Design and Development of Environmental chamber for solar cell testing

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Design and Development of Environmental chamber for solar cell Testing

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Declaration

I certify that this research work titled "*Design and development of environmental chamber for solar cell testing"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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My Sister Bibi Raad

And My nieces Sara and Ammara

Abstract

In this research work a lightweight compact and portable chamber is designed and developed for testing of solar cell behavior at various temperatures. This chamber is used for testing of the solar cell at both positive and negative temperature. Cold finger design was used for producing localized cold surface at the flat surface on which solar cell is to be mounted. Inside the chamber, a controlled environment is produced by a solar cell, i.e. controlled the temperature so that we can test the output performance of solar cell at desired temperature within a specific temperature range. Proper control and instrumentation of the chamber were carried out using data acquisition cards (DAQ) of National Instruments (NI) using LabVIEW software through PID control. Preliminary tests were calibration and repeatability of temperature and voltage measurement.

Key Words: *Environmental Chamber, Atmospheric chamber, Instrumentation and control, LabVIEW, Solar Energy, Solar cell, Cryostat, Cold finger, Dry-Ice bath.*

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CHAPTER 1: INTRODUCTION

1.1. Background

Non-renewable energy resources are diminishing very fast and there is a need for more research in sustainable energy resources. A key source of renewable energy is the sun in the form of solar energy. Solar energy can be utilized by different methods to meet our energy demands. Solar panels are powering various electrical devices like mobile phones, laptops, lights etc. In order to power the devices efficiently solar panels must endure their likely environment. Due to the increasing trend of green and renewable energy use the world is shifting toward solar energy. The trend of shifting toward renewable energies is clear from the statistics of the use of energy in last decade. The use of solar energy is tremendously increasing. In 2014 solar energy obtained from the installed modules increased to 177 GW with an increase of 40 GW [1]. $270.2 billion were invested in renewable power in 2014, which is almost 17% higher than previous year [2, 3].

To deal effectively with the demands of the energy and also to resolve the issues related to non-renewable energy resources there is a need for more research and investment in renewable energy resources. Renewable energy comes in different forms e.g. solar, wind energy, biomass, hydropower etc. In order to improve solar panels and modules efficiency, reliability and cost-effectiveness manufacturers are working on it to improve it.

Solar panels are subjected to various environmental conditions. The output voltage of solar cell plays an important role in the efficiency of solar cell. In order to ensure proper working of solar panel, they must pass different environmental tests. Commercially available chambers are costly huge in size, and they are used for solar panel testing. To evaluate the output voltage of a solar cell under different environmental conditions an environmental chamber is used. Various tests are conducted in order to check the durability and reliability of a solar panel. These tests are necessary for ensuring the performance of solar cells. The performance of a solar panel or module is evaluated at different temperatures, pressure, and humidity etc. The standard solar test chambers available commercially are primarily designed to test the structural integrity of solar cells under various environmental parameters.

1.2. Aim and Objectives

The basic aim of the project was to design and develop a lightweight compact, economical and portable chamber to analyze the performance of single solar cell at different environmental conditions.

The overall objectives of the project are listed below.

- Design & development of Environmental Chamber for PV cell Testing.
- Design & Development of Cold finger design for low temperature.
- Instrumentation of Chamber.
- Design & implementation of PID controller using LABVIEW for Temperature Control.
- Temperature Testing of Chamber.

1.3. Organization of thesis

Chapter 1 gives the background and introduction to the environmental chamber. Chapter 2 covers the literature portion of the project. Chapter 3 and 4 focuses on methodology, instrumentation, and control of the chamber. Chapter 5 covers the results and discussion part and chapter 6 includes conclusions and future recommendations.

Chapter 2 Literature Review

The performance of solar cells is strongly dependent upon the temperature in which it operates. Solar panels, modules, and cells are subjected to different environmental conditions ranging from high to low temperature, pressure humidity level etc. Lifetime testing and degradation studies, carried out in a controlled atmospheric condition are progressively becoming an essential part of the several techniques used in the study of Organic Photovoltaics devices [4]. A vast research has been carried out in the field of organic solar cell focusing on their stability, lifetime studies, and degradation phenomenon that occur in organic solar cells [4-7].

The degradation effect is different for different solar cells. Inorganic or silicon based solar cells are more stable as compared to organic solar cells which degrade [7] and drop their stability in varying environmental conditions. The reason behind their instability is the presence of the elements in the solar cells that cannot sustain the environmental condition and as a result, their physical or chemical properties get changed. Lifetime testing is also very important to ensure the reliability of solar cells. Different PV technologies were exposed in the outdoor for 28 months and its long-term reliability was studied. The test procedure includes visual inspection, thermal imaging, and I-V Characteristic measurements and degradation analysis was carried out by STC (Standard Test Condition) Comparisons of various technologies and rate of decay per year was also mentioned as 0.4%, 0.5%, 0.36% for a-Si, multi C-Si and HIT (Hetero Intrinsic Thin Layer) modules respectively [8].

A compact multi-chamber environmental setup was designed having the facility of testing multiple solar cells on a glass substrate with independent temperature and atmospheric control. The setup was designed for IV characterization of multiple solar cells simultaneously under constant illumination for a long time (41000 h) subjected to different and controlled atmospheres. The setup was having good control and data acquisition system [6]. In another study, three different types of polymeric solar cells were studied for long term stability testing in an outdoor environment and it was observed that P3HT-PCBM cell degraded much slower as compared to the other two cells and the P3CT-C60 device was noted to be most stable [5]. Organic and polymeric solar cells degrade and are very unstable in outside environmental conditions.

Degradation phenomenon that occurs in organic and polymeric solar cell also needs attention and there is a strong need to produce such solar cells that show good performance in different environments. A chamber with good control and instrumentation was developed for organic solar cell life study and solar cell aging with time. Both accelerated and long-term lifetime studies were conducted for bulk heterojunction solar cells in controlled environmental conditions [7].

For studying the performance of solar cells, and panels under different environmental conditions environmental chambers are used. Photovoltaic devices are being tested in the environmental test chamber in a controlled environment with good automation and control to analyze their performance in different working environments. Solar PV testing- A white paper discusses environmental chamber design guidelines and standard testing methods of solar modules. This paper also gives the details of various test necessary for testing the solar PV modules[9]. Electrical parameters like short circuit current, open circuit voltage, fill factor and efficiency of solar cells have strong dependency on the operating environment and also on the base material. CIGS (Copper Indium Gallium Selenide) based solar cells performance was efficient at 60 oC, 60% RH and CdTe based solar cells performed well at 85 oC and 85% RH [10].

Temperature and light intensity have a strong contribution to output parameters of solar cells[8, 11-23]. Normally open circuit voltage decreases with increase in solar cell temperature and vice versa [24]. The cell temperature is a prominent parameter in deciding the quality and performance of crystalline silicon solar cell [13, 15, 25, 26].

In a study, the working of solar cells at elevated temperature in a range of 25-200 oC was evaluated. Temperature dependence on the performance of solar cells both theoretically and experimentally was observed. Different types of solar cells were studied during this research at different conditions. Certain types of solar cells were observed that can work at high temperatures range without the significant drop in output voltage and efficiency [24]. Performance parameters of monocrystalline and polycrystalline cells vary with temperature. The open circuit voltage V_{oc} of both the monocrystalline and polycrystalline solar cells showed a decreasing trend with increasing the temperature of the solar cell [16]. For both mono and polycrystalline silicon, solar cells the open circuit voltage has a decreasing trend with increasing temperature. In another study, linear interpolation model was used to find out the temperature and irradiance dependency on I-V characterization of different solar cells [20] .

In a similar study, the effect of temperature and light intensity was studied using the solar simulator for different cell temperature range (15 ^{o}C to 60 ^{o}C) and intensity level (200 to 500 W/m^2). Solar intensity coefficient a new term was defined for characterization of the solar radiation dependency on the solar cell current [14]. 69 % decrease was reported in the efficiency of a single solar cell when operated at 64 ^{o}C. A decrease of 0.06 in the value of efficiency was observed per degree rise in absolute temperature [27]. In another research, a drop of 0.4 % in the efficiency was observed for single degree rise in temperature (in degree centigrade) for silicon solar cells [18].

Amorphous silicon solar cells showed comparatively little temperature dependency when operated in the equilibrated state but when the temperature changes over a short period of time, a-Si solar cells exhibit a strong dependence on temperature. The output performance of a-Si PV cells is much better than other solar cells or modules at elevated temperatures [21].

Chapter 3 Methodology

This chapter comprises of the details of the selection of design, material selection and manufacturing of the chamber and its components.

3.1 Design Selection and considerations

Environmental chamber should be strong enough to endure the various environmental conditions to which it is subjected. It should withstand different environmental conditions. Design selection comprises of various critical decisions. The table below shows the design consideration for which the chamber was designed.

Table 1. Design consideration parameters of Environmental chamber

Parameter	**Range/No./ Dimensions**
Temperature	-20 ^{O}C to 65 ^{O}C
No. of solar cell	1
Chamber size	150*150*140 mm^3

3.2.Material selection

Considering the availability and other properties of materials, two possible options were there. Steel and Aluminum. Both of the materials have their pros and cons. Due to lightweight and easy machining we selected Aluminum 6061 Alloy for the environmental chamber. Other reasons for selecting Aluminum Al6061 alloy are listed below. Distinctive properties of aluminum alloy 6061 comprise.

- Medium to high strength
- Good toughness
- Good surface finish
- Excellent corrosion resistance to atmospheric conditions

Chamber designing was carried out keeping in mind the availability of single solar cell. Two possible geometrical configurations were possible for the chamber. i.e. cylindrical and rectangular. Both of them have their pros and cons which are listed in the table below. Based on the reasons listed in table rectangular geometry was selected due to its easy manufacturing, and also it has sufficient space for proper instrumentation that was needed to be installed over there, for data collection.

Table 2. Comparison of Rectangular and cylindrical chamber.

Rectangular chamber	**Cylindrical chamber**
Easy fabrication	Difficult to fabricate
Sufficient space available for instrumentation	Not sufficient space available for instrumentation
Machining can be easily done	Machining is difficult for cylindrical
The rectangular glass window is required for the incident of sun rays which didn't alter the incident rays angle.	The curvy glass window is required which change the incident sun rays at different angles.
Sealing can be done easily	Sealing is difficult

For proper sealing of chamber, O-rings were selected and the groove was made using gland design guidelines for groove manufacturing. Two O-rings were used to perfectly seal the two openings of the chamber.

Cold finger design was selected which is used for producing localized cold surfaces. For cold finger design, copper of 99% purity was selected due to its good thermal properties. Cold finger was designed such that it should have a maximum surface area in contact for the high rate of conduction. One side of the cold finger was made flat where the solar cell is to be mounted. To increase the contact surface area finned cold finger is designed for good heat transfer.

In order to heat the flat surface of the cold finger, a heater was used. Different types of heaters are available, like cartridge heaters, strip heaters, ring heaters. A strip heater was selected due to its uniform heating. The heater was designed so that it can heat the surface in a single direction. i.e. only the side to which it is attached. The reason for making the heater of unidirectional heat transfer was to avoid unnecessary heating of the chamber and also to avoid heat loss. A 200W, 220 Volts heater was selected and was mounted on the backside of cold finger.

3.3.Manufacturing of chamber and its components

The environmental chamber assembly comprises the following components

- Environmental Chamber
- Cover plate
- Glass window
- Cold finger
- Heater
- Ice Bath Container

These components are discussed in details as under

3.3.1. Environmental Chamber

Aluminum Al6061 alloy was selected for environmental chamber due to its light weight and easy machining. The environmental chamber was fabricated using CNC milling machine. For cold finger installation, a hole was drilled in one of the sides of the environmental chamber. A groove was made for O-ring using gland design guidelines on the top side of the environmental chamber to seal the chamber. The detail specifications are listed in table 3.

Table 3. Environmental chamber specification.

Material	Aluminum Al6061 alloy
Dimensions	150*150*140 mm3
Hole dimension	D= 90mm thru hole
Wall Thickness	15 mm

The 3D model of the Environmental chamber is depicted in figure 1.

Figure 1. 3D model of Environmental chamber

3.3.2. Cover Plate

A cover plate of 150*150*8mm3 was made for covering the chamber. For light to travel into the chamber, a slot of the rectangular cross-section of 100*80 mm2 was made for glass window, where glass is to be seated. The glass was installed in the cover plate slot and was sealed with silicone to perfectly seal the opening. Cover plate specification are listed in table 4.

Table 4. Cover plate specifications.

Material	Aluminum Al6061 alloy
Dimension	150*150*8 mm^3
Glass window seat	100*80 mm^2
Glass	100*80*2 mm^3

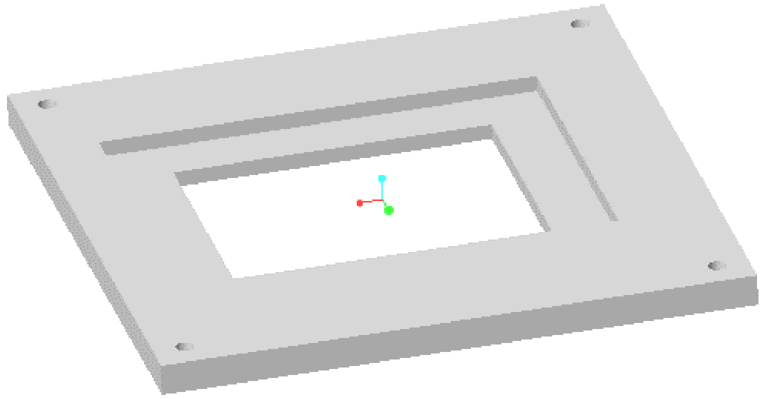


Figure 2. Cover Plate

3.3.3. Glass window

The plane glass was used on the cover as a window in the cover plate to allow solar irradiance to reach the photovoltaic solar cell and also to seal the environmental chamber from outside environment. It was selected due to its easy availability. A 2mm thick glass was used as a glass window.

3.3.4. Cold Finger

For efficient and fast heat transfer we designed a cold finger made of copper. Copper was selected due to its high thermal conductivity and good heat transfer properties. Cold finger design was selected as it is used to produce localized cold surfaces with the less loss of heat energy. The cold finger was designed based on the size of the solar cell available in the market and so that it must have a maximum surface area available for heat transfer. The cylindrical portion of the cold finger was made finned to increase the surface area. Cold finger was made in two pieces for easy assembly and installation. One side of the cold finger was made flat which serve as a seat for a solar cell, where the solar cell is to be seated. A groove for O-ring was made in the cold finger in order to seal the opening hole in which the cold finger was mounted. The O-ring groove was designed according to gland design considerations. Cold finger specifications are given in table 5.

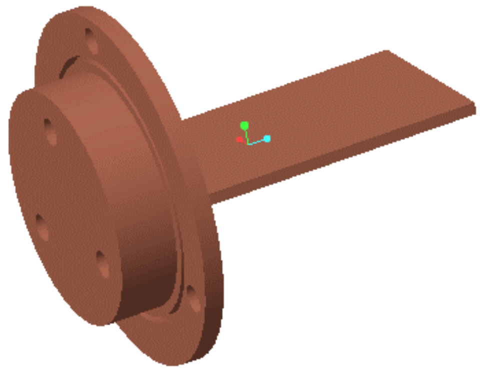


Figure 3. Cold finger (a)

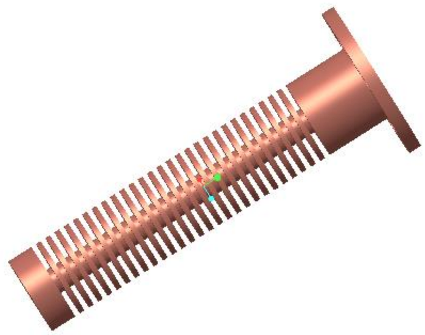


Figure 4. Cold finger (b)

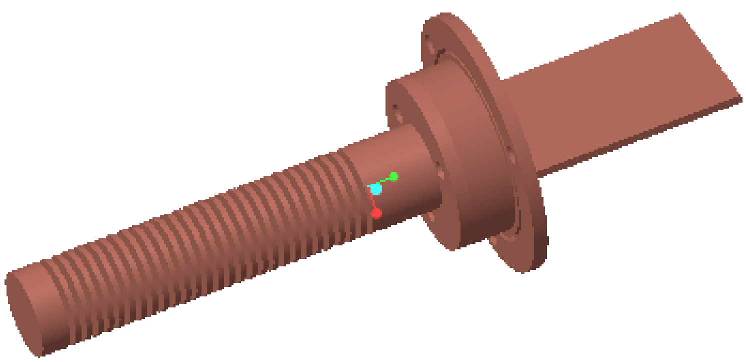


Figure 5. Assembled Cold Finger

Table 5. Cold finger specifications.

Material	Copper
Dimension	D= 30mm, L= 150 mm D= 90 mm, L= 20 mm Rectangular portion 80*50*3 mm^3

3.3.5. Heater

A heater was needed, for direct heating of the flat side of the cold finger on which the solar cell has mounted. A wide range of heaters is available in the market like cartridge heaters, glow plug heaters, plate or strip heater etc. A strip heater was selected due to its uniform heating of the surface on which it is mounted. A heater of 200 W 220V rating was selected keeping in view the temperature for which we designed the chamber. The heater was made in a way that it can provide heating in a single direction where it was required. Another side of the heater was insulated to avoid heating in the other direction. The heater was controlled using PID control and a solid-state relay. The specifications of strip heater are listed in table 6.

Table 6. Heater specifications.

Heater Type	Strip/plate Heater
Power rating	200 Watts, 220 V
Current drop	0.9 Ampere
Dimension	70*40*5 mm^3
No. of heater	1

3.3.6. Dry Ice chamber

A chamber was made for dry ice bath that act as a source of cooling below zero degrees centigrade. Dry-Ice bath comprises of Dry-Ice (Solid Carbon dioxide) and Ethanol (C_2H_5OH) and is in the form of a solution. i.e. liquid form. The cylindrical finned part of the cold finger was completely submerged in the dry-ice bath to cool down the other part on which the solar cell was mounted.

3.3.7. Solar cell

A solar cell is an electronic device that converts sunlight into electrical energy. Solar cells work on the principle known as the photovoltaic effect. When sunlight strikes, the solar cell surface a hole and electron are formed which move towards the opposite sides of the p-n junction. i.e. electron move towards p junction and hole moves towards n junction. A voltage is created in this way and solar cell act as a battery and as a result, an output voltage and current are produced as the light fall on the solar cell surface.

The solar cell can be broadly categorized into two categories. Inorganic solar cells and organic solar cells. Both of the categories have a further classification, but our focus in this research was a single monocrystalline silicon-based solar cell. The solar cell available in the market is of 53*30 mm2 area. The details of the solar cell are listed in table 7.

Table 7. Solar cell Specification

Solar cell Material	Inorganic silicon based
Solar cell type	Mono crystalline single solar cell
Dimension	53*30*2 mm^3
Maximum Output Voltage	6.3 Volts

3.4.Schematic diagram

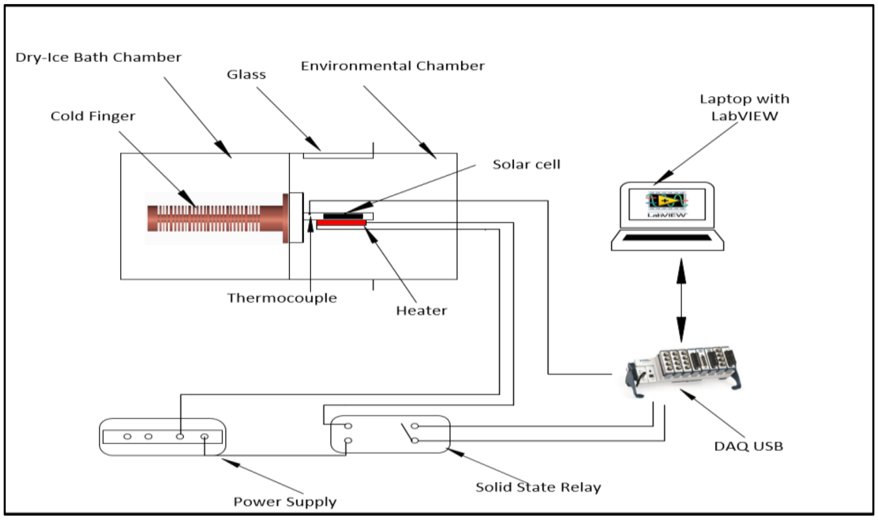


Figure 6. Schematic diagram

Figure 6 shows the schematic of assembled environmental chamber. The two rectangular boxes were placed next to one another with the cold finger installed in it. A photovoltaic cell was placed on the flat side of the cold finger and the heater is installed just below the surface. A thermocouple was also installed on the same surface to measure the temperature of the solar cell. Dry-ice bath container contains dry-ice bath and the cylindrical part of a cold finger for heat conduction. The heater was controlled through PID control using LabVIEW software and DAQ cards. Solid state relay was used as a switch for turning the heater on and off. Data acquisition and control was carried out using LabVIEW.

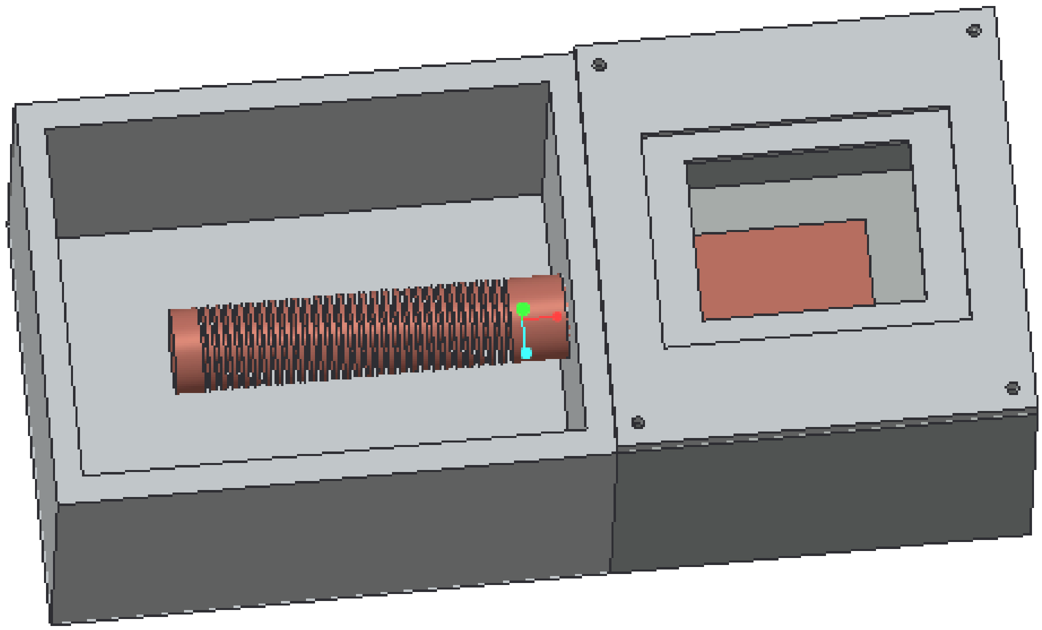


Figure 7. Complete assembled model of the environmental chamber

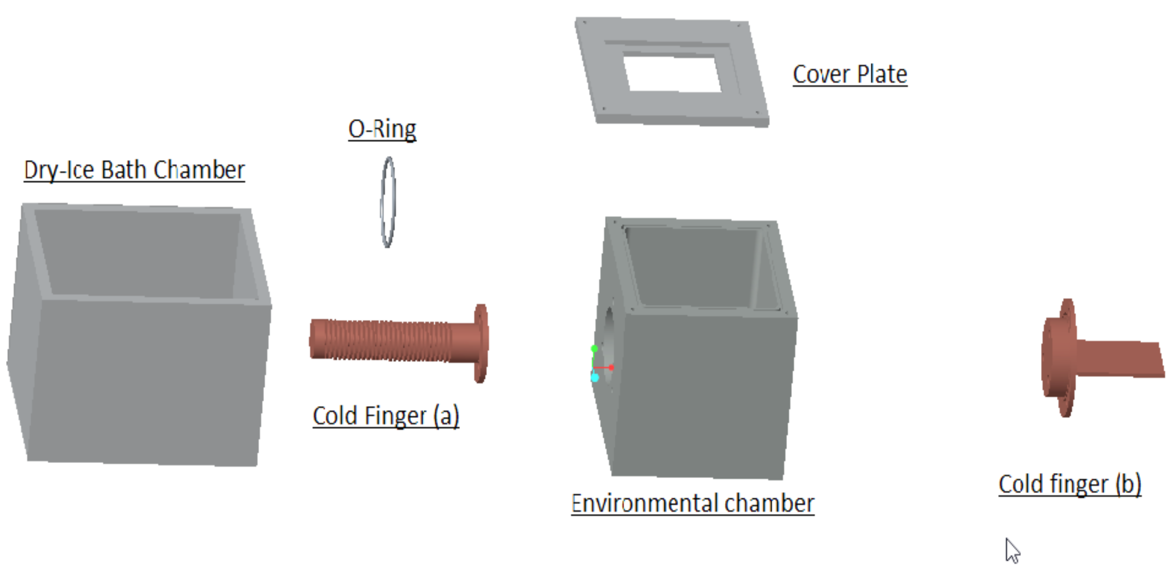


Figure 8. Exploded view of the assembly.

Chapter 4 Instrumentation and control

For proper data logging and acquisition, we need different sensors like a thermocouple, light meter, and data acquisition devices to acquire and note down the value of various parameters. We used a thermocouple, light meter, data acquisition card of National Instruments (NI) in our chamber. Following is a list of the Instruments and sensor that we used in our chamber.

- Heater
- Thermocouple
- Solar cell
- DAQ Card for data acquisition
- Solid State Relay
- Opto-coupler
- Lux Meter
- Voltmeter

4.1.Instruments used

4.1.1. Heater

A 200W,220V strip heater was selected and was installed on the back surface of the cold finger. The heater was controlled using a solid-state relay and PID control using LabVIEW and DAQ cards to attain the desired temperature on the surface on which the solar cell is mounted. The heater was connected with the AC main and was also properly grounded.

4.1.2. Thermocouple

To sense the temperature of the flat surface of the cold finger on which the solar cell is mounted, a temperature sensor is needed. A K-type thermocouple with point probe was selected due to its quick response, easy installation, and availability. We used epoxy to ensure probe is in proper contact with the surface for correct measurement of temperature. The thermocouple was installed in closer proximity with the solar cell to measure the temperature of the solar cell exactly.

4.1.3. Solar cell

Monocrystalline single solar cell (Inorganic Solar cell) was selected which was tested in the chamber. The solar cell was mounted on the top face of the flat portion of the cold finger. The output voltage of the solar cell was logged into the computer using a DAQ cards.

4.1.4. DAQ Card and Chassis

DAQ cards were used for sensing the physical signal and giving a digital output to the system. i.e. Computer. Two DAQ cards were used for sensing the physical signals i.e. Temperature, solar cell output voltage and a digital input/output card for turning the heater on and off using a solid-state relay. For interfacing of the DAQ cards and the sensors LabVIEW software was used to note and log the data into the system.

Figure 9. DAQ cards and Chassis

LabVIEW is a powerful tool for instrumentation and it uses graphical language which makes it more versatile and user-friendly to work with.

4.1.5. Solid State Relay

To turn on and off the heater, solid state relay was used due to its advantages over the DC or electromechanical relay. Solid state relay was connected to the AC main, heater and was controlled using a PID controller to operate the heater and to maintain a specific temperature on the surface of the cold finger on which we mounted the solar cell.

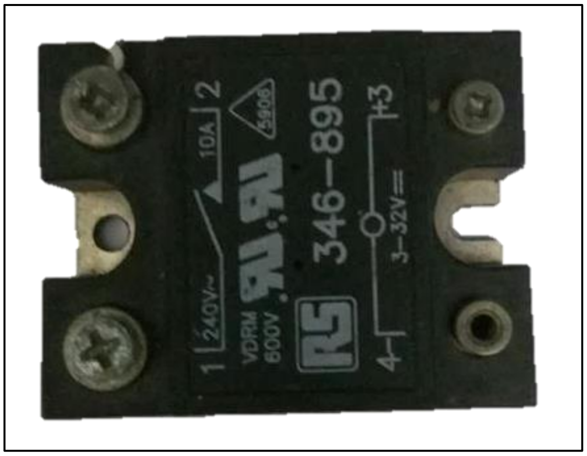


Figure 10. Solid state relay

4.1.6. Opto-Coupler

An optocoupler was used to avoid back e.m.f and also to prevent the DAQ card from getting damaged. The signal from the PID controller was fed into the optocoupler and then to the solid-state relay to complete the circuit.

4.1.7. Lux-Meter

For measurement of light intensity, we used Lux meter. The Lux meter was kept in closer proximity to measure the light intensity correctly.

4.1.8. Voltmeter

For counter checking the output voltage of the solar photovoltaic cell, a voltmeter was also used to ensure the correct voltage measurement on the DAQ system.

4.2. Data acquisition

Data acquisition includes collecting signals from measurement sources and digitizing the signals for storage, analysis, and presentation on a PC. DAQ systems originate in various forms of PC technology to provide flexibility when selecting your system. For data acquisition DAQ cards are used that contain built-in sensors that acquire data using the software. DAQ card 9219 was used for sensing the output of thermocouple and also the output of solar cell with high accuracy.

4.3. Control System

A control system contains various components and circuits that work together to continue the process at the desired working condition. Almost every house and industry have the very basic control of temperature, a thermostat that maintains a set temperature. In industry, a control system may be used to control some aspect of fabrication of parts or to maintain the speed of a motor at a set value. There are two main types of control system. Open loop control system and closed loop control system. The open loop control system has no feedback control system and does not monitor the output of the system. Closed loop system has a feedback system which monitors and control the output of the system and compares it with a set point. Closed loop system contains a controller that maintain the system in a set condition.

Feedback control system continuously compares input and output value. The desired value of the system is set and is known as the set point. The output of the plant is known as the measured value and is continuously compared with the set point. The difference between set point value and measured value is known as error.

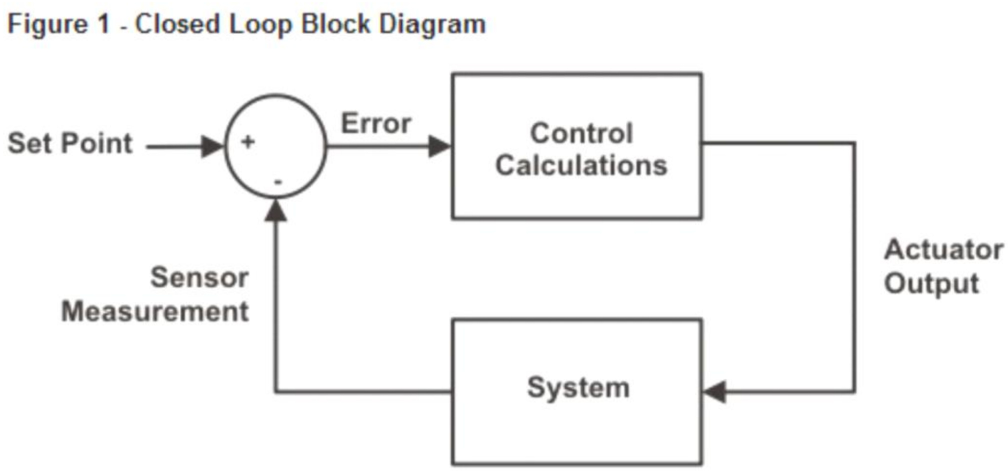


Figure 11. Closed loop controls system

4.4.PID Control

PID compensator is the most commonly used compensator in feedback control system. It is also known as three terms control compensator as it contains three different parameters i.e. proportional, integral and derivative terms. If *e(t)* is considered as controller input and *m(t)* output, then PID controller can be defined by the equation

$$m(t) = K_p e(t) + K_I \int_0^t e(\tau) d\tau + K_D \, de(t)/dt$$

K_p = proportional gain,

K_I = integral gain

K_D = derivative gain of the PID controller

e= tracking error

The term P depends on the present error, the term I on the summation of past errors, and the term D is an estimate of future errors, based on the current degree 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.

4.4.1. Proportional Term

The proportional term results in an output value that is proportional to the current error value. By multiplying the proportional gain term with the error, the proportional response can be adjusted.

The proportional term is given by

$$P_{out} = K_p e(t)$$

A high proportional gain results in a large change in the output for a given change in the error. A high proportional gain value results in instability of the system while a small proportional gain value will result in a large input error and a less sensitive controller.

4.4.2. 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 amount of the instantaneous error over time and gives the accumulated offset that should have been modified previously. The accumulated error is then multiplied by the integral gain (K_I) and added to the controller output.

The integral term is given by

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

4.4.3. Derivative term

The derivative term of the process error is the product of slope of error over time and derivative gain value K_d. The magnitude of the contribution of the derivative term to the entire control action is called the derivative gain, K_d.

The derivative term is given by

$$D_{out} = K_D \, de(t)/dt$$

Derivative action predicts system behavior and thus improves settling time and stability of the system.

4.5. System overview

Let E be defined as the difference between the set and measured value in our case it is temperature for which PID is implemented. So, we can write

E = Set temperature – Measured Temperature

$$E = T_{set} - T_{meas}$$

A set value of temperature was fed into the system and the values of gains of P, I and D controller were changed and the output of the system was observed. First, we set the value of P controller, i.e. gain of the proportional controller was set. Then the value of Integral gain was set while observing the behavior of the system. The value of the derivative gain was not changed and was kept at zero. In our case, we just used PI controller as it was working fine and the system was tuned. Pulse width modulation was also used to control the power needed for operating the heater and to reach the set temperature easily in the desired time.

For operating a heater, it works well if the average power is controlled rather than keeping the power exactly same at all the time. Power averaging is a basic method of power control and is carried out using pulse width modulation. PWM give an output that is either high or low, but with timing that is determined by the error signal.

When we use PWM, we use LabVIEW to calculate a percent on-time, also called the duty cycle. Duty cycle is in between 0 to 100 %. As the DAQ output ranges from 0 to 5 V so this limitation is not confining us. LabVIEW was used to turn off the solid-state relay when the output was low and was turned on when the output was high. Note that pulse width modulation allows us to select either the analog or the digital outputs from our data I/O device. The analog outputs vary in very fine increments over a wide voltage range. The digital outputs have two state low which is 0 V and high which is 5 V in our case, so they are good for switching of relay and PID control only with a PWM controller. The signal of the PID controller was fed into the DAQ card which was then used as a power source for the relay. Thus, heater was controlled using an SSR and a PID controller.

4.6.LabVIEW code overview

Two DAQ cards 9219 and 9401 were used for data acquisition and control. Thermocouple signal and output of the solar cell was logged into the computer using 9219 DAQ card. Built-in DAQ assistant was used which is an express VI. The output of the first VI was fed into the PID VI and then it was modulated using pulse width modulation. The output of PWM was fed to the DAQ VI and was used as a power source for relay using 9401 DAQ card.

4.6.1. LabVIEW Program

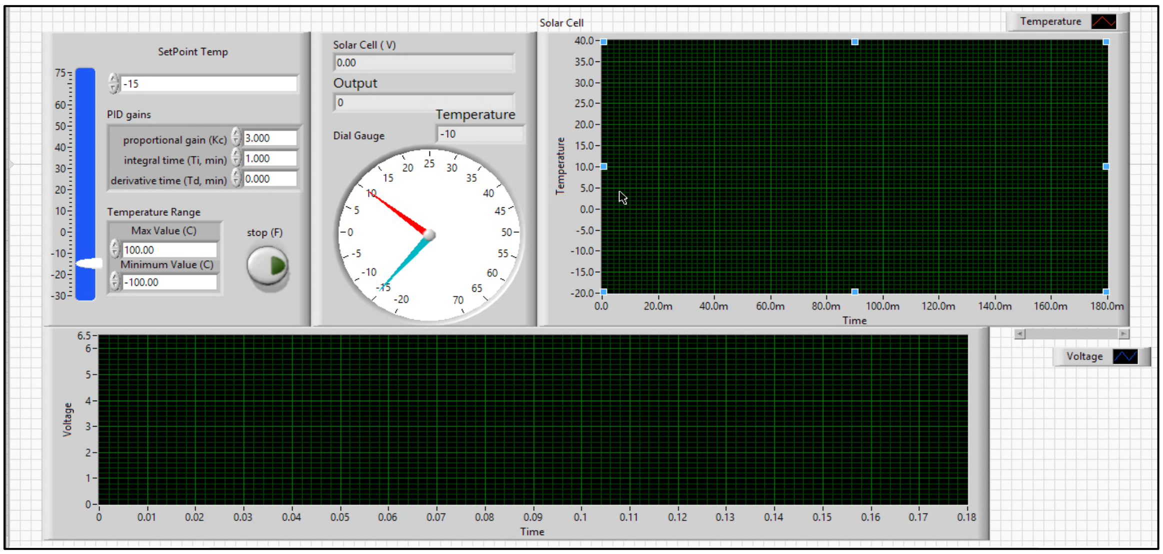


Figure 12. Front Panel of the LabVIEW code

The temperature control system of the environmental chamber works on the principle of PID temperature control. Heating system comprises a plate heater which directly heats the "cold finger". The heater was installed to raise the temperature of the plate to the desired set temperature. The plate heater was connected to the main AC power supply of 220 V and solid state relay. The solid-state relay has been connected to DAQ 9219 USB which was interfaced with the LabVIEW to control the temperature of the bracket at the required point through 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.

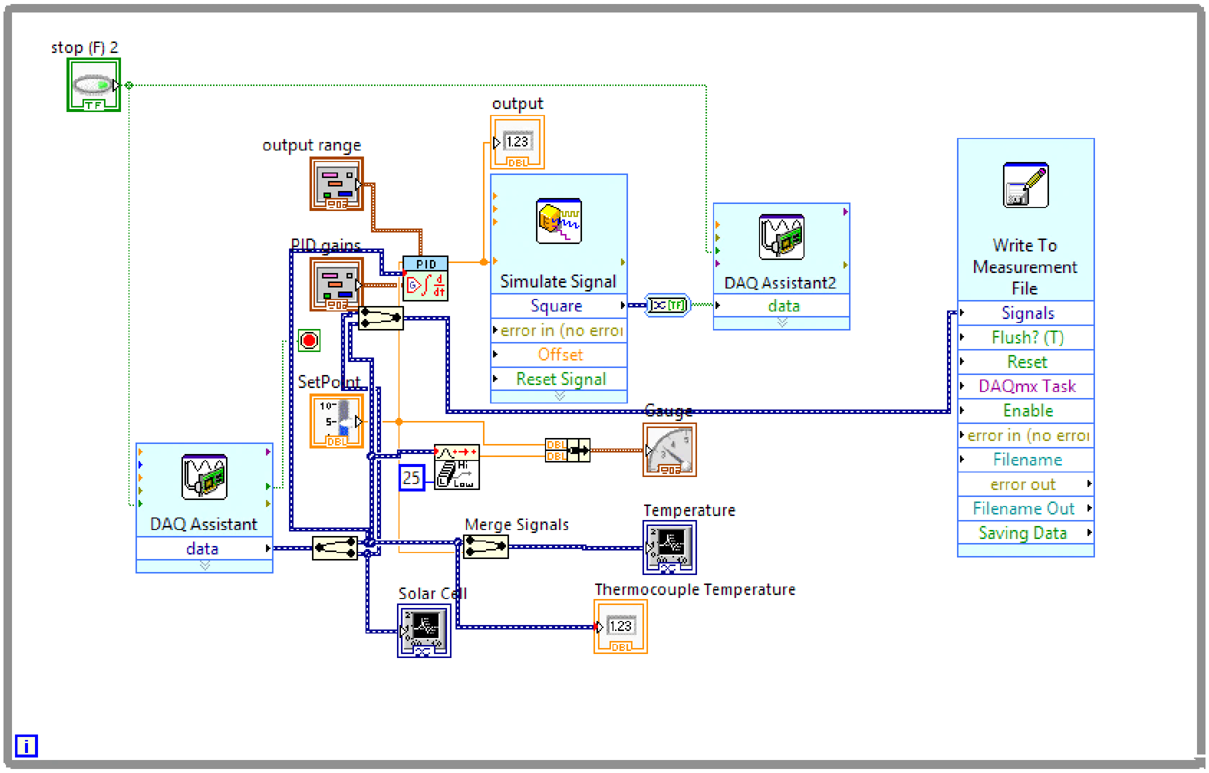


Figure 13. Block diagram of the LabVIEW code

Figure 14. Complete assembly of the setup

Chapter 5 Results and Discussion

This chapter covers the details of the experimentation carried out. It also covers the results and discussion portion of the thesis.

5.1.Experimentation

The photovoltaic solar cell was mounted on the flat side of the cold finger with the heater installed on the backside of the same surface. The circuit was made completed and the essential connections were made. The heater was properly grounded to avoid any shock. DAQ cards, SSR, and the electrical circuit was connected to the AC main power source and also with the Laptop. The chamber was covered with the cover plate and both of the chambers were placed next to one another. For a temperature range of 20 ^{o}C to 65 ^{o}C, normal ice was used as it was working properly. For temperature below 20 ^{o}C to -15 ^{o}C Dry-ice ethanol mixture was used. Dry-ice bath chamber was fed with dry-ice first and then ethanol was added after starting the experiment to get the temperature below zero degrees centigrade. Safety precautions were taken throughout the experiment.

The temperature was set to the desired value and the system was turned on then. The readings of temperature values, the output voltage of the solar cell and light intensity were noted simultaneously using LabVIEW. The data was then plotted on a graph.

5.2.Design of Experiment

A wide temperature range was selected in which the solar cell can be used. The temperature range was selected ranging from -20 ^{o}C to 65 ^{o}C. Three different values of light intensity were selected to find the behavior of the output voltage while changing the temperature. A five-degree gap was kept in the temperature values and the output voltage of solar cell was observed at each successive five degrees.

Table 8. Design of Experiment

Parameter	**Range/Value**
Temperature	-20 ºC to 65 ºC
Light Intensity	30000, 60000 and 90000 Lux
Output Voltage of solar cell	Was observed and noted down

5.3.Results and Discussions

The following graphs and data was observed after the experiment and was plotted on the graph.

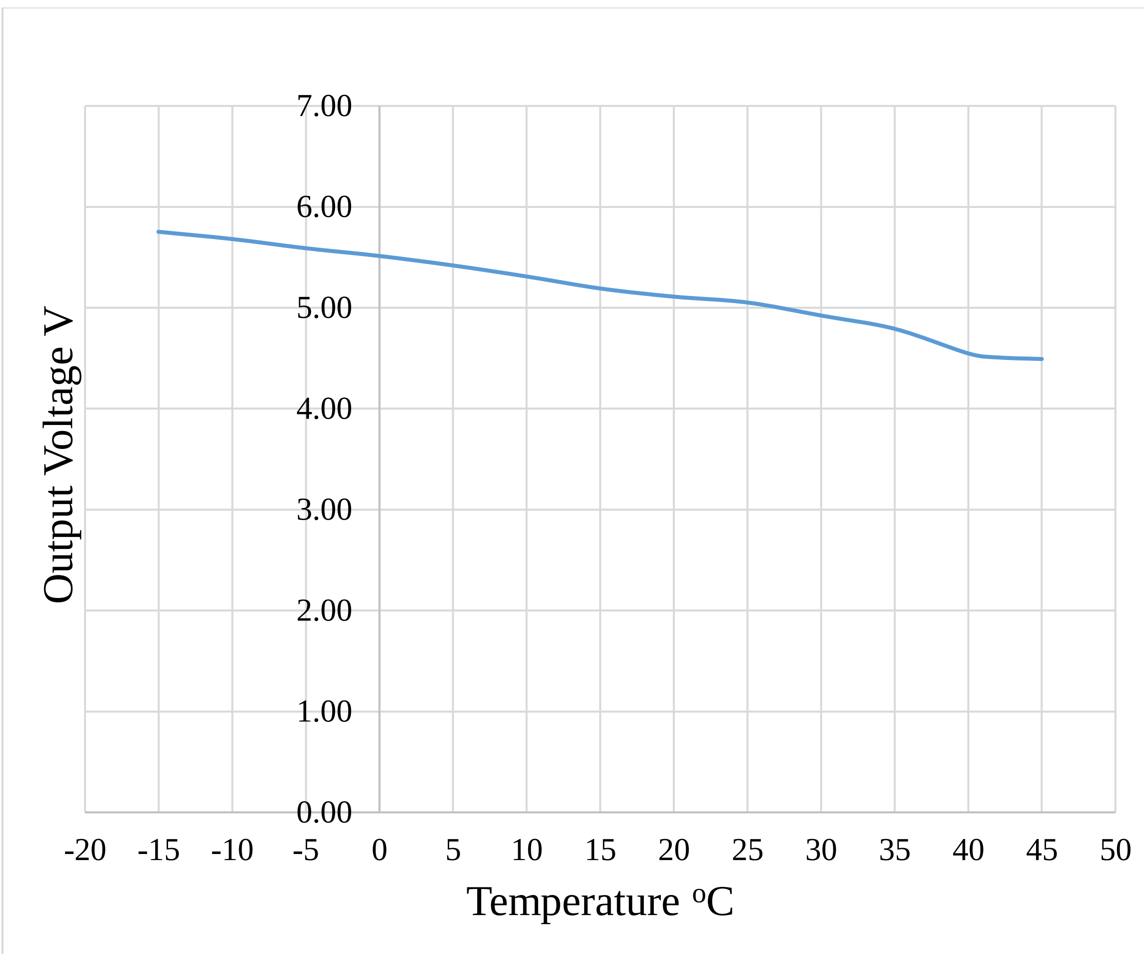


Figure 15. Temperature Vs Output Voltage at 30000 Lux

Table 9. Temperature, Output voltage and change in output Voltage at 30000 Lux

Temperature °C	**Output Voltage V**	**Change in Output Voltage V**
65	4.14	--
60	4.19	0.05
55	4.29	0.10
50	4.38	0.09
45	4.49	0.11
40	4.51	0.02
35	4.55	0.04
30	4.79	0.24
25	4.92	0.13
20	5.05	0.08
15	5.11	0.11
10	5.19	0.08
5	5.31	0.12
0	5.42	0.11
-5	5.51	0.09
-10	5.59	0.08
-15	5.68	0.09
-20	5.75	0.07

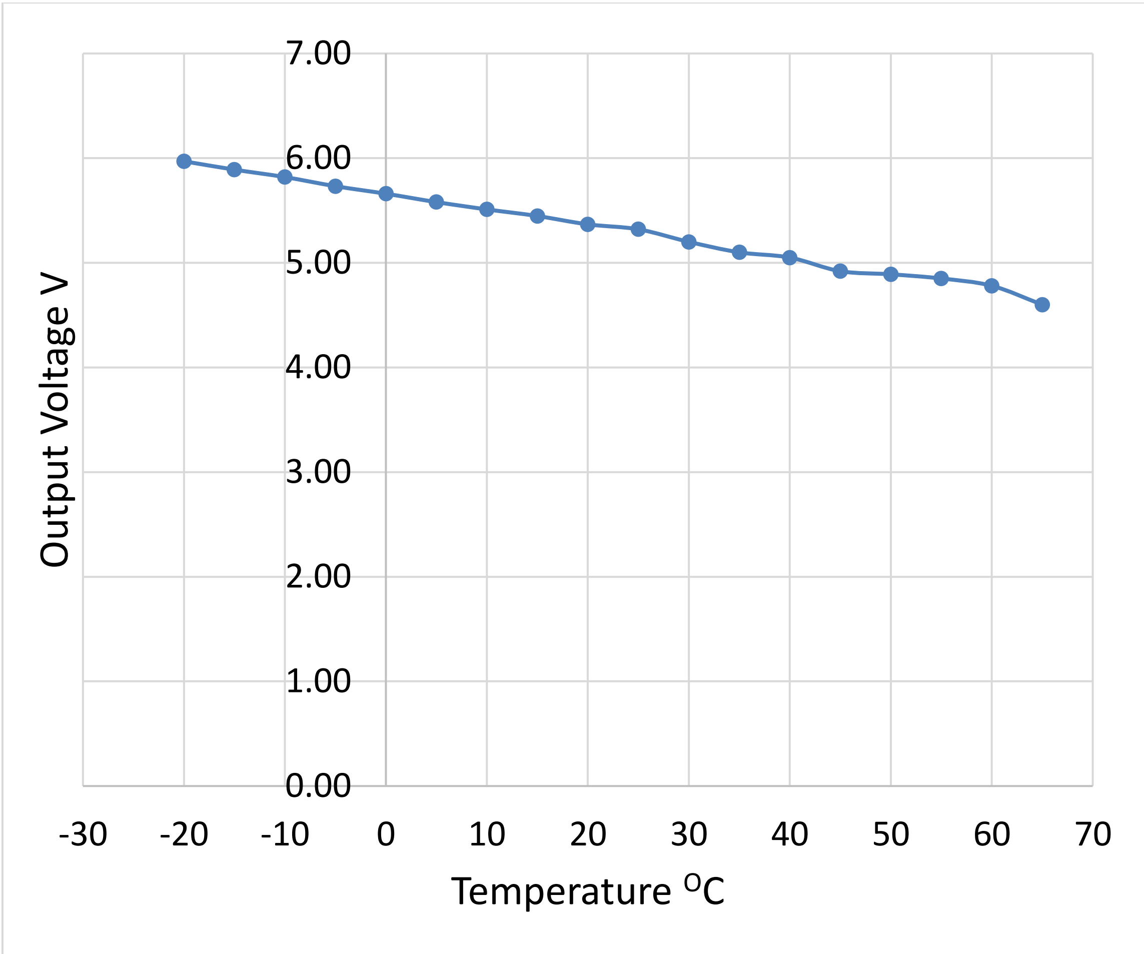


Figure 16. Temperature Vs Output Voltage at 60000 Lux

Table 10. Temperature, Output Voltage and change in output Voltage at 60000 Lux

Temperature ºC	Output Voltage V	Change in Output Voltage V
65	4.60	
60	4.78	0.18
55	4.85	0.07
50	4.89	0.04
45	4.92	0.03
40	5.05	0.13
35	5.10	0.05
30	5.20	0.10
25	5.32	0.12

20	5.37	0.05
15	5.45	0.08
10	5.51	0.06
5	5.58	0.07
0	5.66	0.08
-5	5.73	0.07
-10	5.82	0.09
-15	5.89	0.07
-20	5.97	0.08

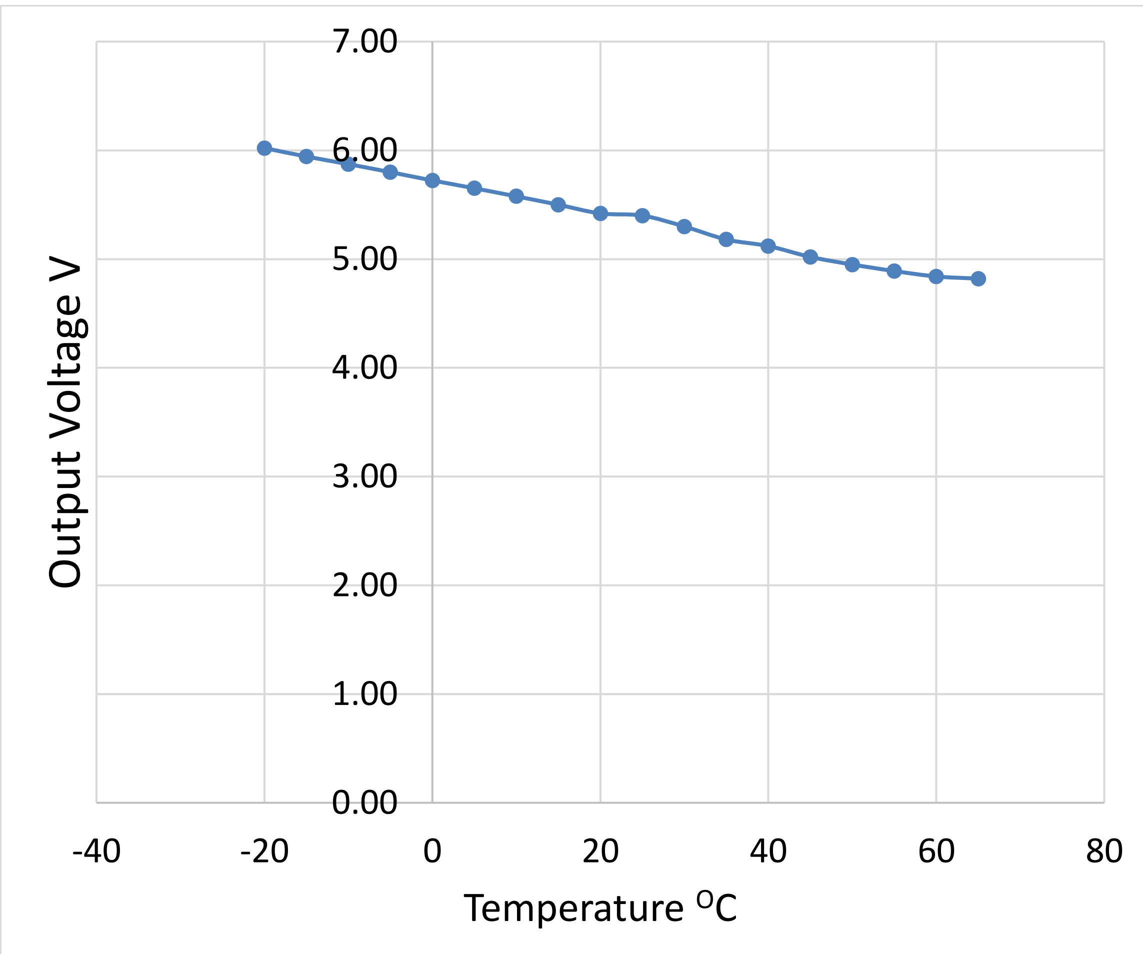


Figure 17. Temperature Vs Output Voltage at 90000 Lux

Table 11. Temperature, Output Voltage and change in output voltage at 90000 Lux

Temperature ^oC	Output Voltage V	Change in output Voltage V
65	4.82	
60	4.84	0.02
55	4.89	0.05
50	4.95	0.06
45	5.02	0.07
40	5.12	0.10
35	5.18	0.06
30	5.30	0.12
25	5.40	0.10
20	5.42	0.02
15	5.50	0.08
10	5.58	0.08
5	5.65	0.07
0	5.72	0.07
-5	5.80	0.08
-10	5.87	0.07
-15	5.94	0.07
-20	6.02	0.08

The monocrystalline single solar cell was tested under real sun conditions in the outdoor environment and the data was plotted. In figure 1 the solar cell was tested at 30000 Lux solar intensity and the maximum output voltage of 5.74 Volts was observed at -20 ^oC, the lowest temperature on which the solar cell was tested. As the temperature was increased the output voltage of the solar cell was getting lower and lower and at 65 ^oC an output voltage of 4.14 Volts was observed. Average change per five-degree rise while keeping the intensity constant was 0.09 Volts for 30000 Lux solar intensity.

In figure 2 and 3 the solar cell shows the same trend and at the lowest temperature keeping the intensity constant the output voltage was maximum. The output voltage of the solar cell keeps decreasing as the temperature was increased keeping the solar intensity constant. The average change in the output of the solar cell was 0.08 Volts for 60000 Lux and 0.07 for 90000 Lux per five-degree rise in temperature. The change in the output of the solar cell is slight in the optimum conditions and get a bit increased as the temperature increased beyond 40^{o}C. We tested solar cell on a wide range of intensity as solar intensity under real condition varies from time to time throughout the day.

Chapter 6 Conclusions

This chapter includes the finding of the project and also future recommendations. The objectives of the thesis were to:

- Design & development of environmental chamber for solar cell testing.
- Design & Development of Cold finger design for low temperature.
- Instrumentation of Chamber.
- Design & implementation of PID controller using LABVIEW for Temperature Control.
- Temperature Testing of Chamber.

6.1. Conclusions

The performance testing of the solar cell is very critical to ensure proper working of the solar cell, panel, and module. Solar panel and modules are tested in an environmental chamber at standard test conditions but outside environment in which they are operated isn't the same. In this research, a lightweight, compact and portable environmental chamber was developed having the facility of testing single solar cell at controlled temperature using PID controller and DAQ cards. Preliminary tests were also conducted for calibration and testing of the chamber. Temperature testing of a single solar cell was carried out in a temperature range of -20 ^{o}C to 65 ^{o}C at atmospheric temperature and the results were in accordance with reported literature.

6.2.Future Work

Preliminary tests were carried out for calibration and repeatability testing of the environmental chamber designed in this research. The chamber was used for temperature testing of a single solar cell, and the behavior of output voltage of solar cell was studied at different temperature keeping the intensity constant. The future work of the project includes the following work.

8.2.1 Testing and Evaluation of different types of available solar cells

Different types of available solar cells are monocrystalline Si PV cells, polycrystalline Si PV cells, amorphous Si PV cell, Organic solar cells etc. Further research should focus on the performance of various types of available solar cells at different temperatures. The performance of different kind of available solar cells can be evaluated at different light intensities.

Testing & Evaluation of PV cells at different wavelength of light

Another possible area of future research would be to investigate the effect of the wavelength of solar spectrum on the performance of different types of solar cell available in the market. For this purpose, different glass filters can be used to evaluate open circuit voltage of PV cells at a different wavelength of light.

8.2.2 Effect of pressure on performance of PV cells

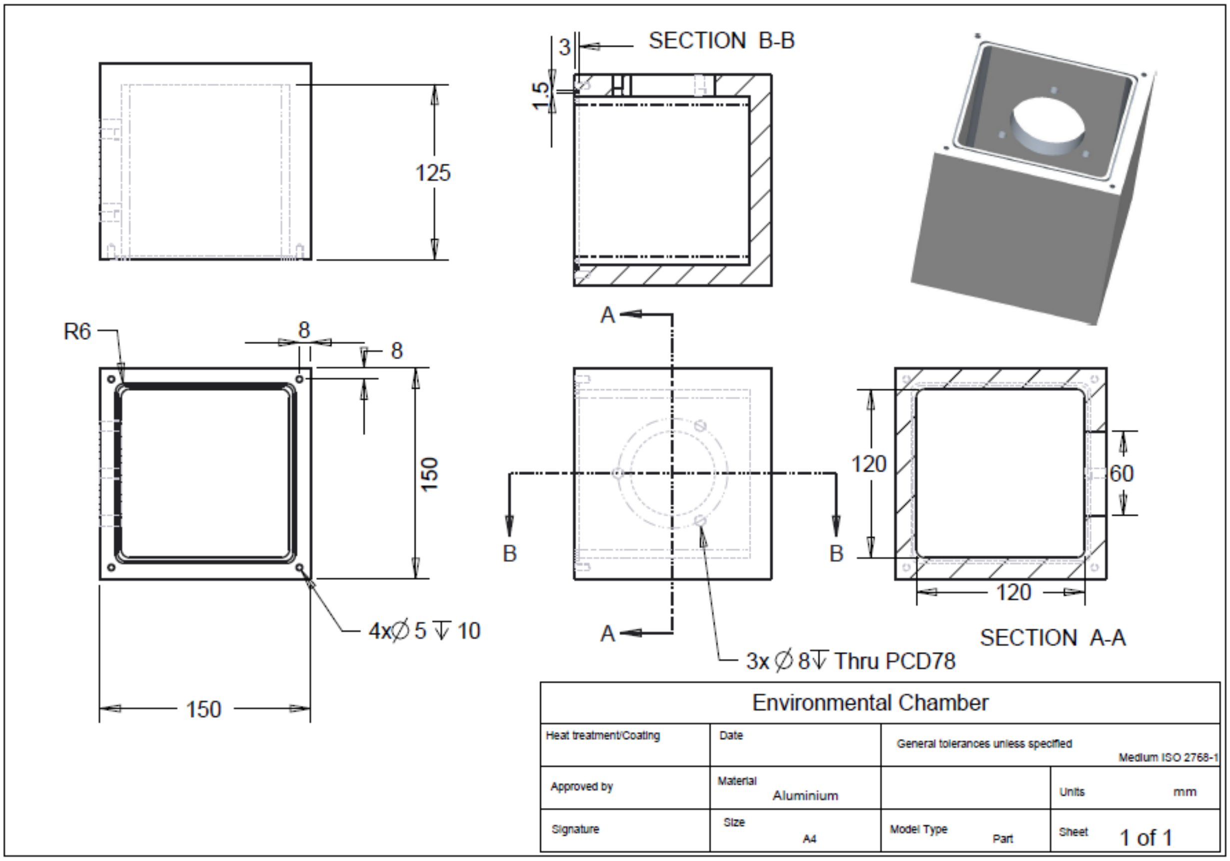
More research is needed to better understand the effect of pressure on the performance of the solar cell. Testing and evaluation of different available solar cells should be carried out in a pressurized chamber, at a constant temperature, for studying the lifetime degradation. The same study could be carried out for vacuum conditions while keeping the temperature constant first and then varying it.

The future work can be summarized as follows.

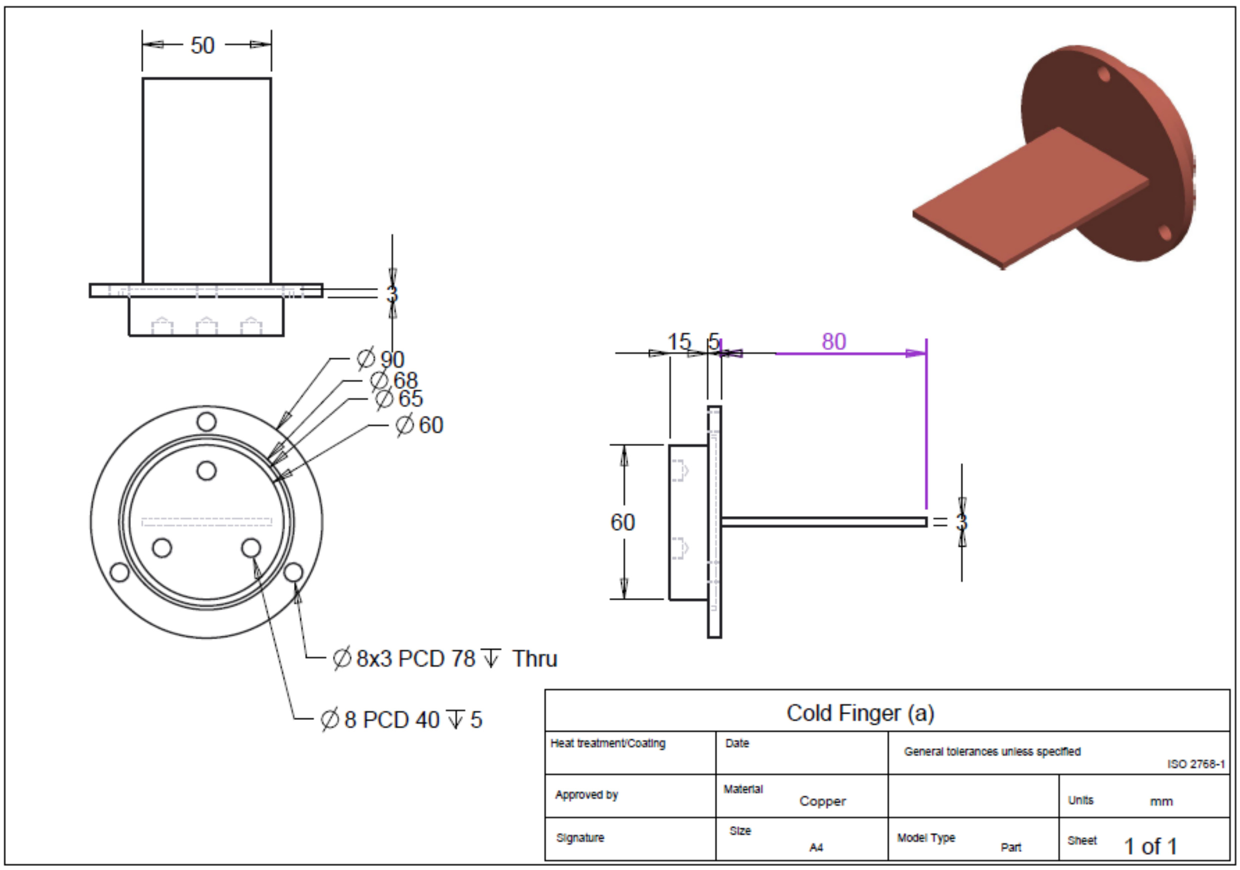
- Performance and evaluation testing of PV cells at different temperature and intensities at atmospheric pressure.
- Testing and Evaluation of PV cells at pressurized and vacuum pressure.
- Performance testing of solar cells at the different wavelength of sunlight.

APPENDIX A

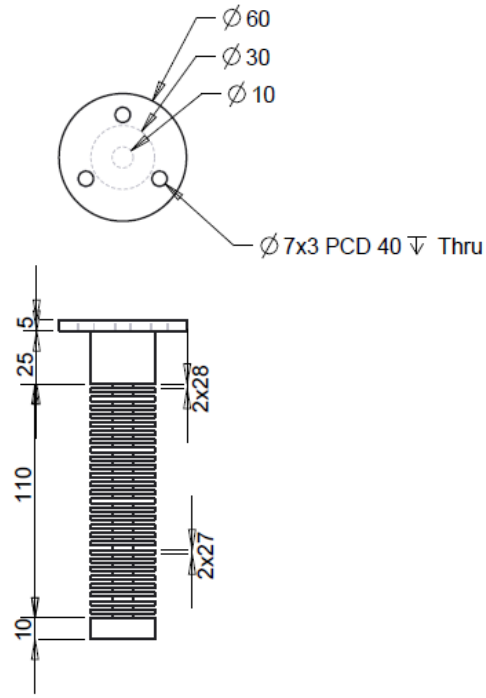
Environmental chamber

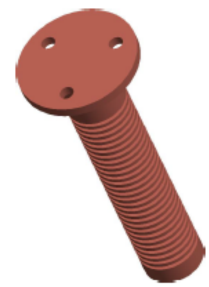


Cold Finger (a)



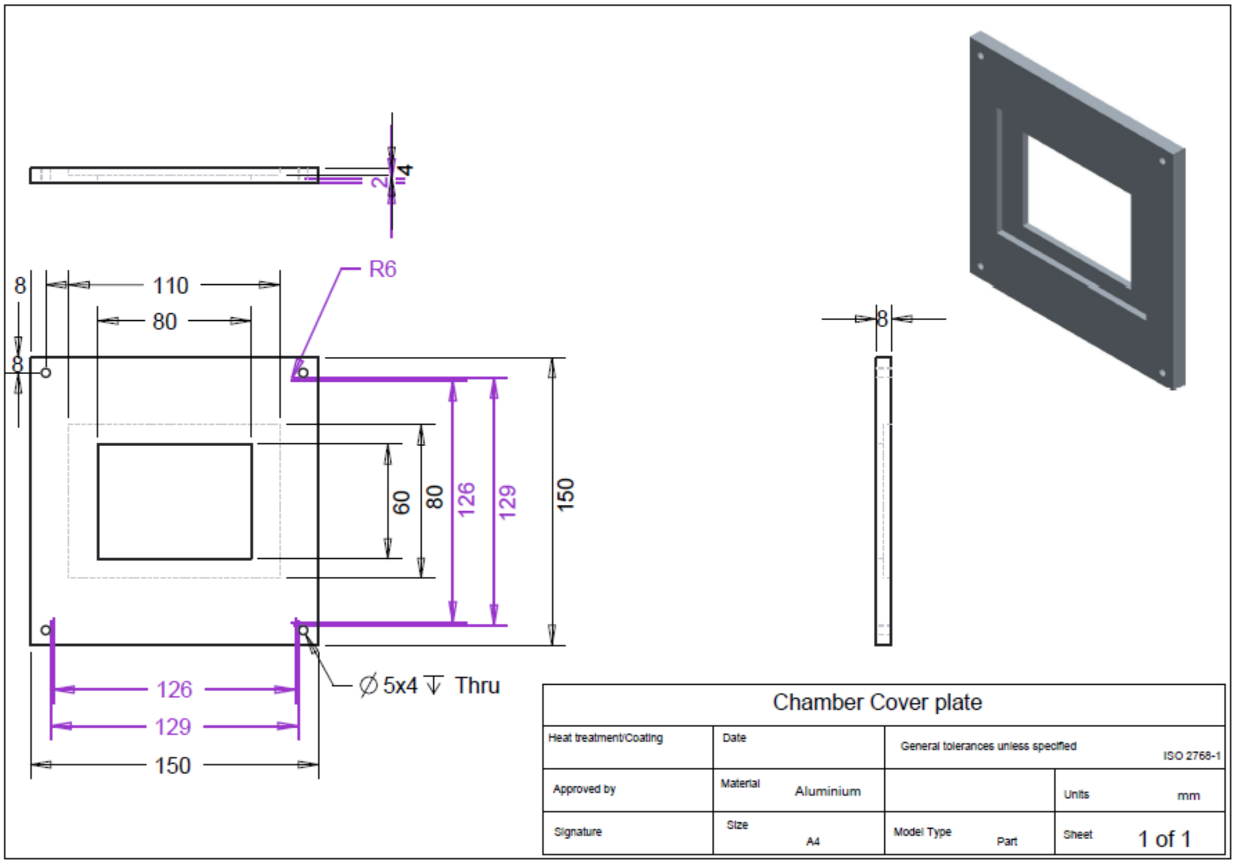
Cold finger (b)





Cold Finger (b)			
Heat treatment/Coating	Date	General tolerances unless specified ISO 2768-1	
Approved by	Material Copper		Units mm
Signature	Size A4	Model Type Part	Sheet 1 of 1

Chamber Cover Plate



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