CHAPTER 1
INTRODUCTION

1.1 Background of Study

For many years, solar energy has been the power supply of choice for Industrial applications, where power is required at remote locations. This means in these applications that solar power is economic, without subsidy. Most systems in individual uses require a few kilowatts of power. Solar energy is also frequently used on transportation signaling for example offshore navigation buoys, lighthouses, aircraft warning lights on pylons or structures, and increasingly in road traffic warning signals. Solar is used to power environmental and situation monitoring equipment and corrosion protection systems (based on impressing a current) for pipelines, well-heads, and bridges or other structures. Solar's great benefit here is that it is highly reliable and requires little maintenance so it's ideal in places that are hard to get to.

Drying is a mass transfer process resulting in the removal of water moisture or moisture from another solvent, by evaporation from a solid, semi-solid or liquid (hereafter product) to end in a solid state. To achieve this, there must be a source of heat, and a sink of the vapor thus produced. In the most common case, a gas stream, such as air, applies the heat by convection and carries away the vapor as humidity. Important parameters to control drying process such as air temperature, humidity and flow rate.

Nowadays, people use either electrical drier or natural air drying process to dry the clothes. Natural drying process is done by hanging the clothes under direct sunlight or in spaces with air flow. Most driers consist of a rotating drum called a tumbler through which heated air is circulated to evaporate the moisture from the load. The tumbler is rotated relatively slowly in order to maintain space between the articles in the load. In most cases, the tumbler is belt-driven by an induction motor. Using these machines may cause clothes to shrink and to fade in color. For these reasons, as well as environmental concerns, many people still use the natural air drying method.

***Figure 1.1**: Natural air drying process*

***Figure 1.2**: Conventional electrical drier*

The project was initiated by the concept of living in healthier and environmental friendly lifestyle by producing energy saving daily application. The idea was to develop a cloth drier by using solar collector as the source of heat instead of heater that will surely consume a large amount of electricity. This project will require a lot of knowledge about solar thermal energy and how we can use the renewable energy like solar power in our daily application. A lot of research needs to be done to identify the most suitable component and configuration for the project. The design of the solar collector will be based on the amount of heat transferred into the closet while the design criteria for the ducts and the closet will depend on the installation condition at home.

1.2 Problem Statement

People in a hot country just like Malaysia used to dry their cloth by hanging them under the direct sunlight outside their house. Almost every textiles and fibre is affected by the powerful radiations of sunlight. Some will decompose and deteriorate fairly rapidly, losing tensile strength and changing colour due to the effect of UV (Ultra-Violet) rays which may harm our delicate wardrobe such as expensive lingerie's, coats, handbags or even shoes. It is also will be exposed to the environmental condition such as a sudden rain, strong wind that can fly the cloth away and dust. There are also possibilities that the cloth can be stolen when hanged outside the house. The conventional drier will surely consume a lot of electricity to operate and cause the clothes to wrinkles and therefore need to use iron. Again, this process will consume lot of electricity. Besides, the drying and the storage space are separate therefore will require extra time to put out the clothes from the drier and keep it in the storage space. This project will surely solve the problems above and also help to conserve the world by using renewable energy like solar power.

1.3 Objectives

The objectives of this design project are:

- To design a clothes drying system that use solar power as the source of heat.
- To develop the detailed design drawings of the system.
- To fabricate a prototype of the cloth drying closet and testing.

1.4 Scope of Study

Research about the existing cloth drier design in market was carried out to identify any weaknesses and modification that need to be done while using solar collector as the heat source. Following to the problems identified, some related measurement and quantification will be carried out to determine the requirements and specifications for the cloth drying closet. Most of the quantification is about the investigation on the hot air circulation system such as the flow rate of air and amount of heat being transferred. There will be two phases during the designing stage which are the conceptual design and the detailed design phase. Conceptual design is generated to gives a rough picture of the complete cloth drying closet. The design then will be analyzed accordingly to the specification required before proceeding into the detailed design stage. The prototype of the design was fabricated before proceed to testing and analysis work.

CHAPTER 2
LITERATURE REVIEW

2.1 Solar Collector

Solar collector has been used in many applications such as, water heater for household, produce stem in order to generate the electricity by using steam turbine and also in drying purpose. There are many type of solar collector, for example unglazed EPDM collector, flat plate collector, parabolic and evacuate tube that is used for producing different outlet fluid temperature.

According to Duffie & Bechman (1991) a simple flat plate collector consists of an absorber surface (usually a dark, thermally conducting surfaces), a trap for reradiation losses from the absorber surface (such as glass which transmits shorter wavelength solar radiation but blocks the longer wavelength radiation from the absorber), a heat transfer medium such as air, water, etc, and some thermal insulation behind the absorber surface. Flat plate collectors are used typically for temperature requirements up to 75^{o}C although higher temperatures can be obtained from high efficiency collectors.

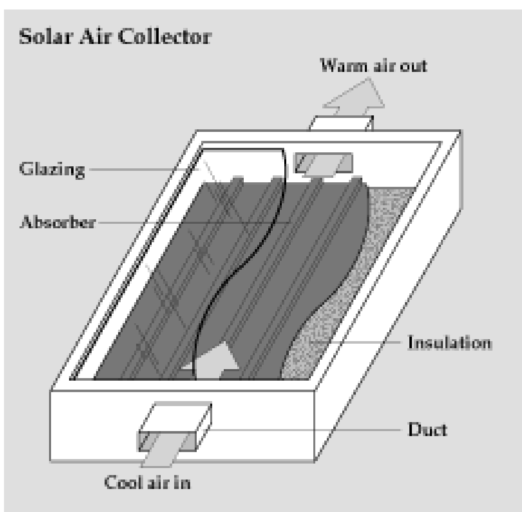


***Figure 2.1**: Single glazing solar air collector*

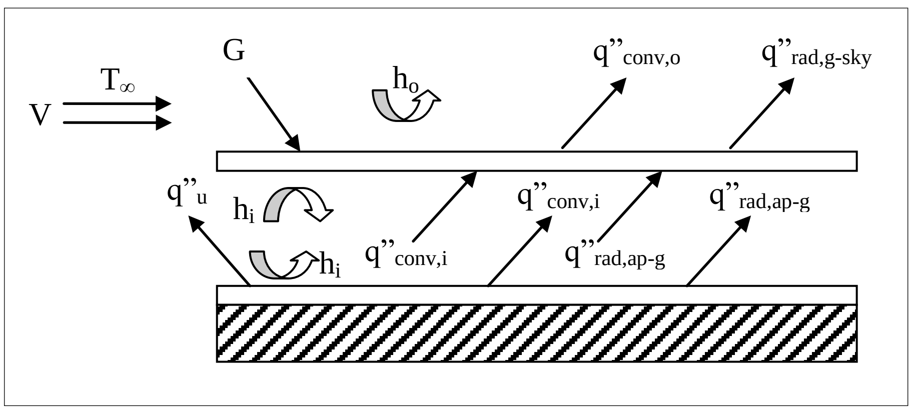
Air types of collectors are more commonly used for agricultural drying and space heating applications. Their basic advantages are low sensitivity to leakage and no need for an additional heat exchanger for drying and space heating applications. However, because of the low heat capacity of the air and the low convection heat transfer coefficient between the absorber and the air, a larger heat transfer area and higher flow rates are needed as stated by Frank & David (2002).

2.1.1 Energy Balance

The energy balance for the solar flat plate collector can be expressed as the energy gain is equal to energy loss,

$$E''_{in} = E''_{out} \tag{2.1}$$

From the figure 2.4 below, the energy balance equation can be determine.



Source : Frank P. Incropera and DeWitt, Introduction to Heat Transfer, 5th ed. (Asia : John Wiley & Sons, 2007)

Figure 2.2: *Energy balance on solar collector.*

At absorption plate, the solar energy absorbed is equal to useful energy + energy loss due to convection + energy loss due to convection.

Solar $\text{Energy}_{absorbed,absorberplate} = \text{Energy}_{useful} + \text{Energy}_{Loss(convection)} + \text{Energy}_{Loss(conduction)}$

$$\alpha_{ap,s} (\tau_{g,s})\, G_s = q''_u + q''_{conv,i} + q''_{rad,ap-g} \tag{2.2}$$

So,

$$q''_u = \alpha_{ap,s} (\tau_{g,s})\, G_s - h_i (T_{ap} - T_g) - (\sigma\, [T_{ap}^{\;4} - T_{cp}^{\;4}] / [(1/\varepsilon_{ap}) + (1/\varepsilon_g) - 1]) \tag{2.3}$$

At cover plate, sum of the solar energy absorbed by glass, energy loss due to convection from absorber plate and energy loss due to radiation from absorber plate is equal to sum of energy loss due to convection from glass and energy loss due to radiation from glass.

Solar $Energy_{absorbed,glass}$ + $Energy_{Loss(convection,absorber\_plate)}$ + $Energy_{Loss(radiation,absorber\_plate)}$ = $Energy_{Loss(Convection,glass)}$ + $Energy_{Loss(radiation,glass)}$

$$\alpha_{g,s}\,(G_s) + q''_{conv,i} + q''_{rad,ap\text{-}g} = q''_{conv,o} + q''_{rad,g\text{-}sky} \qquad (2.4)$$

so,

$$\alpha_{gs}\,(G_{gs}) + h_i(T_{ap} - T_g) + (\sigma\,[T_{ap}^{4} - T_g^{\,4}] / [(1/\varepsilon_{ap}) + (1/\varepsilon_g) - 1]) = h_o(T_g - T_\infty) + \varepsilon_g\sigma(T_g^{4} - T_{sky}^{4}) \qquad (2.5)$$

At fluid flow, the useful energy is equal to energy absorbed to the fluid,

$$q''_u = \dot{m}_a C_p \Delta T \qquad (2.6)$$

2.1.2 Glazing Material

Solar energy from the sun is formed of short radiation. After the energy reached to the earth’s surface, it will re-radiate into surrounding or deep space as long wave radiation. So the power of solar energy source which is short wave radiation has to capture to prevent it from being re-radiated directly to the atmosphere. The selection of the cover is based on cost, non-degradability, durability, specific heat. So, glass is used for glazing because the ability to allow the passage of short radiation and retain them in solar collector because the wave becomes long wave radiation and energy to dissipate is less.

Table 2.1: Absorptivity, emissivity and transmittance for different types of glass

Type of Glass	Absorptivity, α	Emissivity, ε	Transmitance, τ	Effective transmittance-absorptance, τ α	Long-wave infrared transmittance
Crystal Glass	0.13	0.83	0.91	0.1183	0.02
Window Glass	0.13	0.83	0.85	0.1105	0.02
Perspex polymethylmethacrylate (PMMA).	-	-	0.84	-	0.02

Source : Radiative heat transfer, MODEST, MICHAEL, Amsterdam : Academic Press, 2003 and Godfrey Boyle, 2004. Renewable Energy, Oxford Universiti Press

2.1.3 Absorber Plate Material

Absorber plate is used to absorb heat from the incoming solar radiation. The more thermal conductivity, the more heat will absorb.

Table 2.2: Thermal conductivity of selected materials for absorber

Materials	Density, ρ (kg/m³)	Specific Heat, C (J/kg.K)	Thermal conductivity, k (W/m.K)
Aluminum 1100	2379	903	237
Copper	8933	385	401
Carbon Steel	7832	434	60.5
Tin	7310	227	66.6

Source : Frank P. Incropera and DeWitt, Introduction to Heat Transfer, 5^{th} ed. (Asia : John Wiley & Sons, 2007). pp A1-A8.

2.1.4 Insulation Material

Selection of the insulation is based on the lowest thermal conductivity and the material cost of different types of materials. Selected materials that can be use for the solar collector as stated in Table 2.3.

Table 2.3: Thermal conductivity of selected materials for insulation

Materials	Thermal conductivity, k (W/m.K)
Rigid foam	0.026
Glass Fiber	0.043
Blanket	0.038
Cotton	0.06
Sawdust	0.06
Straw	0.09
Paper	0.18
Plaster / gypsum	0.48

Source : Garg, H.P. and PrakashJ. (2000), "Solar Energy Fundamentals and Applications", McGraw Hill.

2.1.5 Coating Material

The characteristic of coating that should select for absorber plate is determined by solar absorptance,α and emittance,ε of the material. The flat black paint is selected for coating because it is locally available and cheap compare to Black Nickel or Black Chrome plating.

Table 2.4: *Performance ratio for selected coatings*

Material	Absorptivity, α	Emissivity, ε	Performance Factor, α/ε
Black chrome on copper	0.95	0.12	7.92
Nonmetallic black surfaces: carbon	0.92	0.94	0.98
Flat black paint	0.97	0.86	1.13
Gray paint	0.75	0.95	0.79

Source : Garg, H.P. and PrakashJ. (2000), "Solar Energy Fundamentals and Applications", McGraw Hill.

2.2 Heat Transfer

Heat transfer is a process that occurs whenever there is a temperature gradient within a medium, from sides of one medium to another mediums side. It can also be quantified as energy transfer in the form of heat, that take place between two bodies or through a single body solely due to temperature difference, Frank & David (2002).

2.2.1 Conduction Heat Transfer

Conduction occurs through intervening matter and does not involve any obvious motion of matter. It is a mechanism where internal energy transfers from one part of the substance to another part by direct communication. The molecules physically touch each other and transfer heat as they touch. The minus sign is because of the fact that heat is transferred in the direction of decreasing temperature. Rate of conduction heat transfer, Q_c is stated by Frank & David (2002) as,

$$Q_c = -kA(T_2 - T_1) \tag{2.7}$$

2.2.2 Convection Heat Transfer

Convection is a heat transfer mechanism that occurs in fluid by the motion of fluid. Convection can be due to either forced flow or natural flow. Natural convection occurs due to change in the density of fluid correspondingly the natural buoyancy forces will cause convection current, Frank & David (2002). The flow of fluid can be forced by using fans and blowers or it can be from natural sources such as the wind itself. The convection coefficient or film coefficient expresses the resistance to heat transfer at the solid boundary. It is usually determined experimentally.

$$Q_v = hA(T_{fluid} - T_{surface}) \tag{2.8}$$

2.2.3 Radiation Heat Transfer

Radiant heat is transferred by electromagnetic waves. Thereby it is not necessary for the two bodies to be physically in contact and it is also not necessary for a medium to be present for heat transfer to occur. As suggested by Frank & David (2002), the ability of a surface to emit and absorb radiant energy is referred to as emissivity of a surface.

Emissivity ranges from 0 to 1.0, with 1.0 being a perfect emitter. The amount of radiant exchange between two objects may be expressed as below:

$$E = \varepsilon\sigma T_{surface} \tag{2.9}$$

All radiation falling on surface will be absorbed by the surface, reflected by the surface, or transmitted through the surface. Distribution of radiant energy falling on a surface is represented in the Figure 2.2:

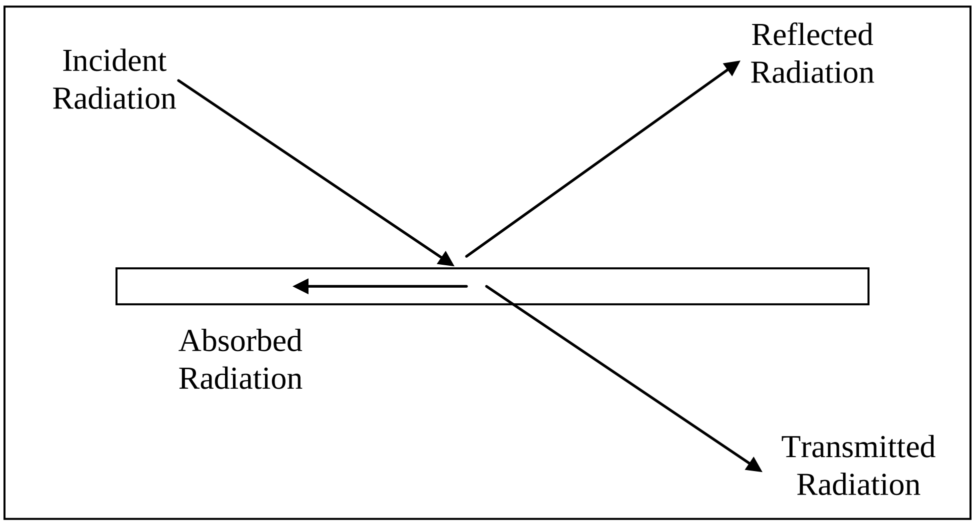


Figure 2.3: *Distribution of Radiant Energy on a surface*

2.3 Psychrometry

According to Michel a. Saad (1997), psychrometry is the science of studying the thermodynamic properties of moist air and the use of these properties to analyze conditions and processes involving moist air. The air condition can be determined by using a Psychrometric Chart. Common properties used in the charts includes

- Dry-bulb temperature
- Wet-bulb temperature
- Relative humidity (RH)
- Humidity ratio
- Specific volume
- Dew point temperature

- Enthalpy

With two known properties it is possible to characterize the air in the intersection of the property lines, the state-point. With the intersection point located on the chart or diagram, other air properties can be read directly.

2.3.1 Dry-bulb Temperature - T_{db}

Dry bulb temperature is usually referred to as air temperature, is the air property that is most common used. When people refer to the temperature of the air, they are normally referring to its dry bulb temperature. It can be measured by using a normal thermometer. The dry-bulb temperature is an indicator of heat content and is shown along the bottom axis of the psychrometric chart. The vertical lines extending upward from this axis are constant-temperature lines, Michel a. Saad (1997).

2.3.2 Wet-bulb Temperature

Wet bulb temperature is associated with the moisture content of the air. Wet bulb temperature can be measured with a thermometer that has the bulb covered with a water moistened bandage with air flowing over the thermometer. Wet bulb temperatures are always lower than dry bulb temperatures but they will be identical with 100% relative humidity in the air (the air is at saturation line). On the psychrometric chart, the wet bulb lines slope a little upward to the left, and the temperature is read at the saturation line, Michel a. Saad (1997).

2.3.3 Relative Humidity – RH

Relative humidity is the ratio of the water vapor pressure, p_w, to the vapor pressure of saturated air at the same temperature, p_{ws}, expressed as a percentage. Relative humidity is a relative measure. The moisture holding capacity of air increases with air temperature. In practice relative humidity indicates the moisture level of the air compared to the air moisture holding capacity. The moisture holding capacity of air increases dramatically with temperature.

Relative humidity lines in the psychrometric chart are curved lines that moved upward to the right. The line representing saturated air where the relative humidity, RH is 100%, is the uppermost curved line in the psychrometric chart, Michel a. Saad (1997).

2.3.4 Dew Point - T_{dp}

As noted by Michel a. Saad (1997), dew point is the temperature at which water vapor starts to condense out of the air, the temperature at which air becomes completely saturated. Above this temperature the moisture will stay in the air. This temperature can be read by following a horizontal line from the state-point to the saturation line. Dew point is represented along the 100% relative humidity line in the psychrometric chart.

2.3.5 Specific Volume of Humid Air – v

Specific volume represents the space occupied by a unit weight of dry air (ft3/lb), and equal to 1/(air density). Specific volume is shown along the bottom axis of the psychrometric chart with constant-volume lines slanting upward to the left, Michel a. Saad (1997).

2.3.6 Moisture Content and Humidity Ratio – x

Moisture content and humidity ratio differs from relative humidity in that it is the amount of water vapor by weight, in the air. The dry-basis moisture content of air is expressed as the weight of water vapor per unit weight of dry air. Humidity ratio is indicated along the right-hand axis in the psychrometric chart, Michel a. Saad (1997).

2.3.7 Enthalpy – h

Internal energy of a substance added with energy in the form of work due to flow in or out of the control volume is termed as enthalpy also known as total heat content. Main component of enthalpy would be internal energy which is associated with motions and configuration of particles due to temperature change or heat addition, Michel a. Saad (1997). Enthalpy is read from where the appropriate wet-bulb line crosses the diagonal scale above the saturation curve. Air with same amount of energy may either be dry hot air (high sensible heat) or cool moist air (high latent heat).

2.4 Sensible Heat and Latent Heat

Substances such as fluids and solids are known to store heat and the form of heat involved is sensible heat and latent heat. Sensible heat content as it changes will result in temperature changes in the substance. It can be measured by using an ordinary thermometer. In the case of air, the temperature measured due to sensible heat change is referred to as dry bulb temperatures.

Latent heat on the other hand is usually associated with the phase change of a substance. Phase change processes such as melting, solidification, condensation evaporation and sublimation requires either heat to be added or removed. The heat added or removed to facilitate these processes is called latent heat. Adding or removal of latent heat will not result in temperature changes. This can be seen when boiling water, as heat is added by heating coils to water until all of the water boils away as steam, the temperature remains constant at 100ºC.

Moist air is a mixture of dry air and water vapor. In atmospheric air, water vapor content varies from 0 to 3% by mass. The enthalpy of moist and humid air includes the:

- Enthalpy of the dry air – the sensible heat
- The enthalpy of the evaporated water – latent heat

Specific enthalpy, h (kJ/kg) of moist air is defined as the total enthalpy of the dry air and the water vapor mixture per kg of moist air. Specific enthalpy of moist air as stated by Michel a. Saad (1997), can be expressed as:

$$h = h_a + xh_w \quad (1) \qquad (2.10)$$

2.4.1 Specific enthalpy of dry air – Sensible Heat

Assuming constant pressure conditions the specific enthalpy of dry air as stated by Michel a. Saad (1997), can be expressed as:

$$h_a = c_{pa}\mathrm{t} \qquad (2.11)$$

Where,

c_{pa} = specific heat capacity of air at constant pressure (kJ/kg.ºC, kWs/kg.K)

T = air temperature (ºC)

For air temperatures between -100ºC and 100ºC the specific heat capacity can be set to c_{pa} = 1.06(kJ/kg. ºC)

2.4.2 Specific Enthalpy of water vapor – Latent Heat

Assuming constant pressure conditions the specific enthalpy of water vapor as stated by Michel a. Saad (1997), can be expressed as :

$$h_w = c_{pw}t + h_{we} \qquad (2.12)$$

Where

c_{pw} = specific heat capacity of water vapor at constant pressure (kJ/kg.ºC, kWs/kg.K)

t = water vapor temperature (ºC)

h_{we} = evaporation heat of water at 0ºC (kJ/kg)

For water vapor the specific heat capacity can be set to

c_{pw} = 1.84(kJ/kg.ºC)

The evaporation heat can be set to

h_{we} = 2502 (kJ/kg)

Using (2.11) and (2.12), (2.10) can be modified to

h = c_{pa}t + x[c_{pw}t + h_{we}]

or

h = 1.01 (kJ/kg.ºC) t + x[1.84(kJ/kg.ºC) t + 2502 (kJ/kg)]

2.5 Drying Principle

In drying process, the latent heat of vaporization is supply to the water in the clothes. As a result the water vapor is removed from the clothes. So, the process involves the application of heat and the removal of the moisture to yield a solid dry product. Drying is carried out the passing of hot air that provides the latent heat for water to having the evaporation process. The moisture form then is transferred from the clothes to the air by the movement of the air.

In a drying operation, either one of limiting factor could affect the governing rate of drying, although it is occur simultaneously throughout the drying cycle [3]. When the dry hot air is having a contact with the wet clothes, the vapor pressure in the clothes will be higher than in the air. This will cause the evaporation of water from the clothes surface until it reach an equilibrium state. In order for the clothes to lose the moisture as water vapor, the equilibrium latent heat must be applied to the liquid of water. In the absent of an external heat source, this latent heat is normally absorbed from the clothes itself, resulting in the lowering of its temperature. This is called evaporative cooling [3]. Also goes on in the dry hot air, the latent heat is provided to water existence in the wet clothes, and also lowering the air temperature.

As moisture content in the product diminishes, the internal moisture will not migrate as easily as before, and the drying outer surfaces start to offer resistance to the moisture transfer. The temperature of the leaving air will begin to increase above the wet bulb temperature, and the leaving air will not be saturated. The inlet air temperature is still greater than the outlet air temperature. Eventually, equilibrium conditions are reached when no further drying takes place. At this stage, the moisture content in the air will be in equilibrium with that in the clothes. There will not be any heat and mass transfer under these conditions. The clothes temperature is equal to the outlet air temperature, which is also equal to the inlet air temperature.

2.5.1 Moisture Content

There are two ways in expressing the moisture content of the clothes that is can be reported as a percentage or fraction either on a wet basis (% wb) or on a dry basis (% db). In calculating the moisture content on wet basis, the equation below is used.

$$\text{Moisture Content (\% wb)}, M_{wet} = \frac{m_{water}}{m_{water}+m_{Solid}} \times 100 \qquad (2.13)$$

Where M is moisture content and m is the weight. While the calculation for moisture on dry basis, the equation is followed,

$$\text{Moisture Content (\% db)}, M_{dry} = \frac{m_{water}}{m_{Solid}} \times 100 \qquad (2.14)$$

The wet and dry basis moisture content can be related using the following equation,

$$M_{dry} = \frac{M_{wet}}{100-M_{wet}} \qquad (2.15)$$

2.5.2 Mass and Energy Balance of Air Drying

Considering the drying process is on continuous basis and the clothes and air is entering the closet then leaving with the opposite condition as in figure 2.4 below,

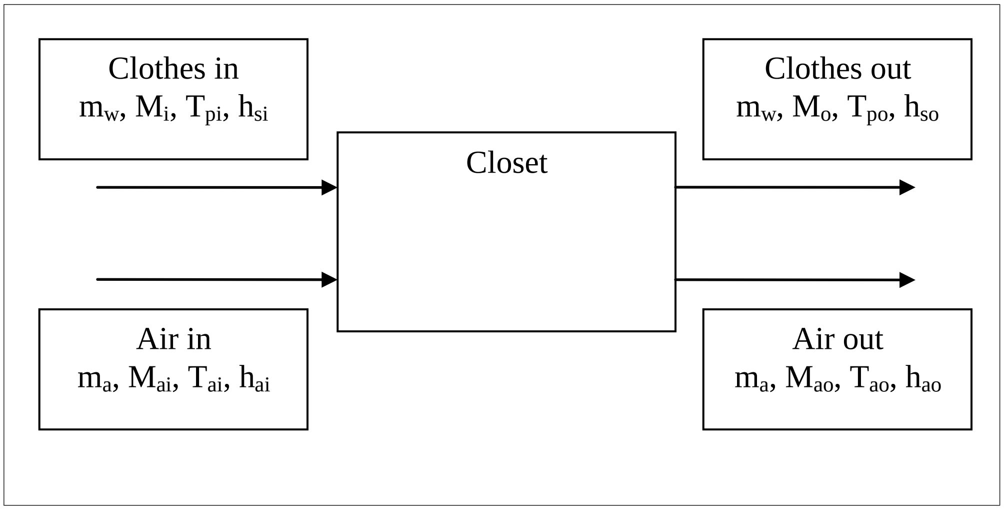


Figure 2.4: *Schematic diagram of a drying process*

Where the m_w is weight of clothes, m_a is a weight of air entering and leaving the dryer. M_i and M_o are the product moisture contents (db). T_{pi} and T_{po} are product temperature. h_{is} and h_{so} are product enthalpy. M_{ai} and M_{ao} are air moisture content. T_{ai} and T_{ao} are temperature of air. h_{ai} and h_{ao} are enthalpy of the air.

The mass balance indicates that the moisture coming in must equal to moisture going out. Therefore:

$$m_wM_i + m_aM_{ai} = m_wM_o + m_aM_{ao} \quad (2.16)$$

By rearranging the equation showing the moisture lost by the product is equal to moisture gained by air,

$$m_w(M_i - M_o) = m_a(M_{ao} - M_{ai}) \quad (2.17)$$

The energy balance of the closet, assuming the ideal adiabatic unit working at steady-state condition, is expressed by:

$$M_wh_{si} + m_ah_{ai} = m_wh_{so} + m_ah_{ao} \quad (2.18)$$

Rearrangingthe equation indicates that the heat gained by the product is lost by the supply air:

$$m_w(h_i - h_o) = m_a(h_{ao} - h_{ai}) \qquad (2.19)$$

In other term, the energy balance for drying process can be expressed as

$$m_w L = m_a C(T_{ai} - T_{ao}) \qquad (2.20)$$

where L is the latent heat of the water at respective temperature and C is the specific heat of the air.

CHAPTER 3

METHODOLOGY

3.1 Project Activities

The sequence of the project is shown in **Figure 3.1**. To ensure that this project runs smoothly and successfully, it has been divided into 2 major parts. The project started with the problem identification and the literature survey. The first part is the conceptual and literature review such as identifying the most suitable types of solar collector, the flow rate of air, amount of heat transfer and etc. This is basically a study and research of fundamental and theoretical review conducted via searching through journals, websites and related articles and text books. Then the project continue with monitoring of the data that will be used to calculate the design specifications of the cloth drying closet and develop the basic concept of the design. After all the design analysis been done and meet the specification, a detailed design will be generate by using CATIA/AutoCAD software. The second part of this project will be focusing on the development of the cloth drying closet which is acquisition of the main components and assembly to become a prototype. Testing and analysis will be done after the fabrication work completed.

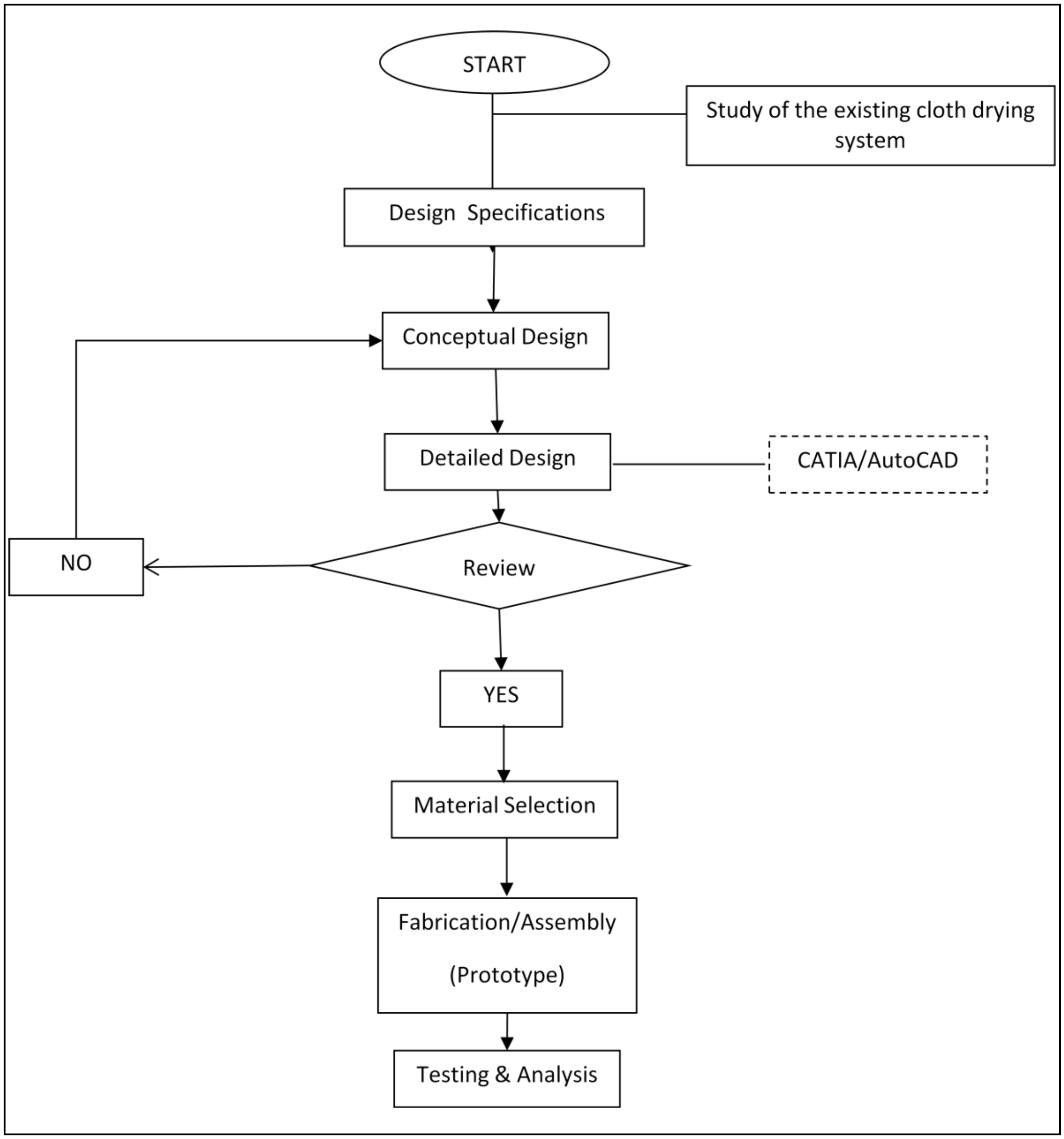


Figure 3.1*: Flow diagram showing the sequence of work*

3.2 Tool/Equipment Required

Tool and equipment that being considered for this project are as follows:

- AutoCAD and CATIA Software
- Mechanical tool for fabrication
- Mechanical laboratory
- Testing equipments

3.3 Design Feature for the Clothes Drying Closet

After doing a lot of study about solar collector, ducting system, insulation and heat analysis, finally a schematic diagram was generated. **(Figure 3.2)** showing the general arrangements of the components for the cloth drying closet. From the sketch, the solar collector can be mounted on the roof or outside the house positioning towards the sunlight. The duct is installed from the output of the solar collector to the bottom part inside the closet. This duct will be transferring the heat from the solar collector into the closet by using air as a transfer medium. The heat will be use to dry the wet clothes hanging in the closet. A fan is installed at the top of the closet so that the air can circulate around the system.

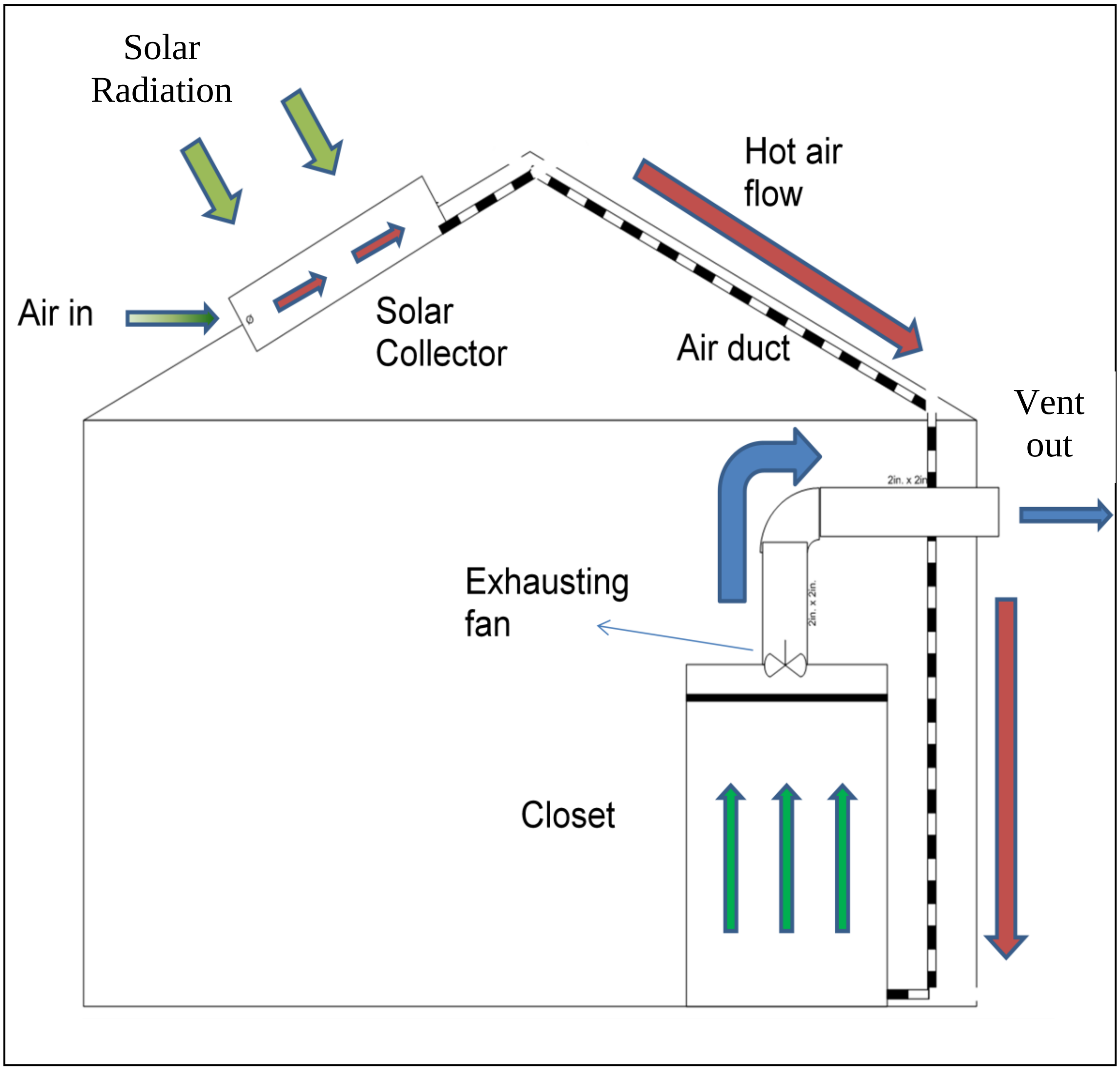


***Figure 3.2**: Schematic diagram of the Cloth Drying Closet*

3.3.1 Design Considerations for the Cloth Drying Closet

The closet can be used as the drying compartment and clothes storage since the closet can be placed inside the house. The dimension of the closet was assumed to be as standard size which is 3ft x 1.5ft x 6ft and it can store a maximum 16 hanged clothes. The heated air flow from bottom through the wet clothes and release to outer vent from top. The air flow inside the closet is drive by an exhausting fan installed at the top of the closet. The drying time of the clothes are expected to be time consuming but as long as the exhausting fan is operating, the drying process will still continued. The following points were considered in the design of the cloth drying closet using solar energy:

- The amount of water need to be removed during the drying process.
- The quantity of heat needed to evaporate the water.
- The size and type of the air solar collector.
- The daily solar radiation to determine energy received by solar collector.
- The daily sunshine hours for the selection of the total drying time.

3.3.2 Sample of Data

The data gathering process involve some measurement of the design parameters which are the solar radiation, wind velocity, ambient temperature and relative humidity. The data was taken every half an hour interval from 9 am until 4 pm for six days. The data was included in the Appendix B. **Figure 3.3** shows the distribution of the solar radiation for 7 hours.

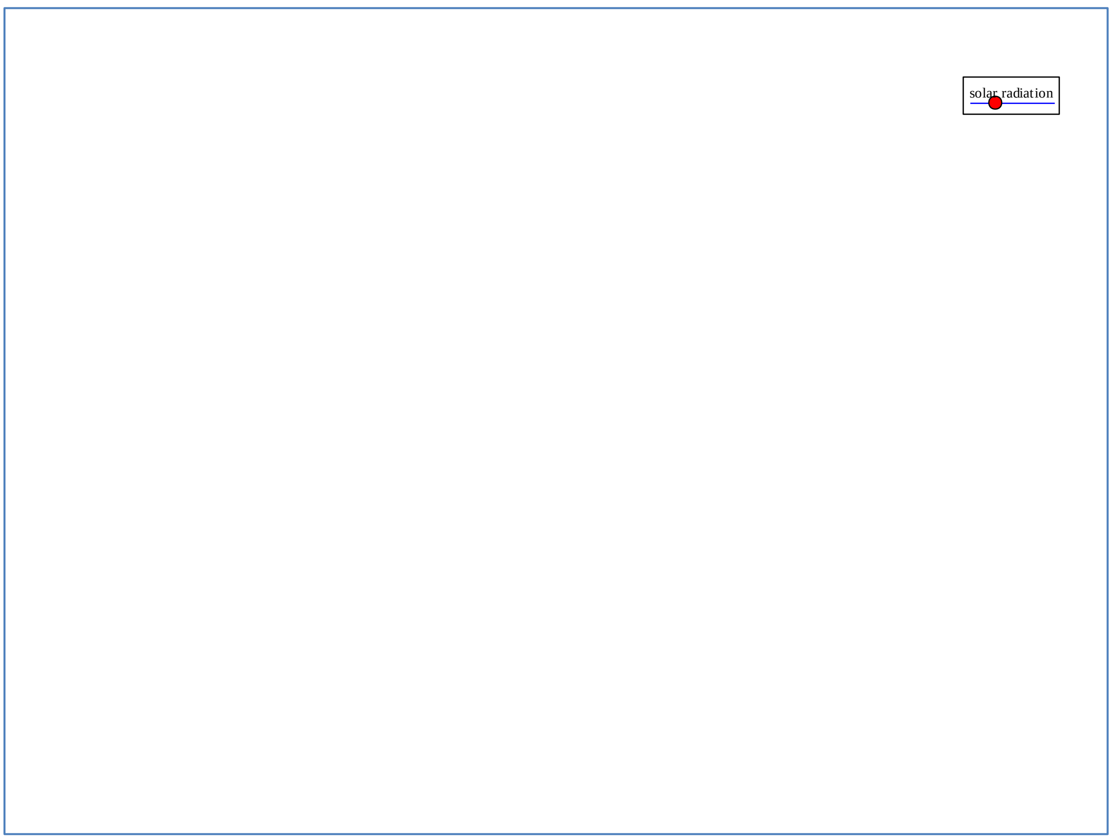


Figure 3.3: *Graph showing variation of solar radiation with time of the day (April 16, 2008)*

The graph above shows that the maximum solar radiation received during that day is 744.6 W/m^2 which occurred at 1330 hr and the average solar radiation received during the day is 557.3 W/m^2. Table 3.1 shows the dry and after spinning weight of some common clothes. This data will be used to calculate the amount of water need to be removed from the clothes during the drying process.

Table 3.1: Weight of some clothing type

Items	Dry weight (g)	After spin weight (g)
T-shirt – cotton, M-size	200	350
Shirts – cotton, L-size	170	300
Jersey – polyester, free-size	150	280
Jeans – Levi’s	600	1020
Total => 4 items	1120	1950

3.3.3 Sample of Design Calculation

To carry out design calculations and size of the solar collector, the design conditions applicable to Tronoh area are required. The conditions and assumptions summarized in **Table 3.3** are used for the design of the cloth drying closet. From the conditions, assumptions and relationships, the values of the design parameters were calculated.

i. The total amount of water need to be removed from clothes during single drying operation.

By taking as average 16 hanged clothes during one cycle, **Table 3.2** will shows the average type of clothing assumed during one batch of drying.

Table 3.2: Average type of clothing for single operation

Items	quantity	Total dry weight (g)	Total wet weight (g)
T-shirt	5	1000	1750
shirts	5	850	1500
Jersey	4	600	1120
Jeans	2	1200	2040
Total =>	16	3650	6410

Therefore, the total amount of water need to be removed from the clothes can be calculated from:

6410g – 3650g = 2760g

= 2.76kg

ii. Quantity of heat needed to evaporate the water during the drying process.

$$Q = m_w \times h_{fg}$$

Where:

Q = The amount of energy required for the drying process, kJ

m_w = mass of water, 2.76 kg

h_{fg} = latent heat of evaporation, 2256.2 kJ/kg H_2O

So, the quantity of heat needed is Q = 6227.1 kJ. The drying time is assumed to be 7 hours from 9am until 4pm everyday. To express the heat energy as a unit of power, the quantity of heat is divided by the drying time:

6227100 J / 7 x 60 x 60 s = 247.1 Watts

iii. The air solar collector area

$$A_c = E / I \eta$$

Where,

E = total useful energy, watts

I = average solar radiation, W/m^2

η = collector efficiency

By taking the average solar radiation for the day is 557.3 W/m^2 and by assuming a typical efficiency of an air solar collector as 0.40, the collector area is:

A_c = 247.1W / 557.3 W/m^2 x 0.40

= 1.108 m^2 x factor of safety, 2

= 2.216 m^2.

Table 3.3: The design parameter condition and assumption

Items	Condition / Assumption / Value
Location	Tronoh, Perak
Maximum drying per batch	16 hanged clothes
Closet dimension	Standard size, 3ft x 1.5ft x 6ft
Drying time	9am to 4pm, 7 hours
Ambient air temperature	33.4 ºC (April 16, 2008)
Ambient relative humidity	72.0 % (April 16, 2008)
Maximum solar radiation	744.6 W/m^2 (April 16, 2008)
Average solar radiation	557.3 W/m^2 (April 16, 2008)
Collector efficiency	0.40
Factor of safety	2
Amount of water need to be removed	2.76 kg
Quantity of heat needed	6227.1 kJ
Total useful energy	247.1 Watts
Solar collector area	2.216 m^2
Latent heat of evaporation	2256.2 kJ/kg H_2O

3.3.4 Drawing

As per design, the drawing of the solar closet is done by using AutoCAD software for producing the 2D drawing and CATIA software in producing the 3D drawing. The drawing set of the solar closet is shown in APPENDIX D.

3.4 Fabrication

The fabrication of the clothes drying closet required manufacturing tools and equipments in the workshop/laboratory. The solar collector was taken from the previous project done by other student. Therefore some modifications have been made to the flat plate solar water heater to make it an air solar collector. Before fabricating the prototype, the author went through several equipment and tools familiarization sessions with the lab technologists in UTP. All tasks were carried out independently by the FYP candidate with the help of some technicians.

The main criteria for determining the material and equipment required to build the prototype of the solar powered clothes drying closet include; material availability, the system completely sealed to improve efficiency, transportation for the solar collector, air flow rate to optimize heat absorption, and convenient to measure the temperature during testing and analysis stage.

The following is the list of materials, services, consumables along with the units and cost according to each compartment. Some units are left without any cost as the material/tool/services have been obtained in-house or have yet to be given a quotation. Some of the materials were available in campus with no charge while others were from quotation and receipts from vendors and service providers.

Table 3.4: Items purchased/ obtained for fabrication

Items	Size	Quantity	Unit Cost	Total
Wheel	-	4	RM 3.00	RM 12.00
Fastener	-	50	-	-
Aluminum sheet	900mm X 2400mm X 1mm	1	RM 5.00	RM 5.00
Exhaust fan	20cm ø X 30W	1	RM65.00	RM65.00
Plastic Closet	70cm X 45cm X 135cm	1	RM 43.00	RM 43.00
Flexible Duct	10cm ø X 10m	1	RM56.00	RM56.00

The solar collector was modified from the previous project flat plate solar water heater. The copper plate, straw and fiber wool was first removed from the collector. Then, hole are made to the side of the collector for the duct connection. Aluminum sheet are pasted on all surfaces inside the collector so that all the solar heat will be reflected and carried away by the flowing air. Six plywoods was cut evenly and put vertically for the air passage way and also as a mechanism to support the weight of the glass cover. A wood sheet was attached to the left side of the closet base for the duct connection and at the top of the closet where the exhaust fan will be installed. Figure 3.4 shows the actual prototype.

Figure 3.4: ***a)*** *Air solar collector* ***b)*** *The plastic closet*

Figure 3.5*: Actual prototype of the solar closet*

3.5 Testing and Analysis of Overall System

Testing of the prototype started with the preparation of the data collection equipment, the solar closet, and the place of testing. For the testing space, the solar collector must be placed at the wide sky area which is the radiation of solar to the solar collector from morning to evening is not interrupted by the trees or buildings while the closet must be placed at a space where there is no direct sun rays. This is because in the real application the closet will be placed inside a house.

Testing of the solar closet is done outside of Building 15, UTP from 9.00 am until 5.00 pm for 4 days. Testing is done mainly to investigate the ability of the design system to dry clothes within the specified time. Parameters are recorded for every interval of 30 minutes. Among the parameters that are monitored during the test are;

I. Average solar radiation
II. Ambient temperature
III. Ambient relative humidity
IV. Closet inlet temperature
V. Closet outlet temperature
VI. Closet inlet relative humidity
VII. Closet outlet relative humidity
VIII. Clothes weight

A major problem encountered during the testing is to find a suitable space for the solar collector to get uninterrupted solar radiation and also to place the closet where there are no sun rays at all. In order to solve this problem, the prototype was placed at three different locations during morning, afternoon and evening for the testing. Besides, on the first day of testing, the data was taken until 12.30 pm because of heavy rain until evening.

3.5.1 Equipment for Testing

The data collection process involves several measurement equipments and tools as shown in the table below.

Table 3.5: Tools/ equipments used for testing

No	Tools/ Equipment	Purpose
1	Dry Bulb Thermocouple	To measure the closet inlet and outlet temperature
2	Humidity Meter	To measure the relative humidity
3	Digital Solarimeter	To measure the solar radiation
4	Thermo- Anemometer	To measure the air velocity and the ambient temperature
5	Data Logger	To monitor the temperature measured by thermocouples
6	Weight Scale	To measure the clothes weight

Figure 3.6: *Hygro-Thermo-Anemometer with a) anemometer vane probe + temperature sensor b) humidity probe + temperature sensor*

Figure 3.7: *Weight Scale*

***Figure 3.8**: a) FLUKE Data logger b) removable Universal Input Module*

***Figure 3.9**: Digital Solarimeter*

***Figure 3.10**: Thermocouple position at a) closet inlet b) closet outlet*

CHAPTER 4

RESULT AND DISCUSSION

The testing of the solar closet prototype was carried on for four days. The data is collected and analysed through this chapter to get the result of the experiment. The testing result is provided in the Appendix C.

4.1 Environment Condition

During the experiment, the data of the environment condition is collected. The data is then converted into graph and it is shown in figures below. The variation of the ambient temperature with time of the day is shown in figure 4.1. From the graph, the ambient temperature is increasing from morning until 12 noon and after that randomly increased and decreased until 5.00 pm. This is due to the cloud appearance that suddenly blocked the sunlight path to the testing place. The variation of the ambient relative humidity with time of the day is shown in figure 4.2.

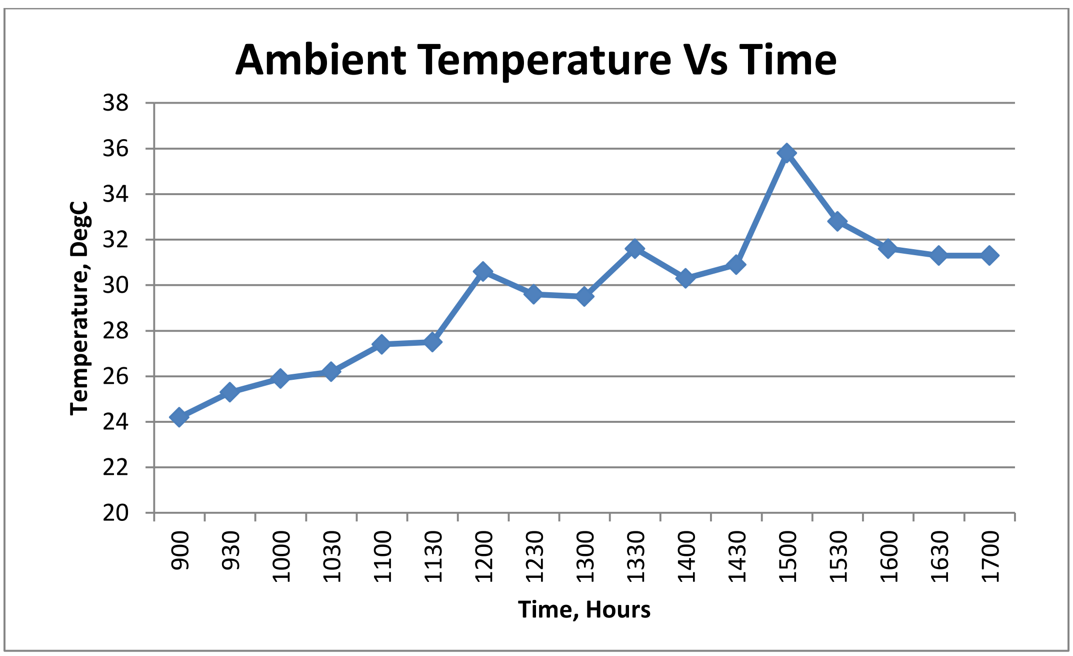


Figure 4.1: *Graph showing variation of ambient temperature with time of the day (November 11, 2008)*

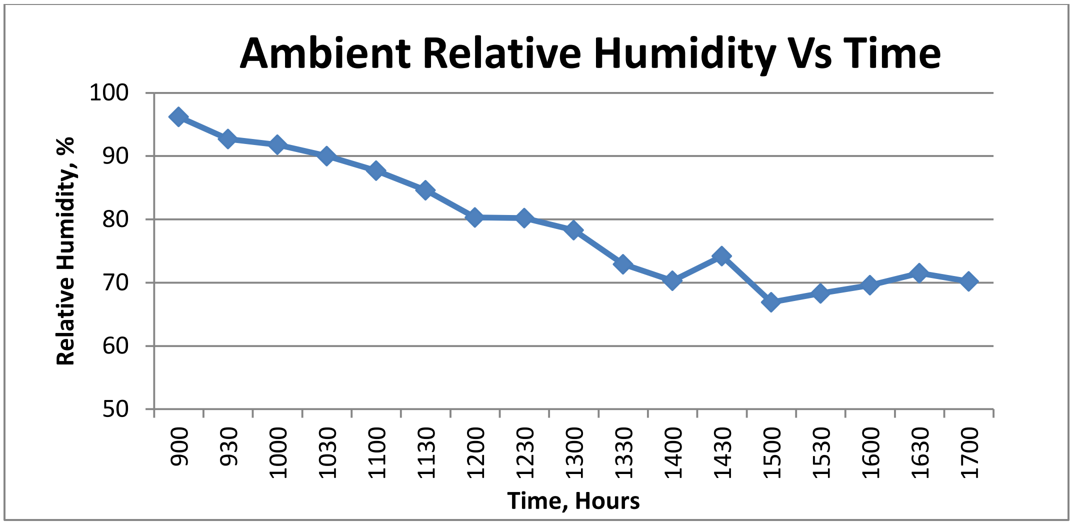


Figure 4.2: *Graph showing variation of ambient relative humidity with time of the day (November 11, 2008)*

From the two graph above, it is shown that the condition of the experiment day is in good condition with the exception from 12 noon until 5.00 pm there are a sudden cloud that appear sometime between this time interval.

For the solar radiation falling on the earth surface, the graph is shown in the figure 4.3. It is shown that the solar radiation was slowly increasing until 11.30 am and increased to the maximum value of 624.6 W/m^2 which happen at 12.30 pm. At 1.30 pm, the value decreased due to the cloud appearance during taking the measurement.

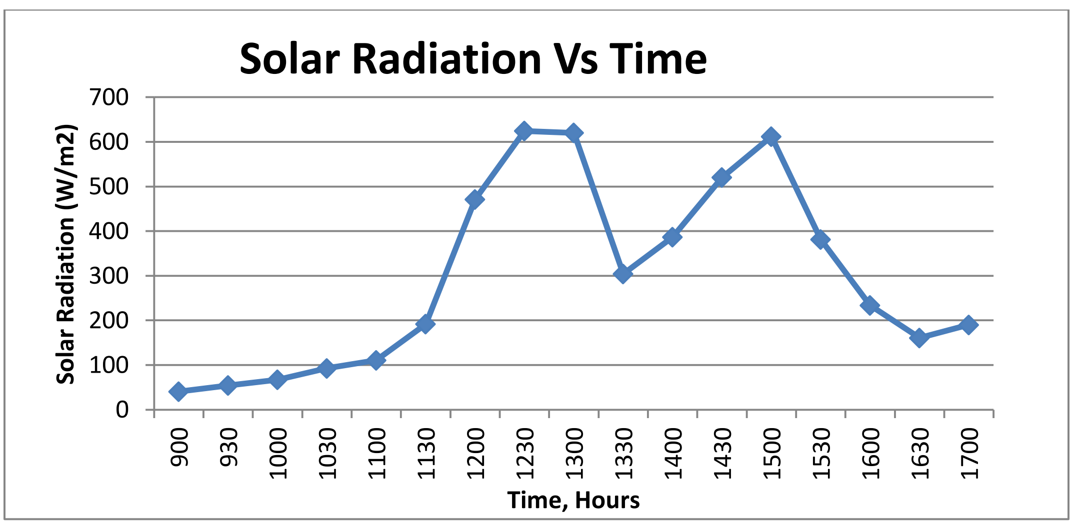


Figure 4.3: *Graph showing variation of solar radiation with time of the day (November 11, 2008)*

4.2 Performance of the Solar Drying Closet

4.2.1 Solar Collector

The temperature of air entering the solar collector is equal to the ambient temperature. The solar collector outlet temperature is measured at the end of the duct length which is equal to the drying closet inlet temperature. The measurement of temperature at the solar collector outlet is not convenience because of the fixed connection of the flexible duct at the solar collector end. The only way to take measurement at the outlet will destroy the duct fitting and also will contribute to air leaking. Therefore, the analysis of the solar collector will involve the ducting system. The temperature difference is calculated in order to calculate the useful heat delivered from the solar collector to the drying closet by using equation 2.6. The efficiency for this solar collector is calculated using the equation below:

$$Solar\ Collector\ Effeciency, \eta = \frac{Q_{useful}}{Solar\ Radiation\ Falling\ on\ surface\ x\ Area\ of\ Collector}$$

Table 4.1: Solar Collector Efficiency

Time	Radiation (W/m^2)	T_{inlet} (^0C)	T_{outlet} (^0C)	ΔT	Heat Useful (W)	Efficiency
0900	40.46	24.2	24.7	0.5	68.22425	1.405179
0930	54.39	25.3	25.7	0.4	54.5794	0.836235
1000	67.18	25.9	26.6	0.7	95.51395	1.184801
1030	92.47	26.2	26.9	0.7	95.51395	0.860765
1100	110.63	27.4	27.4	0	0	0
1130	191.93	27.5	28.3	0.8	109.1588	0.473952
1200	471.1	30.6	31.2	0.6	81.8691	0.144819
1230	624.6	29.6	32.7	3.1	422.9904	0.564348
1300	620.3	29.5	32.6	3.1	422.9904	0.56826
1330	304.2	31.6	35.9	4.3	586.7286	1.607299
1400	386.7	30.3	34.6	4.3	586.7286	1.264392
1430	520.4	30.9	33.6	2.7	368.411	0.589948
1500	611.9	35.8	36.8	1	136.4485	0.185826
1530	381.4	32.8	36.3	3.5	477.5698	1.043458
1600	233.7	31.6	34.7	3.1	422.9904	1.50831
1630	160.7	31.3	33.9	2.6	354.7661	1.839691
1700	189.92	31.3	33.2	1.9	259.2522	1.13755

From the table above, it is shown that the temperature difference is relatively small which is not more than 1^0C during the morning time and not more than 5^0C for the rest of the testing time. This is due to the outlet temperature is taken with the ducting system. Some of the heat absorbed at the solar collector is dissipated along the ducting system. The heat absorbed by the solar collector also decreased because of high flow rate of air within the system which is taken from the exhaust fan specification booklet stated at 7.0 m^3/min. Other factors that contribute to the lower efficiency of this solar collector is high length between air passage way inside the collector. Because of this factor, the air will flow along the middle of the passage way and will not touching the passage wall therefore the air cannot absorb heat from the wall.

4.2.2 Drying Operation

During the experiment, the closet needs to dry 8 hanging after spin clothes of different material. The variation of the drying closet inlet and outlet temperature is shown in figure 4.4. From the graph, there are different between the inlet and outlet temperature. This is happening due to the heat transfer process in drying where the heat energy is being used to evaporate the water from the wet clothes.

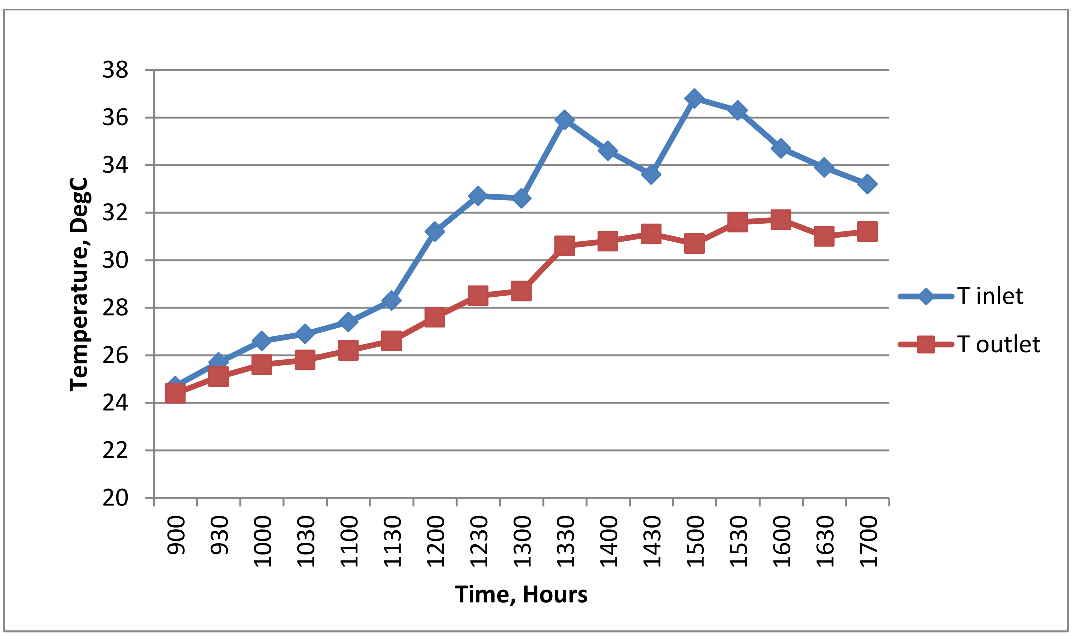


Figure 4.4: *Graph showing the variation of the drying closet inlet and outlet temperature with time of the day (November 11, 2008)*

The variation of the drying closet inlet and outlet relative humidity with time of the day is shown in figure 4.5. The graph shows that the closet outlet relative humidity is higher than inlet. This is due to the fact that during drying operation the heated air absorbs the water moisture from the wet clothes.

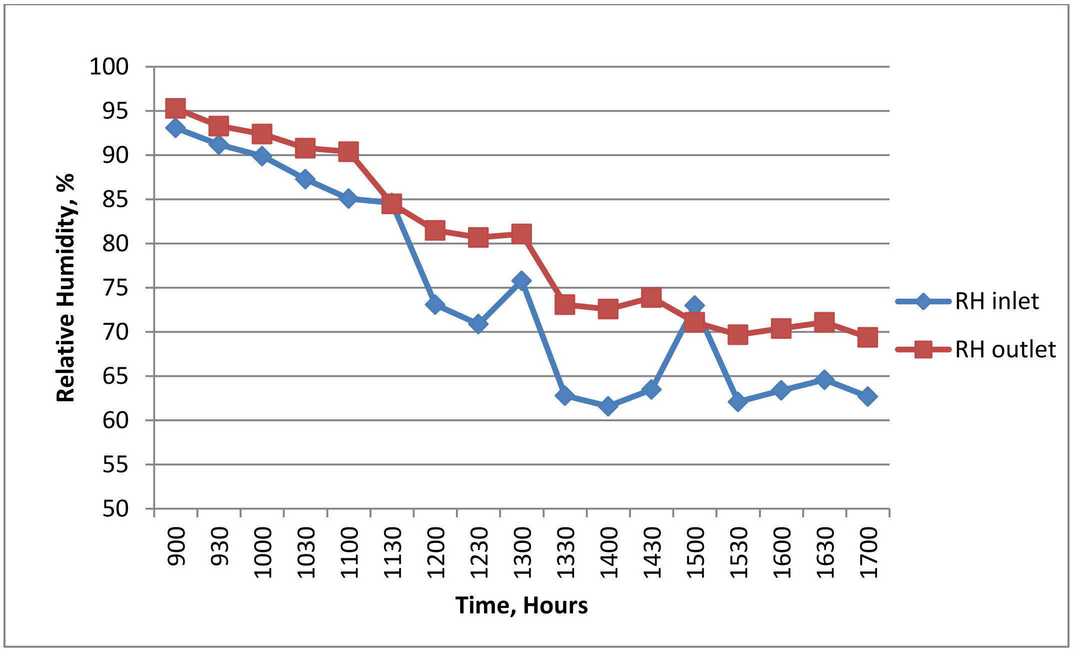


Figure 4.5: *Graph showing variation of the drying closet inlet and outlet relative humidity with time of the day (November 11, 2008)*

Figure 4.6 shows the variation of the clothes weight during the drying operation. In the drying process, the water moisture within the wet clothes is removed. By that principle, the weight of the wet clothes will be reduced. The weight of the clothes is measured as a whole. From the graph, the weight of the clothes is slowly decreasing from 2.4 kg until 1.78 kg at 4.00 pm. The weight is not reduced after that since all the clothes has already dried.

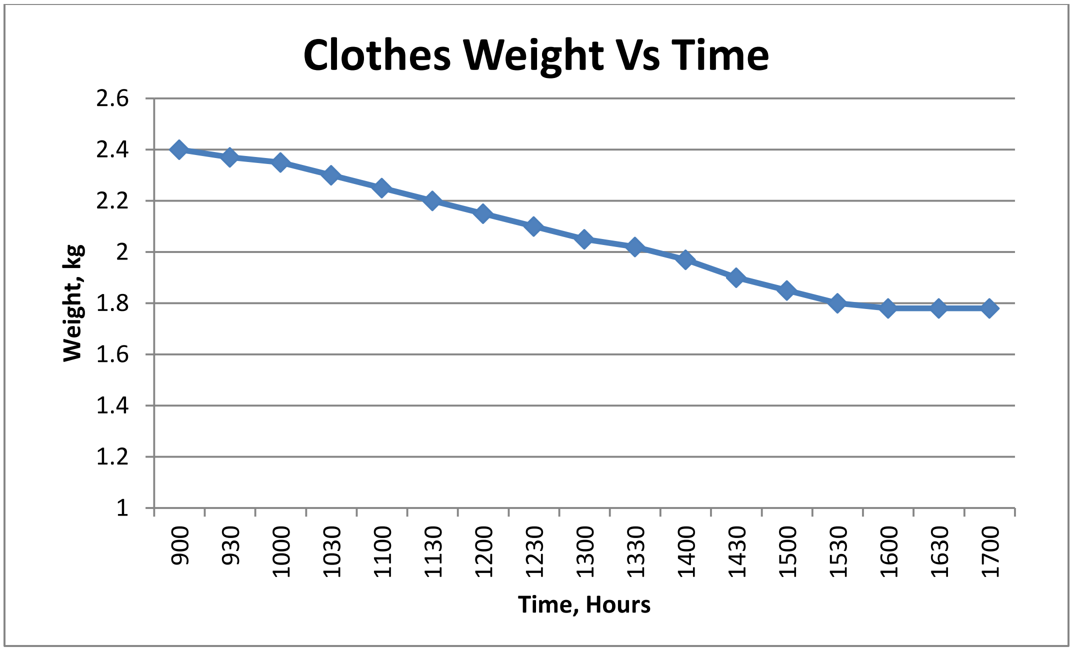


Figure 4.6: *Graph showing variation of clothes weight with time of the day (November 11, 2008)*

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project has further widened the applications of the solar resources in our daily usage equipment. The concept development and embodiment design phase has been completed with the schematic diagram of the cloth drying closet as a result. The detailed design work was completed and the technical drawing set was available in the appendices. The fabrication works which include purchase of materials, fabrication, assembly and testing is carried out after the drawing has been approved. Testing and analysis has been done to evaluate the performance of the proposed system to dry clothes.

The analysis of the solar collector involved the ducting system. The solar collector efficiency is relatively small with the average at 1% due to the heat loss at ducting system, high air flow rate which is 7.0 m^3/min, and distance between walls inside the collector is far.

During drying process, the difference between the closet inlet and outlet temperature is due to the heat transfer process in drying where the heat energy is used to evaporate water from the wet clothes. The closet outlet relative humidity was found higher than the inlet because of the heated air absorbs the water moisture from the wet clothes during the drying process. The clothes weight was slowly decreasing from initial value of 2.4 kg until final value of 1.78 kg because all the water moisture within the wet clothes has been removed. The final weight value indicates the dry clothes weight.

As the whole conclusion, with full commitment towards completing the project tasks, this project is successful as it is meet the objective of the project through hard work and good engineering judgment.

5.2 Recommendations

The project can be improved by properly designed the closet so that it will be completely sealed and also to avoid air leakage. The efficiency of the solar collector can be increased by using a V-corrugated or finned type of absorber plate. Also, thinner metal can be used for v-groove collectors, as triangles are structurally stable from the construction point of view. Double pass operation also further increases the efficiency of the collector. The amount of heat transfer can be maximized by reducing the ducts length and also develop a bigger collector area.

The prototype testing result can be improved by redesigning the solar collector air passageway and the exhaust fan. The gap between walls inside the solar collector should be reduced so that during operation, the air flow will touches the walls and carried away the heat absorbs by the walls. The exhaust fan can be replaced with a smaller size and power so that the air flow rate can be decreased to allow ample time for the air to absorb heat from the solar collector.

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