Design & Development of Environmental Chamber for Solar Cell Testing

A Thesis Submitted for Partial Fulfillment
Of the Requirement for the Award of the Degree of
Bachelor of Science in Mechanical Engineering

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ASTRACT:

Use of renewable energy is becoming extremely important with time due to depleting fossil fuels and increasing CO2 levels causing global warming. In this aspect Solar energy has shown promising prospects to fulfill modern energy demands. Therefore, a strong need has arisen to develop economically viable and efficient technologies to harness the huge energy potential provided by the sun. Commercially huge testing chambers are used for the testing of solar panels but there is a lack of unified testing chamber for the testing of a single solar cell. We have developed a one of its own kind of environmental chamber for performance testing of a single solar cell at different solar illumination levels under known temperature and environmental conditions. This chamber will focus on testing of different types of solar cell against variation of environmental parameters. The chamber has a controlled environment wherein the solar cell shall be mounted. A temperature control system has been incorporated in the test chamber that has the ability to control and maintain temperature surrounding the cell at desired level

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CHAPTER 1

INTRODUCTION

1.1 Background:

With the increasing World energy demands and increasing fossils fuels prices, Renewable energy has gain more importance in the recent years. In 2008, total worldwide energy consumption was 474 exajoules (132,000 TWh). This is equivalent to an average power use of 15terawatts.[1] The annual potential for renewable energy is:

- solar energy 1,575 EJ (438,000 TWh),
- wind power 640 EJ (180,000 TWh),
- biomass 276 EJ (77,000 TWh),
- hydropower 50 EJ (14,000 TWh) [2][3][4]

The estimates of remaining non-renewable worldwide energy resources vary, with the remaining fossil fuels totaling an estimated 0.4 YJ (1 YJ = 10^{24}J) and the available nuclear fuel such as uranium exceeding 2.5 YJ. Fossil fuels range from 0.6 to 3 YJ if estimates of reserves of methane are accurate and become technically extractable. The total energy flux from the sun is 3.8 YJ/year, though not all of this is available for human consumption. The IEA estimates for the world to meet global energy demand for the two decades from 2015 to 2035 it will require investment of $48 trillion and "credible policy frameworks." [5]

According to IEA (2012) the goal of limiting warming to 2 °C is becoming more difficult and costly with each year that passes. If action is not taken before 2017, CO2 emissions would be locked-in by energy infrastructure existing in 2017. [6]

Therefore, focus on Renewable Energy has been increased manifold in the past few years. Energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat.[7] Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services.[8]

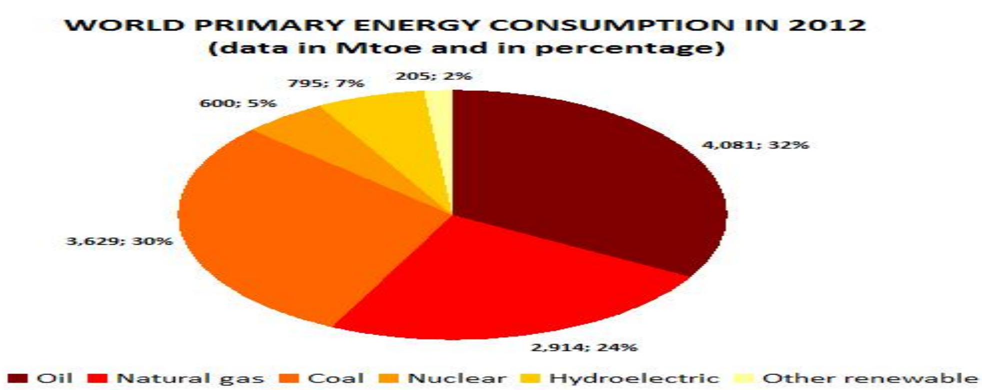

Figure 1.1 [9]

Renewable energy resources all have one common source of energy in the form of the sun. Most of the world's high energy resources are from the conversion of the sun's rays to other energy forms after being incident upon the planet. Some of that energy has been preserved as fossil energy; some is directly or indirectly usable; for example, via solar PV/thermal, wind, hydro- or wave power. The amount of energy is measured by satellite to be roughly 1,368 watts (1.835 HP) per square meter [10]. It is therefore natural for researchers to look towards harnessing this huge potential in order to meet mankind's growing energy needs. Furthermore, solar energy is clean and environment friendly, thus eliminates potential ill effects on the environment in the form of greenhouse emissions and pollution.

Solar Cells are Converters of sun energy to electrical energy. Only some part of sunlight energy is converted to useable electrical energy and remaining energy is wasted due to low efficiency of solar cell [11]. Like chloroplasts in plants, solar cells can only absorb specific wavelengths of light. Remaining sunlight is reflected, transmitted or absorbed into the substrate. In 2012, solar panels available for consumers can have an efficiency of up to about 17% [13] while commercially available panels can go as far as 27%. It has been recorded that a group from the The Fraunhofer Institute for Solar Energy Systems have created a cell that can reach 44.7% efficiency, which makes scientists' hopes of reaching the 50% efficiency threshold a lot more feasible. [14-16]

Therefore great research potential is present in the area of development of efficient technologies for the conversion of solar energy into usable energy. In order to address this issue a testing chamber has been developed for the testing of single solar to check the efficiency under different environmental conditions. The testing chamber incorporates temperature control system as well as the feature of testing the solar cell against specific wavelengths of radiation. This study is focused on the effect of rise in temperature on the solar conversion efficiency of the cells at different sunlight intensity.

1.2 Aim & Objectives:

The basic aim of the project is as following

- To develop a innovative and portable cost effective environmental testing chamber for solar cell performance evaluation at various environmental conditions.

The overall objectives of the project are as follows:

- Perform literature review for solar cell testing and performance evaluation.
- Design & development of Environmental Chamber for PV cell Testing.
- Design & Development of Temperature controlled PV Cell Bracket.
- Instrumentation of Chamber
- Design of PID controller using LABVIEW for Temperature Control.
- Temperature control Testing of Chamber.

1.3 Literature Review:

1.3.1 Introduction:

In this chapter, we collect information about previous testing chambers setups and testing of solar cell under different conditions. The information has been collected from various journal papers and conference papers.

1.3.2 Testing Chamber Setups:

THERMOTRON- Solar PV Testing (A white paper) gives information for overview plan for designing of Environmental chamber for PV panels. This also gives requisite standards for PV panel's testing [17]. C. James Taylor focus on automatic control of temperature and ventilation rate inside chamber by good programming using software's like MATLAB and Simulink. He selected aluminum for the chamber material [18]. Michael D. Kempe satisfactorily tested photovoltaic devices in accelerated stress chamber by using xenon arc lamplight for evaluation of 20 years of exposure effect. Largely focused areas were Transmissivity and power efficiency [19]. Suren A. Gevorgyan, Michael Jorgensen Frederik C. Krebs made an atmostphere chamber under artificially created vacuum conditions for polymer photovoltaic cell testing [20]. Sarah Kurtz and her companions investigate temperature varying factors and give analysis how long term and short term degradation of material occur [21].

1.3.3 Testing methods Information:

Suren A. Gevorgyan and his companions analyze long term degradation mechanism in organic devices. Four parameters are discussed and analyzed to find the degradation mechanism i.e. Short circuit current, open circuit voltage, fill factor, Power conversion efficiency [22]. Oliver Haillant describes sunlight, humidity and temperature test and their accelerated effects on organic and polymeric PV devices. He also describes reliability and durability of a product [23]. Tony Smaples and his companions give analysis of damp heat test. The four parameters i.e. short circuit current, output control voltage, fill factor and Max, pressure are discussed [24]. Joseph Burdick, Jim Pruett, Elvira Beck give analysis of module qualification testing procedure for thin crystalline photovoltaic modules. In this procedure, the requisite parameters for thin film crystalline photovoltaic modules are being analyzed [25]. Mathew O. Reese, Suren A. Gevorgyan, Mikkel Jorgenson conduct various types of tests to evaluate the reliability of tests and to find out the operational accuracy of organic solar cells. The tests include thermal cycling tests laboratory testing outdoor testing and shelf life testing etc. The tests consist of different chambers with various types of controlled conditions used [26].

1.3.4 Summary:

This chapter gives brief information about various testing chamber setups which are existing nowadays. It also gives brief information about various testing principles which are performing inside testing chambers.

Chapter Two

METHODOLOGY

This chapter covers full details of how manufacturing of the chamber. This starts from the designing of the chamber to the testing of the solar cell.

2.1 Design Specifications

2.1.1 Introduction:

Our goal is to have a compact chamber for testing of photovoltaic cell. The design requirements consist of material selection according to our required parameters.it will show a very Low pressure and very high temperature regulation inside the chamber.

2.1.2 Parameters to Control inside Chamber:

Temperature, Humidity and pressure are the three parameters which should be applied and control in the chamber but on present stage we are dealing with two parameters e.g. temperature and pressure. These parameters should be generated inside the chamber and the chamber should be sealed and properly insulated from the outside environment so that the environment set up inside won't be distorted.

2.1.3 Design Requirements for Environmental Testing chamber:

Before going into the detailed methodology of the manufacturing of the environmental testing chamber, first I would like to investigate into the initial design requirements of our testing chamber. All the components specification depends upon the design requirements for environmental testing chamber. The temperature range inside our chamber should largely vary. The max temperature we should attain should be 70°C and minimum temperature it should attain is 0°C. The low pressure should be attaining through vacuum pump and it max value should be -26 inch of Hg or -66 cm of Hg. The solar intensity level is 200-1000 wb/m2. The chamber has the capacity to test only 1 photovoltaic cell at a time.

The following table shows all the design criteria for the required environmental testing chamber setup.

Table 2.1 Testing Chamber Specifications:

Temperature range	0° to 70°
Operating pressure	-26 inch of Hg or -66 cm of Hg
No of PV cell	1
Required radiation level	200 to 1000 Wb/m2
Chamber size	200mm width 200mm length 200mm heigth

2.1.4 Basic Design and Material specification for various components:

2.1.4 .1 Dimensions and design of chamber box:

The chamber dimension has been finalized according to the solar cell availability and the bracket size .As we are not doing internal space heating and space cooling so volumetric heat calculation doesn't need to be sorted out. We have done the chamber size selection by putting 2 design in front of us i-e square box and cylindrical . Both of the design has their merits and demerits given below.

Rectangular chamber	Cylindrical chamber
Easy to fabricate	Difficult to fabricate
Proper spacing is available for internal component to adjust within	Different components haven't proper spacing so disarrangement is possible
Machining can be easily done	Machining is difficult for cylindrical
Rectangular glass window is needed for the incident of sun rays which didn't change the incident rays angle.	Curvy glass window is needed which alter the incident sun rays at different angles.
Heat calculation per unit volume can be done in X Y Z coordinates	Heat calculation per unit volume can be done in cylindrical coordinates which leads to error.
Sealing media can be easily coated on rectangular walls	Sealing media can be difficulty coated on cylindrical walls
Proper facial view and top and bottom face differentiation with legs on bottom end to stand upon.	No such top and bottom face recognition and rotation can be possible to misalign the internal components.

On the basis of the above discussion we have finally selected the square chamber.

The dimensions were finalized such that accordingly to the availability of the solar cell in the market. Our dimension was 200x200x200(mm). It is finalized so that we have enough space for instrumentation inside the chamber and also have clear and full light incident on the PV cell placed on the bracket.

2.2 Material selection for the chamber:

2.2.1 Material selection for the chamber Cover:

We have selected material on the basis of the good machinability and good corrosion resistance.

Two options were there first Aluminum and the other one is stainless steel. Aluminum is very fine and light weights but the difficulty we have by selecting it is that its welding is difficult job so we have discarded it and selected Galvanized Mild Steel called MS instead of stainless steel because it has the same properties as stainless steel have but it is very cheap and economical.

Mild Steel or Plain Carbon steel

Mild steel, also known as **plain-carbon steel**, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications, more so than iron.

Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm^3 (7850 kg/m^3 or 0.284 lb/in^3) and the **Young's modulus** is 210 GPa (30,000,000 psi).

Table 2.2 Mild Steel Specifications:

Type	Mild steel or plain carbon steel ASI 1018
Max thickness req.	5mm
Machinability	78%
Corrosion rate	25-50 **(µm)**[a]
Density	0.284 lb/in^3
Hardness brinell	131
Tensile Strength, Ultimate	65300 psi
Tensile Strength, Yield	45000 psi
Modulus of Elasticity	29000 ksi
Thermal Conductivity	360 BTU-in/hr-ft^2-°F

- **µm = micrometer**
- [a] **= the thickness loss values are after the first year of exposure. Losses may reduce over subsequent years.**

2.2.2 Design and material selection for bracket:

Design and Dimensioning:

The design has been selected according to the chamber shape and size and solar cell availability. The solar cell available in the market has a dimension of 50×30 mm size. The heaters we have to use for the heating of the bracket have dimensions i-e 75 mm. So our bracket dimension must be more than 75 mm so that it can compensate the heaters completely. The shape of the bracket must be square or rectangular according to the PV cell. So we have finalized our bracket design and shape to be a square having dimensions of 80x80×40 mm. such that we will place one solar cell in the middle plus we have space for the heaters to be inserted in the bracket and also have channels for cold water to flow across.

Table 2.3 Temperature Control Bracket Specification:

Bracket size	80 x80 ×40 mm
No of PV cell	01
PV cell size	30x 50 mm

Material Selection for bracket

Material should be selected on the basis of good thermal conductivity good corrosion resistance and good machinability.

We select Aluminum Alloy 6020 because it has the following characteristics.

- Good heat transfer
- Excellent machining
- Low density
- High corrosion resistance.
- Economical
- Good conductor

Table 2.4 Aluminum Specifications:

The table below shows the specification of Al alloy 6020

Type	AL alloy 6020
Machinability	90%
Corrosion rate	0.001 mg/mm2 per hour
Thermal conductivity	1190 BTU/Ft2/In/hr
R-Value	0.61/in thickness
Yield strength	42 Ksi

2.2.3 Material selection for insulation of the chamber and glass window:

We should select the rubber pads for glass windows to resist permeability of outside environment into inside environment. We should select rubber pas which have very low gas permeability. The rubber pad should sustain requisite high and low temperature inside the chamber.it should have a very good protection against pressure difference as we have to maintain a very low pressure inside the chamber so it might prevent air leakage inside the chamber. We should need rubber pads with requirements which will show in the table below.

Table 2.5 Insulation Material Specifications:

Temperature range	0-70
Pressure sustain range	1 atm to – 66 cm of Hg
Permeability to Gas	0.001 mm2
Size range	Width 3mm and depth 3mm

Selection of material for chamber insulation

We select Butyl O-ring because it mostly matches the above requirements. The characteristics of the Butyl O-ring are shown in Table below

Table 2.6 O-ring Specifications:

Type	Butyl O-ring
Temp	0-70 degree centigrade
Butyl O-ring hardness	65
Permeability to Gases	0.015mm2
International size standards specification applicable	AS568B(-028 size)
International size range available in market	Min Thickness 1.78± 0.088

2.2.4 Insulation of the nozzles and glass windows and cold water flow channels:

The required insulation should have a good high thermal resistance low air permeability and low noise resistance. The testing chamber should be isolated from outside environment. There should be no infiltration of outside environment to impact on inside chamber . The insulation should be selected by considering following below parameters

- High thermal resistance
- Air resistance

The following table will show us the requirements of the insulation type specification

Table 2.7: Insulation Specifications:

Thermal conductivity	< 5 BTU/hr FtF®
Water absorption	40%
R-value	7
Temp range	0 to 70°C
Thickness tolerance	2.54 mm + 0.2mm

We selected spray gel silicon   for the sealing purposes of chamber. Its specification meets our requirements.

Table 2.8: Silicone Gel Spicifications:

Type	Silicone gel insulation
R value	6/inch
Water absorption	70%
Thermal conductivity	2 btu/hr.ft at 93°C
Permeability	0.2%
Air absorption	99%

2.2.5 Design of heating system and heaters:

Heating system:

Since our heating system involves the direct heating of aluminum block called solar cell bracket, in order to achieve this we have made 2 holes in our aluminum block each 10mm and has put the cartridge heaters inside it. The power rating of each heater is 300 watts. The purpose of the heaters is to raise the temperature of the block to the required testing temperature as it will be connected to the main 220v and it will interfaced with the lab-view through PID controllers and PWM to control the temperature of the block at the required point through a temperature sensor called K-Type thermocouple.

Heaters and it types:

There were so many heaters available in the market like glow plug of diesel engine, spring heaters plate heaters but we have selected the cartridge heater which can be easily interfaced with the LabVIEW and relay system.

Table 2.9: Cartridge heater specification

Type	Cartridge heaters
Power rating	300 watt each
No of heaters required	02
Battery rating	220 v Ac
Current drop	1.36A each
Dimensions	10mm diameter and 75mm length

Note : initially we have used the glow plugs for heating system but it has a draw back as it draw more current i-e 10-12A which is too much for a relay to control and also DC battery with this much current rating is not available in the department.

2.2.6 Design of Cold water flow through pipes and cooling system:

Cold water is used to pass through the bracket in order to cool down the temp of the Bracket heated initially by the heaters. As we are heating the Aluminum block directly through heaters and there will be no Air inside the chamber so cooling down the bracket will take a lot of time, for this purpose we will use a flow of cold water at 4°C through the bracket to bring down the temperature of the bracket to the required temp.

Design selection:

Since we have a bracket dimension i-e 80x80×40 so in order to have a maximum flow rate through the Al block we have distributed our cold water flowing channel such that they will have a uniform cooling effects throughout the block.

We have made three holes each diameter of 12.5mm and center to center distance is 30mm in the middle of the Al block as shown in the figure below.

Table 2.10 Cooling Mechanism Specifications:

No of channels in AL bracket	03
Diameter of each channel	12.5mm
Flow rate of pump	0.2L/sec
Capacity of water sump	10L

Purpose of using cold water:

The main purpose of the cold water is to dampen the system which means to control the whole temp rising and temp downing of the system. The temp will rise by the heat given from the heaters and it will be controlled at a certain point by the signal switching off from the LabVIEW. The water will serve the purpose of dragging down the temperature and the heater will shoot it up and a certain point will reach where the temperature will be stabilized after brief duration of time.

Parts of cooling system mechanism:

There are many parts which are used in cooling system mechanism. We will explain one by one in detail.

Parts of cooling system mechanism

- Water pump
- Water sump
- Water flowing channels
- Nozzles
- Multi channels to single channel converter
- water

2.2.7 Pump:

Since our cooling mechanism needs to flow water across the block continuously. So for that purpose we need a pump to do so. Different pump has been analyzed and its flow rate has been measured. We can use different pumps for cold water flowing purpose but we had selected aquarium pump for the aforementioned purpose.

Properties of the Aquarium pump:

- It is submersible in the water
- It is small in size and can fit into a small sump.
- It has very good flow rate.
- Cheap and economical

Table 2.11: Water Pump Specifications:

Pump type	Aquarium pump
Flow rate	0.2L/sec
Battery required	220-240 AC
Current drop	0.05A
Type	submersible

Water Sump:

The water sump we had used has the capacity of 10L of water storage. The pump has been submersed in the sump and the water will flow out and in to the sump continuously and will flow across the Al bracket.

Table 2.12: Sump Specification

Type	Close bucket Sump
Capacity	10L

Nozzles and Multi channels to single channel converters:

Nozzles

Nozzles or nipples have been used for the channel connecting with the AL block. Each nozzle has a dimension of 12.5 mm diameter. Six 12.5 mm diameter nozzles has been used and had connected with the Al bracket through which channels had been tied.

Rubber channels:

The rubber channels have been used for the connecting purposes and flowing of cold water through the whole Al bracket, water pump and sump.

Multi to single channel convertor:

A GI convertor has been used with the nipples to convert the single to 3 channels flow of cold water which can pass through the bracket for cooling purposes and back to single channels from 3 channels to flow again into the cold water reservoir.

Table 2.13 Pipes and Convertor Specifitions:

Type	Quantity and dimensions
Nozzle	06 , 12.5 mm dia each
Rubber pipe	6 m, 10 mm dia
Single to multi stage convertor	02 , 16 mm dia each

Water as a cooling media:

Water has been used as cooling media and is continuously circulated across the system through the pump. Water is considered as the best cooling media because it has a high heat capacity and it can better absorb out the heat efficiently for a very long duration of time. The temp of the water has kept low by putting the ice manually into the water sump which can keep the temp of water at 4°C for a very long duration of time.

Table 2.14: Cooling Medium Specifications:

Water heat capacity , C	41.6
Water quantity used	10L
Water temp maintained in the sump	4°C

2.2.8 Vacuum pump:

In order to have a very low pressure inside the chamber we will acquire vacuum pump for that purpose. The low pressure has been needed, because we only do bracket heating and cooling and for that purpose we didn't need any inside air in the box or chamber. So in order to evacuate out the Air from the inside we have connected the vacuum pump to the box and the Air has been evacuated up to the certain limit i-e – 26 inch of Hg or -66cm of Hg.

Vacuum pump has been searched in the market but we didn't find any suitable vacuum pump. The second alternative we have to use the compressor of the small refrigerator connected on the opposite side will work as a vacuum pump. So the small compressor is connected to the chamber such that it will evacuate the air from the inside leaving a very low pressure. The purpose is to maintain a very low pressure and strict environment inside the chamber.

Regulation of the pressure:

The pressure can be regulated through the relieve valve connected with vacuum pump and pressure gauge. We can set our inside pressure according to our own requirements.

Table 2.15: Vacuum Pump Specifications:

Pressure range	1 atm to -26inch of Hg
Vacuum pump size	Small refrigerator compressor
Weight	12kg

2.2.9 PV Cell:

The solar cell which is also called PV cell has been used as a testing material. Different PV cells are available in the market. We had selected the silicon based solar cell. The dimension of the solar cells is the one which are made available from the industry. The solar cell will work in the following pattern

Working of the solar cell:

When the solar rays falls upon PV cell surface the electron and holes get energized and start jumping towards the opposite poles i-e electron towards the P junction and the holes which are positive charged move towards the N-junction. So by this mean they will create a polarity at the respective junction and PV cell will work like a battery. The solar cell will give out the volts in the form of output as long as the solar rays are incident on it.

Testing:

The required testing temperature has been gained through PID controllers and thermocouple interface with the Lab-view. Once the temp has been maintained inside the chamber the solar cell testing should be done by measuring its output according to the intensity of the solar arrays falling upon its surface. The intensity of the solar rays should be determined through lumen meter and the output graph in the form of varying volts should be plotted against intensity.

Table 2.16: Solar Cell Specifications:

Solar cell type	Silicon
Dimension	50x30 mm
Thickness	2mm
Max output	2 volts

2.2.10 Thermocouples:

Mounting:

Thermocouple should be mounted on the bracket near the PV cell. So that it can detect the temperature of the nearby surface of the AL bracket.

Working:

Thermocouples used as a sensors for sensing the temperature of the bracket which is heated by the cartridge heaters supplied by the main 220v AC. Since it is a temp sensing element so it will work to detect the required temp and giving its signal output to the lab-view software interfaced with it through DAQ Data Acquisition USB.

When the temp should reach to the targeted temp it will give signal to the LabVIEW accordingly in the form volts. The function of the lab-view is to control the temp through PID controllers by switching off and on the relay system connected with DAQ and main 220VAC.

The LabVIEW will give a switch off signal to the relay and automatically the heaters will be off by cutting off the main 220vAC.

Thermocouple type:

The type of the thermocouple used in our project is called the K-Type thermocouple. We can use K-Type thermocouple because it can be easily interfaced with the lab-view system and also it has a vast range of temperature sensing range. Also it is very sensitive and it senses the temperature change very quickly.

Table 2.17: Thermocouple Specifications:

Thermocouple type	K-Type
Temperature range	-200 to 1350 °C
Size	Micro level

2.2.11 Glass window:

Different type of glass window should be used for the testing of solar cell under the sun rays.

- Tempered glass
- Ultra violet glass
- Plane glass
- Infrared glass

We used plane glass in our project. The fact in using the plane glass is that it is easily available in the market plus it can’t filter the solar rays. The rest of the glass window should be used only when there should be the filtering of the solar rays for the testing.

Purpose of the Glass window:

The glass window should do the following two purposes i.e.

- Sealing the box from external environment
- Providing a transparent media to solar rays to fall on the PV cell.

Safety measures:

The glass shouldn’t be scratched otherwise it will spoil our result. Also scratched glass will lead us to miscalculation plus the solar cell wouldn’t be fall directly straight upon the PV cell as it will be changed through the angles made by the cracks and scratches.

Complete methodology of manufacturing of the environmental testing chamber using solar cell:

The methodology of our project consists of design which has been described above and now this chapter will cover the manufacturing of the chamber system. The last chapter will cover the final result of testing the solar cell

2.3 Manufacturing of the components:

2.3.1 Chamber

The chamber is manufactured from the following processes

- Cutting
- Welding
- Filing
- Riveting
- Machining
- Drilling

a) **Cutting:**
First the plate size and dimension has been finalized. After the design and dimension has been finalized the plate has been cut into the required pieces. The plain carbon or Mild steel plates are used and its cutting is done with heavy End mill saw.

b) **Welding:**
The plate size 200×200×5 mm has been connected with each other to form a box through welding. The welding has been done through electric welding appliance placed in the NUST MRC.

c) **Filing:**
After the welding has been done the box so formed has been filed to remove the flashes left behind after the welding. So the filing of the plates has been done through files available in the MRC NUST.

d) **Machining:**
In order to seal the box we have made the lid design like it will have a 16mm strip with a grove at the 3mm depth from the inside. For that purpose we cut the plate size 200×200 mm. the plate is cut in a shape such that a piece of size 168x168mm has been cut off in the middle remaining a square thin strip of 16mm on each side.
Now the machining of the strip has been done. A groove has been made on a distance 3mm from the inside and the depth of the groove is 3mm. the purpose of the groove is to put an O ring inside the groove to seal it off.

e) **Riveting:**
The upper plate has been placed has been on the box to make it completely sealed. For that purpose riveting or joining has been done. Screw size M5 has been used.

f) **Drilling:**
Drilling has been done for holes size M5.

2.3.1.1 Chamber Lid Manufacturing:

The manufacturing of the top Lid or plate has been done through the following processes.

- Milling
- Cutting
- Drilling.

1-Milling

First the plate size 200×200x7 mm has been milled and extra material has been removed. The uneven surface and chips has been removed through milling. After the milling has done. It is ready for cutting.

2 – Cutting

Plate has been cut in the middle i-e the material has been removed for adjusting the glass. The size of the glass window is 100×100 mm. so the material from the inside is removed and window has been created for placing the glass which will allow the sun ray to fall on the solar cell.

3 – Drilling

The M5 size holes have been made through drilling in the plate.t they will serve for the adjusting of the plate with chamber or box.

2.3.2 Manufacturing of bracket for solar cell:

The bracket has been manufactured the following processes,

a) Milling
b) Drilling

1 – Milling.

Bracket has been manufactured from Aluminum through Milling in CNC milling machine. Raw Al block has been refined and cut into the required size. After the cutting it has been machined and shined through CNC milling machine. The groove has been made for placing the solar cell with the dimension 54x 32 mm.

2 – Drilling

Drilling has been done through the same CNC milling machine. Two holes made into the block for cartridge heater and other 3 holes are made for passing the cold water through the channel.

The dimensions of the Holes are 10 mm for heater and 12.5mm for cold water channel.

2.3.3 Placement of bracket in the chamber:

A plain carbon strip has been welded in the inside of the box. The dimension of the strip is 40mm width and 200 mm length. The strip is welded on the height of 100 mm from the base of the chamber. Two M6 holes are being made into the welded strip in the middle. A wooden pocket used for placing the Al bracket is joined with the welded strip through screws size M6. The basic purpose of the wooden strip is to make the chamber insulated from the Al bracket. No heat loss can flow through the bracket to the chamber. Also the chamber is insulated from any electrical current flow from Al bracket to the chamber.

Drilling of holes for the pipes in the chamber:

The holes are used for the passing the pipes through chamber wall which will further connected with the bracket through nozzle. The basic purpose of these channels is to pass the cold water through the AL bracket to make it temperature low for controlling purposes.

Six holes each size 12mm has been made through drilling in the chamber wall. The height at which these holes are made are at a 140 mm above the base line of the chamber. The distance between each hole is 30 mm according to the distance between nozzles in the AL bracket. The pipes has been passed though these holes and sealed with silicone gel.

Glass window in the Lid:

The glass has been clipped or joined in the window made in the upper plate called sealing Lid. The glass has been joined with the silicone gel and is completely sealed thoroughly.

2.3.4 Connection of vacuum pump with the chamber:

The vacuum pump used for the purpose of making the vacuum inside the chamber is connected with the chamber. The lead of the vacuum pump connected with the pressure gauge is inserted in the hole drilled in the chamber wall. The lead and the hole are completely insulated through silicone gel.

2.4 Schematic Diagram:

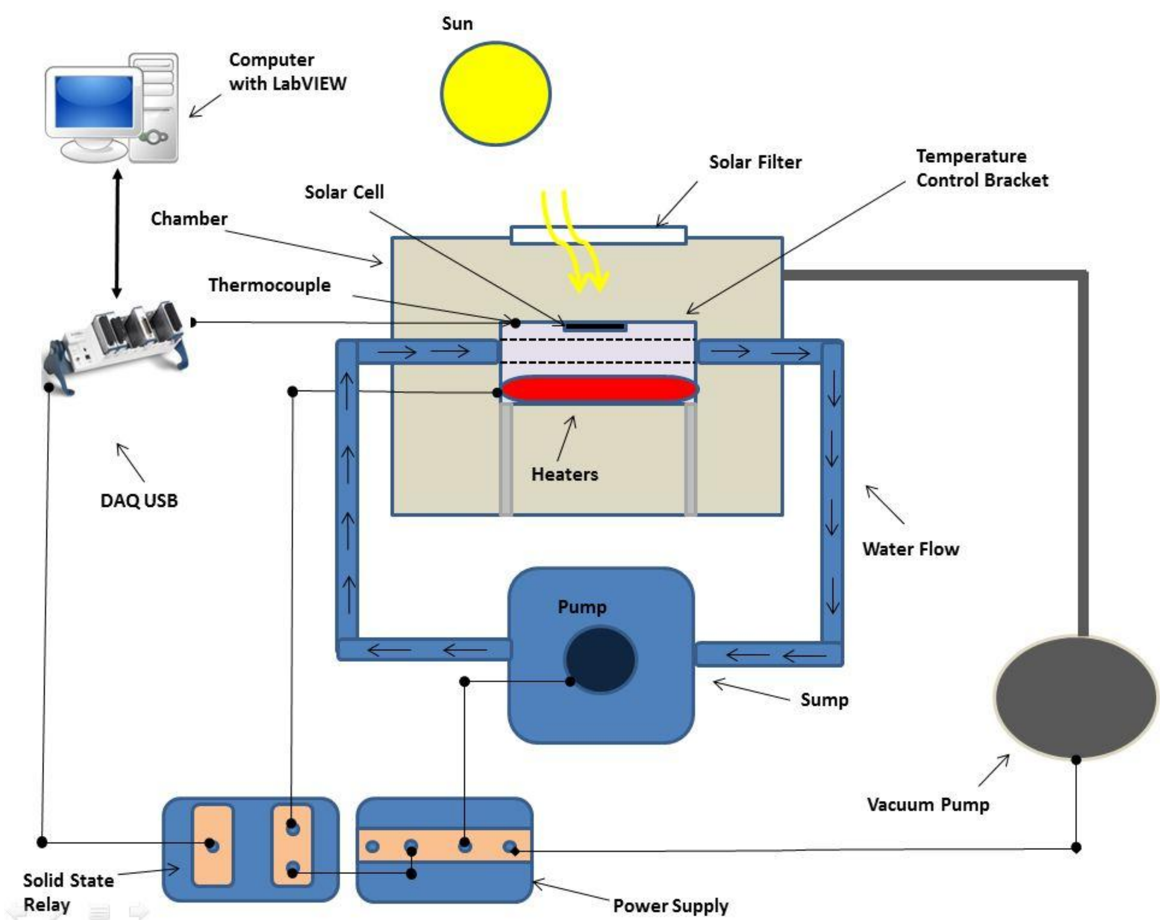

Figure 2.1 Schematic Diagram

CHAPTER 3

Instrumentation & Control:

3.1 Instrumentation:

The instrumentation of our project includes the installation of the following appliances and sensors in the chamber and AL bracket.

- heater
- solid state relay
- pump
- DAQ USB
- thermocouple
- vacuum pump

3.1.1 Heater:

The heaters are connected with the 220V main Ac. The heater is inserted in the AL block at an equal distance. The ground of the both the heater are connected with each other and then connected with negative end of the solid state relay. The other end of the heaters are connected with the one end of the 220V Ac and the other end of the 220V AC is connected with the positive of the solid state relay.

3.1.2 Solid state relay:

Solid state relay is used for the switching of the heaters with the PID controller used with PWM. Solid state relay is operating on DC 3-32 V and it is used for switching of the heaters with the 220V AC.

3.1.3 Pump:

The pump has been connected with the external 220V AC. It will run continuously to circulate the cold water flowing in the channel. The water is kept cool by putting the ice manually into the water Sump.

3.1.4 NI DAQ USB:

The Ni Data Acquisition USB is connected with Lab-view software through computers. It takes the signal from the thermocouple connected on the surface of the Al block. The signal has been manipulated in the software and compared with set point and the output signal generated on the I/O port is given to the relay system passes through PWM to the relay for switching on /off.

3.1.5 Vacuum Pump:

The vacuum pump is connected with the main 220V AC. The vacuum is running continuously till the required pressure is achieved. It will be then manually turned off once the required low pressure is achieved.

3.1.6 Thermocouple:

K-type thermocouples are used for the sensing of the temperature. The thermocouple is installed on the surface of the AL block. The thermocouple is used for the conversion of the temperature to volts. The output of the thermocouple is feed into the DAQ USB which is in term is used for the controlling of the temperature of the AL block.

3.2 Control:

Introduction

Main software used in instrumentation and signal processing is LABVIEW 2011.

Below is overview of the software.

3.2.2 INTRODUCTION TO LABVIEW

LabVIEW TM (Laboratory Virtual Instrument Engineering Workbench), a product of National Instruments, is a powerful software system that accommodates data acquisition, instrument control, data processing and data presentation. LabVIEW which can run on PC under Windows, Sun as well as on Apple Macintosh computers, uses graphical programming language (G language) departing from the traditional high level languages such as the C language, Pascal or Basic.
All LabVIEW graphical programs, called Virtual Instruments or simply VIs, contain a Front Panel and a Block Diagram. Front Panel has various controls and indicators while the Block Diagram consists of a variety of functions. The functions (icons) are wired inside the Block Diagram where the wires represent the flow of data. The execution of a VI is data dependent which means that a node inside the Block Diagram will execute only if the data is available at each input terminal of that node. By contrast, the execution of programs such as the C language program, follow the order in which the instructions are written. The version used for our project is LabVIEW 2011.

DATA ACQUSITION USING LABVIEW

Data acquisition (DAQ) is the process of acquiring an electrical or physical phenomenon such as voltage, current, temperature, sounds or pressure with a computer. A DAQ system consists of a DAQ card or sensor, hardware from which data is to be acquired and a computer with associated software. A DAQ card has various features which can be designed for different purposes. For data involving very high accuracy the sampling rate of the card should be high enough to reconstruct the signal that appears in the computer. NI USB-9219 DAQ can be used to get data related to impulse voltage which require very high accuracy.

CONTROL SYSTEM OVERVIEW:

A control system consists of components and circuits that work together to maintain the process at a desired operating point. Every home or an industrial plant has a temperature control that maintains the temperature at the thermostat setting. In industry, a control system may be used to regulate some aspect of production of parts or to maintain the speed of a motor at a desired level.

3.2.3 Open Loop v/s Close Loop:

Control systems can be divided into two types.

Open loop systems supply an output in response to some user input but do not monitor the result that the output is having on the system or environment. One example is a burner on a typical stove. The user selects the power input to the burner, but the actual temperature at the burner will depend on the burner characteristics as well as the condition of the material that is being heated and the temperature of the surrounding air. Effective open-loop control requires that the user understand how the input affects the system output.

Closed loop systems compare the user input to a value measured from the system to determine the output to send to the actuator. One simple example is an oven with a thermostatic switch. The user needs only to set the desired temperature and the switch controls the average power input by turning the heat on and off.
The use of feedback in a closed-loop control system can accommodate a large degree of ignorance of the system characteristics. However, in order to create a control system that follows the desired output closely, we usually want to apply some knowledge of how the system responds to actuation. In addition, high performance control systems usually respond to the difference between the desired and measured values (the error), not just to being over or under the setpoint.

Although a control system can be of open loop type, it is more common to use negative feedback. The block diagram shown in Figure 1 illustrates the basic structure of a typical closed loop control system. The Process represents any physical characteristic that must be maintained at the desired operating point.

The purpose of feedback is to provide the actual or the voltage value of process variable. In this system, it is the temperature that is to be maintained at the desired value. A thermocouple is used to monitor the temperature.

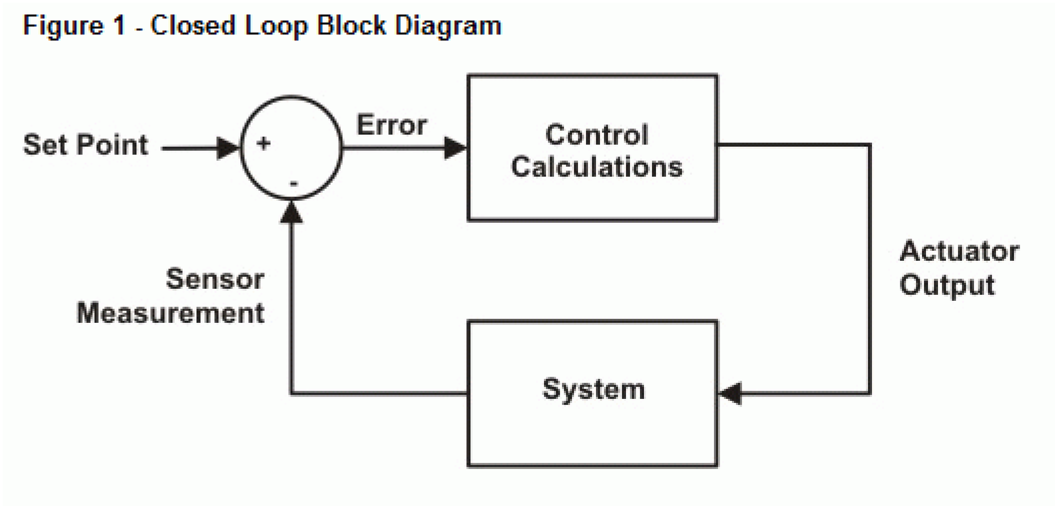

Figure 3.1 PID Controller

The Set Point, designated as VSP, represents the user input. It is the desired value of the Process Variable, temperature in this application. The two signals, VPV and VSP are applied to the difference amplifier whose output is the Error signal VE = VSP – VPV.

The Controller block in Fig.2.3 is the heart of a control system. It accepts the Error signal VE and produces an appropriate output. In practice a control may be one of several types: ON/OFF, Proportional, Proportional plus Integral or Proportional plus Integral plus Derivative (PID). These controllers differ in the manner in which they operate or process the Error signal.

Where VE = Error Voltage, VSP= Set Point Voltage, VPV= Process Variable Voltage

3.2.4 PID control

Introduction:

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called **three-term control**: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

In the absence of knowledge of the underlying process, a PID controller has historically been considered to be the best controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the setpoint, and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action

PID Control Theory:

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$\mathrm{u}(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

Where

K_p: Proportional gain, a tuning parameter
K_i: Integral gain, a tuning parameter
K_d: Derivative gain, a tuning parameter

Proportional Term

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain constant.

The proportional term is given by:

$$P_{\mathrm{out}} = K_p\, e(t)$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller [27].

Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (Ki) and added to the controller output.

The integral term is given by:

$$I_{\text{out}} = K_i \int_0^t e(\tau)\, d\tau$$

The integral term accelerates the movement of the process towards setpoint and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the setpoint value (see the section on loop tuning) [27].

Derivative term

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

The derivative term is given by:

$$D_{\text{out}} = K_d \frac{d}{dt} e(t)$$

Derivative action predicts system behavior and thus improves settling time and stability of the system. An ideal derivative is not causal, so that implementations of PID controllers include an additional low pass filter for the derivative term, to limit the high frequency gain and noise [27]

3.2.5 System overview:

For the following discussion, let us define the error E as the difference between the desired and measured temperatures: E = TSET − TMEAS. Each gain component is G and the subscripts P, I and D, stand for proportional, integral and differential. The gain can have whatever units you need to get the input and output to match up. The simplest feedback control system is proportional, such that the controller output equals **GPE**. For a thermal system we want the output to be power: the farther the measured temperature is below the setpoint, the more power we want to apply. On the other hand, if the measured temperature is above the setpoint, we want to pull power out. This is very difficult. But if we let the block cool off by room air then this will take a lot of time to cool. So we will be passing the cold water through channels to cool the block. The cooling water will cool the block within matter of seconds thus saving a lot of time and stabilizing temperature quickly.

To improve system performance, integral and differential terms can be added, such that This type of system is known as a proportional-integral-differential (PID) controller. The flow chart for every PID controller is the same, and the gains **GP, I, D** are adjusted to produce the desired system behavior.

3.2.6 Pulse width modulation:

For purposes of heating a resistor, it works just as well if we control the average power rather than keeping the power exactly right all of the time. This power averaging is the basis of a method of power control pulse width modulation (PWM). PWM controllers provide an output that is either off or at full power, but with timing that is determined by the error signal. Whereas an oven with a standard on/off thermostat would be at full power all of the time as the temperature rose from Ttarget–20° to Ttarget–1°, an oven with a proportional thermostat using PWM might be at full output 80% of the time when the temperature deficit is 20°, but only 5% of the time when the temperature deficit is 1°. The fluctuations are typically rapid, cycling several times per second. The resistor has some heat capacity and heat resistance, so it behaves like a low-pass filter that damps out the thermal oscillations. At locations away from the actual point of heat application (e.g. at the thermocouple), it is impossible to tell that the heat has been applied in pulses. We calculate average power = max power * on-time fraction, where on-time fraction is pulse width / pulse period.

When we use PWM, we use LabVIEW to calculate a percent on-time, also called the duty cycle. Obviously the duty cycle must be between 0 and 100%. This limitation does not seem so bad when we realize that the DAQ output is finite too, ranging from 0 to 5 V. We use LabVIEW to turn the DAQ output on and off, where “off” is usually 0 V and “on” is somewhere from 3 to 5 V. Note that pulse width modulation permits us to choose either the analog outputs or the digital outputs from our data I/O device. The analog outputs can be varied in very fine increments over a wide voltage range, but we don’t need that here. The digital outputs are either 0 or 5 V, so they are good for switching of relay and PID control only with a PWM controller. Each digital output is one bit of a binary number, so to use these outputs for thermal control we simply turn the desired bit on or off at the appropriate rate.* In either case, the current supplied by the data I/O device is small, so it is necessary to connect a solid state relay which will turns on the heater connected to 220 volts power supply.

3.3 LabVIEW Program:

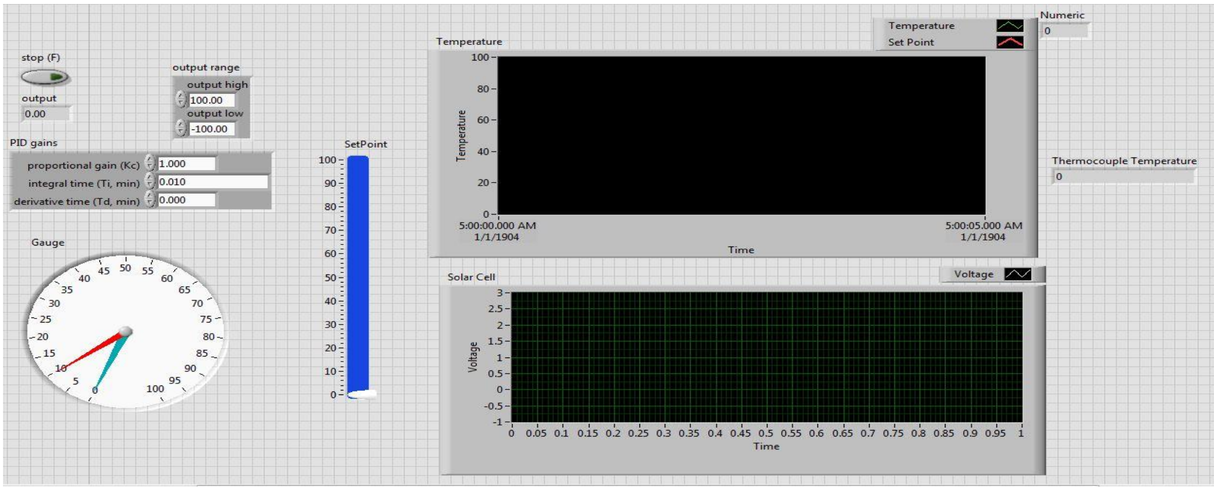

Figure 3.2 FRONT PANEL LabVIEW:

The temperature control system of the testing chamber works on the principle of PID Temperature Control. Heating system involves 2 cartridge heaters which directly heat the “Temperature Control bracket”. To achieve this 2 holes were made in “Temperature Control bracket” and placed the cartridge heaters inside it. The purpose of the heaters is to raise the temperature of the block to the required testing temperature. The heaters have been connected to the main power supply of 220v and solid state relay. The solid state relay have been connected to DAQ 9219 USB which have been interfaced with the LabVIEW to control the temperature of the bracket at the required point through a temperature sensor called K-Type thermocouple.

Closed loop tuning method was used for the tuning of PID controller. The output of the PID controller is given to the Pulse Width Modulation to control the duty cycle of the signal. A duty cycle is the percentage of one period in which a signal is active [12].
As the bracket is directly heating through heaters and there will be no Air inside the chamber so cooling down the bracket will take a lot of time. So, to achieve fast stabilization cold water will be passing through water channels made in temperature control bracket continuously which will bring down the temperature quickly.

The main purpose of the cold water is to dampen the system which will be used to control the stabilization of the temperature. The temperature of the bracket will rise by the heat given from the heaters and it will be controlled at a certain point through relay switching using PID controller in LabVIEW. The water will serve the purpose of dragging down the temperature to minimize the time of temperature stabilization at a certain point.

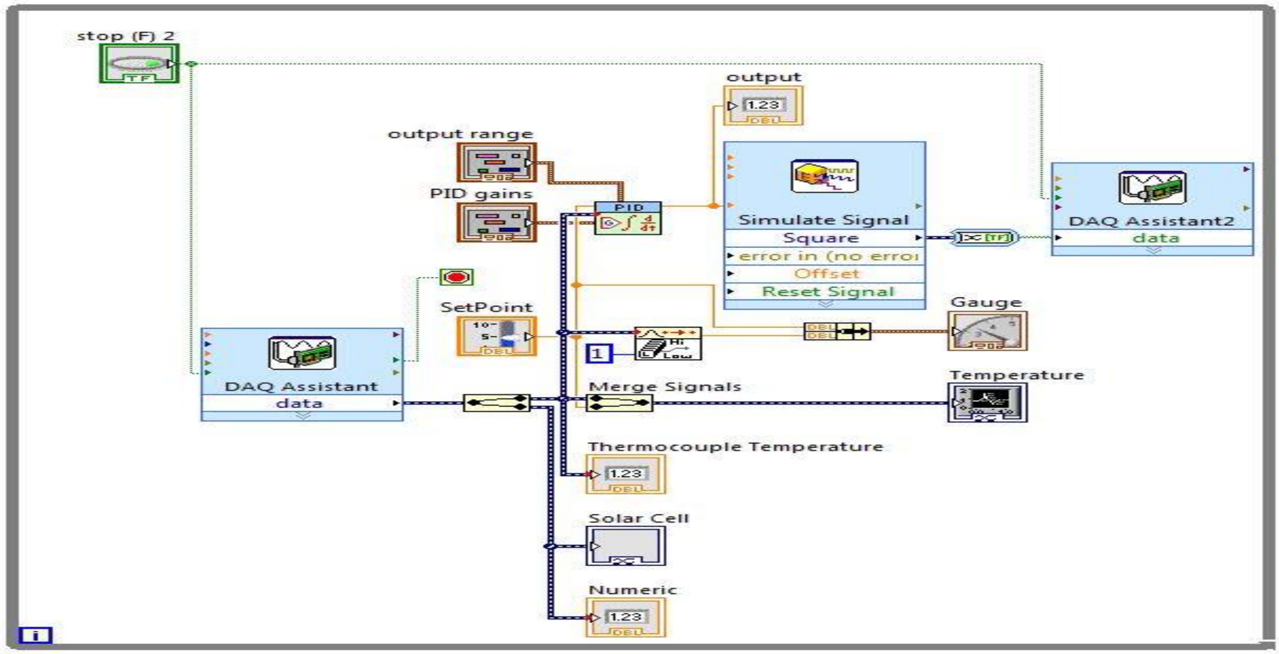

Figure 3.3 BLOCK DIAGRAM LabVIEW

The DAQ Assistant will take the signal from thermocouple and solar cell. The signal will be then split into separate entities using signal splitter. Solar cell voltage signal will be then pass on to the wave form chart while thermocouple temperature signal will be pass on to the waveform graph as well as to the PID controller for PID calculations. PID will give output to the PWM controller which will control the switching of relay accordingly to achieve the desired temperature.

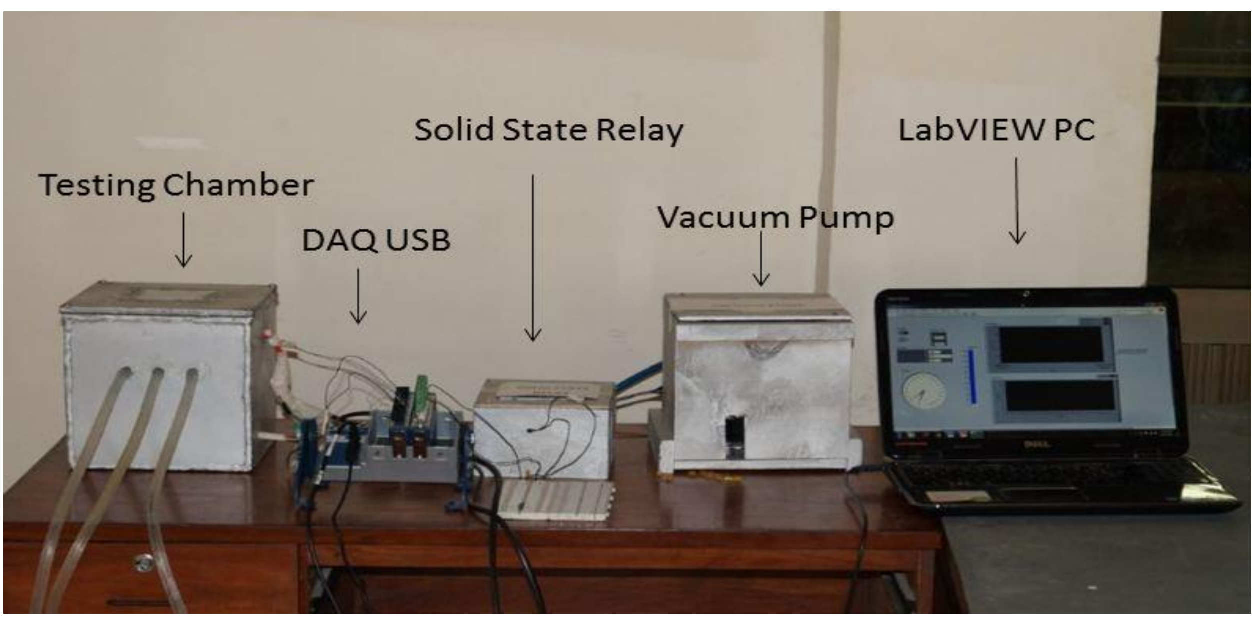

Figure 3.4 Complete Assembly Setup

CHAPTER 4

TESTING & EVALUATION:

4.1 Summary:

The photovoltaic device being tested shall be mounted on the bracket attached to the cold finger. The environmental parameters shall be set to standard atmosphere unless the device is being tested against one or more of these parameters. In the latter case, the test level of these parameters must be documented and reported. The test chamber must remain sealed throughout the test duration to prevent fluctuations in the environmental parameters being maintained .The required solar filters be installed on the window and properly documented to identify the radiation the test cell is being subjected to during the test. In case the test cell is being tested against natural sunlight, no filter shall be installed. The window and filters must be properly cleaned and maintained to avoid scratches that could tamper test results. The level of input (light intensity) shall be plotted against the output (electrical power being produced) for the duration of the test. In case the effect of any other variable is being investigated, that variable will be plotted against the output. The levels of all parameters held fixed must be documented. In case the performance is being tested against time, input shall be maintained at a fixed level, that will be documented, and the output will be plotted against time

4.2 RESULTS:

The following graph has been observed by plotting the value of the solar cell voltages against the temperature increases in the MATLAB SIMULINK.

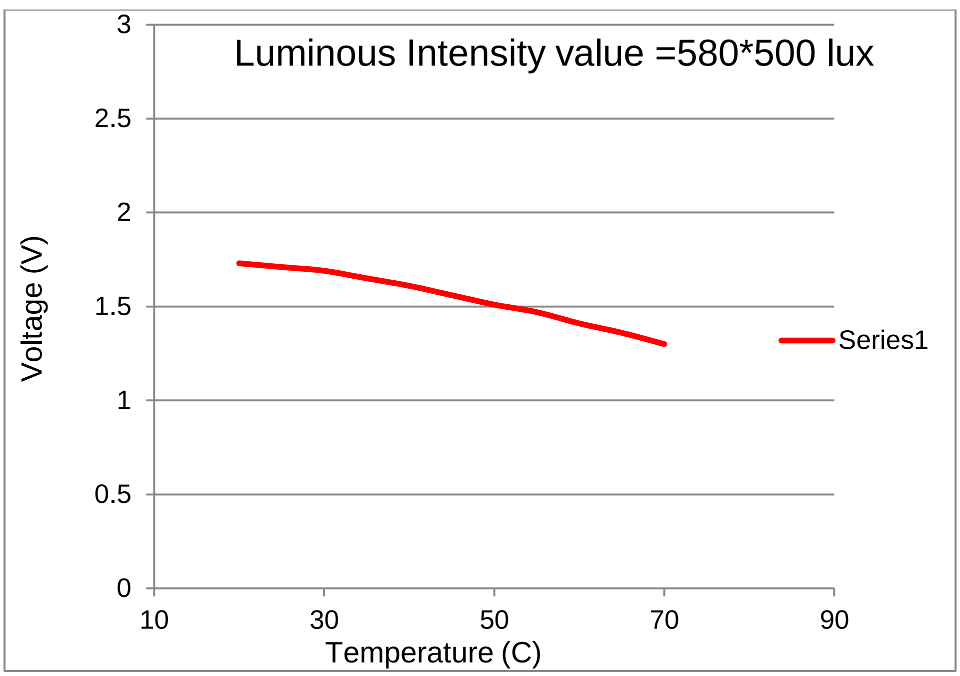

Figure-4.1 Graph of Voltage vs. Temp at the intensity value of 580*500 Lux

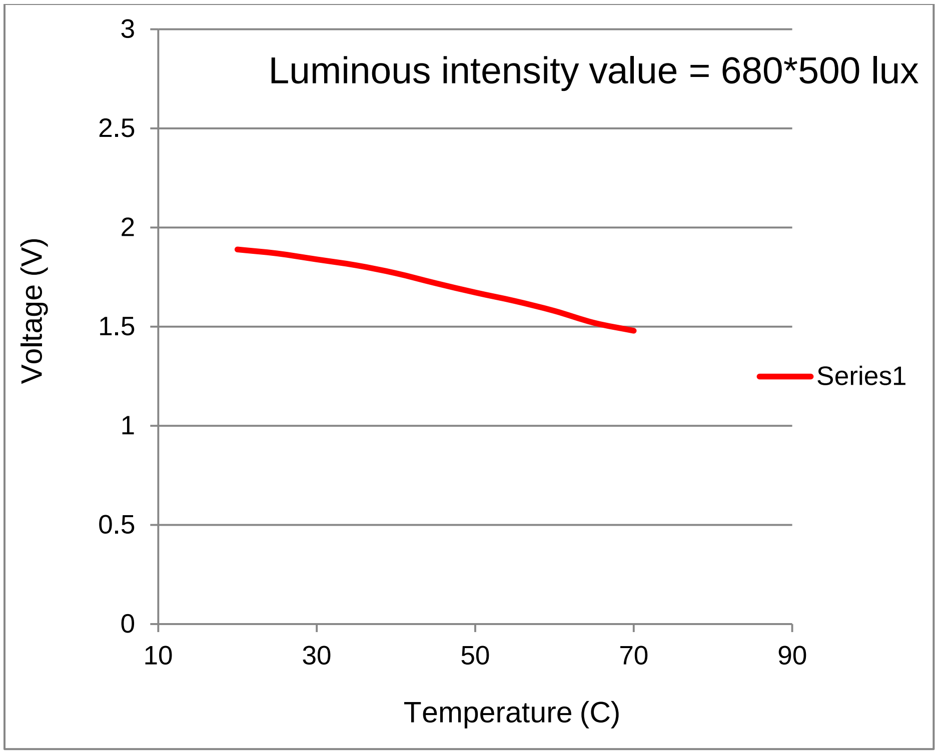

Figure-4.2 Graph of Voltage vs. Temp against the Intensity value of 680*500 lux.

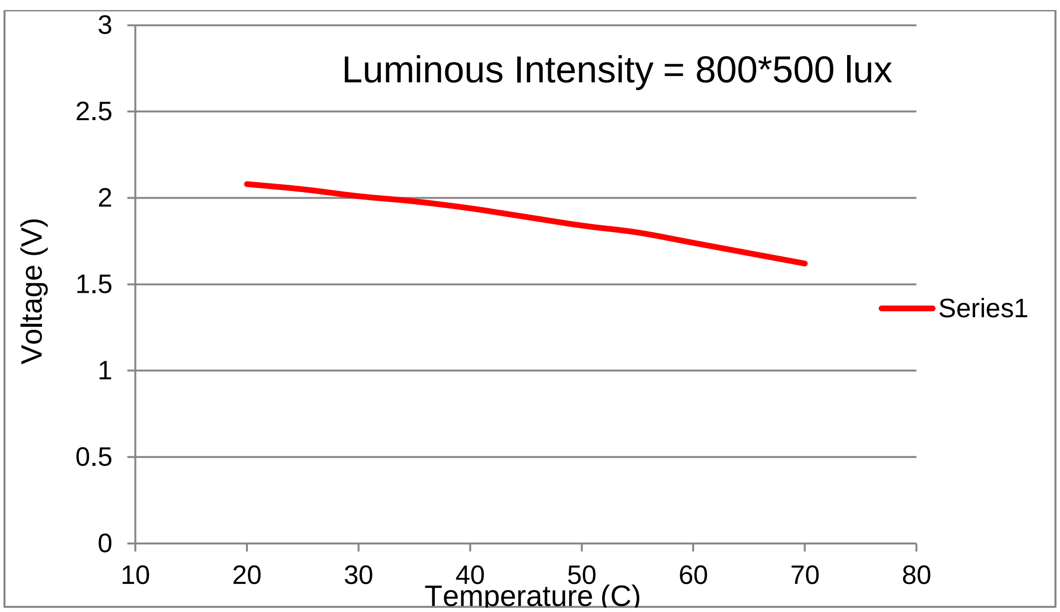

Figure-4.3 Graph of the Voltage vs. Temp as the intensity value of 800*500 lux.

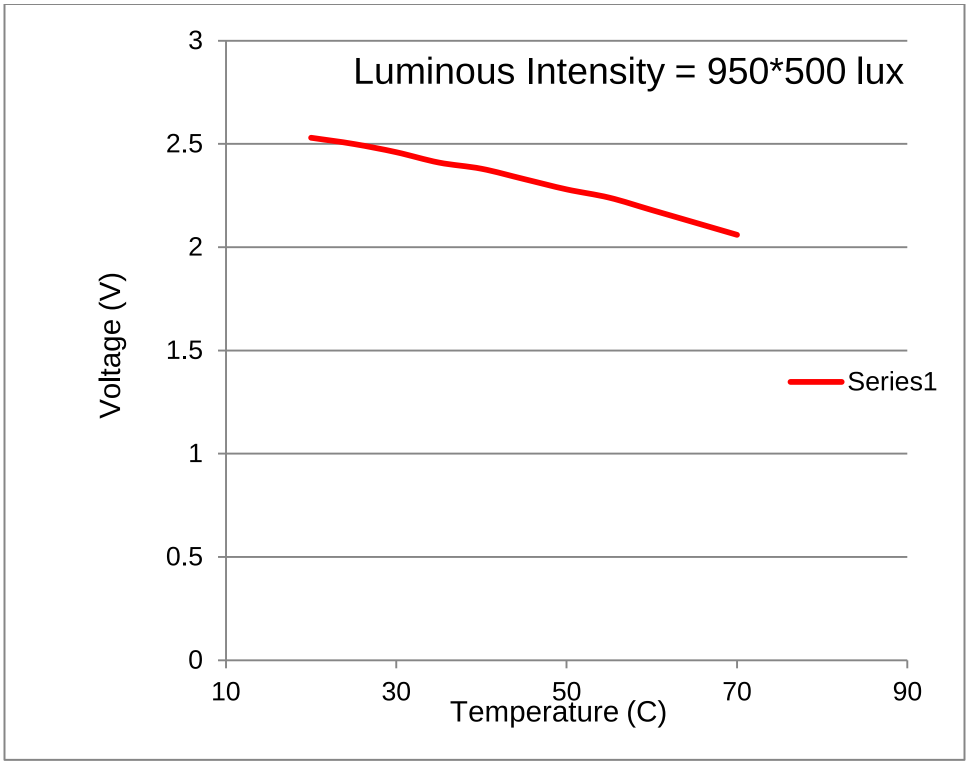

Figure-4.4 Graph of the Voltage vs. Temp at the intensity value of 950*500lux

4.3 Discussion on Results:

We have done different testing on solar cell in a close air tight environment. We have got some real life problem results after exposing the solar cell to the solar rays in a close environmental chamber with controlled varying temperature. From all the result is it has been concluded that the temperature of the solar cell strongly depend upon the heating temperature of the solar cell. It means that the temperature has been viewed to be dropped continuously by rising the temperature against the fixed Lux of the solar rays.

4.4.1Discussion on the figure-1:

In the figure 1 it has been showed that initially when the Lux value has been fixed i-e 580 lux. The value of the voltage of the solar cell at temperature 20°C is 1.76v. Also by increasing the temperature at keeping the intensity of solar cell fixed the value of the voltage of the solar cell started decreasing. Initially it the decrease in the voltage is slight when the temperature is in the range if the optimum temperature, but when temperature is increased above the 45°C the decrease in the voltage slightly shoots up. The voltage in the end at 70°C is 1.35 at intensity of 580lux.

4.4.2Discussion on the figure-2:

In the figure 2 the test has been recorded against the increased intensity value of the solar cell i-e 680 lux. The value of the voltage increases up to certain level. Now the same temperature range has been applied keeping the value of the lux constant. The temperature dropped has been recorded and almost a straight line relationship has been viewed.

4.4.3 Discussion on the figure-3:

In 3rd figure the intensity level has been increased further to the value i-e 800lux. The value of the voltage increases accordingly. The solar cell has been tested against the same varying temperature range i-e 20 to 70°C. Initially the temperature is 20°C, voltage value was maximum when the temperature value has been increased the voltage of the solar cell started decreasing accordingly. When the temperature was operating in the optimum region the voltage drop was less and when the temperature value crosses the intense temperature range i-e 50°C the drop in the voltage per degree rise shoots up.

4.4.4 Discussion on the figure-4:

In the last figure the intensity value is maximum upon which the solar cell was giving the maximum value. Increasing the intensity level beyond that point didn't increase the voltage value. So it means that the saturated intensity level/point of the solar cell is achieved. Again the same temperature range has been applied and a voltage drop against temperature raises behavior has been observed.

4.4 CONCLUSIONS & FUTURE WORKS:

The age of low cost fossil fuels is over and that warrants serious research into the development of alternate fuels. The detailed characterization of PV cells can improve the efficiency of the system and lower the overall cost of the PV system. Already extensive research is being carried out towards the development of economically viable photovoltaic technology. A need was felt to unify the testing procedure and equipment so that new technologies being developed can be tested and rated against a common standard. Ultimately, this proposed equipment and procedure will evolve into a comprehensive and unified testing standard that would be used for the testing and characterization of photovoltaic devices.

4.4.1 Conclusions:

The following conclusions have been drawn by testing the photo voltaic cell. The solar cell is efficiently working in the optimum temperature range i-e 20-35°C. Increasing the temperature of the cell decreases the output voltage which causes the efficiency decreases in the performance of the solar cell. Sun light consist of the different wavelengths in the bright white light ray. So the test we have done just consist of the all the wavelength passes through the plane glass.

Thermal radiation from the sun is largely lost on most silicon solar cells. Up-converters transform the infrared radiation into usable light, however. Researchers have now for the first time successfully adapted this effect for use in generating power**.** There is more to solar radiation than meets the eye: sun- burn develops from unseen UV radiation, while we sense infrared radiation as heat on our skin, though invisible to us. Solar cells also 'see' only a portion of solar radiation: approximately 20 percent of the energy contained in the solar spectrum is unavailable to cells made of silicon – they are unable to utilize a part of the infrared radiation, the short-wavelength IR radiation, for generating power.

Silicon is the material of choice for visible light photo detection and solar cell fabrication. However, due to the intrinsic band gap properties of silicon, most infrared photons are energetically useless.

We also have concluded that infrared rays are harmful for solar cell because they can increases the temperature of the solar cells material which causes to lower down the voltage output of the cell. So such materials are to be used in the solar cell in future which filters the solar rays infrared wavelength and allow or pass the ultraviolet waves to give the output voltage.

Normally, metal is vapor-deposited on the backside, enabling current to flow out of the solar cells – so no light can shine through normally. "We equipped the solar cells with metal lattices on the front and rear sides so that IR light can pass through the solar cells. In addition, the light can be used by both faces of the cell – we call this a bi-facial solar cell," explains Fischer. Scientists have applied specialized anti-reflection coatings to the front and rear sides of the solar cell. These cancel reflections at the surfaces and assure that the cells absorb as much light as possible. "This is the first time we have adapted the anti- reflection coating to the backside of the solar cell as well. That could increase the efficiency of the modules and raise their energy yields. The first companies are already trying to accomplish this by implementing bi-facial solar cells

4.4.2 Future works in the project:

The future work will consist of the following test that we should do in order to fully investigate the behavior of the solar cell. We should do the same test for the different other glasses placed above the window. The same temperature controlled test should be done for tempered glass, for UV filtering glass and for infrared filtering glass and the result should be noted.

The test performed above is done in the open atmosphere we would also perform our test in a close environment using solar simulator which will generate different strict environment and we will put our chamber in solar simulator. That will create and maintain a strict solar environment that shouldn't be disturb by wind and any other environmental factors and we will get our results.

The cooling system can be further enhanced by placing the radiator on the channels that is using for the water flowing. By installing the radiator it will cool the water automatically and there will be no need for the manual ice cubes filling in the water sump for dragging the temperature of the water down.

4.4.3 Future works in solar cell renewable energy:

Nowadays the need for converging to the renewable energy is growing day by day. People utilize and harness the sun light in different ways for different purposes. It will be also very useful if we got successful in harnessing the solar rays for creating the electricity because there is shortage of electricity in our country. Fossils fuel energy is declining day by day and one day it will be completely declined. The electricity we can also create from hydro energy but that is not sufficient. So we might switch towards the solar energy which is clean energy and easily and abundantly available. For utilizing the solar rays for electricity solar cell are the element used for solar energy conversion to electricity. Only up to 20% of the solar rays is being utilizing for the electricity conversion the rest is going into waste in different forms like heat wastages and incapability of the solar cells. So our main purposes are to improve the efficiency of the solar cell and subtract such factors which might not add up into efficiency increase of the solar cell.

In the end we are trying and putting our efforts in the invention of such a solar cell which has more efficiency than the currently using solar cell. That will utilize almost all the rays of solar cell i-e infrared and UV etc. and that will give out much voltages than indigenous using solar cell. Also the solar cell we will have should work in the high temperature range efficiently without dropping the voltages by using it in elevated temperature.

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[23] (Olivirer Haillant) Accelerated weathering testing principles to estimates service life of organic PV modules 2010- Atlas Material Testing technology GMBH, Vogelsbergstrasse 22, D-63589 Linsengericht Altenhasslau, Germany

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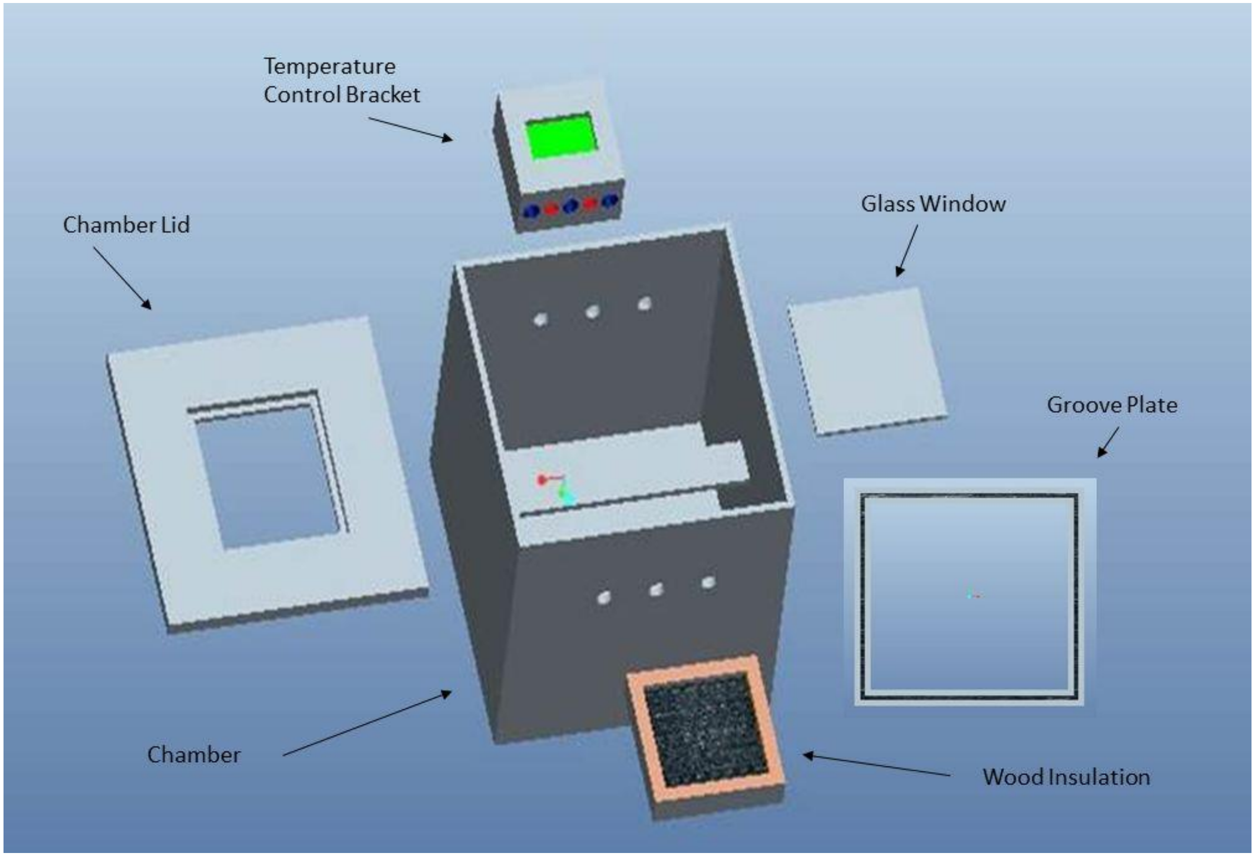
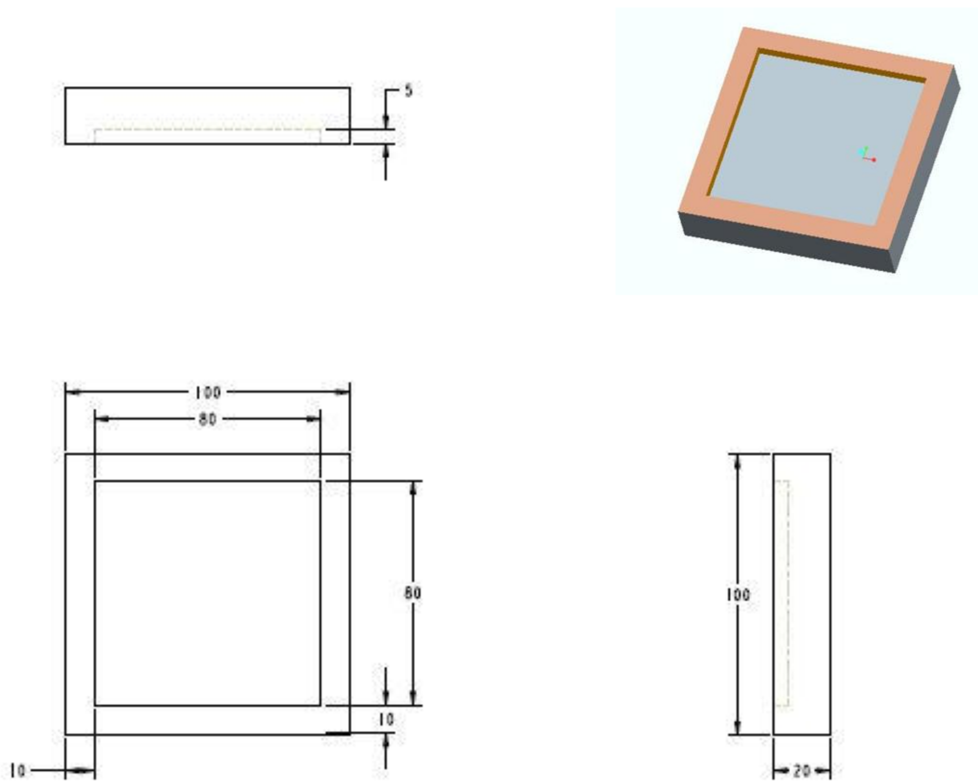
APPENDIX A:

Complete Assembly Model:

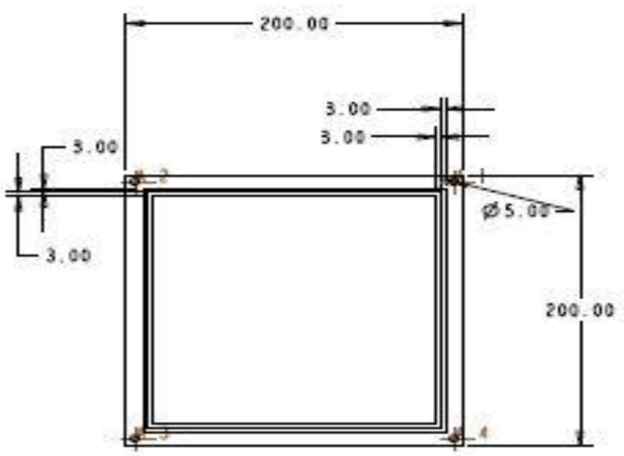


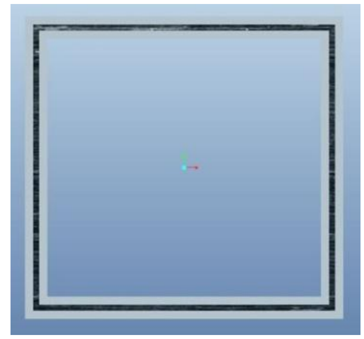
Title	Chamber Assembly
Drawing No.	Ass-01
Next Assembly	N/A
Material	Mild Steel, Wood, Aluminum, Glass

Sr#	Name	Dwg #	Qty
1	Wood Insulation	01A	1
2	Groove Plate	01B	1
3	Chamber Lid	01C	1
4	Chamber	01D	1
5	Bracket	01E	1

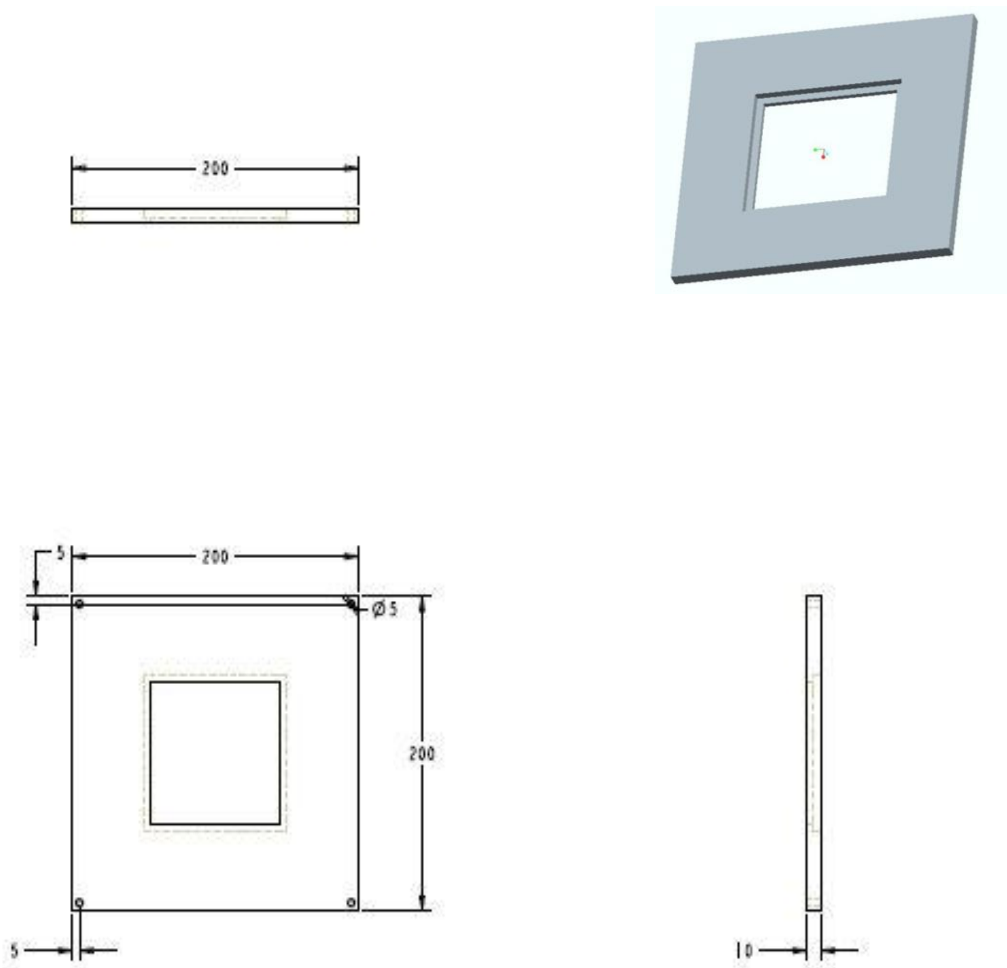


Title	Wood Pocket
Drawing No.	01A
Next Assembly	N/A
Material	Wood
Tolerance acc.ISO 2748 u Otherwise specified	3rd Angle Projection

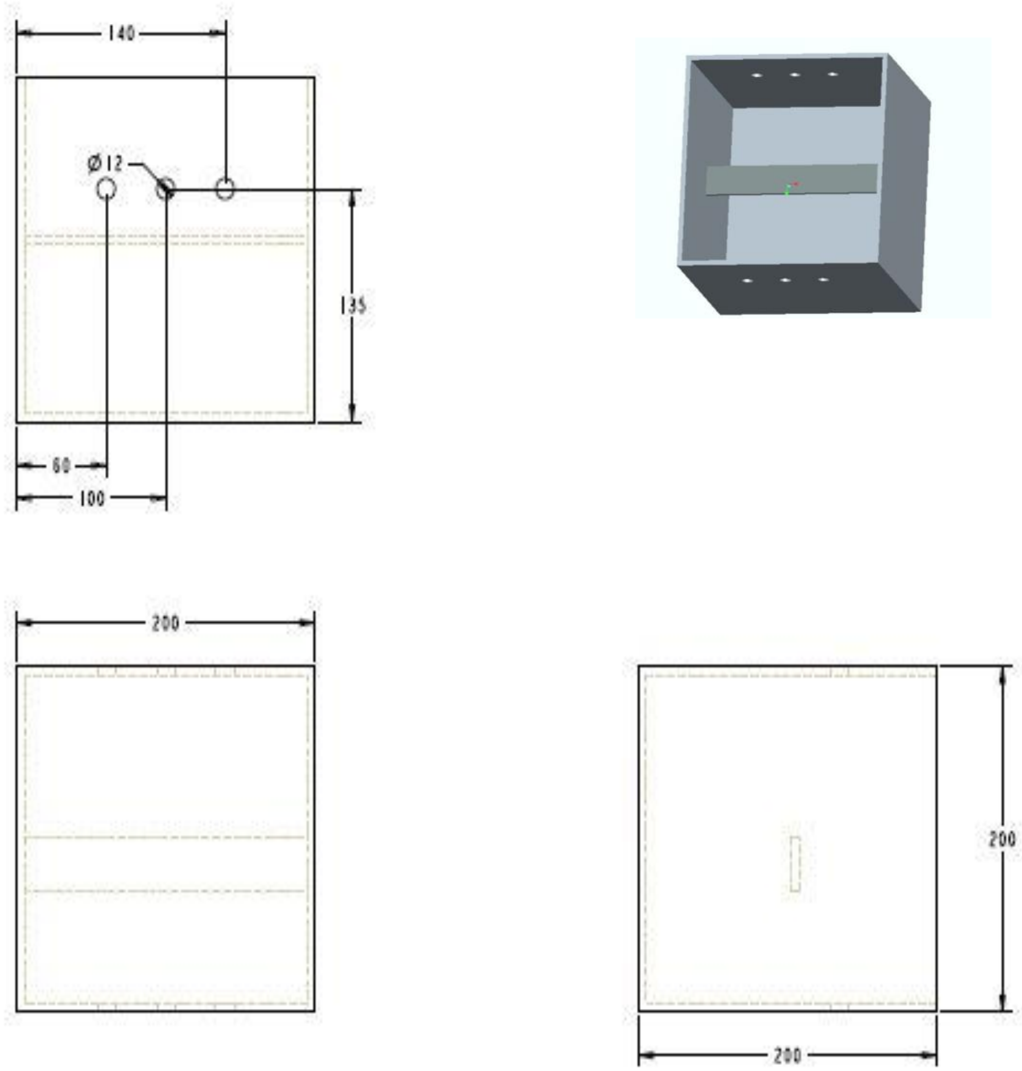




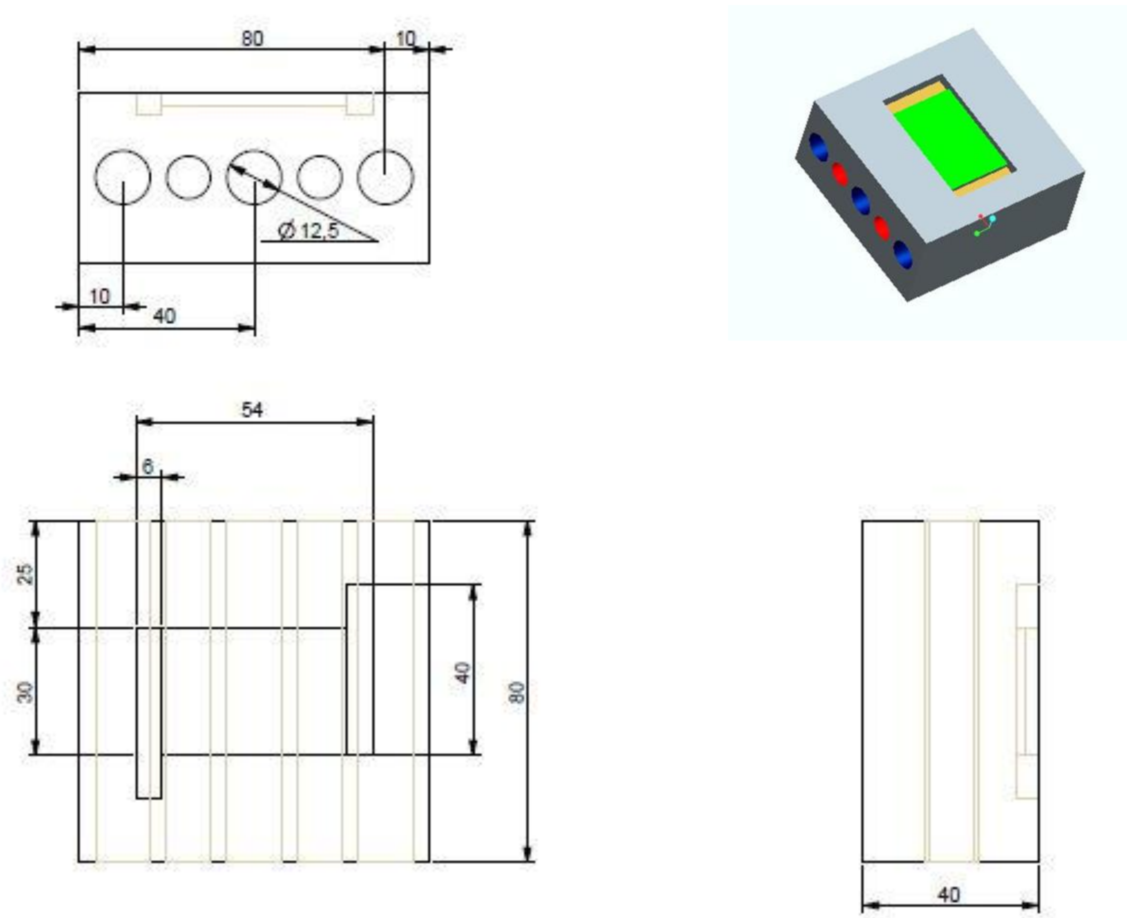
Title	Chamber Groove Plate
Drawing No.	01B
Next Assembly	N/A
Material	Mild Steel
Tolerance acc.ISO 2748 u Otherwise specified	3rd Angle Projection



Title	Chmber Lid
Drawing No.	01C
Next Assembly	N/A
Material	Mild Steel
Tolerance acc.ISO 2748 Otherwise specified	3^{rd} Angle Projection



Title	Environmental Chamber
Drawing No.	01E
Next Assembly	N/A
Material	Mild Steel
Tolerance acc. ISO 2748 Otherwise specified	3^{rd} Angle Projection



Title	Solar Cell Bracket
Drawing No.	01F
Next Assembly	N/A
Material	Mild Steel
Tolerance acc. ISO 2748 Otherwise specified	3rd Angle Projection

APPENDIX B:

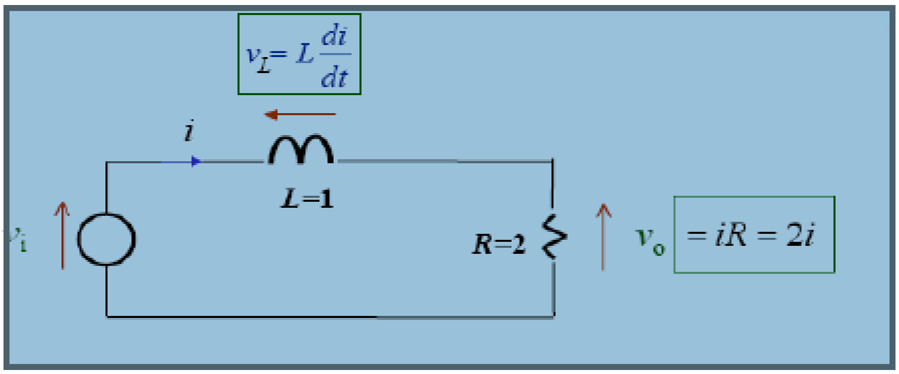
Calculations:

PID Gains Calculations:

We have assumed the following values for our Relay.

L=1 R=2

We depict the relay diagram as follows.



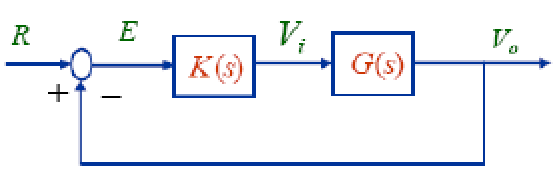
By KVL,

Vi= Vl + Vo = L * di/dt + iR + 2i =di/dt +2i =Vi

Taking Laplace transform on both sides of above ODE, we have

sI(s) +2I(s) = Vi(s) thus (s+2)i(s) = V(s) so I(s)/Vi(s) = 1/s+2

Vo(s)/Vi(s) = 2I(s)/Vi(s) = 2/s+2 = **Transfer Function**



• Control System

Vo(s) = G(s)*Vi(s) = G(s)*K(s)*E(s) = G(s)*K(s)[R(s) – Vo(s)]

[1+ G(s)*K(s)]Vo(s) = G(s)*K(s)*R(s) thus Vo(s)/R(s) = G(s)*K(s)/1+ G(s)*K(s)

Now G(S) = 2/s+2 and for PID controller Transfer function is K(S)= Kp+Ki/s+Kd*s

We have H(S)= (2/s+2)(Kp+Ki/s+Kd*s)/1+(2/s+2)(Kp+Ki/s+Kd*s)

→ 2Kp+2Ki+2Kds^2/(1+2Kd)s^2+2(1+Kp)s+2Ki

Now comparing it with following standard 2nd order Equation

$$H(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

We have **ω**n^2=natural frequency ζ=Damping-ratio

1+2Kd=1 , thus Kd=0.04

2ζ**ω**n=2(1+Kp), Kp= ζ**ω**n-1

ωn^2=2Ki Ki= **ω**n^2/2

as we have an overshoot of 5%,so using overshoot-damping ratio graph

ζ=0.9

Now rising time is Ts=30s

Ts=4.6/ ζ**ω**n **ω**n=4.6/ ζTs=4.6/0.9*30 **ω**n=0.17

Kp=1- ζ**ω**n =1-0.17*0.9=0.84

Ki= **ω**n^2/2=0.0145

Calculation for the heat gain by water:

We have a submergible pump whose flow rate m* is

m*=1000liter/hr=0.27litr/s

and 1litr=0.001m^3s

so 1m^3=1000litr

now m*=0.27*10^-3m^3/s

as for water

Cp=4.186*10^3j/kg.C

Now Q*=m*CpΔT

So if ΔT=1C i.e Heat required to raise 1 degree temperature is

Q*=0.27*10^3*4.18*10^-3=1.12W

And time taken to raise 1 degree temperature is

T=10^-2*4.18*10^3*1/300=7.1s