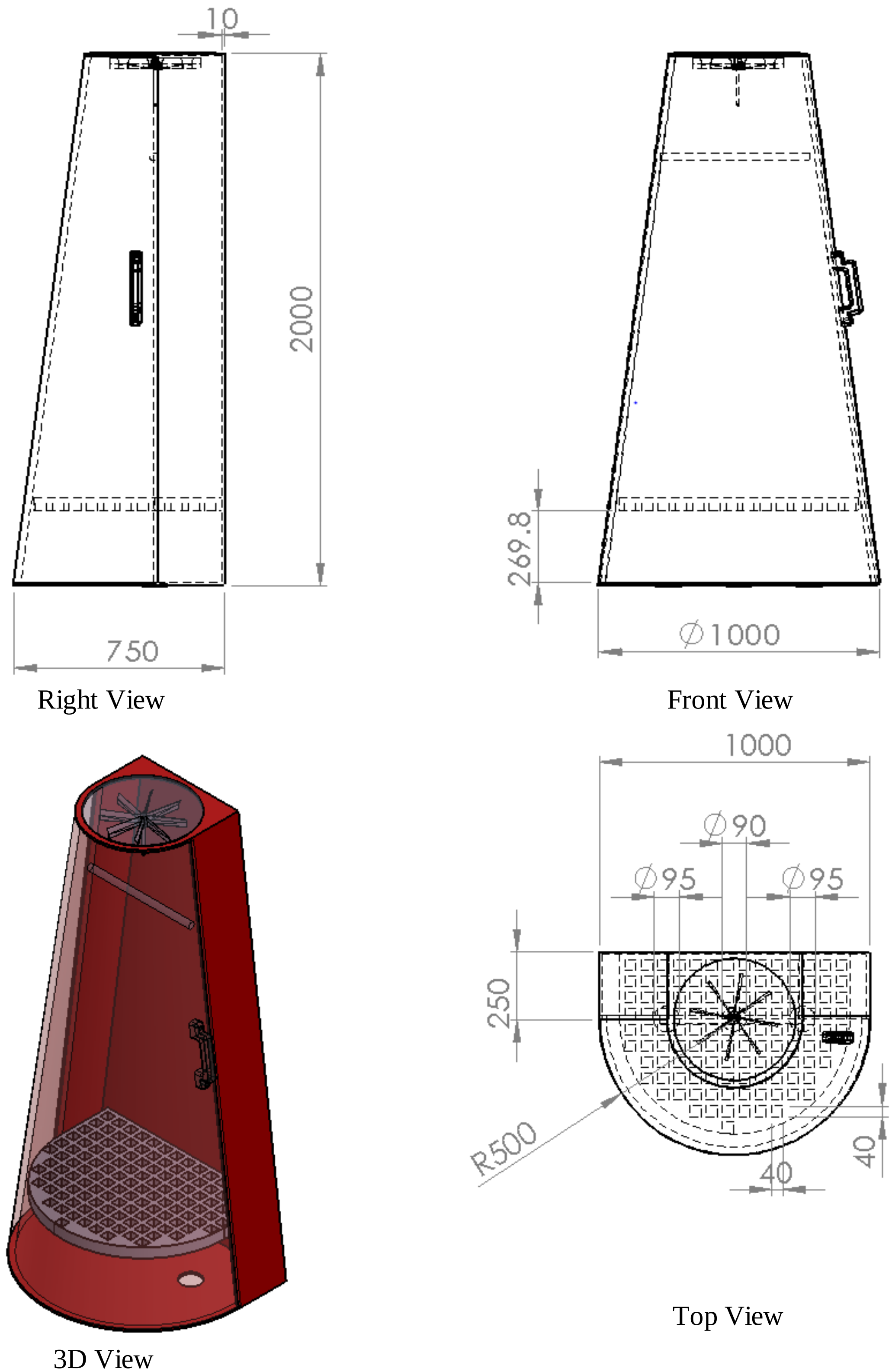


Figure 3.10: Technical drawing for concept D

3.7 PUGH CONCEPT

Pugh concept is a Pugh Analysis Charts which similar to the pros vs. cons lists. These are used for evaluating multiple options against each other, in relation to a baseline option. The method was invented by Stuart Pugh, University of Strathclyde in Glasgow, Scotland as an approach for selecting concept alternatives.

The spreadsheet will serves as a template for recording the Pugh Concept Selection Process, for iteratively screening a large number of alternative preliminary concepts. It is intended for preliminary concept screening in sequential rounds of concept generation, Pugh concept down-selection comparison analysis, and refined subsequent off-line investigations of new ideas. All concepts should have concepts sketches and input ratings.

Table 3.1: Judged Evaluation for Pugh Concept

Score	Judged Evaluation
-1	Alternative is worse than the Datum on the Criteria
0	Alternative is indistinguishable from the Datum on the Criteria
1	Alternative is better than the Datum on the Criteria

The positive, same, and negatives are summed. These should be contrasted to define better concepts worthy of carrying forward into further more detailed investigations.

Table 3.2: Concept criteria description

Concept Criteria	Description
Drying clothes	How many clothes can be dry in one time?
Stability	How the designs maintain to stand with a lot of clothes inside?
Installation size	Based on the space to install the design and maximum clothes can dry inside the design.
Safety	Safety feature in the design such as cover for the heat waste and cover for the fan.
Appearance	The design can attract people to buy or not.
Economic	The roughly cost to built the design meaning the design manufacturing cost.
Ergonomic	Means focusing on ease to use, easy to attach and easy to detach.
Environmental friendly	The design are friendly to the environment means free green house effect and other bad effect for earth.
Complexity	Easy to fabricate or not
Specialty	Based on the feature in the design

Table 3.3: Evaluation of design concept based on the concept criteria

Concept Criteria	Reference	Concept A	Concept B	Concept C	Concept D
Drying clothes	0	1	1	0	-1
Stability	0	1	1	1	1
Installation size	0	1	0	0	0
Safety	0	1	1	0	-1
Appearance	0	-1	1	1	1
Economic	0	1	-1	1	1
Ergonomic	0	0	1	1	0
Environmental friendly	0	1	1	1	1
Complexity	0	0	1	0	1
Specialty	0	-1	1	0	-1
Total score	**0**	**4**	**6**	**5**	**2**

3.8 FINAL CONCEPT

The final decision about which concept to be decided can be a source of anxiety for some innovators. Using a well structured, rigorous approach, like the one outlined in Pugh Concept, can help boost confidence and increase the likelihood of a successful result. Based on the Pugh Concept, the total score for concept A is 4, concept B is 6, concept C is 5 and concept D is 2. So the concept B as Figure 3.11 was chosen as the final concept that will be used for further development.

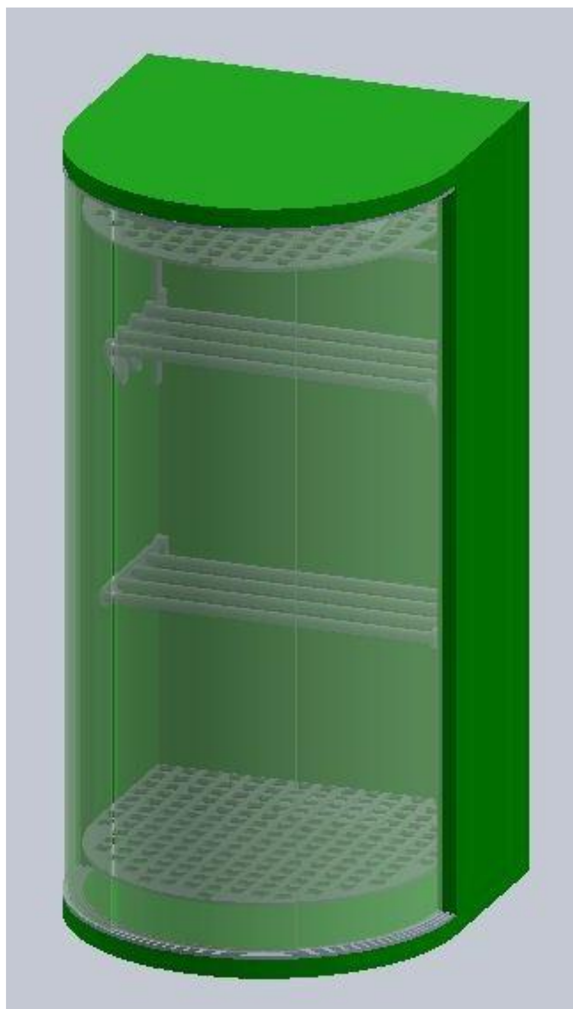


Figure 3.11: Final concept

Although concept B was chosen as a final concept by the Pugh analysis, the design must go through flow simulation to determine the performance heat flow through the entire wall. This is because to make sure all the clothes drying equally gets a heat to dry. So, proceeding to the flow simulation, actual data for the air conditioning is very important. It is compulsory to measure the velocity and temperature that blow from it. This variable was the input for CFD analysis.

3.8.1 Data for Air Flow from Air Conditioning System

Air flow modeling has been utilized by using Computational Fluid Dynamic (CFD) flow simulation. This simulation is used to choose better performance from the chosen concept or the other concept that have higher score too. The simulation is also to simulate the air flow from the air conditioning unit as heat waste input through the dryer. The air conditioning is shown in the Figure 3.12, which the heat outlet hole was big and the flow was dispersed to the surrounding. So to make sure the data is accurate, there are some tips and method to take the data.

Figure 3.12: Heat blow from air conditioning system

a. Tips

i. The data will run in several points to get the average temperature and velocity.

ii. Make a small hole from the big hole at the air conditioning.

b. Equipment

i. Air conditioning at lab Faculty of Mechanical (FKM).

ii. Anemometer – sensor to measure temperature and velocity.

iii. Air flow cone.

iv. Box.

c. Procedure

i. Make a small hole from the air flow cone.

ii. Then, put the air flow cone and the box at the air conditioning heat outlet as shown in Figure 3.13. Make sure all the hole was covered by the air flow cone and the box.

iii. Put anemometer as shown in Figure 3.14 at the center and measure the temperature and velocity data.

iv. After that, all the value was recorded in the table and the average temperature and velocity was calculated to get the exact value of it.

v. Finally, the data were used as an input data in the CFD flow simulation.

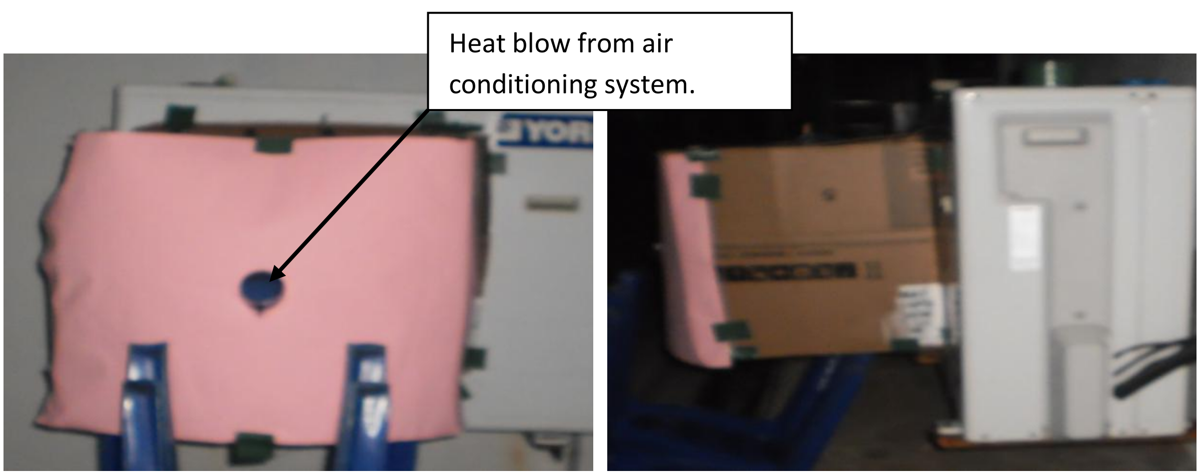


Figure 3.13: Air flow cone at air conditioning heat outlet

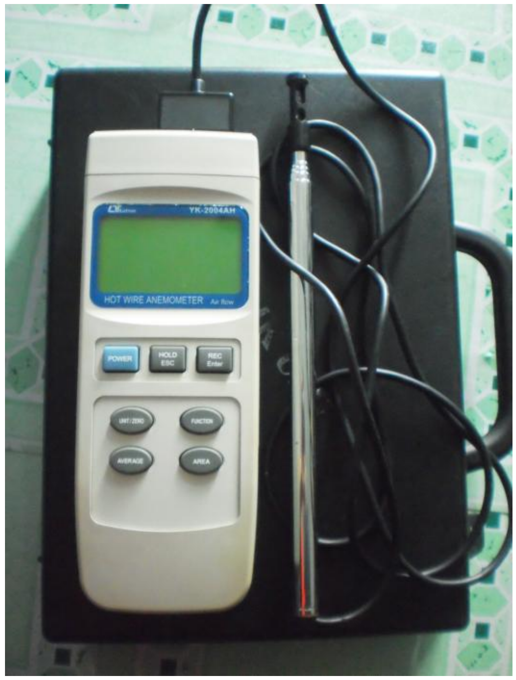


Figure 3.14: Anemometer

3.8.2 Experimental Setup for Comparing Cloth Dry with Other Dryer Concept

Based on the assumption at drying concept, the experiment was conducted to obtain the drying rate for drying clothes in outdoor natural drying, indoor natural drying and drying using air conditioning heat waste. The experiments follow the assumptions that already make to minimize error on the result.

a. Assumption

i. Outdoor natural drying.

- Hang it outside the building without the roof top.
- Run in daylight only.

ii. Indoor natural drying.

- Hang it inside the building of the hall or any room inside the building.
- Run in daylight and night.

iii. Drying using air conditioning heat waste.

- Hanging the wet spin clothes in front of the outlet heat air conditioning to make sure all the hot air blow is equally distributed to all surfaces of the material tested.
- The experiment was conducted inside a box that is interpreted as the drying process in cabinet dryer.

iv. All the clothes must be spin first before drying process.

b. Procedure for outdoor natural drying.

i. First, weight the clothes before it is being washed and record it.
ii. Then, wash the clothes by washing machine and spin.
iii. Next, weight the clothes again and record it.
iv. Hanged wet spin clothes outside the building with open surroundings.
v. After that, weight the hanging clothes every 10 minutes until the clothes do not change its weight.
vi. Record all the data in the table below.
vii. Finally, 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 removed in every 10 minutes.

c. Procedure for indoor natural drying in daylight.

i. First, weight the clothes before it is being washed and record it.
ii. Then, wash the clothes by washing machine and spin.
iii. Next, weight the clothes again and record it.
iv. Hanged wet spin clothes inside the room.
v. After that, weight the hanging clothes every 30 minutes until the clothes do not change its weight.
vi. Record all the data in the table below.
vii. Finally, 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 removed in every 30 minutes.
viii. Repeat number (i) until (vii) for natural drying in night.

d. Procedure for drying using air conditioning heat waste.

i. First, weight the clothes before it is being washed and record it.
ii. Then, wash the clothes by washing machine and spin.
iii. Next, weight the clothes again and record it.
iv. Built a box like Figure 3.13.
v. Hanged wet spin clothes inside the box.
vi. After that, weight the hanging clothes every 10 minutes until the clothes do not change its weight.
vii. Record all the data in the table below.
viii. Finally, 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 removed in every 10 minutes.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the research will set out the result and discussion of the study. It is divided into three parts: prerequisite testing which comprises natural drying and heat waste drying, description of the data flow, and the discussion of the study result.

4.2 PREREQUISITE TESTING

The study is aimed at investigating the combined effect of other drying method. This study is carried out outdoor natural drying, indoor natural drying (midday and night) and heat waste drying. The data include the mass flow rate of air, drying rate in constant-rate drying period (CRDP), drying rate in falling-rate drying period (FRDP), specific moisture extraction rate (SMER) and drying rate. Before the data are analyzed by calculation of the drying rate, the data are divided into three major groups as follows:

a. Data of the experimental outdoor drying.
b. Data of the experimental indoor drying (midday and night)
c. Data on the experimental utilization using heat waste drying.

4.2.1 Data of the Experimental Outdoor Drying

Data from the experiments for outdoor drying was taken between times 2 pm to 5 pm outside the house. The initial weight was recorded before putting it in the washing machine. Then, after washing, the weight of spin dried cloths was recorded. After that, the final weight of cloth was recorded until there is no different in the data. The data were recorded as shown in Table 4.1 and Table 4.2.

Table 4.1: The result of weight and moisture remove during the drying process

Time (s)	Weight (kg)	Moisture Remove (kg)
0	0.45	0.00
600	0.44	0.01
1200	0.43	0.02
1800	0.42	0.03
2400	0.41	0.04
3000	0.40	0.05
3600	0.39	0.06
4200	0.38	0.07
4800	0.37	0.08
5400	0.36	0.09
6000	0.35	0.10
6600	0.34	0.11
7200	0.33	0.12
7800	0.32	0.13
8400	0.31	0.14
9000	0.30	0.15
9600	0.29	0.16

Table 4.2: The calculation of drying rate in CRDP, drying rate in FRDP and drying rate

N_{CRDP} (kg/s m^2)	N_{FRDP} (kg/s m^2)	T_{CRDP} (s)	T_{FRDP} (s)	DR (kg/h)
$5.54\text{x}10^{-4}$	$1.76\ \text{x}10^{-3}$	1200	110.96	0.060

4.2.2 Data of the Experimental Indoor Drying

The data from the experiments indoor drying was taken between 2 pm to 5 pm for midday and 8 pm to 5 am for the night in the house with fan. The initial weight was recorded before putting it in the washing machine. Then, after washing, the weight of spin dried cloths was recorded. After that, the final weight was recorded until there is no different in the data. The data were recorded as shown in Table 4.3 to 4.6.

Table 4.3: The result of weight and moisture remove during drying process (midday)

Time (s)	Weight (kg)	Moisture Remove (kg)
0	0.45	0.00
1800	0.42	0.03
3600	0.40	0.05
5400	0.38	0.07
7200	0.36	0.09
9000	0.34	0.11
10800	0.32	0.13
12600	0.30	0.15
14400	0.29	0.16

Table 4.4: The calculation of drying rate in CRDP, drying rate in FRDP and drying rate (midday)

N_{CRDP} (kg/s m^2)	N_{FRDP} (kg/s m^2)	T_{CRDP} (s)	T_{FRDP} (s)	DR (kg/h)
3.43 x10^{-4}	7.90 x10^{-4}	1800	409.69	0.040

Table 4.5: The result of weight and moisture remove during drying process (night)

Time (s)	Weight (kg)	Moisture Remove (kg)
0	0.45	0.00
1800	0.44	0.01
3600	0.42	0.03
5400	0.40	0.05
7200	0.39	0.06
9000	0.38	0.07
10800	0.37	0.08
12600	0.36	0.09
14400	0.35	0.10
16200	0.34	0.11
18000	0.33	0.12
19800	0.32	0.13
21600	0.31	0.14
23400	0.30	0.15
25200	0.29	0.16

Table 4.6: The calculation of drying rate in CRDP, drying rate in FRDP and drying rate (night)

N_{CRDP} (kg/s m^2)	N_{FRDP} (kg/s m^2)	T_{CRDP} (s)	T_{FRDP} (s)	DR (kg/h)
1.72 x10^{-4}	3.95 x10^{-4}	3600	819.38	0.023

4.2.3 Data of the Experimental Utilization using Heat Waste Drying

The data on the experimental utilization using heat waste drying was taken between times 8 pm to 10 pm inside the box as the drying cabinet at the heat source of air conditioners. The main characteristic of air conditioner and the velocity and temperature that blow from the box was taken and measured by using an anemometer. The data were recorded and shown in Table 4.7 and 4.8.

Table 4.7: Main characteristic of air conditioner

Characteristics	Technical Description
Type	Split unit
Volt/Ph/Hz	220-240/1/50
Refrigerant	R-22
Rated capacity	2.654 kW
Nominal Ampere	11.6 A
Area of the box	P = 0.345 m, L = 0.305 m

Table 4.8: The velocity and temperature that blow from the box of air conditioner

No	Velocity (m/s)	Temperature (^{o}C)
1	6.9	46.8
2	7.0	47.0
3	6.8	46.9
Average	**6.9**	**46.9**

Next, the initial weight was recorded before putting it in the washing machine. Then, after washing, the weight of spin dried cloths was recorded. After that, the final weight was recorded until there is no different in the data. The data were recorded are shown in Table 4.9 and 4.10.

Table 4.9: The result of weight and moisture remove during the drying process

Time (s)	Weight (kg)	Moisture Remove (kg)
0	0.45	0
600	0.4	0.05
1200	0.37	0.08
1800	0.34	0.11
2400	0.31	0.14
3000	0.29	0.16

Table 4.10: The calculation of mass flow rate of air, drying rate in CRDP, drying rate in FRDP, specific moisture extraction rate (SMER) and drying rate

N_{CRDP} (kg/s m^2)	N_{FRDP} (kg/s m^2)	T_{CRDP} (s)	T_{FRDP} (s)	DR (kg/h)	SMER
8.71 x10^{-4}	1.33 x10^{-3}	600	375.30	0.192	0.086

4.2.4 Summary of the Experiments

Table 4.11 shows the summary of the comparison result from the experiments. The experiments show the ranking for the drying rate. Based on the results of all experiments, the case that has the highest drying rate is heat utilizing from air conditioners, followed by experiment at outdoor, then experiment at indoor (midday) and the lowest drying rate is an experiments at indoor (night).

Table 4.11: Comparison result of the experiments

Case	N_{CRDP} (kg/s m^2)	N_{FRDP} (kg/s m^2)	T_{CRDP} (s)	T_{FRDP} (s)	DR (kg/h)
Outdoor	5.54 x10^{-4}	1.76 x10^{-3}	1200	110.96	0.060
Indoor(Midday)	3.43 x10^{-4}	7.90 x10^{-4}	1800	409.69	0.040
Indoor(Night)	1.72 x10^{-4}	3.95 x10^{-4}	3600	819.38	0.023
Heat Utilizing	8.71 x10^{-4}	1.33 x10^{-3}	600	375.30	0.192

The data in the Table 4.11 were calculated using the equation (2.5) until (2.17) from the literature review. The example of detail calculation for the experiment of utilization heat from air conditioning shown below;

The amount of mass flow rate for air can be calculated by using the equation;

$$\dot{m}_{air} = A\ \rho\ v$$
$$= (\pi\ x\ 0.054^2)\ (1.225)\ (6.9)$$
$$= 0.0774\ kg/s$$

The drying rate in a CRDP can be calculated by using the equation (2.8). The initial moisture content (X_o) is obtained as below;

$$X_o = \frac{(0.45-0.29)}{0.29} = 0.5517\ kg/kg$$

And, the critical moisture content is calculated as follow;

$$X_{cr} = \frac{0.05}{0.29} = 0.1724\ kg/kg$$

Thus, the drying rate in CRDP is;

$$N_{CRDP} = \frac{(Xo - Xcr)\ W_d}{A\ tcr}$$
$$= \frac{(0.5517 - 0.1724)0.29}{0.2104\ (600)}$$
$$= 8.71\ x\ 10^{-4}\ kg/s\ m^2$$

So after determining the drying rate in a CRDP, the drying rate in FRDP can be determined by the equation below. First determine the volume-average moisture content (dry-basis);

$$X = \left(\frac{(0.30-0.29)}{0.29}\right) + \left(\frac{(0.45-0.29)}{0.29}\right) = 0.2931\ kg/kg$$

Then, the drying rate in FRDP is;

$$N_{FRDP} = N_{CRDP}\left(\frac{X - XE}{Xcr - XE}\right)^n$$

$$= 8.71x10^{-4} \left(\frac{0.2931 - 0}{0.1724 - 0}\right)^{0.8}$$

$$= 1.33 \text{ x } 10^{-3} \text{ kg/s m}^2$$

After determining the drying rate, its duration can be calculated. The duration from the initial point to any drying instant within the CRDP can be determined by the following equation;

$$T_{CRDP} = t_{cr} = 600 \text{ s}$$

With the duration time for CRDP is equal to the time critical. Thus, the drying rate in FRDP can be determined by the equation below. First, determine the free moisture content;

With,

$$X_{EA} = \frac{(0.3-0.29)}{0.29} = 0.0345 \text{ kg/kg}$$

Thus,

$$F = 0.0345 – 0 = 0.0345 \text{ kg/kg}$$

Then, determine the critical free moisture content;

$$F_{cr} = 0.1724 – 0 = 0.1724 \text{ kg/kg}$$

Therefore, the duration time for FRDP is;

$$T_{FRDP} = \frac{W_d}{A\,(1-n)} \frac{Fcr^n}{NCRDP} \left[F^{(1-n)} - Fcr^{(1-n)}\right]$$

$$= \frac{0.29}{0.2105\,(1-0.8)} \frac{0.1724^{0.8}}{8.71E-04} \left[0.0345^{(1-0.8)} - 0.1724^{(1-0.8)}\right]$$

$$= 375.30 \text{ s}$$

SMER is calculated by the following equation;

$$SMER = \frac{X}{[\dot{m}air \;\; Cpair \; (Tout - Tin) x \; Win \,]}$$

$$= \frac{0.29}{[\,0.0774 \times 1.005 \; (\,319.9 - 303.6) \times 2.654\,]}$$

$$= 0.086$$

And the drying rate is;

$$DR = \frac{X}{DT}$$

$$= \frac{0.16}{\left(\frac{50}{60}\right)}$$

$$= \; 0.192 \; kg/h$$

4.3 DESCRIPTION OF THE DATA FLOW

Computational fluid dynamic analysis for the design was determined by using Solidwork Flow Simulation. Solidwork Flow Simulation combined a high level of functionality and accuracy with ease-of-use. Solidwork Flow Simulation can be used in a diverse array of applications and has been designed to be extremely flexible. Proceeding to the flow simulation, actual data for the air conditioning is very important. So, the result from Table 4.8 has before been used for further developments in flow simulation.

4.3.1 Example Analysis Step by Solidwork Flow Simulation

Solidwork flow simulation is fully integrated within Solidwork 3D CAD software so that every designer can get the benefits of flow simulation at any stage of product development to design with better insight. The flow of heat or air inside all cabinet design and animate the streamlines to see the movement of the airflow can utilized by using Solidwork Flow Simulation. The analysis by Solidwork Flow Simulation will determine a better design with a good performance of the airflow and distribution of the heat. The steps of analysis by using Solidwork Flow Simulation are described below:

a) Open the Solidwork Model

- Click File, Open, Browse to Concept B asem 1c. SLDASM and click Open.
- Solidwork Flow Simulation can only analyze fluid flow in a fully enclosed volume that includes at least one inlet and one outlet. Before analyzing the flow, close all the model openings by adding lids.
- Click Insert, Component, New Part. Select the face and click convert entities. Select the edge to extrude then click  . Click Extruded Boss/Base. Under Direction 1, chose the mid plane and set depth 10 mm then click  as shown in Figure 4.1 below.

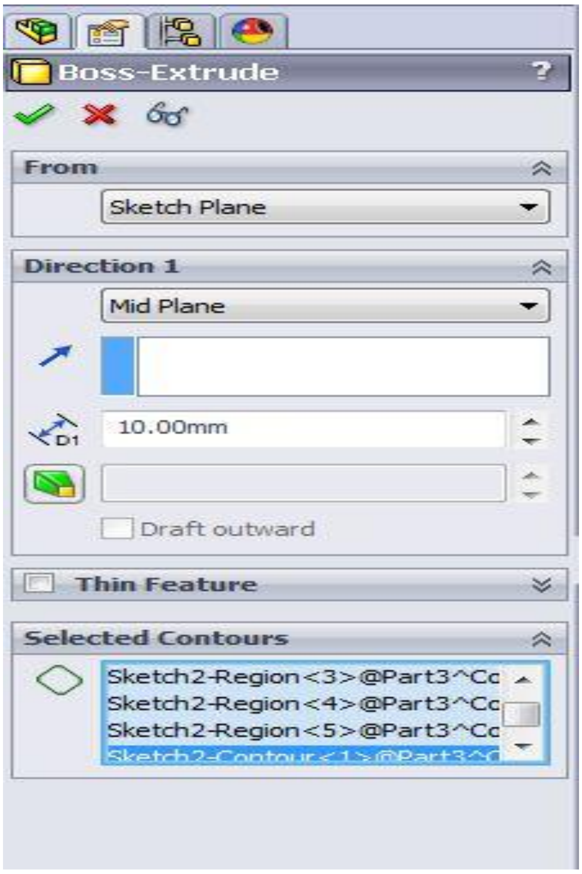


Figure 4.1: Extruded Boss/Base

b) Check Geometry

- To ensure the model is fully closed, click Flow Simulation, Tools, and Check Geometry as shown in Figure 4.2.
- Click Check to calculate the fluid volume of the model. If the fluid volume is equal to zero, the model is not closed.

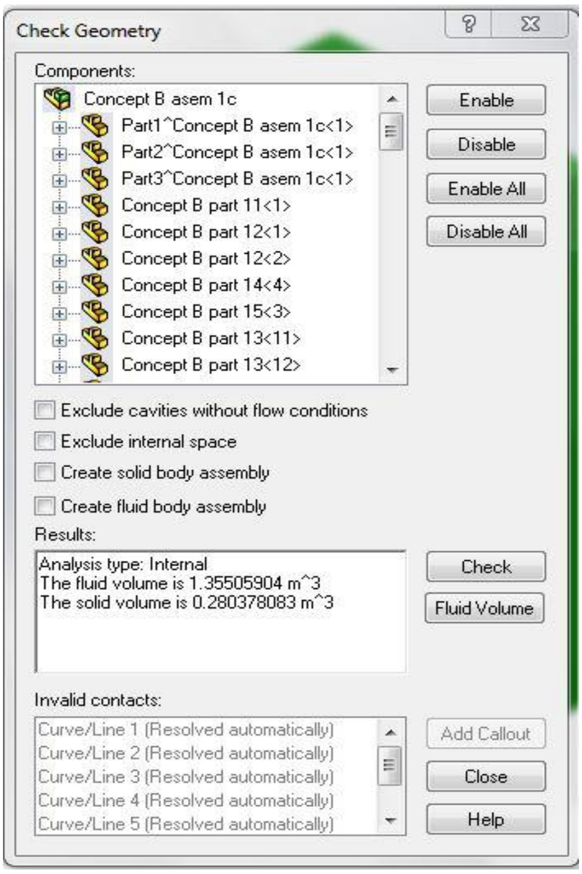


Figure 4.2: Check Geometry

c) Create Flow Simulation Project

- Click Flow Simulation, Project, Wizard.
- Once inside the Wizard, select Create new in order to create a new configuration and name it Design B. Click Next (Figure 4.3).

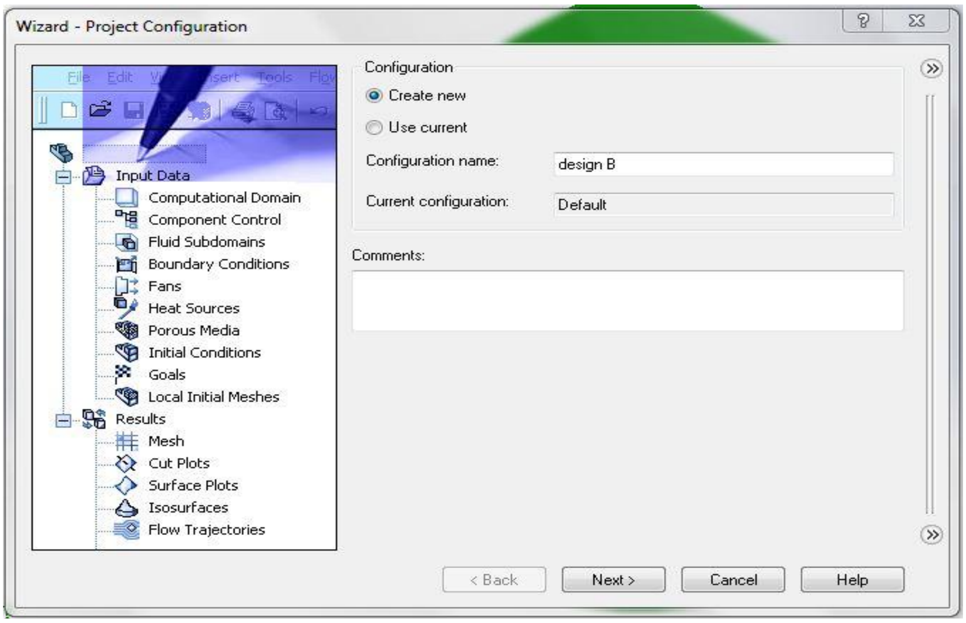


Figure 4.3: Wizard – Project Configuration

- Choose the system of units (NMM (mm-g-s)). For the velocity entry, change to m/s. Click Next.
- Leave the default internal analysis type. Do not include any physical features. Click Next.
- In the Fluids tree expand the Gases item and choose Air as the fluid. Can either double-click Air or select the item in the tree and click Add. In the Flow Characteristic click at the humidity. Click Next.
- Click Next accepts the default wall conditions.
- Change the temperature to 46.9 °C for the initial conditions. Click Next
- Accept the default for the Result Resolution.
- Click Finish.

d) Now flow simulation creates a new configuration with flow simulation data.

- Go to Flow Simulation Analysis Tree and open all the icons.
- Right-click the Computational Domain icon and select Hide to hide the black wireframe box (Figure 4.4).

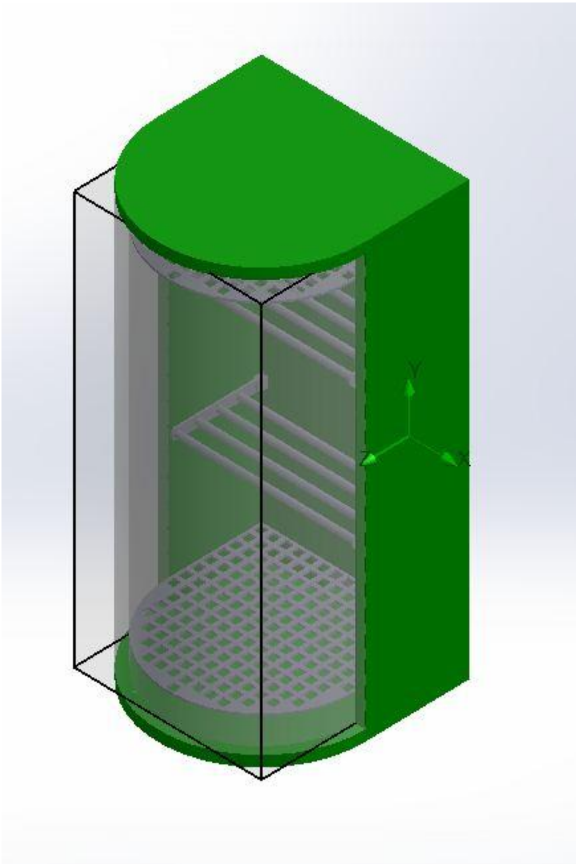


Figure 4.4: Black wireframe box

e) Boundary Conditions

- In the Flow Simulation Analysis Tree, right-click the Boundary Conditions icon and select Insert Boundary Condition.
- Select the inner face of the inlet. Select Flow Openings and Inlet Mass Flow. Set the $\dot{m}$ to 0.0774 kg/s.
- Click OK  . The new Inlet Mass Flow 1 item appears in the Flow Simulation Analysis Tree (Figure 4.5).

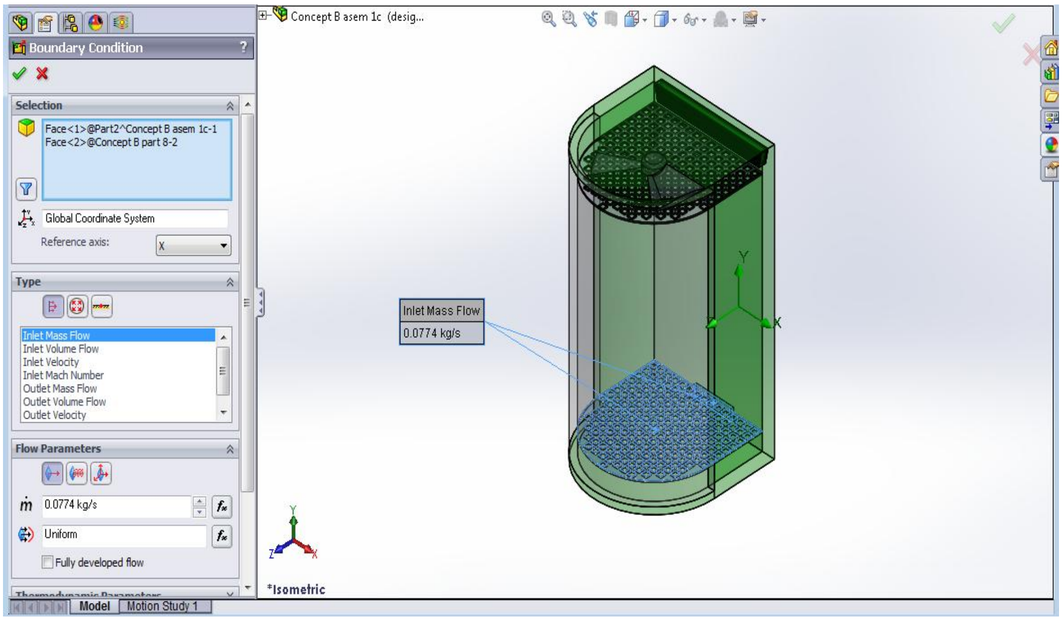


Figure 4.5: Inlet Velocity 1

- Select the inner face of the outlet. In the Flow Simulation Analysis Tree, right-click the Boundary Conditions icon and select Insert Boundary Condition.
- Select Pressure Openings and Static Pressure. Keep the default in Thermodynamic Parameters, Turbulence Parameters, Boundary Layer and Options group boxes.
- Click OK  . The new Static Pressure 1 item appears in the Flow Simulation Analysis Tree (Figure 4.6).

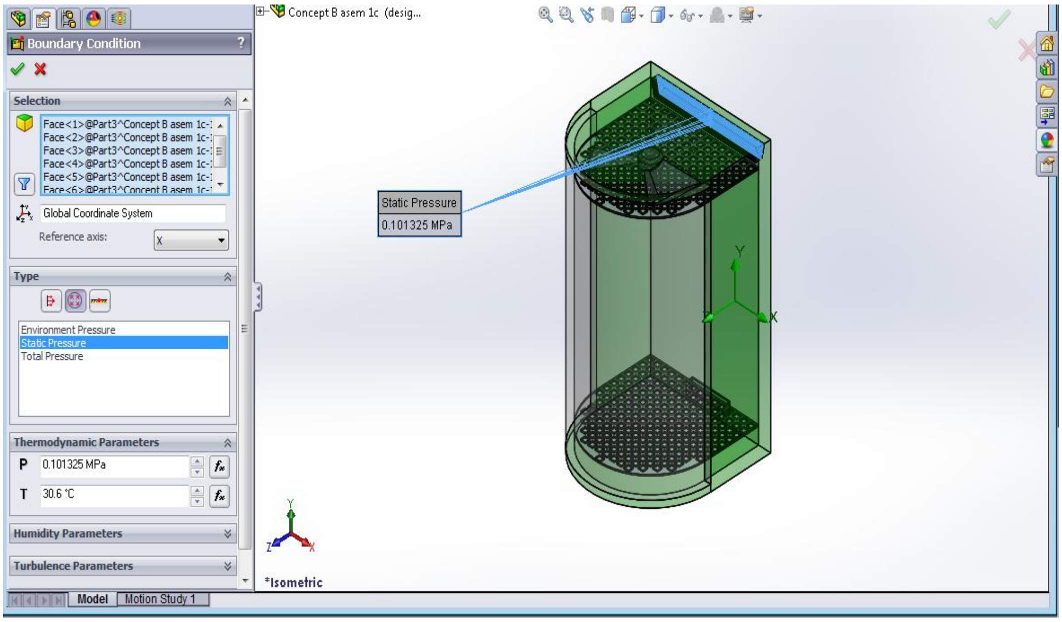


Figure 4.6: Static Pressure 1

- In the Flow Simulation Analysis Tree, right-click the Boundary Conditions icon and select Insert Boundary Condition.
- Select all inner wall design. Select Wall and Real Wall. Click OK . The new Real Wall 1 item appears in the Flow Simulation Analysis tree (Figure 4.7).

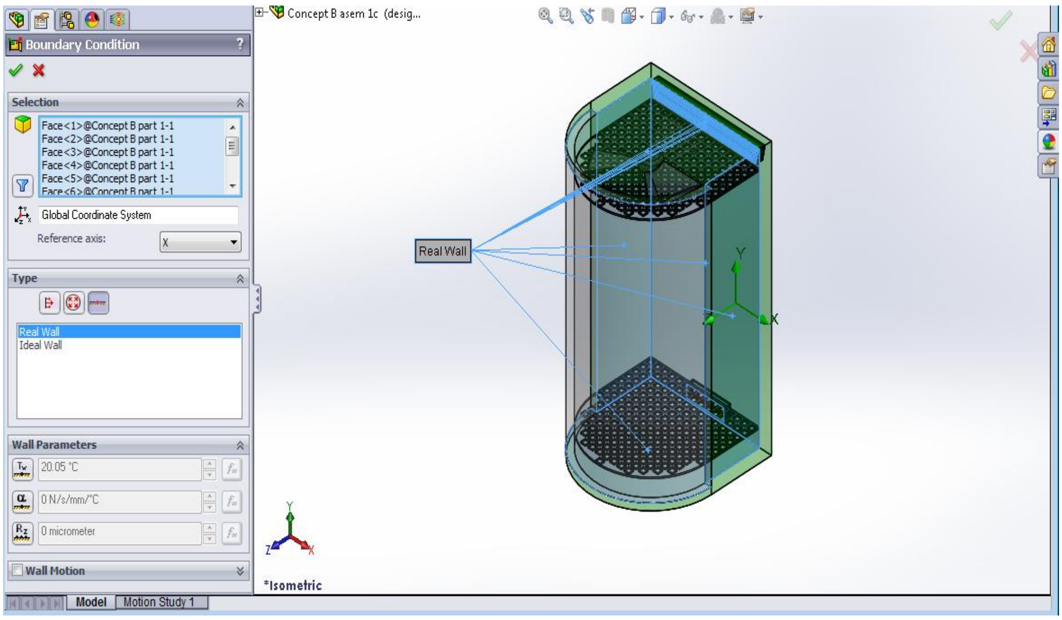


Figure 4.7: Real Wall 1

f) Define the engineering goal.

- Right-click the Flow Simulation Analysis Tree Goals icon and select Insert Surface Goals.
- Click the Flow Simulation Analysis Tree tab and click the Inlet Mass Flow 1 item to select the face where it is going to be applied.
- In the Parameter table select the Av check box in the Static Pressure row. Already Use for Conv. (Use for Convergence Control) check box means that the created goal will be used for convergence control.
- Click OK. The new SG Av Static Pressure 1 item appears in the Flow Simulation Analysis Tree (Figure 4.8 and 4.9).

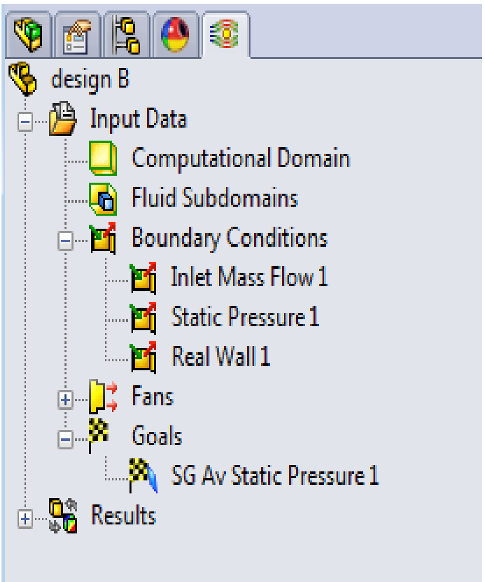


Figure 4.8: SG Av Static Pressure 1

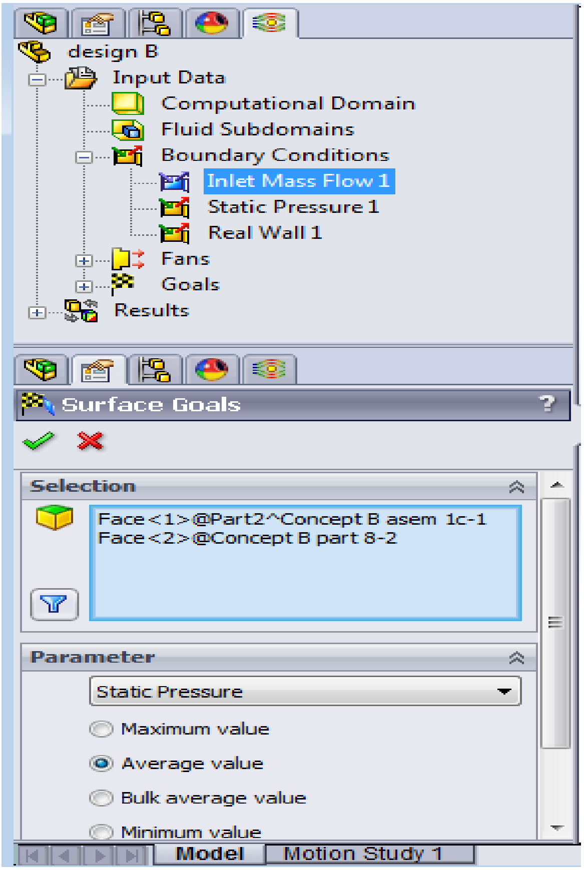


Figure 4.9: Surface Goals

g) Define the Fan

- Click Flow Simulation, Insert, Fan. The Fan dialog box appears (Figure 4.10).
- Select Internal Fan as fan type. If the fan is on the outside, can select external inlet of outlet fan.
- Select the face of the fan as faces fluid exits the fan and faces the fluid enters the fan.
- In the Fan list select the Papst 412 items (description for fan) under Pre-Defined, Axial, Papst.
- Under Thermodynamic Parameters check that the Ambient Pressure is the atmospheric pressure.
- Click OK  . The newest Fans folder and the Internal Fan item appear in the Flow Simulation Analysis tree.

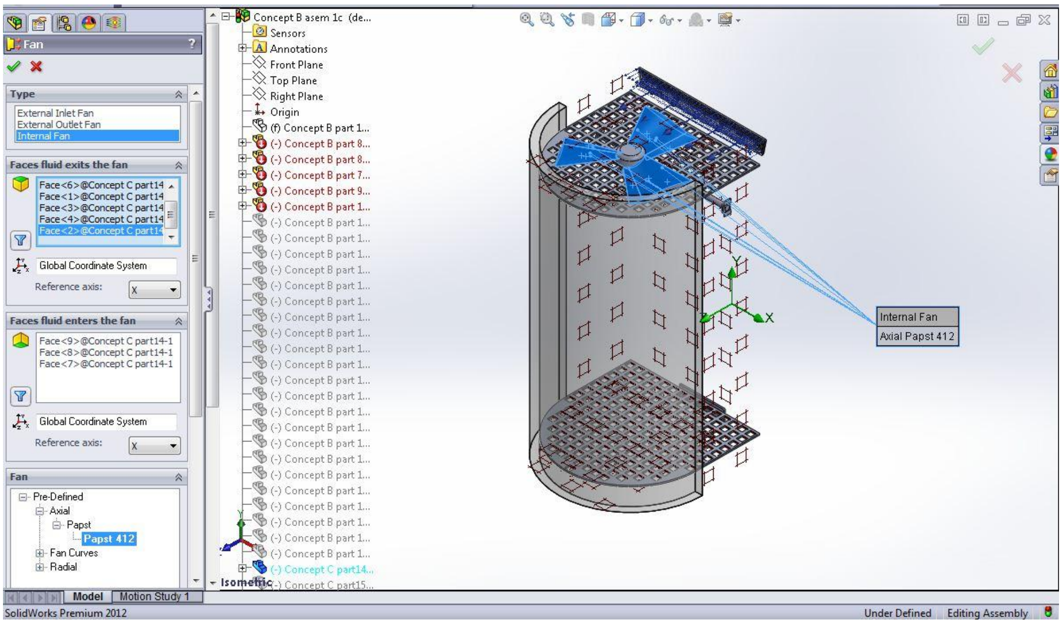


Figure 4.10: Internal Fan

h) Changing the geometry resolution

- Click Flow Simulation, Initial Mesh (Figure 4.11).
- Select the Manual specification of the minimum gap size check box
- Enter 20 mm for the Minimum gap size.

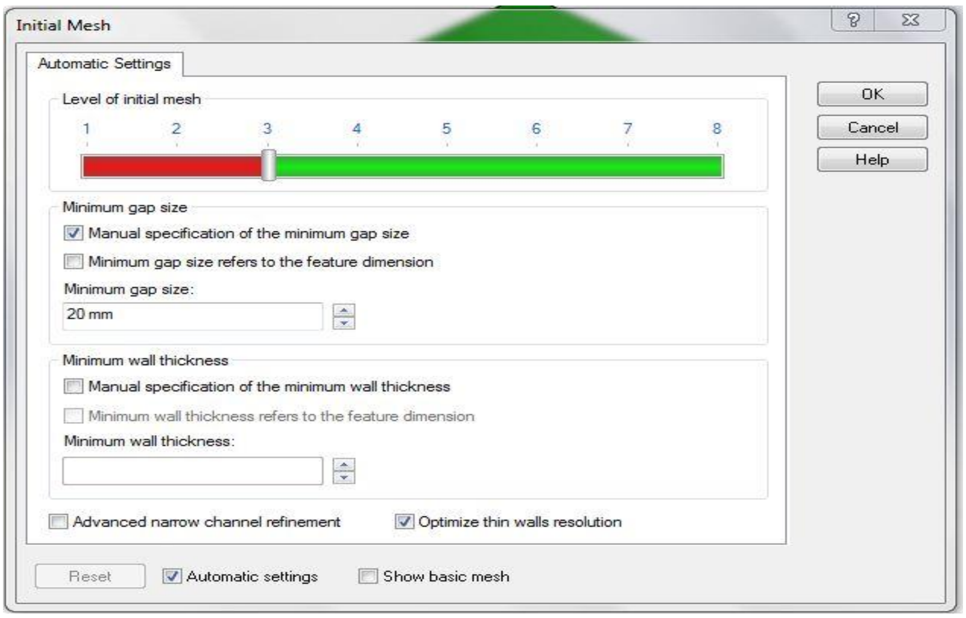


Figure 4.11: Initial Mesh

i) Solution

- Click Flow Simulation, Solve, Run.
- Click Run (Figure 4.12).

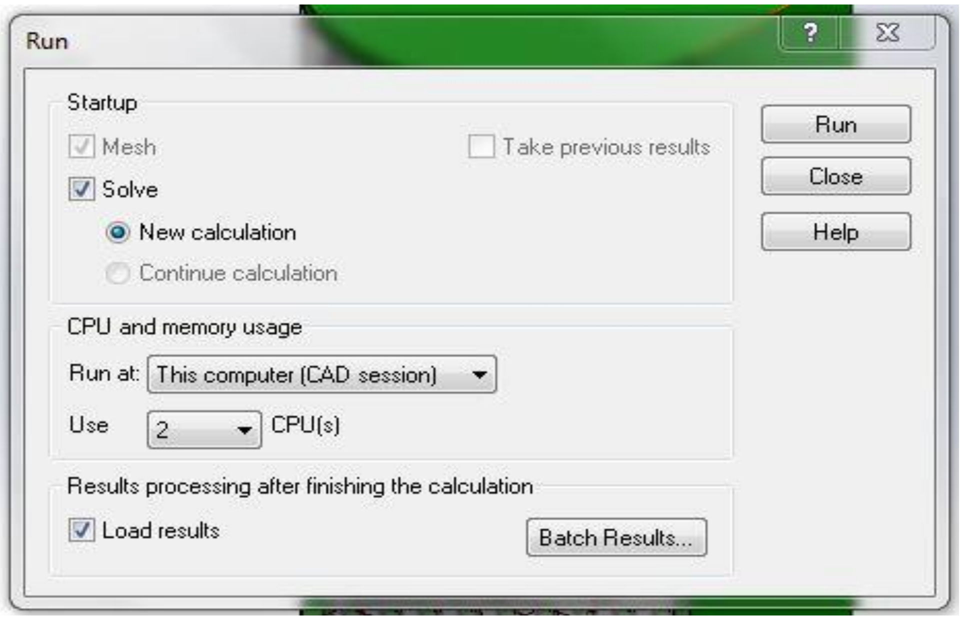


Figure 4.12: Run

- When the solver is finished, close the monitor by clicking File, Close. The solver takes about twenty to thirty minutes to run on the analysis (Figure 4.13).

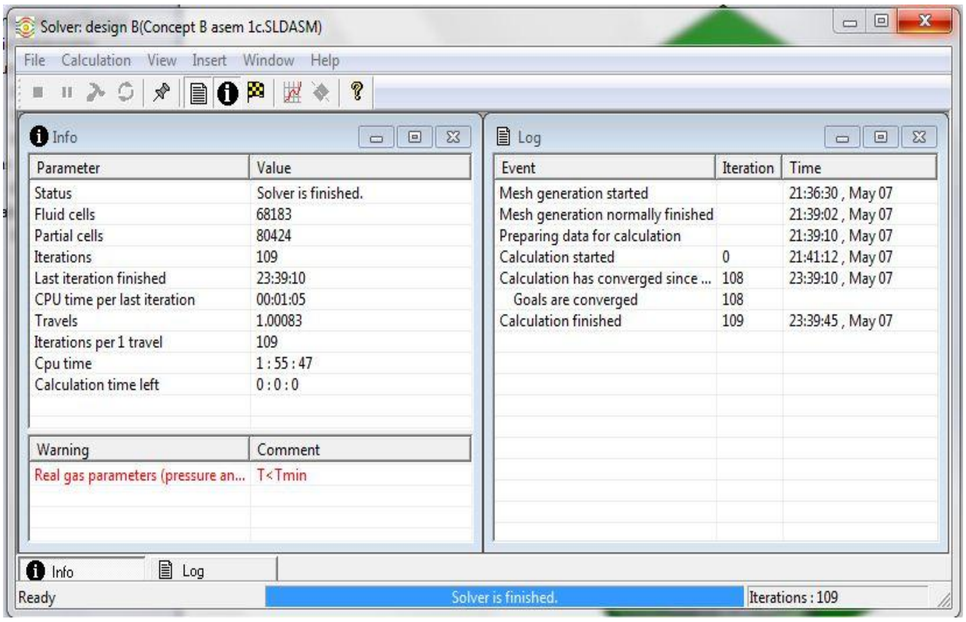


Figure 4.13: Solver Monitor

j) Adjust Model Transparency

- Click Flow Simulation, Results, Display, Transparency and sets the model transparency to 0.75 (Figure 4.14). Click OK.

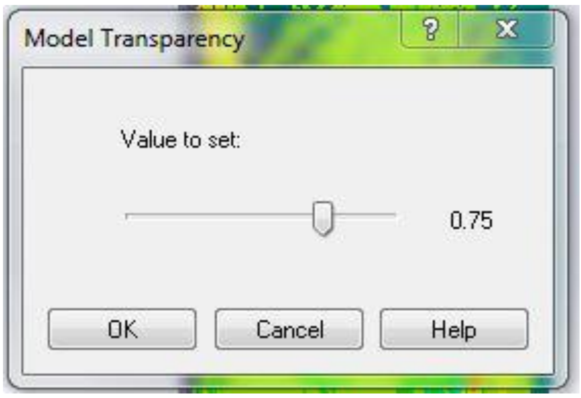


Figure 4.14: Model Transparency

k) Surface Plots

- In the Flow Simulation Analysis tree, right-click Surface Plot icon and select Insert.

- Select the Use all faces check box.
- Click OK and get the result.

l) Flow Trajectory Plots

- Right-click the Surface Plot 1 icon and select Hide.
- Right-click the Flow Trajectories icon and select Insert.
- Click the Flow Simulation Analysis Tree tab and then click the Inlet Velocity 1 as the Starting Points.
- Set the Number of Trajectories to 100.
- Click OK and get the result.

m) XY Plots

- Sketch a line in the middle of the design of the inlet to the outlet.
- Right-click the Flow Trajectories 1 icon and select Hide.
- Right-click the XY Plots icon and select Insert.
- Choose Velocity and Temperature as physical Parameters. Select Sketch 1 from the flyout Feature Manager Design tree. Leave all other options as defaults.
- Click OK . MS Excel will open and generate two columns of data points together with two charts for Velocity and Temperature respectively and get the result.

n) Lastly the Flow Simulation Analysis Tree will show like the Figure 4.15 above.

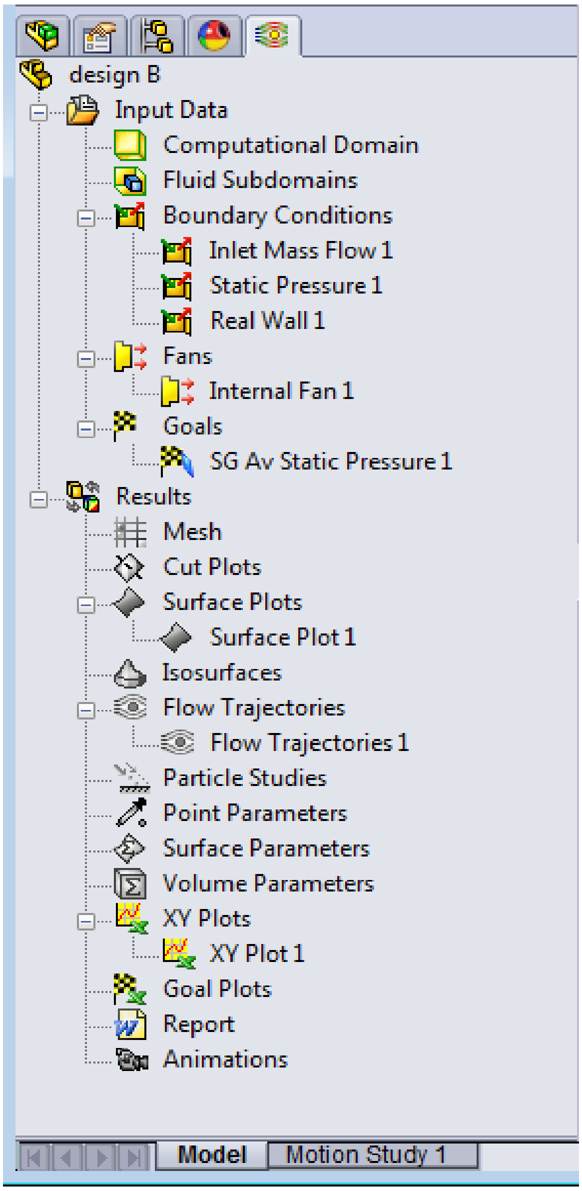


Figure 4.15: Flow Simulation Analysis Tree

4.3.2 Distribution of Heat in All Concepts

Figure 4.16 to 4.19 show the simulation of the result from the distribution of heat in the entire surface for all concepts. The results show that all concepts are equally distributing the heat. This is due to the assistance of the stabilizer that exhibits a unique honeycomb structure made of polypropylene.

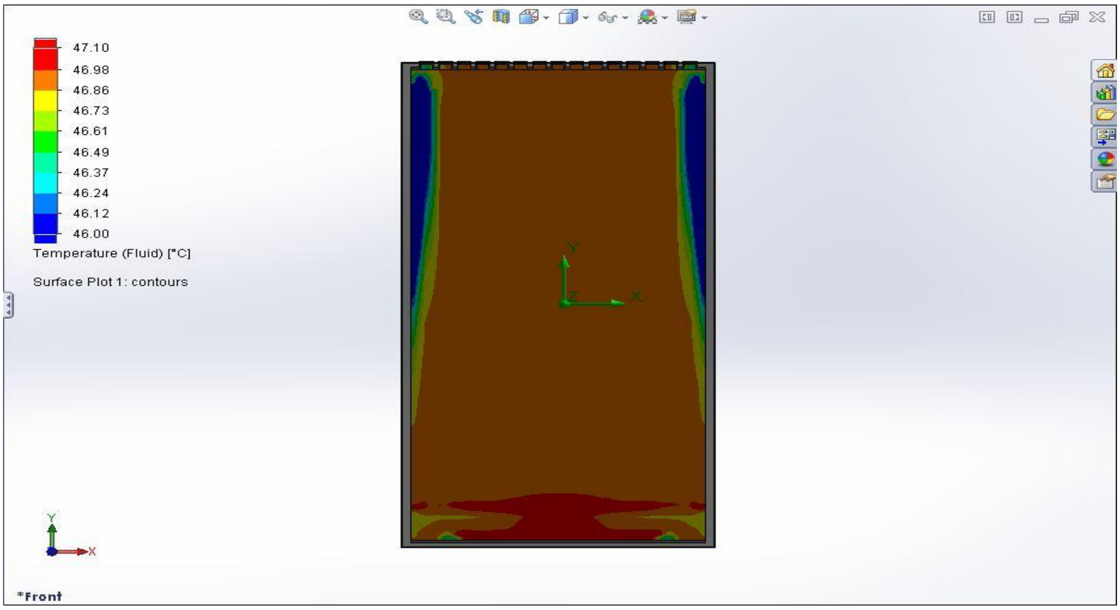


Figure 4.16: Distribution of heat in concept A

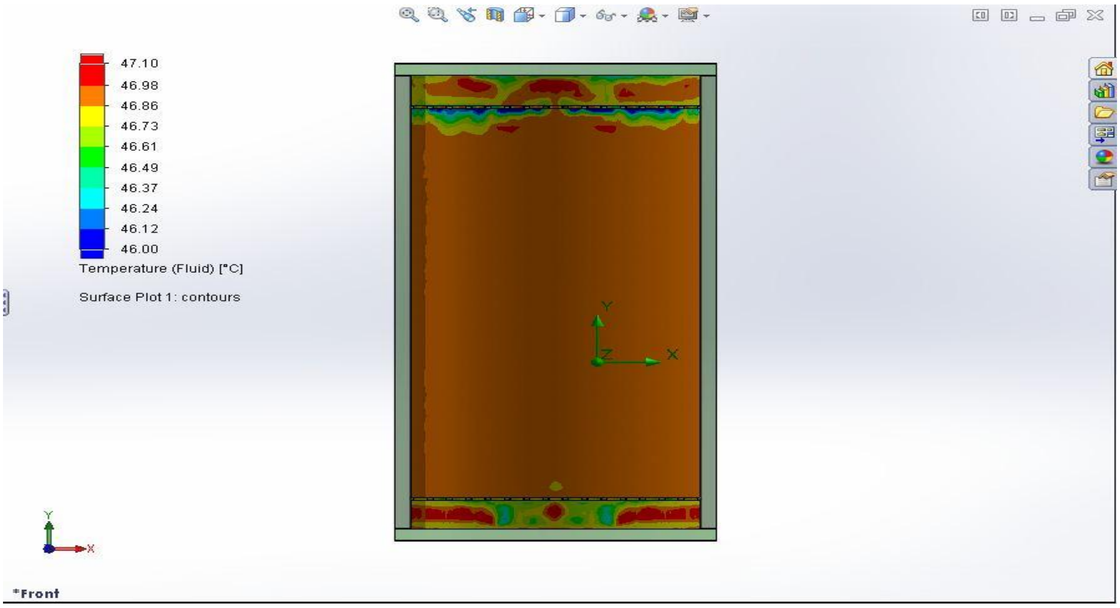


Figure 4.17: Distribution of heat in concept B

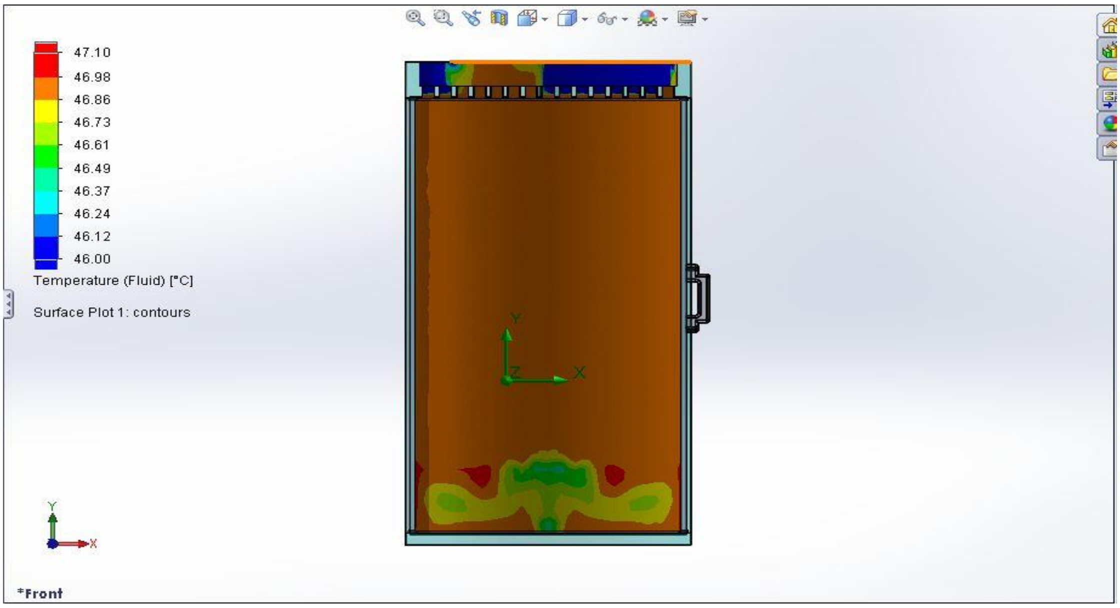


Figure 4.18: Distribution of heat in concept C

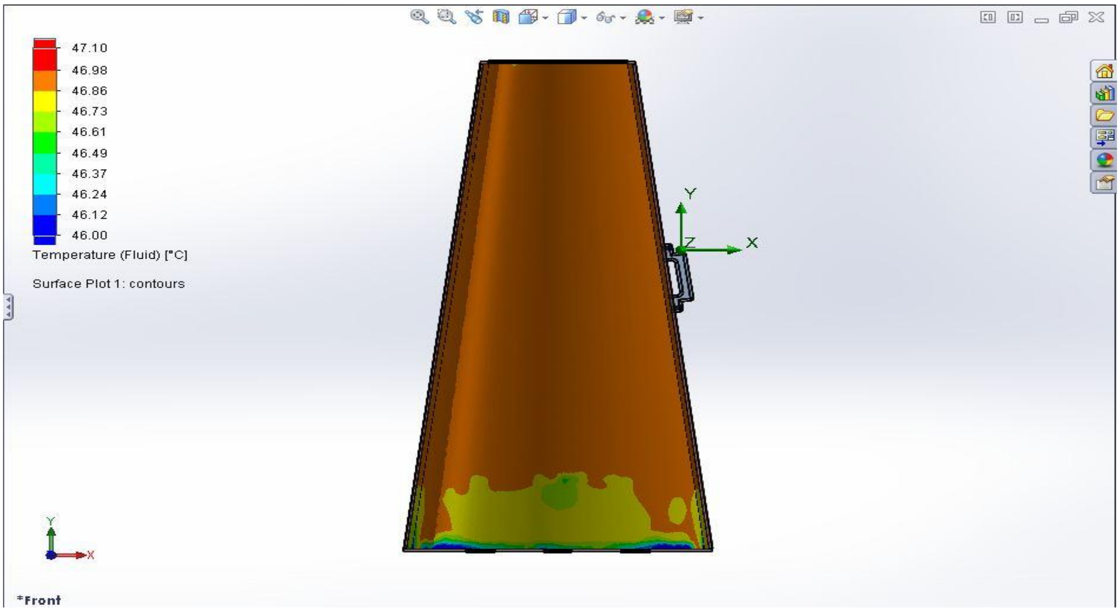


Figure 4.19: Distribution of heat in concept D

4.3.3 Air Flow Simulation for Temperature

Figure 4.20 to 4.23 show the simulation of the result from the air flow for temperature for all concepts. The results show that for all concepts the maximum air flow for temperature is from concept A, then followed by concept D, next concept B, and the minimum air flow for temperature is concept C.

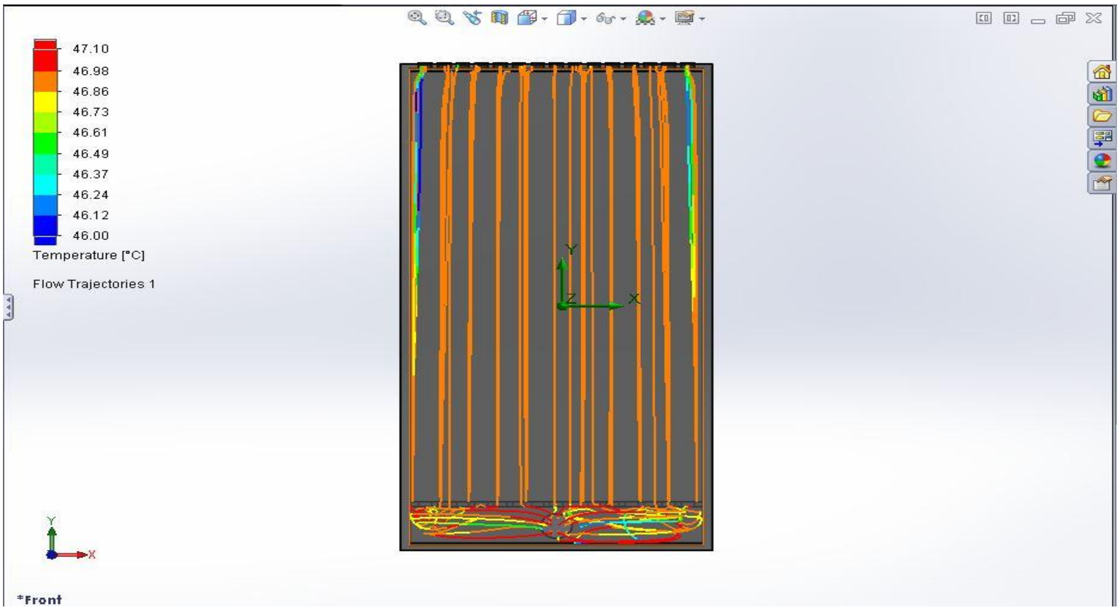


Figure 4.20: Temperature air flow simulation for concept A

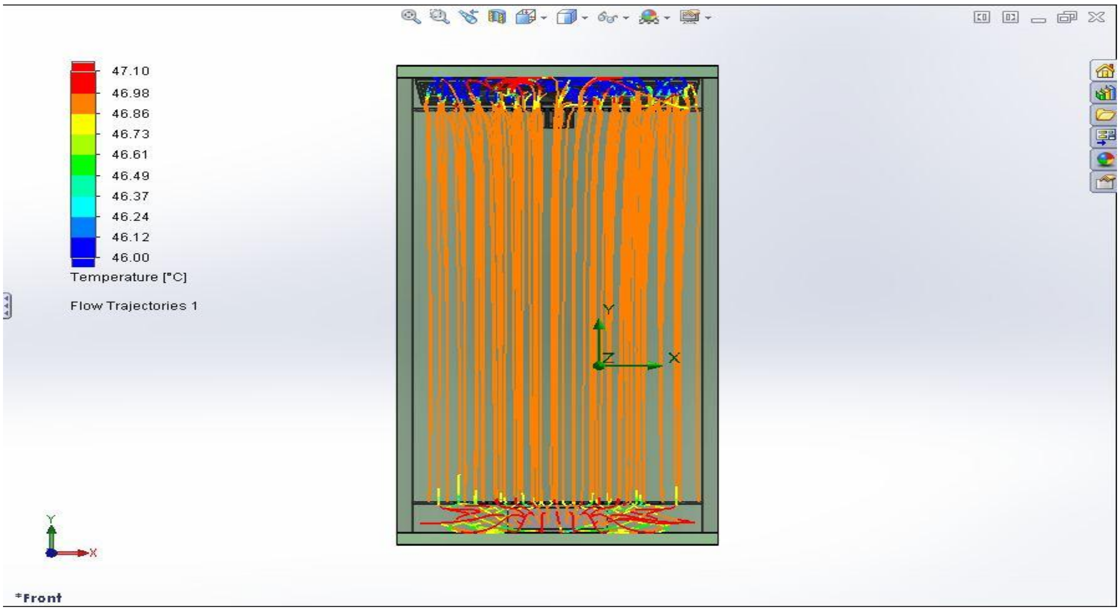


Figure 4.21: Temperature air flow simulation for concept B

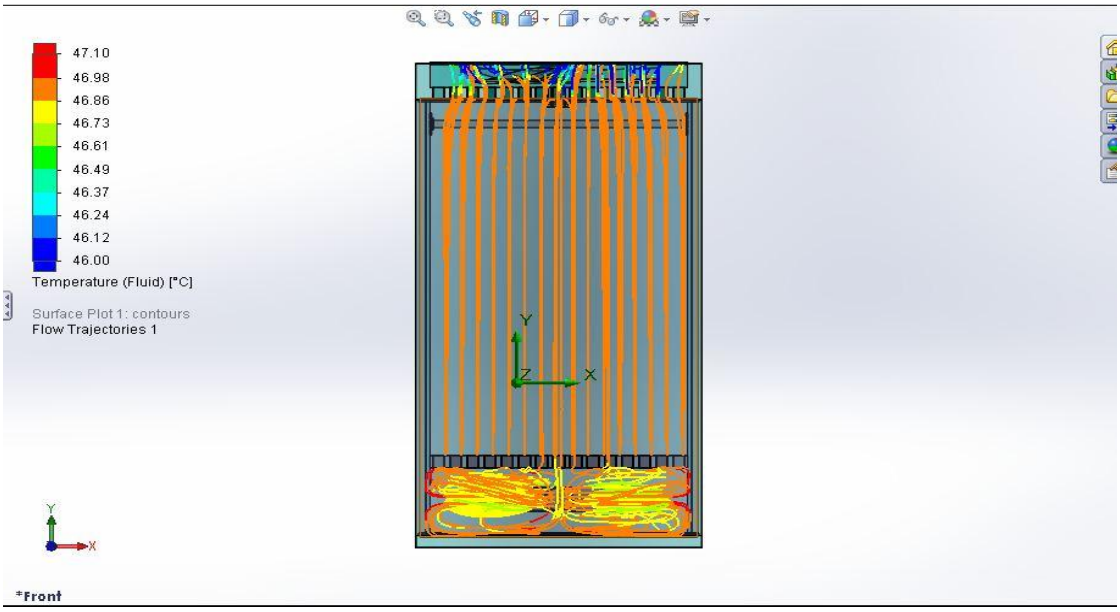


Figure 4.22: Temperature air flow simulation for concept C

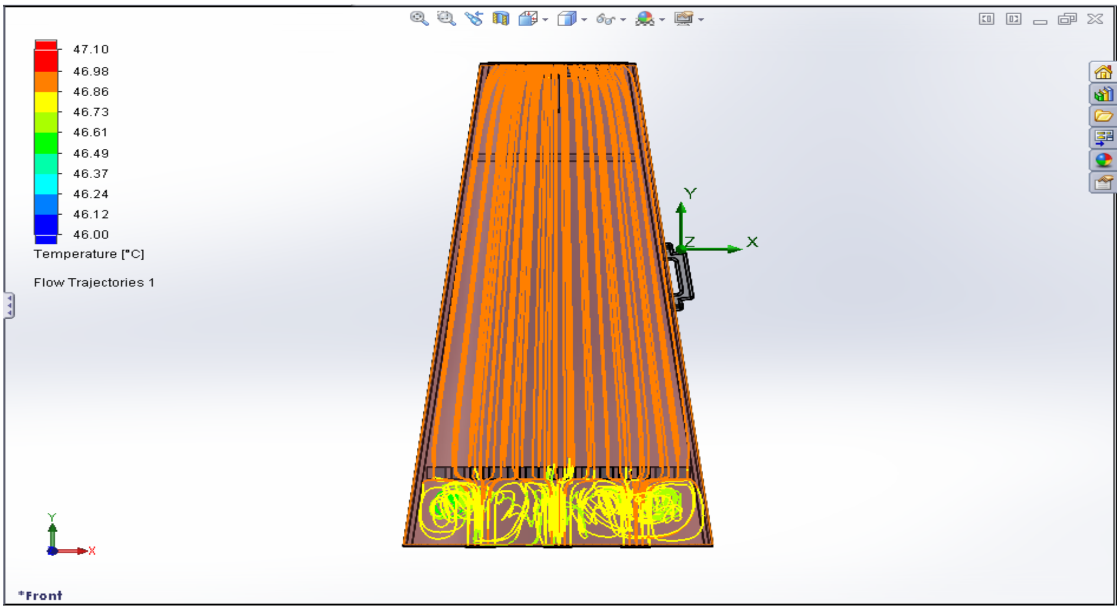


Figure 4.23: Temperature air flow simulation for concept D

4.3.4 Air Flow Simulation for Velocity

Figure 4.24 to 4.27 show the simulation of the result from the air flow for velocity for all concepts. The results show that for all concepts the maximum air flow for velocity is from concept D, then followed the air flow for velocity are concept A, next is concept C, and the minimum air flow for velocity is concept B.

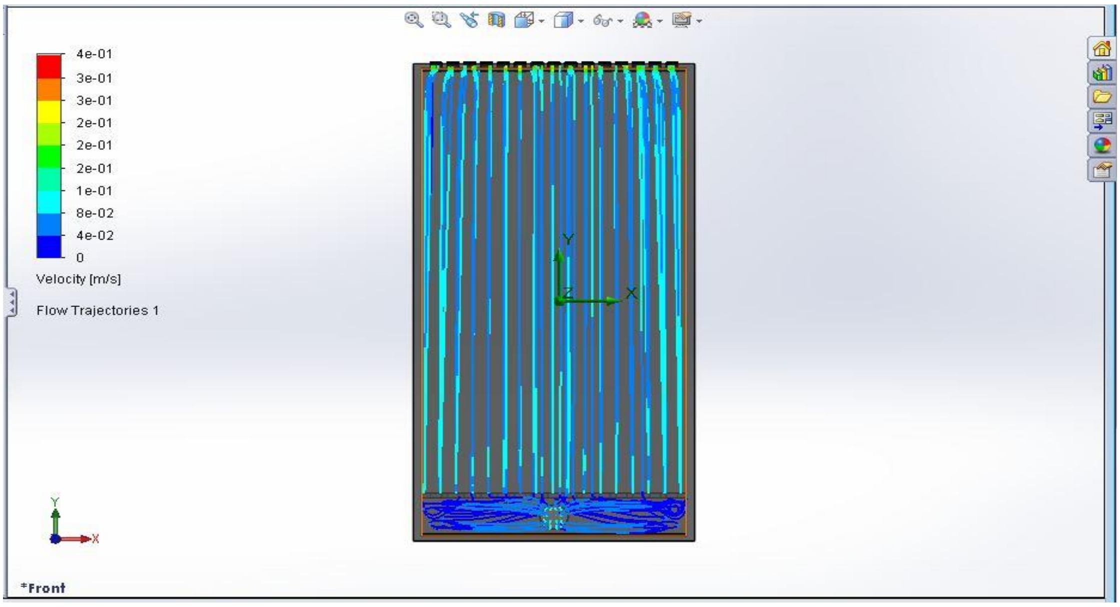


Figure 4.24: Velocity air flow simulation for concept A

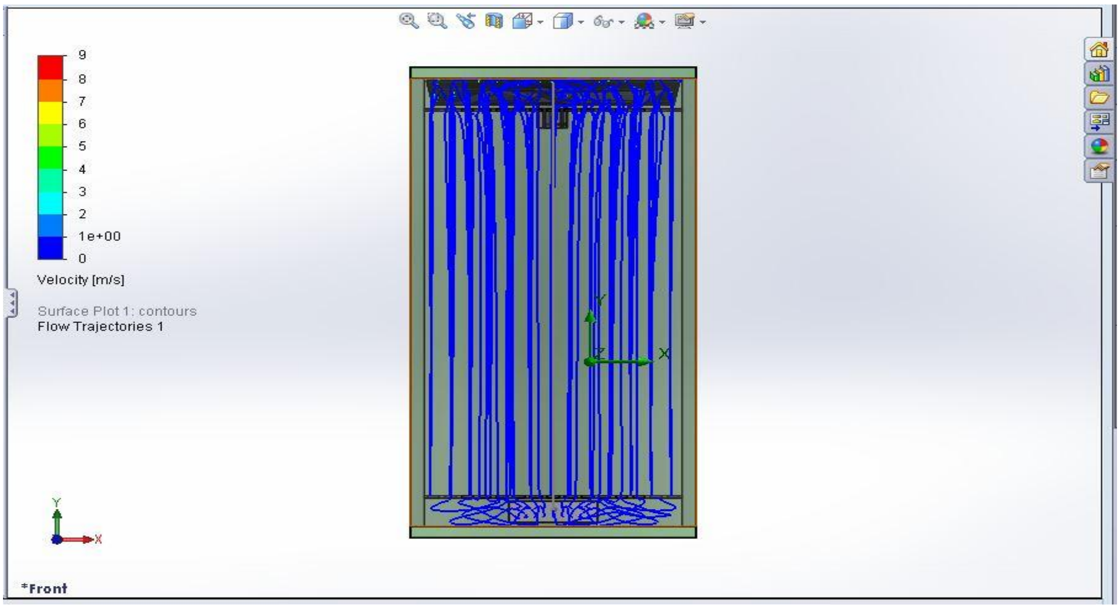


Figure 4.25: Velocity air flow simulation for concept B

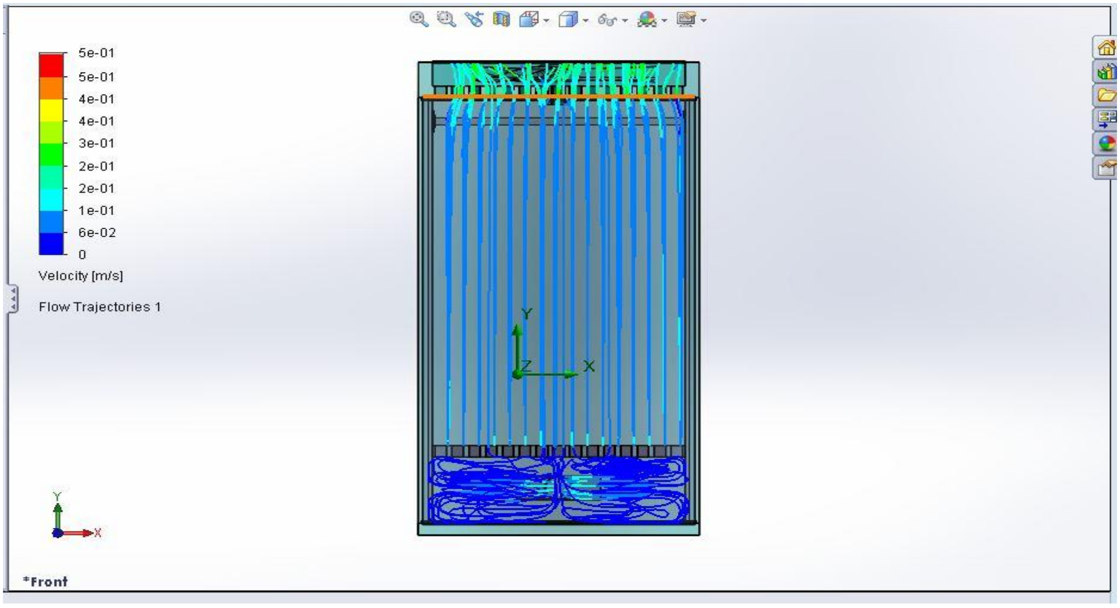


Figure 4.26: Velocity air flow simulation for concept C

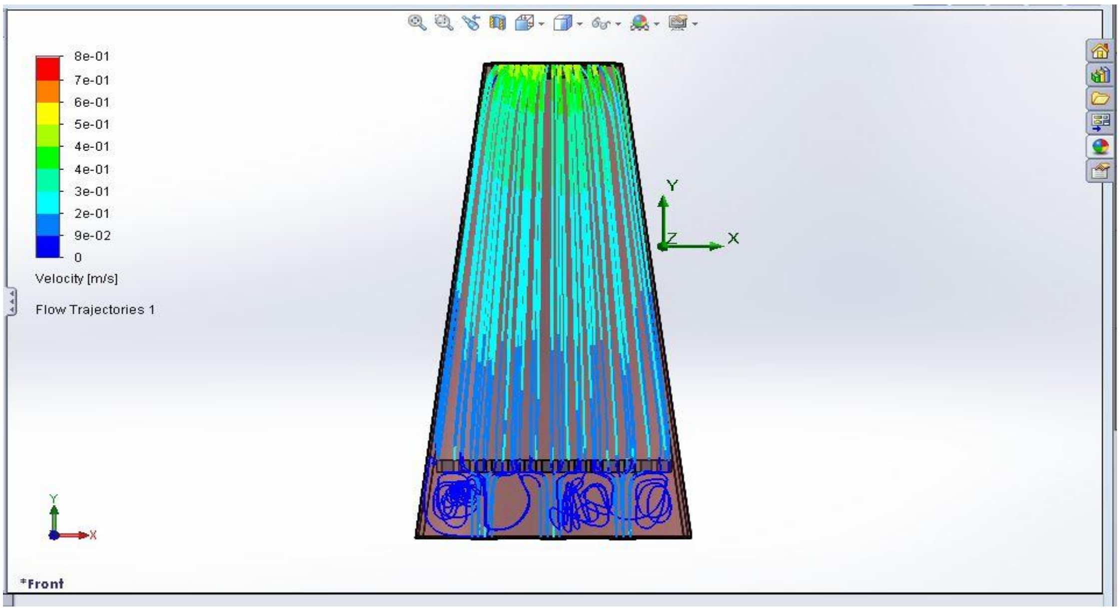


Figure 4.27: Velocity air flow simulation for concept D

4.3.5 Graph Velocity Versus Length of the Cabinet

Figure 4.28 shows the simulation graph of velocity versus the length of cabinet for all concepts. The results show that for all concepts the maximum velocity if from concept D, followed concept A, concept C and the minimum velocity is concept B.

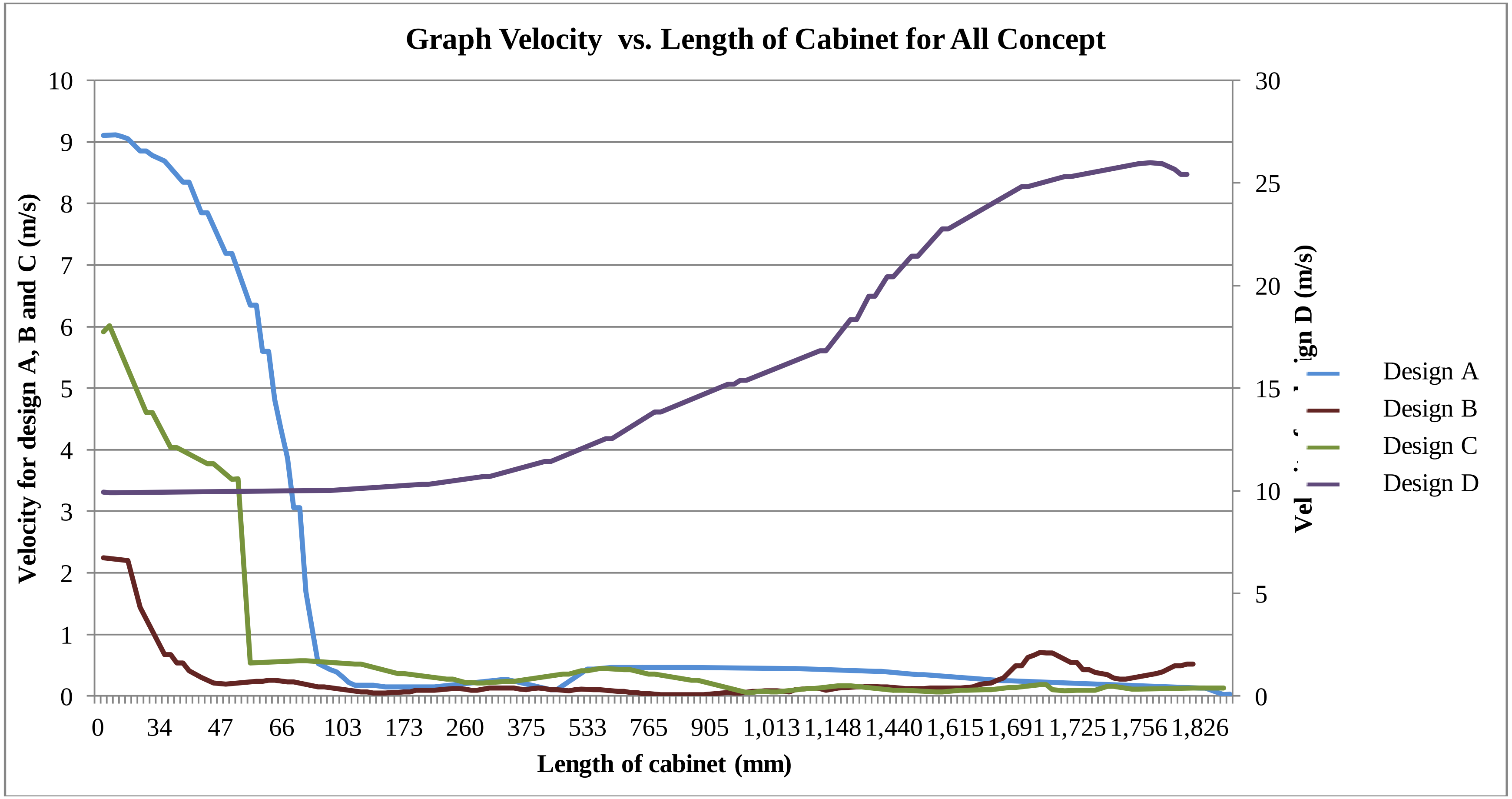


Figure 4.28: Graph velocity vs. length of cabinet for all concepts

4.4 DISCUSSION

After describing the result of the study, in this section it will discuss the result. In relation with the result of the study, the discussion is divided into two parts as follows;

4.4.1 Summary of Prerequisite Testing which Comprises Natural Drying and Heat Waste Drying

Summary of prerequisite testing which comprises natural drying and heat waste drying can be shown in Table 4.11. Table 4.11 shows that the maximum drying rate is from the heat utilizing from air conditioning, then followed by outdoor drying, indoor midday drying and the minimum drying rate is from indoor night drying case. Therefore, the value for drying rate is also accorded the sequence above which is 0.192 kg/h, followed 0.060 kg/h, 0.040 kg/h and 0.023 kg/h and the value for drying rate in constant-rate period is also same with 8.71 $x10^{-4}$ kg/s m^2, followed 5.54 $x10^{-4}$ kg/s m^2, 3.43 $x10^{-4}$ kg/s m^2, and 1.72 $x10^{-4}$ kg/s m^2. This is because it depends for the time the clothes get dry.

For example, indoor night drying much more take time for drying than the other case. The moisture of the clothes is durable to remove because of the low temperature of surroundings at night compared with the temperature in midday. That is the reason why the indoor night has a lower drying rate than the other case. The energy used to evaporate the water also influences the data. In other words, the higher the temperature around the clothes, the more energy that can be used to evaporate the water and the clothes can be dried faster.

For example, by using heat waste from the air conditioning and outdoor drying case which the heat is more hot that surrounding temperature, the clothes are faster in drying. That is why, the time taken for drying weight are smaller than the other case which the different time taken are 10 minutes than 30 minutes for the other two cases. Moreover, the clothes drying also depend on the area that exposed to the heat or hot surrounding temperature. The high disposed area, the high potential to dry faster. All the parameter can be proved by using the equation (2.5) until (2.17) where the area is inversely proportional to the drying rate or the time and the time inversely proportional to the drying rate.

4.4.2 Summary of Description of Data Flow to All Concept

Figure 4.16 until Figure 4.19 shows graphically the description of the data flow in all concepts. Figure 4.20 until Figure 4.23 shows the simulation of the result from the air flow for temperature of all concepts meanwhile Figure 4.24 to Figure 4.27 shows the simulation of the result of the air flow velocity for all concepts. Besides that, the result from air flow simulation for temperature shows that the maximum is from concept A and the minimum is concept C. While the result from air flow simulation for velocity shows that the maximum is from concept D and the minimum is concept B.

In addition, the same heat distribution shows that all the clothes can be dried by drying evenly. The line with the red color shows good result for temperature and velocity. Although the concept B shows another color line but the temperature is the same as the other design because the value of red color are higher than other concepts. Figure 4.28 shows that the graph of velocity versus length of cabinet for all concepts. Some calculations have been done to identify the maximum and minimum velocity of the graph. From the calculated results, concept D shows the maximum velocity with the value is 18.15 m/s, followed by concept A (2.88 m/s), concept C (0.89 m/s), and minimum velocity is from concept B with the value is 0.26 m/s. The calculations are based on the average of the velocity.

Lastly, all concepts goes for evaluation of the performance. So the concept B is chosen to be the better performance concept in the simulation of the distribution of heat and, for the temperature and velocity air flow. The reason is, the slower the velocity of air flow, the higher the temperature gains because the velocity is inversely proportional to the temperature.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, the author presents her conclusion and in the following sections, she put forward the recommendation.

5.2 CONCLUSION

Based on the previous chapter, some conclusions that can be drawn are cabinet dryer with the better performance of the flow and distribution of the heat by using stabilizer is from the concept B. Moreover, the score from the Pugh Concept is also helping in the chosen better concept. Therefore, the design of the clothes dryer machine using heat waste from the air conditioning that chosen can be used as the other alternative to dry the clothes. The design has been considerate on the economic, ergonomic, environmentally friendly and the other concept criteria evaluation of the Pugh Concept of analysis. There are also have energy efficient and less power consumption went the distribution of the heat and the performance of the air flow of the concept can improve the use of the electric cloth dryer machine to use the concept of utilizing the heat source from the air conditioning as the one of the sustainable energy resources. Switching to energy saving solutions is the answer for reducing costs and the impacts of the energy sector on the environment. There are also to improve competitiveness of products and services in the global market. Anyway, future effort is required to improve the concept and to provide verification using more experimental data.

5.3 RECOMMENDATION

After coming to some conclusions, in this section the writer proposes some recommendations as follows:

1. Improve the design with the controlling program such as auto extra dry, auto dry, warm towels, start and stop button and etc.
2. Safety precaution for the design also need to consider such as when open the door, the dryer cabinet will then stop automatically and can manually start or stop button.
3. Improve the safety of the design by place a sensor that can detect the change in temperature when the dryer start to prevent the clothes dryer fires.
4. Fresh, dry desiccant can always presented to the process air flow by using fan at the inlet and the outlet of the cabinet.
5. The dryer must be designed with suitable material to minimize damage when accidents occur.
6. Study the effect which might occur if the cabinet dryer utilize the heat from the conditioner.
7. One way to improve the energy efficiency in the cabinets is to optimize the size of the inlet hole to increase the heat flow into the cabinet.
8. Ascertaining the optimum position of the partition around the condensing unit for directing hot air towards the hung clothes before leaving the chamber.
9. Create a piping system in the inlet and outlet hole with portable for any position of condensing unit to prevent the heat from entering the house.
10. Further measurements can be carried out in the cabinet with the potential to validate the simulation software to identify the appropriate technology and design prototypes to confirm viability.
11. Improve the simulation by simulating the design with the cloth hanging inside the cabinet to get a better design.
12. Additional research work is necessary to resolve several advanced technical and environmental issues before heat waste energy can become a real sustainable energy source in the future.

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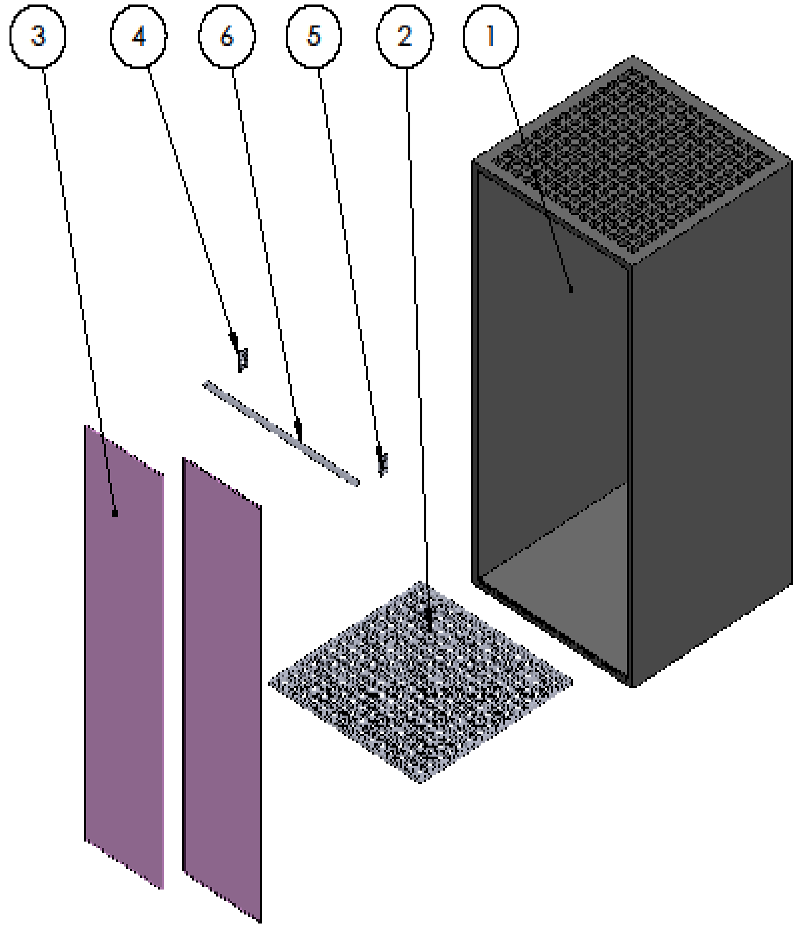
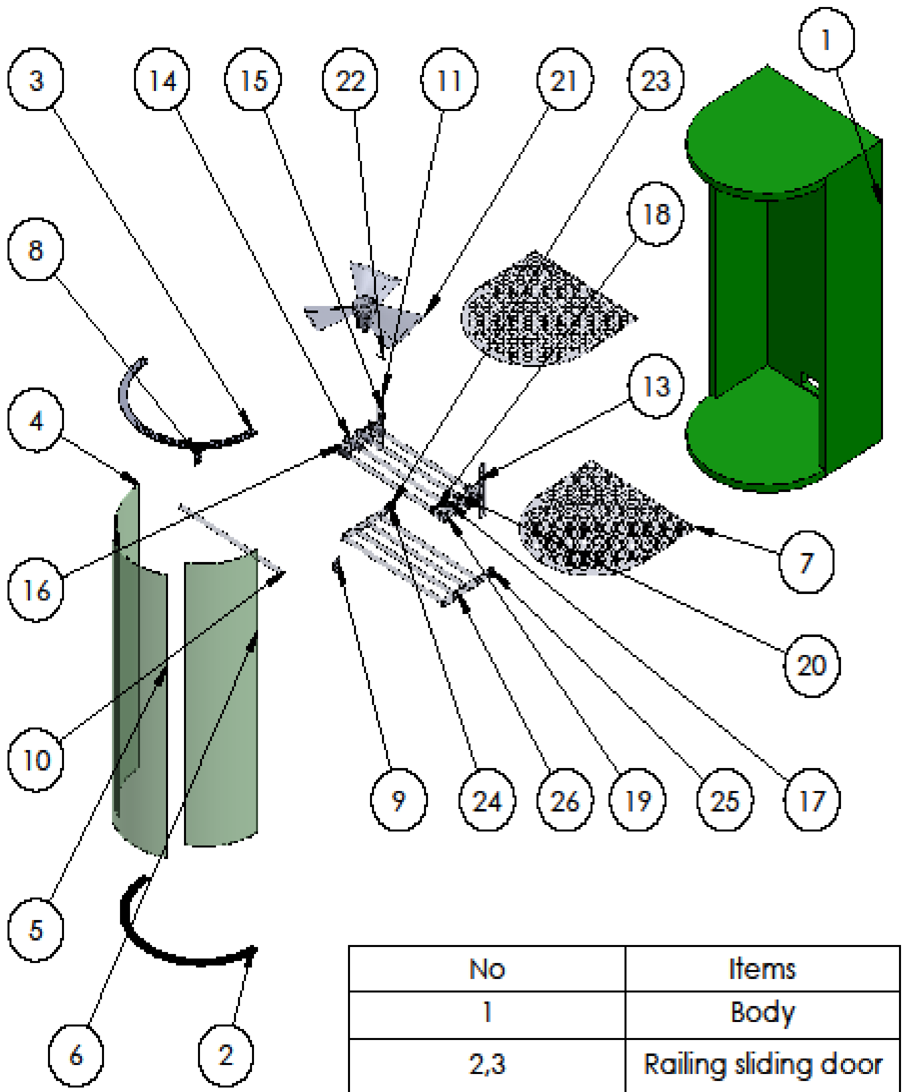
APPENDICES



No	Items
1	Body
2	Stabilizer
3	Sliding door
4,5,6	Hanger

ALL DIMENSIONS ARE IN MILLIMETRES (mm) UNLESS OTHERWISE SPECIFIED		NAME	DATE	Figure A1: Extruded view and list of items for concept A
	DRAWN	H.Najihah	2011	
	CHECKED	M. Yusof	2011	
ID NUMBER MA08127	APPROVED	M. Yusof	2011	
FACULTY OF MECHANICAL ENGINEERING	Universiti Malaysia PAHANG			SIZE A DWG. NO. Concept A
DO NOT SCALE DRAWING				SCALE:1:2 WEIGHT: SHEET 1 OF 1



No	Items
1	Body
2,3	Railing sliding door
4,5,6	Sliding door
7	Stabilizer
8,9,10	Hanger
11 until 20	Flexible hanger
21,22	Fan
23 until 26	Flexible hanger 2

ALL DIMENSIONS ARE IN MILLIMETRES (mm) UNLESS OTHERWISE SPECIFIED

	NAME	DATE
DRAWN	H.Najihah	2011
CHECKED	M. Yusof	2011
APPROVED	M. Yusof	2011

ID NUMBER MA08127

FACULTY OF MECHANICAL ENGINEERING

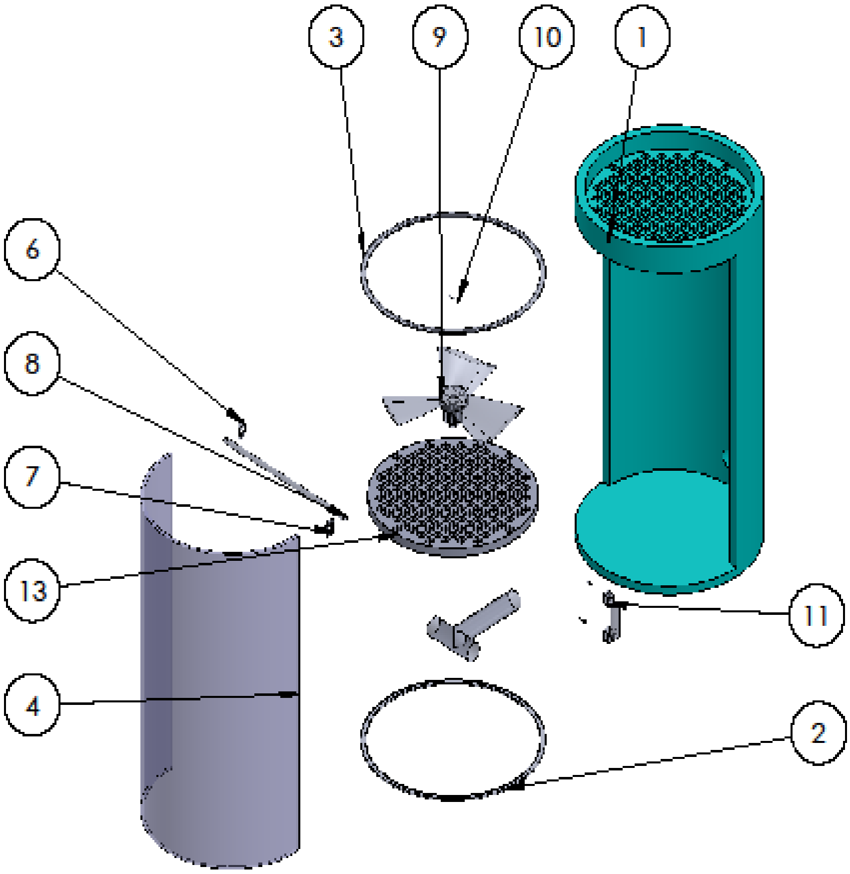
DO NOT SCALE DRAWING

Universiti Malaysia PAHANG

Figure A1: Extruded view and list of items for concept B

SIZE A | DWG. NO. Concept B

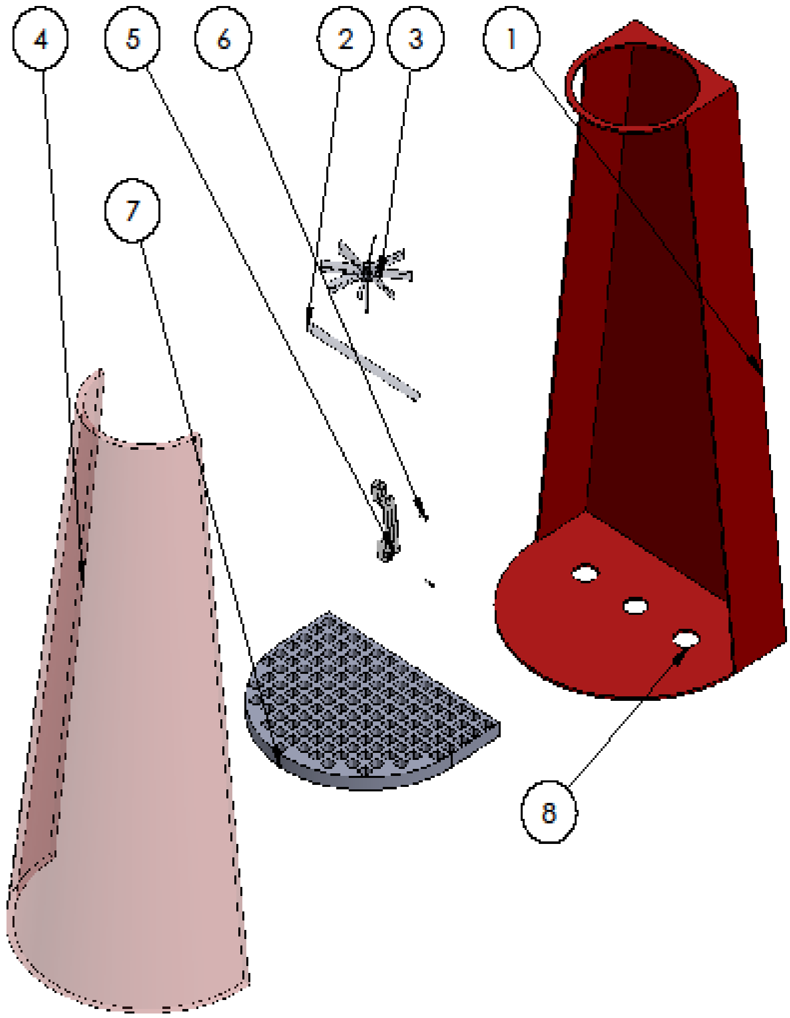
SCALE 1:2 | WEIGHT: | SHEET 2 OF 4



No	Items
1	Body
2,3	Railing sliding door
4	Sliding door
6,7,8	Hanger
9,10	Fan
11	Door holder
13	Stabilizer

ALL DIMENSIONS ARE IN MILLIMETRES (mm) UNLESS OTHERWISE SPECIFIED		NAME	DATE	Figure A1: Extruded view and list of items for concept C
	DRAWN	H.Najihah	2011	
	CHECKED	M. Yusof	2011	
ID NUMBER MA08127	APPROVED	M. Yusof	2011	
FACULTY OF MECHANICAL ENGINEERING	Universiti Malaysia PAHANG			SIZE A; DWG. NO. Concept C
DO NOT SCALE DRAWING				SCALE:1:3; WEIGHT:; SHEET 3 OF 4

Figure A1: Extruded view and list of items for concept C



No	Items
1	Body
2	Hanger
3	Fan
4	Sliding Door
5,6	Door holder
7	Stabilizer
8	Inlet heat

ALL DIMENSIONS ARE IN MILLIMETRES (mm) UNLESS OTHERWISE SPECIFIED		NAME	DATE	Figure A1: Extruded view and list of items for concept D
	DRAWN	H.Najihah	2011	
	CHECKED	M. Yusof	2011	
ID NUMBER MA08127	APPROVED	M. Yusof	2011	
FACULTY OF MECHANICAL ENGINEERING	Universiti Malaysia PAHANG			SIZE A · DWG. NO. Concept D
DO NOT SCALE DRAWING				SCALE 1:2 · WEIGHT: · SHEET 4 OF 4