EML 4551 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

3-DIMENSIONAL SOLAR PANEL
25% Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Muhammad Arif, Karel Jie Tjoe Foek, and Christian Bernard and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

Karel Jie Tjoe Foek	Muhammad Arif	Christian Bernard
Team Leader	Team Member	Team Member

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Abstract:

Solar panel research and development has been around for many years, since the 1800s, and in recent times they have become more popular as a means of primary power generation. Since the sun's energy is an unlimited energy resource, it has the potential to become the main source of energy in the future. All other forms of energy can be indirectly sourced back to the sun and solar movements. The main objective of our project is to find the most efficient geometry possible for a solar panel, in order to maximize the energy generated for a given base area. With our design, we plan on harvesting the sun's energy in the most efficient manner, thus reducing dependence on fossil fuels, and greatly reducing the cost of electricity.

Problem Statement:

Due to the dependence on fossil fuels as an energy source, and the inefficiency of alternate sources, our goal is to design a 3-dimensional solar panel that offers a better energy generation and efficiency than the basic rectangular-shaped solar panel. The sun is a moving source, and therefore the amount of sunlight and the angles of approach are always changing. The most efficient position for a solar panel will always be ninety degrees, or perpendicular, to the rays of sunlight. We have come up with three possible geometries that will give us this maximum absorption at all times: a dome, a parabolic bowl, and a pyramid. Since our design will be portable, we will be able to reach remote areas that either do not have an energy source, or cannot afford one.

A secondary input into our design will be the use of reflectors. By implementing mirrors between the solar cells and/or around the panel itself, the stray sunlight that bounces off the panel can be reflected back to the solar cells where it will be absorbed and utilized, hence increasing absorption of sunlight energy.

Literature Survey:

The idea of solar technology is not new. History of solar technology spans from the 7th century B.C to present [4]. Civilizations in the past have used glass and mirrors to concentrate the sun's heat to light fires. In present time, technology has developed rapidly. For instance, green buildings are being constructed which are powered by solar panels. Solar technology is being implemented in automobiles, ships, boats, highways, Un-manned Air Vehicles (UAV), furthermore the clothes we wear. Research and developments in solar technology will continuously expand as we discover new materials, cell designs, and overall panel geometry. Solar panels are made from several Photovoltaic (PV) cells, also called solar cells, interconnected to form a solar panel. Conventional PV cells are made from silicon, and they are in a flat plate form. These panels are very efficient and manufactured with ease. Another type of solar cell are those that are made from thin-films. These cells are made from amorphous silicon or non-silicon materials such as; Cadmium Telluride, Gallium Arsenide, Amorphous Silicon, and Copper Indium Dieseline [6]. Modern solar cells have reached efficiencies of around 35% in some cases [3]. In our survey, we will present the engineering behind Photovoltaic cells which include the design and material used. We will also present the various solar panels.

Photovoltaic (PV) Cell:

Photovoltaic is a process of converting the absorption of light into energy at the atomic level. Light consists of photons and electrons. Some materials have a property called photoelectric effect such as silicon. This effect causes such materials to absorb photons and release electrons [7] [8]. From the captured electrons, it induces an electric current which can be used as a power source [5].

Conventional solar cells are made from silicon in a flat plate form (rectangular shape), and these cells are made from mono-silicon or poly-silicon. Mono-silicon cells are processed from a single crystal and poly-silicon cells are made from melting different crystals together.

Figure 1 – Mono Silicon

Figure 2 – Poly Silicon

Silicon is a good semiconducting material; therefore, it transports the electric current very efficiently. PV cells are made from a minimum of two silicon film layers, and these layers have two different operating functions. The first layers have a positive charge, and it is called *p-type* [5] [9]. Second layers have a negative charge, and it is called *n-type* [5] [9]. When sunlight strikes the semiconducting material, it absorbs the photon and releases the electrons. The flow of electrons is captured by an electric circuit that connects the two layers. This process is called photoelectric effect [5].

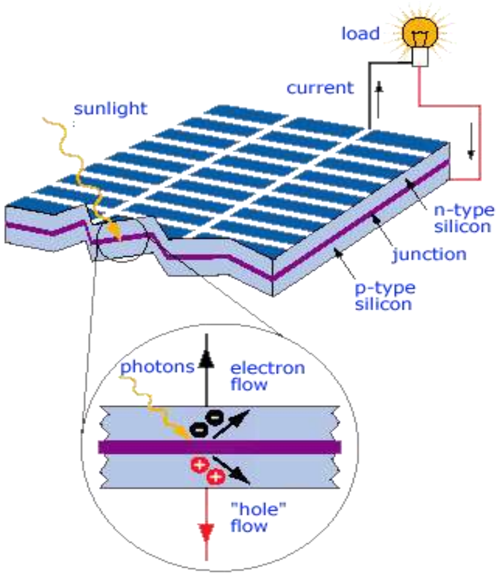

Figure 3 – Photoelectric effect [5]

Solar Panels:

There are several types of solar panels: Mono-crystalline silicon panels, Polycrystalline silicon panels, Building Integrated Photovoltaic (BIPV) panels, and Thin-film panels. Traditionally, these panels are square or rectangular in shape. Mono-silicon panels are shown to be the most efficient out of the four. These are also called single silicon panels. One does not need multiple panels to compare to the other three to generate the same amount of power. Mono-silicon panels are expensive because it is in pure form.

Figure 4 - Solar Cell Mono crystalline silicon [10]

Polycrystalline panels are also called multi-silicon because they are made of mixture of other materials. This type of panel is less efficient compared to the other three but it is cheaper. Their design modification can improve the efficiency.

Figure 5 - Polycrystalline Solar Cell [10]

Building integrated Photovoltaic (BIPV), these types of panels are overall part of a building such as a roof, and furthermore, the installation is made to look like regular roofing tiles. These types of panels are the least efficient compared to the rest of the panels. Since these panels are the most expensive, the other three types of panels are a better choice.

Figure 6 - Integrated photovoltaic panels

Thin-film layer panels are light weight, but it has very low efficiency and is cheaper than the previously mentioned panels. These types of panels are commonly used in huge projects.

Figure 7 - Thin film layer [11]

Solar panels have recently made a significant impact worldwide. Energy generation from solar technology has revolutionized in the past two decades worldwide. Many of the European countries are shifting towards solar technology. Germany is the leading county that produces more than 50 percent of its energy from solar power [2]. Solar panels are environment friendly and considered safe technology.

Motivation:

Within the last 20 years, environmental impact has been a major consideration in the design and manufacturing fields worldwide. “Going green” has become a world-renowned slogan that influences many decisions in our everyday life. Since the first working plant in the 1980s, Photovoltaic Solar plants have become more abundant, especially in Europe, where ¾ of the worlds’ solar plants are based [20]. In order to reduce the dependence on fossil fuels, implement cleaner energy, and reduce electricity costs, we must focus on alternate energy sources, mainly solar. The sun’s energy is an unlimited resource, and when harvested efficiently, has the potential to become our primary energy source. In our design, we plan to advance the methods of solar energy intake by testing alternate geometries to maximize energy generation and efficiency of the panel.

There are many countries, and entire regions that either do not have a reliable energy source or cannot afford one. Parts of Central America and Africa for example, that experience a year round supply of hot climate and sunshine, can focus on solar energy as a means of power. The 3-dimensional solar panel is designed to be portable with the absence of a solar tracker and can easily reach remote areas and provide a cheap, efficient energy source that will solve this crisis.

Project Objectives:

1. Design and construct a 3-dimensonal solar panel to maximize absorption of sunlight and maximize efficiency.
2. Use a geometric shape that remains perpendicular to the rays of sunlight at all times.
3. Adapt the solar panel to residential needs by making it portable and convenient.
4. Effectively utilize renewable energy by making use of the sun's unlimited energy.

Conceptual Design:

Solar panel design takes into account a number of factors that will play a significant role in the efficiency of such a panel. Typically, a solar panel is made of a set of photovoltaic modules that are electrically connected and arranged on a given structure. The typical solar panels that can be found in markets today are of a rectangular shape. These solar panels have an efficiency of up to 17% [3]; however, there are other commercially available solar panels that have an efficiency of 27% [3]. The goal for this project is not to increase the overall efficiency of solar panels, but rather increase the energy generated. Several design alternatives have been taken into consideration to make this goal a reality, one of which is to use different geometries for the solar panel design. The idea behind a 3-dimensional geometry is to increase the base area of the solar panel compared to the stationary rectangular shape. This will allow a possibility for increased energy generation. Another consideration for this design is to implement reflectors. The reflectors can be placed between the solar cells or around the solar panel itself. Stray sunlight that bounces off the panel can be reflected back to the solar cells where it will be absorbed and utilized as stored energy.

Proposed Design:

The solar panel relevant to the project objective and design is a 3-dimensional photovoltaic structure. The focus here is set on the increased base area compared to a rectangular solar panel [1]. A dome shaped geometry will be the main area of focus for this project. The sun is the earth's most predominate energy source and as such, it is of great importance to harvest as much of that energy as possible. Since the earth revolves around the sun, the angle of approach that the irradiation waves make with a solar panel is always changing. With a dome shaped solar panel the angle of approach will almost always be at ninety degrees, which is optimal for energy generation. Since the angle of approach will be close to ninety at any solar time of the day, there will be no need for a sun tracker. Typical rectangular shaped solar panels need a sun tracker to be effective. The absence of a sun tracker will also reduce the cost of installation for a three-dimensional solar panel, which is always a goal when engineering a new product.

Timeline:

Table 1 – Timeline

	Fall								Spring							
Months	September		October		Novemeber		December		January		February		March		April	
Definition																
Planning																
Design Research																
Choose final design																
Assembly																
Testing																
Simulation																
10% report																
25% report																
Final report																

Team Responsibilities:

- Muhammad Arif: Material selection, Geometric calculations
- Christian Bernard: Parts selection, CAD simulations, Power generation calculations
- Karel Jie Tjoe Foek: CAD design and simulation, Specific geometric calculations

Table 2 - Total hours spent (Fall-2013)

Hours Spent				
Date	**Activities**	**Karel**	**Christian**	**Muhammad**
27/08/13	Topic research	6	6	6
30/08/13	Talk to various professors	4	4	4
03/09/13	Choosing a topic	2	2	2
04/09/13	Find an advisor	1	1	1
09/09/13	Solar Panel Research	5	5	5
10/09/13	Meeting with Dr. El-Zahab	1.5	1.5	1.5
13/09/13	Team responsibilities	1	1	1
16/09/13	Solar panel research	3	3	3
24/09/13	Finding relevant journals	1	1	1
26/09/13	Working on first presentation	2.5	2.5	2.5
1/10/13	Solar panel research	2	2	2
7/10/13	Meeting with Dr. El-Zahab	1.5	1.5	1.5
15/10/13	Working on project synopsis	2	2	2
17/10/13	Research and reading	2	2	2
21/10/13	Synopsis due	0	0	0
28/10/13	Final 10% report	4	4	4
29/10/13	Team poster & GL presentation	4	4	4
11/11/13	Preparing for final presentation rehearsal	2	2	2
19/11/13	In-class presentation rehearsal	1	1	1
25/11/13	25% Report Due	5	5	5
26/11/13	Formal presentation rehearsal	2	2	2
3/12/13	Final team poster due	1	1	1
Total	----------	53.5		

Table 3 - Future hours (Spring-2014)

Future hours				
Date	**Activities**	**Karel**	**Christian**	**Muhammad**
6/01/14 – 25/04/14	Construction, meetings with the team and Dr. El-Zahab, buying materials, testing, calculations, programming	137	137	137
Total	----------	137		

Analytical Analysis:

The analytical analysis for the design of a 3-dimensional solar panel requires an understanding of mathematical formulas and heat transfer concepts such as radiation.

The analysis of power production is of utmost importance for the design and development of a 3-dimensional solar panel. The main objective for this project is to increase the power production of a solar panel. A series of steps must be taken in the analysis of a solar panel. First, the power required to operate appliances. For testing purposes appliances will be used that have known power consumption. This will aid in the calculation of power consumption. Second, the amount of energy that the battery can store must be determined. Third, the energy generation for a solar panel must be determined.

Once these factors are known, the main focus can be set on collecting the solar energy. In order to complete this task, a few equations will be used to calculate the angle between a solar panel and a central ray from the sun. This angle is known as the angle of incidence. It is instrumental in solar panel design, because the maximum amount of sun radiation that can reach the surface of the panel is reduced by the cosine of this angle.

Power consumption:

Appliance power consumption [Wh] = P [W] x hours of use [h] [19]

Battery storage:

$$\text{Battery capacity [Ah]} = \frac{\text{Total appliance power consumption} \quad \text{Wh}}{(\quad \text{attery loss} \quad \text{ep th of discharge} \quad \text{nominal battery voltage})} \quad \text{d ays of use} \text{ [19]}$$

Battery loss = 0.85 [19]

Depth of discharge = 0.6 [19]

Solar panel energy generation:

Solar panel energy needed [Wh] = Appliance power consumption [Wh]   energy loss factor [19]

Energy loss factor = 1.3 [19]

Angle of incidence:

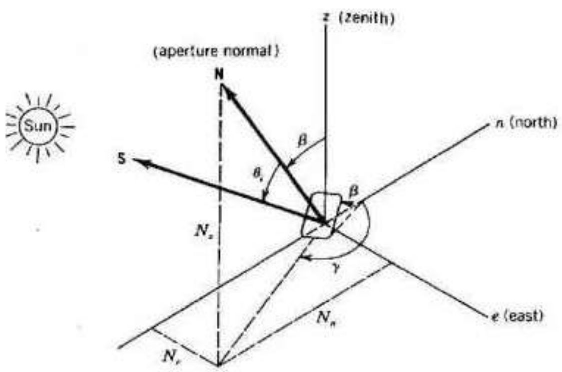

Figure 8 - Solar Panel Orientation towards the Sun [18]

N = unit vector normal to the panel

S = unit vector pointing from the panel towards the sun

θ_i = angle of incidence

β = tilt angle

γ = azimuth angle

$N_e = \cos\beta$ [18]

$N_z = \sin\beta \sin\gamma$ [18]

$N_n = \sin\beta \cos\gamma$ [18]

Angle of incidence: $\theta_i = \cos^{-1}(\boldsymbol{S} \cdot \boldsymbol{N})$ [18]

Major Components:

As the diagram below shows, there are four main components that are required in the energy generation process to convert the sun's energy into usable current for appliances. These are the solar panel, charge controller, battery and inverter.

Figure 9 - Solar Energy Generation Process [12]

Solar panel:

The solar panel is made up of photovoltaic cells, which absorbs the sun's radiation and converts it into electricity. These cells are made up of two silicon film layers: the positively charged layer (p-type) and the negatively charged layer (n-type) [5] [9]. When the sunlight strikes the surface of the PV cells, photons are absorbed and electrons are released. Silicon is a semiconducting material, so it transports electric current efficiently. The electric circuit that connects the two layers then captures the flow of electrons. Below is a diagram showing the make-up of the photovoltaic array that covers the surface area of the solar panel.

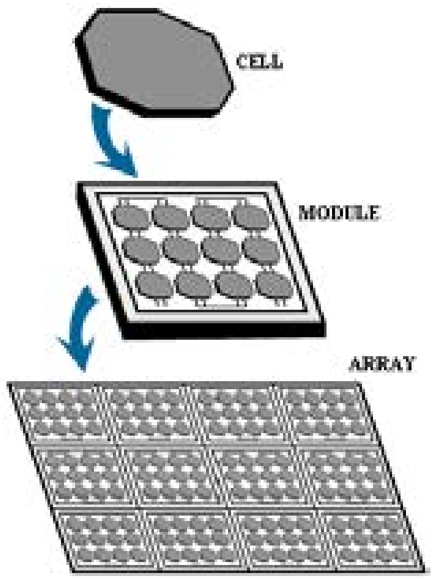

Figure 10 - Make-up of Photovoltaic Array [13]

Charge Controller:

The charge controller is used to regulate the output voltage between the solar panel and the battery. This voltage needs to be regulated so that no damage is done to the battery due to voltage overload. Charge controllers use a 3-stage cycle [14]:

- Bulk: batteries draw maximum current while voltage rises to bulk level.
- Absorption: current decreases while voltage remains at bulk level.
- Float: batteries draw small amount of current while voltage is lowered to float level.

The diagram below shows the current and voltage during the three stages.

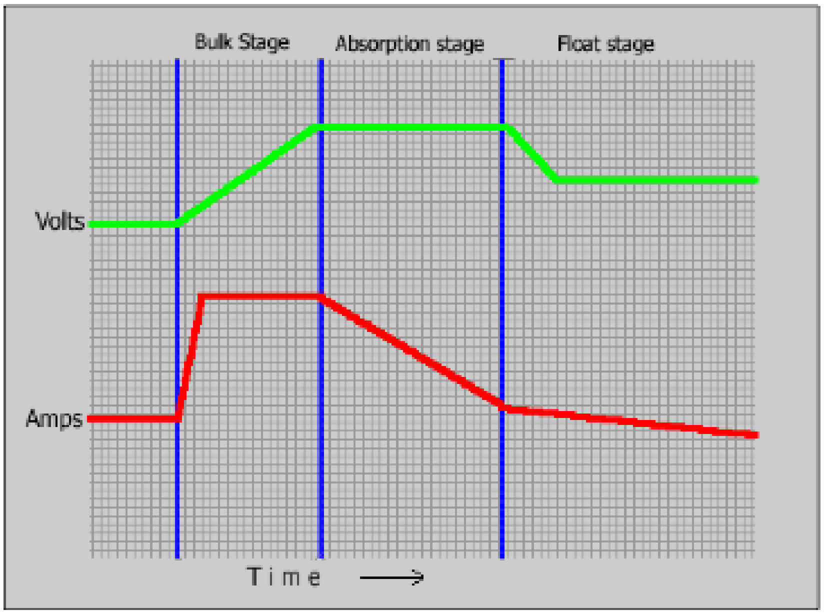

Figure 11 - 3-Stage Cycle of Charge Controller [14]

Battery:

The battery is used for storing the energy absorbed. The system is inoperable without the battery, since the power is stored and drawn from the battery to be used or converted. The energy stored in the battery is determined by the voltage and charge capacity in the relation:

$$\text{Energy Stored} = \text{voltage} \times \text{charge capacity}$$

Another important factor in the battery is the cycle capability or efficiency. This is determined by:

$$\text{Efficiency} = \frac{\text{energy output of discharge}}{\text{energy input to restore}}$$

Inverter:

The inverter is used to convert the DC supply to the AC output. Most appliances run off of 120 V power sources, so the low voltage DC produced must be converted in order to be usable. There are different types of power inverters, but we will be utilizing a Moderate Sine Wave Power Inverter. It produces an AC waveform that is a cross between a square wave and a sine wave. A True Sine Wave Inverter is the most efficient, but also the most expensive, so due to financial restrictions, we will be using the moderate, which is half the price.

Structural Design:

In our research of solar panels thus far, the majority of information comes from the basic, rectangular solar panel geometry. In order to meet the project goals, our structure must be of a geometry that is able to give us greater efficiency than the average 17% efficiency of this basic geometry. A total of four possible geometries were considered as potential candidates for our design, and the pyramid geometry (shown below) was finally chosen for its geometry and convenience. In order to maximize the energy generation of the panel, we are also implementing reflectors into the design. These reflectors will surround the panel, positioned at an angle to catch the stray sunlight and reflect it back to the areas of the panel that are not in direct sight of the sunlight.

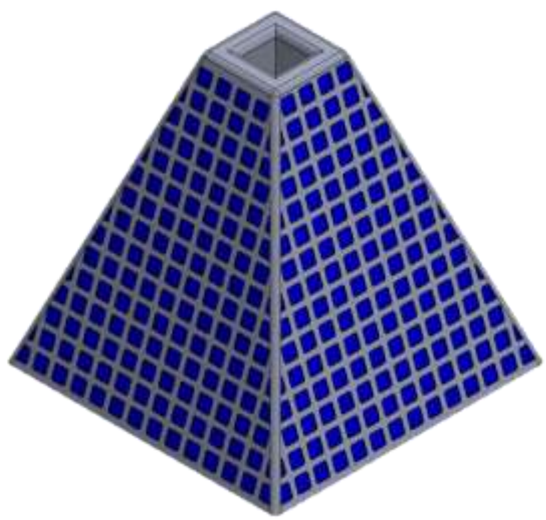

Figure 12 - SolidWorks model of the Solar Panel

The structure of the panel is made of polycarbonate material. This makes up the actual base of the panel for the photovoltaic cells to be attached on. This material is used as a base in many electrical components, such as cell phones. For example the iPhone 5C is made of a colored polycarbonate structure. It is a durable material that can be used over a wide temperature range, and can undergo large plastic deformations without cracking or breaking. It is especially applicable for our design, as it is a good electrical insulator, and has heat-resistant properties. The pyramid has a square base of side 15 inches, and a height of 20 inches. The properties of polycarbonate are shown in the table below.

Table 4 - Polycarbonate Properties [16]

Polycarbonate	Value	Unit
Density	1210	kg/m^3
Refractive Index	1.585	--------
Young's Modulus	2.2	GPa
Tensile Strength	65	MPa
Poisson's Ratio	0.37	--------
Melting Temperature	428	K
Specific Heat Capacity	1250	J/(kg-K)
Thermal Conductivity	0.205	W/(m-K)

Cost Analysis:

The total cost of the project is comprised of labor, parts, materials and testing. In this section labor will the main topic of concern, since many man hours will be spent on this project. The team met every week and spent at least 5 hours working on the project. The table below shows all the hours spent on the project by each team member. For every man hour of work a cost of $30 will be factored in.

Table 5 - Cost Analysis of Man Hours spent

Description	Days	Karel Jie Tjoe Foek	Muhammad Arif	Christian Bernard	Cost/hour
--------	--------	Hours	Hours	Hours	($30/hour)
Research	50	12	12	12	$1,080
Analysis	31	9	9	9	$810
CAD	15	6	6	6	$540
Simulations	10	6	6	6	$540
Total	106	33	33	33	$2,970

Prototype Construction:

Prototype System Description:

Photovoltaic solar systems already exist and are becoming a common product for energy production. Most of these solar panels are of rectangular geometry, so our prototype will be constructed as a pyramid, and compared to a rectangular panel of same surface area. Our goal is to make it more efficient by choosing the pyramid geometry, and also implementing reflectors to make use of stray sunlight.

Prototype Cost Analysis:

The prototype is being constructed at a size that is big enough to produce significant power, but small enough to be portable, convenient and cost effective. Since it is not a funded project, budget is a main factor in our decisions and expenditure. The prices and images of the main components are shown below:

Table 6 - Prototype Cost Analysis

Part	Amount	Cost
Solar Cells	100	$105
Charge Controller	1	$ 225
Battery	1	$ 130
Inverter	1	$ 1030

Figure 13 – Charge Controller [15]

Figure 14 – Power Inverter [15]

Figure 15 - Battery [15]

Figure 16 - Polycrystalline Solar Cell [21]

Plan for Test on Prototype:

The prototype will be tested by placing it outdoors for a full day of solar exposure, along with a rectangular solar panel of the same surface area, so that data can be recorded and compared between the two panels. This will determine whether our design is indeed more efficient than the basic design.

Conclusion:

In the design of the 3-dimensional solar panel, we are trying to increase sunlight absorption and efficiency of the panel. The sunlight is absorbed by the photovoltaic cells, and converted into usable energy. We are using three potential geometries in our analysis and simulation, and due to costs, we will only build the one that we find to be most effective.

We believe that our project will have a positive impact on the environment and on society. By implementing solar power into residential and commercial areas, eventually it can become the primary power source, and reduce the dependence on fossil fuels and the negative environmental impacts that come with it. Not only is solar energy clean, but also it is in abundance and comes from an unlimited resource; the sun.

We are still in the research phase of our design, and as of now, our main objective is to gather all the important and necessary information for our analysis, and choose our final design based on the analysis and simulations. We are also trying to keep costs at a minimum due to the lack of a sponsor for the project, and also we plan on designing an affordable product that will be successful in the market.

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Appendices:

Appendix A:

Climate data for Miami, Florida.

Table 7 - Average Climate Data for Miami, Florida [17]

	Jan	Feb	March	April	May	June
Average high in °F	76	78	81	84	87	89
Average low in °F	60	60	64	68	72	75
Av. precipitation - inch	1.89	2.09	2.56	3.35	5.51	8.54
Days with precip.	6	5	6	7	10	13
Hours of sunshine	222	227	266	275	280	251

Table 8 - Average Climate Data for Miami, Florida [17]

Annual average high temperature	84.2 °F
Annual average low temperature	69.1 °F
Average temperature	76.6 °F
Average annual precipitation	58.5 in.
Days per year with precipitation	128 d.
Average annual hours of sunshine	2903 h

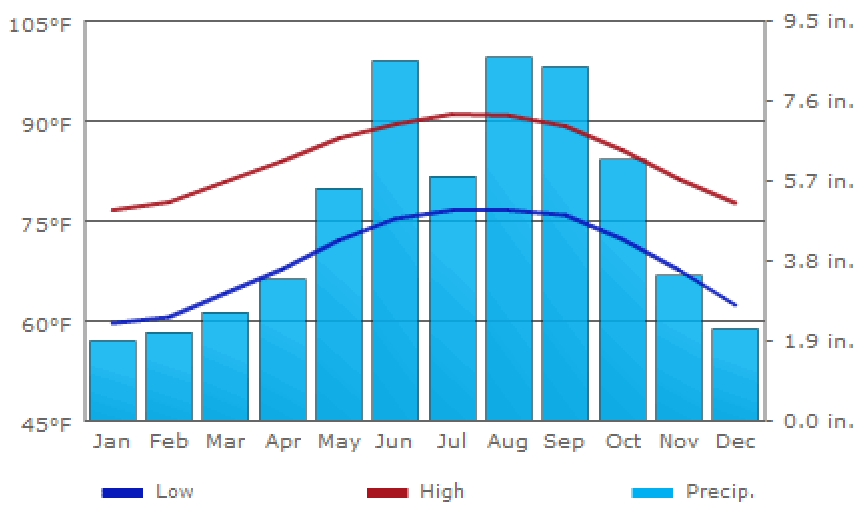

Figure 17 - Miami, Florida Climate Chart [17]