2A09 INVESTIGATION OF STANDARD TEST CONDITION REQUIREMENT IN ESTABLISHING RELIABLE CURRENT-VOLTAGE CHARACTERIZATION SYSTEM FOR DYE – SENSITIZED SOLAR CELL (DSSC) AS AN ALTERNATIVE FOR COMMERCIAL SOLAR SIMULATOR AND PHOTOVOLTAIC MEASUREMENT SYSTEM

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ABSTRAK

Ciri-ciri keluaran nominal mana-mana sel suria yang direka atau modul dinilai secara konvensional berdasarkan keperluan standard yang dipanggil sebagai Keadaan Ujian Standard (STC). Untuk mematuhi keperluan STC ini sebelum produk dikomersialkan, setiap sel/modul suria fabrikasi mesti menjalani beberapa ujian seperti pengukuran voltan arus di bawah tiga keadaan persekitaran: sinaran suria 1000 W/m^2, suhu sel 25°C dan jisim udara (AM) 1.5. Secara amnya, lampu berasaskan xenon biasanya digunakan sebagai sumber pencahayaan utama 1000 W/m^2 dan istilah 'AM1.5' terutamanya distrukturkan berdasarkan penapis AM1.5 berasaskan kaca yang tersedia secara komersial dalam simulator suria biasa. Walau bagaimanapun, teori terperinci bagaimana dan mengapa semua keperluan ini samada ianya harus atau tidak harus distrukturkan jarang dibincangkan dan didedahkan dalam literatur. Oleh itu, kajian ini akan menjalankan penyiasatan mendalam dalam membangunkan metodologi yang betul dan relevan supaya sistem pencirian voltan arus yang boleh dipercayai dapat diwujudkan dengan mematuhi keperluan STC ini.

ABSTRACT

Nominal output characteristics of any fabricated solar cells or modules are conventionally evaluated based on standard requirement that is called as Standard Test Condition (STC). In order to comply with this STC requirement before products are being commercialized, each fabricated solar cell/module must undergo several tests such as current-voltage measurements under three environmental conditions: solar irradiance of $1000\mathrm{W/m^2}$, cell temperature of 25°C and air mass (AM) of 1.5. Generally, xenon-based lamps are commonly utilized as main illumination source of $1000\mathrm{W/m^2}$ and the term 'AM1.5' is mainly structured based on commercially-available glass-based AM1.5 filter in typical solar simulators. However, the detailed theories how and why all these requirements should or should not be structured is rarely discussed and revealed in the literatures. Therefore, this study will conduct deep investigation in developing proper and relevant methodologies so that the reliable current-voltage characterization system can be established by complying these STC requirements.

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LIST OF SYMBOL

°C	Degree Celcius
W/m^2	Watt per meter square
RM	Ringgit Malaysia
K	Kelvin
L	Solar radiation path length through the atmosphere
z	Incident at a zenith angle
L_0	Atmosphere thickness in the direction
Lm/W	Luminance per Watt
s	Second
Q	Outflow of water
H	Head
P_g	Power generator
kWp	Kilo Watt peak
MW	Mega Watt
I_{sc}	Short circuit current
V_{oc}	Open circuit voltage
A	Ampere
V	Voltage
P-type	Positive-type
N-type	Negative-type
m^2	Meter square
cm	Centi meter
y	y-axis
=	Equal
m	Gradient
+	plus
x	x-axis
c	Line cuts the y-axis
lx	Lux
T_{amb}	Ambient Temperature
T_{cell}	Cell Temperature
I-V	Current-Voltage

LIST OF ABBREVIATIONS

STC	Standard Test Condition
AM	Air Mass
PV	Photovoltaic
DSSC	Dye-Sensitized Solar Cell
LED	Light-Emitting Diode
ASTM	American Society for Testing Material
ASTM E-490	Air Mass Zero Reference Spectrum
CSI	Compact Source Iodide
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
ELC	Electronic Load Capacitor
IES	Instituto de Energia Solar
UPM	Universidad Politecnica de Madrid
NDT	Non-Destructive Testing
AE	Acoustic Emission
VCC	Vapor Compression Cycle
SABC	Subatmospheric Brayton Cycle
COP	Coefficient of Performance
3-D	3-Dimension
BTMS	Battery Thermal Management System
EV	Electronic Vehicles
FTKEE	Fakulti Teknologi Kejuruteraan Elektrik & Elektronik
LCD	Liquid Crystal Display
UMP	Universiti Malaysia Pahang
KK 5	Kolej Kediaman 5

CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, the growth in renewable energy generation has led to an increased need to develop, manufacture and test components and subsystems for solar simulator, photovoltaic (PV), and concentrating optics for both simulator and electrical solar applications. Photovoltaic is the most common renewable energy resources that has been used broadly around the globe [1]. Solar cells that made from crystalline silicon, thin film and organic dye-based compounds are materials used to be conventionally measured by the simulator to produce output current-voltage characteristics. However, in order to get the current-voltage characterization, the solar simulator must be achieved the three environmental Standard Test Condition (STC) such as solar irradiance of $1000 \mathrm{W/m^2}$, cell temperature of 25°C and air mass (AM) of 1.5 [2].

A solar simulator is a device that produces light with the same intensity and spectrum composition as real sunlight. Solar simulators, often known as sunlight simulators are pieces of scientific equipment that simulate sunlight in controlled laboratory settings. They are required for the development and testing of goods and processes that utilise or are impacted by sunlight, such as solar cells, solar fuels, sunscreens, polymers, coatings, and other photosensitive materials [3][4]. A light source and power supply, optics and filters to adjust the output beam, and the controls required to run the simulator are the main components of solar simulators. Because of variations in how artificial light is produced, additional procedures must be taken to match the intensity and spectral composition of sunshine.

These factors will have an effect on the panel specs, resulting in higher performance outcomes. A side from that, it is hoped that by taking the proper approach, it would be possible to improve the performance of the solar simulator so that it may be used in the same way as an outside environment to provide output data for current-voltage characterisation. As a result, the goal of this project is to examine the Standard Test Condition requirements for developing a reliable current-voltage characterization system for Dye-Sensitized Solar Cells (DSSC) as an alternative to commercial solar simulators and photovoltaic measuring systems [5].

1.2 Problem Statement

In developing solar simulator, there are several critical requirement that must be fulfilled, which is called as Standard Test Condition. Those parameters are solar irradiance of 1000W/m2, cell temperature of 25°C and Air Mass (AM) 1.5. Understanding the true meaning and how to properly achieve this STC are the main points to be revealed in this study since several arguments can be raised for each parameter such as;

a) **Solar irradiance (1000W/m2)** – Logically, PV cell and solar cell absorb energy directly from sunlight. Solar irradiance meter is used to measure the direct sunlight. Since this device (silicon-based) follows the sunlight spectrum, if the different light source is change to other types of lamp such as Xenon, Tungsten Halogen Arc lamp or LED, there are possibilities that the measurement cannot be performed properly due to this different spectrum absorbed by the solar irradiance meter. Conventionally, the calibrated solar reference cell is used to do the calibration but it is very costly and difficult for small-scale development. Other solutions is needed - such as, use the meaning in term of lux because lux can be measured any light intensity. Further study correlation relationship should be deeply investigated and further analysed.

b) **Cell Temperature (25°C)** – Commonly, the temperature can be stabilized used any available cooling devices (fan, peltier, liquid coolant). However, the ambient temperature $Tamb$ will keep increase over exposure time from illumination of the light source which consequently rise up the $Tcell$, simultaneously. Therefore, how much the tolerance (temperature) is considered and do the cell temperature keep stable at 25°C for the whole time during the measurement? How much time is needed for the cell temperature to become stable?

c) **Air Mass (1.5)** – AM 1.5 filter already with costly almost RM10, 000 to filter sunlight spectrum. It is necessary to understand the practical meaning of Air Mass and need to be analysed other solutions are needed.

1.3 Objective

1) To study the correlation between illuminance (lux) and solar irradiance using several light resources.
2) To propose a mechanism in stabilizing the cell temperature at 25°C even under high illuminance condition.
3) To construct a structure based on related angle concept in order to comply with AM 1.5 requirement.

1.4 Scope of Project

- Size of tested solar cells: 2.5cm x 2.5cm (DSSC) and 6cm x 6cm (Silicon solar cell)
- Design development small-scale solar simulator of controlled-environment measurement platform that consists of the Standard Test Condition (STC) requirements which are 1000 W/m^2 of solar irradiance, cell temperature of 25°C and Air Mass (AM) 1.5.
- Development of cooling system for measurement setup of Dye-Sensitized Solar Cell (DSSC).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In study on some literature review, there are some method and approach to identify the performance solar simulator based on Standard Test Condition (STC) requirement factor. Most of the journal carry on about the investigation of lamps (argon arc, metal halide, tungsten halogen, xenon arc, and LED), solar irradiance (illumination and lux), Air Mass (AM) 1.5, and cell temperature of 25°C. A part from that, another journals are mentioning the specification to build up solar simulator like current-voltage (I-V) measurement and cooling system. Most of the parameter related to each other. The assessment consists of define the parameters, measurement tools, method used, clarifying and summarizing the literatures. The title of journal, name of author, year published and study aim also been stated. All of the information is summarized in Microsoft Excel.

2.2 Standard Solar Simulator

These space solar simulators set the foundation for most of today's basic research and testing in solar modelling [6]. Solar simulators are required in order to compare solar devices and create big arrays on a consistent basis. This produced a demand in the industry for testing solar cells and other devices under controlled settings, as well as a demand for easily available solar simulators. Solar simulators are critical for photovoltaic measurements in both research and industry, and because the illuminated current-voltage (I-V) is sensitive to spectrum, intensity, and temperature, the search for new light sources and the development of higher accuracy optical systems based on leading standards became a priority [7].

2.2.1 Blackbody Radiator Spectrum

A blackbody is a perfect emitter and absorber of radiation [8]. At a given temperature, a blackbody radiator has the highest conceivable spectral radiance for a heated body. As a result, this temperature is commonly utilised as a handy baseline for comparison with real-world radiation sources [9]. At a temperature of 5777 K, which can be estimated to 5800 K, the sun can be thought of as a blackbody radiator.

2.2.2 Solar Spectrum

Because of absorption in the cold peripheral solar gas [10], the real solar spectrum differs from a blackbody radiance at 5800 K. Direct solar radiation is absorbed and scattered by gaseous molecules such as nitrogen, oxygen, aerosols, and water vapour as it travels through the earth's atmosphere. As a result, once the solar radiation has passed through the atmosphere, an Air Mass (AM) coefficient has been created to characterise the solar spectrum [11]. The AM coefficient is defined as the product of the solar radiation path length through the atmosphere (L) incident at a zenith angle (z) and the atmosphere thickness in the zenith direction (L_0) [12]:

$$\mathbf{Air\ Mass\ (AM)} = \frac{\mathbf{L}}{\mathbf{L_0}} = \frac{\mathbf{1}}{\mathbf{cos\theta}}$$

Although this relationship can be improved by modelling more realistic route thicknesses over the horizon [13], the equation above is still widely used to determine standard conditions for solar applications. It is denoted in term of "AM" followed by the number.

Extra-terrestrial solar spectrum AM 0 is utilised to characterise PV panels used in spaced applications [15]. There are several types of solar irradiance spectra that may be generated using single or multiple measurement sets or models [16]. However, the ASTM E490 standard is typically used for space solar power applications. Because the majority of the world's largest solar installations and industrial centres are located in the mid-latitudes, an AM number for a zenith angle of 48.19° was determined [17].

2.3 Lighting of Solar Simulator

The most important aspect of designing a solar simulator is selecting an appropriate light source to imitate sunlight and its intensity. A light source for solar radiation modelling should normally be evaluated in terms of; 1) spectral characteristics; 2) uniformity of illumination; 3) collimation; 4) flux stability; and 5) range of flux available [18]. Various lamps have been suggested throughout the history of solar simulation, including the Quartz Tungsten Halogen lamp, Xenon Arc lamp, Metal Halide Arc lamp, and Light-Emitting Diode (LED).

2.3.1 Quartz Tungsten Halogen Lamp

The colour temperature is the temperature of an ideal black body radiator with the same peak irradiance as the test source. Quartz tungsten halogen lights like other filament lamps, can only operate at 3500 K. The output of a Quartz Tungsten Halogen lamp is given below, Table 2.1.

Table 2.1: The Performance of Quartz Tungsten Halogen Lamp [19]

Advantages	Drawbacks
The AM 0 has a color temperature of around 5900K.	Because of the color temperature of 3400K, shorter wavelengths (blue and UV) are weaker.
Infrared component is stronger.	
Low cost, high light output, easy maintenance, and increased consistency.	

2.3.2 Xenon Arc Lamp

The xenon arc lamp is the most common light source used in practically all types of solar simulators, and is notably popular among commercial standard solar simulator makers[20][21]. Furthermore, high pressure short arc xenon lamps may provide a brighter point source than other light sources, which is needed to produce a collimated high intensity light beam. Because of these benefits and disadvantages, Quartz Tungsten Halogen lamp and Metal Halide Arc lamp outperform Xenon light in the construction of new solar simulators with low spectrum and intensity requirements. The following from Table 2.2 depicts the performance of a Xenon Arc light.

Table 2.2: The Performance of Xenon Arc Lamp [22]

Advantages	Drawbacks
Ultra-violet (UV) spectral properties that remain stable.	Power supply must be more complicated and costly.
Infrared emission lines between (800-1000) nm are quite strong.	Security risk is high.
Variation in power has no discernible effect on spectral balance.	As the lamp ages, the peak of irradiance shifts somewhat from UV to IR.
	Instability of the light output's amplitude.

2.3.3 Metal Halide Arc Lamp

When the Compact Source Iodide (CSI) was created, a metal Halide Arc lamp was provided as a light source option for solar simulators [23]. As a result, CSI lamps are mostly utilised in solar simulation applications that need non-collimated light, such as collector testing solar simulators and some Photo-Voltaic (PV) testing solar simulators that require merely steady large-area lighting and less precise spectrum features [24]. Table 2.3 show the performance of metal halide arc lamp.

Table 2.3: The Performance of Metal Halide Arc Lamp [25]

Advantages	Drawbacks
High light efficiency of more than 90 lm/W.	UV part is insufficient.
In spectral conditions, there is a good balance.	Poor collimation quality.
Close sunlight matching and a lengthy life time over 1000 hours.	The UV part is insufficient.
Price is relatively low.	
Irradiate with a high level of intensity.	
Low cost and broad spectrum coverage.	

2.3.4 Light-Emitting Diode (LED)

When electrically biased in the forward direction of the p-n junction, an LED creates a narrow-spectrum light. The method through which LEDs emit light is not comparable to that of a filament or arc lamp. Because of its modest light intensity, LEDs were first utilised solely as indicators and signs. LEDs were offered as a new light source option for solar simulator architecture during the start of the 2000s, with the introduction of high power LED technology [26]. A good cooling system is therefore necessary, but it also decreases output efficiency. In conclusion, the benefits of LEDs exceed the disadvantages, making them an ideal candidate light source for future improved solar simulator design, at least for presently concentrating type solar simulators. The performance of LED lamp will be shown from Table 2.4 below.

Table 2.4: The Performance of LED Lamp [27]

Advantages	Drawbacks
Fasting controlled in microseconds or less.	The light output energy, efficiency, and longevity of the junction decrease as its operating temperature rises.
For a long period, it was steady at a single light output intensity.	The output spectrum's relationship to the amount of light produced (drive current).
Except for white LEDs, the output spectrum has a rather small monochromatic range.	For concentrating solar simulator designs, the light intensity of LEDs is still modest.
Colors and wavelengths are available in a wide range.	
LEDs with light intensities of up to $1000 W/m^2$ are now available.	
In general, the lifespan is very lengthy, ranging from (50,000-100,000) hours.	
Compacter and more energy-efficient.	

2.4 I-V Measurement

The (I-V) measurement can be divided into three themes based on article from journal of energy such as electronic load, load capacitive and MOSFET. This concept to apply for solar simulator if the STC requirement will be achieved. The article will be reviewed below.

2.4.1. Electronic Load

The mechanical power of the water flow determines the turbine rotational speed, and the generator speed is determined by the load connected to the generator. If the flow of water entering the turbine or the consumer load connected to the generator varies, the generator output voltage and frequency vary proportionally [28]. In the event of steady water flow into turbines, ELC maintains a nearly constant load on the generator by turning on and off fake loads when consumer loads linked to the generator drop or grow. As a result, the generator creates a consistent voltage and frequency when fed a constant water supply. Because it turns on and off fake loads using electronic switches, ELC has a very quick reaction time [29]. The ELC maintains the frequency and voltage at the agreed-upon levels without the need for human intervention. Switching dummy loads at sine wave peaks can generate strong sparks that harm electronic switches and consumer loads connected to the generator. The generator's output will no longer be a pure sine wave [30].

2.4.2 Load Capacitive

The capacitive load is the most frequent approach used by commercial equipment to measure the (I–V) curve of PV devices and it is recommended by international recommendations and standards for evaluating PV arrays ranging from 2 to 50 kWp [31]. In 1994, the IES–UPM created a former load based on this technology, which was employed for the first time in the quality control of PV arrays at the 1 MW Toledo-PV facility.

Although this latter load is still operational, it has certain drawbacks for example, it’s inconvenient mobility and lacks several functions that must be done individually in array short-circuit. These considerations prompt us to create a new and improved capacitive load based on IGBTs, the practical design of which is described in order to encourage the development and use of similar equipment not only by research laboratories or universities, but also by small-scale organisations such as promoters, companies, and utilities involved in PV electrification projects. The load is capable of measuring the (I–V) curve of PV arrays with short-circuit currents (I_{sc}) of up to 80 Amp and open-circuit voltages (V_{oc}) of up to 800 V. Until present, the load has been successfully evaluated with over 30 PV arrays in the context of quality acceptance procedures used in various PV rural electrification projects in Algeria, Morocco, and Tunisia [32].

2.4.3 MOSFET

Power MOSFETs, an essential component of power electronic systems, have great properties such as a high switching frequency, a large input impedance, and a low conducting resistance. Power MOSFETs are more costly than other electrical devices, and the risk of breakdown is higher. As a result, research into an effective strategy for CM of power MOSFETs is both important and required [33]. The theoretical study establishes a connection between the MOSFET's on-resistance and the junction temperature, as well as three temporal constants that describe the junction's transient reaction. The various time constants are used to analyse the die, module, and heat sink.

AE Non-Destructive Testing (NDT) is widely used in the detection of rail, container, building, and power electronics devices because to its capacity to perform dynamic monitoring [34]. As a result, the AE sensor can monitor the power MOSFETs in real-time.

2.5 Cooling System

The concept of cooling system to stabilize the temperature of 25°C for apply to solar simulator later. The concept of peltier system, solar cooling system, radiator system and air cooling system also will be reviewed below.

2.5.1 Peltier System

Peltier devices are used as a source of coolness in this system. In contrast to a thermoelectric effect [35]. When two metals come into touch with each other, the thermoelectric effect occurs. The thermoelectric voltage is formed and the current begins to flow when one connection is heated to a greater temperature. When produce an electrical current in this circuit, heat occurs on one side and flows through the other.

The peltier element is therefore made up of two P-type and N-type semiconductors, as well as connecting bridges. The majority carriers in an N-type semiconductor are electrons, whereas the minority carriers are holes. These are pulled from the chilly side to the warm side and towards the positive pole. The majority carriers in a P-type semiconductor are holes, whereas the minority carriers are electrons. They are transported to the polar opposite, from cold to hot [36]. As a result of the process, the number of free charge carriers in the coupling bridge on the cold side decreases, and the thermoelectric voltage between the bridge and the semiconductors decreases.

The efficiency of heat transmission like peltier components is low and highly reliant on the temperature differential maintained. This appears to be the most significant drawback in comparison to other methods, such as the compressor. However, substantially less cooling performance may be feasible, which is not required for over-performance. In comparison to the huge compressor system, this offers energy savings. The compact size of the cooling element is another advantage of peltier systems [37]. Heat is removed from a region of up to square centimetres in size. Furthermore, the system comprised of these pieces is readily transportable and, if necessary, may be powered by a battery. Various freezers for outdoor stays as an example, might be listed.

2.5.2 Solar Cooling System

The condenser, evaporator, and expansion valve are the same components used in the Vapour Compression Cooling (VCC) system. The mechanical compressor of the VCC machine, on the other hand, is replaced with a group of equipment that act as a thermal compressor, such as a generator, absorber, and circulation pump. Heat exchangers can be added between the generator and the absorber to further warm the dilute solution before it enters the generator, or between the condenser and the evaporator to increase the evaporator's cooling capacity [38]. A cooling tower is often required to deliver cooling water to the absorber and condenser in order to reject heat from absorption and condensation.

The limitation of the water/lithium bromide solution is that it can only be used at evaporation temperatures above 0 C, limiting its applications to air conditioning, whereas the ammonia/water pair has the advantage of being able to be used at a wide range of concentrations without the risk of crystallisation that is found in the case of ammonia and some salts [39]. SABC systems have coefficient of performance (COP) values ranging from 0.6 to 0.8 for single stage chillers and from 0.9 to 1.3 for double effect chillers, and require heat temperature supply ranging from 80 to 95 degrees Celsius for a single stage and between 130°C and 160°Ce for double stage SABC.

The results showed a reduction in cooling season energy usage of 26.70% when compared as well as a lower yearly cost when compared to a typical solar absorption-compression cascade cooling system. Stationary compound parabolic solar collectors propelled the absorption subsystem. Peak instantaneous cooling power and coefficient of performance were determined to be 4 kW and 0.69, respectively [40].

2.5.3 Radiator System

Before the experimental results from on-site testing were obtained, the vehicle radiator cooling system was theoretically modelled [41]. By adjusting the solar heat flux input, water mass flow rate, and water inlet temperature to the cooling block, a three-Dimensional (3-D) modelling was built to simulate the temperature at the cooling block's centre point (the hottest point). Furthermore, the heat rejection by the vehicle radiator was calculated using heat transfer formulae for varying fan wind speeds and cooling fin surface areas. The goal of theoretical modelling for both the car radiator and the cooling block is to assist us in improving the prototype cooling system's intended characteristics such as wind speed and water flow rate. The next parts show the results of the extensive theoretical analysis and simulation.

The heat rejection rate of an automotive radiator is investigated in this section utilising analytical methods based on forced convection by air and heat dissipation by radiation. The overall surface area of the vehicle radiator is $3.8m^2$, with a fan covering just $2.2m^2$. Convection is only considered on the areas of the radiator covered by the air-flow provided by the fan in our heat rejection study, whereas radiation is evaluated on the whole surface area of the radiator. The conduction heat transfer rate of the vehicle radiator is minimal and may be ignored [42]. Because forced convection and radiation are the primary heat transfer mechanisms in car radiators, the total heat removed by the automotive radiator is the sum of heat removed by both forced convection and radiation.

2.5.4 Air Cooling System

Air cooling is one of the most popular methods of heat dissipation in BTMS of EVs due to a variety of benefits such as simple structural design, low cost, lightweight, ease of maintenance, long life, ease of single-cell replacement, and modest parasitic power consumption at low battery discharge rates, all of which contribute to overall EV efficiency [43].

Given the benefits of air cooling solutions discussed above, it is implemented in many commercial EVs, as seen in Figure 4. The Honda Insight and Toyota Prius were the first commercially available hybrid electric vehicles that employ BTMS air cooling methods [44]. The Honda Insight battery pack included 20 modules of cylindrical batteries, each with a capacity of 144 V and 0.94 kWh, but the Toyota Prius battery pack contained 38 modules of prismatic cells, each with a capacity of 273.6 V and 1.78 kWh. Both EV's battery packs were cooled with conditioned air from the cabinet, and the heat absorbed was then discharged into the environment [33]. Many other EVs, including as the Nissan Leaf, Mitsubishi i-MiEV, Reynolds ZOE EV, and Renault Zoe, have utilised air-cooled BTMS.

Although air-cooled battery thermal management strategies offer various benefits over other approaches, its shortcomings include a limited heat capacity of air and the necessity of a greater volumetric flow to achieve the same cooling performance as other BTMS [45]. Further study is needed to construct an efficient and modern BTMS capable of regulating the temperature of the battery pack within an optimal performance range and maintaining temperature uniformity while consuming less parasitic power and requiring less system complexity.

2.6 Summary of Literatures

The summarization about study aim, content, parameters, measurement tool, method and conclusion are shown in Appendix B.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss about the methodology used to investigate Standard Test Condition Requirement (STC) in establishing reliable Current-Voltage (I-V) characterization system for Dye-Sensitized Solar Cell (DSSC) as an alternative for commercial solar simulator and photovoltaic measurement system. The planned of this project in methodology process is consists of 3 stages based on the flowchart of methodology from Figure 3.1.

The first thing to do is comparison between solar irradiance (W/m^2) and lux (k lx) by using several light resources. The condition will be divide in two (2) categories which is outdoor condition and indoor condition. The measurement irradiance and lux at outdoor condition performed below under sunlight, while the measurement at indoor condition performed by using halogen lamp and LED grow light. The variety of lamp selection depend by the performance light source need for apply STC requirements into solar simulator. The second stage will stabilizing temperature of 25°C that focusing about time taken cell temperature (T_{cell}) and ambient temperature (T_{amb}) to reach and maintain at 25° C. Other than that, the third stage is a structuring of Air Mass (AM) 1.0 and 1.5 of solar simulator. For the data analysis of this project, the result obtained of major Standard Test Conditions (STC) of solar simulator will be analysed and further discussed.

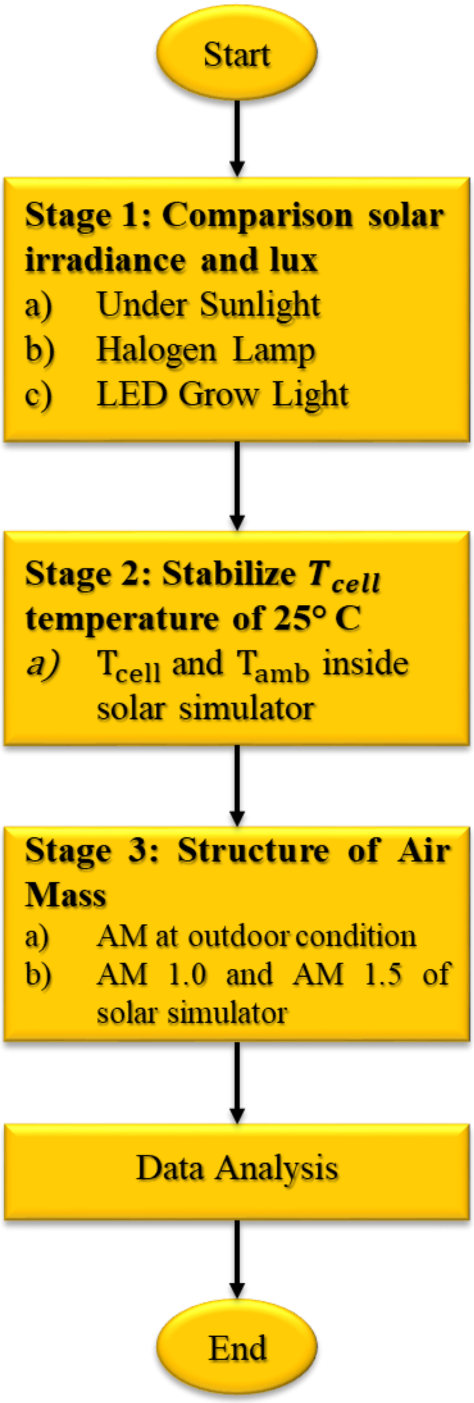

Figure 3.1: The Flowchart of Methodology STC Requirements

3.2 Stage 1: Comparison Solar Irradiance and Lux

3.2.1a) Under Sunlight

For the comparison solar irradiance and lux, this measurement use two (2) instruments which is solar irradiance meter and lux meter to collect and analysis data under sunlight instead of outdoor condition, Figure 3.2. Other than that, Table 3.1, Table 3.2 and Table 3.4 has been shown the expected output measurement must have been day, date, reading measurement, the value that will be testing between solar irradiance and lux, also have timing in 24-hour system to be recorded. Furthermore, parameter to be measured have in two terms such as solar irradiance of (200-1100) $\mathrm{W/m^2}$ and the illuminance (lux) of (200-1100) k lx for the expected output measurement.

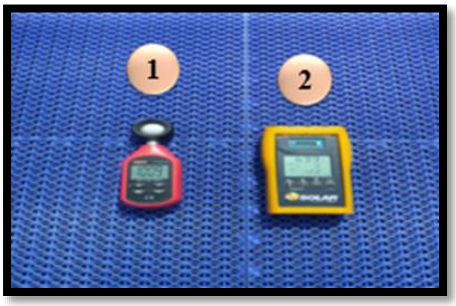

Figure 3.2: The Instruments of Lux Meter and Solar Irradiance Meter

Day:			
Date:			
Testing of	Reading 1-4		
	W/m^2	Lux (k)	Time (24-hour)
200			
250			
300			
350			
400			
450			
500			
550			
600	To be measured		
650			
700			
750			
800			
850			
900			
950			
1000			
1050			
1100			

Table 3.1: The Expected Output Measurement of Under Sunlight

Location measurement outdoor condition at UMP Pekan which is a) Basketball's Court of Figure 3.3, b) in Front PAP of Figure 3.4 and c) Environment at Kolej Kediaman 5 (KK5) of Figure 3.5 below. The data measurement of stage 1(a) at outdoor condition by using solar irradiance meter and lux meter.

Figure 3.3: Basketball's Court

Figure 3.4: In Front of PAP

Figure 3.5: Environment at Kolej Kediaman 5 (KK5)

3.2.1b) Halogen Lamp

This investigation is want to know the specification Halogen lamp based on performance during later measurement under indoor condition. This measurement of halogen lamp performed at Faculty Technology Electrical & Electronic in alternative energy lab. It's also to analyse the solar irradiance and illuminance compare with another light sources. The parameter to be measure by referring parameter under sunlight which is irradiance and lux. From the Figure 3.6 till Figure 3.10 below, show the views of Halogen lamp in varieties sides.

Figure 3.6: Front Side View of Halogen Lamp

Figure 3.7: Left Side View of Halogen Lamp

Figure 3.8: Right Side View of Halogen Lamp

Figure 3.9: Back Side View of Halogen Lamp

Figure 3.10: The Measurement of Halogen Lamp Following AM 1.0 Concept

Day:		
Date:		
Testing of	Reading 1	
	W/m2	Lux (k)
200		
250		
300		
350		
400		
450		
500		
550	To be measured	
600		
650		
700		
750		
800		
850		
900		
950		
1000		
1050		
1100		

Table 3.2: The Expected Output Measurement of Halogen Lamp

The measurement performance of Halogen lamp were applied in Air Mass (AM) 1.0 concept by referring Figure 3.10. This is because the AM 1.0 gives the effective way of irradiance and in some of light source especially the Halogen lamp value during measurement. The output result involved solar irradiance in term of W/m^2 and illuminance in term of kilo lux (k lx) will be state further in result and discussion.

3.2.1c) LED Grow Light

Figure 3.11: Back Side View of LED Grow Light

Figure 3.12: Front side view of LED Grow Light

Brand	GREENSINDOOR
Manufacturer	GREENSINDOOR
Part Number	C40395-1US
Item Weight	3 pounds
Product Dimensions	2.56 x 0.87 x 2.2 inches
Item model number	C40395-1US
Assembled Height	5.59 centimetres
Assembled Length	6.5 centimetres
Assembled Width	2.2 centimetres
Style	Modern
Color	Yellow
Material	Iron
Number of Lights	3
Voltage	110 Volts
Shade Color	Gray
Shade Material	Iron
Power Source	Corded Electric
Switch Style	Push Button
Type of Bulb	LED
Wattage	600 watts
Colour Temperature	3500 Kelvin (more reddish red)
Spectrum	660 nm of red light (during bloom)

Table 3.3: Specifications of LED Grow Light

Figure 3.11 and Figure 3.12 shows the view sides of LED Grow Light for measurement in term of irradiance and lux. The main features of LED Grow Light is high efficiency of LED chips that has 96 pieces of LED quantity. The efficient light source of LED Grow Light will be improving plant growth and save on electricity costs. Other than that, this LED give the super strong output more than 100k lx depend on the variety of height from 6 inch until 30 inch. Significantly to increase flower density deliver greater harvest weight. The highlight specifications of LED Grow Light suitable for all stages of plant growth like seedling, vegetative, flowering and harvest by referring Table 3.3.

Day:		
Date:		
Testing of	Reading 1	
	W/m2	Lux (k)
200		
250		
300		
350		
400		
450		
500		
550		
600		
650		
700		
750		
800		
850		
900		
950		
1000		
1050		
1100		

To be measured

Table 3.4: The Expected Output Measurement of LED Grow Light

This investigation about the specification LED Grow Light based on performance during later measurement under indoor condition. The measurement cover the parameter irradiance and lux of light source from Table 3.4. It’s also to analyse the solar irradiance and illuminance compare with another several light resources. The irradiance and lux of LED Grow Light will be measure dividing two concept which is AM 1.0 and AM 1.5.

3.3 Stage 2: Stabilizing T_{cell} temperature of 25° C

3.3.1a) T_{cell} and T_{amb} Inside Solar Simulator

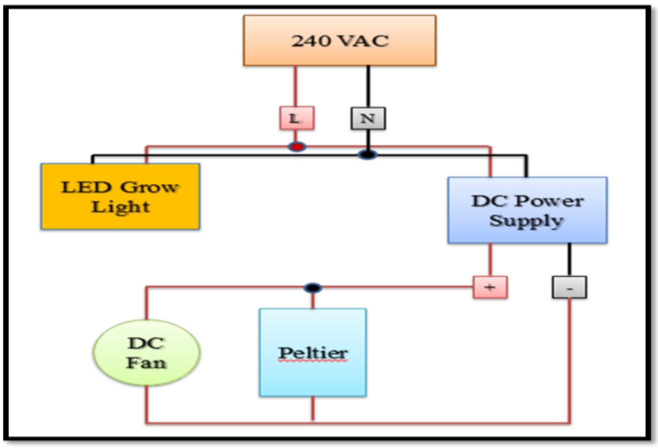

Figure 3.13: The Schematic Diagram of T_{cell} and T_{amb} Temperature Measurement

The electrical connection T_{cell} measurement will show by Figure 3.13. From 240 VAC that has the terminal live and neutral to connect series to LED Grow Light and DC power supply. Other than that, DC fan and peltier in the parallel connection to terminal positive and negative from DC power supply.

Figure 3.14: The Circuit Connection before Measurement

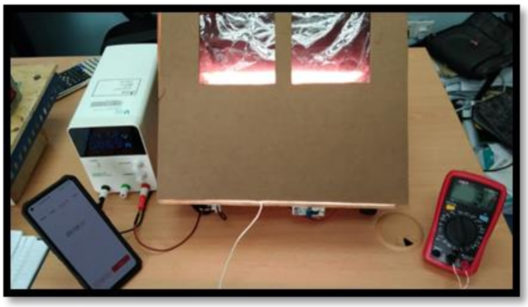

Figure 3.15: The Circuit Connection during Measurement

Figure 3.16: The Enclosed of T_{cell} and T_{amb} Temperature Measurement

When the LED Grow Light, cooling system and time taken in 'OFF' condition, only the initial T_{cell} and T_{amb} temperature value that has collecting data before during measurement that show from Figure 3.14. During measurement of T_{cell} temperature, the LED Grow Light and DC power supply in condition of cooling system will be becoming 'ON'. Then, calibrated the DC power supply to find the best tune the voltage (Volt) and current (Ampere) to analyse time taken of T_{cell} reach and maintain 25° C with together start the time taken until 10 minutes of each measurement by referring Figure 3.15. The solar simulator need in enclosed condition, so as not to influence by external circumstances, Figure 3.16. At the end, the procedure will be show below of measurement T_{cell} at 25° C that applied into solar simulator below. The step by step procedure of T_{cell} temperature measurement at 25° C has been details in Figure 3.17 until Figure 3.22 by referring the flowchart of measurement.

Figure 3.17: The Procedure 1 of Initial Condition

Figure 3.18: The Procedure 2 of LED Grow Light ‘ON’

Figure 3.19: The Procedure 3 of Setup DC Power Supply

Figure 3.20: The Procedure 4 of Observation T_{cell} and T_{amb} Temperature Measurement

Figure 3.21: The Procedure 5 of Time Taken during 10 minutes

Figure 3.22: The Procedure 6 of Data Analyse T_{cell} Reach and Maintain at 25° C

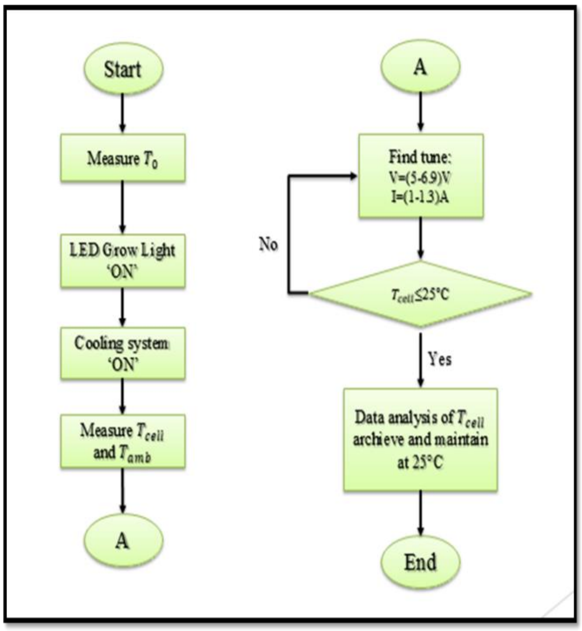

Figure 3.23: The flowchart of T_{cell} measurement for reach and maintain at 25° C

Before understanding the procedure of temperature measurement, the details of this flowchart is about mechanism in stabilizing the cell temperature, T_{cell} at 25° C even under high illumination have explain first. Stabilizing temperature of 25°C of flowchart has 2 part. The first one is the flowchart of procedure during measurement temperature will be showed above by through the Figure 3.23. For the second part A of flowchart to calibrate the best tune voltage and current DC power supply that affected T_{cell} for time taken reach and maintain at 25° C. This system use the instruments like multimeter for analyse the time taken of T_{cell} and T_{amb} reach and maintain 25° C, thermocouple cable for detected T_{cell} and T_{amb} temperature inside solar simulator Figure 3.17, time taken that from the phone application Figure 3.21 and DC power supply as a function to find better tune voltage and current for T_{cell} temperature reach and maintain equal below (≤25° C), Figure 3.19 and Figure 3.20.

3.4 Stage 3: Structure of Air Mass (AM)

3.4.1a) Air Mass (AM) at Outdoor Condition

The Figure 3.24 show the location of Air Mass (AM) 1.0 and 1.5 that focusing to the sample. This structure maybe for build-up solar simulator if the STC requirement will be achieved. The both height of air mass (AM) 1.0 and 1.5 is 13cm from the calculation of Figure 3.25 below. The angle of air mass (AM) 1.0 is 90° (perpendicular) while for angle of air mass (AM) 1.5 in 48.2°. The both direction from (AM) 1.0 and 1.5 always will be focused to the sample such as solar cell (silicon-based) and DSSC's sample.

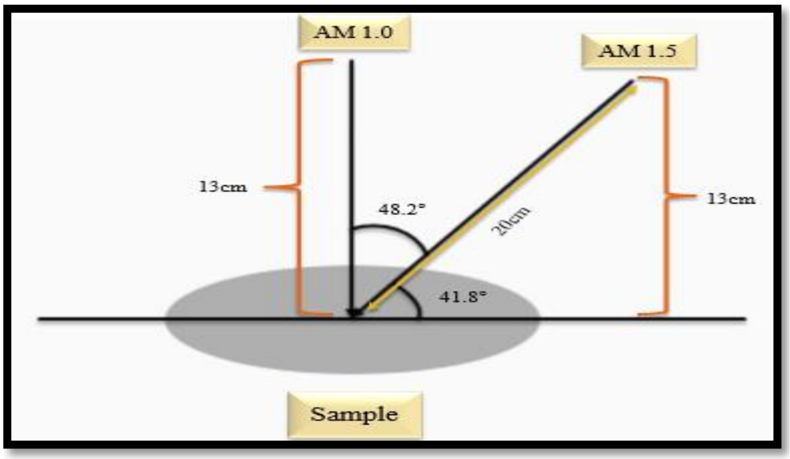

Figure 3.24: The Structure of Air Mass (AM) 1.0 and 1.5

Other than that, the calculation from Figure 3.24 obtained to determine the specific dimensions of the hardware design and the suitable placement for an artificial sunlight. The calculation have consideration such as suitable size that not to large, the height of artificial sunlight or light source with solar cell, the light illuminance to the solar cell and the specific angle as required in STC which is 48.2°.

$$\cos\theta = \frac{a}{h}$$

$$h\cos\theta = a$$

$$20\cos\theta\, 48.2 = a$$

$$a = 13.33 \approx 13\,cm \text{ (the height of AM1.0)}$$

$$\sin\theta = \frac{o}{h}$$

$$h\cos\theta = o$$

$$20\sin\theta\, 41.8 = o$$

$$o = 13.33 \approx 13\,cm \text{(the height of AM1.5)}$$

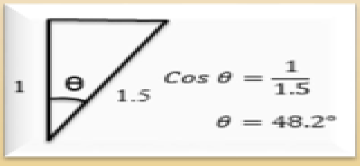

Figure 3.25: The Calculation of Structure Air Mass (AM) 1.0 and 1.5

3.4.1b) Air Mass (AM) 1.0 and 1.5 of Solar Simulator

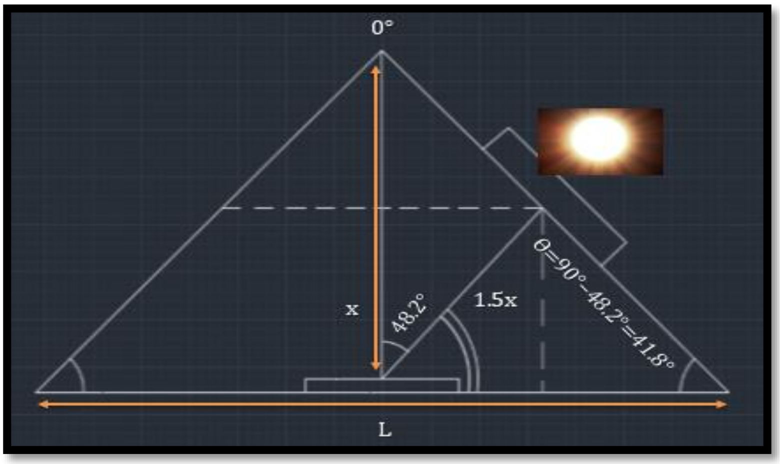

Figure 3.26: The Technical Concept AM 1.5 of Solar Simulator

$$\text{AM}(\Theta^\circ) = \frac{1}{\cos\Theta} = \frac{1}{1.5} = \cos^{-1}\left(\frac{1}{1.5}\right) = 48.2^\circ$$

$$\text{AM 1.5}(\Theta^\circ) = 90^\circ - 48.2^\circ = 41.8^\circ$$

Figure 3.27: The Calculation of Technical Concept AM 1.5 by Solar Simulator Structure

Figure 3.25 shown about the technical concept Air Mass (AM) 1.5 of solar simulator. This concept to design by using software AutoCAD. There are have some elements to be prove the angle of Air Mass (AM) 1.0 and 1.5. The meaning of x element in term of angle Air Mass (AM) 1.0 and 1.5. Furthermore, the element of x represented by angle of Air Mass (AM) 1.0 in 48.2° while the element of 1.5x represented by angle of Air Mass (AM) 1.5 in 41.8° from trigonometry calculation that applied into solar simulator, Figure 3.26. During build up the solar simulator, the technical concept calculation of AM 1.0 and AM 1.5 also gives the important investigation between theoretically and technically concept to archive the Standard Test Condition (STC) requirements.

CHAPTER 4

RESULT & DISCUSSION

4.1 Introduction

From the proper understanding of methodology, this chapter 4 will be discussing the result Standard Test Condition (STC) requirements for applied into solar simulator. The results of STC requirements such as the irradiance of 1000 W/m^2 that related to illuminance of how much kilo lux (k lx) with comparing under sunlight and several light resources (Halogen lamp and LED Grow Light) performance for applied into solar simulator. The lamp selection also need to be decide the best choice to similarly with the solar irradiance and illuminance under sunlight performance. Other than that, the cell temperature of 25° C also gives the reaction the time taken to reach and maintain at 25° C and can know the equation between cell temperature, T_{cell} and T_{amb} during 10 minutes until sixth measurement. Moreover, Air Mass (AM) 1.0 and 1.5 that applied into solar simulator which is construct a structure based by using the variety of instruments.

4.2 Stage 1: Comparison Solar Irradiance and Lux

4.2.1a) Under Sunlight

This measurement solar irradiance and illuminance already done until four days means four repeated step. Furthermore, the measurement start from 26 December 2021, Sunday till 29 December 2021, Wednesday at the certain time in one day starting from 9AM until 5PM of target measure, Table 4.1 until Table 4.4. After do the combination Graph Solar Irradiance vs. Lux which is justify the straight line or linear curve (y = mx + c) from Figure 4.5. As shown in table, the solar irradiance of $1000\mathrm{W/m^2}$ equal to 1 sun. Also, solar irradiance of $1000\mathrm{W/m^2}$ equal to 100K lx that will be included.

Day: Sunday			
Date: 26/12/2021			
Testing of	Reading 1		
	W/m^2	Lux (k)	Time (24-hour)
200	201	25.59	8:51
250	254	31.1	9:07
300	302	31.71	9:00
350	371	42.36	9:06
400	407	54.92	10:30
450	456	69.67	11:25
500	511	75.7	10:35
550	N/A	N/A	N/A
600	N/A	N/A	N/A
650	660	93.35	10:29
700	703	97.16	10:37
750	753	105.8	10:22
800	810	111.8	13:28
850	850	119.2	16:10
900	905	130.2	15:00
950	951	136.4	13:00
1000	1000	147.4	12:17
1050	N/A	N/A	N/A
1100	N/A	N/A	N/A

Table 4.1: Data Measurement of Day 1

Day: Monday			
Date: 27/12/2021			
Testing of	Reading 2		
	W/m^2	Lux (k)	Time (24-hour)
200	228	35.22	9:10
250	251	40.95	9:18
300	303	41.91	9:21
350	361	51.61	16:16
400	400	42.34	16:10
450	453	63.81	10:15
500	500	68.95	10:17
550	550	75.99	10:18
600	603	85.28	17:13
650	653	93.47	11:08
700	708	109.4	15:14
750	N/A	N/A	N/A
800	802	118.4	13:13
850	853	125.7	12:03
900	900	130.9	12:17
950	950	139.5	13:19
1000	1000	145.7	13:22
1050	1050	145.4	13:28
1100	N/A	N/A	N/A

Table 4.2: Data Measurement of Day 2

Day: Teusday			
Date: 28/12/2021			
Testing	Reading 3		
of	W/m^2	Lux (k)	Time (24-hour)
200	218	33.38	13:08
250	265	33.23	9:00
300	315	46.21	11:13
350	361	52.28	13:06
400	426	62.08	13:19
450	464	62.02	11:28
500	509	73.45	12:20
550	565	78.92	10:01
600	600	78.38	16:13
650	651	95.79	13:14
700	717	98.52	15:13
750	751	104	15:11
800	808	112.7	15:24
850	N/A	N/A	N/A
900	900	98.73	14:17
950	950	139.8	11:16
1000	1000	140.6	11:18
1050	1050	155.3	12:10
1100	1134	164.9	12:16

Table 4.3: Data Measurement of Day 3

Day: Wednesday			
Date: 29/12/2021			
Testing	Reading 4		
of	W/m^2	Lux (k)	Time (24-hour)
200	207	24.57	17:00
250	251	30.44	16:57
300	310	42.83	17:05
350	357	51.06	12:06
400	400	51.92	9:15
450	450	61.12	16:52
500	500	64.2	16:51
550	556	80.62	14:08
600	613	82.26	10:18
650	656	86.44	16:23
700	714	101.4	11:03
750	750	107	11:04
800	800	113.9	10:22
850	861	125.6	11:17
900	903	135.5	13:03
950	950	133.6	16:28
1000	1000	150.4	13:09
1050	1051	153.9	12:11
1100	1114	165.4	14:17

Table 4.4: Data Measurement of Day 4

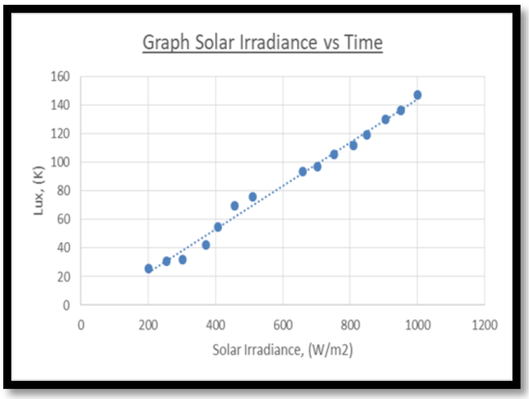

Figure 4.1: Measurement Data of Lux and Solar Irradiance for 26^{th}Dec. 2021

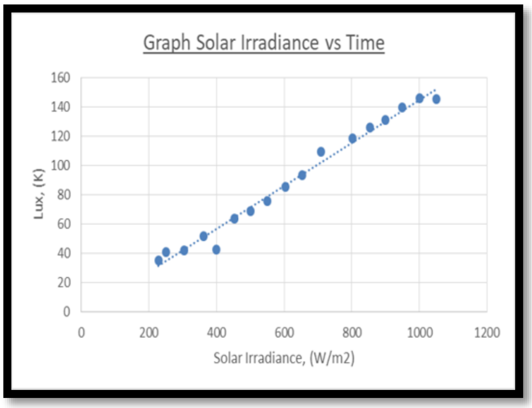

Figure 4.2: Measurement Data of Lux and Solar Irradiance for 27^{th}Dec. 2021

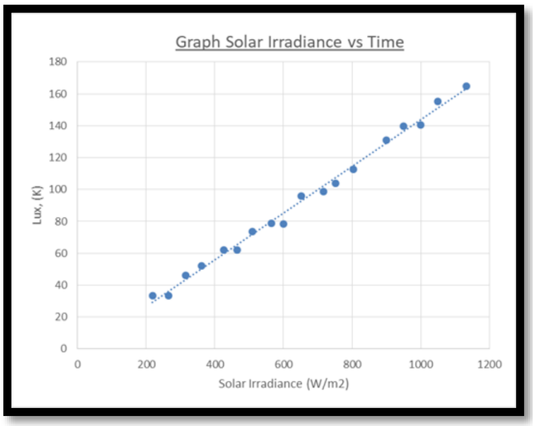

Figure 4.3: Measurement Data of Lux and Solar Irradiance for 28^{th}Dec. 2021

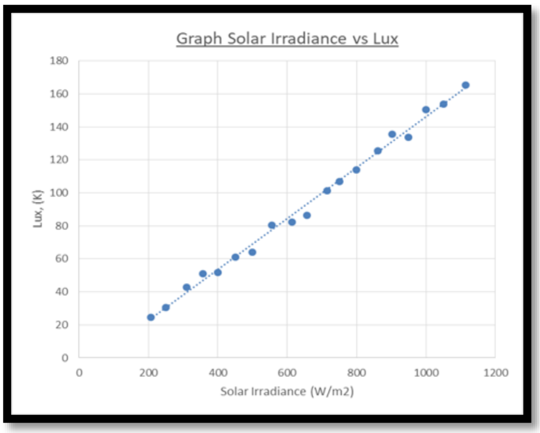

Figure 4.4: Measurement Data of Lux and Solar Irradiance for 29^{th}Dec. 2021

After analyze data measurement of solar irradiance and lux at outdoor condition which means under sunlight, the observation on all four measurement gives approximately the same value for the irradiance and illuminance of lux parameters. For the Table 4.1 is shown 1000 W/m^2 of irradiance equal to 147.4 k lx of illuminance on the Day 1 measurement while Table 4.2 shown the 1000 W/m^2 of irradiance equal to 145.4 k lx of illuminance on Day 2 measurement Then followed by a measurement on the Day 3 that gives 1000 W/m^2 of irradiance equal to 140.6 k lx of illuminance, Table 4.3 and the measurement for Day 4 in Table 4.4 is last measurement for investigation solar irradiance and lux under sunlight. The last measurement shown 1000 W/m^2 of irradiance equal to 150.4 k lx of illuminance.

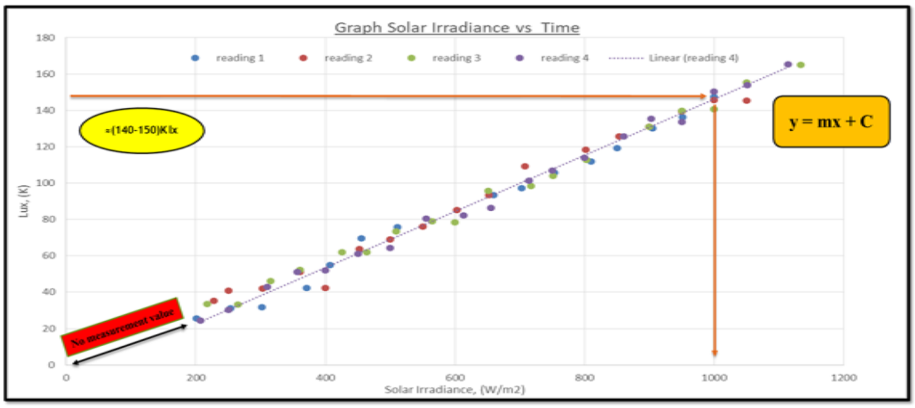

Figure 4.5: Measurement Data Combination All Graph Solar Irradiance vs. Lux under Sunlight

A part from that, overall data of each measurement have convert into Graph Solar Irradiance vs. Lux. For analyzed overall graph Day 1 until Day 4, it’s shown in shape of linear graph. Hereby, an equation derivative has been issued by linear graph equation that is y=mx+c. The data measurement of graph Day 1 until Day 4 were combined into one graph by used the Excel to obtain the actual value between irradiance and lux for under sunlight, Figure 4.1 until Figure 4.4. Furthermore, the last justify by overall graph founded 1000 W/m^2 of irradiance equal to (140-150) k lx o illuminance after analyzed the overall data measurement irradiance and lux, Figure 4.5.

4.2.1b) Halogen Lamp

G (W/m2)	Lux (k)
214	2094
268	2874
307	3532
355	4179
417	5577
453	5849
515	7772
554	7903
602	9148
656	9806
708	11190
750	12660
817	13990
865	14420
910	17230
961	17730
1004	19860
1069	22140
1114	21550

Table 4.5: Data Analysis of Halogen Lamp for Irradiance and Lux

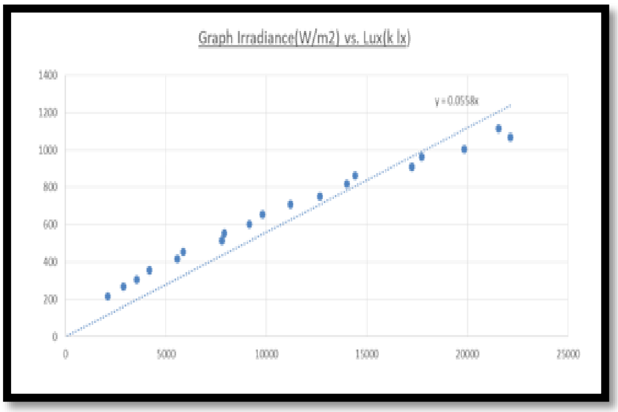

Figure 4.6: Measurement Data Irradiance vs. Lux of Halogen Lamp

The both parameter which is irradiance and lux covered in around 200 until 1100 for this expected value. After analyse data, the data irradiance and lux of Halogen lamp shown by Table 4.5. For this observation result, the performance of Halogen lamp in term of 1004 W/m^2 of irradiance equal to 19.86k lx of illuminance, Figure 4.6. The irradiance of Halogen lamp has been archived to 1000 W/m^2 while the lux of Halogen lamp showed the values that are too small to reach (140-150) k lx to equate with under sunlight.

The lux of Halogen lamp that given the value is too far away from range under sunlight. Maybe because of specification the Halogen lamp which is affected in terms of designing surface lamp that radiated toward to the solar irradiance meter from silicon-based and lux meter. For information, the spectrum of Halogen lamp also can gives the main reason that effected to wavelength, cause the illuminance of lux Halogen lamp hard to reach similarly under sunlight. Therefore, Halogen lamp provides a rapid heating in a very short duration less than 1 minutes of each during measurement, maybe it's not suitable for measuring lux to reach (140-150) k lx similarly under sunlight.

The investigation by using Halogen lamp can be related the different between small-scale and large-scale development of solar simulator. For this final year project to build up the solar simulator with means in small-scale development given the different with the large-scale of solar simulator industry because of used the advance technologies instruments and selection lamp.

4.2.1c) LED Grow Light

The measurement of LED Grow Light are have two part. The first part is measured the LED Grow Light with AM 1.0 without used the solar simulator. For second part, the LED Grow Light have measured with applied AM 1.5 concept by used a solar simulator. The Figure 4.7, Figure 4.8 and Figure 4.9 below shown the variety of height during measurement such as upper, middle and deeper position. This position gives the significant value of solar irradiance.

During upper position shown the maximum and minimum irradiance of 427 W/m^2 and 165 W/m^2 that equal to 57.27 k lx of illuminance, Figure 4.7. Other than that, Figure 4.8 show result 712 W/m^2 of maximum irradiance and 216 W/m^2 of minimum irradiance equal to 130.9 k lx of illuminance in the middle position measurement of LED Grow Light. After that, the deeper position given the 766 W/m^2 of maximum irradiance and 473 W/m^2 of minimum irradiance by equal 137.3 k lx of illuminance, Figure 4.9. In addition, the data analyse irradiance and lux of LED Grow Light converted into Graph Irradiance vs. Lux after measurement, Figure 4.13. From that, Table 4.6 are shown the output irradiance and lux of LED Grow Light that generated the linear graph in y=mx+c equation based Graph Irradiance vs. Lux.

Figure 4.7: Upper Position Measurement of LED Grow Light

Figure 4.8: Middle Position Measurement of LED Grow Light

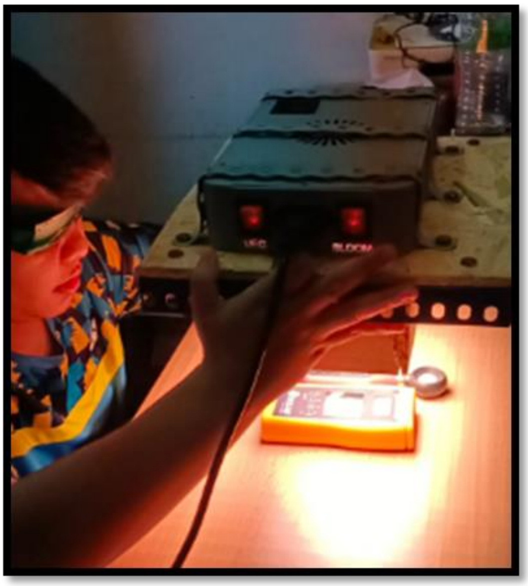

Figure 4.9: Deeper Position Measurement of LED Grow Light

Figure 4.10: Before the Lux Measurement of AM 1.5

Figure 4.11: During the Lux Measurement of AM 1.5

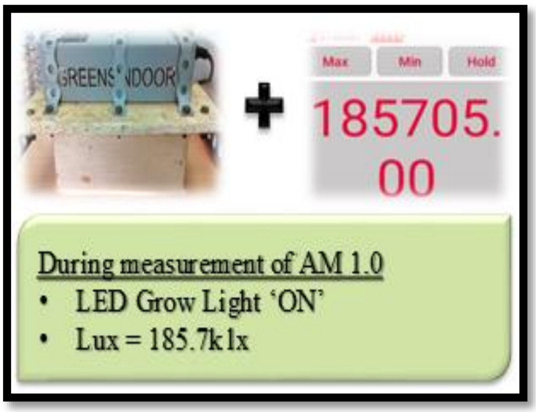

Figure 4.12: During the Lux Measurement of AM 1.0

Testing value of	Lux (k lx)	Irradiance	
		Max	Min
200	20.13	141	117
250	25.03	180	156
300	31.17	230	185
350	35.7	307	122
400	40.17	329	131
450	46.46	363	158
500	51.13	396	266
550	57.27	427	165
600	62.14	643	291
650	65.79	445	266
700	71.73	509	238
750	75.45	458	273
800	80.43	622	308
850	86.35	565	420
900	90.64	646	522
950	95.21	791	366
1000	101.3	667	299
1050	104.7	460	215
1100	111.8	608	352
1150	114.7	611	296
1200	121.5	598	463
1250	127.4	693	409
1300	130.9	712	216
1350	137.3	766	473
1400	142.6	719	427
1450	145.4	680	543
1500	150.7	848	362
1550	155.5	859	435
1600	160.2	808	603
1650	165.2	838	401
1700	170.3	935	722

Table 4.6: The Data Analysis of LED Grow Light for Irradiance and Lux

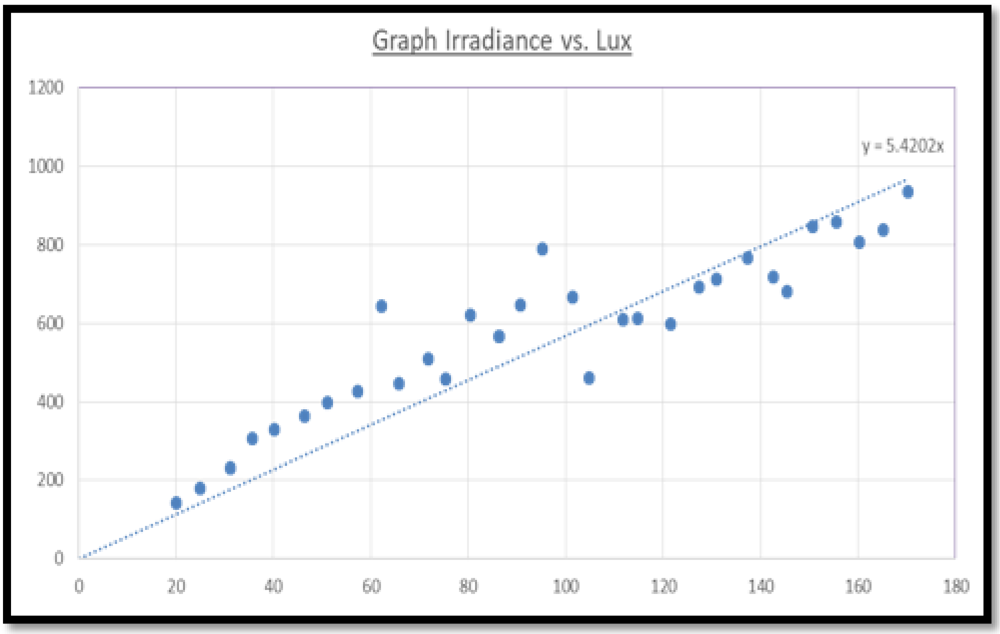

Figure 4.13: Measurement Data Solar Irradiance vs. Lux of LED Grow Light

In term of variety of height, the irradiance of LED Grow Light shown the fluctuate value which is maximum irradiance, G_{max} and minimum irradiance, G_{min} but the illuminace of lux will reached until 170.3 k lx that over with lux under sunlight in (140-150) k lx, Table 4.6. This is because of wavelength caused from lamp's factor spectrum from 96 pieces of microchip LED Grow Light that not unmeasurable in term of irradiance value.

Furthermore, the best effective procedure during measured solar irradiance of LED Grow Light because fluctuate of irradiance have founded. The new procedure in measured irradiance of LED Grow Light which is only measured the illuminance of lux in concept AM 1.0 and AM 1.5 of solar simulator. After measured the lux of LED Grow Light, the observation that got the lux in AM 1.0 equal to 185.7 k lx, Figure 4.10 while the illuminance of lux in AM 1.5 solar simulator is equal 142.4 k lx during LED Grow Light 'ON', Figure 4.11. Next procedure, applied the 185.7 k lx of Figure 43 and 142.4 k lx of Figure 4.12 to linear graph equation, Figure 4.13. The irradiance of 1006.5311 W/m^2 equal to 185.7 k lx in AM 1.0, while the irradiance of 765.3322 W/m^2 equal to 142.4 k lx of solar simulator in AM 1.5 for final procedure of measurement performance of LED Grow Light, Figure 4.13.

4.3 Stage 2: Stabilizing T_{cell} Temperature of 25° C

4.3.1a) T_{cell} and T_{amb} Inside Solar Simulator

Measurement	LED Growth Light	T_{cell} (°)	T_{amb} (°)	Voltage (V)	Current (A)	Time Taken (min)
1	OFF	30	31	-	-	0
	ON	20	34	6.69	1.33	1
		22	35	6.13	1.2	2
		23	35	6.13	1.2	3
		23	36	6.13	1.19	4
		24	36	6.13	1.2	5
		24	37	6.13	1.2	6
		25	37	6.13	1.2	7
		25	37	6.53	1.29	8
		25	37	6.53	1.29	9
		25	38	6.14	1.21	10
`2	OFF	35	36	-	-	0
	ON	24	36	6.03	1.19	1
		24	36	6	1.16	2
		25	36	5.55	1.06	3
		25	37	5.55	1.04	4
		25	37	5.55	1.04	5
		25	38	6	1.13	6
		25	38	6	1.13	7
		25	38	6.36	1.23	8
		25	39	6.36	1.23	9
		25	39	6.36	1.22	10

Table 4.7: The 1^{st} and 2^{nd} Measurement of T_{cell} Temperature Stabilizing 25° C

3	OFF	34	36	-	-	0
	ON	22	36	6.12	1.15	1
		23	36	6.13	1.18	2
		23	37	6.12	1.17	3
		24	37	6.13	1.15	4
		25	37	6.13	1.2	5
		25	38	6.13	1.19	6
		25	38	6.13	1.18	7
		25	38	6.13	1.18	8
		26	38	6.13	1.18	9
		26	39	6.13	1.18	10
4	OFF	36	37	-	-	0
	ON	26	39	6.01	1.18	1
		26	39	6.01	1.18	2
		25	38	6.01	1.15	3
		25	39	6.01	1.15	4
		25	38	6.54	1.24	5
		25	38	6.51	1.26	6
		25	39	6.51	1.26	7
		25	39	6.51	1.26	8
		26	39	6.51	1.26	9
		26	39	6.51	1.26	10

Table 4.8: The 3^{rd} and 4^{th} Measurement of T_{cell} Temperature Stabilizing 25° C

5	OFF	36	37	-	-	0
	ON	24	38	6.51	1.26	1
		24	38	6.51	1.26	2
		24	38	6.51	1.26	3
		25	38	6.51	1.25	4
		25	39	6.51	1.25	5
		25	39	6.51	1.25	6
		25	39	6.52	1.24	7
		26	39	6.51	1.25	8
		26	39	6.51	1.26	9
		26	39	6.51	1.25	10
6	OFF	36	37	-	-	0
	ON	24	38	6.51	1.27	1
		24	38	6.51	1.27	2
		24	38	6.51	1.27	3
		25	38	6.51	1.27	4
		25	38	6.51	1.26	5
		25	38	6.51	1.26	6
		25	39	6.52	1.24	7
		26	39	6.52	1.25	8
		26	39	6.52	1.26	9
		26	39	6.52	1.23	10

Table 4.9: The 5^{th} and 6^{th} Measurement of T_{cell} Temperature Stabilizing 25° C

The investigation of T_{cell} temperature is about how long the time taken to reach and maintain in term of stabilized temperature at 25° C. For the stabilized the temperature were proposed a mechanism which is cooling system that already connect to LED Grow Light, DC power supply, peltier, DC fan, thermocouple, multimeter and circuit breaker (CB).

The T_{cell} temperature at 25° C of solar simulator take time until 10 minutes of each measurement. During 10 minutes of Measurement 1 and Measurement 2, only (2-6) minutes to reach at 25° C of T_{cell} temperature and T_{cell} temperature also keep maintain (4-8) minutes from the data analysis, Table 4.7. Otherwise, continue for analyse the T_{cell} temperature of Measurement 3 and Measurement 4. During this measurement, time taken T_{cell} around (2-4) minutes to reach 25° C and will keep going maintain around (3-6) minutes at 25° C, Table 4.8. For the second last data analyse of measurement 5 and measurement 6, the time taken for T_{cell} temperature around 3 minutes to reach 25° C and T_{cell} temperature will be constant around 4 minutes at 25° C, Table 4.9. In addition, measurement 5 and measurement 6 are effective measurements of T_{cell} to achieve and maintain at 25° C in (6.51-6.52) Volt and (1.24-1.27) Amp which is the best tune from calibrated DC power supply, Table 4.9. When cell temperature, T_{cell} at 25° so, ambient temperature T_{amb} also analyze the value at 38° C that already found the relationship between T_{cell} and T_{amb} temperature By the way, the real effective measurement of T_{cell} ≤ 1 minute to archived and maintain at 25° C in solar simulator industry by using halogen lamp.

4.4 Stage 3: Air Mass (AM) 1.5

4.4.1a) Air Mass (AM) 1.5 of Solar Simulator

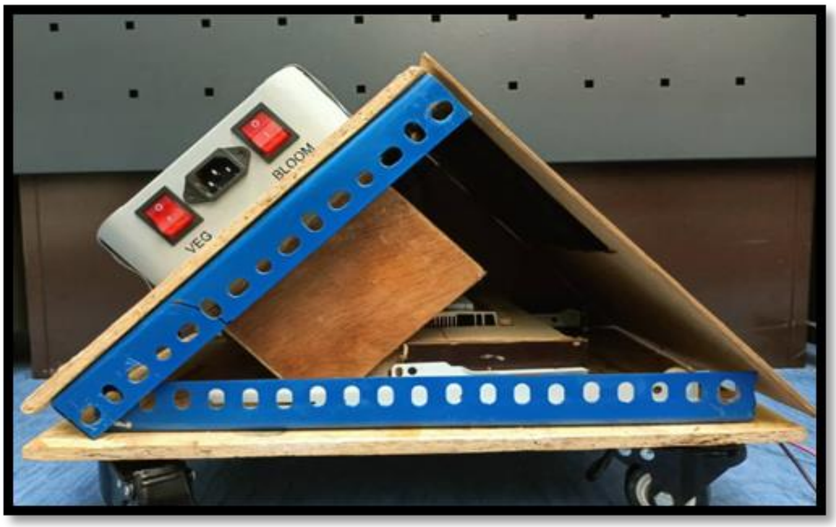

Figure 4.14: The Angle 41.8° of AM 1.5

Figure 4.15: The Measurement of Height Peltier's Casing

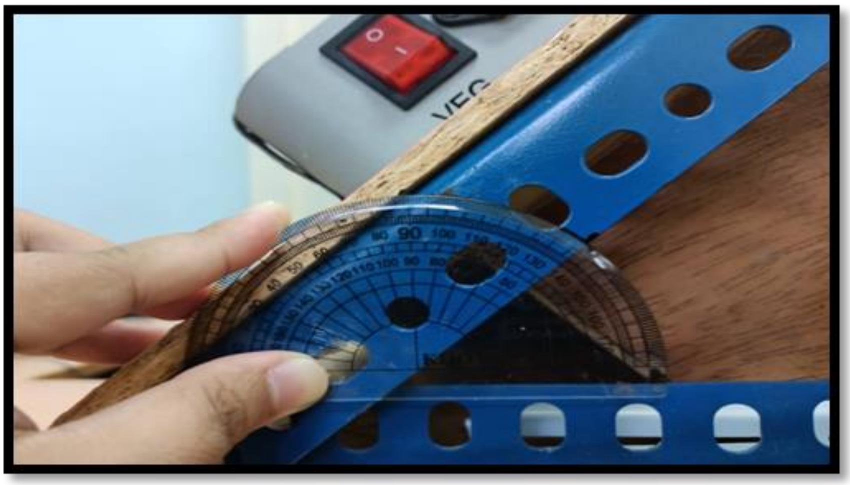

Figure 4.16: Double Check the Angle of AM 1.5 by Used Protector

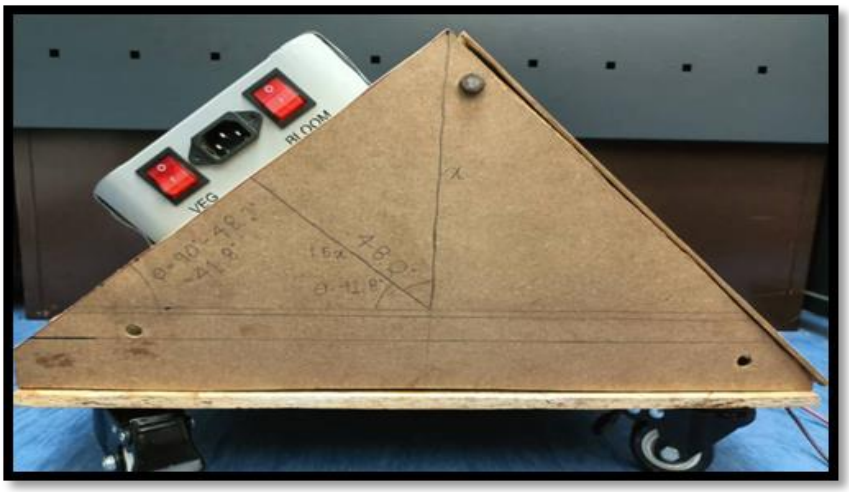

Figure 4.17: Sketch the Angle of AM 1.0 and AM 1.5 at the Left Side Solar Simulator

Build up the solar simulator progress by applied a technical concept of Air Mass (AM) 1.5 which is used the trigonometry calculation to find the accurate angle of 41.8° matched in term of AM 1.5 between theoretically and technically. The angle 41.8° of AM 1.5 solar simulator as shown from Figure 4.14. However, the height of the peltier casing should be taken deeply during the measurement of AM 1.5 solar simulator to avoid any angular distortion and obtained an angle 41.8° of AM 1.5 included to STC requirements. Other than that, the height of peltier casing is 4 cm and the height of location peltier or sample radiated from LED Grow Light is 2cm, Figure 4.15. The angel of AM 1.5 has done double check by used the instrument like protector, Figure 4.16.

After that, sketched the angle of AM 1.5 which means 48.2° and AM 1.5 which means 41.8° at the left side board, Figure 4.17.

The AM 1.5 at outdoor condition can we apply to solar simulator and related between theoretically concept and technical concept. In this research, the effective solution that knowing the angle of AM 1.0 (48.2°) and AM 1.5 (41.8°) by using calibrated solar cell. This instrument can find the best angle of Air Mass (AM 1.5) easily during build up the solar simulator even small and large scale. However, this instrument also very extremely costing in scope budget.

CHAPTER 5

CONCLUSION & RECOMMANDATION

5.1 Conclusion

Based on the results and analysis, the value of irradiance under sunlight, halogen lamp and LED Grow Light give the different output value of irradiance that will be equal how much lux. This is because of the nature factor for measurement at outdoor condition. The right lamp selection is plays an important roles too by through the specification lamps (LED, halogen and xenon) for applying to solar simulator. The irradiance 1000 W/m^2 under sunlight = (140-150) k lx but the irradiance solar simulator cannot arrived to 1000 W/m^2 because of the specification of LED. The LED Grow Light only reach 810.2 W/m^2 = 142.4k lx at AM 1.5. It's not a problem that irradiance solar simulator is not archived but, can know the real irradiance on the solar simulator based on the design that has been made. Maybe to archived 1000 W/m^2 irradiance must build up the proper development solar simulator (extra instruments and budget) for the next research.

At the outdoor condition, the measurement T_{cell} of 25° C suitable for countries that has four (4) seasons. For solar simulator, the investigation is about how fast reaction T_{cell} temperature to archived and maintain ≤ 25° C by setup voltage and current. The (6.51-6.52)V and (1.24-1.27)A is the best tune for T_{cell} measurement that will be 3 minutes to reach 25° C and 4 minutes to maintain at 25° C. The time taken T_{cell} for reached and maintain 25° C influenced by calibrated from DC power supply. Other than that, T_{amb}>T_{cell} for 10 minutes measurement of cell temperature. The best tune voltage and current that calibrated from DC power supply over time of T_{cell} andT_{amb} has done mention and analyze for reference in the next generation

The AM 1.5 at outdoor condition can applied to solar simulator and related between theoretically concept and technical concept. In this research, the effective solution that knowing the angle of AM 1.0 (48.2°) and AM 1.5 (41.8°) by using calibrated solar cell. This instrument can find the best angle of Air Mass (AM 1.5) easily during build up the solar simulator even small and large-scale. However, this instrument also very extremely costing in scope budget. The theoretical and technical concept of Air Mass 1.0 and 1.5 have done archived that apply for small-scale development of solar simulator.

For solar simulator industry, the specifications instruments and advance technology were used the extremely high (costly) to build up a solar simulator that have power source, light source, filters, lens and work surface. Other than that, the time taken of cell temperature T_{cell} measurement which is below 1 second. This is because the solar simulator industry use the advanced specification of light source such as Halogen, Xenon and LED lamp. By used the Halogen and Xenon lamp, so the measurement is very short below 1 second because of produce hot early compare with LED. The flash light shoot to the DSSC's sample not more than 1 minute. By refer in the performance aspect, this Halogen and Xenon lamp produce heat that can will be affected to the time taken shortly measurement to avoid the risk of DSSC' sample degradation.

5.2 Recommendation

The objective of this project has been accomplished. For the continuation of this research, the light source from Halogen, Xenon and LED need to do more analysis and discussion resources to archive the Standard Test Condition (STC) requirement. There are many specifications need to be considered such as the full spectrum of the light source that include the wavelength and light energy output similarly under sunlight. The wavelength of Halogen lamp and LED Grow Light given the different spectrum affected the overall irradiance value during measurement that applied for small-scale development of solar simulator.

Other than that, need the proper mechanism during establishing the cell temperature, T_{cell} at 25° C by applied the car air-conditioning concept even under high illuminance condition. For the future research of solar simulator, the advanced instruments need to be hiring because of stabilizing the tcell measurement for proper cooling system and the time taken for measurement shortly below 1 minute that reach and maintain until 25° C.

REFERENCES

[1] Tavakoli, M., Jahantigh, F., Zarookian, H., 2020. Adjustable high-power-LED solar simulator with extended spectrum in UV region. Sol. Energy Accepted 25 May 2020, https://doi.org/10.1016/j.solener.2020.05.081.

[2] Ventosinos, F., Klus´ aˇcek, J., Finsterle, T., Künzel, K., Haug, F., Holovský, J., 2018. Shunt Quenching and Concept of Independent Global Shunt in Multijunction Solar Cells. IEEE J. Photovolt. 8, 1005–1010.

[3] hu, Q., Xuan, Y., Liu, X., Yang, L., Lian, W., Zhang, J., 2020. A 130 kWe solar simulator with tunable ultra-high flux and characterization using direct multiple lamps mapping. Appl. Energy 270, 115165.

[4] Kim Sin, Kissick J, Spence S, Boyle C. Design, analysis and performance of a polymer–carbon nanotubes based economic solar collector. Sol Energy 2016; 134:251–63. http://dx.doi.org/10.1016/j.solener.2016.04.019.

[5] Dong X, Nathan GJ, Sun Z, Gu D, Ashman PJ. Concentric multilayer model of the arc in high intensity discharge lamps for solar simulators with experimental validation. Sol Energy 2015; 122:293–306. http://dx.doi.org/10.1016/j.solener. 2015.09.004.

[6] Tawfik, M., Tonnellier, X., & Sansom, C. (2018). Light source selection for a solar simulator for Thermal applications: A review. *Renewable and Sustainable Energy Reviews*, *90*, 802–813. https://doi.org/10.1016/j.rser.2018.03.059

[7] Yellowhair, J. E. (2020). Solar simulator. *Field Guide to Solar Optics*. https://doi.org/10.1117/3.2567289.ch54

[8] Moss, R. W., Shire, G. S. F., Eames, P. C., Henshall, P., Hyde, T., & Arya, F. (2018). Design and commissioning of a virtual image solar simulator for testing thermal collectors. *Solar Energy*, *159*, 234–242. https://doi.org/10.1016/j.solener.2017.10.044

[9] Colarossi, D., Tagliolini, E., Principi, P., & Fioretti, R. (2021). Design and validation of an adjustable large-scale solar simulator. *Applied Sciences*, *11*(4), 1964. https://doi.org/10.3390/app11041964

[10] Ines, M., Paolo, P., Roberto, F., & Mohamed, S. (2019). Experimental studies on the effect of using phase change material in a salinity-gradient solar pond under a solar simulator. *Solar Energy*, *186*, 335–346. https://doi.org/10.1016/j.solener.2019.05.011

[11] Solar Resource and Irradiance. (2022). *Step-by-Step Design of Large-Scale Photovoltaic Power Plants*, 79–100. https://doi.org/10.1002/9781119736592.ch5.

[12] Fischer, S., Ivaturi, A., Jakob, P., Krämer, K. W., Martin-Rodriguez, R., Meijerink, A., Richards, B., & Goldschmidt, J. C. (2018). Upconversion solar cell measurements under Real sunlight. *Optical Materials*, *84*, 389–395.https://doi.org/10.1016/j.optmat.2018.05.072.

[13] Esen, V., Sağlam, Ş., & Oral, B. (2017). Light sources of solar simulators for Photovoltaic Devices: A Review. *Renewable and Sustainable Energy Reviews*, *77*, 1240–1250. https://doi.org/10.1016/j.rser.2017.03.062.

[14] Fischer, S., Ivaturi, A., Jakob, P., Krämer, K. W., Martin-Rodriguez, R., Meijerink, A., Richards, B., & Goldschmidt, J. C. (2018). Upconversion solar cell measurements under Real sunlight. *Optical Materials*, *84*, 389–395. https://doi.org/10.1016/j.optmat.2018.05.072.

[15] Michael, P. R., Johnston, D. E., & Moreno, W. (2022). A study on solar irradiance and Lux Illuminance: Conversion guide. *Innovations in Science and Technology Vol. 4*, 40–56. https://doi.org/10.9734/bpi/ist/v4/15405d.

[16] Michael, P. R., Johnston, D. E., & Moreno, W. (2020). A conversion guide: Solar irradiance and lux illuminance. *Journal of Measurements in Engineering*, *8*(4), 153–166. https://doi.org/10.21595/jme.2020.21667.

[17] Li, J., & Lin, M. (2021). Unified Design Guidelines for high flux solar simulator with controllable flux vector. *Applied Energy*, *281*, 116083. https://doi.org/10.1016/j.apenergy.2020.116083.

[18] Jenkins, R., Aldwell, B., Yin, S., Meyer, M., Robinson, A. J., & Lupoi, R. (2019). Energy efficiency of a quartz tungsten halogen lamp: Experimental and numerical approach. *Thermal Science and Engineering Progress*, *13*, 100385. https://doi.org/10.1016/j.tsep.2019.100385.

[19] Li, J., Hu, J., & Lin, M. (2022). A flexibly controllable high-flux solar simulator for concentrated solar energy research from extreme magnitudes to uniform distributions. *Renewable and Sustainable Energy Reviews*, *157*, 112084. https://doi.org/10.1016/j.rser.2022.112084.

[20] Song, J., Wang, J., Niu, Y., Wang, W., Tong, K., Yu, H., & Yang, Y. (2019). Flexible high flux solar simulator based on optical fiber bundles. *Solar Energy*, *193*, 576–583. https://doi.org/10.1016/j.solener.2019.10.002.

[21] Meyer, E. L., & Nwodo, J. C. (2020). Autonomous Dynamic Adaptability System to maintain irradiance levels in a steady-state solar simulator. *Applied Sciences*, *10*(13), 4534. https://doi.org/10.3390/app10134534.

[22] Martínez-Manuel, L., Wang, W., & Peña-Cruz, M. I. (2021). Optimization of the radiative flux uniformity of a modular solar simulator to improve solar technology qualification testing. *Sustainable Energy Technologies and Assessments*, *47*, 101372. https://doi.org/10.1016/j.seta.2021.101372.

[23] Siegel, N. P., & Roba, J. P. (2017). The design and experimental characterization of high flux solar simulators using metal halide arc lamps. *Light, Energy and the Environment*. https://doi.org/10.1364/ose.2017.rth2b.4.

[24] Shah, M. A., Butt, H., Farooq, M., Ihsan, M. N., Sajid, M., & Uddin, E. (2020). Development of a truncated ellipsoidal reflector-based metal halide lamp solar simulator for characterization of photovoltaic cells. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1–15. https://doi.org/10.1080/15567036.2020.1842557.

[25] Tavakoli, M., Jahantigh, F., & Zarookian, H. (2021). Adjustable high-power-led solar simulator with extended spectrum in UV region. *Solar Energy*, *220*, 1130–1136. https://doi.org/10.1016/j.solener.2020.05.081.

[26] Song, J.-Y., Zeng, R.-M., Xu, D.-Y., Wang, Y., Ding, Z., & Yang, C. (2021). A compact AAA-compatible multispectral solar simulator based on spherical cap chamber. *Solar Energy*, *220*, 1053–1064. https://doi.org/10.1016/j.solener.2021.03.074.

[27] ur Rehman, U., & Riaz, M. (2018). Design and implementation of Electronic Load Controller for Small Hydro Power Plants. *2018 International Conference on Computing, Mathematics and Engineering Technologies (ICoMET)*. https://doi.org/10.1109/icomet.2018.8346450.

[28] Singh, R. R., Kumar, B. A., Shruthi, D., Panda, R., & Raj, C. T. (2018). Review and experimental illustrations of electronic load controller used in standalone micro-hydro generating plants. *Engineering Science and Technology, an International Journal*, *21*(5), 886–900. https://doi.org/10.1016/j.jestch.2018.07.006.

[29] Ofosu, R. A., Normanyo, E., Kaberere, K. K., Kamau, S. I., & Otu, E. K. (2022). Design of an Electronic Load Controller for Micro Hydro Power Plant using fuzzy-pi controller. *Cogent Engineering*, *9*(1). https://doi.org/10.1080/23311916.2022.2057115.

[30] Chen, T., Cheng, C., Cheng, H., Wang, C., & Mi, C. (2022). A multi-load capacitive power relay system with load-independent constant current outputs. *IEEE Transactions on Power Electronics*, *37*(5), 6144–6155. https://doi.org/10.1109/tpel.2021.3123542.

[31] Chen, T., Cheng, C., Cheng, H., Wang, C., & Mi, C. C. (2022). A load-independent power-repeater capacitive power transfer system with multiple constant voltage outputs. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 1–1. https://doi.org/10.1109/jestpe.2022.3180029.

[32] Jin, S., Zhang, D., Bao, Z., & Liu, X. (2018). High dynamic performance solar array simulator based on a SIC MOSFET linear power stage. *IEEE Transactions on Power Electronics*, *33*(2), 1682–1695. https://doi.org/10.1109/tpel.2017.2679190.

[33] Das, S., Rashid, M. M., Firdous, J., & Haque, M. N. (2020). Design, analysis and simulation of a solar powered DC motor using MOSFET H-bridge converter. *2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*. https://doi.org/10.1109/icccnt49239.2020.922558.

[34] Nimmagadda, L. A., Mahmud, R., & Sinha, S. (2021). Materials and devices for on-chip and off-chip peltier cooling: A Review. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *11*(8), 1267–1281. https://doi.org/10.1109/tcpmt.2021.3095048.

[35] Najera-Ruiz, O., Martinez-Gamboa, I., Sellschopp-Sanchez, S., Santana, G., Escalante, G., & Alvarez-Macias, C. (2018). Efficiency improvement of photovoltaic cells by cooling using peltier effect. *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*. https://doi.org/10.1109/pvsc.2018.8547996.

[36] Gao, Y.-W., Lv, H., Wang, X.-D., & Yan, W.-M. (2017). Enhanced Peltier cooling of two-stage thermoelectric cooler via pulse currents. *International Journal of Heat and Mass Transfer*, *114*, 656–663. https://doi.org/10.1016/j.ijheatmasstransfer.2017.06.102.

[37] Plytaria, M. T., Bellos, E., Tzivanidis, C., & Antonopoulos, K. A. (2019). Numerical simulation of a solar cooling system with and without phase change materials in radiant walls of a building. *Energy Conversion and Management*, *188*, 40–53. https://doi.org/10.1016/j.enconman.2019.03.042.

[38] Alahmer, A., & Ajib, S. (2020). Solar Cooling Technologies: State of Art and perspectives. *Energy Conversion and Management*, *214*, 112896. https://doi.org/10.1016/j.enconman.2020.112896.

[39] Albers, J. (2020). Improved Solar Operation Control for a solar cooling system of an IT center. *Applied Sciences*, *10*(10), 3354. https://doi.org/10.3390/app10103354.

[40] M'hamed, B., Che Sidik, N. A., Akhbar, M. F., Mamat, R., & Najafi, G. (2016). Experimental study on thermal performance of MWCNT Nanocoolant in Perodua Kelisa 1000cc Radiator system. *International Communications in Heat and Mass Transfer*, *76*, 156–161. https://doi.org/10.1016/j.icheatmasstransfer.2016.05.024.

[41] Li, X., Wang, H., & Luo, B. (2021). The thermophysical properties and enhanced heat transfer performance of SiC-mwcnts hybrid nanofluids for car radiator system. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *612*, 125968. https://doi.org/10.1016/j.colsurfa.2020.125968.

[42] Pang, W., Yu, H., Zhang, Y., & Yan, H. (2019). Solar photovoltaic based air cooling system for vehicles. *Renewable Energy*, *130*, 25–31. https://doi.org/10.1016/j.renene.2018.06.048.

[43] Xie, J., Ge, Z., Zang, M., & Wang, S. (2017). Structural optimization of lithium-ion battery pack with forced Air Cooling System. *Applied Thermal Engineering*, *126*, 583–593. https://doi.org/10.1016/j.applthermaleng.2017.07.143.

[44] Yang, W., Zhou, F., Zhou, H., & Liu, Y. (2020). Thermal performance of axial air cooling system with bionic surface structure for cylindrical lithium-ion battery module. *International Journal of Heat and Mass Transfer*, *161*, 120307. https://doi.org/10.1016/j.ijheatmasstransfer.2020.1203.

APPENDIX A
GANTT CHART

Elements	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Introduction of Project Title													
Brief explanation													
Problem statement													
Objectives & Scopes													
Literature Review													
Journal reading													
Understanding information's													
Discussion of the STC/solar cell/DSSC													
Methodology													
Compare spec of lamp													
Stabilize the temperature of 25°C													
Setup AM 1.5													
Data analysis of measuremnet													
Presentation													
Presentation slide													
Thesis													
Completion of logbook													

Table 1: Gantt Chart of Final Year Project (FYP) 1

Elements	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Introduction of Project Title													
Brief explanation													
Problem statement													
Objectives													
Methodology													
Investigation STC requirements of solar simulator													
Design/troubleshoot /maintenance the solar simulator technically													
Measurement the LED and Halogen lamp													
Results													
Analysis the STC requirements of solar simulator													
Comparison the specification of the lamp (LED & Halogen)													
Analysis data of T_{cell} and T_{amb}													
Construct the AM 1.5 of solar simulator													
Presentation													
Presentation slide													
Thesis													
Completion of logbook													

Table 2: Gantt Chart of Final Year Project (FYP) 2

APPENDIX B
SUMMARIZATION OF LITERATURE REVIEW

No.	Author	Title	Journal	Keywords	Material	Conduction mechanism	Spec LED	Evaluated parameters	Measurement tools	Finding
1	Shogo Kohraku, Kosuke Kurokawa	A fundamental experiment for discrete-wavelength LED solar simulator	Journal of Solar Energy Materials & Solar Cells 90 (2006) 3364-3370	Light-emitting diode (LED), Spectral response, Measuring method	1. The solar cell measurement performance has been improved, but it is still expensive since Xenon and Halogen lamp. **(have short**	1. Solar cells and modules must maintain sufficient reliability. 2. Not corresponding with characteristics of natural sunlight because	approximately up to 10 mW=cm2. 2. light-emitting diode (LED) is energy saving, within budget, and needs a small light source, and recent	1. Characteristics of monocrystalline Si solar. 2. Spectral response (SR) and I-V characteristics of solar cells. 3. SR curve can be	emitting diode (LED) as a light source. 2. A test cell is irradiated by monochromatic light together with white light as bias light and	1. The four color LED (including three monochromatic) solar simulator is used for as light source. 2. SR and I-V characteristics of mono-crystalline Si
2	Jia-Yong Song, Rui-Min Zeng, Dao-Yun Xu, Yi Wang, Zhao Ding, Chen Yang	A compact AAA-compatible multispectral solar simulator based on spherical cap chamber	Journal of Solar Energy Volume 220, 15 May 2021, Pages 1053-1064	Solar simulator, Multispectral channel, Spherical cap chamber, Uniformity	1. A one-dimensional model. 2. The LED layout is optimized by Monte Carlo ray tracing. 3. Use solar spectrumlike light sources such as xenon lamps, metal halide	1. Heat dissipation strategies are introduced to stabilize the system. 2. Outdoor natural light is affected by uncontrollable factors such as unpredictable	1. Seven types of LEDs are adopted to simulate the solar spectrum, and its maximum deviation between the AM 1.5G is − 8.82%. 2. Combination of	1. provide multiple independent color. 2. Analyze locations of maximum power point which may degenerate the spatial homogeneity channels. 3. Two structural	broadband IEC60904-9 standard in terms of illumination nonuniformity, stability and solar-like spectrum. 2. heat sinks and	1. A good illumination uniformity can be achieved if they are rotational symmetrically distributed. 2. Criteria of solar simulators can be summarized into three aspects: spectral
3	Mehdi Tavakoli, Farhad Jahantigh, Hamik Zarookian	Adjustable high-power-LED solar simulator with extended spectrum in UV region	Journal of Solar Energy Volume 220, 15 May 2021, Pages 1130-1136	Solar simulator, Light-emitting diodes (LEDs), AM1.5G, Uniformity, Spectral match, Temporal instability	1. The first generation of solar simulators used conventional light sources such as Xenon, metal halide arc, carbon arc, quartz	1. Solar simulator is an artificial device that can offer intensity and spectrum close to the natural sunlight. 2. Used in the indoor testing and research of	1. The Class AAA specifications in the all three categories for the test plane of 2.3 × 2.3 cm at a distance of 8.7 cm from the LEDs. 2. Highly efficient light	tunable, versatile, light emitting diode (LED) based solar simulator that employs 19 different wavelengths controlled independently by high	1. The spectral tunability and extended spectrum of this solar simulator. 2. MiniSol model LSH-7320 from Oriel/Newport	characteristics of high-power LEDs outweigh their disadvantages and make them a preferable candidate as a light source in
4	J. Hofbauer, M. Rudolph, S. Streif	Stabilising the Light Spectrum of LED Solar Simulators Using LQG Control	Journal of IFAC PapersOnLine Volume 53, Issue 2, 2020, Pages 6583-6590	Solar simulator, LQG control, LED, spectrum estimation, solar cells	1. Using LED technology. 2. Use of colour filters **(usually for the colour components red, green, and blue)**. 3. Measured using an intensity sensor and	1. The drift in the light colour can only be compensated with spectrally adjacent LEDs. 2. LED based solar simulator work with an array of different colour current -	1. Use LED technology as light source, it possible to control light intensity without additional colour filters. 2. The LED light spectrum depends on the current and the	1. The light spectrum and light intensity of the considered LED solar simulators is time varying due to current induced heating of the semiconductor. 2. For	was designed for the stabilisation of the time-varying spectrum. 2. A controller is required to regulate the temperature effect which keeps the	response of peak wavelength, measurement data with linear approximation. 2. Comparison of goodness of fit with respect to state equation and simplified

Table 4: Literature Review of Part 1

No.	Author	Title	Journal	Keywords	Material	Conduction mechanism	Spec LED	Evaluated parameters	Measurement tools	Finding
4	J. Hofbauer, M. Rudolph, S. Streif	Stabilising the Light Spectrum of LED Solar Simulators Using LQG Control	Journal of IFAC PapersOnLine Volume 53, Issue 2, 2020, Pages 6583-6590	Solar simulator, LQG control, LED, spectrum estimation, solar cells	1. Using LED technology. 2. Use of colour filters **(usually for the colour components red, green, and blue)**. 3. Measured using an intensity sensor and	1. The drift in the light colour can only be compensated with spectrally adjacent LEDs. 2. LED based solar simulator work with an array of different colour current -	1. Use LED technology as light source, it possible to control light intensity without additional colour filters. 2. The LED light spectrum depends on the current and the	1. The light spectrum and light intensity of the considered LED solar simulators is time varying due to current induced heating of the semiconductor. 2. For	was designed for the stabilisation of the time-varying spectrum. 2. A controller is required to regulate the temperature effect which keeps the	response of peak wavelength, measurement data with linear approximation. 2. Comparison of goodness of fit with respect to state equation and simplified
5	M. Tureka, K. Sporledera, T. Luka	Spectral characterization of solar cells and modules using LED-based solar simulator	Journal of Solar Energy Materials and Solar Cells Volume 194, 1 June 2019, Pages 142-147	Quantum, Efficiency, Reflectivity, Solar simulator, LED	1. Using LED solar simulators, they are completely in-line capable as they can be performed in less than one second. 2. Solar simulators are major characterization tools yielding the	1. To develop advanced measurement approaches yielding valuable additional information on the performance and possible loss mechanisms within a	1. These light sources can be designed such that they provide a very high conformity with norm spectra, i.e. the AM1.5 spectrum. 2. LED based solar simulators also provide a number	1. Measure the quantum efficiency and the reflectivity that takes the spectral broadening of the LEDs fully into account. 2. Type of measurement system can be used to obtain spectral	1. Present a rapid EQE measurement and data analysis scheme as well as an approach to determine the spectral reflectivity. 2. Show that self-consistent iterations	approach that can applied to any quasi-monochromatic light source with a finite spectral peak width independent of the peak shape. 2. Demonstrated our
6	M. Tawfika, X. Tonnelliera, C. Sansom	Light source selection for a solar simulator for thermal applications: A review	Journal of Renewable and Sustainable Energy Reviews Volume 90, July 2018, Pages 802-813	Solar simulator, Sunlight, Solar spectrum, CSP, Metal halide, Tungsten lamp	1. Four main lamp types are discussed in detail, namely argon arc, the metal halide, tungsten halogen lamp, and xenon arc lamps. 2. Review shows that	1. The light sources available for both low and high-flux solar simulators used for thermal applications. 2. Light sources with the same colour	1. Light source selection is the principal step in designing a solar simulator with suitable simulated solar radiation. 2. Spectral	lamp wavelength spectrum with the solar spectrum, lamp intensity, cost, stability, durability, and any hazards associated with use. 2. Describing	1. A solar simulator is a device with a light source which offers both an intensity level and a spectral composition close to	applications testing, four lamp types have been employed: argon arc, metal halide, tungsten halogen and xenon arc. Since the early 1970s,
7	Hasan Sabahi, Ali Asghar Tofigh, Iman Mirzaee Kakhki, Hosein Bungypoor-Fard	Design, construction and performance test of an efficient large-scale solar simulator for investigation of solar thermal collectors	Journal of Sustainable Energy Technologies and Assessments Volume 15, June 2016, Pages 35-41	Solar simulator, Light simulation, Light field, Solar thermal test	1. Commercial lamps are applied in solar simulators so as to be capable of providing an environment that is similar to daily changes of radiated sunlight especially in course of illumination	1. Provides an effective and repeatable condition to test the performance of the solar thermal collectors. 2. High-flux solar simulator scan was used for controlling conditions and	1. They obtained high irradiance by employing high pulsing voltages to LEDs. 2. It has full wavelength range of interest for Si-PV with an extension in the UV, matching AM1.5 g from 350 nm to	1. Design and construction of an efficient multiple-lamp solar simulator for investigating the performance of the solar collectors for scientific and industrial purposes. 2. The non-	uses lamp to simulate sunlight. However, lamp cannot create all wavelengths of sunlight. 2. 400 W and 1000 W halogen lamps as a heat source has been	1. This approach was designing and manufacturing an efficient test stand for testing solar collectors that consume less energy and fewer cost of construction by using a intelligent. 2.

Table 5: Literature Review of Part 2

3	Xiang Zou, Yunze He, Zhenjun Zhang a, Mengchuan Li, Saibo She, Xuefeng Geng, Yun Bai, Xiangzhao Dang, Dantong Ren, Zhiyu Chen	Experimental study and signal analysis of acoustic emission from power MOSFET	Journal of Microelectronics Reliability 127 (2021) 114411	1. The mechanical stress wave (MSW) and electromagnetic wave (EMW) generated from power metal-oxide-semiconductor field-effect transistor (MOSFET) are analyzed under low voltage condition for the first time. 2. The testing system is set up based on acoustic emission (AE)	1. AE signals generated by power MOSFET under pulse excitation can be divided into low-frequency and high frequency components with the boundary of 300 kHz. 2. The relationship between low-frequency components and gatesource voltage (Vgs) is approximately linear and the high-	1. The generated AE signal generated by turn-on or turn-off processes of power MOSFET contains the high-frequency and low-frequency components. 2. For the analysis of the high-frequency component of AE signal, the amplitude of the positive pulse in EMW at the time of the appearance and
4	Zdenek Slanina Martin Uhlik Vaclav Sladecek	Cooling Device with Peltier Element for Medical Applications	Journal of IFAC Papers OnLine 51-6 (2018) 54–59	1. The peltier device. 2. The analysis capabilities of cooling system with peltier device as actuator.	1. The peltier device. 2. The efficiency peltier evaluated with an example of parameters selected cells. 3. The second part of peltier is the design and implementation of the regulation in cooling system itself.	1. An analysis of individual cooling methods was conducted, focusing on the cooling of living tissue. 2. A detailed description of the Peltier phenomenon physical principle follows, followed by an overview of the important parameters of the Peltier elements produced. 3.
	M. Mortadi , A. El Fadar	Performance, economic and environmental assessment of solar cooling systems under various climates	Journal of Energy Conversion and Managemen	1. The investigation of different solar cooling systems, namely: solar absorption, solar adsorption, photovoltaic and photovoltaic thermal cooling systems on the basis of performance, economic and environmental aspects. 2. The main objective is to	1. A numerical simulation is performed on EnergyPlus software to determine the cooling loads of a typical office building for air-conditioning purpose. 2. Performance, economic and environmental analyses are carried out in terms	1. PVT cooling system exhibits the best performance results given its high solar coefficient of performance ranging from 36 to 52%, depending on the climate condition. 2. Lower DPP values were observed in regions with high solar irradiation. 3. The increase of solar fraction has a

Table 6: Literature Review of Part 3

APPENDIX C
THE PLATFORM OF SOLAR SIMULATOR

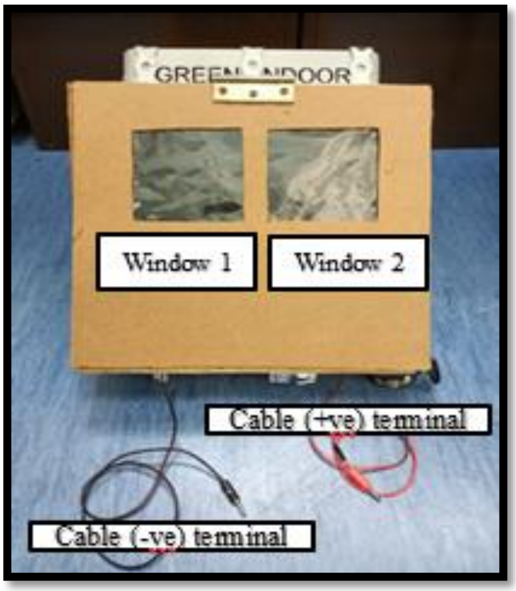

Figure 1: Front Side View of Solar Simulator

Figure 2: Left Side View of Solar Simulator

Figure 3: Right Side View of Solar Simulator

Figure 4: Back Side View of Solar Simulator

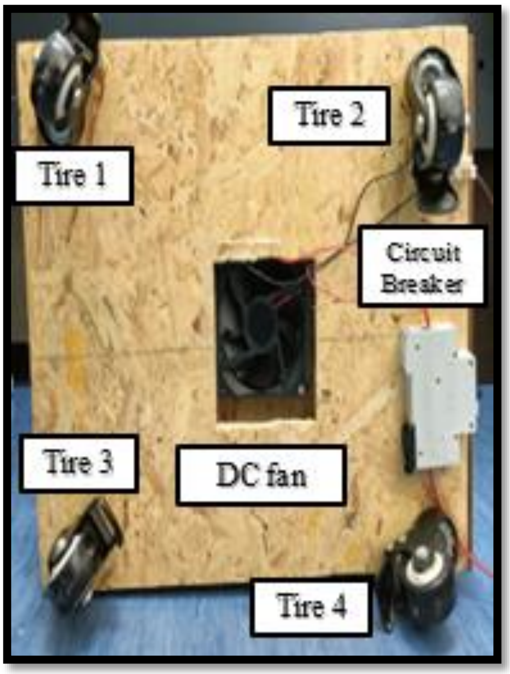

Figure 5: Front Side View of Solar Simulator

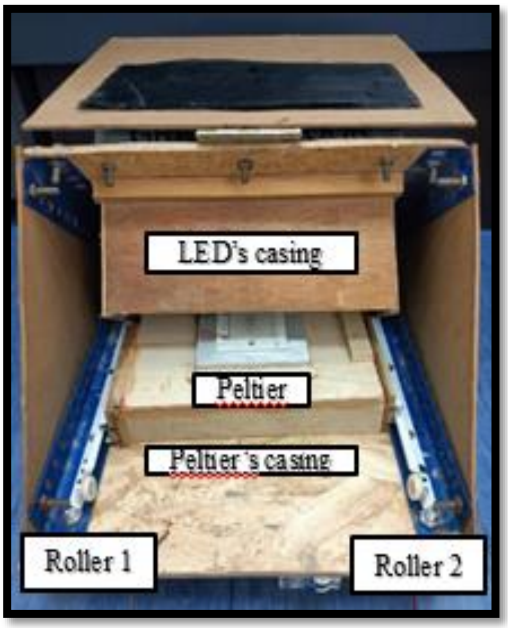

Figure 6: Inside View of Solar Simulator

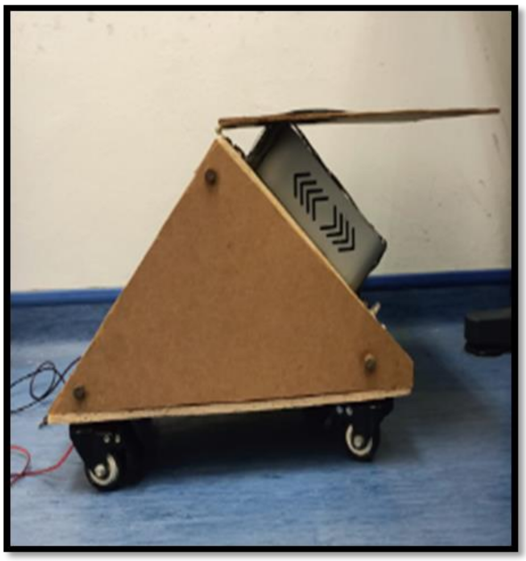

Figure 7: The Angle of 0° Front Board Solar Simulator

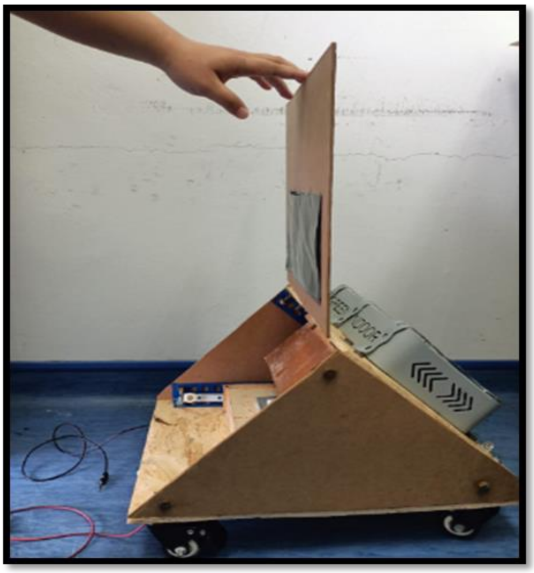

Figure 8: The Angle of 90° Front Board Solar Simulator

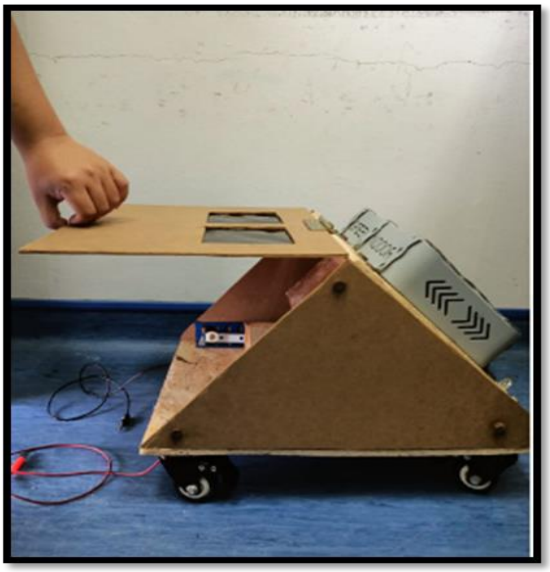

Figure 9: The Angle of 180° Front Board Solar Simulator

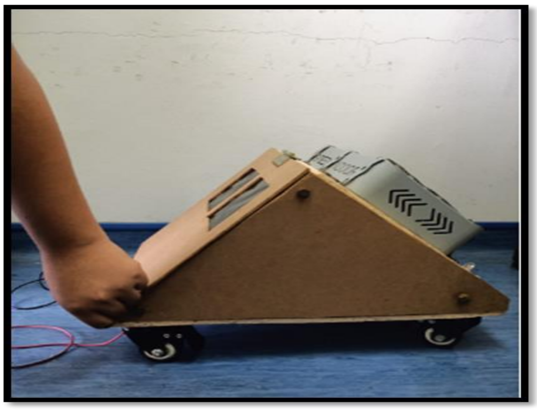

Figure 10: The Angle of 225° Front Board Solar Simulator

APPENDIX D
COOLING SYSTEM

Measurement	LED Growth Light	Ambient Temperature (°C)	DC Power Supply		Time Taken (min)
			Voltage (V)	Current (A)	
1	OFF	32	-	-	0
	ON	25	2.71	0.49	1
		26	2.71	0.49	2
		28	2.79	0.51	3
		25	5.02	1.03	4
		23	5.02	1.03	5
2	OFF	36	-	-	20
	ON	24	5.03	1.07	1
		25	4.91	0.99	2
		26	4.91	0.99	3
		26	4.89	0.99	4
		27	4.89	0.99	5
		27	5.01	1.01	6
		26	5.54	1.13	7
		26	5.65	1.16	8
		26	5.82	1.19	9
		25	5.92	1.22	10
		25	6.23	1.28	11
		25	6.24	1.28	12
		25	6.23	1.27	13
		25	6.23	1.27	14
		25	6.23	1.27	15

Table 7: The 1^{st} and 2^{nd} Measurement of T_{amb} Temperature

3	OFF	38	-	-	20
	ON	19	6.23	1.32	1
		20	6.23	1.31	2
		21	6.23	1.29	3
		22	6.23	1.29	4
		22	6.23	1.29	5
		23	6.23	1.29	6
		23	6.24	1.28	7
		23	6.24	1.29	8
		24	6.24	1.28	9
		24	6.24	1.28	10
		24	6.23	1.28	11
		24	6.24	1.28	12
		24	6.24	1.28	13
		24	6.23	1.28	14
		24	6.23	1.28	15
4	OFF	39	-	-	0
	ON	20	6.56	1.38	1
		20	6.56	1.37	2
		21	6.56	1.36	3
		22	6.56	1.36	4
		22	6.56	1.36	5
		21	7.13	1.49	6
		21	7.13	1.49	7
		22	7.56	1.59	8
		22	6.56	1.36	9
		23	6.05	1.22	10
		24	6.06	1.24	11
		24	6.06	1.24	12
		24	6.06	1.24	13
		24	6.06	1.24	14
		24	6.06	1.24	15

Table 8: The 3^{rd} and 4^{th} Measurement of T_{amb} Temperature

5	OFF	32	-	-	0
	ON	26	1.71	0.32	1
		21	5.02	1.08	2
		27	2.52	0.46	3
		24	5.04	1.07	4
		23	5.04	1.07	5
		23	5.04	1.07	6
		24	5.04	1.05	7
		24	5.04	1.05	8
		25	5.04	1.05	9
		25	5.04	1.05	10
		25	5.04	1.05	11
		25	5.04	1.05	12
		26	5.04	1.05	13
		25	6.11	1.27	14
		26	5.04	1.04	15

Table 9: The 5^{th} Measurement of T_{amb} Temperature

6	OFF	36	-	-	20
	ON	23	5.56	1.17	1
		23	5.56	1.17	2
		24	5.56	1.17	3
		24	5.56	1.17	4
		24	5.56	1.17	5
		24	5.56	1.17	6
		24	5.56	1.17	7
		24	6.01	1.26	8
		25	5.54	1.15	9
		25	5.54	1.15	10
		25	5.54	1.15	11
		25	5.54	1.15	12
		25	5.54	1.15	13
		25	5.54	1.15	14
		25	5.54	1.15	15
7	OFF	36	-	-	20
	ON	20	5.52	1.16	1
		21	5.52	1.16	2
		22	5.52	1.14	3
		22	5.52	1.14	4
		23	5.52	1.14	5
		24	5.52	1.14	6
		24	5.52	1.14	7
		24	5.52	1.14	8
		24	5.52	1.14	9
		24	5.52	1.14	10
		25	5.52	1.14	11
		25	5.52	1.14	12
		25	5.52	1.14	13
		25	5.52	1.14	14
		25	5.52	1.14	15

Table 10: The 6^{th} and 7^{th} Measurement of T_{amb} Temperature

8	OFF	26	-	-	0
	ON	15	6.25	1.38	1
		16	6.25	1.38	2
		16	6.25	1.39	3
		17	6.25	1.35	4
		18	6.25	1.34	5
		19	6	1.27	6
		19	6	1.27	7
		20	6	1.27	8
		20	6	1.27	9
		20	6	1.27	10
		20	6	1.27	11
		17	Invalid	Invalid	12
		17	Invalid	Invalid	13
		17	Invalid	Invalid	14
		17	Invalid	Invalid	15

Table 11: The 8^{th} Measurement of T_{amb} Temperature

9	OFF	30	-	-	20
	ON	14	5.55	1.21	1
		15	5.55	1.21	2
		16	5.55	1.2	3
		16	5.55	1.19	4
		18	5.02	1.05	5
		19	5.02	1.05	6
		20	5.02	1.05	7
		20	5.02	1.05	8
		21	4.5	0.93	9
		22	4.5	0.93	10
		23	4.04	0.83	11
		24	4.04	0.83	12
		25	4.04	0.83	13
		25	4.04	0.83	14
		25	4.04	0.83	15
10	OFF	29	-	-	20
	ON	17	4.03	0.86	1
		18	4.03	0.85	2
		19	4.04	0.84	3
		20	4.04	0.83	4
		21	4.04	0.83	5
		22	4.04	0.83	6
		23	4.04	0.82	7
		23	4.04	0.82	8
		24	4.04	0.82	9
		24	4.04	0.82	10
		24	4.04	0.82	11
		25	4.04	0.82	12
		25	4.04	0.82	13
		25	4.04	0.82	14
		25	4.04	0.82	15

Table 12: The 9^{th} and 10^{th} Measurement of T_{amb} Temperature

11	OFF	31	-	-	0
	ON	25	2.56	0.47	1
		26	2.99	0.6	2
		26	3.54	0.71	3
		25	3.54	0.71	4
		25	3.54	0.71	5
		25	3.54	0.71	6
		26	3.54	0.71	7
		25	4.05	0.82	8
		25	4.07	0.82	9
		25	4.07	0.82	10
		25	4.07	0.82	11
		25	4.07	0.82	12
		25	4.07	0.82	13
		25	4.07	0.81	14
		26	4.07	0.81	15

Table 13: The 11^{th} Measurement of T_{amb} Temperature

12	OFF	33	-	-	20
	ON	22	3.57	0.73	1
		23	3.57	0.73	2
		24	3.58	0.73	3
		25	3.58	0.73	4
		25	3.58	0.73	5
		25	4.09	0.83	6
		25	4.09	0.83	7
		25	4.04	0.82	8
		25	4.04	0.82	9
		25	4.04	0.82	10
		26	4.04	0.82	11
		26	4	0.8	12
		26	4.04	0.81	13
		25	4.58	0.93	14
		24	4.58	0.93	15
13	OFF	33	-	-	20
	ON	27	2.56	0.47	1
		25	3.57	0.73	2
		25	3.57	0.73	3
		26	3.57	0.72	4
		26	3.57	0.72	5
		25	4.1	0.82	6
		25	4.1	0.82	7
		25	4.1	0.82	8
		25	4.1	0.82	9
		25	4.57	0.93	10
		24	4.57	0.93	11
		25	4.57	0.93	12
		25	4.5	0.91	13
		25	4.25	0.86	14
		26	4.25	0.86	15

Table 14: The 12^{th} and 13^{th} Measurement of T_{amb} Temperature

Measurement	LED Growth Light	Cell Temperature (°C)	DC Power Supply		Time Taken (min)
			Voltage (V)	Current (A)	
1	OFF	27	-	-	0
	ON	22	3.56	0.7	1
		24	3.12	0.6	2
		25	3.11	0.6	3
		25	3.11	0.6	4
		25	3.54	0.68	5
2	OFF	30	-	-	20
	ON	24	3.12	0.62	1
		25	3.12	0.62	2
		25	3.12	0.63	3
		26	3.43	0.71	4
		26	3.44	0.71	5
3	OFF	31	-	-	20
	ON	25	3.32	0.64	1
		26	3.32	0.64	2
		25	4.11	0.83	3
		25	4.11	0.83	4
		26	4.11	0.83	5

Table 15: The 1^{st}, 2^{nd} and 3^{rd} Measurement of T_{cell} Temperature

4	OFF	29	-	-	0
	ON	25	3.12	0.58	1
		26	3.12	0.58	2
		26	3.67	0.68	3
		26	3.67	0.68	4
		26	4.58	0.83	5
		25	4.58	0.83	6
		26	4.58	0.83	7
		25	5.01	0.95	8
		25	5.01	0.95	9
		25	5.01	0.93	10
		25	5.01	0.93	11
		25	5.01	0.93	12
		25	5.01	0.93	13
		25	5.01	0.93	14
		24	5.01	0.93	15
5	OFF	29	-	-	20
	ON	23	5.02	1.02	1
		24	5.02	1.02	2
		25	5.02	1.02	3
		25	5.02	1.02	4
		25	5.02	1.03	5
		26	5.02	1.01	6
		26	5.02	1.01	7
		26	5.55	1.12	8
		25	5.55	1.12	9
		26	5.6	1.13	10
		25	6.04	1.23	11
		25	6.04	1.24	12
		25	6.04	1.24	13
		25	6.04	1.24	14
		25	6.04	1.24	15
6	OFF	30	-	-	20
	ON	23	5.09	1.05	1
		23	5.09	1.05	2
		24	5.1	1.04	3
		24	5.1	1.04	4
		25	5.1	1.04	5
		25	5.1	1.04	6
		25	5.1	1.04	7
		25	5.1	1.04	8
		25	6.04	1.25	9
		25	6.04	1.25	10
		26	6.04	1.25	11
		24	5.52	1.12	12
		25	5.52	1.12	13
		25	5.52	1.12	14
		25	5.52	1.12	15

Table 16: The 4^{th}, 5^{th} and 6^{th} Measurement of T_{cell} Temperature