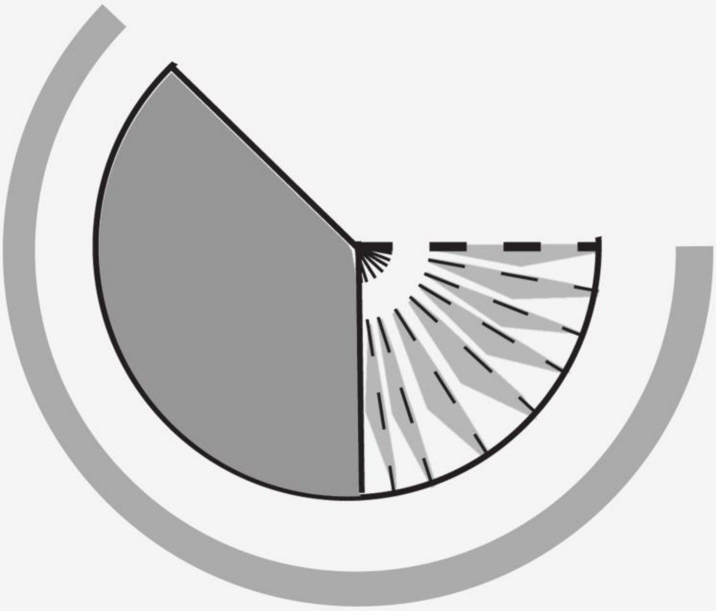
Helio tracker

P.V. integrated shading device

Graduation Thesis

By Shefalika Sukhen Padmanabha



Helio tracker

P.V. integrated shading device that draws inspiration from the solar tracking qualities of heliotropic plants

Shefalika Sukhen Padmanabha

Student id: 5100992

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Theme: Sustainable structures

Mentor 1: Prof. dr. Mauro Overend

Field of study: Structural Design

Mentor 2: Dr. Eleonora Brembilla

Field of study: Climate Design

Delft University of Technology

Faculty of architecture and the built environment

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Abstract

The EU is committed to reducing the energy used and Co_2 produced by 2050. Every component plays an important part in building an energy efficient building. This thesis looks at P.V. integrated shading devices.

Shading devices are designed to block the excess solar radiation coming into the building to reduce the energy load of a building. This surface can be utilized to generate electricity by adding P.V. panels. P.V. panels are more efficient if they track the sun's movement to increase the amount of solar radiation falling on the surface. The existing solar tracking devices fail due to multiple gears and the load of the panel on the rotational device.

To tackle this problem heliotropic plants were studied. Heliotropic plants follow the sun's movement to receive more solar radiation for photosynthesis. The internal mechanisms and forces of a sunflower (heliotropic plant) that cause this movement was analysed through an experiment and digital image correlation. The analysis showed that the sunflower's stem utilizes water to expand and contract the sides of the stem in a diurnal pattern so that the stem can track the sun. This expansion and contraction curves the stem to move it 14 degrees which is sufficient to increase the solar radiation on the plant.

This property of expansion and contraction was taken forward to design a sun tracking P.V. integrated shading to produce more energy. The expansion and contraction of the device were enabled by utilizing segments that were moved by piezo electric actuators. The Piezo electric actuator uses the energy generated from the P.V. panel and converts it to mechanical energy which enables the rotation of the device.

To find the angle for rotation a simulation was made to find the angle at which the P.V. panel produces the most energy and the angle at which the shading device reduces the load on the heating or cooling device. The device is designed to track the change in the sun's altitude as this rotation produces the most energy for a P.V. panel and a shading device. The device responds to the change in altitude four times a year as this corresponds to the seasons to which the shading device rotates.

There were two simulations made for the energy saved by the P.V. integrated shading device. The first simulation was for the Netherlands, factoring the energy saved by the shading device and the energy losses by the mechanical parts the device produces 196kW/ year and reduces the heating and cooling load by 16%. In Abu Dhabi, the same device produces 777kW/ year which reduces the cooling load by 15%.

Key words: P.V. integrated shading device, heliotropic plants, and solar tracking.

Acknowledgments

Through this thesis, nature has been a mammoth cavern of information of which I feel I have just started to learn the basics. This thesis journey started with the simple curiosity of learning from nature which opened a treasure trove of information that I could not stop researching about. I truly believe that nature has developed over the years to perform each function optimally and we can learn a lot from it.

The path to understanding the different layers of the movement of heliotropic plants was possible because of my mentors Prof. dr. Mauro Overend and Dr. Eleonora Brembilla. They constantly shared their knowledge, motivated me, and encouraged me to ensure that I was successful in this journey. They helped provide a structure that narrow downed the field of study and were always positive to all my queries.

At every biological finding, they asked the right questions which helped dive into more details and ensure that I don't stray away from researching about the movement of heliotropic plants as there is immense information and it is difficult to decipher which is relevant. At every step, they gave me qualitative feedback which helped bring the project to fruition.

My sincere thanks to Prof. Overend for providing the Dino light microscope to study the sunflowers and other equipment that aided in the experiment. Dr. Brembilla for the hobo data loggers. A special thanks to the University of TU Delft for providing me with electrical equipment for the experiment. I would like to acknowledge the assistance of the Stef and Richard from the TU Delft Science Centre who gave me material to make the tent for growing the sunflowers.

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I am grateful to Dr.Rishikesh Damble and Dr. Ganesh who broke down complex biological terminology with simple analogies which were instrumental in my thesis. They were always patient and answered all my innumerable basic questions.

A big thank you to my parents, friends, and family from India for their constant love, support, and encouragement. To all my friends in Netherlands who were my emotional and mental support through these difficult times.

Hope you enjoy reading this thesis!

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1. Introduction

1. Introduction

The total energy used by humans in 2020 was 567,186,800 Tera joules. 40% of this energy is used by the building industry. The building industry is responsible for 20 % of the Co_2 emitted (Huang et al., 2018). The EU is committed to reducing the amount of energy used and Co_2 produced by 2050 as per the Paris climate agreement. It is important for the building industry to comply with this and move towards energy efficient buildings.

Every component in a building plays a part in making an energy efficient building. This thesis looks at P.V. integrated shading devices.

Passive shading devices have been used for generations in different shapes, sizes, and materials. The fundamental role of a shading device is to protect the interior of the building from harsh solar radiation depending on its geographical location. If a shading device is designed optimally, it can reduce the cooling load of the building by up to 35% (Minseok, 2018).

On the other hand, P.V. panels are designed to take in these harsh solar radiations and convert them into electricity. The immense research in this field has led to large scale availability in all sizes, shapes, colours, and transparencies.

P.V panels in the 1970s were integrated into façades. As shading devices protect the interior of the building from harsh solar radiation and P.V panels utilize these radiations to produce energy, the two ideas were integrated into shading devices with P.V panels.

Due to the earth's revolution, the sun's position changes throughout the year, in the summer the sun is at a higher altitude whereas in the winter the sun is at a lower altitude. For efficient P.V. panels, the sun's rays have to fall perpendicular to the panel's surface.

To increase the efficiency of P.V panels the panels are designed to track the sun to utilize more solar radiation for energy production. These sun tracking devices can generate 39% more electrical energy than a stationary panel (Anshul et.al, 2020).

This thesis looks at designing a P.V. integrated shading device that can track the sun's movement to produce more energy.

To design a sun tracking device this thesis looks at nature to understand solar tracking properties exhibited in certain plants.

A plant that follows the movement of the sun is called a heliotropic plant. This can be seen in sunflowers when it moves its head along with the sun's movement. The sunflower moves from east to west in the morning and west to east in the night. This phenomenon happens every day till the flower matures without the stem breaking.

This thesis utilizes the rhythmic movement of solar tracking sunflowers as an inspiration to design a P.V. integrated shading device that tracks the sun's movement.

An example of a nature-inspired design is the bullet train in Japan. They were designed after the kingfisher bird's beak. The design helped create fewer pressure waves reducing the sound boom after the train's exited tunnels making the trains run faster and use lesser energy (High Speed Train Inspired by the Kingfisher, 2018). Similarly, this thesis takes inspiration from nature to evaluate the design possibilities for P.V. integrated shading devices.

1.1 Aim

This thesis looks at designing a shading device that reduces the energy load on a building. A shading device receives harsh solar radiation and protects the interior of a building from heating up. By placing a P.V. panel on a shading device it can produce energy. To increase energy production this thesis looks at solar tracking devices.

This thesis looks at combining P.V. panels, shading devices, and solar tracking properties.

For the solar tracking mechanism, the aim is to look at heliotropic plants that tracks the sun's movement and to find a mechanism that can infer from the movement of the plant.

The energy produced by the P.V. panels and the energy saved by a shading device will be analysed to check if the design is energy efficient.

1.2 Problem statement

The problem lies in the rotational system of solar tracking and shading devices. The rotational devices contain complex systems that use gears and these gears undergo wear and tear, leading to their failure. Further, these devices cannot withstand heavy loads. They often require heavy maintenance and have a short lifespan. Shading devices come with a warranty of only 5 years (North Solar Screen LLC, 2021).

1.3 Research questions

How can P.V. integrated sun shading devices utilize the mechanisms (external Stimuli and internal mechanics) of heliotropic plants?

1.4.1 Sub research question

The research sub questions are divided into three parts. The first part is the P.V. integrated shading device. The second part is about heliotropism. The third about the design of a P.V. Integrated shading device.

1.5.1 P.V. integrated shading device

- What are the problems in existing mechanisms and problems for shading devices and solar trackers?
- What is the optimal angle and size for a P.V. panel and a shading device, such that it produces the most amount of energy?

1.5.2 Biological aspects of heliotropism

- What causes heliotropic plants to track the sun? What components are involved in their movement?
- How do you measure and test the movement of a plant?
- What are the forces responsible for the movement of the plant?

1.5.3 Design of P.V integrated shading device

- What properties of heliotropism can be incorporated into the device?
- How will it tackle the problems faced by the existing systems?
- Is the device energy efficient?

1.3 Focus and limitations

The thesis will focus on the rotatory movement of the P.V. integrated shading device as this is a weak point. The thesis will also focus on the integration of the P.V. with a shading device.

The study will look at P.V. panels at an introductory level to determine the most efficient P.V. panel. It will not dive into the different components and parts of a P.V. panel.

The limitation of this device will be dictated by the orientation of the device on the building. The Photovoltaic cells will not be as efficient if it is covered by shadow or masked by other elements (building shadow, overcast skies, trees, etc.), these elements are not considered as these aspects are subjective to the location the device is placed. It will focus on the mechanism of movement by the device.

Shading devices cannot be designed universally as different locations have different parameters. In desert regions, devices need to protect the building from solar radiation throughout the year. Whereas in temperate climates it is important to allow the solar radiation inside the buildings in the winter, to heat the building and reduce the energy load of the building.

The orientation of the panel also plays an important role in the P.V. production. The simulations are for a south-facing facade in the Netherlands. This is scenario is when the P.V. panel can produce the maximum energy.

1.5. Methodology

This research looks at nature for its inspiration and it plays an integral part in the design of the device. The thesis is broken down into four components:

- Literature study and Case study
- Rotational analysis of heliotropic plants
- Optimization for P.V panels and shading devices
- Design

1.5.1 Literature and case study

The literature study consists of two parts. The first one about P.V. integrated shading devices and the second about heliotropic plants.

The first part of the literature study is understanding the mechanism of the existing P.V. panels and shading devices. It also involves analysing solar radiation, different parts and types of P.V. panels, and sun-tracking devices. Further, an understanding of the mechanisms involved in the movement of shading devices and solar trackers.

The second part of the literature study looks at the existing literature on heliotropic movements. This includes talking to botanists and experts from the field along with reading research papers to develop a complete understanding of the mechanism.

The case studies look at examples where biology has inspired the design of an object.

1.5.2 Rotational analysis of heliotropic plants

The main aim is to identify the movement of heliotropic plants and to analyse the stress and strain caused by the bending of the plant. The load transfer of the plant and its durability also needs to be analysed.

The experiment involved placing heliotropic plants in a controlled environment to understand its movement. To design the experiment there were consultations with botanists and other experts. A contingency for the experiment proved effective due to the ongoing pandemic.

The movement of the plants were analysed using different software. This analysis was co-related to the biological literature and conclusions were drawn for the movement of the heliotropic plants.

1.5.3 Optimizing P.V. P.V panels and shading devices

The next part looked at finding the right type of rotation and the right angle for a P.V. Integrated shading device to produce the most amount of energy.

1.5.4 Design

The design involved bringing different aspects together shading device, P.V. panels, and solar tracking properties of heliotropic plants. The chart below 1.5 is an explanation of the different elements that are studied and the method to combine them. In the chart, the top layer was the initial knowledge assimilation. The boxes in grey are the synthesis and performance requirements. The last part is the final design.

This chart was instrumental in reaching the final design

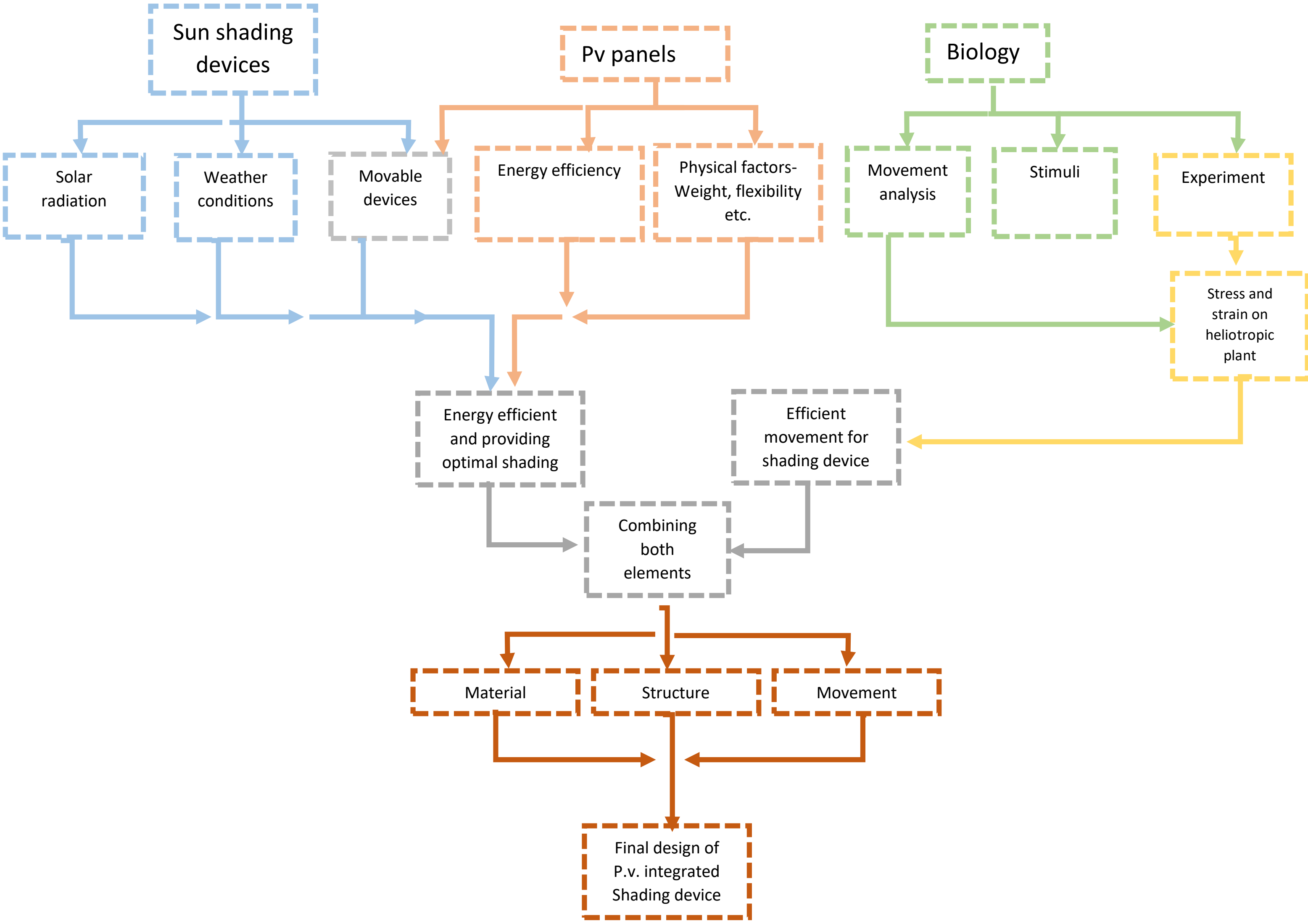


Table 1.5 shows the path taken to combine the different subjects and reach the final design of P.V. integrated shading device.

1.6 Timeline

This image below was the structure for completing the different tasks for the thesis. The first phase looks at the research phase the second aspect is the experimental phase followed by the design.

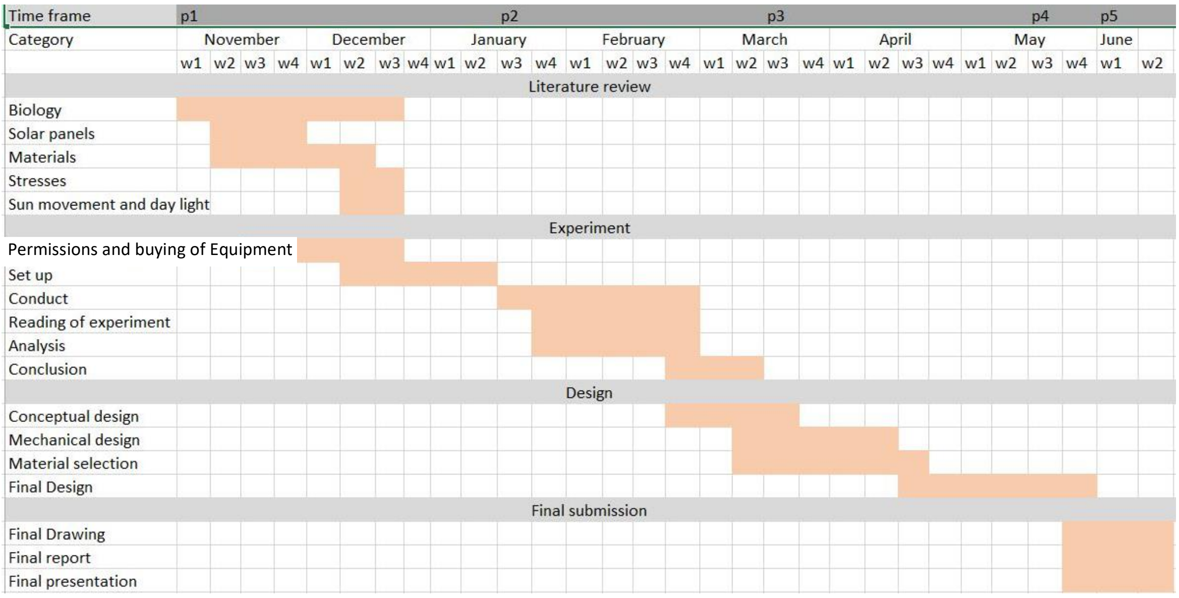


Table 1.6 Timeline for literature review, experiment, design and final submission

2. Literature study

P.V. panels and solar tracking devices

2. Research - Solar analysis

The sun dictates many aspects of human life. In 1876 William Grylls Adams and Richard Evans Day discovered that selenium produces electricity when exposed to light. This was developed into selenium wafers. Through various stages of research semiconducting materials that exhibit photovoltaic effect were developed into photovoltaic devices that convert light into electricity. In 1970 the first grid P.V. system enabled storing energy generated by the panels. In 1980 P.V. panels were designed such that they could be placed on rooftops. Since then 99% of the P.V. panels are found on rooftops and only 1% are integrated with buildings (Tilmann, 2020). This creates the opportunity to look into different surfaces and components in which the panel can be incorporated.

To understand the design of shading devices and P.V. panels one must first understand the source of solar radiation and the method of calculation.

2.1 Introduction

The earth rotates around an axis that is tilted at 23.45 degrees. It takes 24 hours for the earth to complete one rotation and 365.25 days to complete one revolution around the sun. The sun is the largest source of light on the earth's surface. The light and dark pattern of day and night is dictated by the rotation. The longer days during summer and shorter days during winter are dictated by the revolution of the earth around the sun. This affects the light and shade falling into the building and onto the building surfaces.

There is a wide range of electromagnetic radiation. The electromagnetic radiations include radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays. The wavelength and frequency are related to light and energy.

The shorter wavelengths with higher frequency have more energy and longer wavelengths with lower frequency have less energy (NASA,n.d.). This energy can be converted into heat and electricity.

Though there are different wavelengths some of them get absorbed before they reach the earth's surface. The portion of the atmosphere that sun rays go through depends on the clouds, fog, storms, etc. which varies the amount of light received on the earth.

The light from the sun is a form of energy and travels in a wave-like motion in one direction. In this waveform, the distance between identical or adjacent crests is called a Wavelength. The Amplitude is the distance between the top of the crest and the bottom of the trough. The amplitude determines the intensity or the brightness of the light. The higher the amplitude more the brightness (SCi center, 2000).

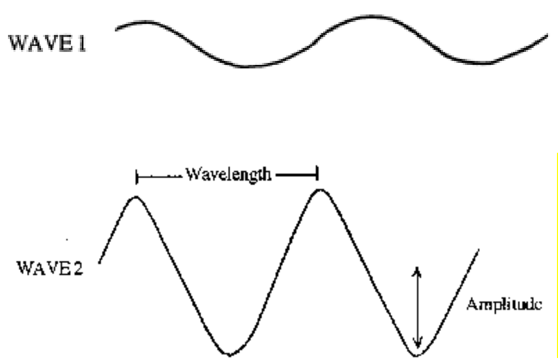


Image 2.1 Amplitude and wavelength determine the brightness of light Source: (light*,2018).*

2.2 Solar Irradiance and Luminance

The electromagnetic radiation from the sun is called solar radiation. The total amount of solar radiation energy received on a surface is called irradiation. The power over a unit area received in the form of electromagnetic radiation is called solar irradiance (NASA, 2008). The SI unit for solar irradiance is watt per square meter (W/m^2). The solar irradiance depends on several factors such as the tilt of the measuring surface, height of the sun, and atmospheric conditions.

Luminance is the brightness of an object as seen by the eye. The technical definition for luminous is the intensity emitted per unit area of a surface in a particular direction. The SI unit for luminance is candela per square meter (cd/m2). The luminous efficacy (lm/W) of a source is a measure of the efficiency with which the source provides visible light from emitted energy.

The solar cycle is responsible for the circadian cycle, which ranges from 23 to 25 hours based on the sunlight. The body clock synchronizes with the circadian rhythm of light and dark cycles. This cycle regulates sleep, body temperature, and blood pressure. The spectral intensity, timing, and exposure to the light effects how an organism reacts to the circadian rhythm (Jung, 2019).

2.3 Calculating the Sun's position

The sun's position has a great influence on the amount of energy generated. When the sun's rays are perpendicular to the panel it receives maximum intensity allowing more energy to be generated. If the panel is not perpendicular the efficiency reduces. For this reason, P.V panels use solar tracking methods to optimize their energy production.

The sun's position can be calculated. The sun moves from east to west as seen on earth. Further, the sun is at a higher position in the sky in the summer and a lower position in the sky in winter for the northern hemisphere.

The sun's position can be described at any point of the year, month, or day as shown below in image 2.3. Point c marks the position of the sun with respect to the magnetic south. Az measures the solar azimuth and α is the solar altitude angle. The solar azimuth can be measured by the angular distance between the 0 (which can be considered as the north) and the projecting line made from the sun's position. The solar altitude is the earth's angle in relation to the horizon. This can be calculated using a sun path diagram.

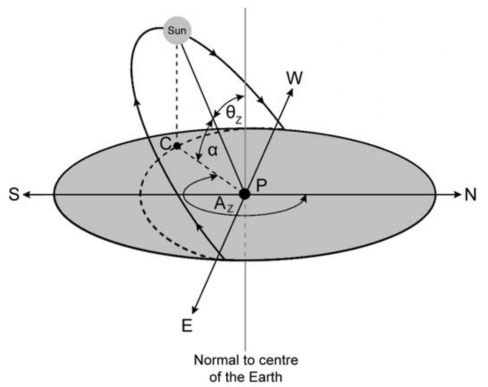


Image 2.3 Calculating the sun's position: Source: (Stuart*,2019).*

A sun path diagram is a chart that shows the solar elevation (also known as solar altitude) and solar azimuth (image 2.3.1) for a particular time and a particular month.

The chart seen in image 2.3.2 is a sun path diagram for delft. This can determine the sun's position throughout the year. A simple program developed by (University of Oregon, 2015) can be used to determine the sun path of any location.

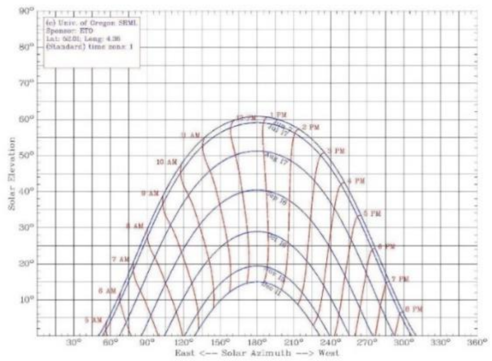


Image 2.3.2 Sun path diagram for delft Source: (O.Hory 2019)

In image 2.3.2 the red lines indicate the time. For example on June 7th at 7 am the Solar elevation is 20 degrees and the solar azimuth is 68 degrees east. From this chart, it can be inferred that, as the sun moves from east to west the solar elevation angle increase. It is at the peak when it is overhead and the values drop as the sun goes down. Also as the sun goes from the east to the west the solar azimuth increases as the solar azimuth is marked from a position in the east. Image 2.3.3 shows the sun's complete journey in a day on June 21 and December 21.

2.4 Solar and P.V.

Photovoltaic cells convert solar energy to electricity by semiconductor diodes that consist of a pn-junction. A Pn- junction is the boundary where two parts of a semiconductor meet. The p side contains excess holes and n side contains excess electrons. When the sunlight strikes the solar cells the photons are transferred to the silicon electrons in the pn-junction to free electrons. This flow of the free electrons through an external circuit generates the electric current. The energy created in a solar cell can be stored in generators and connected to grids. The amount of energy produced depends on the solar irradiance available.

For solar panels, the optimum range for maximum solar irradiance is between 380 and 780nm, which lies in the visible range as this is where the maximum irradiance lies as seen in image 2.4.

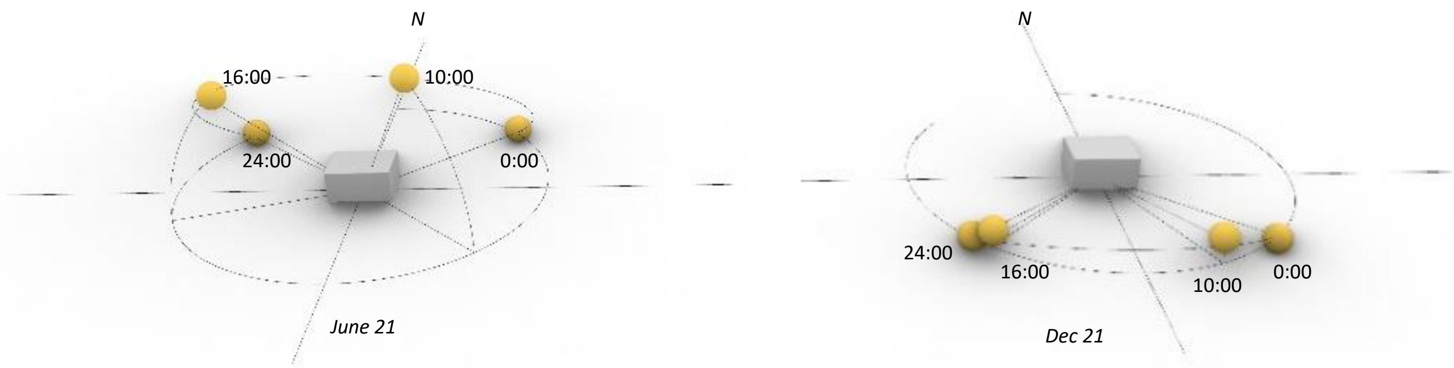


Image 2.3.3 Sun's position on June 21 and December 21 Source: Own work

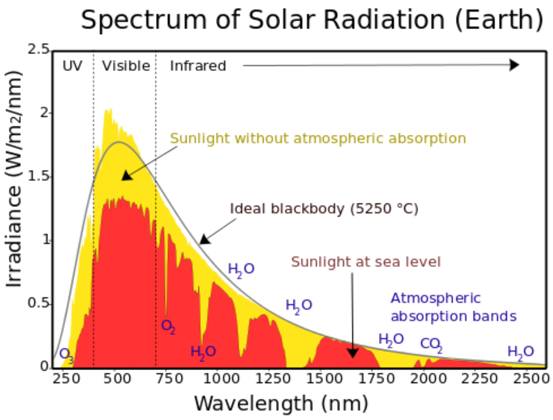


Image 2.4 Solar irradiance Source: (Stuart,2019).

The total solar irradiation is approximately 1000 kWh/m^2 per year in the Netherlands and 2200 kWh/m^2 per year in the Sahara. The peak energy gathered by P.V. cells is at this irradiation level. On cloudy days, due to the scattering of light in the atmosphere, solar irradiation is 50% - 60 % of its original value. The solar radiation in the summer is 7 times higher than what is available in the winter (Stuart,2019).

The amount of energy produced by P.V. panels also depends on the geographical location, weather conditions, seasonal conditions, etc. The efficiency of the panel increases if the panel is perpendicular to the sun's rays. To optimize the efficiency of panels solar trackers were designed to rotate the panel based on the sun's position. There are software's to calculate the sun's position.

2.4.1 Direction and tilt of P.V. panels

The sun's position can be easily calculated. This information can be used to calculate the optimum direction and tilt of the panel. It is also necessary to calculate the maximum amount of solar radiation received.

P.V. panels near the equator can be positioned parallel to the horizon. As the sun is at the same altitude throughout the year. In the northern hemisphere, P.V. panels face south and in the southern hemisphere, it faces north as they receive the most amount of radiation in this position. As the panel is placed further away from the equator the more the tilt of the panel.

The maximum solar radiation received by a panel is in June in the northern hemisphere as it is closest to the sun in this position (Honsberg, 2019).

When the absorbing surface of the P.V panel is perpendicular to the sunlight, the power density is at its maximum equal to that of the sunlight. Image 2.4.1 shows how the angle is calculated for the P.V. panel.

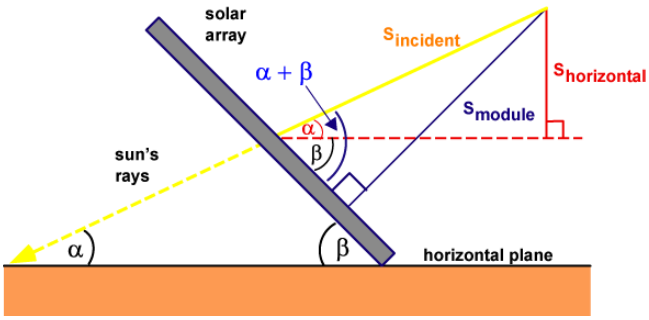


Image 2.4.1 Calculating the tilt of the P.V. panel Source : (Honsberg, 2019).

To calculate the angle the following equation could be used where α is the elevation angle and β is the tilt angle of the panel.

$$S_{module} = \frac{S_{Shorizontal}\sin(\alpha + \beta)}{\sin \alpha}$$

2.4.2 Solar azimuth and elevation diagram

The Solar azimuth and elevation have been explained in detail in chapter 2.3.

Date	21/06/20		21/12/20	
hour	Elevation	Azimuth	Elevation	Azimuth
6:00;00	20.56°			
7:00;00	29.74°	55.65		
8:00:00	38.93°	66.8		
9:00:00	47.66°	77.91°	0.61°	131.19°
10:00:00	55.18°	89.25°	6.87°	143.47°
11:00:00	60.24°	101.69°	11.49°	156.59°
12:00:00	61.34°	116.36°	14.12°	170.44°
13:00:00	58.03°	134.96°	14.52°	184.63°
14:00:00	51.51°	159.1°	12.65°	198.64°
15:00:00	43.24°	187.42°	8.69°	212.05°
16:00:00	34.2°	214.09°	2.96°	224.62°
17:00:00	24.97°	235.25°		
18:00:00	15.94°	251.58°		
19:00:00	7.46°	264.92°		

To find the precise position of the sun for a particular date and time there are many software tools available. The sun's position for delft is seen in table 2.4. Using the software (sun earth tool, 2018) the sun's position was calculated for two days. The first condition is during the summer in 21/06/2020 and the second is a winter conditions 21/12/2020. June 21st is the longest day on the northern hemisphere when the sun shines for 16 hours and 16 minutes, and on December 21st is one of the shortest days when the sun shines for 7 hours and 77 minutes. This huge variation plays a role in the amount of solar radiation falling inside the building.

2.4.3 P.V. Angle for the Netherlands

The optimum angle for maximum power generation for on-grid PV panels (on and off grid explained in 2.7) in the Netherlands for a stationary P.V. panel is 36 degrees from the horizontal facing the south direction. If the P.V. panel is facing south an inclination from 15 to 57 degrees will ensure the efficiency of 95% (Broersma, 2008).

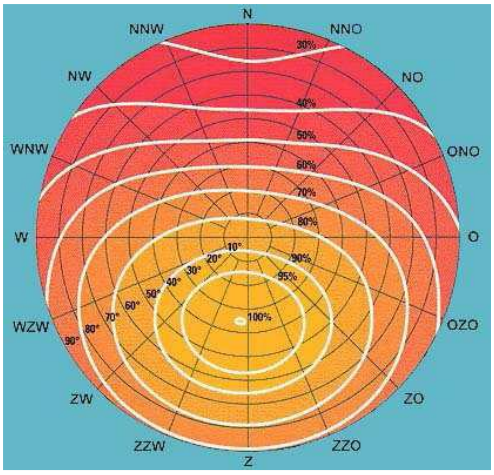


Table 2.4 Data showcasing the elevation and azimuth of the sun in the Netherlands. Source: (sun earth tool, 2018)

Jan	Feb	Mar	Apr	May	Jun
22°	30°	38°	46°	54°	62°
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
54°	46°	38°	30°	22°	14°

Table 2.4.4 showcasing the angle of tilt in relation with the month.

The orientation of the panel also plays an important role. Figure 2.4.3 shows the relation between the direction of P.V. panel tilt and efficiency. As the P.V. panel is turned in a direction away from the south towards the north the efficiency reduces as the rays are not perpendicular to the panel

Detailed calculations for the angle of tilt can be made. Table 2.4.4 is the summarized values of the angle of tilt of P.V. panels through the year (Boxwel, 2019). These values are the optimum tilt angles from a vertical surface for P.V. panels in Rotterdam.

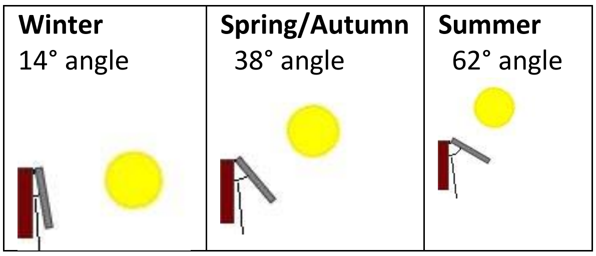


Image 2.4.5. showcasing the angle of tilt in relation with the month. (Boxel, 2019)

2.5 Parts of a P.V panel

A typical P.V panel is made of the components listed below. Image 2.5 shows the different layers (Svarc, J. ,2020).

1. Aluminium frame: This is a lightweight frame that holds the layers together. It protects the panel from external stresses and forces such as wind. There are different types of frames with different levels of stiffness that can be pressed, clamped or screwed together.
2. Tempered glass: The glass protects the P.V. cells from harsh weather conditions. The glass thickness varies based on the type. The general thickness is 4 mm. Tempered glass is used as the glass does not shatter and affect the P.V. cells if broken.
3. Encapsulant EVA – This is an ethylene vinyl acetate that encapsulates the solar P.V. cell. This layer is durable in extreme temperature and humidity. It prevents moisture and dirt from affecting the solar cell.
4. Solar P.V. cells- There are two main types monocrystalline and polycrystalline silicon. They are responsible for converting sunlight into direct current. The P.V. cells consist of a positive p-type positive silicon and n-type negative silicon which allow the electrons to jump and create a current.
5. Junction Box- The junction box is located behind the panel. It has a diode which is connected to the solar cell and allows the current to flow in only one direction. They also ensure that the current does not go back to the cells.

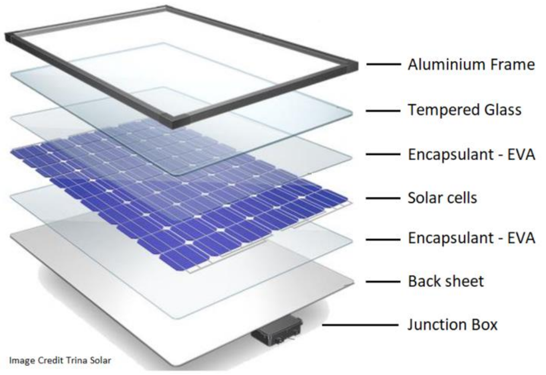


*Image 2.5. Parts of P.V. panel Source (*Svarc, J. ,2020).

2.5.1 Types a P.V. panel

P.V. panels come in all sizes, shapes colour, and different amounts of transparency. All these attributes affect the efficiency and cost of the panels. The common types of P.V. cells are mono-crystalline silicon, polycrystalline silicon, thin film, and third-generation organic P.V.s cells. The properties of the three main types of panels are compared in table 2.5.2.

Mono-crystalline	Poly- crystalline	Thin Film
Cut from one piece of silicon	Made of a blend of silicon	Thin conducting layer deposited on a glass or plastic
Maximum energy output per m^2 (efficiency 20%)	Medium energy output per m^2 (efficiency 15%)	Minimum energy output per m^2 (efficiency 13%)
Heavy weight (10 kg/m^2)	Medium weight (8 kg/m^2)	Light weight (0.46 kg/m^2)
Rigid	Rigid	Flexible
Expensive – 0.45 cents per watt	Medium - 0.22 cents per watt	Expensive – 0.5 cents per watt

Table 2.5.1 Types of P.V. panel Own work

2.5.2 Measurement of P.V. energy

Solar energy is converted to electrical energy by the P.V. cells. Therefore the unit of measurement for P.V. panels is watts. Each P.V. cell is 6 inches by 6 inches (approximately 152mm*152mm). Each one of these cells produces a voltage of 0. 3- 0.6 V. Multiple cells are joined together to form on the P.V. panel. If 36 cells are joined they give a voltage of 12 Volts. The voltage(V) fluctuates based on the irradiance of the cell. The current (I) produced by the cell is dependent on the light intensity.

The power(P) of one P.V. cell is measured by the formula:

$P = V \times I$

For a typical P.V. cell it has a Voltage of 0.46 and a current of 3.

$P= 0.46*3 = 1.38$ watts.

A typical P.V. panel with 36 cells is connected in series to a 12-volt battery. This gives an output of 20.8-volt peak output. If this solar panel generates 100 watts it will take 6-8 hours of full sunlight to recharge this 12-volt battery. Further, in the Netherlands one household uses 3400 kWh per year, (Rijksdienst Voor Ondernemend Nederland, n.d) this would then require P.V. panels of a surface area of 43 m^2.

The efficiency of the panel is measured by “the ratio of electrical power outlet to the input of energy from the sun” (Honsberg, 2019). The other factors that affect the efficiency of a solar cell are the intensity and spectrum of sunlight. According to the Standard Test Conditions (STC) if a panel is stated at 15 % efficiency, then it must produce 150 watts with $1m^2$ of the surface area according to the following conditions. The panel is placed in a position such that the light hitting the panel is incident on a day when the irradiance of 1,000 W/m2and the temperature is 25°C. (Honsberg, 2019)

2.5.3 Maintenance of P.V. panels

P.V. panels come in all sizes and shapes. These panels need protection as they are fragile. The glass and the frame of the PV panel plays an important role. Further, P.V. panels get dirty due to the rain, dust, snow, etc. Cleaning the panels will increase their efficiency. The panels should be placed such that they are accessible from the outside. The P.V. panels must also have direct access to the junction box. The wiring of the device plays an important path as it should not be placed in an area where it can snap or be cut.

2.6 Types of solar trackers

Solar tracking systems can collect up to 50 % more energy than fixed P.V. panels, as tracking the movement of the sun to allow incident light to fall directly on the panel (Mateo, 2018). Direct solar irradiation provides more energy in the P.V. cells. There are three main types of solar trackers:

1. Manual solar trackers – This is when the P.V. panel is physically rotated.
2. Passive solar trackers – These are trackers that use a thermal expansion of liquid or gases to tilt the P.V. panels.
3. Active solar trackers – These consist of motors or hydraulic cylinders that are connected to a system that has a pre-programed algorithm that moves the panel based on calculations of the sun. These active trackers are divided into two parts one where it rotates on a single axis the other where it rotates on a dual axis.

2.6.1 Types of movement in solar trackers

Solar tracking devices are mostly divided into two types, single-axis and Dual-axis. The P.V. panel is generally placed on a rotating arm to increase the energy generated. A fixed horizontal P.V. panel can produce up to 784 kW/year. But if a panel is inclined to 36 degrees it could provide up to 959 kW/year. A single-axis tracking system could provide up to 1012 KW/year. However, a dual axis could provide around 1218 – 1300 KW/year. (Broersma, 2008). Table 2.6.1 shows the different types of solar tracking systems and their features.

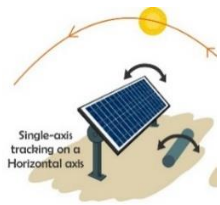
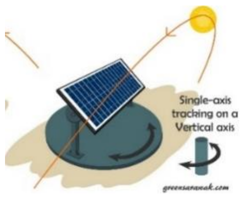
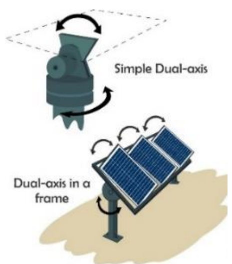
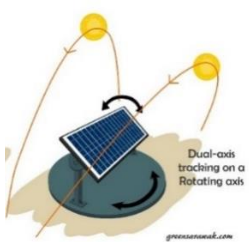
Sun tracking system	Image	Tracking characteristics	Features
Single axis Horizontal tracker		Follows the position of the sun from east to west.	Simple system with side support. Suited for lower latitudes where the sun is higher. Is not supportive of seasonal changes.
Single axis Vertical tracker		Tracks the position of the sun from east to west.	Placed on big vertical units. Suited for higher latitudes where the sun is lower. Is not supportive of seasonal changes.
Single axis Tilted tracker		Fixed at a particular angle and moves around an axis.	Good for high and low latitudes. Has better efficiency when compared to other single-axis tracking devices. Difficult installation.
Dual Axis tracker in a frame		Tracks the altitude and azimuth of the sun. The panels individually rotate east to west. This frame can also change its angle catering to the change in altitude.	Higher efficiency of P.V. cells as the panel can be placed incident to the sun rays. High cost, the problem of partial shading, difficult to integrate with buildings.
Dual Axis tracker in a frame		Tracks the altitude and azimuth of the sun. The panels rotate with the frame to move with the change in altitude. The base of the panel rotated to encounter the east to west movement.	Higher efficiency of P.V. cells as the panel can be placed incident to the sun rays. High cost, the problem of partial shading, difficult to integrate with buildings.

Table 2.6.1 Different types of movement in solar trackers. Source: (Lane,2020)

2.6.2 Components of a dual axis frame P.V. panels

A dual solar axis consists of several components. It consists of a sensor that is attached to a control box that monitors the movement of the panel. The panel is held by a steel case. The rotation of the rotatory system consists of a worm gear drive. The worm gear drive is connected to a circuit that feeds information on the angle of the panel. This gear is prone to wear and tear. (mtm scientific, n.d.)

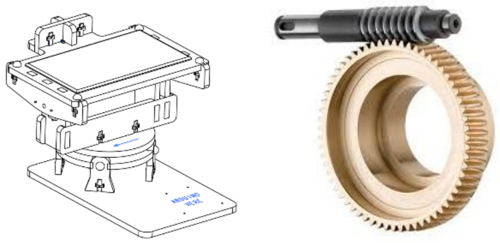
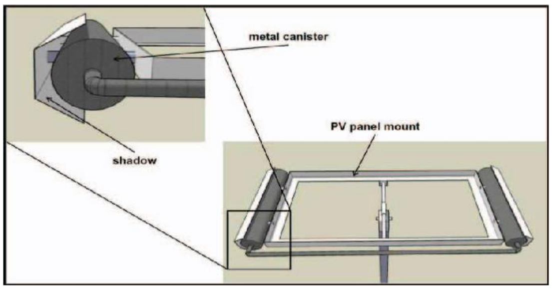


Image 2.6.2 dual axis frame and worm gear. Source: (mtm scientific, n.d.)

2.6.3 Passive solar systems

Passive solar systems are devices that do not contain any gears. It consists of two canisters that is pivoted on a frame. There is a conduit between the two canisters. The canisters contain a volatile fluid that is in vapour form. The fluid used is Freon-12 as it has a low boiling point of -26.3 degrees.

When the sun is in the east, the fluid moves into the east canister tilting the panel towards the east. When the sun moves towards the west the fluid flows into the west canister tilting the panel to the west. The frame has an equal amount of liquid when the sun is overhead. This can be seen in image 2.6.3. The problem is that the panel takes time to re-orient itself to the east in the morning as the previous day it was facing west. This causes the panel to lose energy. The system also has shock absorbers to protect from the wind. It produces more energy than a fixed tracker. There is no maintenance cost involved. (Hombale, 2015)



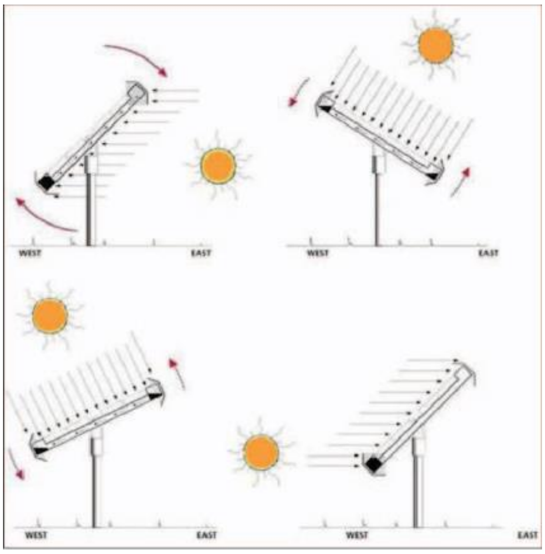


Image 2.6.3 Passive solar system Source : (Hombale, 2015)

2.6.4 Off grid and on grid energy systems

An on-grid energy system is connected to a utility grid. An off-grid energy system is not connected to a utility grid.

In an on grid system, the excess energy is connected to the grid. In this manner there is a constant supply of energy and one does not need to depend on solar energy for all the requirements of the house.

The energy produced by the off grid system can be stored in a battery and can make the house sustainable without being reliant on additional energy.

2.7 Shading devices

Windows are built to allow light and ventilation into the room. Intense solar radiation can cause internal spaces to heat up making the space uncomfortable. The increase in heat increases the energy used by a cooling device. To reduce the excess heat in a building passive shading devices were added to the exterior of the building.

There are two types of shading devices, interior, and exterior. Interior devices consist of curtains, blinds, internal louvers etc. These reduce the daylight and are not as efficient as external devices to reduce the heat gain from solar irradiation (Ylenia, 2009). This solar gain within the building is dependent on the location of the building. In the Netherlands, there is excess heat in the summer and the device should block the rays. However, in the winters it is favourable to have the sun to heat the building. A moving shading device that adapts to these requirements is seen in image 2.7. The solar gains within the room can easily be calculated through different software.

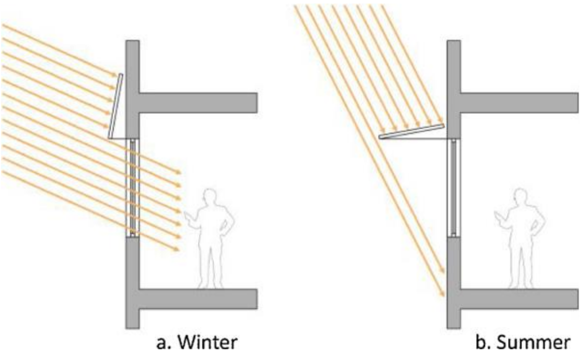


Image 2.7 to showcase the movement of shading devices for summer and winter. Source: (Meysam, 2020)

2.7.1 Types of shading devices

Shading devices come in all shapes and forms. The most common shading device is an external shading device. However, there are other shading devices such as reflecting surfaces, landscape units such as mounds, trees, hedges, etc.

External fixed shading devices have been seen in Ancient Greece since 800 B.C as projecting slabs. These devices are more effective than internal shading devices as they help reduce the cooling load in a building. The length of the overhang plays a crucial role in determining the amount of radiation allowed into the building. The length of the overhang plays an important role in daylight and glare inside the building. The image shown below is suitable for buildings in temperate climate. The length of the overhang is sufficient to block the sun at a higher altitude in the summer. It allows the full sunlight in the winter when the sun is at a lower altitude allowing the room to heat up.

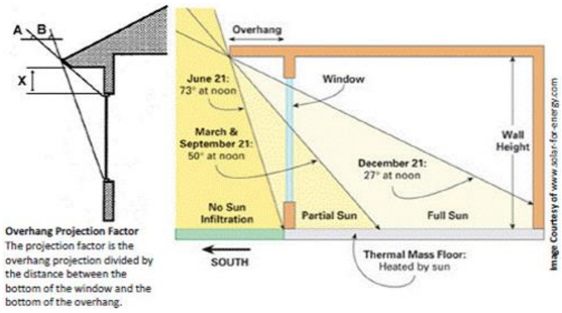


Image 2.7.1 Ideal length of overhang in temperate climates Source (Donald, 2016)

Further, in external shading devices, different types of shading devices are designed to block different positions of the sun. In table 2.7.1.1 the different types of shading devices are seen.

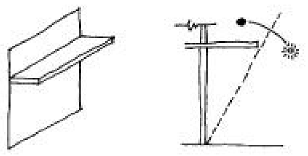
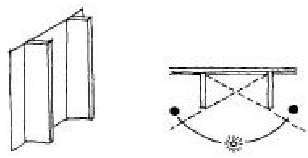
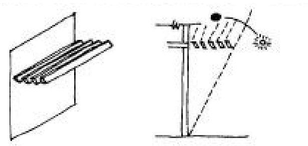
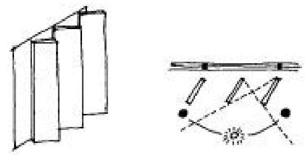
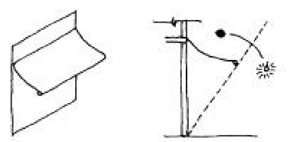
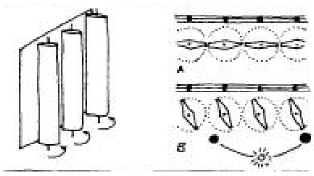
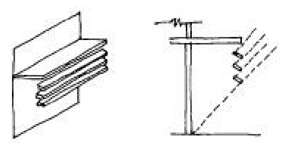
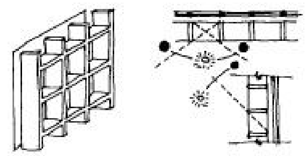
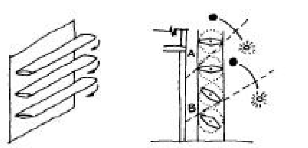
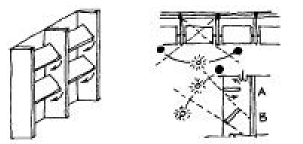
Horizontal fixed shading device	Description	Vertical fixed shading device	Description
	A typical overhang shading device blocks the sun at a high altitude		Vertical shading devices block the sun at the extreme azimuths.
	Fixed horizontal fins placed at an angle. This allows streams of light into the room.		An inclined vertical surface can allow the sun inside the building partially.
	A retractable canopy allows diffused light to enter the room.		Rotating vertical fins are efficient in blocking the sun whenever required.
	Drop down vertical fins from an overhang, They prevent the sun from coming in at a lower angle.		Honeycomb shading devices can block the sun at different azimuths and altitudes.
	Rotating horizontal fins can block the sun at different altitudes		Honeycombs with rotating fins are more efficient in blocking the sun

Table 2.7.1.1: Types of shading devices. Source: (Monroe,2004)

In the Netherlands, the warmer months are between April to September and the colder months from October to March. The overhang should therefore block the sun between April to September during this period the altitude of the sun is between (42.82- 45.92 degrees) and in the colder months from October to March the sun can be allowed in, the altitude of the sun is between (34.27- 30.77 degrees). Assuming that the window is on the south-facing wall. The window is of a height of 1.2 meters and a width of 1.5 meters. The length of the overhang can be easily calculated. Table 2.7.1.2 looks at the performance of a shading device on June 21 and December 2.

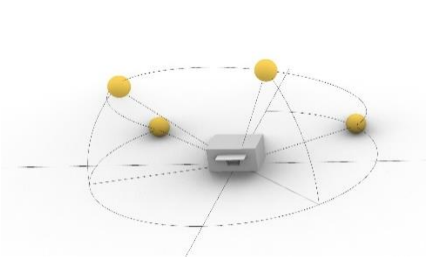
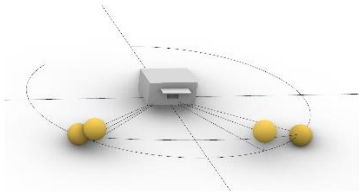
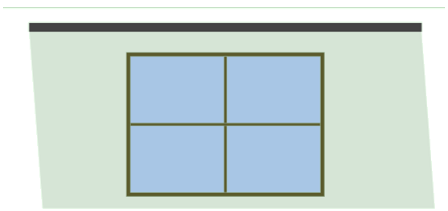
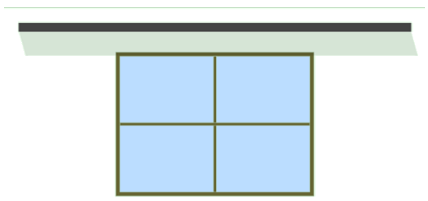
	June 21	December 21
Position of sun		
	As seen in the image above the sun is at a higher position and the maximum radiation is on the roof and overhang.	As seen in the image above the sun is at a lower position and the maximum radiation is on the façade and light is seen traveling inside the room.
Shading device analysis using susdesign tool		
	Analysis of the length of the overhang to ensure that the sun falling on the window is blocked. A length of 3 meters is taken here to provide optimal shade.	Analysis of the depth of the overhang to ensure that the sun is allowed into the building. A depth of 0.75 m is optimal.

Table 2.7.1.2: Comparison of shading device on June 21 and December 21.

The tool Sus design provides a deeper analysis of a monthly and hourly analysis of the shading percentage and heat gain by the overhang. The shading percentage is the percentage of the window that is shaded. As seen in 2.7.1.3 the first image. There is a higher percentage of shading from April to September between 9:00 to 16:00. These values are desirable as we need to protect the interior of the building from the harsh rays. The second image showcases the amount of solar heat gain through the window during the entire month. The maximum heat gain is between October to March between 10:00 to 14:00. Due to the short daylight hours in the winter, this is the best possible outcome.

	MORNING									AFTERNOON								
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	MONTHLY	
Jan						4%	2%	20%	21%	20%	15%	4%						Jan	12%
Feb					5%	2%	36%	40%	41%	40%	36%	23%	5%					Feb	25%
Mar				7%	23%	48%	64%	67%	68%	68%	64%	48%	23%	8%				Mar	44%
Apr			20%	19%	37%	64%	80%	83%	83%	83%	80%	64%	38%	19%	20%			Apr	53%
May		20%	17%	16%	37%	62%	75%	77%	78%	77%	75%	62%	37%	16%	17%	20%		May	46%
Jun	22%	19%	16%	16%	31%	57%	70%	74%	74%	74%	70%	57%	31%	16%	16%	19%	22%	Jun	40%
Jul	23%	20%	17%	16%	34%	59%	72%	75%	75%	75%	72%	59%	34%	16%	17%	20%	23%	Jul	42%
Aug		22%	19%	18%	39%	64%	77%	80%	80%	80%	77%	64%	39%	18%	19%	22%		Aug	48%
Sep			23%	14%	30%	58%	79%	82%	82%	82%	78%	58%	30%	14%	23%			Sep	50%
Oct				5%	12%	3%	2%	50%	51%	50%	47%	33%	12%	5%				Oct	25%
Nov					2%	10%	2%	26%	27%	26%	21%	9%	2%					Nov	14%
Dec						2%	9%	15%	16%	15%	9%	2%						Dec	10%
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	ANNUAL	
	MORNING									AFTERNOON								34%	

	MORNING									AFTERNOON								
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	MONTHLY	
Jan						6.4	14	14.7	15.4	14.7	12.2	6.3						Jan	84
Feb					3.9	10.9	10.3	11.4	11.8	11.4	10.3	8.5	3.9					Feb	82
Mar				1.5	5.8	7	6.4	6.7	7	6.7	6.4	6.9	5.8	1.5				Mar	62
Apr			0.4	1.5	3.7	3.9	2.9	2.9	3	2.9	2.9	3.9	3.7	1.5	0.4			Apr	34
May		0.3	0.9	1.6	2.8	3.3	3.1	3.4	3.5	3.4	3.1	3.3	2.8	1.6	0.9	0.3		May	34
Jun	0	0.6	1.1	1.7	2.5	3	3.1	3.4	3.5	3.4	3.1	3	2.5	1.7	1.1	0.6	0	Jun	34
Jul	0	0.4	1.1	1.7	2.6	3.2	3.2	3.5	3.6	3.5	3.2	3.2	2.6	1.7	1.1	0.4	0	Jul	35
Aug		0	0.7	1.5	3.2	3.6	3.1	3.3	3.4	3.3	3.1	3.6	3.2	1.5	0.7	0		Aug	34
Sep			0	1.6	4.7	5	3.5	3.3	3.5	3.3	3.5	5	4.7	1.6	0			Sep	40
Oct				0	5.3	12.3	17.1	10.2	10.6	10.3	9.4	8.4	5.3	0				Oct	89
Nov					0	7.4	14.4	13.6	14.2	13.6	11.6	7.4	0					Nov	82
Dec						3.7	11.2	14.4	15.2	14.4	11.2	3.7						Dec	74
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	ANNUAL	
	MORNING									AFTERNOON								680	

Image 2.7.1.3 The first image shows Shading percentage the second image shows Heat gain.

2.7.2 Active shading devices

Active Shading Systems are devices that respond to heat, daylight, ventilation, or energy generation. These systems can be internal or external systems and respond to various stimuli through sensors and controls or through smart technology. These systems help improve the energy efficiency of the building by mechanically controlling the movement to allow or block solar radiation into the building. Active shading devices are mainly divided into smart glazing, external kinetic shading devices, and renewable energy-generating shading devices. The kinetic shading devices include rotating and folding systems. The renewable energy generating shading devices include shading devices with PV, facades with algae that can generate electricity or through its collectors. (Joud, 2017)

2.8 P.V. integrated shading device

The building surfaces are a good space to generate electricity. P.V. facades are becoming a common phenomenon as they are an easy source for electrical generation and are called Building Integrated P.V. (BIVP).

Currently, in the Netherlands, only 0.04% of the potentials of BIVP have been used. They can reduce the cooling load by up to 10%. The BIVP can be used on roofs, façade cladding, and shading devices.

A survey conducted by (Xiang,2018) on BIVP shading devices showed that the electricity produced from a south-facing device had an efficiency of 12%. A BIVP shading device used in Indonesia showed a 35% reduction in the electrical energy consumed.

2.8.1 Case study

One example of this is building 31 that was renovated by bear architects in the Netherlands. To prevent the building from overheating, the south façade is covered with a BIVP shading device. To make it more efficient there is the distance between the panels which diffuses the sunlight getting into the building. The PV from this façade and the roof will produce 56,400kWh per year. Which reduces the overall demand for the building (Reijenga, 2018).

Image 2.8.1 South façade of building 31. Source: Reijenga, 2018

2.8.2 Movement of panels

The key aspect in the performance of the BIVP shading device is its inclination to the sun. These systems can be made even more efficient if they track the sun.

A louver system can be used to change the angle of the panel. This is the simplest method. This can be automated or manually done. An automatically controlled system has sensors that detect the sun’s position. Then a signal is sent to the motor that controls the movement of the louver. The louvers move in an up and down manner based on the commands it receives. The panels should also be designed such that louvers do not overshadow each other. Dust accumulation in the grooves of the louvers restrict the movement of the louvers. Due to the rain, moisture gets trapped in the hinges of the louver is prone to rust.

Another example of BIVP shading device is the use of hybrid actuators. These devices are 50% more efficient than stationary P.V. panels.

They have a sensor that determines the orientation of the panel. It uses a thin-film PV panel and a dual-axis soft actuator to move the panel.

The actuator is made of corrugated chambers of Neoprene rubber and has a metal holder that is attached to the thin film. The centre of the structure is hollow in the centre to allow cables from the P.V. panels and the sensors to pass through them. They are suitable for harsh weather conditions. However, the structure can hold only thin-film panels. It cannot carry panels with large loads. These systems are expensive and are not affordable for everyone (Nagy et al., 2016).

2.9 Existing mechanical systems

The existing rotational system was studied in more detail to understand all the components in the rotatory mechanisms. The key component is a motor. The motor consists of a circuit and an electromagnet. When an electric current passes through a wire to the electromagnet it turns and converts electric energy into mechanical energy (Jared Owen, 2020).

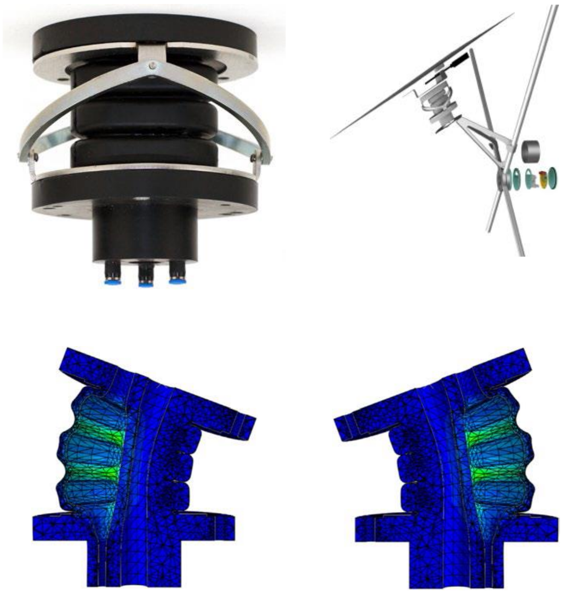


Image 2.8.2 Movement of Actuators Source: (Nagy et al., 2016)

Image 2.9 shows a rotor that has an electromagnet inside and is connected by wires to produce a rotational movement. This rotor has an axel to which there are gears that help in the turning. For a shading device, a similar rotatory machine is used. It utilizes 120V and 1.6 amps, which is 192 Watts. (North Solar Screen LLC, 2021)

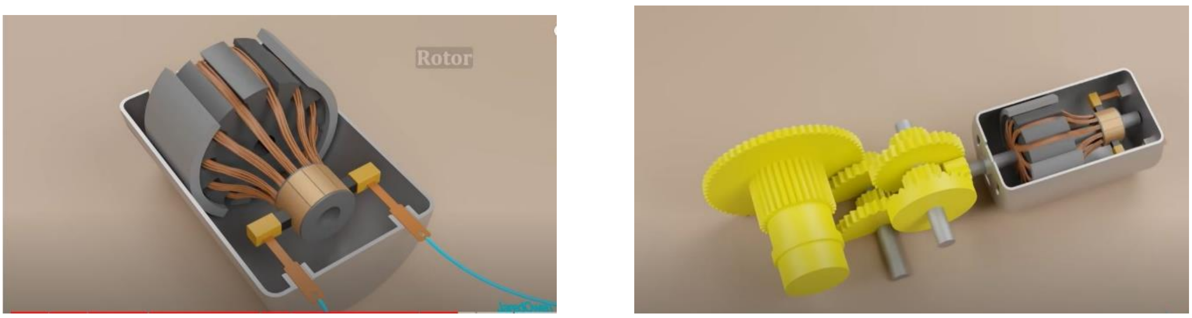


Image 2.9 Movement of Actuators Source: (Jared Owen, 2020)

2.10. Problems P.V. integrated shading device

The problems are divided into two parts for P.V. panels and shading devices.

2.10.1 P.V. panels

P.V. panels come in all sizes and shapes. Having smaller P.V. panels will help reduce the load on the rotating mechanism. However, if the panels' are too small they create a shadow on each other. In a solar panel with 36 cells, if one cell is shaded it can reduce the power output by 75% as stated by (Brown, 2021). Image 2.10.1 shows different P.V. panels shading each other. The cells are connected by a link and the energy output is dependent on the weakest link. Therefore it is not advised to have smaller PV panels.

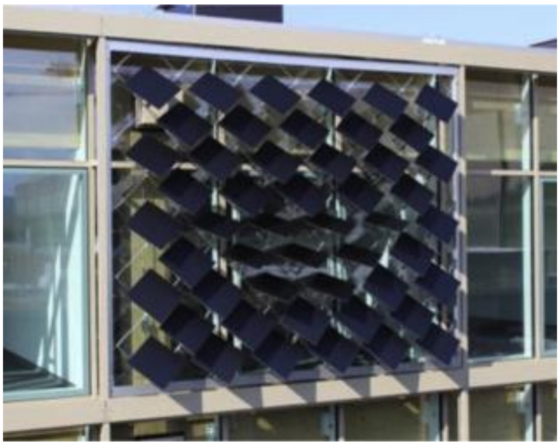


Image 2.10.1 of P.V. panel shading each other. Source: (AnolisRE, 2012)

2.10.2 Shading device

In shading devices, the most common problem is the rotational system. These motors often fail due to the many components. The gear systems are complicated, heavy, and bulky with many interconnecting parts that may fail. They also consume immense energy to rotate the system. Most manufacturers have a warranty of 5 years for rotational shading devices (Krarti, 2021).

2.10.3 P.V. integrated shading devices

There are very few commercial manufactures that specialize in P.V. integrated devices. There are a few research papers and tests done in laboratories. But there is no wide-scale application of this device. Therefore it makes it difficult to assess the advantages of disadvantages of a P.V. integrated shading device in the market. However, the main concern in a P.V. integrated shading device is the rotational system (Krarti, 2021).

2.11 Climate change.

Climate change also plays an important role in the requirements of shading devices. As temperatures rise, the shading devices will act as an important respite from the heat.

2.12 Conclusion

Shading devices can reduce the cooling load of the building by 35%. In temperate climates, the shading device should shade the opening of the building to prevent solar radiation from heating the interior of the building. Whereas in the winter the solar radiation provides heat to the room which reduces the heating and cooling load.

The amount of solar radiation falling on the shading device or in the room is dependent on the position of the sun which and can be easily calculated at any time of the day using the (sun earth tool, 2018). In the summers the sun is at a higher altitude whereas in the winters the sun is at a lower altitude. This change in the Sun’s altitude can help design shading devices that allow the sun in winter and block the sun in the summers.

Solar radiation plays a key role as it carries energy. The energy can be used to generate electricity in P.V. panels. P.V. panels come in all sizes shapes and forms. Monocrystalline is the most efficient but the most expensive, heavy, and least flexible. Whereas thin film is the least efficient but lightweight and flexible. The efficiency of the panel also depends on other factors such as the tilt of the panel.

In the Netherlands, there is a solar radiation of 1000 kWh/m2*year which is sufficient to harvest solar energy. Solar energy has advanced in history and has been optimized to be extremely efficient. Solar panels are the most efficient when inclined to the sun. In the Netherlands, a fixed panel's optimal tilt is 37 degrees. However, for single-axis panels the optimal tilt ranges between 62 degrees and 14 degrees based on the altitude of the sun. For more efficiency, P.V. panels can be designed on a dual axis system. This allows the P.V. panel to move in two directions, to take care of the changing azimuth and altitude. Further, the orientation of the panel also plays an important role. For panels in the northern hemisphere orienting the panel towards the south is more efficient as it can harvest the solar energy from morning to evening.

Active solar trackers used computed values of the sun to track it and feed to a machine that rotates to the required angle. Many of these systems contain gears that are prone to wear and tear and require high maintenance. These systems are bulky and large and the rotating system is the weak point in this system. Louver based solar tracking systems collect dust and cannot withstand heavyweights. Actuators can only hold thin-film panels that do not produce sufficient energy. Passive solar trackers are not efficient as they cannot track the morning sun and take time to turn in the morning from west to east.

A P.V. integrated shading device needs to consider the requirements of a P.V panel and a shading device.

There are limited studies of P.V. integrated shading devices. As it is relatively new to the market it has not been used commercially in many projects. Therefore the complete life cycle of the panel is not tested.

3. Literature study

Heliotropism

3. Biological understanding of tropism

Tropism defined by (Gilroy, 2008) is a "directional growth in response to a directional stimulus". This growth can either be towards or away from the stimulus. Plants have a large range of sensory systems that respond to their environment. The different types of stimuli are light, gravity, minerals, temperature, atmospheric components, etc.

When a plant moves towards the light it is called phototropism. Phototropism is a form of tropism. Positive phototropism is when the plant moves towards the light. Whereas, negative phototropism is when the plant moves away from the light. Positive phototropism is often seen in most plants. When a plant is kept in a dark room with a small sliver of light, you see the plant moving towards it. This is an example of positive phototropism.

Similarly, heliotropism is a form of tropism where the plant reacts to the direction of the sun in a diurnal motion (daily cycle). The sunflower head is seen moving from east to west during the day. In the night the head moves from west to east, this is to ensure that the sunflower can repeat this movement the next day. This phenomenon can also be seen in marigolds, buttercups, arctic poppies, and ranunculus adoneus.

3.1 Phototropism

This is a process that occurs in most plants, where the plant moves towards a light source. The plants have sensors at the tip, this tip senses the direction of the sun and determines the side of the plant facing the sun. The plant then releases a hormone called auxin. The auxin is distributed as a gradient along the stem. More auxin is distributed along the shaded part of the plant. This hormone lowers the pH level in the cells and breaks the cell wall. This causes water to enter the cell and increases the turgor pressure elongating the cell (Atamian et al. 2016). As seen in the images below 3.1.1, The cells in the shaded region elongate, and the cells in the cells in the light retain their size. As the cells elongate on one side, it forces the stem to bend.

This phenomenon was first discovered by Charles Darwin (DARWIN, 1881), he conducted an experiment where he covered the tip of one plant with a foil and let the other one grow normally. He placed the plant in a room with the light source towards the right. The plant without the foil bent to the light source (to the right). The plant that was covered in foil grew vertically upward. This proved that the plant tip is where the sensor is located.

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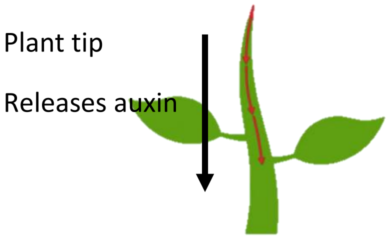
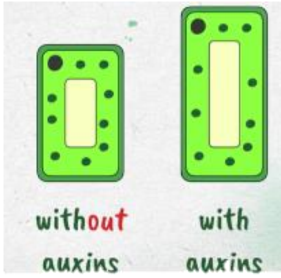
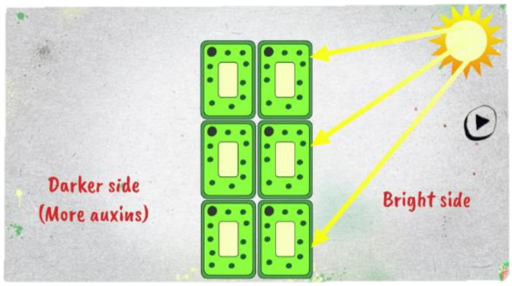
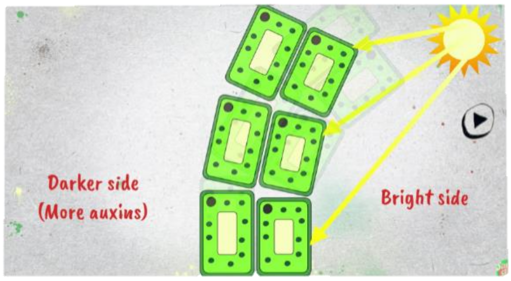
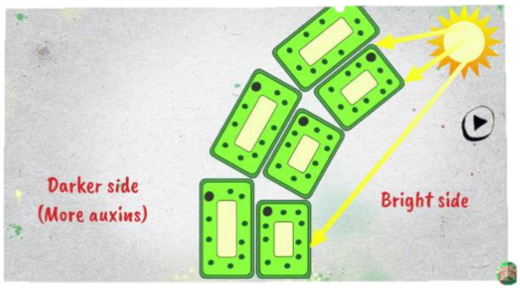
<tr><td>
</td><td>
</td></tr>
<tr><td>The plant senses the light and releases the auxin hormone down the stem.</td><td>One cell without auxin and the other with auxin.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Step 1 the plant senses the light and releases a gradient of hormone called auxin</td><td>Step 2 the auxin is distributed such that there is more auxin in the plant cell where it is darker. The auxin elongates the cell as explained in 3.1</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>Step 3 Position of stem during the east position</td></tr>
</table>

Image 3.1.1 shows the bending of plants source: (Science Sauce, 2020)

3.2 Heliotropism

This phenomenon was also studied by Charles Darwin. Heliotropism is a form of tropism where the plant reacts to the direction of the sun in a diurnal motion (daily cycle). This phenomenon seen in flowers like the sunflower is called floral tropism.

During the day the eastern part of the stem elongates forcing the flower head to move towards the west. During the night a similar process happens. The stem on the west elongates turning the head of the sunflower back to the east for the morning

This movement is guided by the pulvinus. The pulvinus is the swollen part that occurs at the back of the stem or leaf. It acts as a sensor that guides the movement of the plants. When the pulvinus is exposed to light it forms an asymmetrical gradient of hormones that change the turgor pressure. The hormone causes an influx of potassium and chlorine ion on one side which causes the cells to increase in size and increase the turgor pressure. The turgor pressure is the force within a cell that pushes the plasma membrane against the cell wall (Lee, 2014).

Some theories state that the rotation in sunflowers happens due to the circadian rhythm. Further, The gynoecium is a heliotropic plant, where the plant tracks the sun and rotates the flower to avoid the centre of the flower to heat up.

3.2 Circadian Rhythm.

The circadian rhythm is a natural process that is based on the earth's 24-hour cycle. It is an internal process that regulates the sleep and wake system in humans. The system also regulates brain waves, cell generation, hormone production, and other activities. This phenomenon is observed in plants, animals, fungi, and bacteria. The sunflower has an internal circadian rhythm clock that guides the stem movement from east to west. In the night it guides the flower from west to east to be prepared to continue this movement the next day. It is called a Diurnal rhythm when the flowers complete an oscillation in 24 hours.

3.4 Plant and light spectrum.

During photosynthesis, plants use light and convert it into chemical energy. Due to this reason, plants need to detect the source of light. There are photoreceptors in plants that are covalently bonded to a light-absorbing pigment called chromophore according to(lumen learning ,2018). These photoreceptors absorb light in particular regions of the spectrum. Tests have shown that blue light allow plants to sense the direction of the sun and the amount of sunlight. The wavelength that the plants respond to are from the wavelength of (290–500 nm). This is why it is commonly stated that blue light and Uv light evoke phototropic responses. The red light also plays an important role in the growth of the plant.

Detection of the seasons plays an important role in plants as that can determine the flowering seasons. Temperature is a good indicator, but plants use the length of the day to determine the time of year. The photochrome a type of photo receptors have two form Pr and Pfr. Pr is the active state that absorbs red light (670 nm) and Pfr absorbs far red light (730 nm). Sunlight is rich in red light but deficient in far red light. In the night the plant converts active Pfr to Pr. This is a slow process. In the summer when the nights are shorter than the winter all the Pfr are not converted to Pr. Based on the amount of Pfr and Pr the plant senses which time of the year (Lumen learning ,2018).

3.5 Movement of a sunflower

The sunflower movement from east to west and back were observed from the videos of (Atamian et al. 2016). It was analyzed that it is not just the head of the sunflower but the entire stem of the sunflower that moves. Parts from the video are seen below in image 3.5.

Image 3.5 Showcasing the stem movement in the sunflower, Source :(Atamian et al. 2016)

3.6 Movement of stem

A video of the existing movement of the stem (Atamian et al. 2016) was analysed it was realized that not just the head but the whole flower moves from side to side. The sunflower moves like a pendulum. It takes the same amount of time to move from east-west and then from west to east. The images below showcase one complete cycle of the sunflower starting in the east and turning to the west at night and throughout the night it reverts back to the original east position. Video stills of the movement are seen in table 3.6

When the sunflower reaches maturity around 75 days to 120 days, the flower turns east and stops oscillating. One of the reasons for this is that pollinators visit the sunflower in the morning. So the flower turns to the east to warm up the flower to attract pollinators.

Stem facing the east in the morning. (6 am)	**Stem facing up in the afternoon. (12 pm)**	**Stem facing the west in the evening. (6 pm)**
		
Stem facing west after sunset. (7 pm)	**Stem facing up in the middle of the night (12 am)**	**Stem reaching initial position before the morning. (5 am)**
		

Table 3.6 Showcasing the complete cycle of heliotropism in sunflower Source :(Atamian et al. 2016)

3.7 Structure of stem

The sunflower stem is classified as a dicot stem. A dicot stem is when the vascular bundles are arranged in a circular format in the core. The stem is divided into 3 parts, the epidermis, cortex, and stele (Plant Structure II, 2007). Image 3.7 shows the different parts of the sunflower.

1. Epidermis: It is the outer protective layer made of parenchyma cells.

2. Cortex: This is further divided into 3 parts. Hypodermis: 3-6 layers of collenchyma cells that provide mechanical support. Middle Cortex: is involved with photosynthesis. Inner cortex: It stores food and helps in gaseous exchange.

3. Stele: this is further divided into 3 parts. Epicycle: A multi-layer parenchymatous and occurs between the vascular bundle and the endodermis. Vascular Bundle: These are the transportation system which includes the xylem and the phloem. The Xylem transports water and mineral salts from the roots up to other parts of the plant. The cambium is a layer of actively dividing cells between **xylem** (wood) and **phloem** (bast) tissues that is responsible for the secondary **growth** of **stems** and **roots** (second ary **growth** occurs after the first season and this results in an increase in thickness) (increases as it grows). The Phloem transports sucrose and amino acids between the leaves and other parts of the plant. They are arranged in a ring around a pith. Pith: it is the central space that stores water and nutrients and throughout the plant.

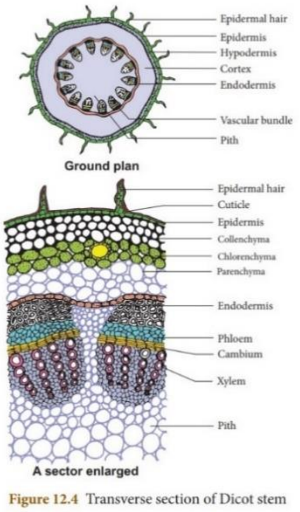


Image 3.7 showcasing the cross section of the stem, Source: (Plant Structure II, 2007).

3.8 Microscopic view of stem

A microscopic view of the stem of the sunflower was analysed. The stem here has been dyed with iodine. This shows a more detailed image of the vascular bundles. This shows the vascular bundles in a circular ring around the core of the stem. It can be seen below in image 3.8.1

This image 3.8.2 shows a detailed cross section of the vascular bundle. The vascular bundle consists of the parenchyma, phloem, cambium, xylem, pith etc.

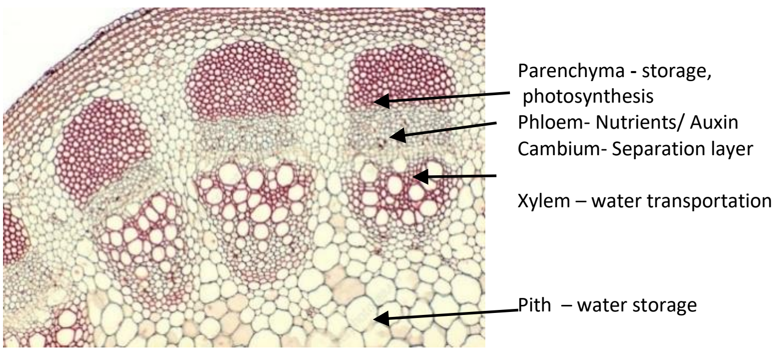


Image 3.8.2 microscopic view of Vascular bundle, source Kieth(2020)

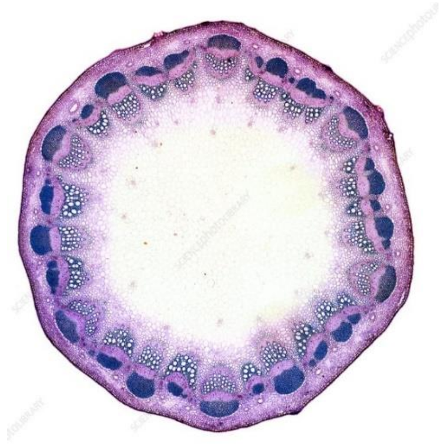


Image 3.8.1 microscopic view of stem, source Keith (2020)

3.9 Conclusion

Tropism is the directional response to a stimulus. Plants respond to different types of stimuli such as light, gravity, minerals, temperature, atmospheric components, etc.

Heliotropism is a form of tropism where the plant reacts to the direction of the sun in a diurnal motion (daily cycle). During the day the eastern part of the stem elongates forcing the flower head to move towards the west. A simple example is a sunflower.

Sunflowers use the circadian rhythm to control their movement. The circadian rhythm is a natural process controlled by the sun's 24 hour clock to govern its movement. The plant uses the internal clock of the circadian rhythm to move from east to west in the morning and west to east in the night. This is done as there is no sensor in the night for the sunflower to return back to the east when the flower reaches maturity, it stops moving from east to west.

For the stem to move from east to west, the plant detects the position of the sun. It then releases a hormone called auxin. The auxin is released as a gradient across the stem. There is more auxin in the shaded portion of the stem, which causes the cells to elongate on the shaded portion of the stem. This causes the stem to bend towards the light. The auxin breaks the cell wall and allows water to fill into the shaded portion of the plant so that it elongates towards the light. Therefore heliotropic plants use turgor pressure within their cells to move from east to west.

Through the video by (Atamian et al, 2016) it was clear that the movement was done by the stem and not the head of the sunflower.

The increase of height in one side of the stem is due to cells elongating by increasing the amount of water in them. The water is a simple mechanism that controls the movement of the plant.

Different layers perform different functions, the epidermis acts as an outer protective layer, the vascular bundles are responsible for the movement of the cells.

The literature review of heliotropism does not provide all the answers. A few of the unanswered questions are:

- How does the expansion of the stem happen at a cross- sectional level?
- What is the sequence of events that lead to the expansion and contraction?
- How much displacement is created by the heliotropic stem?
- What is the angle created by the heliotropic stem?
- What are the forces acting on the stem?
- Material properties of the stem

4. Case study

4. Case studies.

4.1 Hygroscopic Pine cone inspired material

In the paper "4D pine scale: biomimetic 4D printed autonomous scale and flap structures capable of multi-phase movement" (Correa, 2019) studies the Butan pine cone and its hygro responsive nature. The pine cone closes when it is wet to protect the seeds inside and open up when dry. This opening and closing are done by two layers. An active layer that dictates the swelling and a passive layer that dictates the drying of the cone. There is no bonding material between the layers, but a soft matrix of brown tissue that holds them together. The composition of the two layers creates compression which facilitates the movement. It produces a biaxial two-phase hygro movement.

A pine cone scale can generate a force of up to 3N when the cone swells. The stress created by the swell is measured. When the scale is wet a transversal upward curvature is seen. When it is dry, the scale flattens.

The cells were analysed with the help of a light microscope. They developed a system emulating the Butan pine cones movement by 3D printing wood.

The composition of the active and passive layer of the pine cone was replicated with a wood polymer composite filled with wood fibres.

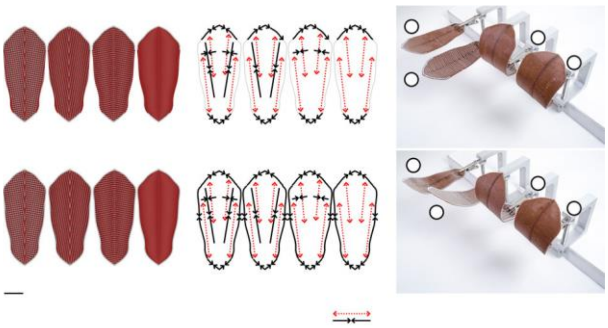


Image 4.1.2 Final results of a 3D printed hygro responsive matrial. Source: (Correa,2019).

The other material was Acrylonitrile Butadiene Styrene (ABS), it was considered as the resistance layer as it does not swell when moisture is added and adds stiffness to the entire composition. These two materials were woven by a 3D printer to mimic the hygroscopic layer of the cone.

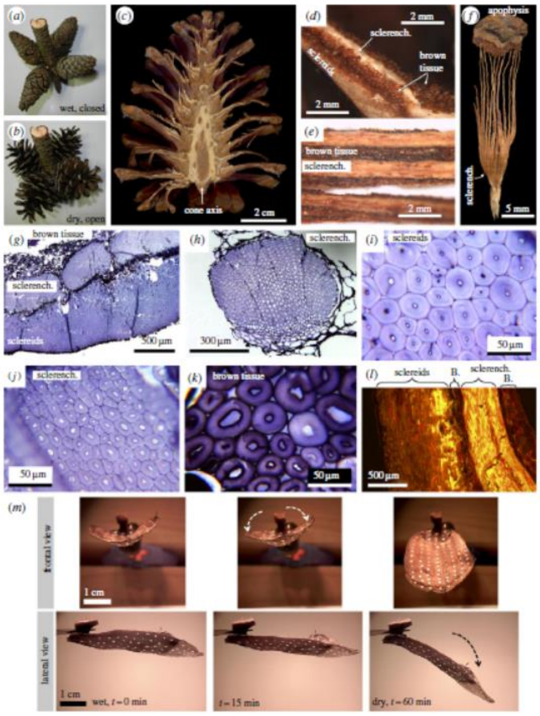


Image 4.1.1 Detailed analysis of the pine cone: Source: (Correa,*2019).*

The methodology of understanding the pine cone movement and converting it into a movable panel acts as a guide for the methodology for this thesis.

The paper first looked at the movement from a larger scale to movement at the tissue level. The force generated when the wood swells up is measured by a load cell. The Light microscopy and Fluorescence microscopy were used to study the movement of different parts of the pine cone. Digital image correlation was used to analyse the strain on the cone.

For movement analysis they used the software GOM Aramis Professional (GOM GmbH, 2016) a system that allows one to extract abstract deformation and strain from 3D movies with high resolution. For the structure, they used 3D-printing as this allowed them to experiment with different geometries and arrangements of the actuating regions. Humidity sensitive flaps were built with plywood as it was cheap and easy to handle.

4.2 Phototropic inspired material - Sun Bot

In the paper "Artificial phototropism for omnidirectional tracking and harvesting of light" (Qian , 2019) developed a material (Sun Bot) that takes inspiration from heliotropism. The sunbot is a nanostructured light responsive polymers that aligns itself to the direction of incident light. This material has a built in feedback loop that can bend in any direction. This material was inspired by heliotropism.

The issue faced by most electromagnetic devices is the loss of energy if the rays are oblique. To counter this they designed a material that bends towards the sun. Like the sunflower rotates its head to maximize the amount of sun it can receive.

To emulate heliotropism they used a cylindrical hydrogel that bends towards a stimuli to cause an asymmetric deformation. When light shines on one part of the sunbot it deforms and bends towards the light.

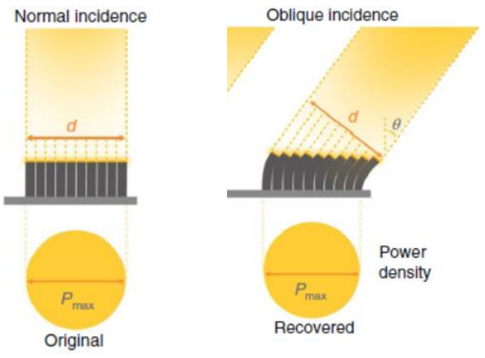


Image 4.2.1 SunBot Source: (Qian , 2019)*.*

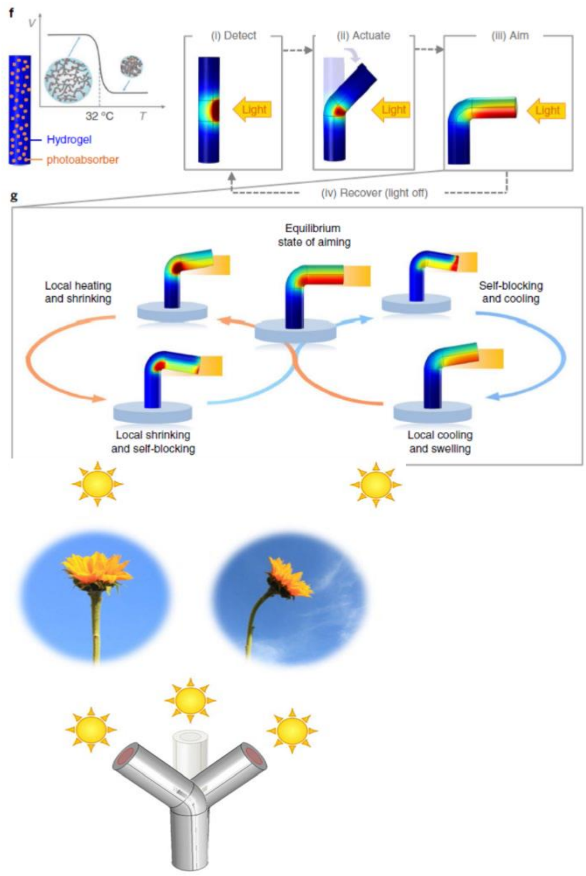


Image 4.2.2 SunBot: thermal priorities Source: (Qian , 2019)*.*

The light heats up the hydrogel which causes it to los its stiffness. This forces the hydrogel to bend towards the light. This is a self-regulating system, when the illumination changes it changes as well.

The feedback loop of self-regulation where the hydrogel can rotate at any angle. It also has the ability to bend and get back up several times without a dependency on external devices. This system also acts as a self blocking system when the intensity is higher than anticipated.

This system is very close to the actual movement of the sunflower. However, the material developed is 5 nanometers and does not have any practical applications at the moment, and needs to be developed further. The future use of this material could be adaptive signal receivers, smart windows, self-contained robotics, guided surgery, or self-regulating optical devices. The materials used in this product is harmful to humans unless properly encased. This material still needs time to develop into a useable product.

4.2.1 Hygroscopic materials

Hygroscopy is when a material changes its form, volume or any other physical characteristics when water molecules are added to the material. There are a range of hygroscopic materials available which can expand when water is placed on the material. In the 3D printed wood developed by (Correa, 2019) they used a wood polymer composite filled with wood fibres, as wood warps when it comes in contact with water. They also used Acrylonitrile Butadiene Styrene (ABS), a resistance layer to add stiffness to the entire composition as it does not swell up when moisture is added. This expansion and contraction helps the 3D printed hygroscopic material moves up and down when water is added to it.

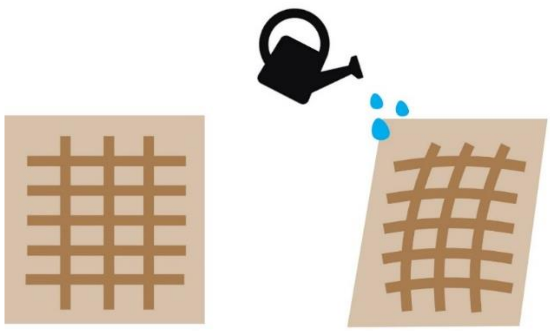


Image 4.2.1 Hygroscopic materials change shape or form when moisture is added to them. Source: Own image

Other examples of hygroscopic materials are cellulose fibres like
cotton, sugar, ethanol, wood, there are many salts such as sulphuric acid, zinc chloride, drying agents like silica gel etc.

Hygroscopic materials also play an important role in vapour barriers and have the potential to improve the indoor air quality.

4.3 P.V. piezo electric flag

To generate more energy researchers added Piezo electric strips to a flexible P.V. panel. Piezo electric strips can generate electricity upon mechanical movement. This device was allowed to float in the wind. As the device moved the P.V. panel generated energy and the piezoelectric strip also generated electricity due to the movement (*Researchers Develop Flags That Generate Energy from Wind and Sun*, 2019). As seen below in image 4.3. This a good example of the versatility of P.V. panels.

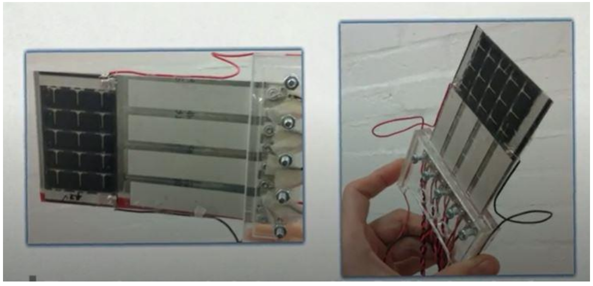


Image 4.3 Shows the Piezo strips moving along with P.V. panels.

4.3.2 Piezo Electric

The Piezoelectric Effect is defined as the electric charge that accumulates in certain solid materials in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure and latent heat. Some materials such as Berlinite, apatite crystals, topaz, quartz (SiO_2) and Rochelle salt ($NaKC_4H_4O_6–4H_2O$), etc. can produce electricity when they are compressed or struck by a force. The reverse can also be seen in some materials and it is called reverse piezo electricity. This is when electricity is supplied to the material and the material moves (image 4.3.2). Naturally occurring piezo electric materials often have limitations and are synthesised into piezoelectric ceramics, A few commonly used ones are barium titanate ($BaTiO_3$), lead titanate ($PbTiO_3$), and lead zirconate titanate (PZT) (Liu et al., 2012).

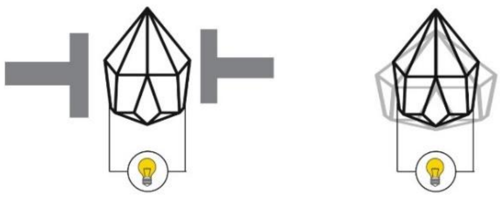


Image 4.3.2 piezo electric effect Source: Own Image

Piezoelectric actuators can be easily found in different applications such as hydraulic valves, small-volume pumps, micro electromechanical system, special-purpose motors, etc. These are actuators that produce linear or rotary motions. Compared to electromagnetic motors, piezoelectric actuators have a smaller response time, better accuracy, is quieter and, no electromagnetic radiations (Liu et al., 2012).

4.4 Soft robotics

Soft robotics is a sub field of robotics that looks at living organisms as inspirations for accomplishing their tasks. It utilizes soft materials in robots to perform tasks. This increases its flexibility and adaptability in robots. The idea is for robots to be more adaptable to their surroundings.

Image 4.4 shows a terrestrial robot-based with two soft-legged wheels. The wheels are designed to passively climb over stairs and adapt to slippery grounds using two soft legs embedded in their structure (Sadeghi et al., 2016).

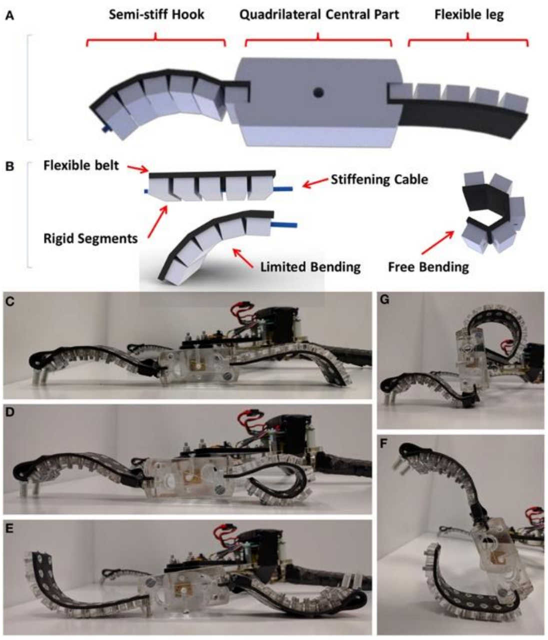


Image 4.4 soft robot (Sadeghi et al., 2016)

5. Analysing stem movement in a sunflower

5. Analysing stem movement in a sunflower

As stated in the chapter 3 heliotropic plants have the ability to move from east to west and west to east in a continuous cycle. In this chapter the stem has been analysed for its changing positions, internal mechanism of the stem and structure.

This chapter aims to understand the following points through a series of experiments and analysis:

- Strain and forces on stem
- Shape and structure of the stem
- Angle of rotation
- Material properties of stem
- The inner mechanism that creates the motion in the stem

5.1 Experiment

To analyse the heliotropic movement of plants, an experiment was set up. The aim of the experiment was to track the sunflower movement to understand the strain caused by the sunflower stem. The strain will provide the limits of how much the stem can bend and the forces it can withstand.

First, the principles of phototropism (phototropism explained in 3.1) were tested with an experiment. Green gram seeds were placed in a shoebox with a single light source. The plant shoots detected the light source and grew in that direction, proving that phototropism is a common occurrence in plants. A more detailed explanation with images can be seen in appendix A.

The second experiment was to understand the properties of heliotropism. Sunflower plants were grown in a grow tent. A grow tent is an enclosed chamber with light and humidity controlled to enable the suitable growth of plants. The light source was placed

Image 5.1 Experimental Setup; Source: Own work.

to mimic the movement of the sun. The aim was to have a strain gauge to measure the strain on the stem of the plant. Image 5.1 shows the setup of the experiment.

Details of the experiments, materials used, measurement tools, the cost involved, room selection, Growth of plants, etc. can be found in appendix A.

Unfortunately, the experiment could not be completed as there was a pest infestation that killed all the plants. The experiment was conducted during the lockdown, which made it difficult to get the required materials and space to conduct this experiment.

5.2 Inferences from the Experiment.

Even though the experiment was unsuccessful, it provided insight into the movement of the sunflower plant.

The shape of the stem was analysed. The analysis can be seen in table 5.2.

The experiment also revealed that the stem in its early stages also showcases the properties of heliotropism. Some plants were seen bending up to 90 degrees and required support as when they are young they cannot support the weight of the leave. The weight of the weight of the sunflower head to the weight of the stem can be seen in 5.5. As stated in the literature review. Turgor pressure plays an important role in the cells. Through the experiment the stems started to wilt when they lost their moisture. The importance of water is investigated 5.4.

Further, planning a contingency plan proved to be effective as the Netherlands went into lockdown.

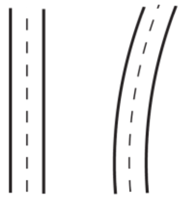
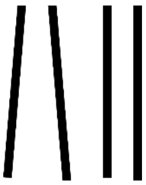
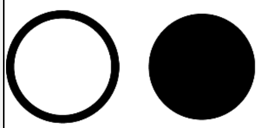
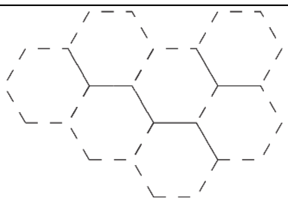
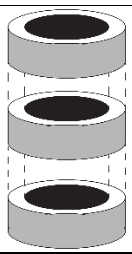
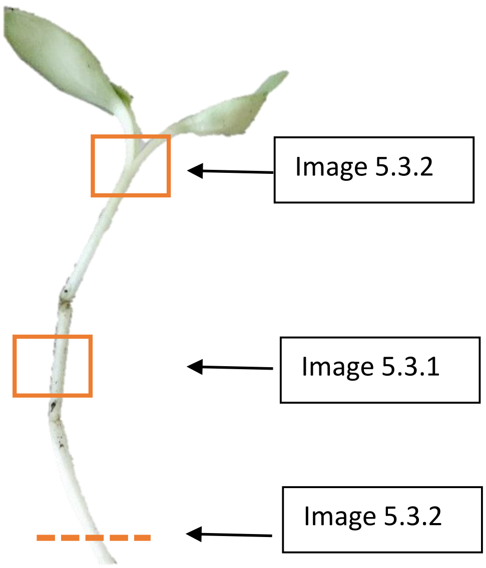
Category	Image	Description
Bending angle of sunflower		When the stem bends, the curvature of the stem bends towards to head of the sunflower. The curvature is a shallow curve. This ensures all the forces are not concentrated at one point.
Tapering stem		The sunflower stem is wider on the bottom and steeper on the top. This enables less mass on the top reducing the load of the structure. This also provides greater lateral stiffness at the base of a structure which overturns movement from the wind.
Tubular section		A hollow cylinder is stronger than a full cylinder. Both of them can handle the same amount of stress. But, a hollow cylinder has a better strength to weight ratio.
No Interconnection of cells		The cells work as a system. All the cells on one side expand causing the movement. There are no interlinking components
Cell wall load distributed		The cell wall carries the load and it is transferred linearly.

Table 5.2: Analysing the shape of the sunflower stem.

5.3. Analysing the stem under a microscope.

To analyse the stem in more detail it was studied under a microscope. The aim of the microscopic analysis is to understand the inner workings of the stem and the material properties of the outer layer of the stem. The plant analyzed is a sunflower as it is easily available and shows heliotropic properties.

There were two types of microscopes used for the analysis. The first one was a Dino Light microscope which was used for a broader understanding of the different parts. This microscope has a resolution of 1.3 Megapixels. After the initial analysis, a Keyence digital microscope with a resolution of 5 Megapixels was utilized. This microscope has the ability to detect the depth in surfaces. Table 5.3 shows a few selected images with an explanation of the properties analysed. For a more in-depth analysis refer to Appendix B.

<table>
<tr><th colspan="2">Images of sunfllower plant used for analysis</th></tr>
<tr><td></td><td></td></tr>
<tr><th>Images</th><th>Explanation</th></tr>
<tr><td>
</td><td>Sample 1
Microscope: Dino light microscope.
There were 3 samplings with a height of 20 cms and a thickness of 2mm that were analysed. The saplings were 20 days old.</td></tr>
</table>

<table>
<tr>
<td></td>
<td>Image no : 5.3.1
Position : Middle of stem
Time: 2 days after cutting
Cut : Longitudinal
Magnification: 59.8x
Date :29/01/2020

Observations: The surface of the stem has fibrous long strands. These longitudinal strands provide strength to the plant.</td>
</tr>
<tr>
<td></td>
<td>Image no : 5.3.2
Position : Junction of stem and leaves
Cut : None
Magnification: 25.9x
Date :29/01/2021

Observations: These undulations are seen on both sides of the leaves. These undulations help the movement of sprouting leaves. These undulations are effective at the point where the leave These help the plant leaves to open out. They are not seen after the leaves mature.</td>
</tr>
<tr>
<td></td>
<td>Image no : 5.3.3
Position : Junction of stem and leaves
Cut : transverse
Magnification: 17.6x
Date :29/01/2021

Observations: White strands seen on the inner surface of the stem are the growth of the vascular bundles.</td>
</tr>
<tr>
<td colspan="2">When the sunflower is 20 days old it is difficult to analyse the stem in more detail as the stem is not fully developed. This step was during the lockdown and during this stage the plants died due to a pest attack. For these reasons a fully grown sunflower was purchased and viewed under a microscope with a higher magnification.</td>
</tr>
</table>

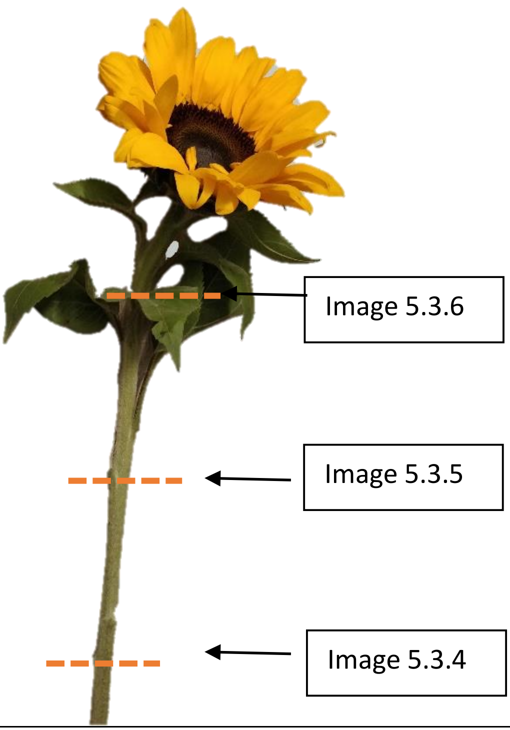
 	The following images are taken from a fully grown sunflower which is around 90 days old. The Keyence digital microscope was used to analyse the stem in more detail. A cross section of the stem was taken in 3 different locations.
	**Image no : 5.3.4** Position : Lower end of the stem ($1/3^{rd}$ position) Cut : Transverse section Magnification: 20x Date :05/03/2021 Diameter of stem:12mm Diameter of pith:6.1 mm Observations: There are two clear colours that are seen in these images. The white membrane is the core or the pith and the outer green is the parenchyma.
	**Image no : 5.3.5** Position : Middle of the stem ($2/3^{rd}$ position) Cut : Transverse section Magnification: 30x Date :05/03/2021 Diameter of stem:14 mm Diameter of pith:10mm Observations: In this image the pith or the core is larger than in the previous image. This proves that the size of the pith increases as it moves upwards.

	**Image no : 5.3.6** Position : Upper end of the stem (head of stem) Cut : Transverse section Magnification: 30x Date :05/03/2021 Diameter of stem:18 mm Diameter of pith:14.5mm Observations: In this image the porous core can be seen along with the vascular bundles located on the outside.
	**Image no : 5.3.7** (magnified image of 5.3.5) Position : Upper end of the stem ($2/3^{rd}$ position) Stem : Healthy Time: 5 days after being cut from source. Cut : Transverse section Magnification: 50x Date :05/03/2021 Observations: This is a detailed view of the vascular bundles. It shows that they are hollow. This allows the transport of waters and nutrients.

Table 5.3 : Microscopic images of sunflower plant Source: Own work.

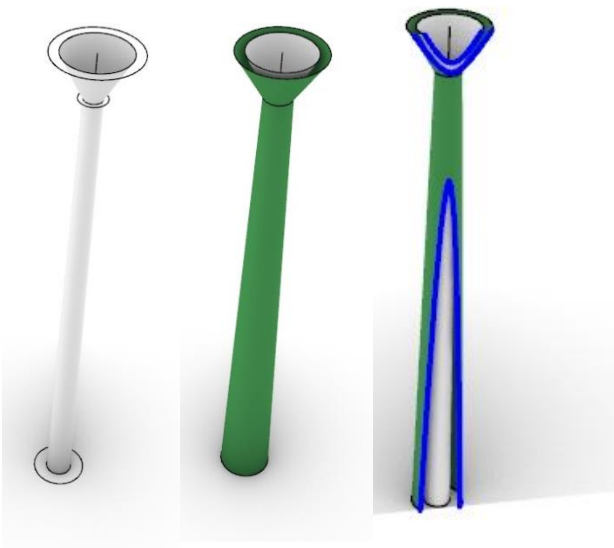


Image 5.3.8 : Ration of Pith of stem to the overall diameter of the stem Source: Own work.

In table 5.3 it seen through images 5.3.4 and 5.3.5 the pith size increases as it reaches towards the head of the sunflower. The literature study showed that the cells in the pith expand and contract. Image 5.3.8 is a diagrammatic view of how the pith expands. It is important to note that the overall size of the stem reduces as it moves towards the head but the size of the pith increases. The increase in the pith enables the upper portion to move, this allows the stem to bend more. This helps in creating the incline of the stem. The stem bends in a curvature rather than an incline which is also facilitated by the larger pith at the base of the head.

In the table 5.4. The cross section provided by Keith (2020) in section 3.9 is compared with the microscopic image of 5.3.6.In this image the vascular bundles are clearly seen. This proves that the sunflower is a dicot stem.

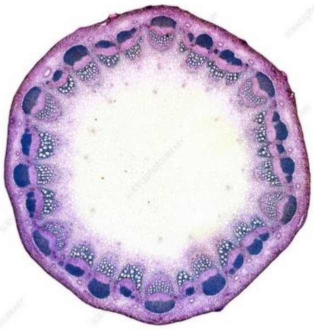
Literature	Microscope
	

Table 5.4 .4 Microscopic images of sunflower plant

5.4 Movement of the stem

Based on the literature study it is known that the hormone Auxin creates a gradient of hormone across the cross section of the stem. The xylem is responsible for the dispersion of the auxin hormone and the Phloem is responsible for the water dispersion. The xylem and phloem are located on the exterior and the central portion is called the pith.

The literature review dos not show the relation between the hormone dispersion and the movement in the stem.

Based on the release of hormone and the motion detected. The two were connected and a schematic diagram of the release of the hormone which causes different parts of the stem to expand moisture is explained in table 5.4.5 The plant generates a gradient of the hormone auxin to help increase the water intake in one side of the stem. This causes the stem to bend towards one side. Based on the circadian rhythm the stem moves from east to west and back from west to east.

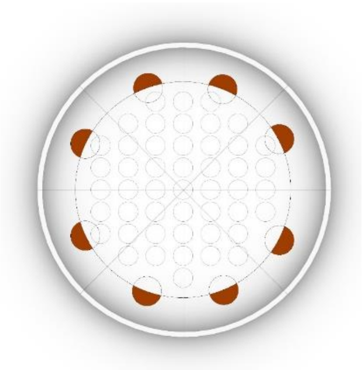
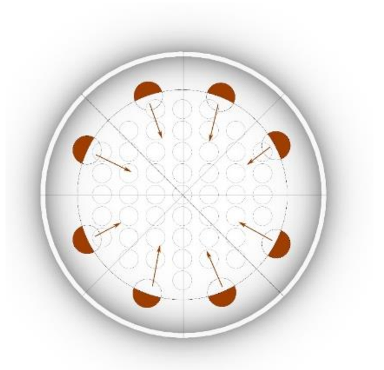
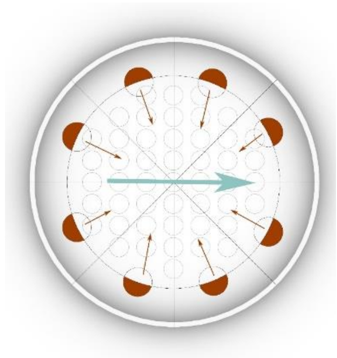
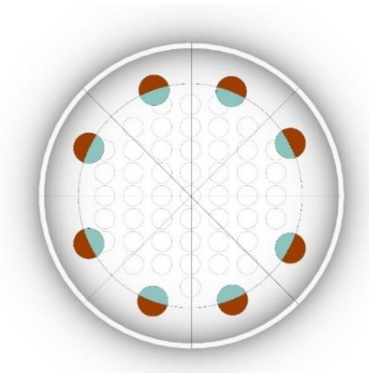
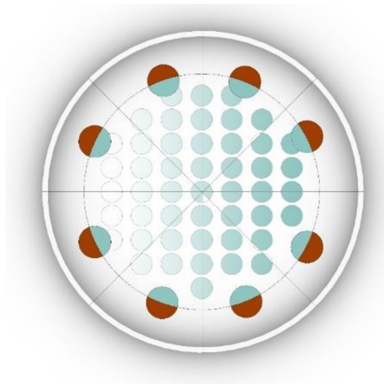
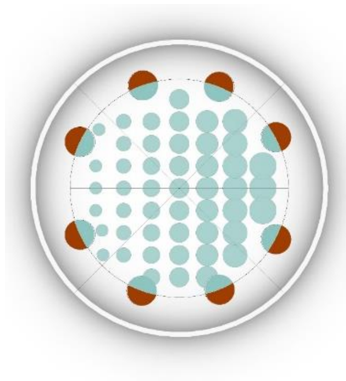
Diagramatic steps involved in the movement of the stem		
		
Step 1: The Phloem is located in a radial pattern on the outer part of the circle marked in red.	Step 2: Phloem Releases Auxin The Phloem releases an Auxin across the pith (central cells).	Step 3: Auxin creates a gradient across pith.
		
Step 4: Xylem releases water.	Step 5: Cells absorb water based on the Auxin.	Step 6: Some cells absorb more water and enlarge.

Table 5.4.5: Steps involved in the movement of the stem Source: *Own wor*

The image 5.4 seen below is a diagrammatic representation of the stem cross section stacked on top of the other. This shows how all the cells that expand and contract with water that cause the stem to bend towards one side.

Image 5.4 Diagrammatic view of cell expansion in the stem. Source: Own work.

5.5 Weight of sunflower head to the stem.

To understand the load the sunflower stem carries. The weight of the head of the sunflower and the stem were measured. The head of the sunflower weighs 48.31 grams. The Diameter of the flower is 12. 5 cm. The stem measured was a cut stem of a sunflower which was 73 cm longs and weighed 45. 5 grams

The height of the stem is 120-180 cm (Atamian et al. 2016). Assuming the stem length is 140 cm. The weight of the stem doubles= 45.5 *2 = 91 grams. In reality the stem will weigh more as the bottom portion of the stem is wider and has more mass.

Therefore the head of a sunflower weighs 48.31 grams and the stem 91 grams. This shows that the weight of the stem is more than the weight of the head. This can be analysed as the structural membrane that carries the weight and causes the movement weighs more than the head which absorbs the solar radiation.

Image 5.5 Diagrammatic view of cell expansion in the stem. Source: Own work.

5.6 Digital Image correlation

The images and data were further analysed using digital image correlation to have a better understanding of the movement of the sunflower stem.

Digital image correlation is used to measure the contours, deformation, and strain of any material. A mat lab script by Christoph Eberl (*Digital Image Correlation and Tracking*, 2010) was utilized to measure the deformation in the stem of a sunflower. For digital image correlation, a series of images are required to understand the movement of the sunflower. A video (Atamian et al. 2016) of the sunflower movement was taken and broken down into a series of images. These images were placed in the mat lab script.

The first image calculation showcased displacement of all elements of the image. The image was cleaned with Photoshop to only show the movement of the stem. The first position of the stem is when it is on the far right position, facing east. Multiple images were taken between the far-right position of the stem and the central position of the stem. Image 5.6.1 shows the two positions of the stem that were considered for the calculations.

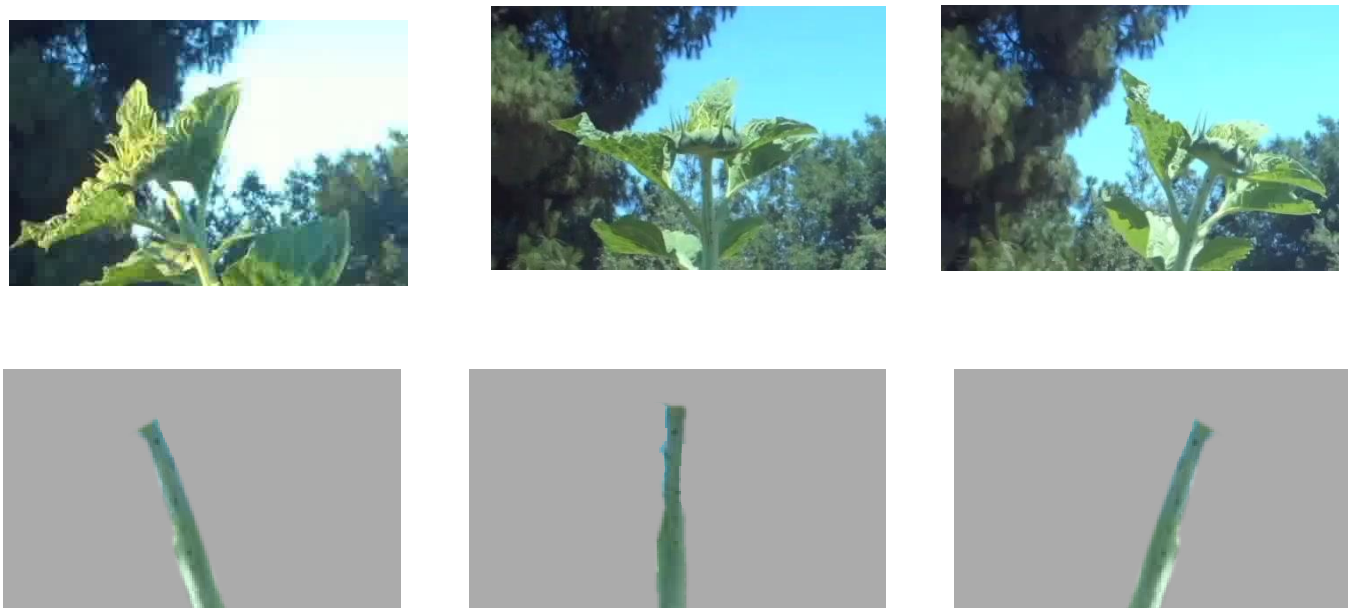


Image 5.6.1 Images showing the maximum extent of the movement of the sunflower that were analysed.

The final simulation results are seen in Image 5.6.2 of the displacement between the first image and the last image a displacement can be seen in the graphs. The displacement showcases a 30-pixel displacement.

Utilizing the displacement in pixels from the mat lab script the picture can be analysed in more detail. The pixels of the entire picture can be found. Utilizing the pixels the width of the stem and the height of the stem can be analgised in pixels. The stem width is 14.3 pixels. The length of the stem as seen in the image is 119.6 pixels. Utilizing the displacement and the length the angle of displacement can be gathered. The angle of displacement is 14 degrees. Image 5.6.3 can be referred.

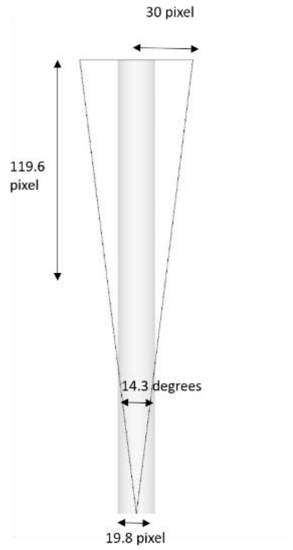


Image 5.6.3 Angle of displacement, calculated from pixels from mat lab script.

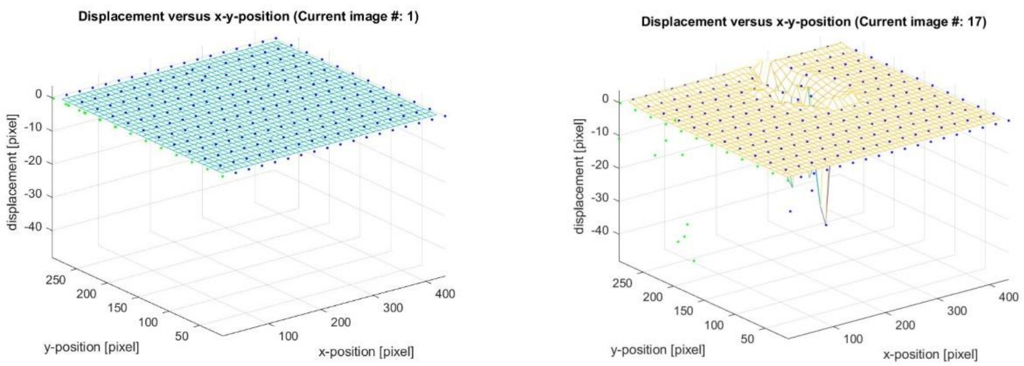


Image 5.6.2 displacement of sunflower stem in extreme right and a central position for analysis in matlab *Source: Own work.*

To check if the head of the sunflower rotates separately from the stem. The sunflower at extreme ends was superimposed onto the image of the sunflower when it was in a central position.

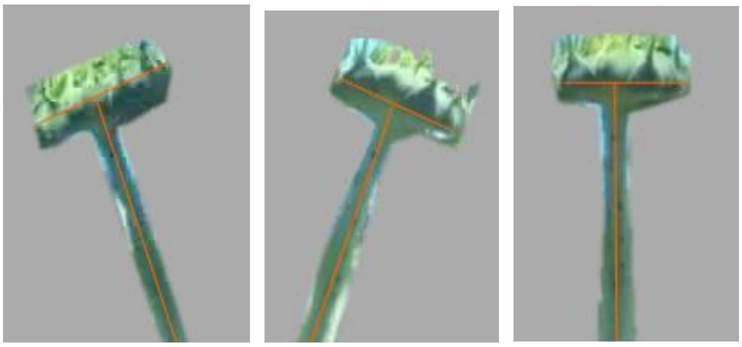


Image 5.6.4 Image of the sunflower with the head along with its axis

Image 5.6.5 Image of the sunflower with its axis superimposed with the central image of the sunflower. *Source: Own work.*

The superimposed images look at the extreme ends(Position in the east and position in the west) of the sunflower image superimposed onto the central image. The image shows that when the superimposed image of the sunflower is not perpendicular but tilts further to increase its exposure to the sun. This tilt enables the sunflower to have a greater angle as the stem only moves 14.3 degrees.

5.7 Stress and strain on the stem

This part measures the stress and strain that occurs on the stem. Strain is a measure of the deformation that occurs when a force is applied to an object. The strain can be measured by the difference in length. The length of the stem in compression and tension are measured. The image shows the stem of the sunflower. The Stem is divided into a

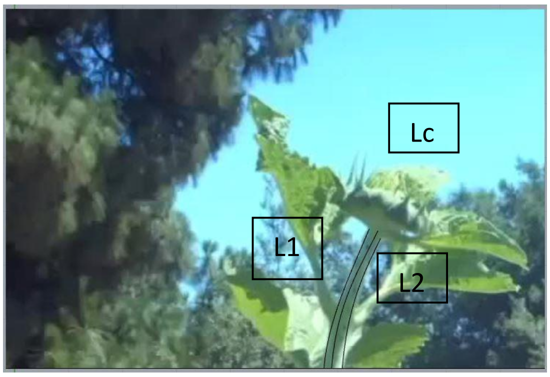


Image 5.7 different sides of the stem

Central line(Lc), a line in tension (L1) and a line in compression(L2). The lines are measured in pixels in Photoshop.

L1= 2.80 pixel

Lc = 2.71 pixel

L2 = 2.62 pixel

Compressive strain and tensile strain

Compressive strain = (2.71-2.62) / 2.71= 0.033

Tensile strain = (2.8-2.71) / 2.8 =0.032

The above values are the strain experienced by the sides of the stem. The strain shows us the deformation from the original length. The poisons ratio can help determine the stress values you would determine the elastic modulus.

To put the compressive strain into context, the compressive strain of concrete is 0.002 to 0.003 and compressive strain of polyethylene is 0.2 to 0.7. A cotton fabric has a strain of 0.08 to 0.02 strain (El-Messiry & Youssef, 2011).

5.8 Conclusion

The stem of a sunflower is hollow, tapering with the load being transferred linearly downwards through the cell wall. This structure of the stem allows the stem to transfer the same amount of stress as a cylinder but with a lower weight.

The microscopic images of the sunflower showed that the skin of the stem is fibrous. The analysis showed that the core of the stem which is called the pith increases in diameter towards the top of the stem. This allows the stem to bend more towards the top of the stem.

For the inner working of the stem. The plant releases a hormone called Auxin. The Auxin hormone creates a gradient of hormone across the cross section of the stem. The auxin is secreted from the phloem that is radially placed around the core of the stem called pith. The amount of auxin governs how much water the cells in the centre should absorb. The phloem releases water into the core of the stem. Based on the Auxin level the centre cells know how much water to absorb. The cells towards one side of the cross section absorb more water causing that side to expand. This cause one side to expand and the other side of the stem to contract. This creates movement in the stem.

The digital image correlation helped analyse the angle of tilt in the sunflower. The sunflower uses a 14 degree angle to create an efficient system. The head of the sunflower is not always perpendicular to the stem, it bends more than the 14 degree angle created by the stem. This is possible as the junction below the head of the stem is more porous and has more cells in the pith. That can produce a parabolic effect in the stem. The strain observed by the stem can be closely compared to a cotton fabric.

6. Shape and angle of P.V. integrated shading device

6. Optimizing shape and angle of P.V. integrated Shading device

A P.V. integrated shading device's shape and angle is reliant on the position of the sun. This determines the angle at which the P.V. panel receives the most amount of radiation. For a shading device, the amount of sun it can allow inside a window is based on its location and orientation. This chapter looks at the shape and angle for a P.V. integrated shading device in the Netherlands

6.1 Constraints of P.V. integrated shading device.

The shape and the angle of a P.V. integrated shading device varies based on its location. The weather conditions and the sun's position are different in different locations. The literature review 2.4.2 explains about the tools that could be used to calculate the sun's position. It is difficult to tabulate the angles for every location on the earth. For this reason, the device is designed for the Netherlands. As stated in chapter 2.4.3 the best orientation for a P.V. panel is the south face. For this reason, a building with a window facing the south façade was chosen. The simulations are run for an office room of 3m*5m. The wall is assumed to have a window of $2m^2$ on a facade of $9m^2$. This room does not have any other openings so that the results are not affected by other factors.

In the Netherlands, a sun shading device is required to block the sun in the summer months as it will reduce the cooling load. On June 21st the P.V. panel is closest to the sun in the northern hemisphere and receives the most amount of solar radiation. Utilizing this as the middle of the summer month the rest of the year is divided into 4 parts. During the other months, the solar radiation is let into the room as this reduces the load on the heating device. Image 6.1 is a temperature graph for delft. It has the temperature prediction for 2050 and 2085. Table 6.1 is the period the days are divided into.

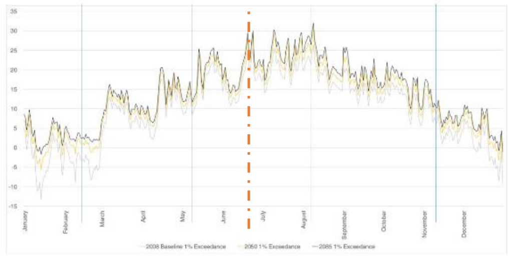


Image 6.1 An analysis, based on The KNMI website for the prediction of the temperature for 2050 and 2085.

The year is divided into the following days:

Season	Date
Spring	06 Feb – 07- May
Summer	08-May to 04-Aug
Fall	05-Aug to 03-Nov
Winter	04-Nov to 05-Feb

Table 6.1 Time period for dividing the four months

6.2 Calculating P.V. energy and effect of shading device

To analyse the shape and angle for a P.V. panel and a shading device a grasshopper script was used. In this script a 15 m^2 room was designed with one window of $2m^2$ and a shading device of (1m*2m) on top.

To calculate the amount of P.V. energy generated by the device a ladybug plugin was utilized. Using ladybug the weather information was derived from an EPW file for Amsterdam. The EPW file can be used to calculate the radiation falling on the device. While calculating the incident radiation on the device the cumulative sky matrix is used. The cumulative sky matrix calculates the radiation coming from each part of the sky. The recorded radiation levels will be lower on cloudy days. Which makes it difficult to determine the angle which is best for P.V. production when it is a cloudy day. For this reason calculating the radiation on a clear sky day will provide the best angle for a P.V. panel which can be used every year as the position of the sun does not change.

The Tau Clear sky honeybee function is used to find the radiation received on a clear sky day. This provides the maximum amount of energy a P.V. panel can produce. Utilizing the Tau Clear sky honeybee function the incident radiation falling on the P.V. panel can be calculated. The incident radiation tool is plugged into the P.V. tool. In this tool, data can be adjusted for different types of cells such as mono- crystalline, poly crystalline etc.

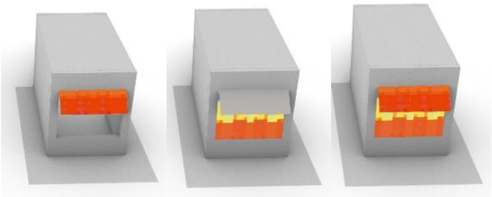


Image 6.2 Radiation falling on the P.V. panel and the radiation falling on the glass behind the P.V. panel.

The function of a shading device is to protect the interior of the building from the solar radiation coming in. To understand the effect a shading device has in a room, it is assumed that there is only one window in the room. An easy method to calculate the amount of energy load is by calculating the radiation falling on the glass of the window. The shading device and the room are assumed as the context and the radiation falling on the glass is calculated. For the summer the option with the least amount of radiation is chosen and for the winter the option with the most amount of radiation falling on the glass is chosen, as more solar radiation during the other three months allows more heat inside the room

For a detailed understanding of the amount of energy saved by a shading device the honeybee energy module is used. A room was constructed using a honeybee room tool, with an aperture of $2m^2$. The amount of energy required to heat and cool load the room was calculated by converting the honeybee room to an open studio model and by running it through an energy plus model.

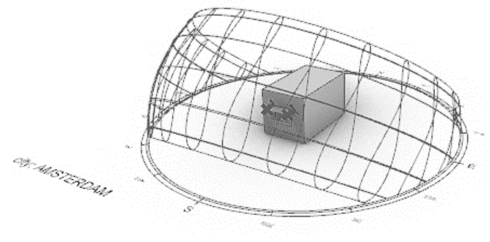


Image 6.2 Image of the room modeled using honeybee room.

By utilizing the energy plus model the simulations use some defaults to calculate the energy generated by a room. The following assumptions are made:

1. The room is assumed as a generic office occupancy. Therefore the schedule of an office is used for the heating and cooling of the room.
2. The Setpoint Temperature for cooling is 24 C° and heating is 21 C°.
3. The simulation uses Climate Design Data of 2009
4. The analysis uses the Köppen climate classification. According to that Netherlands is classified as Marine west coastal (warm summer, mild winter, rain all year)
5. The analysis uses a heating and cooling vent system
6. Occupants are assumed as 1.7 people for 15 m^2.
7. Simulation is run using Energy Plus, Version 9.4.0-998c4b761e
8. Equipment gains 10.3 W/m2.
9. For heating and cooling, it uses an HVAC system.

6.3 Shape of P.V. integrated shading device.

The shape is defined based on the constraints of the P.V. panel and the shading device. In 2.7.1 the different shapes that can be designed for a shading device are explained. But the main problem occurs due to the P.V. panel. P.V panel can be designed in different shapes, but it should not shade itself. Chapter 2.10.1 clearly states a shaded P.V. panel loses 70% of its energy output. For this reason, the P.V. integrated shading device is designed as a single component rather than multiple components.

There were 6 shapes analysed for a P.V. panel and a shading device. The different shapes were analysed for 4 different days to mark the different periods in the 4 seasons (Mar 21, June 21, Sept 21, Dec21). The energy generated by a P.V. panel and the radiation falling on the glass is calculated using the script mentioned in 6.2. The energy is calculated for the entire day. The table shows that a single inclined panel is the best shape option from all the choices. The second best option is the fixed panel.

The larger the length and width of the shading device the more beneficial it is. But the main criteria for determining the length and width is the amount of load the device can handle.

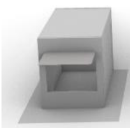
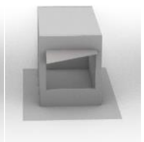
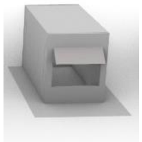
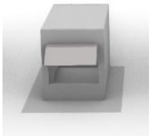
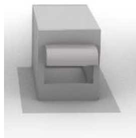
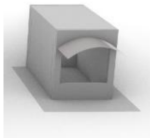
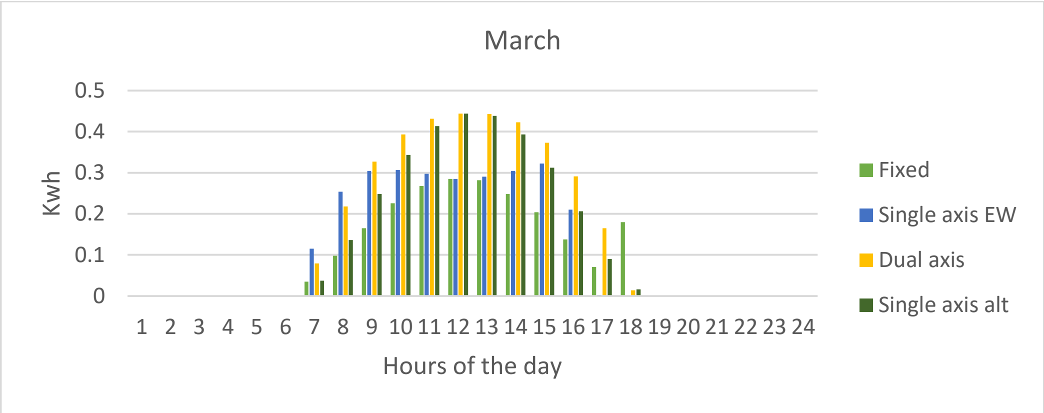
Details	Shape 1	Shape 2	Shape 3	Shape 4	Shape 5	Shape 6
						
Mar 21						
						
P.V. (kWh/m^2)	0.005	0.002	0.008	0.006	0.006	0.005
Rad on window(kW)	3.754654	3.75465	3.754654	3.75465	3.754654	3.754646
Jun 21						
						
P.V. (kWh/m^2)	0.010574	0.0044	0.0098	0.0096	0.0098	0.0107
Rad on window(kW)	11.0723	11.0723	11.0723	11.0723	11.0723	11.0723
Sept 21						
						
P.V. (kWh/m^2)	0.005	0.002	0.008	0.006	0.006	0.005
Rad on window(kW)	3.458	3.458	3.458	3.458	3.458	3.458
Dec 21						
						
P.V. (kWh/m^2)	0.001207	0.000494	0.00339	0.002229	0.002256	0.001269
Rad on window(kW)	1.273681	1.273679	1.273681	1.273679	1.273681	1.273678

Table 6.3.1 design option

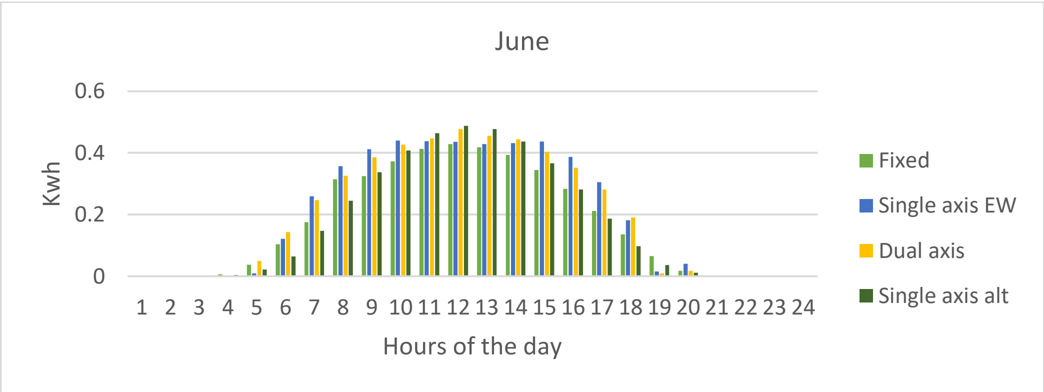
6.3 Selecting optimum angle for P.V. panels and shading device.

6.3.1 Four types of rotation

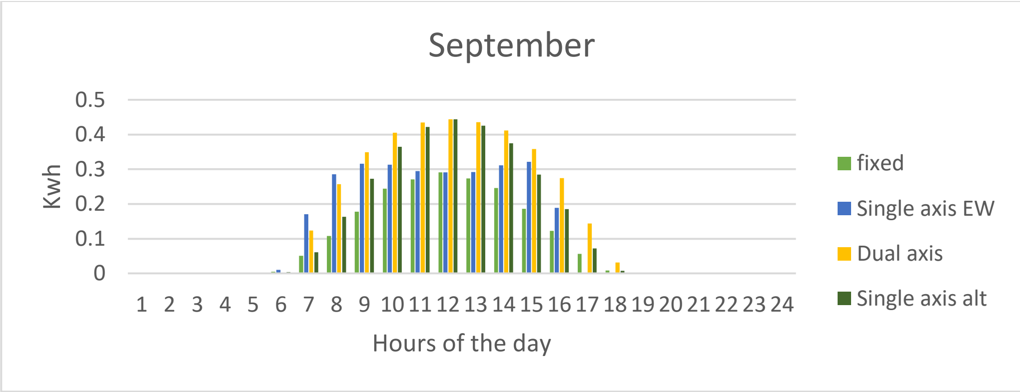
The panel can be rotated in 4 different ways. The first one is a fixed shading device at 90 degrees. The second is a Panel that moves east to west throughout the year. The third one is when the panel moves along the altitude. The fourth one is a dual axis, where the panel moves along the east and west direction as well as along the altitude. The P.V. values are calculated for the full day of March 21st, June 21st, September 21st, and December 21st for these four different rotating mechanisms. Table 6.3.1 shows the amount of energy generated by a P.V. panel. The graphs from 6.3.1.1 to 6.3.1.4 show the amount of energy generated by a panel per hour of the day for the different angles and throughout the four seasons.



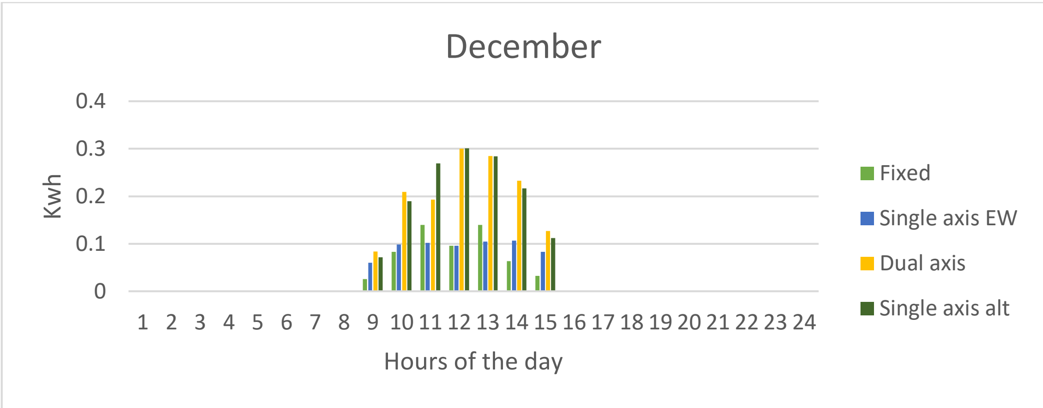
Graph 6.3.1.1: Graph for P.V energy on March 21



Graph 6.3.1.2 Graph for P.V energy on June 21



Graph 6.3.1.3: Graph for P.V energy on September 21



Graph 6.3.1.4: Graph for P.V energy on December 21

The total energy received by a P.V. panel in throughout the day is tabulated in the table below.

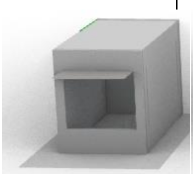
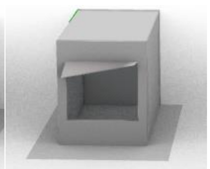
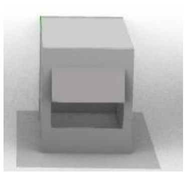
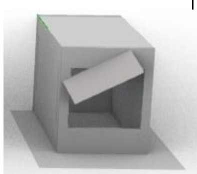
	Fixed horizontally	Single axis (east west)	Single axis (altitude)	Dual axis
				
March 21st				
P.V. energy (W/day)	2.2	2.69	2.516	3.076
Radiation on glass (kW)	3.75	3.75	3.75	3.75
June 21st				
P.V. energy (W/day)	4.045	4.030	4.073	4.659
Radiation on glass (kW)	11.07234	11.0723	11.07232	11.0724
Sept 21st				
P.V. energy (W/day)	2.04	2.79	3.08	3.67
Radiation on glass (kW)	3.45801	3.45800	3.45801	3.4669
Dec 21st				
P.V. energy (W/day)	0.582	0.652	1.445	1.431
Radiation on glass (kW)	1.27368	1.27367	1.27368	0.98169

Table 6.3.2 Different types of rotation

The values show that the dual axis panel is the most effective. However, the angles created by the dual axis are not suitable to act as a shading device as the angle created by the device does not shade the window completely and allows heat to enter from the top of the window. Further, the angle created blocks the view for the people sitting inside such that it looks like the window is split into two.

The angles of the single axis rotation along east to west and along the altitude are compared. The single axis altitude is more efficient as a P.V. panel and as a shading device. This was selected for the movement of P.V panels.

The suitable angle for a panel that rotates along the altitude needs to be calibrated. The best angle for the four seasons was calibrated using a grasshopper script. A shading device of 2m^2 was rotated at all angles from 0 to 90 degrees. When the panel is perpendicular to the façade it is considered as 90 degrees and when the panel is flat it is 0 degrees. Image 6.3.3 shows the 90 degree and 0 degree position.

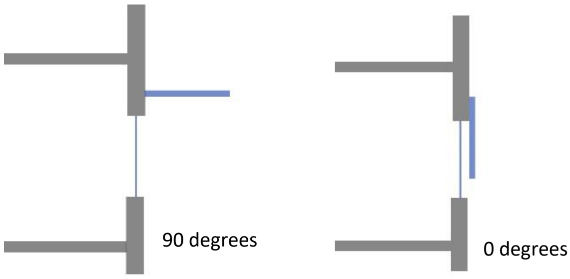


Image 6.3.3 showing 90 degrees and 0

6.3.2 Angle for single axis altitude

The energy generated by a P.V panel and the amount of radiation received on the window for all angles from 0 to 90 were calculated. Table 6.3.3 shows the angle at which the P.V. panel generates the most electricity. It also shows the angle at which the shading device generates the most amount of radiation on the window during March, September, and December and the angle when the radiation is the least. This simulation was run for a window and a P.V. panel for all the facades.

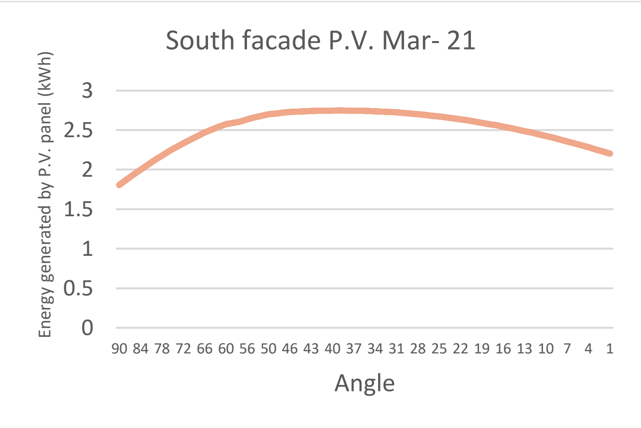


Image 6.3.4 Energy generated by P.V. panel for a south façade for Mar 21st

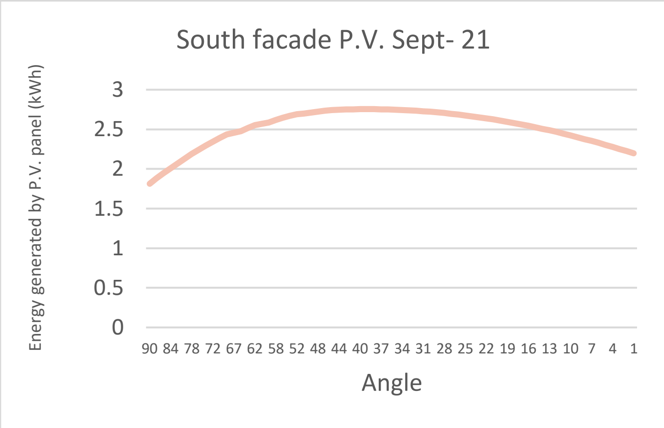


Image 6.3.5 Energy generated by P.V. panel for a south façade for Sept 21st

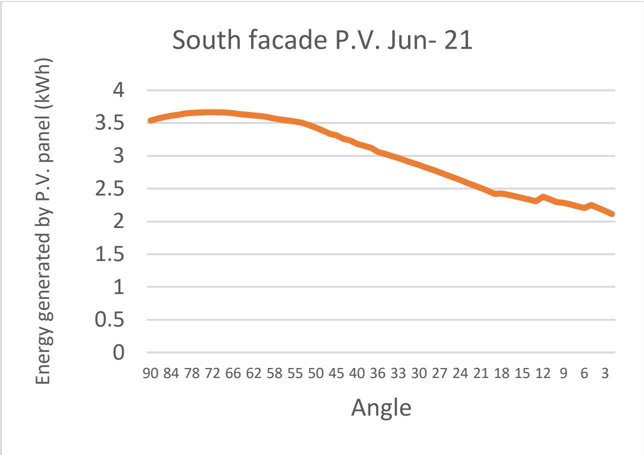


Image 6.3.5 Energy generated by P.V. panel for a south façade for Jun 21st

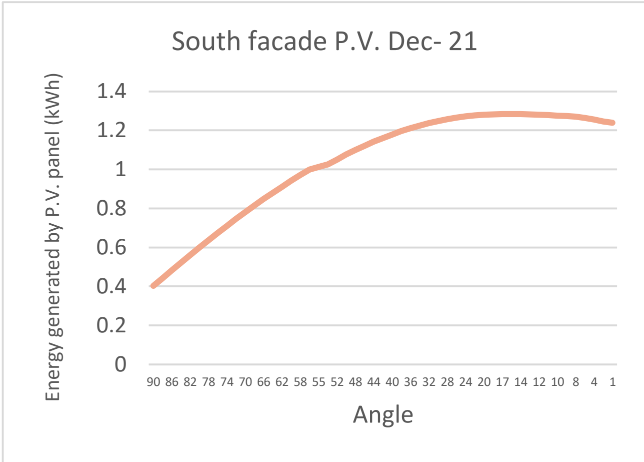


Image 6.3.6 Energy generated by P.V. panel for a south façade for Dec 21st

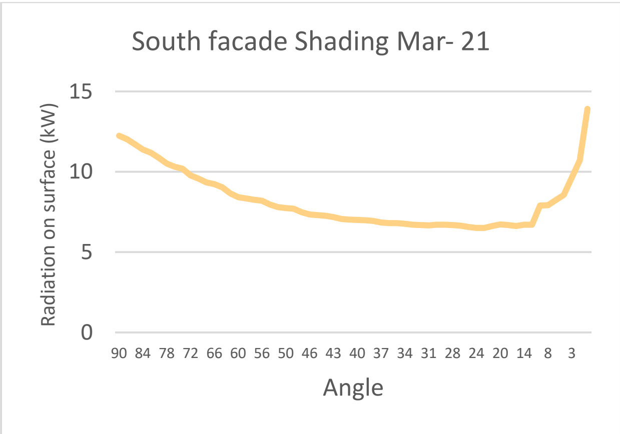


Image 6.3.7 Radiation falling on glass panel for a south façade for Mar 21st

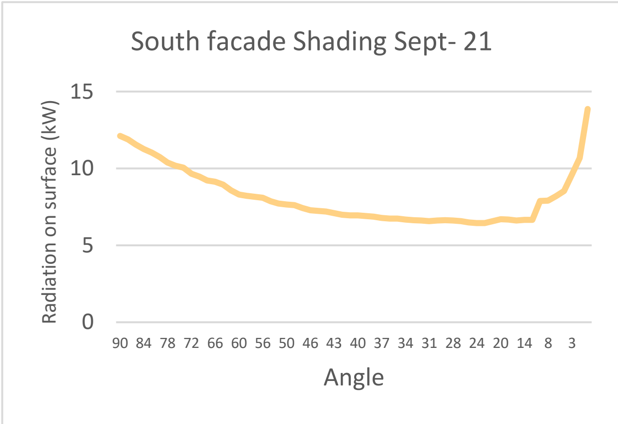


Image 6.3.8 Radiation falling on glass panel for a south façade for Sept 21st

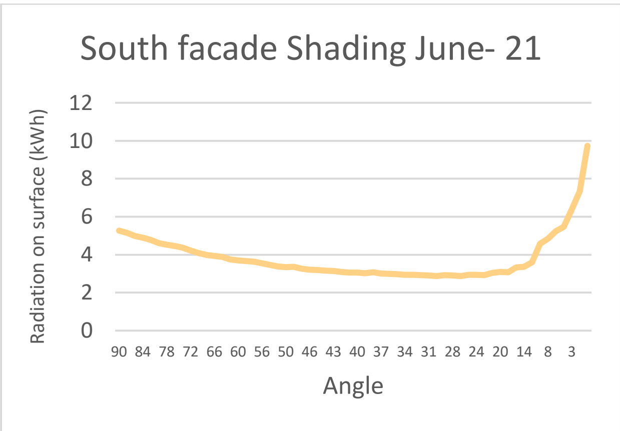


Image 6.3.7 Radiation falling on glass panel for a south façade for Jun 21st

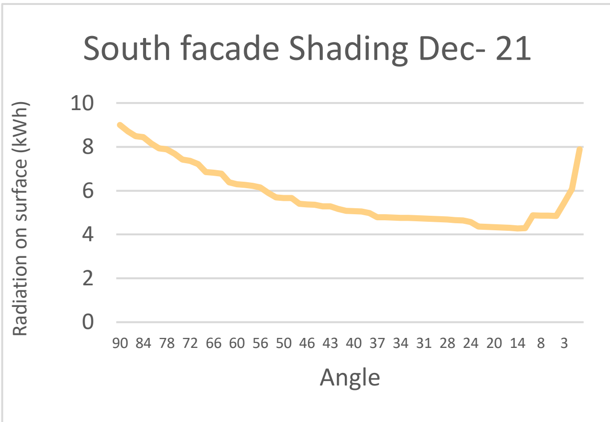


Image 6.3.8 Radiation falling on glass panel for a south façade for Dec 21st

	Mar-21		Jun-21		Sep-21		Dec-21	
	P.V.	Shading	P.V.	Shading	P.V.	Shading	P.V.	Shading
South	38°	90°	72°	30°	38°	90°	17°	90°
East	90°	90°	90°	22°	90°	90°	90°	90°
West	90°	90°	90°	22°	90°	90°	90°	90°
North	90°	90°	90°	13°	90°	90°	90°	90°

Table 6.4 Optimal angle for a P.V. panel and a shading device.

Table 6.4 shows the optimum angle for energy generation by a P.V. panel and the optimum angle for a shading device to have the least radiation in the summer and the most during the other months. To find the angle which is suitable for a P.V. intergraded shading device, the energy saved by the shading device was calculated using the script mentioned in 6.2. In table 6.4.1 the energy generated by the two angles found in table 6.4 is calibrated. The energy generated by the P.V. panel is compared with the energy required to heat or cool the room.

South facade	Angle	PV	Energy for heating/ cooling	
Units	Degree	kW/day	kW/day	difference
Mar 21st	38 °	0.066	5	-4.93
Mar 21st	90°	0.044	4.86	-4.81
Jun 21st	72°	0.087	0	0.087
Jun 21st	30°	0.069	0	0.068
Sep 21st	38 °	0.066	0.032	0.033
Sep 21st	90°	0.044	0.029	0.015
Dec 21st	17°	0.02	2.73	-2.71
Dec 21st	90°	0.01	2.39	-2.38

Table 6.4.1 Energy generated by a P.V. panel and a shading device.

Based on the energy generation of a P.V. panel and the energy saved for a shading device the best angles for a P.V. intergraded shading device is mentioned in table 6.4.2. A detailed calculation can be seen in Appendix C. The huge difference in heating and cooling is seen as the calculations for heating and cooling take into account the temperature. Since the temperature is low in the winter and spring months the heating values are high.

	Spring	Summer	Fall	Winter
South	90°	72°	38°	90°
East	90°	50°	90°	90°
West	90°	50°	90°	90°

Table 6.4.2 Angle for P.V integrated shading device.

This logic can also be utilized for other locations. For example, if the shading device is placed in a warmer region such as Dubai. The same simulation logic can be used and instead of allowing the radiation in during winter, spring and fall. It can be used to block the radiation throughout the year.

	Mar-21	Jun-21	Sep-21	Dec-21
Energy difference between with shading at the angles mentioned above and no shading(kWh)	-0.306	0.002	-0.0002	-0.02
Energy saved for the seasons (kW/ season)	-27.571	0.246	-0.0212	-2.66
Total energy saved by shading device in a year (kW/year)				-30
Energy produced by P.V. panels in a year (kW/year)				234 kW
Total energy saved by P.V. integrated shading device in a year (kW/year)				**203.9**

Table 6.4.3 Energy saved by P.V. integrated shading device

Table 6.4.3 shows that in the spring months of February, March, and April the shading device is not effective. But the loss of energy by the shading device is overcome by the energy produced by the P.V. panel.

6.4 East and west façade

The above analysis was made along the different angles changing in altitude which were suitable for a south facade. The rotation of the east façade was analysed when it moved along the azimuth. The analysis showed that a P.V. panel that rotates along the east and west axis can produce more energy for P.V. if the panel is tilted towards the sun in the morning in the east façade and in the evening it is at 90 degrees. Since this is based in the Netherlands, It means that there is insufficient solar radiation for heating the indoor space. An energy simulation on the energy saved will provide more answers. Analysis along the west façade showed similar answers.

6.5 Peak loads

Using the script the Peak heating load on a winter day: 882.4W. Peak cooling load on a summer day: 1014.4 W.

The energy produced by one panel on a clear day on June 21 is 0.000409 kWh/m^2. Which is 0.000818 kWh or 0.818 Wh. Since energy is produced for 15 hours it produces 12.2 W in one day in June. It produces 1.5% of the energy used by a room.

Similarly, the energy produced by one panel on a clear day on Dec 21 is 0.000111kWh/m^2. Which is 0.000222kWh 0.222Wh. Since energy is produced for 6 hours it produces 1.332W in one day in December.

	Tilted azimuth		90 degree		Tilted along altitude	
	P.V. (kW)	Shading (kW)	P.V.(kW)	Shading(kW)	P.V.(kW)	Shading(kW)
Mar	0.0020	5.87	0.0009	6.10	0.0009	6.10
June	0.0034	6.42	0.0018	8.21	0.001757	5.96
Sept	0.0019	5.16	0.001	6.3	0.001	6.3
Dec	0.0004	1.46	0.0002	1.87	0.0002	1.87

Table 6.4 Angle for P.V integrated shading device east facade.

6.6 Abu Dhabi

The same method was used to calculate the energy produced by a P.V. integrated shading device in Abu Dhabi. Table 6.6.1 shows the optimal angles at which a P.V. panel produces the most energy and a shading device produces the least amount of radiation on the glass. Table 6.6.2 shows the energy produced by a P.V. panel and the energy required to cool the room at the two angles for the four different days. Table 6.5.3 shows the energy saved By having a P.V. integrated shading device.

	Mar-21		Jun-21		Sep-21		Dec-21	
	P.V.	Shading	P.V.	Shading	P.V.	Shading	P.V.	Shading
South	66°	20°	90°	25°	66°	20°	38°	20°

Table 6.6.1 Angle for P.V integrated shading device.

South		PV			Energy for cooling	
		KWh/m2	KWh	KW	KW	difference
Mar-21	66 °	0.00003	0.00006	0.00072	8.582	-8.58
Mar-21	70°	0.000249	0.000498	0.005976	8.203	-8.197
Jun-21	90°	0.000445	0.00089	0.01068	22.39	-22.38
Jun-21	25°	0.000377	0.000754	0.009048	22.44	-22.43
Sep-21	66 °	0.00003	0.00006	0.00072	20.16	-20.16
Sep-21	70°	0.000243	0.000486	0.005832	19.74	-19.73
Dec-21	38°	0.000088	0.000176	0.002112	4.716	-4.714
Dec-21	70°	0.000142	0.000284	0.003408	4.580	-4.576

Table 6.6.2 Angle that produces the most energy for P.V. panels and least energy consumed by the building

	Mar-21	Jun-21	Sep-21	Dec-21
Energy difference between with shading at the angles mentioned above and no shading(kWh)	1.76	0.52	1.88	1.02
Energy saved for the seasons (kW/3 months)	164	49.22	174.47	94.58
Total energy saved by shading device in a year (kW/ year)				482.27
Energy produced by P.V. panels in a year (kW/year)				302
Total energy saved by P.V. integrated shading device in a year (kW/ year)				**784**

Table 6.6.3 Energy saved by P.V. integrated shading device

6.7 Conclusion and Limitations

This chapter looked at finding the right shape and angle for a P.V. intergraded shading device. For the shape, a continuous panel was chosen as multiple parts cast a shadow on each other making the panel inefficient. For a single panel, 6 different shapes were analysed from angular to curved shapes. The analysis showed that an angular single panel produces the most amount of energy.

An angular single panel can be rotated in four ways. Through the simulation it was evident that the dual axis tracking provided the most amount of energy, however, the angle created by the device was not effective as a shading device. The next best rotation was by a single axis rotation along with the altitude. The energy calculations showed that moving the panel along the altitude is the most effective for a P.V panel and a shading device.

To find the angle at which the panel must be rotated a simulation was made to find the angle at which the P.V. panel produces the most amount of energy and the shading device allows the least amount of radiation into the room in the summer and allows the most amount of radiation during the other months in the Netherlands.

The Netherlands requires a shading device only in the summer months. When comparing the values of a shading device at 90 degrees and a building without a shading device, in February, March, and April when the temperatures are still cold and the heating levels are high. The sun is in a higher position than when it is in the spring months. Having a panel at 90 degrees would affect the sun rays coming into the room. This is why the shading device has a negative value for these months. However, the P.V. panel produces sufficient energy to take care of this loss. Based on the calculations a P.V. integrated shading device produces 203 kW.

The same calculations were made for Abu Dhabi. The benefits of having a shading device can be seen in this simulation as the shading device reduces the cooling load by 482 kW. The P.V. integrated shading device produces 784kW.

6.6.1 Limitations:

Shading devices also act as a protection from glare. This simulation does not account for glare which can be felt by the person sitting indoor. This topic is not covered as glare has many factors to its consideration and is beyond the scope of this thesis.

Another important point to consider is the weather fluctuation that affects the use of a solar shading device. If the weather is unusually warm during the fall or spring period or the summer starts at a later period due to the temperature change, the angle for the shading device may be required to change based on human comfort.

For the simulations, the system does not consider factors such as humidity, ventilation rate, and infiltration that can affect the heating and cooling loads.

7. Designing a rotational system

7. Rotation of system

For a solar tracking P.V. integrated shading device, the rotational system plays an important role. In chapter 2.10 the problem of existing rotational systems is explained. This chapter looks at how the mechanism of heliotropic movement and could be incorporated into the rotational mechanism of a P.V. integrated shading device.

7.1 Movement of stem

The movement of the stem is explained in 5.4. The main takeaway points from the movement that were inspirations for the movement were:

- The stem utilizes water to expand the cells which create the bending movement.
- The stem moves from side to side using compression and tension.
- The stem utilizes a small angle for its movement. This angle is enhanced by the flower head which is perpendicular and also moves more than the perpendicular angle.

Concept 1: This was based on the concept of how a stem utilizes water to expand and contract. If the water increases in one portion of the stem this means that the weight increases in one portion of the stem.

The concept is to utilize the mechanism of weight transfer to cause the stem to bend.

The idea was to look at a material that can be passed through pipes to change the weight. The material that would pass through this would be a liquid that was heavy and can easily be moved. When the material was moved towards one side it would be pushed through the other side.

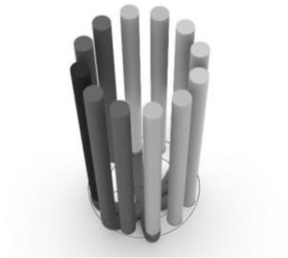


Image 7.1.1 to utilize weight transfer to create a movement. Source: Own image.

This idea was further developed from the inspiration of the sunflower. The core of the sunflower consists of the pith, which occupies a larger portion of the sunflower. The larger the area the more opportunity it has to create a bending movement. This was modified into prismatic-shaped slices through which a liquid is passed for the weight to change. This gave them more volume and more space for the weight to be transferred.

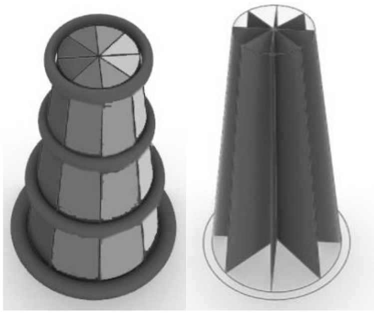


Image 7.1.2 prismatic shaped structure. Source: Own image.

Concept 2: To utilize compression and tension to move the stem.

The stem bends towards one side and during this time one part of the stem is in compression while the other part is in tension. This compression and tension give the stem the flexibility to move in a repeated pattern.

Compression is defined as a decrease in the volume of any object or substance resulting from applied stress. Tension is a stretch or strain by an object resulting from applied stress.

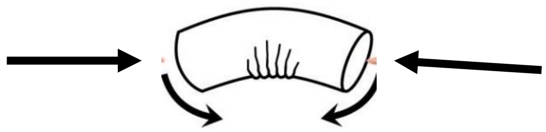


Image 7.1.3: Shows compression and tension. Source: Own image.

By applying a force the material will expand and contract.

When the two concepts were analysed, the second concept utilizes a force that creates a deformation that utilizes compression and tension to cause the movement. While in the first concept the weight transfer acts as the force that creates the compression and tension which causes the movement. Therefore the sunflower uses compression and tension for its movement by utilizing a force. Therefore the idea is to utilize compression and tension for the movement.

Image 7.1.4: A force creates compression and tension. Source: Own image.

Image 7.1.4 is a representation of the idea to utilize a strut that is in compression and tension when a force is applied.

7.2 Materials

Materials that undergo compression and tension when there are stimuli were analysed. The materials analyzed were hygroscopic material, Piezo electric materials, and Soft robotics. The comparison can be seen in table 7.2.3

7.2.1 Hygroscopy

Hygroscopy is explained with an example in chapter 4.1. The main drawback of using hygroscopic materials is the lack of control. As this device will be placed on the exterior of the building it will be exposed to the humidity of the air outside. The device will be required to move according to the position of the sun or according to the comfort of the human comfort levels. If the device rotates on its own it will be difficult to control. Further, it is difficult to remove moisture from the material to gain a certain shape or position. It is easy to add moisture, but difficult to remove the moisture from a device.

7.2.2 Piezo Electric

The Piezoelectric Effect is explained in chapter 4.3. Naturally occurring piezo electric materials often have limitations and are synthesized into piezoelectric ceramics. Piezoelectric actuators have a smaller response time, better accuracy, it is quieter and, no electromagnetic radiations. But they cannot withstand heavy loads and are expensive.

7.2.3 Soft robotics

Soft robotics are robots that are not rigid and can bend using compression and tension upon stimuli from a machine. There are a few problems when it comes to soft robotics. There is a danger of the material part burning out limiting its range of use. Further, they utilize immense energy for small ranges of motion. This requires a high capacity batteries.

Though soft robotics initially seemed like a good option. Soft robotics doesn't directly utilize compression and tension for the movement. Movement is still done by mechanical motors.

Looking at the advantages and disadvantages of all three materials. Piezo electric material can be easily controlled and can respond upon stimuli. It is not affected by atmospheric conditions like humidity. For its movement, it does not depend on motors that have multiple gears like soft robotics.

Therefore utilizing piezoelectric materials to create compression and tension was taken forward.

	Hygroscopy	Piezoelectricity	Soft robotics
Control of movement	Difficult to control as the reaction is very dependent on the moisture level	Easy to control	Easy to control
Precision of movement	Precise up to cm	Precise up to µm	Precise up to mm
Energy utilized	Low energy consumption(Dependent on water)	Medium energy consumption	Heavy energy consumption
Element used for motion	Hygroscopic material	Piezoelectric material	Electric Motor
Development	Still in primary stages of development	Very advanced, Used in actuators	Developed, Used in manufacturing units

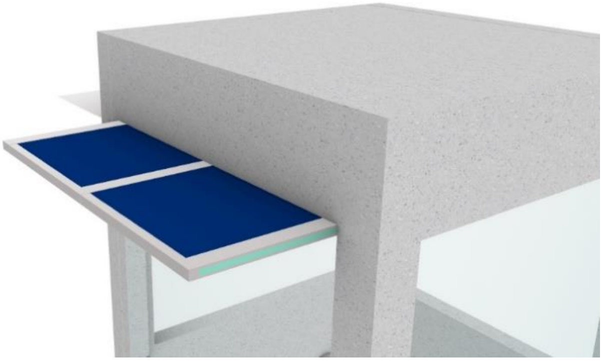
7.2.3 Table comparing the three materials

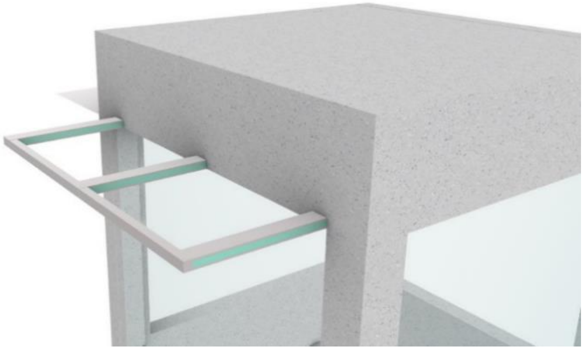
7.3 Piezo electric struts

The design looked at compression and tension as the key principle in the design. The aim was to create a movement using compression and tension with the piezo electric material. Piezo electric strips acted as a supporting member that would hold the P.V. panel.

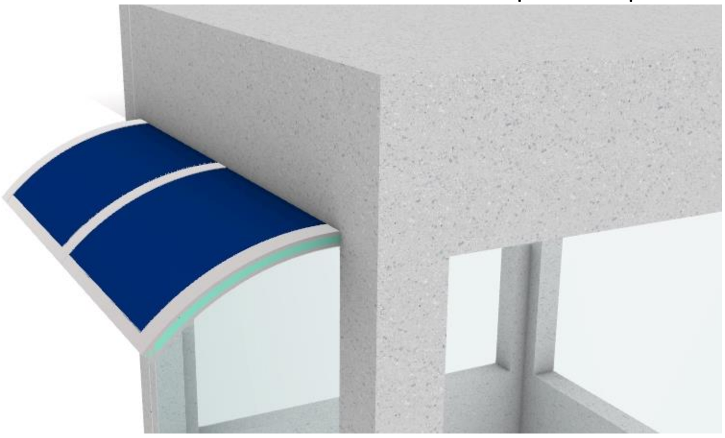
Using case study 4.4 as an example where P.V. piezo electric strips were placed below the P.V. panel to generate electricity.

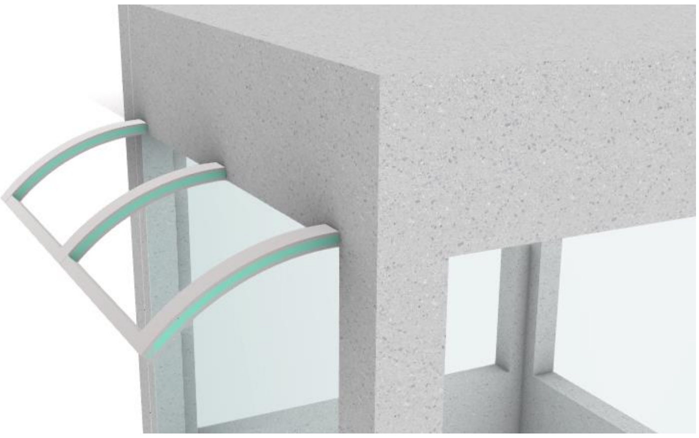
This concept looked at reverse piezo electricity where an electric charge would create a mechanical movement and lower the P.V. panel to the desired angle. Image 7.3 shows the conceptual image of utilizing piezo electric struts with P.V. panels to create the movement.



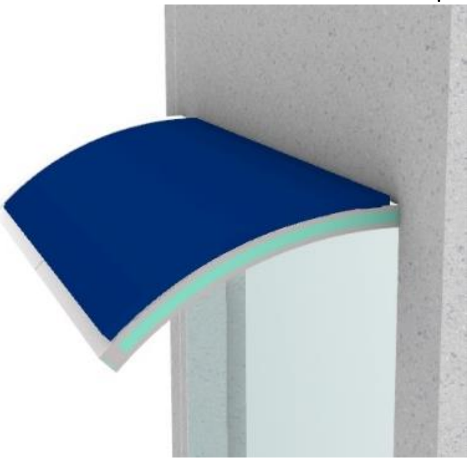


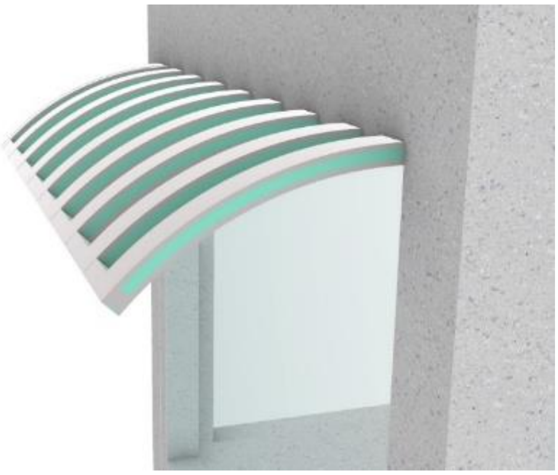
P.V. panels suported by piezo electric struts





P.V. panels that bend when the piezo electric struts bend





P.V. panels suported by multiple piezo electric struts

Table 7.3: Piezo electric struts: Source: Own Work.

7.4 Load of P.V. panel

To calculate the energy generated by a panel, the type of panel needs to be chosen. The most effective type of panel is the mono crystalline panel which weighs the most. The load the rotational device can carry will determine the type of panel.

Assumptions:

Assuming the P.V. panel to be a cantilever beam the load can be calculated.

The wind load plays an important role in the structural analysis. Since the shading device is a freestanding structure the wind affects the load on the canopy. The structure needs to be designed so that it can resist the moment forces. The weakest point lies in the connection. Factors that affect the wind load are the building geometry and the height at which the device is positioned. These two factors determine the upward and downward forces acting on the device. Considering all these factors a wind load of 1.5KN is assumed.

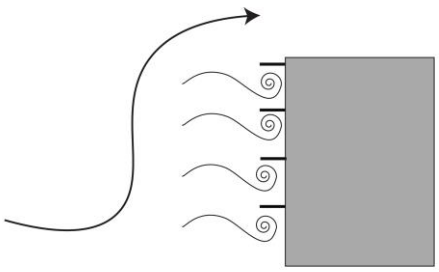


Image 7.4.1 Effect of wind load. Source: Own work

Assuming the P.V panel as a Monocrystaline P.V. - (10 kg/m^2) 0.0980665KN/m^2

Polycrystaline P.V. - (8 kg/m^2) 0.0784532 KN/m^2

Thin film- (0.46 kg/m^2) 0.004511059 KN/m^2

So that the P.V. integrated shading device can be the most efficient, a mono crystalline panel is assumed. The snow load is the pressure exerted by the snow on the device. Since it is a cantilever and the device is situated in the Netherlands. The snow load is assumed as 0.7 KN per sq/m.

The support reaction and moment are calculated for a cantilever of 1meter.

Snow load: 0.7 KN per sq/m

Wind Load: 1.5 KN per sq/m

Total load= 0.098 +0.7+1.5 =2.18KN sq/m

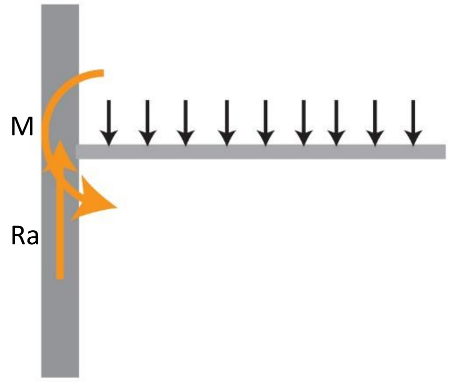


Image 7.4.2 Wind load. Source: Own work

Ra= W*L =2.18*1 = 2.18 KN = 2180 N

M =(WL)/2= (2.18*1)/2 = 1.09KN m= 1090 Nm

This data shows that to move a shading device of one m^2 more than 1090 Nm to move it.

7.4.1 Energy required to move device

The piezo electric actuators of 8mm has a maximum force of 775 Nm that they can move. (P. I. Technology, 2020).

Blocked force = 775N requires 650 V

650V * 0.03 A= 19.5W

It would require 19.5 W to move 775N

Image 7.4.1 bending of Piezo electric strut. Source : Own work

The amount of force required is twice the amount produced by a single actuator. The design will have to be modified or broken down into parts. So that it can carry a load of 1090Nm.

7.5 Design Development

To ease the load on the strut, it is divided into segments that represent the cells. There are three main parts to the design. First piezo electricity acts as the mechanical force that causes the expansion and contraction. The second is the movable layer that responds to the mechanical force and expands. The third is an outer protective coating. Image 7.5.1 shows the first version of the mechanism.

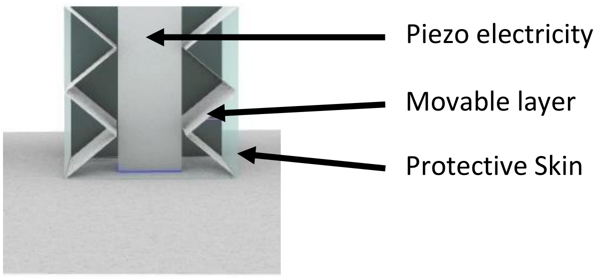


Image 7.5.1: Diagrammatic view of the concept.

The Piezoelectric column in the centre will move to the right when given an electric charge forcing the movable layer to expand. When the piezoelectric column moves to the left. It will cause the movable layer to the left to expand seen in image 7.5.2.

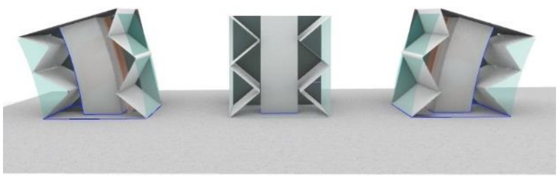


Image 7.5.2: Diagrammatic expansion of the material.

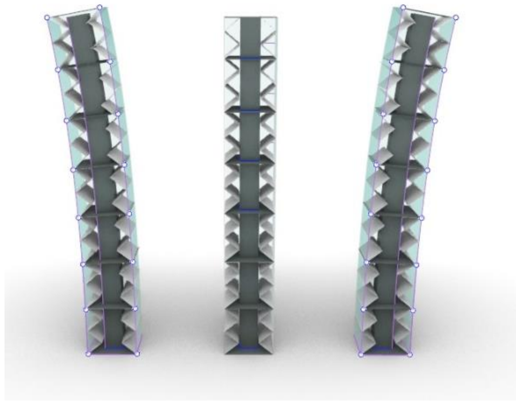


Image 7.5.3: Diagrammatic expansion of the material.

Unfortunately, this idea has a few problems. This will require the piezoelectric core to bend along the moving elements of the stem seen in image 7.5.3. The problem would also be with the locking system. As once locked it will be difficult to release back.

To simplify this mechanism the essence of the movement was broken down into the segments that move up and down. To design a simple mechanism of a stem moving up and down, A piezo electric motion that can push a membrane up and down like the compression and tension motion seen in the sunflower.

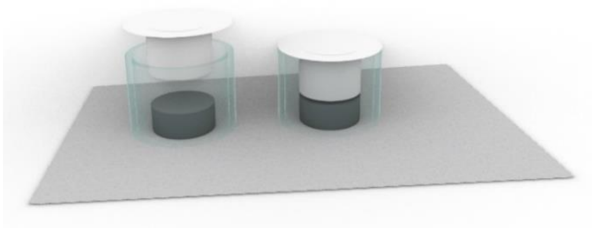


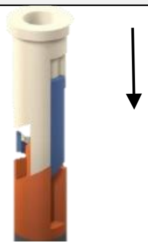
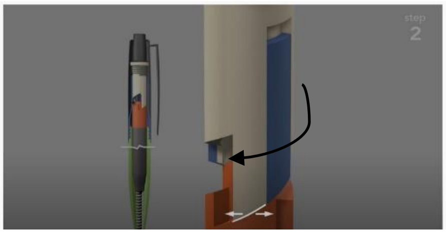
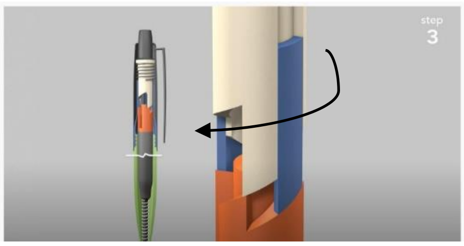
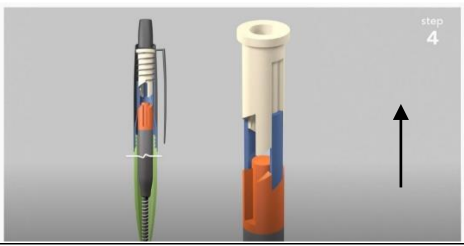
Image 7.5.4: Development of design.

The locking mechanism was incorporated from the ballpoint pen. It requires mechanical energy to move upward and lock. Similarly, the same mechanical energy can be used to get the cylinder down.

7.6 Mechanism of a ball point pen

The ball point pen consists of 3 main parts.

1. Tubular Plunger- This is the part where mechanical energy is applied and that force is passed on to the cam body. It consists of a hollow plastic tube with sharp edges at the bottom. The plunger's teeth go into the cam body.
2. Cam Body- utilizes the force from the mechanical energy and pushes the ink cartridge down and holds it in place. It has angled teeth on one end and flat openings on the other.
3. Stop Members – These members do not move and lock the cam body into place. (Engineer guy, 2015)

Parts of the ball pen	
To push pen outwards	
Step 1: Use mechanical force to push the tubular plunger down.	
Step 2: Using the axial force generated by the spring near the pen nib the tubular plunger rotates 45 degrees on the cam body.	
Step 3: The spring at the rear end unwinds and pulls the tubular upward forcing it to slide on the cam body.	
Step 4: The plunger is released and it rises upwards.	

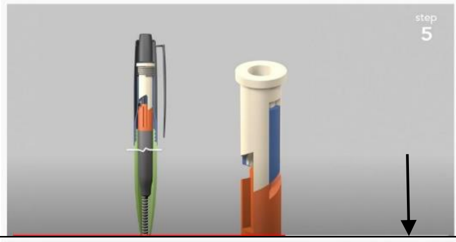
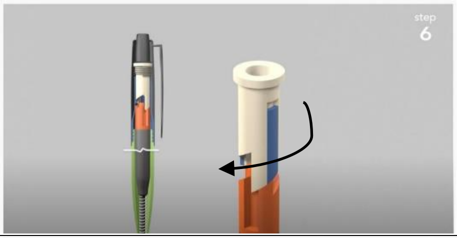
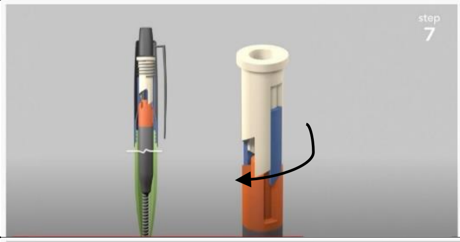
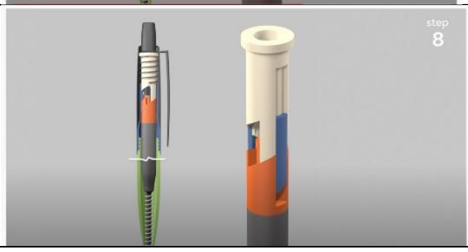
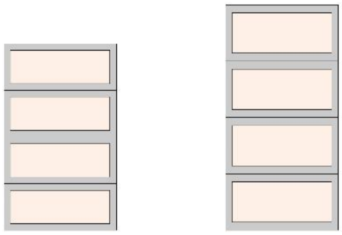
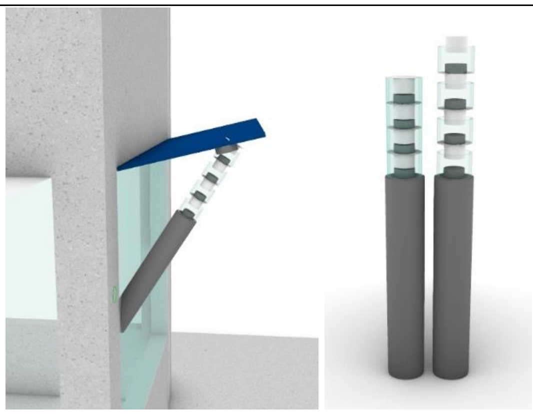
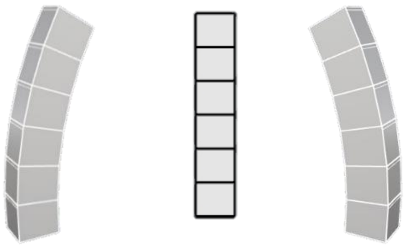
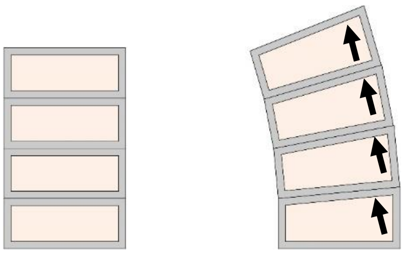
To retract the pen	
Step 5: The plunger is pushed back down.	
Step 6: The cam body rotates to meet the plunger.	
Step 7: The rear spring force the plunger upwards and the in rotates due to the force at 45 degrees.	
Step 8 The mechanical energy is released and the plunger moves upward unlocking itself.	

Table 7.6 Ball pen mechanism Source: (Engineer guy, 2015)

To understand how the force is transferred we look at the cross section of this system. The force is transferred through these small struts. This will determine the load the solar shading device can

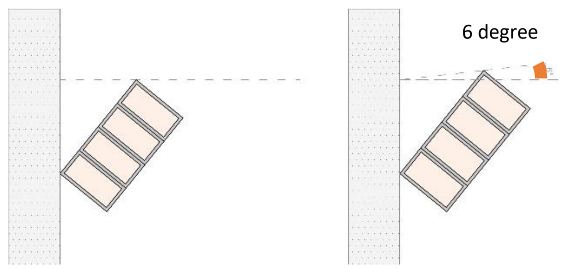
Utilizing the concept of the ballpoint mechanism to move the P.V. panel.

<table>
<tr><td colspan="2">7.7 Design evolution</td></tr>
<tr><td colspan="2">Different design options were looked at. The design looked at small units that move up and down. As it was established in 7.3. a single piezo electric stem cannot be used therefore the support is broken down into smaller units. These units move up and down using the click pen motion. The piezo will provide the mechanical energy required to move the parts up and downwards.</td></tr>
<tr><td>The first step looked at small units that can move up and down. If all the units increase in size the strut can expand and rotate the P.V. panel.</td><td></td></tr>
<tr><td>Since the panel needs to move up and down the first idea looked at support with a fixed lower base with units with the smaller units moving up and down.</td><td>
Image 7.6.1: Diagrammatic view of the concept.</td></tr>
<tr><td colspan="2">Inspiration from sunflowers</td></tr>
<tr><td>The concept looked at the stem of the sunflower as a representation of the strut for the device. The P.V. panel acts as the petals of the panel above it was re-imagined as seen in the image below.

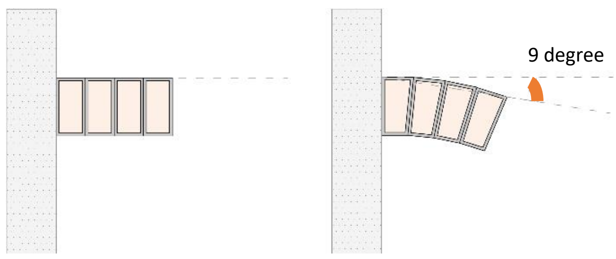
The stem uses compression and tension to move from side to side. This concept looks at a strut that uses a force to bend the strut to use compression and tension.</td><td></td></tr>
<tr><td>This idea looks at segments as a representation of how each cell is expanding and contracting on its own and this leads to creating the overall movement in the stem.</td><td></td></tr>
</table>

Comparing the two types

The angle created by these two types was analysised. Four segments were taken. In the first part, Each segment was raised by 5mm. In the second part. One side of the segment was raised by 5 mm and the other part compressed by 5 mm.



The angle of rotation = 6 degrees

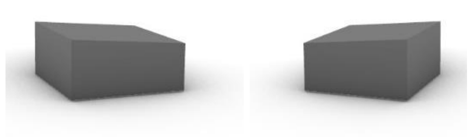


The angle of rotation = 9 degrees

When the two mechanisms were compared the mechanism that uses compression and tension provides a greater angle than the mechanism that expands linearly.

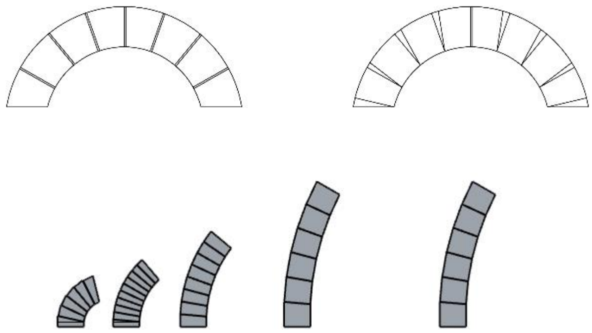
Utilizing compression and tension

Each block would be a trapezoid. The trapezoid would have to change in height on the sides to create the deformation. This block was further analysed to understand the mechanics which can be used for the P.V. integrated shading device.

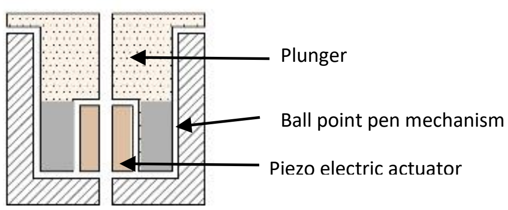


To create the curvature of the strut the formations of arches were looked at for inspiration. There are two types of arches. The first where the stone is a trapezoid and the mortar is rectangular in shape. The second method looks at rectangular blocks with trapezoid mortar to create the shape. The second option was considered as the shape needs to deform and raise its height on different sides.

The arch created depends on the curvature and the number of segments. The more number of segments the more the curvature. The curvature also increases when each trapezoid's inclination increase. The size is determined by the components within the shape

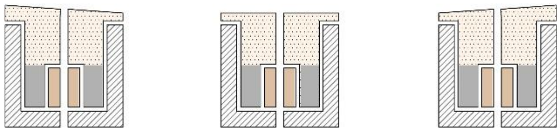


Each unit is divided into two parts, the central space is used to have the wires of the piezo electric run through. The components are encased in a framework. The framework has a piezoelectric material in brown. This acts as the mechanical force. The piezo electric is given a charge and it expands and pushes into the grey area which represents the

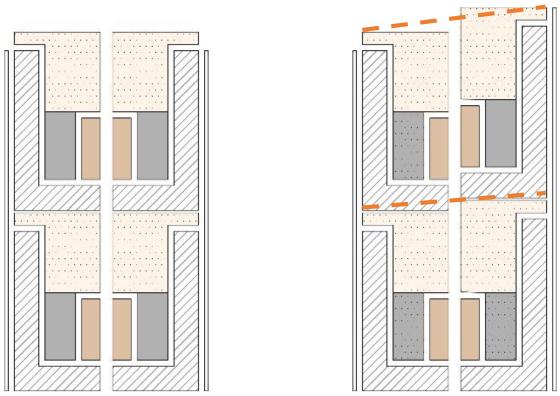


components of a ball pen. When the ball point cylinder is pushed, It pushes up the plunger upwards. To retract and go to its original position. The piezo electric charge pushes the ball point pen mechanism that retracts the plunger.

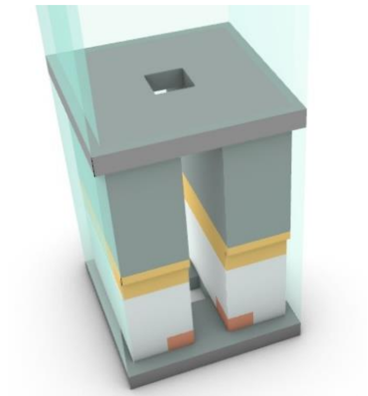
Two options were looked at, the first one was to look at a plunger that is angled the second one is to look at the plunger moving up and down. To have an angular plunger another mechanism is required to move it at an angle. Therefore the design chosen was the second one where the plunger moves up and down to create the movement.



Option 1 : Plunger moves at an angle



Option 2: Plunger moves up and down



7.8 Angle of movement

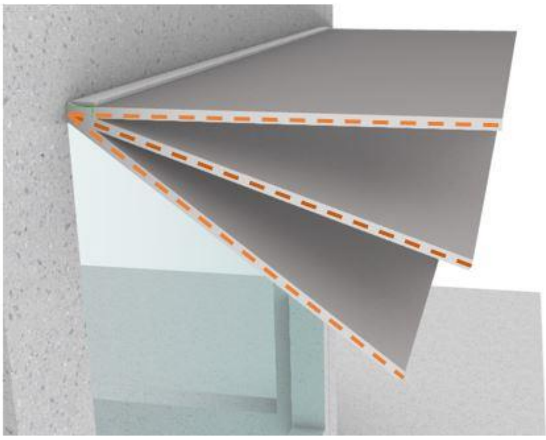
In chapter 6 the angles which provide the most energy are mentioned. However, with this movement, this design also has certain limitations to the angle it can move. If a strut of 1 meter is considered and the segments are limited by the angle The central red line is seen in image 7.8, which is the central position. The stem can move 18.5° upwards and downwards. The stem has a range of 37 degrees.

These are the optimal angles for a shading device.

	Spring	Summer	Fall	Winter
South	90°	72°	38°	90°
East	90°	50°	90°	90°
West	90°	50°	90°	90°

However, due to the restrictions of the shading device, it can only move. in the angles mentioned below.

	Spring	Summer	Fall	Winter
South	90°	71.5°	53°	90°
East	90°	53°	90°	90°
West	90°	53°	90°	90°



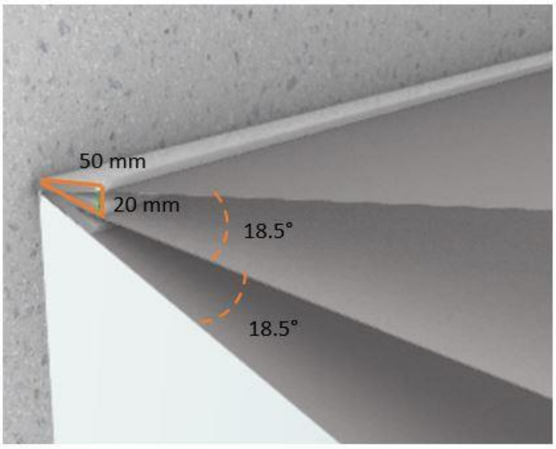
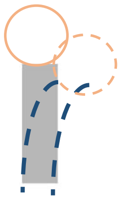
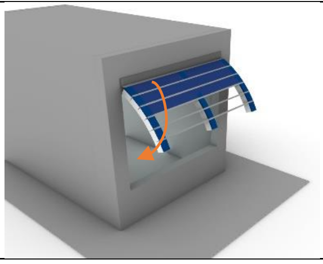
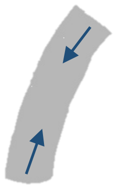
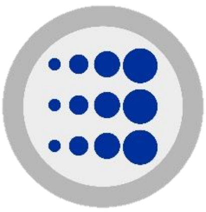
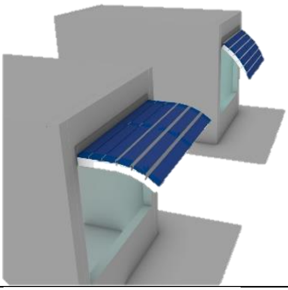
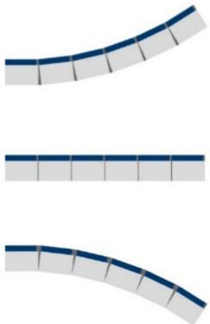


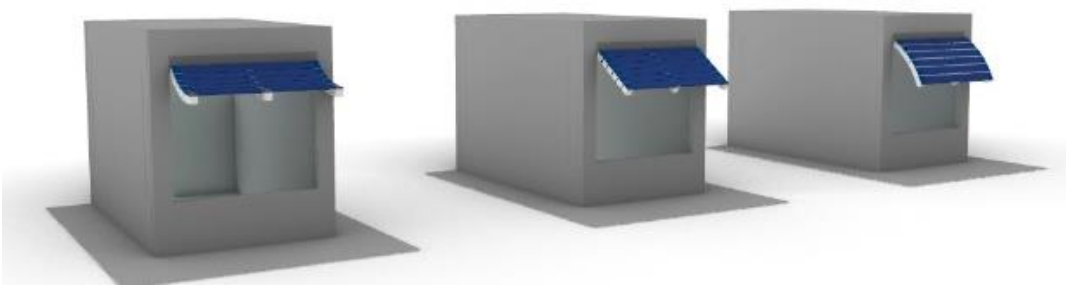
Image 7.8: Angle created by device.

8. Design

8. Design

The design of the solar tracking P.V. Integrated shading device is inspired by the movement of heliotropic plants. The idea is to utilize compression and tension to move the device similar to the sunflower. The table below shows the different elements that were inspired from the sunflower and the benefits of utilizing these mechanisms in the final design.

Sunflower		P.V. Integrated shading device	
Uses the stem for movement		The supports rotate the shading device. This helps reduce the load at one point on the stem. The P.V. panel is placed as strips on the supports which rotate	
Utilizes compression and tension for movement.		Compression and tension allows the support to have a greater angle	
In the cross section of the sunflower stem, each cell expands and contracts on its own which leads to creating the overall movement in the stem.		These strut segments are responsible for creating the movement which leads to a larger variation in its angles that it can bend. The segments bend causing one side of the strut to be in compression while the other one is in tension.	
The stem oscillates between bending to the east and the west. This prevents continuous tension and compression forces to act throughout its life.		Similarly, the central position is considered as the position the P.V. integrated shading device will be in the spring. In the summer it will bend higher up as the sun is higher in the sky. In the winter the device will bend downwards as the sun is lower in the sky. In autumn the device will return back to the central position. As seen in the image below.	



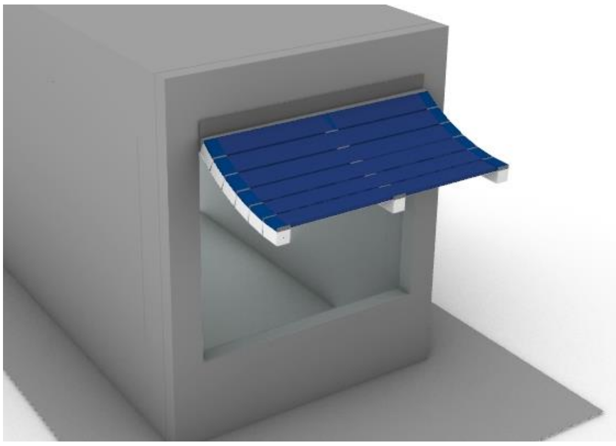
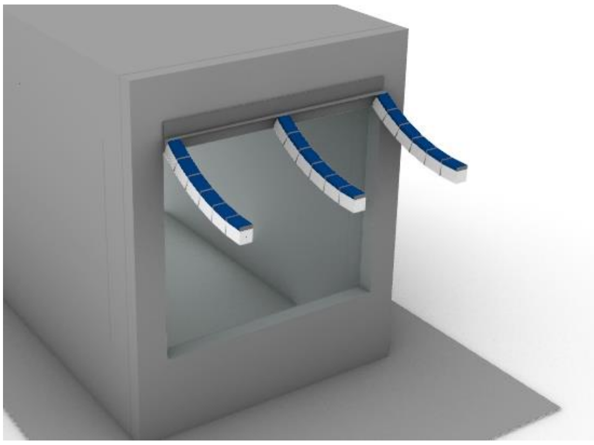
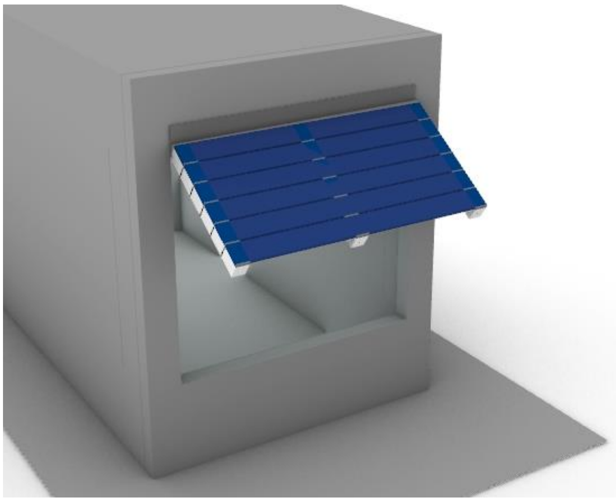
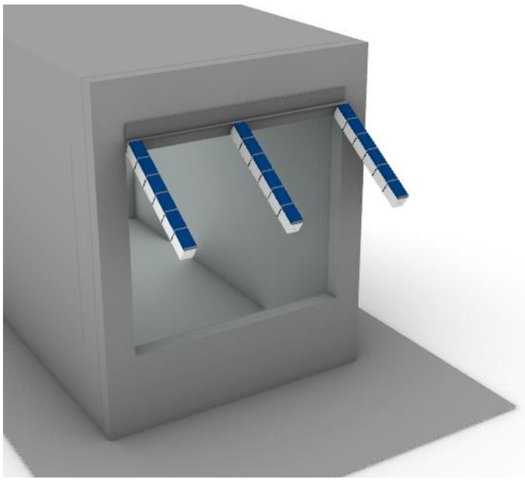
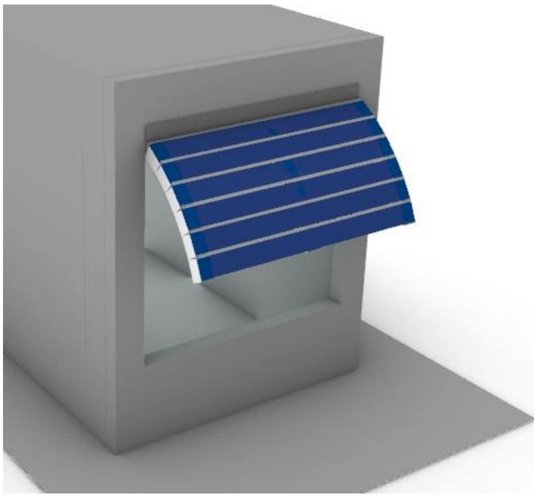
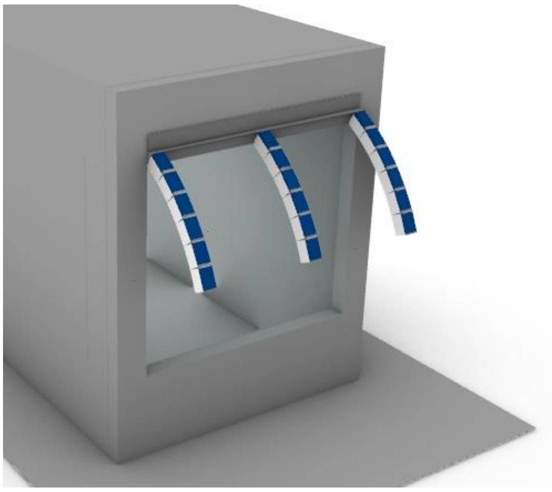
The three positions that the device can move.	
Summer	
	
Spring/ Autumn	
	
Winter	
	

Table 8.1: Angles of the shading device.

8.2 Forces acting on the device

In each segment of the support, the compressive and tension forces acting on them play an important role as they determine the load on the device. Below are the calculations.

Assuming the P.V. integrated shading device to be a cantilever beam. The calculations were made for a monocrystalline panel. From the calculations in 7.4 we know that the moment is 1090Nm and the force at Reaction at th junction where the panel meets the wall is 2180N.

The aim is to balance these two equations. To resist the moment there is going to be compression on the top and tension at the bottom. To resist the moment a moment equilibrium equation is used as shown below.

M= moment

F_c = force in compression

F_t = force in tension

d = depth of material

M= F_c *d

F_c= Area * yield strength

1090= A* yield strength*d

1090= 0.156*d* yield strength*d

Assuming the length of each segment as 0.156 m as that is the length of the solar cell. To determine d we use the equation above. From chapter 7.4 we know that the moment is 1090. Utilizing this formula we can balance the equation. To ensure the material doesn't crush. If the moment is larger than Fc it will collapse.

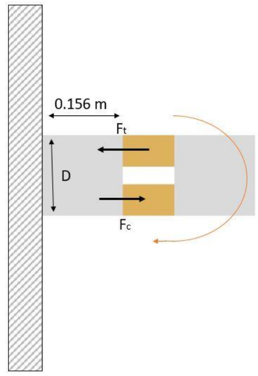


Image 8.2: Forces acting on the turning mechanism in ball point pens.

For the moment the yield strength plays an important role. The yield strength is dependent on the material chosen. In table 8.2.1 4 materials are analysed with their strengths.

There are two forces Fc and Ft are the resisting forces as these are the points through which the force is passed. This will help determine the forces in these two struts. As the system utilizes the ball point mechanism. In chapter 7.6 it is explained how the force is transferred.

Shear stress

From chapter 7.4 the shear stress is 2180N

V= τ*A

τ= Shear stress

A= π*r^2 = Area of the piston where the force is transferred.

Since there are 2= A/2

Therefore the formula is:

V= τ*(A/2)

From the table 8.2.1, it is clear when you consider all the properties stainless steel is the best option. The CES software was utilized to get the values of Stainless steel AISI 444 annealed

For these properties, stainless steel was used.

Moment

$M = F_c * d$

F_c= Area * yield strength

1090= A* yield strength*d

1090= 0.156*d* yield strength*d

$1090 = 0.156*d*290*10^6*d$

$1090 = 45*10^6*d^2$

Assuming the depth as 0.05

$1090 = 45*10^6*0.05^2$

1090 Nm= 1, 13,100 Nm

This proves that utilizing a depth of 0.05 for the body of the structure stainless steel will not fail. The structure can utilize a depth of 0.05 or higher.

Shear

$A = *0.075 = 0.235\ m^2$

2180 = τ*(A/2)

$2180 = 75*10^6*(A/2)$

If you assume area of the strut as

$A = \pi*r^2$

$A = \pi*0.005^2$

$A = 7.8*10^{-5}$

$2180 = 75*10^6*(7.8*10^{-5}/2)$

2180 = 2945

This proves that utilizing a radius for one strut of 0.005m = 5mm in the structureit should not fail. For this design, the supports are at 1-meter distance from each other.

Category	Stainless steel	Carbon steel	Aluminium	Polymer
Yield strength	290-320MPa $290*10^6$ N/sq m	730-860MPa $730*10^6$ N/sq m	330-357MPa $330*10^6$ N/sq m	130-145MPa $330*10^6$ N/sq m
Shear strength	74.5 - 597 MPa $75*10^6$ N/sq m	160 - 180 MPa 160 N/sq m	26 - 28 MPa $26*10^6$ N/sq m	12 - 15 MPa $12*10^6$ N/sq m
Recyclability	Recyclable	Recyclable	Recyclable	Not Recyclable
Advantages	Excellent corrosion and oxidation resistance	Low cost, mouldable and	Low density, high strength.	High strength and stiffness, low frequency electrical properties
Disadvantages	High cost, low thermal conductivity	Magnetic, low strength, easily corrosive	Low tensile strength and low modulus of elasticity	Susceptible to heat

8.2.1 Different materials analysed for their properties.

8.3 Details

Utilizing the minimum requirements by the calculations from the forces the different components can be designed. The design consists of the following components:

1. P.V. cell - The length of a single unit is dependent on the length of one P.V. cell. The average P.V. cell has a dimension of 156mm*30mm. This is for a monocrystalline panel. This is placed as one long strip across the supports. P.V.
2. Expansion joint – This absorbs the compression and tension differences between two units.
3. Piezo electric actuator- This converts electrical energy to mechanical energy to push the ball pen mechanism.
4. Cam body- utilizes the force from the mechanical energy and pushes the piston rod down and holds it in place.
4. Tubular Plunger- This is the part where mechanical energy is applied and that force is passed on to the cam body. It consists of a hollow plastic tube with sharp edges at the bottom. The plunger's teeth go into the cam body.
5. Piston rod- Connecting the tubular plunger to the piston
6. Piston- moves up and down and helps in the bending of the device.

All these components are composed in one unit. There are two of these as the device needs to bend in two directions. There is a hole in the top of the piston as the wire for the piezoelectric actuator needs to pass through. Below is a detailed drawing with dimensions of the cross section of the unit.

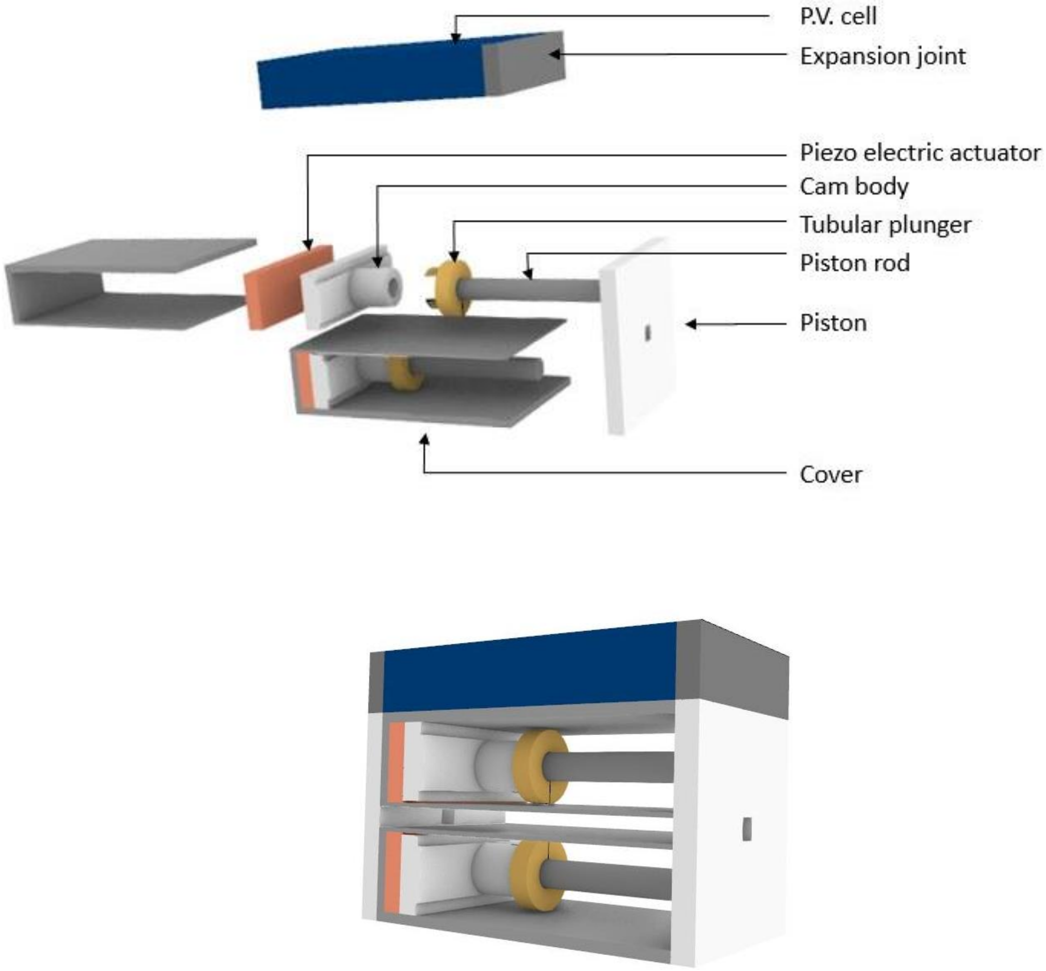


Image 8.3.2 One unit

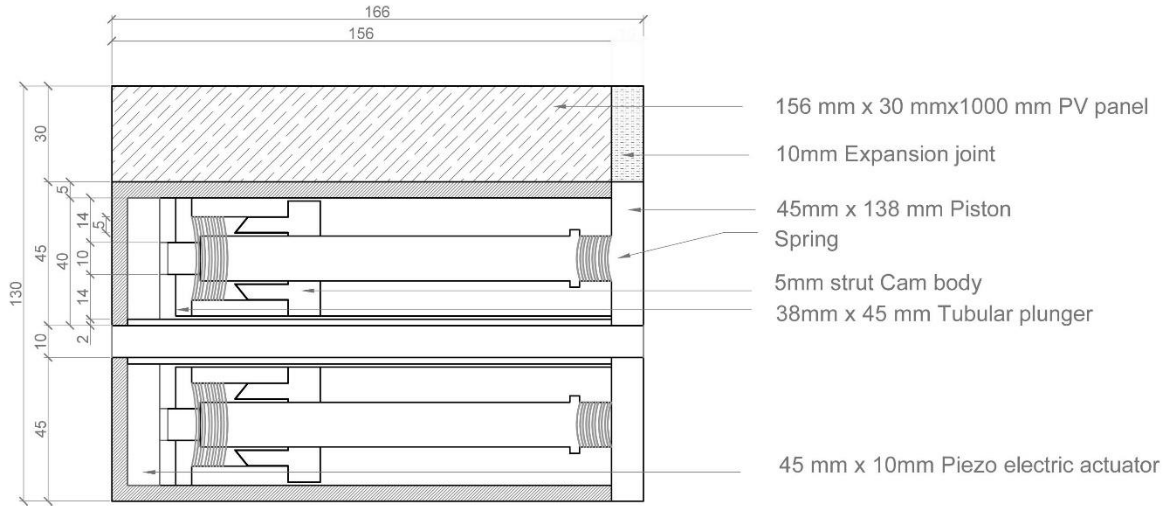


Image 8.3.3: Cross section of one unit.

Image 8.3.3 shows the cross section of a unit. Image 8.3.4 shows two units stacked on top of each other. The piston pushes one unit up by 15mm, this causes the unit above it to bend. This helps create compression and tension in the overall stem.

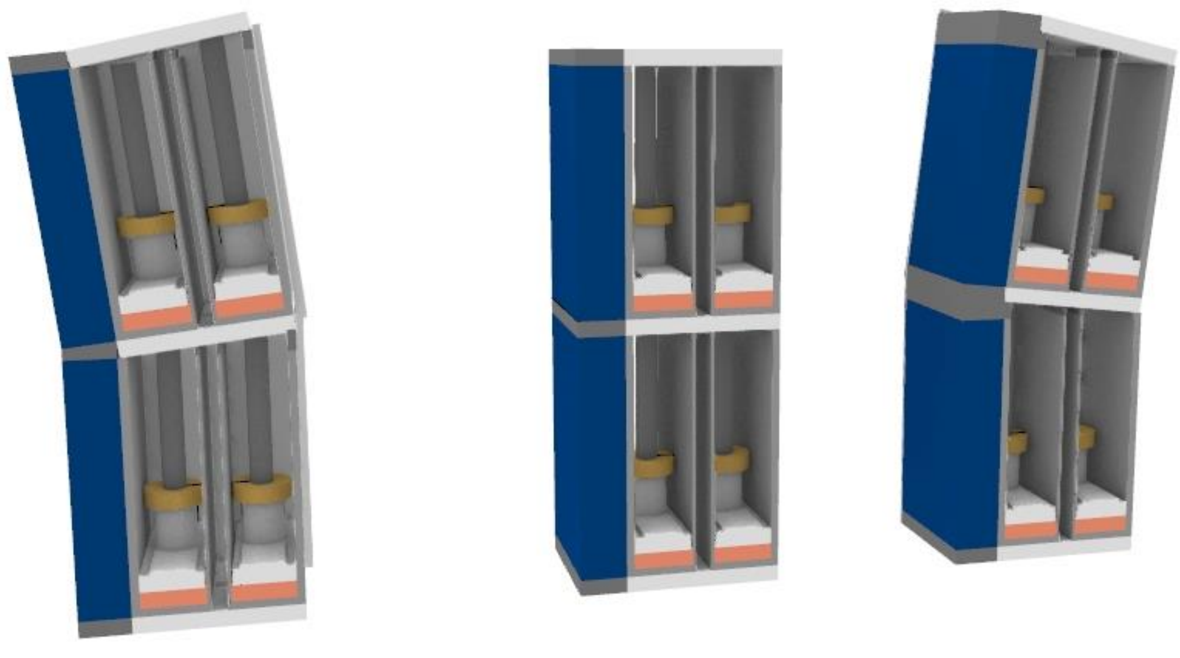


Image 8.3.4: View of inner workings of two units

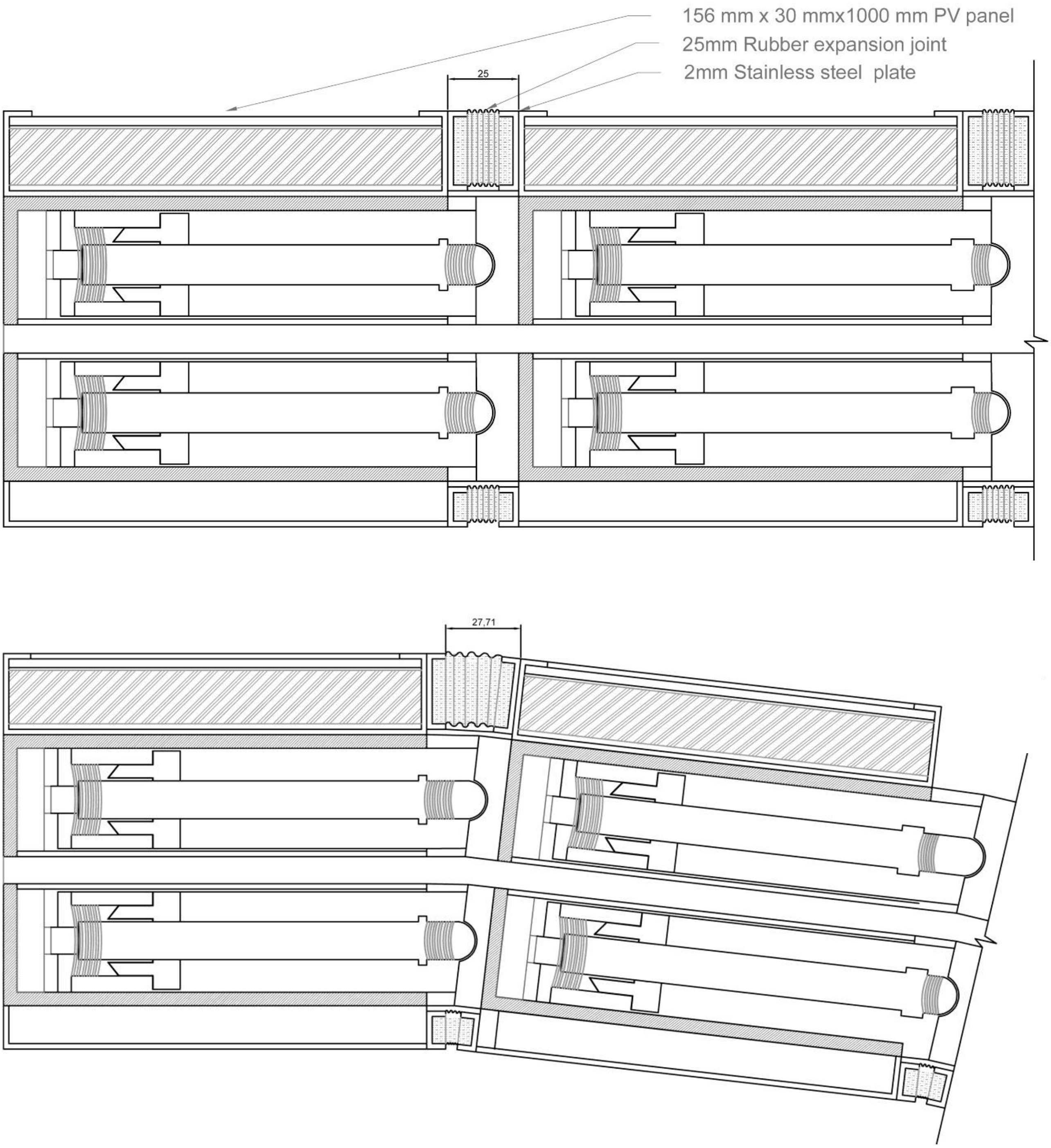
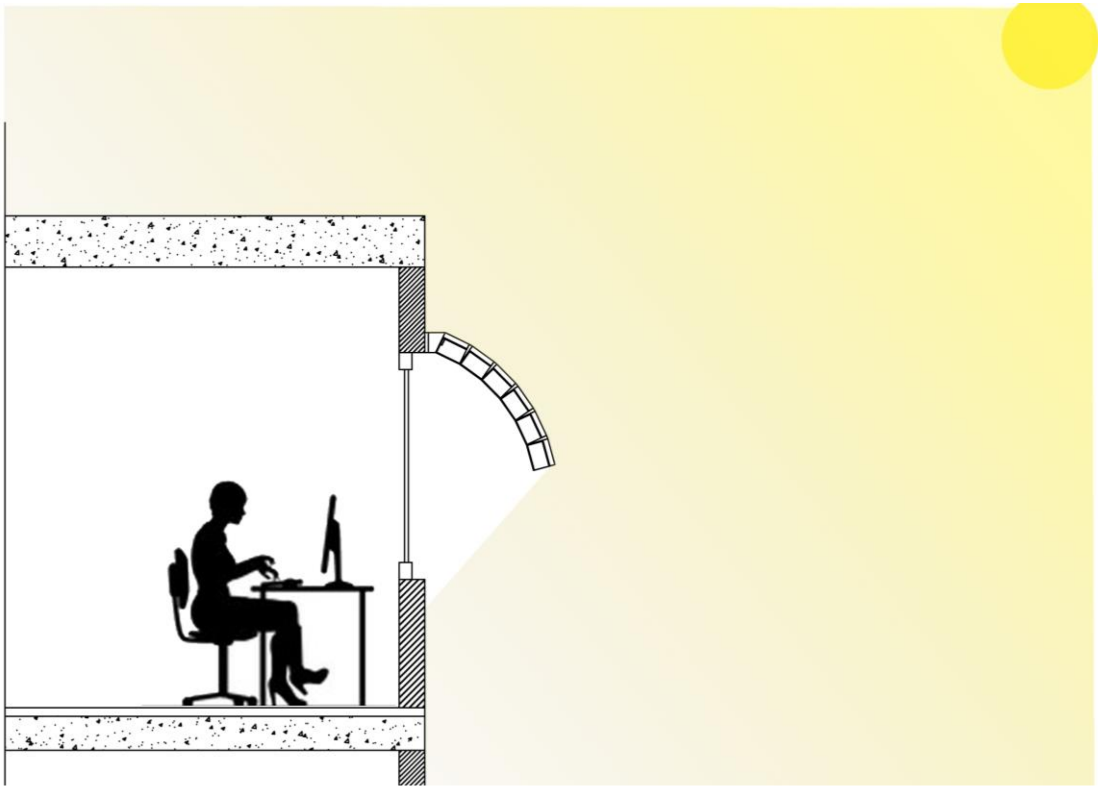


Image 8.3.5: Cross-section of two units

8.4 Movement of panels



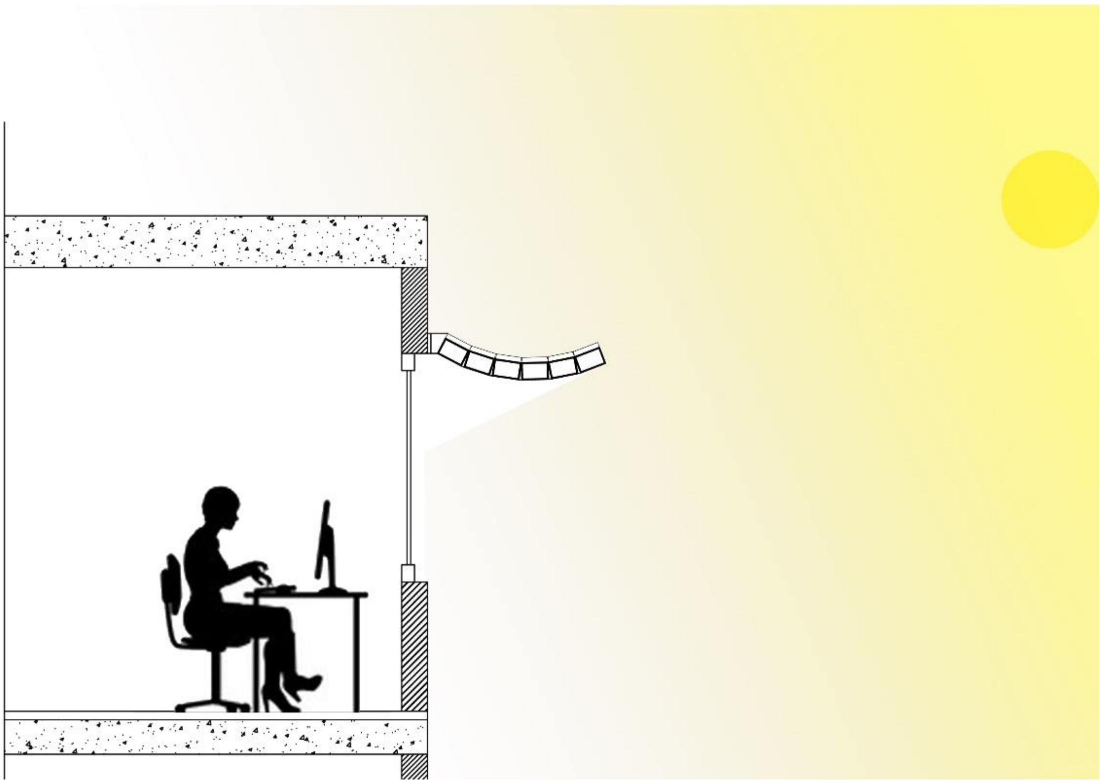


Image 8.3.5 Image in the summer of a south facing window, where the sun rays are blocked by the P.V. integrated shading device.

Image 8.3.5 Image in the winter of a south facing window, where the sun rays come into the room.

Image 8.3.5 interior view of the room in the summer of a south facing window, where the sun rays are blocked by the P.V. integrated shading device.

Image 8.3.5 interior view of the room in the winter of a south facing window, where the sun rays come into the room.

Image 8.3.5 interior view of the room in the winter of a south facing window, where the sun rays come into the room.

Image 8.3.5 interior view of the room in the winter of a south facing window, where the sun rays come into the room.

Image 8.3.5 Mono crystalline panels come in black, blue, and grey.

Image 8.3.6 panel in lowest angle for summer

Image 8.3.7 panel in middle angle for fall

Image 8.3.8 panel in highest angle for winter

Image 8.3.9 panel in highest angle for winter. This image shows how the panel even at 90 degrees can still cast a small shadow which affects the solar radiation coming indoors to heat the space.

8.5 Detail at wall

The details at the wall have an angular stainless steel section that holds the device at an angle. Since the shading device is limited in its range. The angle provides the shading device the opportunity to reach the desired angle. Image 8.5.2 shows how the shading device can reach its maximum potential by rotating using compression and tension.

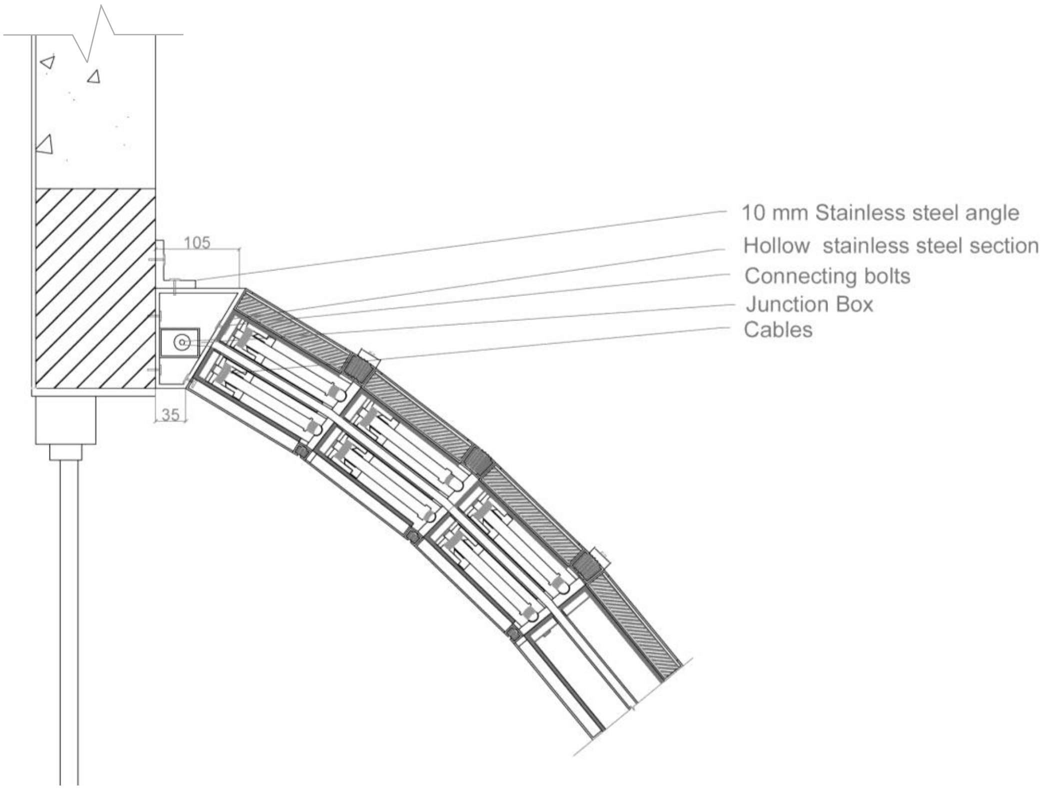


Image 8.5.1 Detail at wall.

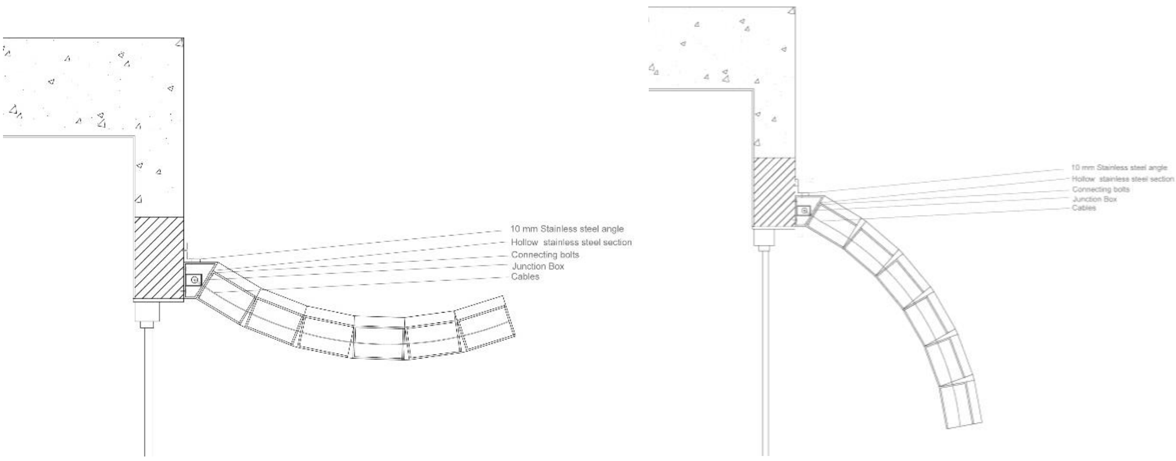


Image 8.5.2 The device moving when fixed at a particular angle.

The first version looks at a fixed stainless steel connection that is angled to provide the optimal angle required by the shading device. The angle of the steel connection can be lowered or increased to meet the required angles needed if this device is used in other parts of the world

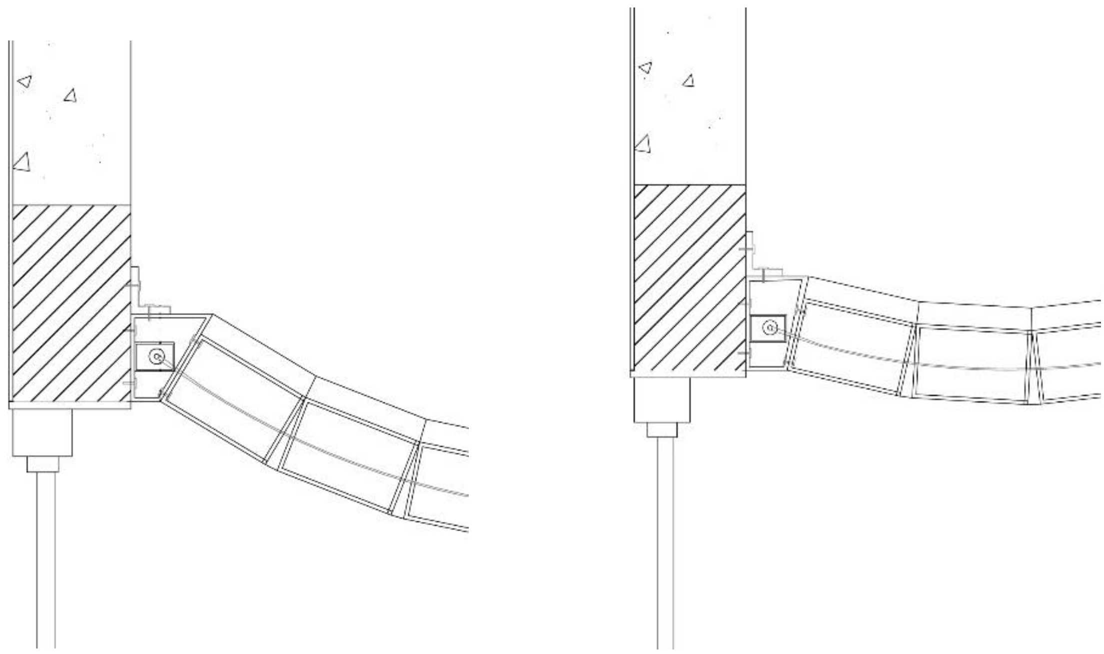


Image 8.5.3 The device moving when fixed at a particular angle.

8.6 Operational cycle

The angles for the P.V integrated shading device are pre-determined. The angle for the shading device changes every 3 months according to the seasons. This change in position will be provided by a clock that will provide an electrical signal to change the angle. The clock will require a steady supply of electrical charge.

The weather also plays an important role in the effect of a shading device. On a cloudy day, the panel P.V. panel is the most effective when it is at 90 degrees. The shading device also does not need to shade the window in this scenario. If the system is connected to a pyrometer that measures the solar irradiance the panel can move back to 90 degrees.

The weather changes frequently and there may be clouds for a few hours and the rest of the day may be sunny. So moving the panel every hour based on the pyrometer will not help.

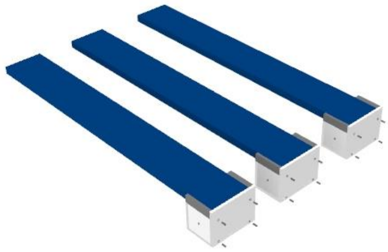
An algorithm can be set up such that every day it uses the weather forecast's prediction of the cloudiness in the sky. The most important period that a shading device needs to work is between 11:00 to 14:00. If the weather is predicted as cloudy for the duration of this period a signal can be sent to the device to stay at 90 degrees for the entire day. A daily movement helps reduce the energy used to move the device.

There will also be a manual override system. Where the user can determine the angle of the P.V. integrated shading device and change the setting.

8.7 Maintenance

Most facades are used for 30 years. So if the panel is moved every day for 30 years it is moved 365*30yrs = 10,950 times. The ball pen mechanism can be used many times. However, all mechanical devices can fail. Since there are more components there is more probability of failure.

For this purpose, the device is designed with an external case that can be removed. When the external case is removed a person can have access to the internal ball point mechanism and piezo electric actuator.



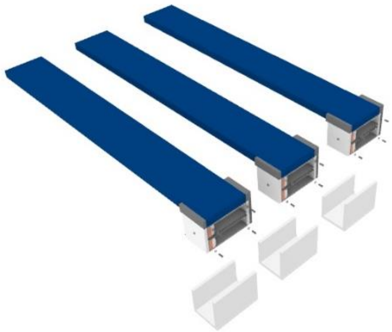


Image 8.5.1: The outer case can be removed with a screw

The ball point mechanism with the piezo electric actuator is designed such that it is a unit that can be pushed and locked into place. When you push the unit it unlocks.

This allows for easy maintenance, if one unit fails, it can be replaced where a single ball point pen mechanism can be replaced

The P.V. Panel has a protective coating. The internal actuator is protected by a stainless steel cover. The stainless steel cover is coated so that it is protected from environmental factors. This ensures that it is weatherproof.

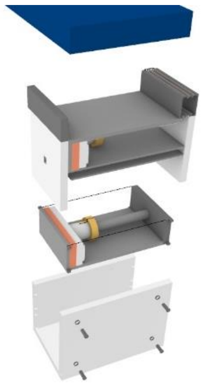


Image 8.5.2: The ball point mechanism can be changed y removing the unit and inserting a new one.

8.8. Energy calculations

To calculate the energy used by the entire device, the energy saved by the P.V. integrated shading device, the energy used by the Piezo actuator,

8.6.1 Energy saved by P.V. integrated shading device.

To calculate the energy efficiency of the device, first, the energy generated saved by the P.V. Integrated shading device was calculated utilizing a grasshopper script mentioned in 6.2. Then the energy required to move the device.

8.6.2 Energy for Piezo actuator

The piezoelectric actuator uses 650 V to move 775N of blocked force. As that is the amount of energy required to move the unit.

Since the total force required to be moved is 1090. This is divided into 6 units. Each unit needs to move 181.6 N. To move 265 N a piezoelectric actuator uses 200 V. These values were taken from a piezo electric actuator manual (P. I. Technology, 2020).

200V * 6 units = 1200V

1200V * 0.03 A= 36W

8 times a year = 288 W /year

For 3 supports = 864 W/ year

If the piezo electric actuator moves every day the energy used:

1200V * 0.03 A= 36W

If the support moves twice for 365 times a year = 26,280 W/year

For 3 supports = 78,840W/ year = 79 kW/ year

8.6.3 Embodied energy

To calculate the embodied energy the properties were taken from the CES software.

	Embodied energy	Weight Kg	Total MJ
Stainless steel	12 MJ/kg	3	36
Piezo electric actuator	1450 MJ/kg	0.00000012	0.000174
P.V. cell	1375 MJ/kg	0.056	77
Expansion joint	36 MJ/kg	0.0036	0.129
Total			113MJ

Table 8.8.1: Embodied energy

Assuming a lifespan of 10 years. The total energy is divided by 10 to understand the energy required per year to take care of the energy used by the materials. 113/10 = 3.7MJ = 3.1389 kWh

8.6.4 Energy used by clock

The energy used by a clock requires a constant supply of electricity which is connected to a microcontroller that will give signals to the actuator to move up and down.

Energy for micro controller (Arduino, 2018)

P= V*A = 5* 0.02 = 0.1 W

Throughout the year = 876 W

Energy by clock = 2500 W

Total energy =3376 W= 3.3KW

8.6.5 Energy calculations for the Netherlands

Utilizing this the energy efficiency of the above calculations unit is calculated.

This looks at energy calculations in the Netherlands if the panel is moved twice every day.

Energy produced by P.V. interatd shading device	+ 203 kW / year
Energy utilized by Piezo actuators	- 79 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**117 kW / year**

Table 8.8.2: Netherlands energy production if it moves everyday

For a room of 3m*5m the heating load is 1028.64 KW and the cooling load is 128.0867 KW. If the panel is moved 4 times a year it can reduce the load on the heating HVAC system by **10%**

This table below looks at energy calculations in the Netherlands if the panel is moved four times a year

Energy produced by P.V. integrated shading device	+ 203 kW / year
Energy utilized by Piezo actuators	- 0.43 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**196 kW / year**

Table 8.8.2: Netherlands energy production if it moves 4 times a year

For a room of 3m*5m the heating load is 1028.64 KW and the cooling load is 128.0867 KW. If the panel is moved 4 times a year it can reduce the load on the heating HVAC system by **16%.**

8.6.5 Energy calculations for Abu Dhabi

This looks at energy calculations in Abu Dhabi if the panel is moved twice every day.

Energy produced by P.V. integrated shading device	+ 784 kW / year
Energy utilized by Piezo actuators	- 79 kW/ year

Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**698 kW / year**

Table 8.8.2: Abu Dhabi energy production if it moves every day

According to the energy simulation done by using the methods explained in 6.2 the room requires a cooling load of 5066.951 KW. This device reduces the cooling load by **13%.**

This looks at energy calculations in Abu Dhabi if the panel is moved four times a year.

Energy produced by P.V. integrated shading device	+ 784 kW / year
Energy utilized by Piezo actuators	- 0.43 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**777.13 kW / year**

Table 8.8.2: Abu Dhabi energy production if it moves 4 times a year

The room requires a cooling load of 5067 KW. This device reduces the cooling load by **15%.**

8.9 Cost of product

The following calculations are made for the cost of the product. They do not include manufacturing cost, installation cost, and other factors that are included in the price of a shading device.

	Cost/Kg	Weight Kg	Total MJ
Stainless steel	0.2	3	0.6
Piezo electric actuator	165	0.00000012	0.00003267
P.V. cell	28	0.056	15.68
Expansion joint	15	0.0036	0.054
Total			16.3 Euros

8.10 Other uses

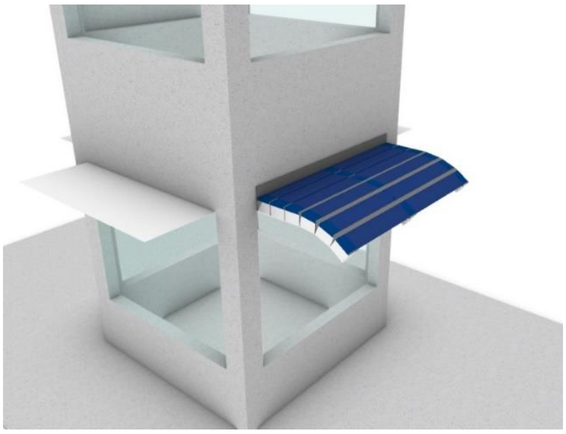


Image 8.3: The shading device that can bend at different angles

The main advantage of this design is the units can be made in other variations so that it is suitable to bend in multiple variations. Since each segment moves based on an electrical signal. The amount the panel bends can be controlled by the signal. This provides the opportunity to move the panel in a different direction.

This methodology can also be used for façades. This will provide the faced with a better angle for a P.V. panel and the façade has more surface area than a shading device. This can produce more energy and the facade will not have the constraints of the shading device.

This device can also be utilized for roofs which has a larger angle of rotation.

8.11 Limitations

The biggest limitation of this design is that it has not been tested. There can be unforeseen problems in the design. The design can

Another major factor that was not considered in the design is the effect of glare on the interior of the room. Shading devices also act as a relief from the glare of the sun. Glare is a large topic and is out of scope for this design.

9. Discussion

9. Discussion

The idea for this thesis was to utilize the solar tracking mechanism of heliotropic plants to design a P.V. integrated shading device. This reflection looks at the three parts to analyse all the data. The first part is the P.V. panels and shading devices. The second part is the heliotropic plants and the last part is the design elements.

9.1 P.V panel and shading

For a P.V. integrated shading device, it is important to balance the requirements of two elements of the P.V. panel and a shading device. The angle plays the most important role. Rotating the panel along the altitude is better than a dual axis system for this device as it takes into account the solar radiation falling onto the glass.

The key feature for designing a P.V integrated shading device is that it should be a single panel so that there are no components that do not shade the P.V. panel and this reduces the efficiency by 70%.

A simulation for the energy generated for a 15m^2 office room with a window facing the south was done using a grasshopper script.

	Spring	Summer	Fall	Winter
South	90°	72°	38°	90°

Table 9.1 Angles suitable for a P.V. integrated shading device

These are the angles that are suitable for a P.V. panel and a shading device. For the Netherlands the months of spring and winter are cold, during this period the heating load is the maximum and the shading device takes precedence. At 90 degrees the device can allow solar radiation to heat the space. The P.V. panel cannot have an angle higher than 90 degrees as it will shade itself and reduce the efficiency of the panel.

The effect of the difference in energy with and without a shading device was done.

	Spring	Summer	Fall	Winter
Energy saved for the seasons (kW/3 moths)	-27.57	0.246	-0.02	-2.66
Total energy saved by shading device in a year (kW/year)				-30.0111
Energy produced by P.V. panels (kW/year)				234 kW
Total energy (kW/ year)				**203.9**

Table 9.2 Total energy produced by shading device in Netherlands

Table 9.2 shows that in the spring months of February, March, and April the shading device is not effective. But the loss of energy by the shading device is overcome by the energy produced by the P.V. panel.

In chapter 8.8. The total energy required for heating and cooling a room of 15m^2 is 1,156.73 KW. If the P.V. integrated shading device moves 4 times a year it produces 196 kW / year when all the losses are taken into consideration. Therefore the P.V. integrated shading device for the Netherlands reduces the load on the heating and cooling system by **16%.**

The same simulation was made for Abu Dhabi.

South			Energy for cooling	
		KW	KW	difference
Mar-21	66 °	0.00072	8.582	-8.58133
Mar-21	70°	0.0059	8.203	-8.19726
Jun-21	90°	0.01068	22.397	-22.3864
Jun-21	25°	0.0090	22.44	-22.4314
Sep-21	66 °	0.00072	20.163	-20.1625
Sep-21	70°	0.0058	19.74	-19.7375
Dec-21	38°	0.0021	4.716	-4.71419
Dec-21	70°	0.0034	4.580	-4.57677

Table 9.3 Angles suitable for a P.V. integrated shading device

The main takeaway from table 9.3 is that the cooling load is significant in the months of June and September. The climatic conditions have a large impact on the impact of the shading device. In warmer regions the shading device has a larger impact on reducing the cooling load as seen in table 9.4.

	Mar	Jun	Sep	Dec
Energy saved for the seasons (kW/3 moths)	164	49.22	174.47	94.58
Total energy saved by shading device in a year (kW/year)	482.27			
Energy produced by P.V. panels (kW/year)	302			
Total energy (kW/ year)	784			

Table 9.4 Total energy produced by shading device in Abu Dhabi

In table 9.4 the energy produced by a P.V. panel is 784 kW. If the P.V. integrated shading device moves 4 times a year it produces 698kW / year when all the losses are taken into consideration. The cooling load is 5067 KW. This device reduces the cooling load by **13%.**

When you look at the overall energy saved by the shading device, the shading device in the Netherlands has more of an impact on the heating and cooling load than in Abu Dhabi. This is due to the high energy load required by the cooling system in Abu Dhabi.

9.2 Heliotropic plants

From the literature review, it was clear that the sunflower tracked the sun by moving the stem rather than the head of the flower.

An experiment was setup to track the movement of the sunflower. However, a pest infestation destroyed all the plants a few months into the experiment. Due to the lockdown, it was difficult to get the sunflower plants and required biological components. I think the biggest learning from this is the ability to adapt and find new solutions within a framework. One should have a fixed set of goals with a timeline. However, there should be freedom within the framework to change and adapt strategies to reach the desired goal. The contingency plan made for the experiment was very effective.

As the experiment was not successful, the movement was analysed from a case study where a video recording of the movement was used. The video was broken down into images and analysed using digital image correlation software from Matlab. The Matlab script provided answers regarding the angle created by the plants. Microscopic images of the stem provided answers for the movement and inner workings of the stem.

The current assumptions of the cell movement in the stem are a theory from the research. To prove that this theory works would require a scientific deep dive with a biological background to look at the cell and the tissue level. The research done in this thesis on the biological aspects of the sunflower has just scratched the surface of the information we can learn from these plants. An in-depth analysis of the curvature of the stem will provide more answers to the blocking forces in the stem.

9.2.1 Future analysis for heliotropic plants

Further, the material properties of the outer skin of the stem will also provide more clues to the expansion and contraction happening in the stem. Months after the experiment was done, a dried piece of the stem was still lying in my house. I had placed this dried piece of stem in a potted plant. As you see in the image below, the brown part of the stem has swollen up months after the stem was cut. This shows that there is a certain quality in the plants' stem that allows it to expand and contract even after it has been cut.

Image 9.1: Swelling of stem

These are some of the possibilities for future exploration. More analysis of the stem will help in designing better solutions for the future. The experimental l framework mentioned in appendix 2 can be taken forward and executed and analysed with the GOM software where the stem movement can be analysed in all directions. Right now the stem was analysed in a 2D plane, further analysis in the third dimension will allow us to understand the movement better.

This design looked at utilizing the method of compression and tension to design the rotational system. A few points to be kept in mind is the water's role in creating this expansion. The flexibility of the material properties of the skin to do the repeated motion.

9.3 Design

Taking the biological movement of plants into the movement of a P.V integrated shading device was not a simple task. Table 9.5 looks at the comparison of the different elements that were analysed before the design started. The movement was divided into different aspects such as angle created while moving, weight transfer mechanism, deformation of shape, movement of tissue, the curvature of the stem, stimuli that created the movement, and so on. The sunflower utilizes all these elements to track the sun.

Looking more closely at the rotational system of the plant, it was evident that the stem uses compression and tension to move the stem of the sunflower from east to west and then back from west to east. This element of compression and expansion was explored in the design phase.

The design uses mono crystalline panels as this provides the most amount of energy. The design looks at strips of mono crystalline panels that are placed on segments of the rotational system. The advantage is that it can be rotated at different angles.

9.4 Limitations of design

Taking into account the size of the shading device it cannot power an entire house due to its scale but every element that adds to the overall energy conservation. The calculations made for the energy used, is a simulation that assumes a room of 3*5 m with only one window. Further, this energy simulation was done for a south facing wall. If this device is placed on any other side the energy generation will be lesser.

The size of the device is dependent on the piston size. If it needs to carry a larger weight the piston size will increase and the overall depth of the support increase.

The design uses the technique of a ballpoint pen. Ballpoint pens can be clicked multiple times and do not fail until the ink dries out.

	Heliotropic Plants	P.V. panels	Shading devices
Sensor	Pulvinous	Light sensor/calculations	Light sensor/calculations
Sun	Tracks the sun with help of circadian rhythm.	Needs to be perpendicular to rays	To block the sun in summer and allow it in winter.
Rotation angle	180 degrees	360 possible	180 degrees
Rotating part	Stem	Head	Arm
Rotating mechanism	Increase of water in the cells	Rotating parts, gears / gas cylinders	Rotating parts, gears/actuators
Lifespan	Till it changes function	20 years for a panel, but rotating systems have a short life span.	Depends on the material used.
Weak point	1/3rd of stem	Rotational points	Joints / Hinge

Table 9.5 Comparison of the different types of movement by different elements.

However, it is difficult to determine how many times this unit can move without performing tests. The problems related to scaling up this ballpoint mechanism from microns to mm are still unknown.

This device cannot be utilized where straight lines are required. It uses a curvature to rotate.

9.5 Comparison between systems

To understand the advantages and disadvantages of this design. A comparison of different rotational systems can be seen in table 9.6. Further, a comparison is made between the designed system and existing and existing solar trackers in table 9.7.

This table compares the different types of rotational systems. The system designed uses piezo electricity to convert electrical energy to mechanical energy. All the systems utilize different rotational systems. The main advantage of using the heliotropic movement is that the movement is created by compression and tension, this provides the device with the ability to bend to create the movement rather than the concentration of load on one point causing all the forces to be at a single point. The disadvantage lies in the time taken to move the device.

The analysis clearly shows that the existing solar trackers consume less energy than the designed Helio tracker. However, the advantage of this design is that it can carry more weight than a solar tracker and the weight of the body itself is lesser than that of a solar tracker. AS the weight is distributed over the two supports in the case of the heliotracker.

	Mechanical rotational system	Heliotropic movement	Soft robotics	Hygroscopy
Mechanism	Electro magnetic motor which uses gears	Piezo electricity and a ball point pen mechanism	The arm	The material itself
Movement	Hinge movement	The structure is utilized to create the movement	The structure is utilized to create the movement	The structure is utilized to create the movement
Material	Metal	Stainless steel	Polymer	Wood fibers
Energy	Electricity	Electricity	Electricity	Water
Load	Heavy load	Medium load 2KN	Medium load	Light load
Load transferee	Load concentrated at one point	Supported at two ends	Supported at two ends	Entire material takes the load.
Control	Precession to the second	Precession to the minute	Precession to the second	Dependent on the water

Table 9.6: Table comparing the different rotational systems

	Helio tracker	Telescopic cylinder	Solar tracker
Load	Blocking force 775N	Upto 30 KN	-
Energy per movement	19.5 W	50 W	8.64 Wh
Weight of panel	20 kg	5kg	7.02kg
Weight of actuator	3Kg	1-3 Kg	5.64kg
Warranty		2 years	5 year

Material	Stainless steel	Aluminium / stainless steel	

Table 9.7. Table comparing the different types of rotational systems.

9.6 Future design possibilities and other uses

This mechanism of utilizing segmented compression and tension is just a start to the innumerable possibilities out there. This technique can be optimized and used in other applications. They can be utilized in facades and retractable roofs, outdoor patios, sunroof coverings, top hung windows, etc. They can be used in other rotational systems that utilize a curvature for rotation.

The amount the panel bends can be controlled by the signal. This provides an opportunity to move the panel at a different angle. Especially for the east and west directions. The panels in the east can rotate towards the east in the morning. Such design iterations can be done by the shading device.

This methodology can also be used for façades. This will provide the faced with a better angle for a P.V. panel and the façade has more surface area than a shading device. This can produce more energy and the facade will not have the constraints of the shading device.

To make it a better design, the shading device can incorporate the effect of glare and radiant losses.

9.7 Societal Impact

This thesis looks at nature to find solutions for a sun tracking device. An example of a nature-inspired design is the bullet train in Japan. They were designed after the kingfisher bird's beak. The design helped create fewer pressure waves reducing the sound boom after the train exited tunnels making the trains run faster and use lesser energy (High Speed Train Inspired by the Kingfisher — Innovation, 2018).

Similarly, this design looks at utilizing compression and tension in a rotational device to have a long-lasting device that can perform repeated motions without breaking down. Further research is required to see if this device can create a significant change as the train. But, the important element is to keep looking for new methods to make every component in the building energy efficient.

Furthermore, the shading device helps reduce the load on the heating and cooling system. By adding P.V. panels to the device, the device can generate more energy. The aim is to utilize a part of the energy generated by the P.V panel to power the rotation of the system. Making this a sustainable system. Having devices that utilize the energy they produce to perform functions play an important role towards reaching sustainable goals such as the Paris climate change.

Further, this idea of utilizing compression and tension can be seen utilized in other rotational systems such as Solar tracking devices, movable louvers, and rotating façade components.

10. Conclusion

10. Conclusion

The EU is committed to reducing the amount of energy used and CO_2 produced by 2050 according to the Paris agreement. Every component in a building plays a part in making an energy efficient building. This thesis looks at P.V. integrated shading devices.

Shading devices are designed to block the excess heat coming into the building which reduces the load on the cooling system. In the Netherlands, an effective shading device must block the sun in the summer months and allow the sun in the winter months. In the summer when the temperatures drop, the solar radiation let into the room warms up the space and reduces the load on the heating system.

On the other hand, P.V. panels are designed to convert solar radiation into electricity. Combining the two elements into a P.V. integrated shading device can utilize the surface of a simple shading device to generate electricity.

When a P.V. panel is perpendicular to the sun's rays it generates maximum energy. A device that tracks the sun's movement is called a solar tracking device. The existing devices are not efficient and often break down. Many of these systems contain gears that are prone to wear and tear and require high maintenance. This thesis looks at nature for its inspiration to design a P.V integrated shading device. It analyses the sun tracking properties in heliotropic plants. This lead to the research question:

How can P.V. integrated sun shading devices utilize the mechanisms (external Stimuli and internal mechanics) of heliotropic plants?

10.1 Heliotropic plants

- What causes heliotropic plants to track the sun? What components are involved in their movement?
- How do you measure and test the movement of a plant?
- What are the forces responsible for the movement of the plant?

Heliotropism is a form of tropism where the plant reacts to the direction of the sun in a diurnal motion (daily cycle). In heliotropism the plant moves from east to west along with the sun, a simple example is a sunflower.

The plant has a sensor that detects the time of day. Then the plant releases a hormone called Auxin. The Auxin hormone creates a gradient of hormones across the cross section of the stem. The auxin is secreted from the phloem that is radially placed around the core of the stem called pith. The amount of auxin tells the cells in the centre how much water they must absorb. The phloem releases water into the core of the stem. Based on the Auxin level the centre cells know how much water to absorb. The cells towards one side of the cross section absorb more water causing that side to expand. This causes one side to expand and the other side of the stem to contract. This creates movement in the stem.

To analyse the stem movement digital image correlation was used. The sunflower uses a 14 degree inclination for its rotation. The head of the sunflower is perpendicular to the stem the small angle the sunflower utilizes to create its movement is quite efficient. Further, the sunflower gets more sunlight on its head, when the head is tilted more than the 14 degrees provided by the stem. This is possible due to the different cell structure at the head of the sunflower.

The sunflower stem bends to move rather than using a hinge system. When the stem bends it causes compression and tension in the stem. When the stem bends towards the east the right side of the stem is in compression and the left side is in tension. When the stem moves towards the west, the right side of the stem is in tension and the left side is in compression. This compression and tension causes the movement in the stem.

10.2 P.V panels and shading devices.

- What are the problems with the existing mechanisms for shading devices and solar trackers?
- What is the optimal angle and size for a P.V. panel and a shading device, such that it produces the most amount of energy?

The most common problem existing in solar tracking devices and shading devices is the rotational system. These motors often fail due to the many components. The gear systems are complicated, heavy, and bulky with many interconnecting parts which fail. They also consume immense energy to rotate the system. Most manufacturers have a warranty of 5 years for a rotational shading device

This thesis focuses on analysing the angle for a P.V. panel in the Netherlands. There are two types of tracking mechanisms, single axis, and dual axis tracking. Through the simulation, it was evident that the dual-axis tracking provided the most amount of energy. However, the angle created by the device with respect to the façade was not effective for a shading device. As it blocked the window in the winter months.

In single axis tracking the energy, calculations showed that moving the panel along the altitude is the most effective. Based on the altitude the panel can move monthly or seasonally. Based on the energy calculations for moving the panel monthly versus seasonally, there was only a 10% increase in energy production, which was not significant. Therefore the year was divided into 4 parts based on the seasons.

To find the angle at which the panel must be rotated a simulation was made to find the angle at which the P.V. panel produces the most amount of energy and the shading device allows the least amount of radiation into the room in the summer and the most amount of radiation during the other months.

The energy saved by these angles was calculated to find the angle at which a P.V. intergraded shading device can save the most amount of energy. Table 10.1 provides the best angle at which a P.V. intergraded shading device can save the most amount of energy for the three facades of a 15m^2 room.

	Spring	Summer	Fall	Winter
South	90°	72°	38°	90°
East	90°	50°	90°	90°
West	90°	50°	90°	90°

Table 10.1 the angle at which a P.V. intergraded shading device can save the most amount of energy

Due to the restrictions of the rotational device the fall angle for a south facing device is 71.5 degrees. The rest of the angles are the same.

The Netherlands requires a shading device only in the summer months. When comparing the values of a shading device at 90 degrees and a building without a shading device, in February, March, and April when the temperatures are still cold and the heating levels are high. The sun is in a higher position than when it is in the winter months. Having a panel at 90 degrees would affect the sun rays coming into the room. This is why the shading device has a negative value for these months. However, the P.V. panel produces sufficient energy to take care of this loss.

Based on the calculations a P.V. integrated shading device produces 204 kW.

Total energy saved by shading device in a year (kW/year)	-30
Energy produced by P.V. panels (kW/year)	234 kW
Total energy (kW/ year)	**204**

The same calculations were made for Abu Dhabi. The benefits of having a shading device can be seen in this simulation as the shading device reduces the cooling load by 482 kW.

10.3 Incorporating heliotropic learnings into a device

- What properties of heliotropism can be incorporated into the device?
- How will it tackle the problems faced by the existing systems?
- Is the device energy efficient?

The stem uses compression and tension to move the stem of the sunflower from east to west and then back from west to east. Compression and tension were used to create movement in a P.V. intergraded shading device.

Each support is divided into 6 segments. Each segment can increase its height on two ends. If all the segments increase their height on the upper portion it will cause the support to expand on top creating tension on the upper part of the support and compression on the lower part of the support. This causes the support to bend downwards.

If the segments increase their height on the lower portion it will cause the support to expand on the bottom creating tension on the bottom part of the support and compression on the upper part of the support. This causes the support to bend upwards. This movement is similar to that of the stem, where, each cell expands and contracts on its own which leads to creating the overall movement in the stem. By utilizing smaller segments the entire weight of the P.V panel is not at one point. This was the point of failure for solar tracking devices.

The heliotropic plant uses water to maintain its turgor pressure and to stay in a particular position. To counter this Piezo electricity is used to create a force and the ball point mechanism is used to hold the support in compression and tension.

To create the mechanical energy required to move the unit piezo electricity was used. Piezoelectricity can convert electrical energy to mechanical energy. The idea was to utilize the energy produced by the P.V. panel to create a mechanical movement. The calculations for a shading device that moves 4 times a year are seen below.

Energy produced by P.V. integrated shading device	+ 203 kW / year
Energy utilized by Piezo actuators	- 0.43 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**196 kW / year**

Table 10.3.1 Energy by P.V. integrated device in the Netherlands

For a room of 3m*5m the heating load is 1029KW and the cooling load is 128KW. If the panel is moved 4 times a year it can reduce the load on the heating HVAC system by **16%.**

Similarly, the calculations were made for Abu Dhabi if the panel is moved 4 times a year.

Energy produced by P.V. integrated shading device	+ 784 kW / year
Energy utilized by Piezo actuators	- 79 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**777 kW / year**

Table 10.3.1 Energy by P.V. integrated device in Abu Dhabi.

According to the energy simulation done by using the methods explained in 6.2 the room requires a cooling load of 5067KW. This device reduces the cooling load by **15%.**

In conclusion, the P.V. integrated shading device uses compression and tension to rotate the device. By utilizing compression and tension. The weight of the panel is broken down such that they are placed on smaller segments of the support and the weight is divided on the two supports. Compared to the weight being held by a cantilever.

Every element, no matter its size plays an important role in designing an energy efficient building. Nature has evolved over millions of years to create an ecosystem where each element has an important role to play. By looking at nature and understanding its principles one can learn a lot. The smallest components often make the largest impact.

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12. Appendix

Appendix A

Shoe box experiment to understand phototropism.

As explained in chapter 4, phototropism is the movement of a plant towards a light source. This can be easily understood by placing a plant in a dark room and having one light source. This was done by placing some mung beans in a simple container and enclosing them in a shoe box. In the corner of the shoe box a small hole was cut to allow light in from one side. Progression of the study can be seen below in image A.1.1

Conclusion from study: Darwin's theory of phototropism was proven to be true. Plants move towards the source of light. It was interesting to note how the stem moves towards the light, in a curved pattern. There was a difference in colour between the leaves that received some light and the others that did not. The stems closer to the light grew longer and were stronger than the others. It was interesting to note how the plant managed its own self load and bent in one direction, while also managing the load of the leaves.

Date(20/11/2020) initial phase

Date(20/11/2020) initial phase

Date(20/11/2020) initial phase

22/11/2020

23/11/2020

26/11/2020

01/12/2020

04/12/2020

04/12/2020

Image A.1.1: Own Work

Permissions

A space was required to conduct the experiment in. Different spaces in the university were researched such as the basement of BK city, the lama lab etc. The space in the university had to adhere to the following conditions, there needs to be enough warmth and humidity for the plants to survive as the experiment will start in January. A space where the heater is switched on even on the weekends. There needs to be access 7 days a week and access to water and electricity.

Therefore the science centre was chosen as it is accessible through ought the week and the heater is on throughout the weekend. Once space was found, A clearance from the bio-safety officer is required as the experiment involves biological elements.

Due to the ongoing pandemic of Covid-19 the experiment is planned such that it can be portable, in case the university shut down due to a lockdown. If the space is not accessible during a lockdown the unit will be moved to my house.

6.5.1 Choosing the flower.

The test heliotropism the following flowers can be studied: Sunflowers, alpine buttercups, artic poppies, Daisies and Marigolds. A visit to the Tuincentrum GroenRijk 't Haantje in Rijswijk saw the availability of Sunflowers and Poppy seeds. The period of starting the experiment could be an issue as these flowers bloom in May. However, some sunflowers were planted and placed under a set up to test their growth in an indoor environment. The image seen below 6.5.1 shows the growth of plants in controlled indoor environments.


01-12-2020 09 -12-2020

Image 6.5.1 Test of intial sunflower growth indoors under a grow light.

6.5.2 Growing Sunflowers and inferences

There are 150 species of sunflowers as stated by (CABI, n.d). Below is botanical information derived from the centre.

Scientific name: Helianthus annus
Family: Asteraceae
Origin: central and southwestern United States
Height: Varying height, max of 4 meters
Stem: 30-60mm diameter
Leaves: Alternate leaves with three main veins.
Soil: 20-25 degree Celsius , but it should not go below 15 degree Celsius.
Growth temperature- 20- 30 degrees Celsius
Required hours of sunlight: 12 hours
Humidity: 50-75 %

In reality growing sunflowers is harder than reading literature. The plants require constant attention and care. A few of the failures while growing the plants include, excess heat leading to drying of leaves, excess water leading to damaging the roots and damaged roots due to roots being pulled out during repotting. Further, the stem of the plant is extremely delicate. Two stems have snapped during the growing period. One pot was accidentally knocked down from a book shelf and the stem snapped. Second, while repotting the stem was tugged to loosen the soil, this lead to the snapping of the stem. The stem snapped at a point where the stem was weak. Before the plant was re potted the stem was drooping and one particular point was weak due to the constant strain along the stem.

Other problems with the plants included two seeds cannot be grown in one pot. One of the plant did not let the other survive. Further, some of the leaves of the sunflower were attacked by pests and white powdered particles were seen below the leaves. Pesticide was then sprayed on the plant to get rid of the pests. The image below 6.5.3 shows the plants that have been repotted to a larger pot of 21cms.

Image 6.5.2 Date of photo 31-12-2020. The plants have been re-potted to larger pots.

Image 6.5.3 Plant sample A. The last image is of the broken stem

Below is some data from the plants growing (Date of measurement- 28-12-2020)

Plant sample A - height 14 cm diameter – 3 cm

Plant sample B - height- 12 cm diameter- 2cm

Further while growing the sunflowers an observation was made, the weight of the sunflower head to that of the stem can be studied. A fully grown sunflower has a diameter of 150mm and has a stem that is 2 meters tall and a width of 18mm. The sunflower head weighs 57 to 73 g. It was also noted that the moisture gave strength to the stem. When the stem was accidentally cut, the day it was broken the stem stood upright with its leaves. However the next day the stem lost its moisture and the leaves wilted and started to droop.

This finding lead to a research study and according to (İnce et al., 2005) the bending stress of a sunflower stem is highest when the moisture is the maximum in the stem. When the moisture was the lowest the bending stress is two times lesser. The modulus of elasticity of a sunflower stem was analysed and the stem is brittle when there is less moisture.

Further inferences from growing plants showed that the sunflower stem is thicker at the bottom and thinner at the top. When the stem was broken one could see that the stem was like a tube with a hollow centre. Initially while growing the plants, only one grow lamp was used and the plant grew upwards. The heliotropic movement is also based on the sensors that detect the sun’s position showing the link between the sensor and the circadian rhythm.

Room for research.

The science centre was chosen to conduct the experiment. The image shown below 6.5.3.1 is the summation of temperature, light and humidity. This was measured by a hobo data logger. A detailed graph is seen in appendix 1. The temperature does not go below 19 degrees when the outdoor temperature was 2 degrees. The humidity levels are at 50 % and the light intensity was around 100 lux as the room is located in the basement and the light came from a window. The room will be okay to conduct the experiment.

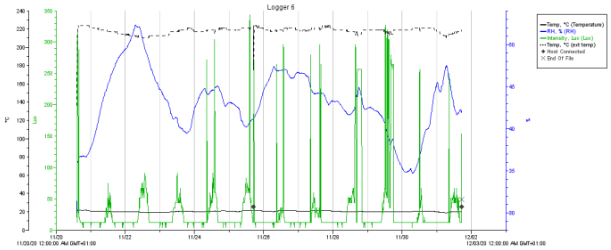


Image A.1 : hobo data logger on table compressed graphs of all parameters.

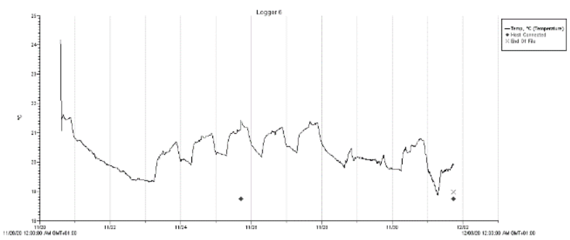


Image A.2 : Hobo data logger on table- Temperature

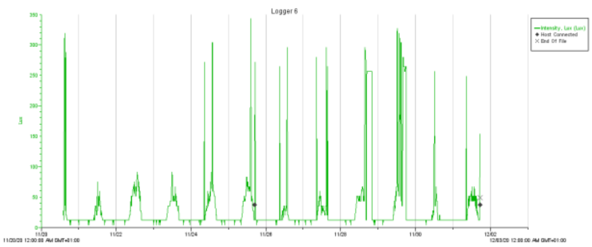


Image A.3 : Hobo data logger on table- Light intensity

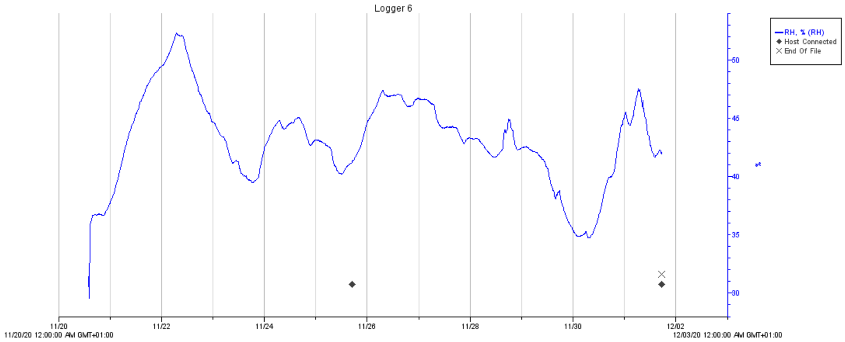


Image A.4 : Hobo data logger on table- Humidity

Readings from my home

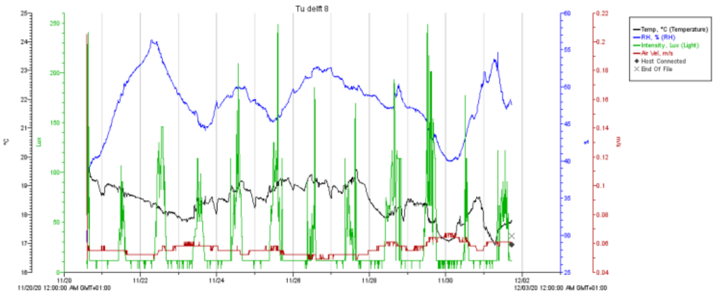


Image A.6 : Hobo data logger near window- compressed graphs of all parameters.

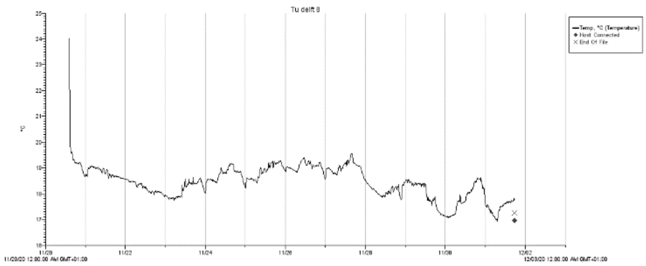


Image A.7 : Hobo data logger near window- Temperature

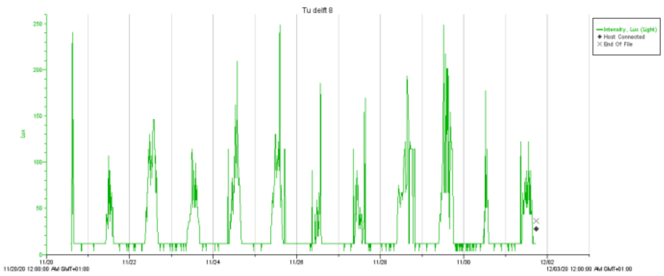


Image A.8: Hobo data logger near window- Light intensity

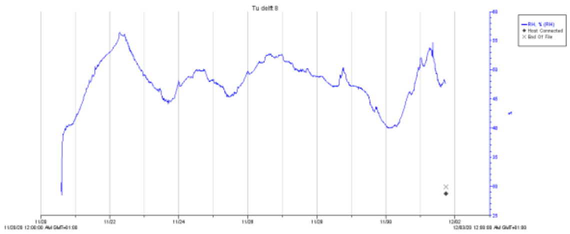


Image A.8 9: Hobo data logger near window- Humidity

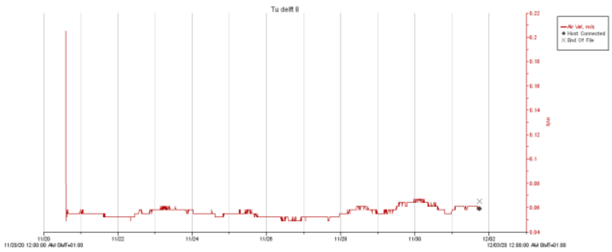


Image A.10: Hobo data logger near window- Air velocity

The blue line represents humidity, the black line temperature, the green light is light intensity

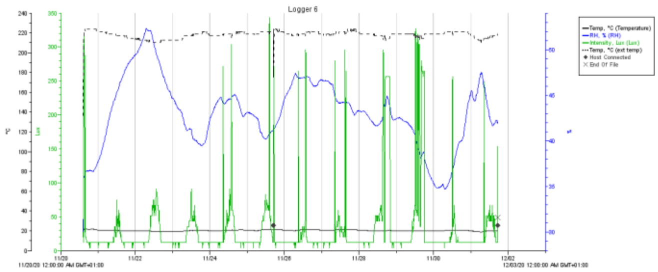
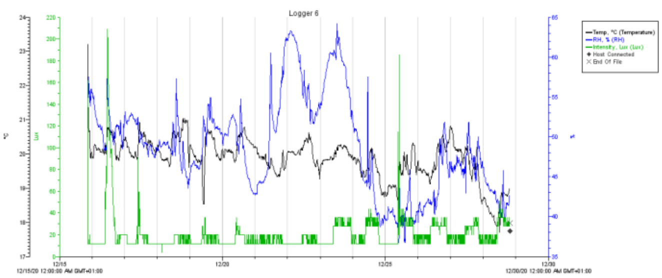


Image 6.5.3.1 hobo data logger on table compressed graphs of all parameters.

However, on 14-12-2020 Prime minister Rutte announced that the Netherlands will be going into a lockdown. The experiment was shifted to my house. The readings below6.5.3.2 are of temperature settings in my house.

This is the data readings from 15th December 2020 till 29th December 2020. There is a huge fluctuation in the temperature graph as the temperature moves from 22 degrees to 18 degrees. The cause of this is due to poor insulation in the room. To solve this issue an addition heater was brought in. However, this did not prove to be effective. Further there is a huge difference in the humidity levels corresponding to increased external humidity. The illumination levels remained relatively low as the plants were placed in a corner and covered with sheets.



6.5.4 Equipment for research

The plants will be grown in an artificial environment. The idea was inspired by a grow tent. It consists of a chamber where plants are grown artificially. To grow plants artificially grow lights are required. They are artificial lights that produce a light spectrum similar to that of the sun. There are different types of grow lights. The most common one is the Led grow lights that come in red and blue light. Red light is important for the growth of the plant and blue light in detecting the sun's position. The importance of the light spectrum is explained in chapter 4.4.

The aim is to place growth lights in an arc to represent the sun's movement. 5 different grow lamps can be placed in an arc and controlled by a timmer. Each lamp would emulate different parts of the day, with varying intensity as shown in the figure below 6.5.4. The intensity of the lamps at the far end will be the least and increasing as they meet in the center. All lamps are tilted towards the centre.

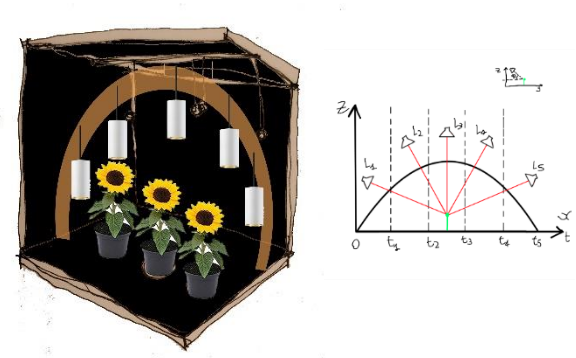


Image 6.5.4. Image of design of placement of lights for experiment

The lights are placed in an arc and require a lamp holder. These are connected to digital timers. The total hours of sunshine required are 12. That gives each lamp 144 minutes each. The first lamp L_1 is turned on at 7:00 , the second one L_2 at 9:24, The third L_3 one at 11:48, fourth one L_4 at 14:12 and the fifth one L_5 at 16:36. The lamp L1 and L2 should have lower intensities to mimic the actual movement of the sun. This can be done by intensity controllers. An extension socket would be required to connect all these components.

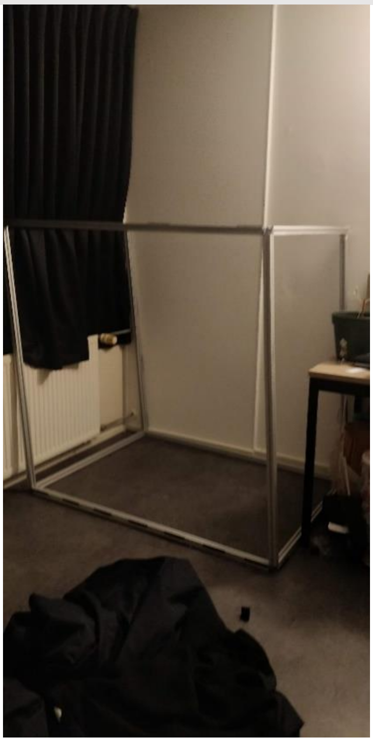
Further Seeds of sunflowers would be required to conduct the experiment with soil, large pots, and fertilizers. As the experiment will be conducted in the winter, grown sunflowers are not be available at this time.

A framework is to be placed around the entire light and plants. This framework will then be covered with a cloth. The cloth is to block any other stray lights that may interfere with the grow light and readings from the equipment. Grow tents are a good example of a sturdy set up for growing the plants. A similar aluminium framework was available in the science centre.

6.5.5 Initial setup of experiment.

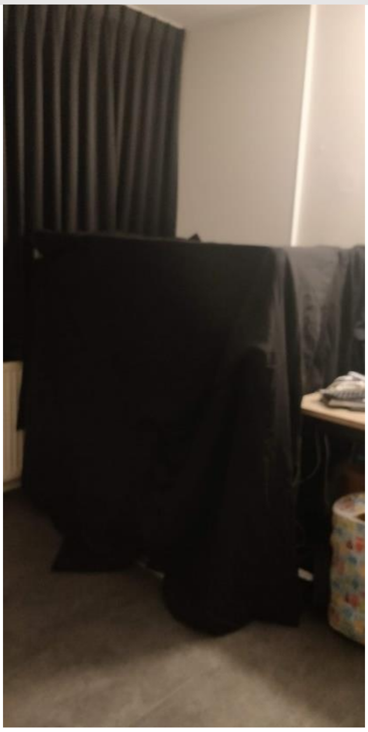
Due to the lockdown measures introduced (14/12/2020), the equipment was shifted to my home. The pictures in 6.5.5 are of the images from the initial setup of the equipment. The framework was screwed together. A rope was placed in the middle from where the lights were suspended. As a test set up only 3 grow lights were done. They were tested for 3 positions of the day. Morning evening and noon.

Images



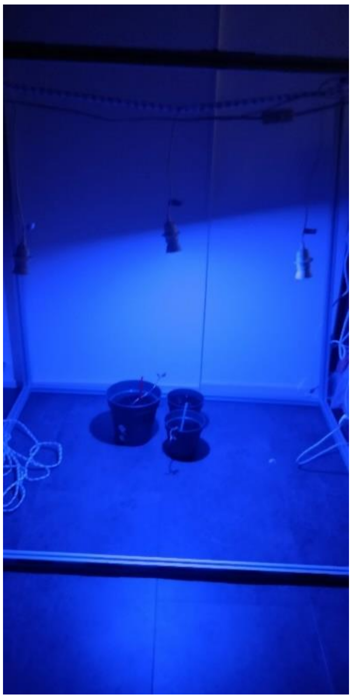
External framework

Middle rope with one grow light

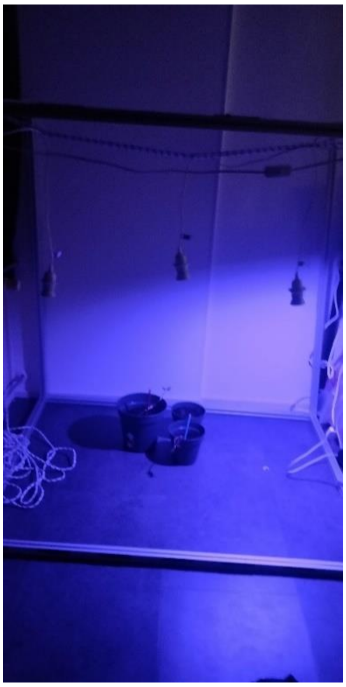


Black cloth to cover the entire framework

1st grow light indicating morning sun



2nd grow light indicating afternoon sun



3rd grow light indicating evening sun

Image 6.5.5. Intial setup of experiment.

6.5.6 Cost of experiment

The experiment consists of various components, below is the cost of the different equipment needed. To source, these items various shops and internet sources were searched.

Product	Purpose	Cost	Numbers	Total
Grow light	This light acts as artificial sunlight to help grow the plants	28	5	140
Lamp Holder	This connects the lamps to the bulbs	14.85	5	74.25
Digital timer indoor	This is to have the lights switch on and off at a particular time	13.75	5	68.75
Extention socket	To connect different cables	11.53	1	11.53
Biological components				
Plastic pots (30 cm deep)	To grow sunflowers	3	10	30
Soil		4	1	4

Seeds		5	1	5
npk	To grow plants fertilizer	10	1	10
Total cost				**388.53**

6.6 Equipment for measuring.

Choosing the right equipment for measuring devices plays an important part. The equipment should provide the required data to further analyze the subject. A steady recording of the environmental factors such as light, temperature, and humidity to understand the factors affecting the plant's growthHobo data loggers will be used throughout the experiment to check the temperature and humidity levels inside theexperimental area.

The literature study showed that the plants stem played an important role in the movement of the plant. A method to analyse the internal turgor pressure in the stem is required.To measure the strain in the stem of the sunflower a load cell or a strain gauge can be can be utilized. To get a more detailed understanding the GOM software can be utilized to measures surface strain through images.

6.6.1 Load cell

A load cell converts force into another form of energy. It can convert forces such as tension, compression, pressure into an electric signal. These instruments are accurate and highly versatile. They consist of a metal body to which strain gauges have been attached. When a force is applied to a load cell, the internal spring effect gets deformed and changes its shape. This results in a resistance and can be measured as a voltage.

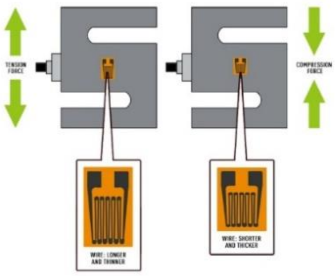


Image 6.5.4. Image of tension and compression in a load cell
Source: (Wikipedia contributors, 2021)

6.6.2 Gom Armis

The GOM Aramis is a professional software that is used for measuring 3D co- ordinates, 3D displacements, and 3 D surface strains. It uses triangulation and a range of sensors to get precise 3D co- ordinates. This further offers a Digital image correlation and 3D motion analysis based on a series of images.

Digital image correlation is used to measure contours, deformation, and strain of any material. The Gom aarmis can help in three point bending tests, crack zone evaluation or shear test. This technique can be used for small and large images. This can be done for 2D images. The Co- ordinates are used to detect displacements and strains in objects. This can be done with images, or videos.

The tensile/ strain calculations are made by using points on the object. Then the strain can be deduced from deformation found in the object. The deformation is best gathered when there is a stochastic pattern sprayed on the object. A stochastic pattern is a pattern that is randomly distributed pattern. Once the pattern is sprayed a camera can be used to record the test. Measure the specimen so that it can be scaled in the software. Images or videos can be imported. Images can be imported in a series as long as the camera is placed in the same position for one to mark the difference in movement. (GOM, n.d)

6.6.3 Measuring devices.

For measuring devices, simple everyday measuring devices such as scales and weighing scales were used, as this stage began in Lockdown. The length of the stem and the diameter of the stem need to be measured and recorded. Initially, a precision calliper was considered. However, as the stem is weak the calliper may destroy the stem. A regular ruler can be used. To look at finer details of plant growth a microscope can be used. The weight of the stem may have an influence on the system. For this a weighing scale is required.

6.7 Contingency plan.

Due to the ongoing pandemic, it was decided early on that a contingency plan is required in case the Netherlands goes into a complete lockdown due to Covid -19. The experiment is to be designed such that it is portable or can be easily dismantled. The materials and measuring devices should also be portable so that they can be moved. The main concern lies in creating a similar environment in another location. In the case of a lockdown the equipment should be moved to my house.

This contingency plan proved useful as the Netherlands went into a full lockdown from 14/12/2020 till 19/01/2020. The university was shut down along with the science centre, where the experiment was initially to be conducted. All the equipment was moved in one day.

6.8 Failure of experiment

As this is an experimental setup there maybe problems with the experiment such as the plants may not be ideal or display heliotropic behaviour due to the artificial growth of the plants. Equipment's may not function properly. Due to the ongoing pandemic, there may not be access to all the equipment. These may be the problems for not getting the required data. By February if there are any unresolved problems. The design will be based on the theoretical understanding of the plants, as these are difficult times.

Appendix B

A sunflower stem was cut and observed under a digital microscope. The aim of this analysis is to have a deeper understanding of the structure of the stem. The first fw images are of the stem when it is a sapling which is 20 days old.

Image	Description
	Sample no : 1 Image no : 1.1 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : longitudinal Date :29/01/2020 Observations: No central filling
	Sample no : 1 Image no : 1.2 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : longitudinal Date :29/01/2020 Observations: Lines running throughout the stem, Xylem, givs structural strengyh, provides
	Sample no : 1 Image no : 1.3 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : longitudinal Date :29/01/2020 Observations: The twisting of the stem

Sample no : 2
Image no : 2.1
Position : middle of stem
Stem : contains moisture
Time: 2 days after dying
Cut : longitudinal
Date :29/01/2020

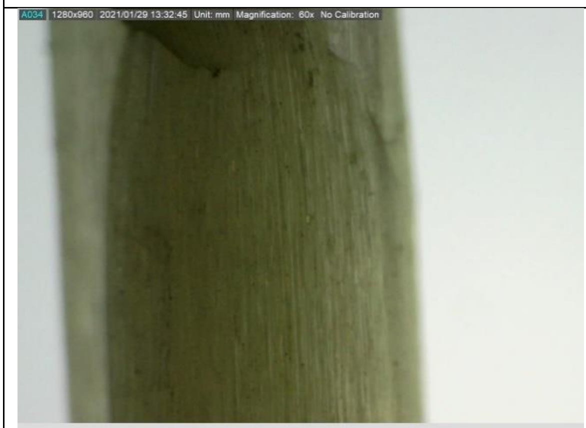
Observations: looks like there are multiple layers and a water bubble. Later research showd that the water bubble is an output from the xylm which leaves water droplets once cut.

Sample no : 2
Image no : 2.2
Position : middle of stem
Stem : contains moisture
Time: 2 days after dying
Cut : longitudinal
Date :29/01/2020

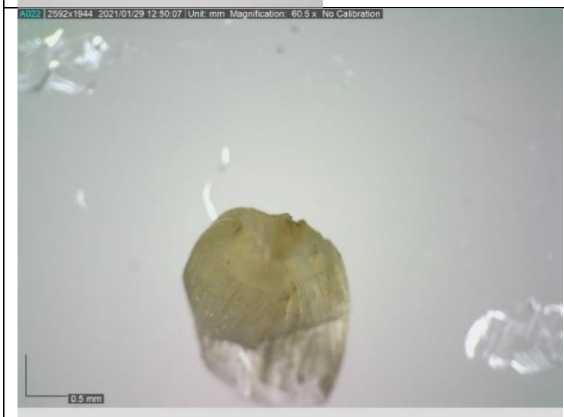
Observations: Second water bubble

	Sample no : 2 Image no : 2.2 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : longitudinal Date :29/01/2020 Observations: Change of colour from light green to brown.
	Sample no : 2 Image no : 2.1 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : longitudinal Date :29/01/2020 Observations: When the stem started to dry. It started to loose moisture and bend.
	

<table>
<tr><td>
</td><td></td></tr>
<tr><td>
</td><td>Sample no : 2
Image no : 3.1
Position : middle of stem
Stem : contains moisture
Time: 2 days after dying
Cut : longitudinal
Date :29/01/2020

Observations: The stem is made from strands.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>
</td><td>Sample no : 2
Image no : 4.1
Position : middle of stem
Stem : contains moisture
Time: 2 days after dying
Cut : longitudinal
Date :29/01/2020

Observations: Fibrous pattern on stem.</td></tr>
<tr><td></td><td></td></tr>
</table>

	Sample no : 2 Image no : 2.1 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : cross section Date :29/01/2020 Observations:
	Sample no : 2 Image no : 2.2 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : cross section Date :29/01/2020 Observations: liquidy central filling
	Sample no : 2 Image no : 2.3 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : cross section Date :29/01/2020 Observations: liquidy central filling. Translucent body with stiations.
	Sample no : 2 Image no : 2.3 Position : middle of stem Stem : contains moisture Time: 2 days after dying Cut : cross section Date :29/01/2020 Observations: water bubble

 	Sample no : 2 Image no : 3.1 Position : junction where stem touches root Stem : starting to dry Time: 2 days after dying Cut : longitudinal section Date :29/01/2020 Observations: lines seen in stem continue till the root
 	Sample no : 2 Image no : 3.2 Position : junction where stem touches root Stem : starting to dry Time: 2 days after dying Cut : longitudinal section Date :29/01/2020 Observations: lines seen in stem continue till the root
 	Sample no : 2 Image no : 3.3 Position : junction where stem touches root Stem : starting to dry Time: 2 days after dying Cut : longitudinal section Date :29/01/2020 Observations: lines seen in stem continue till the root

Sample no : 1
Image no : 4.1
Position : junction where stem touches root
Stem : root starting to dry
Time: 2 days after dying
Cut : longitudinal section
Date :29/01/2020

Observations: The outer skin seems to be thicker than the upper skin

Sample no : 1
Image no : 4.2
Position : junction where stem touches root
Stem : root starting to dry
Time: 2 days after dying
Cut : longitudinal section
Date :29/01/2020

Observations: Brown colouring due to rotting of stem

Sample no : 3
Image no : 4.2
Position : junction of stem and leaves
Stem : healthy
Time: alive
Cut : none
Date :29/01/2021

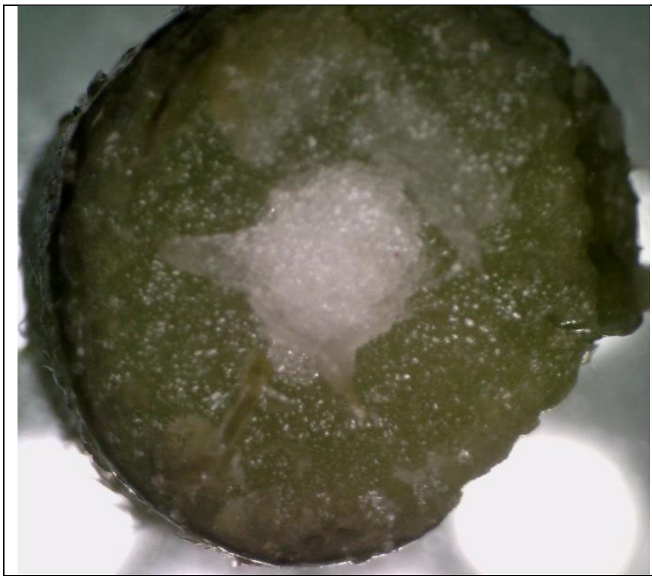
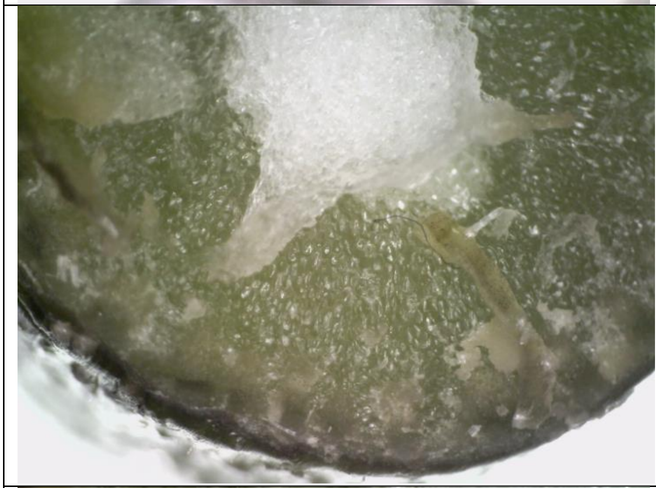
Observations: It is interesting to see these undulations. Im assuming helps bending.

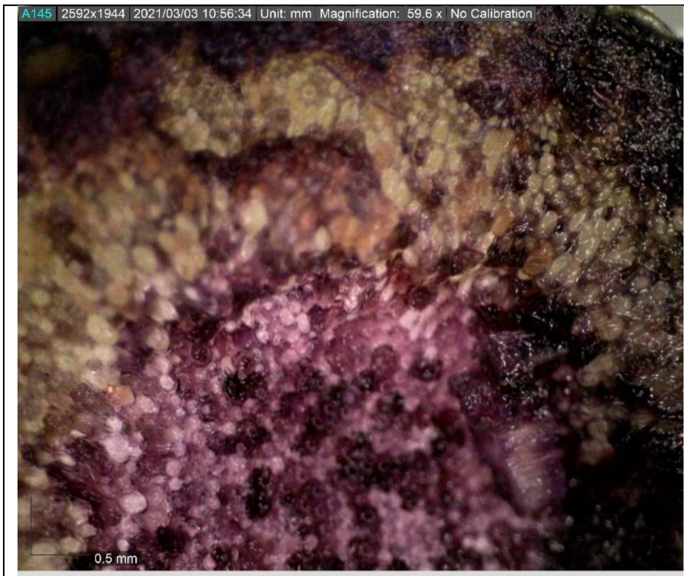
<table>
<tr>
<td>
</td>
<td>Sample no : 3
Image no : 4.2
Position : junction of stem and leaves
Stem : healthy
Time: alive
Cut : none
Date :29/01/2021

Observations: These undulations are seen on both sides of the leaves.</td>
</tr>
<tr>
<td colspan="2">Interesting observation: The stem still had moisture for 2 days even after the leaves dried up. But after the stem was cut open it dried up in 3 hours. The stem has an inner lining that runs from the leaves to the root. The stem has thicker outer layer and a softer inner layer. There were a few water bubbles seen inside. The joint where the stem meets the leaves, there is a corrugated portion, which I assume helps the movement of the leaves.</td>
</tr>
</table>

The following images are of a fully grown sunflower which is around 90 days old.

	Sample no : 4 Image no : 4.1 Position: Outer skin of sunflower. Stem : healthy Time: Cut sunflowers Cut : none Date :27/02/2021
	Zoomed in images of the same stem
	

	Sample no : 4 Image no : 4.2 Position: Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :27/02/2021 The central pith is seen clearly , the vascular bundles are not seen
	Sample no : 4 Image no : 4.3 Position: Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :27/02/2021 The central pith is seen clearly , the vascular bundles are not seen
	Sample no : 4 Image no : 4.3 Position: Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :27/02/2021 The cell formation can be seen in this image.

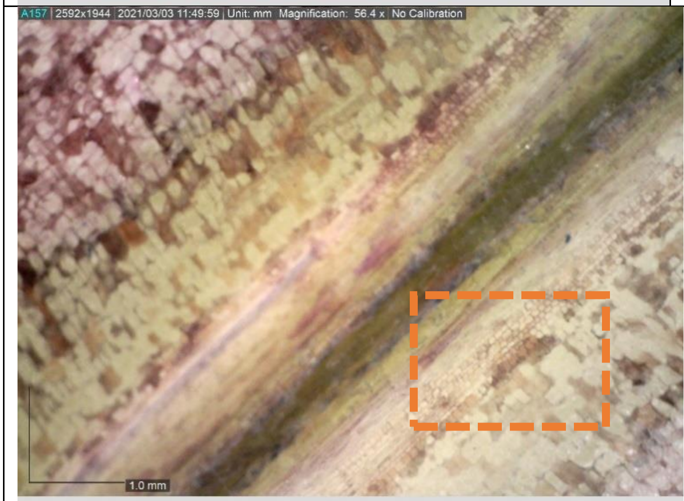


Sample no : 5
Image no : 5.1
Position: longitudinal Cross sectional
Stem : healthy
Time: Unknown
Cut : bottom end of stem
Date :3/03/2021
Tinted with black ink

The cell formation can be seen in this image. The pith gets tinted with black ink.

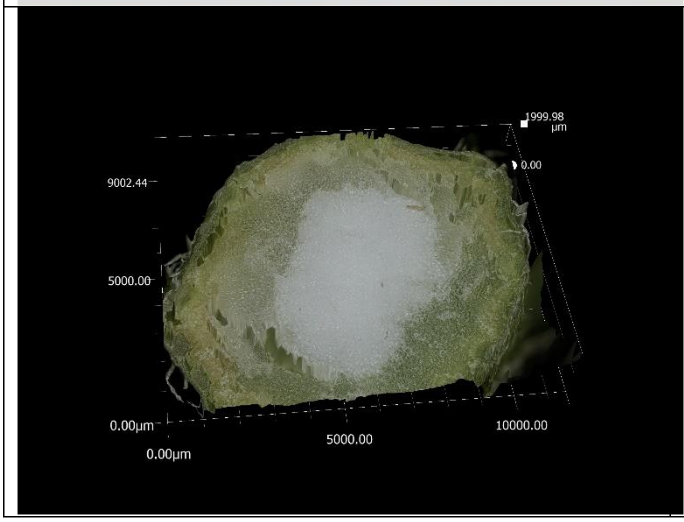
Sample no : 5
Image no : 5.2
Position: longitudinal Cross sectional
Stem : healthy
Time: Unknown
Cut : bottom end of stem
Date :3/03/2021

The cell formation can be seen in this image. The pith gets tinted with black ink.



Sample no : 5
Image no : 5.3
Position: longitudinal Cross sectional
Stem : healthy
Time: Unknown
Cut : bottom end of stem
Date :3/03/2021

The variations in the cell size can be seen in this image.

 	Sample no : 5 Image no : 5.4 Position: longitudinal Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :3/03/2021 This is a zoomed in view of the stem that shows the inside of the stem.
 	Sample no : 5 Image no : 5.5 Position: longitudinal Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :3/03/2021 In this image the vascular bundles can be clearly seen. The vascular bundles are the oval like structure seen around the ring of the core/ The core is tinted with ink and is seen as black in colour.
 	Sample no : 6 Image no : 6.1 Position : lower end of the stem Cut : Transverse section Magnification: 30x Date :05/03/2021 Diameter of stem:19 mm Diameter of pith:5mm*10mm Observations: In this image the porous core can be seen along with deep cuts which show the length of the stem

Sample no : 6
Image no : 5.3.6
Position : Upper end of the stem (head of stem)
Cut : Transverse section
Magnification: 30x
Date :05/03/2021

Diameter of stem:18 mm
Diameter of pith:14.5mm

Observations: In this image the porous core can be seen along with the vascular bundles located on the outside.

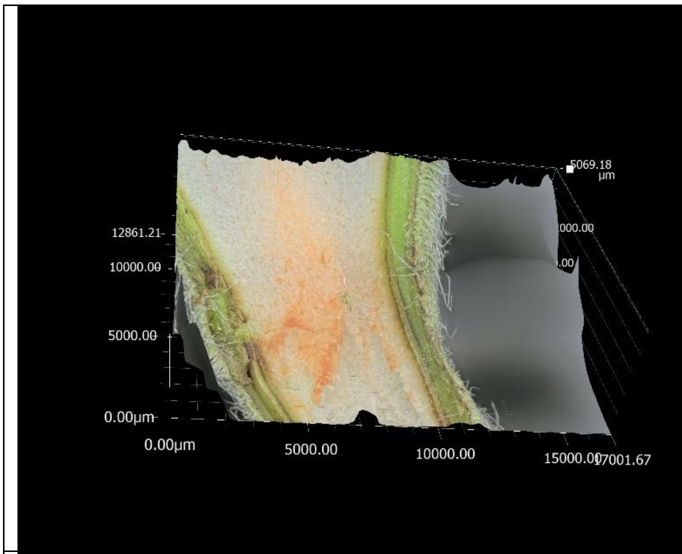
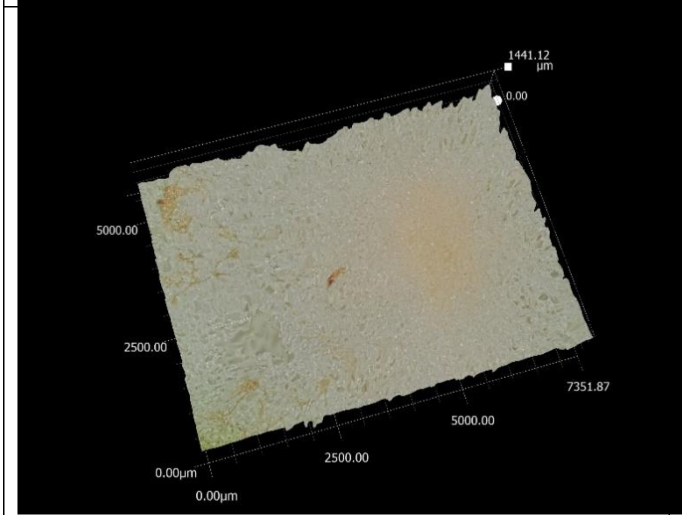
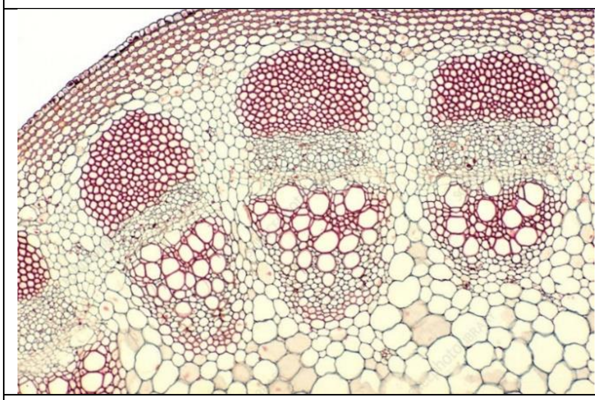
Sample no : 6
Image no : 5.3.5
Position : Middle of the stem (2/3rd position)
Cut : Transverse section
Magnification: 30x
Date :05/03/2021

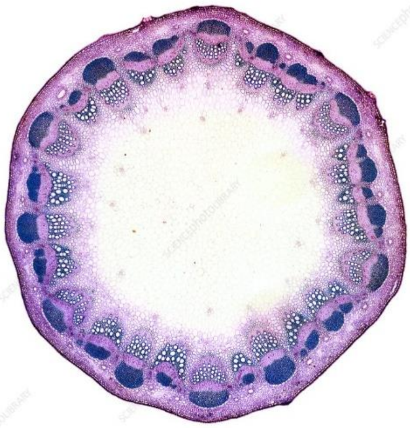
Diameter of stem:14 mm
Diameter of pith:10mm

Observations: In this image the pith or the core is larger than in the previous image. This proves that the size of the pith increases as it moves upwards.

Sample no : 6
Image no : 5.3.7 (magnified image of 5.3.5)
Position : Upper end of the stem (2/3rd position)
Stem : Healthy
Time: 5 days after being cut from source.
Cut : Transverse section
Magnification: 50x
Date :05/03/2021

Observations: This is a detailed view of the vascular bundles. It shows that they are hollow. This allows the transport of waters and nutrients.

	Sample no : 6 Image no : 5.3.8 Position : below head of stem Cut : Longitudnal section Magnification: 50x Date :05/03/2021 Observations: The different layers are seen along with the relation to each other. The core is connected with different layer to the skin. And from the skin the hair like structure that protects the stem is seen.
	Sample no : 6 Image no : 5.3.8 Position : : Upper end of the stem (head of stem) Cut : Longitudnal section Magnification: 100x Date :05/03/2021 The central porous core is seen in the image here.
	Image no : 6.1 Position: longitudinal Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :27/02/2021 Source: Keith (2020)
	Image no : .2 Position: longitudinal Cross sectional Stem : healthy Time: Unknown Cut : bottom end of stem Date :27/02/2021 Source: Keith (2020)



Sample 4
Flower head- 11cm
Stem thickness top - 1.1 cm bottom 1.3 cm (diff in ht65 cm)

Stem zoom in – 138.2x
The zoom in of a sunflower Stem

Appendix 3

Values for the energy generated from the P.V. panel and the radiation generated on thee glass from the shading device. These values were derived using the ladybug script explained in chapter 7.2

South facade									
	P.V. energy				Radiation by shading device				
Angle	Mar-21	Jun-21	Sep-21	Dec-21		Mar-21	Jun-21	Sep-21	Dec-21
90	1.807	3.539	1.814	0.403	90	12.2417	5.264594	12.10267	8.996655
89	1.84	3.553	1.848	0.423	89	12.08804	5.219282	11.93993	8.935135
88	1.874	3.567	1.881	0.443	88	12.02507	5.144219	11.87682	8.705105
87	1.906	3.579	1.914	0.463	87	11.82296	5.006033	11.65377	8.516285
86	1.938	3.591	1.946	0.482	86	11.69965	4.976392	11.55489	8.491201
85	1.97	3.601	1.978	0.502	85	11.48502	4.939419	11.34191	8.475154
84	2	3.61	2.009	0.522	84	11.38774	4.895853	11.25621	8.44735
83	2.031	3.619	2.04	0.541	83	11.24663	4.855416	11.11	8.373659

82	2.062	3.627	2.07	0.56	82	11.17543	4.771624	11.03416	8.15192
81	2.092	3.635	2.101	0.58	81	11.07449	4.643522	10.91806	7.964992
80	2.121	3.642	2.13	0.599	80	10.87365	4.608076	10.73431	7.935287
79	2.15	3.647	2.159	0.618	79	10.70748	4.576666	10.57363	7.922762
78	2.178	3.652	2.188	0.637	78	10.50412	4.529633	10.38756	7.896125
77	2.206	3.657	2.215	0.656	77	10.36231	4.495879	10.24046	7.833128
76	2.233	3.661	2.243	0.674	76	10.30456	4.460647	10.18173	7.684342
75	2.259	3.664	2.269	0.692	75	10.2191	4.38764	10.08984	7.429555
74	2.285	3.666	2.295	0.71	74	10.19243	4.369123	10.05898	7.420279
73	2.31	3.666	2.32	0.728	73	10.02789	4.289724	9.882894	7.391481
72	2.334	3.666	2.344	0.746	72	9.770977	4.225035	9.648171	7.358745
71	2.358	3.664	2.368	0.763	71	9.671326	4.124676	9.563749	7.323385
70	2.381	3.663	2.392	0.781	70	9.566502	4.092263	9.456625	7.216243
69	2.404	3.66	2.414	0.798	69	9.373155	4.01052	9.258809	6.862111
68	2.426	3.657	2.436	0.815	68	9.327531	3.98755	9.210209	6.85095
67	2.447	3.653	2.458	0.832	67	9.292849	3.966447	9.173904	6.849459
66	2.468	3.647	2.479	0.848	66	9.238923	3.940319	9.133023	6.823616
65	2.488	3.64	2.498	0.864	65	9.195942	3.911597	9.087939	6.795019
64	2.507	3.633	2.518	0.88	64	9.039244	3.884071	8.938227	6.780609
63	2.526	3.624	2.536	0.896	63	8.819331	3.829416	8.720154	6.666237
62	2.544	3.615	2.554	0.911	62	8.663824	3.752688	8.562165	6.380989
61	2.561	3.604	2.571	0.927	61	8.619879	3.728461	8.51658	6.299204
60	2.577	3.592	2.587	0.942	60	8.416206	3.695143	8.302297	6.290825
59	2.592	3.58	2.603	0.956	59	8.327494	3.668028	8.210697	6.262476
58	2.607	3.566	2.618	0.971	58	8.267234	3.629569	8.162171	6.218222
57	2.622	3.552	2.632	0.985	57	8.228908	3.578205	8.122538	6.210449
56	2.635	3.537	2.645	0.999	56	8.199799	3.548956	8.09435	6.154253
55	2.648	3.522	2.658	1.012	55	8.09493	3.481302	7.984631	5.913178
54	2.66	3.505	2.67	1.026	54	7.963915	3.459485	7.862344	5.898738
53	2.671	3.488	2.681	1.039	53	7.905128	3.425969	7.805513	5.784318
52	2.682	3.469	2.692	1.051	52	7.803942	3.375313	7.716288	5.700006
51	2.691	3.449	2.701	1.064	51	7.777337	3.363874	7.689872	5.6896
50	2.7	3.429	2.71	1.076	50	7.73831	3.340284	7.649613	5.670103
49	2.708	3.407	2.718	1.087	49	7.709034	3.352496	7.619581	5.664738
48	2.716	3.384	2.725	1.099	48	7.652974	3.308657	7.576536	5.577497
47	2.722	3.361	2.732	1.11	47	7.486693	3.257713	7.427459	5.410503
46	2.728	3.337	2.737	1.121	46	7.334616	3.214822	7.269239	5.368508
45	2.733	3.311	2.742	1.131	45	7.299906	3.19221	7.234506	5.354165
44	2.737	3.285	2.746	1.142	44	7.261194	3.16205	7.192649	5.293153
43	2.741	3.26	2.75	1.151	43	7.173813	3.136573	7.09968	5.281746
42	2.744	3.234	2.753	1.161	42	7.066433	3.0911	6.988043	5.170238
41	2.746	3.207	2.754	1.17	41	7.02634	3.059599	6.949051	5.087764
40	2.747	3.18	2.755	1.179	40	7.008074	3.0499	6.936514	5.060307
39	2.748	3.152	2.756	1.187	39	6.984756	3.029528	6.911002	5.045347
38	2.747	3.122	2.755	1.196	38	6.940171	3.069866	6.866057	4.981596
37	2.746	3.092	2.754	1.203	37	6.848073	3.007112	6.775242	4.794277
36	2.744	3.061	2.752	1.211	36	6.811592	2.986667	6.739239	4.784193
35	2.742	3.03	2.749	1.218	35	6.802491	2.968116	6.730068	4.772874

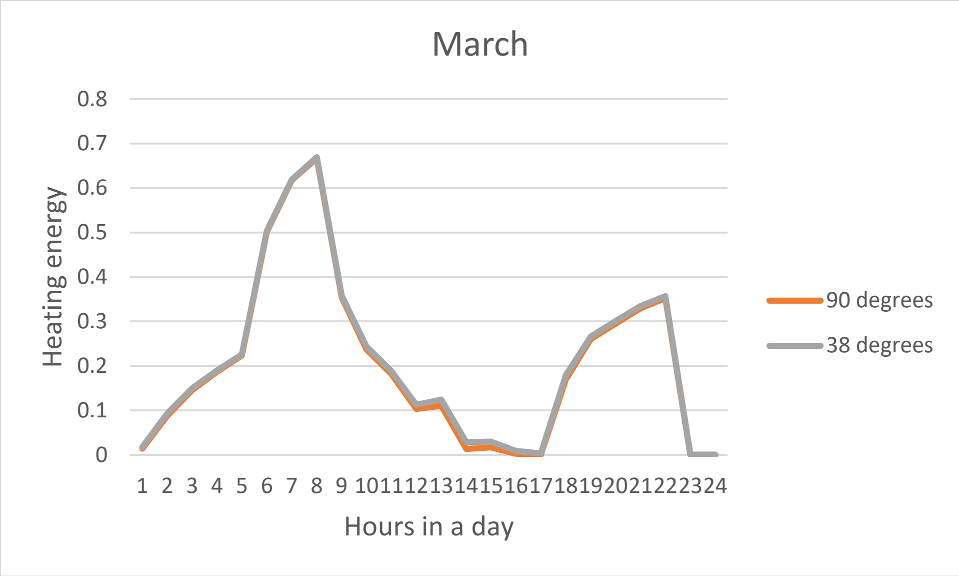
34	2.738	2.997	2.745	1.225	34	6.755937	2.937884	6.683724	4.765579
33	2.734	2.964	2.741	1.231	33	6.711234	2.941116	6.635706	4.752977
32	2.729	2.929	2.735	1.237	32	6.687247	2.913809	6.612249	4.743976
31	2.723	2.894	2.729	1.243	31	6.655385	2.898598	6.574995	4.734019
30	2.717	2.858	2.722	1.248	30	6.70523	2.870776	6.618779	4.709646
29	2.709	2.821	2.714	1.253	29	6.702683	2.928058	6.63328	4.698035
28	2.701	2.784	2.706	1.258	28	6.675305	2.911446	6.611946	4.685447
27	2.692	2.746	2.697	1.262	27	6.64057	2.874861	6.577089	4.661694
26	2.682	2.707	2.687	1.266	26	6.597781	2.974676	6.530034	4.647726
25	2.672	2.667	2.676	1.269	25	6.559652	2.940363	6.491706	4.638909
24	2.66	2.627	2.664	1.272	24	6.514832	2.937277	6.447407	4.567433
23	2.648	2.587	2.652	1.275	23	6.533837	2.881419	6.475467	4.373266
22	2.636	2.547	2.639	1.277	22	6.501533	2.921044	6.441452	4.360191
21	2.622	2.505	2.625	1.279	21	6.615349	3.042266	6.564016	4.351397
20	2.608	2.464	2.61	1.281	20	6.721591	3.089564	6.684791	4.340825
19	2.593	2.421	2.595	1.282	19	6.69816	3.065138	6.659812	4.332773
18	2.577	2.378	2.579	1.283	18	6.688763	3.07046	6.665173	4.319914
17	2.561	2.335	2.562	1.284	17	6.687717	3.309122	6.661787	4.312305
16	2.544	2.292	2.545	1.284	16	6.631467	3.319451	6.604018	4.300018
15	2.526	2.248	2.526	1.283	15	6.61436	3.339151	6.59244	4.288591
14	2.507	2.204	2.507	1.283	14	6.709276	3.363187	6.661886	4.275806
13	2.488	2.159	2.488	1.282	13	6.712992	3.597481	6.655552	4.295364
12	2.468	2.113	2.467	1.28	12	6.838491	3.632253	6.793823	4.284115
11	2.447	2.067	2.446	1.279	11	7.884171	4.473607	7.832587	4.888902
10	2.426	2.426	2.424	1.276	10	7.90619	4.577748	7.873585	4.880817
9	2.404	2.404	2.402	1.274	9	7.937994	4.759357	7.914541	4.877309
8	2.381	2.381	2.378	1.271	8	7.925271	4.841531	7.910759	4.865863
7	2.357	2.357	2.354	1.268	7	8.074434	5.005077	8.030911	4.861857
6	2.333	2.333	2.33	1.264	6	8.235222	5.230761	8.196333	4.860281
5	2.309	2.309	2.305	1.26	5	8.338544	5.299556	8.273535	4.853834
4	2.283	2.283	2.279	1.256	4	8.550943	5.472135	8.519642	4.853981
3	2.257	2.257	2.252	1.251	3	9.641664	6.38264	9.621058	5.462274
2	2.23	2.23	2.225	1.246	2	10.69762	7.335482	10.67002	6.070905
1	2.203	2.203	2.197	1.24	1	13.90645	9.737409	13.86879	7.894321
0					0	18.1864			11.539

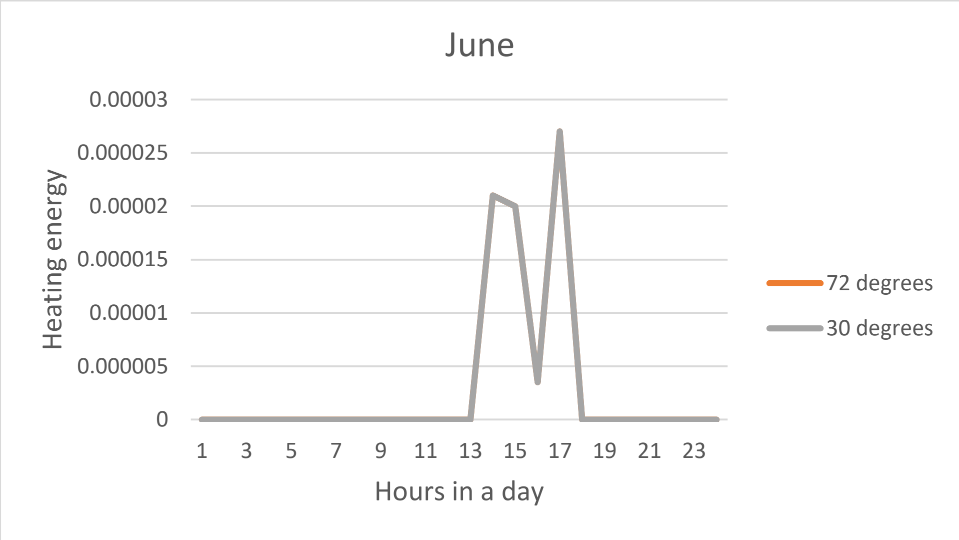
	Mar-21		Jun-21		Sep-21		Dec-21	
	P.V.	Shading	P.V.	Shading	P.V.	Shading	P.V.	Shading
South	38°	90°	72°	30°	38°	90°	17°	90°

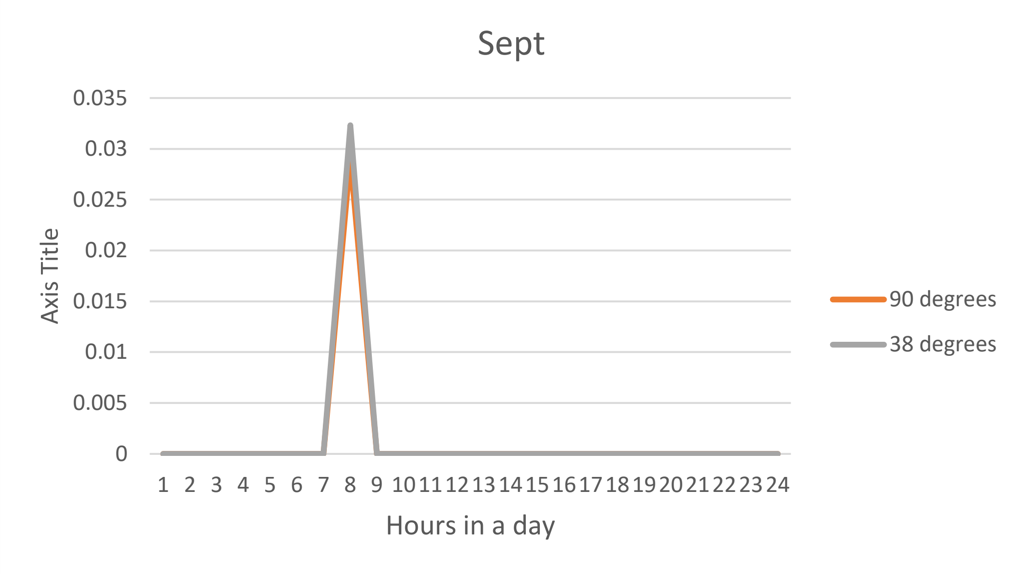
Energy produced by a room when the shading device is at different angles

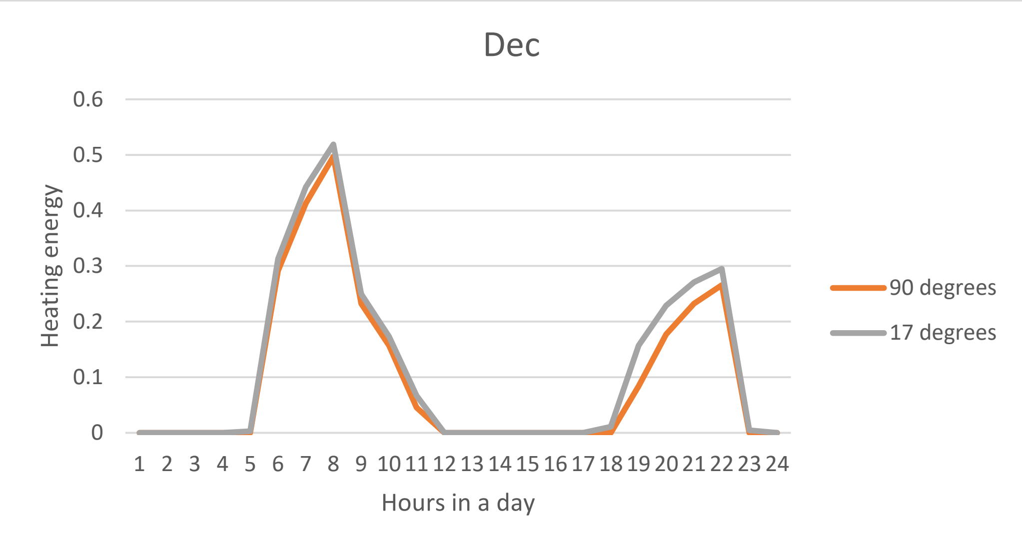
	Mar-21		Jun-21		Sept		Dec	
	heating KWh	heating KWh	cooling	cooling	heating KWh	heatin g KWh		

Hours	90 °	72°	72°	30°	38°	90°	17°	90°
1	0.013645	0.017396	0	0	0	0	0	0
2	0.087827	0.093256	0	0	0	0	0	0
3	0.145736	0.149839	0	0	0	0	0	0
4	0.186392	0.189625	0	0	0	0	0	0
5	0.223393	0.225964	0	0	0	0	0.002713	0
6	0.501832	0.503329	0	0	0	0	0.313038	0.291506
7	0.617192	0.619214	0	0	0	0	0.442401	0.413039
8	0.667389	0.66967	0	0	0.032321	0.0291	0.519115	0.496933
9	0.35358	0.357458	0	0	0	0	0.24951	0.23219
10	0.237317	0.243669	0	0	0	0	0.173083	0.156817
11	0.18182	0.188304	0	0	0	0	0.066643	0.045657
12	0.103118	0.112369	0	0	0	0	0	0
13	0.11034	0.123943	0	0	0	0	0	0
14	0.013225	0.028447	0.000021	0.000021	0	0	0	0
15	0.016899	0.029485	0.00002	0.00002	0	0	0	0
16	0.002039	0.008504	3.51E-06	3.51E-06	0	0	0	0
17	0	0.003105	0.000027	0.000027	0	0	0	0
18	0.169165	0.179046	0	0	0	0	0.010618	0
19	0.260512	0.266307	0	0	0	0	0.157216	0.084202
20	0.294724	0.300555	0	0	0	0	0.228702	0.177103
21	0.32908	0.334351	0	0	0	0	0.271101	0.232078
22	0.352389	0.356883	0	0	0	0	0.294825	0.265922
23	0	0	0	0	0	0	0.004796	0
24	0	0	0	0	0	0	0	0
	4.867614	5.000719	7.15E-05	7.15E-05	0.032321	0.029125	2.733761	2.395447


March
Heating energy
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 101112131415161718192021222324
Hours in a day
90 degrees
38 degrees


June
Heating energy
0.00003
0.000025
0.00002
0.000015
0.00001
0.000005
0
1 3 5 7 9 11 13 15 17 19 21 23
Hours in a day
72 degrees
30 degrees





Energy produced by P.V. at specified angles			
		Energy kWh	Energy for 3 months for a 2m² panel
Mar	90 °	0.013349	29.79497
June	72°	0.034701	77.45263
Sept	90°	0.05494	122.6261
Dec	90°	0.012255	27.35316
Total			257.2268

East facade

PV angle					Radiation on glass				
Angle	Mar-21	Jun-21	Sep-21	Dec-21	Angle	Mar-21	Jun-21	Sep-21	Dec-21

90	1.894	3.598	1.815	0.404	90	6.682067	8.024796	6.781995	2.081174
89	1.807	3.538	1.814	0.403	89	6.662067	9.039186	6.781495	2.071174
88	1.806	3.537	1.813	0.403	88	6.608949	8.921793	6.718992	2.053115
87	1.805	3.534	1.811	0.402	87	6.50856	8.744177	6.614349	2.036906
86	1.803	3.53	1.81	0.402	86	6.458618	8.719352	6.571215	2.028099
85	1.801	3.525	1.807	0.402	85	6.38337	8.594414	6.494236	2.011226
84	1.798	3.519	1.804	0.401	84	6.36239	8.493361	6.47384	2.002371
83	1.797	3.514	1.803	0.401	83	6.264702	8.37801	6.37837	1.980756
82	1.796	3.509	1.802	0.4	82	6.207131	8.213475	6.310418	1.96481
81	1.796	3.504	1.801	0.4	81	6.107131	8.213475	6.310418	1.96481
80	1.794	3.498	1.8	0.4	80	6.065703	8.024796	6.169987	1.942057
79	1.792	3.491	1.798	0.4	79	6.026747	7.940331	6.133455	1.922481
78	1.79	3.483	1.796	0.401	78	5.922384	7.766601	6.029255	1.911756
77	1.787	3.474	1.793	0.401	77	5.882058	7.725716	5.987232	1.897024
76	1.784	3.464	1.789	0.401	76	5.785271	7.604386	5.888343	1.878781
75	1.78	3.453	1.786	0.402	75	5.681754	7.454371	5.772929	1.861395
74	1.776	3.441	1.781	0.403	74	5.664458	7.445201	5.755524	1.850398
73	1.771	3.428	1.776	0.404	73	5.641556	7.321405	5.732401	1.835194
72	1.766	3.413	1.771	0.404	72	5.533169	7.223076	5.630201	1.824974
71	1.761	3.401	1.766	0.405	71	5.502734	7.11138	5.600798	1.808799
70	1.757	3.39	1.762	0.405	70	5.436644	7.00827	5.534432	1.79862
69	1.754	3.378	1.759	0.406	69	5.27669	6.821653	5.361099	1.772661
68	1.752	3.366	1.757	0.406	68	5.26638	6.807169	5.351736	1.762405
67	1.749	3.352	1.754	0.406	67	5.246881	6.776595	5.332068	1.755745
66	1.746	3.338	1.752	0.406	66	5.222602	6.758187	5.30839	1.735304
65	1.743	3.323	1.749	0.406	65	5.199307	6.739852	5.284042	1.729052
64	1.74	3.307	1.746	0.406	64	5.121742	6.643303	5.204251	1.707877
63	1.736	3.29	1.743	0.406	63	5.04541	6.499233	5.134198	1.69376
62	1.732	3.272	1.739	0.406	62	4.903601	6.238844	4.986694	1.679639
61	1.728	3.253	1.734	0.406	61	4.855304	6.146474	4.934009	1.661309
60	1.723	3.235	1.729	0.406	60	4.807252	6.087194	4.886135	1.650403
59	1.718	3.22	1.724	0.406	59	4.762811	6.063854	4.840624	1.630214
58	1.712	3.206	1.719	0.406	58	4.745657	6.043187	4.82255	1.619866
57	1.707	3.191	1.713	0.406	57	4.720101	6.010964	4.797593	1.605437
56	1.701	3.175	1.707	0.406	56	4.642865	5.94917	4.717587	1.589765
55	1.695	3.158	1.702	0.406	55	4.561352	5.887718	4.630686	1.576251
54	1.689	3.141	1.696	0.405	54	4.493273	5.747033	4.56216	1.566623
53	1.682	3.122	1.689	0.405	53	4.471229	5.731658	4.540327	1.555594
52	1.675	3.103	1.682	0.404	52	4.437737	5.556635	4.503356	1.543467
51	1.667	3.083	1.675	0.404	51	4.401543	5.536094	4.464115	1.521652
50	1.662	3.062	1.669	0.404	50	4.379624	5.512667	4.44421	1.511064
49	1.657	3.04	1.664	0.403	49	4.346988	5.483746	4.415221	1.49181
48	1.651	3.018	1.658	0.403	48	4.329268	5.473299	4.396364	1.484694
47	1.645	2.997	1.651	0.403	47	4.21924	5.375894	4.285662	1.461782
46	1.638	2.978	1.644	0.402	46	4.133926	5.330275	4.201263	1.449751
45	1.631	2.959	1.637	0.401	45	4.07302	5.3158	4.138269	1.439728
44	1.624	2.939	1.629	0.401	44	4.054249	5.299968	4.120163	1.423843
43	1.616	2.92	1.621	0.4	43	4.028941	5.281854	4.093747	1.416912

42	1.608	2.9	1.612	0.399	42	3.957089	5.193249	4.022787	1.393977
41	1.599	2.88	1.603	0.398	41	3.924576	5.104983	3.986412	1.380771
40	1.593	2.858	1.596	0.396	40	3.918888	5.103916	3.982679	1.369054
39	1.586	2.836	1.588	0.395	39	3.890804	5.06702	3.953428	1.351815
38	1.578	2.814	1.58	0.394	38	3.849404	5.007643	3.910752	1.339159
37	1.57	2.791	1.572	0.392	37	3.756165	4.93536	3.812667	1.32568
36	1.562	2.767	1.564	0.391	36	3.738041	4.924282	3.794654	1.317403
35	1.553	2.743	1.555	0.389	35	3.725151	4.908186	3.779621	1.297368
34	1.544	2.719	1.546	0.387	34	3.697698	4.874478	3.752896	1.281397
33	1.534	2.694	1.537	0.385	33	3.669539	4.860775	3.724528	1.273977
32	1.524	2.67	1.527	0.384	32	3.65514	4.914798	3.70925	1.274529
31	1.514	2.646	1.516	0.383	31	3.644469	4.901899	3.698839	1.262704
30	1.503	2.621	1.506	0.381	30	3.676504	4.885265	3.720516	1.252776
29	1.492	2.596	1.495	0.38	29	3.661244	4.905444	3.705436	1.244684
28	1.482	2.57	1.485	0.378	28	3.638441	4.892902	3.68569	1.220715
27	1.471	2.544	1.474	0.377	27	3.622531	4.874251	3.669668	1.201323
26	1.459	2.517	1.463	0.375	26	3.619392	4.86157	3.668868	1.193571
25	1.447	2.49	1.451	0.373	25	3.589353	4.887587	3.639366	1.174527
24	1.435	2.466	1.44	0.371	24	3.498813	4.829488	3.543583	1.156761
23	1.424	2.441	1.429	0.369	23	3.436305	4.789536	3.477242	1.139988
22	1.412	2.416	1.417	0.367	22	3.412615	4.767097	3.454716	1.129708
21	1.4	2.39	1.406	0.365	21	3.408007	4.847028	3.451819	1.120123
20	1.388	2.364	1.394	0.362	20	3.4312	4.948915	3.477787	1.112331
19	1.375	2.337	1.381	0.36	19	3.421752	4.927006	3.468097	1.102238
18	1.362	2.31	1.368	0.358	18	3.40388	4.958089	3.449342	1.09198
17	1.348	2.281	1.355	0.355	17	3.40012	4.985415	3.447546	1.081546
16	1.335	2.253	1.341	0.352	16	3.433608	4.982463	3.483841	1.074089
15	1.322	2.223	1.329	0.349	15	3.443026	5.019235	3.497007	1.068401
14	1.309	2.193	1.317	0.347	14	3.496405	5.056734	3.537803	1.069906
13	1.296	2.165	1.304	0.344	13	3.51167	5.059378	3.557003	1.061553
12	1.283	2.138	1.291	0.341	12	3.506695	5.176584	3.551281	1.052208
11	1.269	2.111	1.277	0.338	11	4.053752	6.071109	4.109178	1.198655
10	1.255	2.083	1.264	0.334	10	4.050169	6.164673	4.10448	1.188039
9	1.24	2.055	1.25	0.331	9	4.077831	6.178185	4.138558	1.181135
8	1.226	2.026	1.235	0.328	8	4.085866	6.242224	4.14917	1.177862
7	1.21	1.996	1.22	0.324	7	4.108132	6.422756	4.160565	1.178445
6	1.195	1.966	1.205	0.321	6	4.13215	6.497956	4.185582	1.183277
5	1.179	1.935	1.19	0.317	5	4.214129	6.566072	4.257719	1.188649
4	1.163	1.904	1.174	0.313	4	4.220142	6.764581	4.261216	1.179571
3	1.146	1.872	1.157	0.31	3	4.80087	7.650986	4.855424	1.318397
2	1.129	1.839	1.141	0.306	2	5.36798	8.659036	5.428969	1.467047
1	1.112	1.806	1.124	0.302	1	6.993972	11.3135	7.073801	1.901279

	Mar	Jun	Jun	Sept	Dec
			cooling		
Angle	90°	22°	90°	90°	90°

1	0.029181	0	0	0	0.000211
2	0.106039	0	0	0	0.022571
3	0.159853	0	0	0	0.078166
4	0.197849	0	0	0	0.126152
5	0.233071	0	0	0	0.138543
6	0.508274	0	0	0	0.39101
7	0.625402	0.021487	0	0	0.545333
8	0.673799	0.005392	0	0.045804	0.608463
9	0.35171	0	0.000027	0	0.321967
10	0.230626	0	0.000055	0	0.233784
11	0.181535	0	0.00004	0	0.130371
12	0.118645	0	3.07E-06	0	0.058082
13	0.14454	0	9.79E-06	0	0.110312
14	0.058058	0	0.000023	0	0.04683
15	0.05042	0	0.000019	0	0.029816
16	0.031485	0	3.50E-06	0	0.025759
17	0.025735	0	0.000028	0	0.064997
18	0.195002	0	0.000025	0	0.267727
19	0.277695	0	0	0	0.360301
20	0.313344	0	0	0	0.390138
21	0.346732	0	0	0	0.412325
22	0.368767	0	0	0	0.425886
23	0	0	0	0	0
24	0	0	0	0	0
	5.227762	0.026879	0.000233	0.045804	4.788744

West Facade

PV angle	KW				Radiation on glass				
Angle	Mar-21	Jun-21	Sep-21	Dec-21	Angle	Mar-21	Jun-21	Sep-21	Dec-21
90	1.807	3.539	1.814	0.403	90	6.707681	9.195548	6.840976	2.039134
89	1.806	3.538	1.814	0.402	89	6.624093	9.049299	6.746316	2.020804
88	1.805	3.537	1.813	0.402	88	6.568498	8.94867	6.682459	2.003704
87	1.803	3.534	1.811	0.402	87	6.466165	8.769651	6.583452	1.987929
86	1.801	3.531	1.81	0.401	86	6.417084	8.744742	6.540967	1.979364
85	1.799	3.526	1.807	0.4	85	6.33085	8.619625	6.455388	1.960678
84	1.795	3.52	1.804	0.4	84	6.309048	8.48921	6.434036	1.95115
83	1.794	3.515	1.803	0.399	83	6.228228	8.376487	6.345125	1.9327
82	1.793	3.51	1.803	0.398	82	6.172909	8.240575	6.277095	1.917994
81	1.792	3.505	1.802	0.398	81	6.080306	8.144271	6.184422	1.905601
80	1.79	3.499	1.801	0.398	80	6.031439	8.051952	6.143529	1.8963
79	1.788	3.493	1.799	0.398	79	5.991363	7.972392	6.105716	1.874613
78	1.786	3.485	1.797	0.398	78	5.873487	7.76578	5.991978	1.863845
77	1.783	3.476	1.795	0.398	77	5.83688	7.723528	5.948156	1.851603
76	1.779	3.466	1.792	0.398	76	5.758261	7.611567	5.858951	1.835111
75	1.775	3.455	1.788	0.399	75	5.650616	7.470998	5.749123	1.81778
74	1.771	3.443	1.784	0.399	74	5.632077	7.462042	5.730417	1.806504

73	1.766	3.43	1.78	0.399	73	5.609722	7.340461	5.706591	1.789501
72	1.76	3.416	1.775	0.4	72	5.491015	7.243371	5.596133	1.779267
71	1.755	3.405	1.77	0.4	71	5.460185	7.102452	5.565864	1.766131
70	1.751	3.395	1.767	0.4	70	5.405164	7.003065	5.507859	1.755837
69	1.748	3.384	1.764	0.4	69	5.247955	6.829569	5.338622	1.731557
68	1.745	3.372	1.762	0.4	68	5.23772	6.814933	5.329055	1.7215
67	1.742	3.359	1.76	0.4	67	5.220346	6.78679	5.309923	1.714631
66	1.738	3.346	1.757	0.4	66	5.194917	6.76904	5.285214	1.692209
65	1.735	3.332	1.755	0.4	65	5.171605	6.750566	5.260291	1.686103
64	1.731	3.317	1.752	0.4	64	5.082038	6.653982	5.172261	1.667799
63	1.727	3.3	1.749	0.4	63	5.017306	6.523134	5.104985	1.654125
62	1.722	3.283	1.745	0.4	62	4.88508	6.227347	4.971943	1.640395
61	1.717	3.265	1.741	0.399	61	4.829844	6.148625	4.917597	1.623211
60	1.712	3.247	1.736	0.4	60	4.785035	6.088584	4.865951	1.612036
59	1.706	3.232	1.731	0.4	59	4.735826	6.065596	4.816815	1.589802
58	1.701	3.217	1.726	0.399	58	4.720054	6.045474	4.799571	1.579457
57	1.694	3.202	1.72	0.399	57	4.696011	6.013374	4.775858	1.568065
56	1.688	3.186	1.715	0.399	56	4.613992	5.954632	4.687765	1.552476
55	1.682	3.169	1.709	0.399	55	4.532628	5.889243	4.607479	1.538883
54	1.676	3.151	1.703	0.398	54	4.475952	5.755824	4.546881	1.529504
53	1.669	3.132	1.697	0.398	53	4.452933	5.739808	4.524624	1.519311
52	1.661	3.112	1.69	0.397	52	4.412746	5.549115	4.485851	1.507251
51	1.654	3.092	1.683	0.396	51	4.376147	5.527947	4.447351	1.484148
50	1.649	3.071	1.678	0.396	50	4.355601	5.506	4.427499	1.473626
49	1.643	3.049	1.672	0.396	49	4.323397	5.477817	4.398438	1.458066
48	1.637	3.026	1.666	0.396	48	4.304142	5.467274	4.378238	1.450793
47	1.631	3.005	1.659	0.395	47	4.192985	5.371681	4.271863	1.427828
46	1.624	2.986	1.653	0.394	46	4.118496	5.326152	4.188046	1.415818
45	1.617	2.966	1.645	0.394	45	4.046253	5.311435	4.115997	1.405718
44	1.609	2.946	1.637	0.393	44	4.027703	5.296088	4.097576	1.389885
43	1.601	2.927	1.629	0.392	43	4.002838	5.27735	4.070651	1.383339
42	1.593	2.907	1.621	0.391	42	3.943993	5.195052	4.008688	1.357595
41	1.584	2.886	1.612	0.39	41	3.90394	5.120393	3.969564	1.344664
40	1.577	2.865	1.604	0.389	40	3.893088	5.118047	3.964288	1.33189
39	1.569	2.842	1.597	0.387	39	3.86489	5.080985	3.934239	1.317964
38	1.561	2.819	1.589	0.386	38	3.830416	5.02738	3.892332	1.305985
37	1.553	2.796	1.581	0.385	37	3.735702	4.953029	3.801023	1.293046
36	1.545	2.772	1.572	0.383	36	3.717172	4.942312	3.782099	1.284887
35	1.536	2.748	1.563	0.381	35	3.708471	4.924964	3.770381	1.2662
34	1.526	2.723	1.554	0.38	34	3.681909	4.890288	3.744159	1.250289
33	1.516	2.698	1.544	0.378	33	3.653348	4.876865	3.715349	1.243524
32	1.506	2.674	1.534	0.376	32	3.638589	4.922227	3.699028	1.244169
31	1.496	2.65	1.524	0.375	31	3.627992	4.909995	3.688602	1.232444
30	1.485	2.627	1.513	0.374	30	3.658787	4.893485	3.709082	1.222215
29	1.474	2.602	1.502	0.372	29	3.643689	4.91852	3.693068	1.21454
28	1.464	2.577	1.491	0.37	28	3.616399	4.904531	3.672398	1.187061
27	1.453	2.551	1.481	0.369	27	3.600087	4.885904	3.655748	1.167608
26	1.441	2.524	1.469	0.367	26	3.594604	4.874288	3.653322	1.160564

25	1.429	2.497	1.458	0.365	25	3.563522	4.886397	3.623108	1.14538
24	1.418	2.473	1.446	0.363	24	3.466556	4.832158	3.517794	1.128277
23	1.407	2.448	1.435	0.361	23	3.410293	4.790097	3.462669	1.111965
22	1.395	2.422	1.424	0.359	22	3.386281	4.768415	3.439405	1.101929
21	1.383	2.396	1.412	0.357	21	3.379178	4.841781	3.434961	1.092985
20	1.371	2.37	1.399	0.355	20	3.390963	4.937107	3.462379	1.084826
19	1.359	2.343	1.387	0.352	19	3.381109	4.914855	3.452025	1.075204
18	1.346	2.315	1.374	0.35	18	3.364349	4.953542	3.432882	1.065017
17	1.332	2.286	1.36	0.347	17	3.356608	4.988903	3.428873	1.054843
16	1.319	2.257	1.346	0.344	16	3.403159	4.989711	3.474766	1.047749
15	1.306	2.227	1.334	0.342	15	3.421241	5.014014	3.492421	1.042761
14	1.293	2.197	1.321	0.339	14	3.472552	5.060202	3.531731	1.044397
13	1.28	2.169	1.308	0.336	13	3.479644	5.060865	3.548935	1.036216
12	1.267	2.142	1.295	0.333	12	3.473299	5.174968	3.543069	1.02698
11	1.254	2.115	1.281	0.33	11	4.014745	6.081632	4.099825	1.168796
10	1.24	2.087	1.267	0.327	10	4.012794	6.168935	4.096115	1.158527
9	1.225	2.058	1.252	0.323	9	4.04456	6.179726	4.13313	1.151741
8	1.211	2.029	1.238	0.32	8	4.045548	6.248244	4.142577	1.147488
7	1.196	2	1.222	0.317	7	4.066424	6.458242	4.153565	1.147266
6	1.18	1.97	1.207	0.313	6	4.085985	6.51844	4.181376	1.152926
5	1.165	1.939	1.191	0.31	5	4.162282	6.594278	4.251059	1.158508
4	1.149	1.907	1.175	0.306	4	4.169225	6.789828	4.255197	1.149886
3	1.132	1.875	1.158	0.302	3	4.74611	7.678055	4.853923	1.285141
2	1.115	1.843	1.141	0.298	2	5.302338	8.682401	5.426043	1.430615
1	1.098	1.809	1.124	0.294	1	6.908941	11.34003	7.071266	1.8543

	Mar-21		Jun-21		Sep-21		Dec-21	
	P.V.	Shading	P.V.	Shading	P.V.	Shading	P.V.	Shading
South	38°	90°	62	30	38	90	14	90
East	90°	90°	90	22	90	90	90	90
West	90°	90°	90	22	90	90	90	90
North	90°	90°	90	13	90	90	90	90

	Mar	Jun	Jun	Sept	Dec
Hours of the day			cooling		
	90°	22°	90°	90°	90°
1	0.024729	0	0	0	0.000979
2	0.101836	0	0	0	0.045596
3	0.156667	0	0	0	0.1006
4	0.195389	0	0	0	0.117503

5	0.23069	0	0	0	0.377156
6	0.506707	0	0	0	0.527113
7	0.623831	0	0	0	0.592519
8	0.673144	0	0	0.040462	0.308914
9	0.362466	0	0	0	0.231412
10	0.25634	0	0	0	0.175981
11	0.19825	0	0	0	0.118781
12	0.137161	0	0	0	0.140088
13	0.159056	0	0	0	0.039053
14	0.064754	8.84E-06	0.000021	0	0
15	0.052654	0.00002	0.00002	0	0
16	0.020161	3.60E-06	3.59E-06	0	0.003713
17	0.003418	0.000028	0.000028	0	0.218224
18	0.178611	0	0	0	0.321428
19	0.270483	0	0	0	0.352279
20	0.306997	0	0	0	0.377927
21	0.342015	0	0	0	0.394544
22	0.364668	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	
Total energy	5.230027	6.04E-05	7.26E-05	0.040462	4.44381

Results from simulation

Schedules-SetPoints (Schedule Type=Temperature)

	First Object Used	Month Assumed	11am First Wednesday [C]	Days with Same 11am Value	11pm First Wednesday [C]	Days with Same 11pm Value
generic office heating	thermostat setpoint dual setpoint 1	January	21.00	365	15.60	365
generic office cooling	thermostat setpoint dual setpoint 1	July	24.00	365	26.70	365

Report: Adaptive Comfort Summary

For: Entire Facility

Timestamp: 2021-06-22 18:29:07

Time Not Meeting the Adaptive Comfort Models during Occupied Hours

	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	CEN15251 Category I Acceptability Limits [Hours]	CEN15251 Category II Acceptability Limits [Hours]	CEN15251 Category III Acceptability Limits [Hours]

Abu Dhabi

	Energy generated by P.V. Panels					Radiation on glass by shading device			
Angle	Mar-21	Jun-21	Sep-21	Dec-21		Mar-21	Jun-21	Sep-21	Dec-21
90	0.00202	0.002461	0.002022	0.001353		5.887624	3.163149	5.879757	13.54082
89	0.002033	0.002457	0.002035	0.00138		5.89888	3.097276	5.897075	13.18762
88	0.002046	0.002452	0.002048	0.001405		5.865967	3.077092	5.865668	13.12166
87	0.002057	0.002447	0.00206	0.001431		5.814167	3.054604	5.815007	13.04203
86	0.002068	0.002441	0.002071	0.001455		5.785474	3.048413	5.785225	13.02541
85	0.002079	0.002434	0.002082	0.00148		5.696605	3.015393	5.684218	12.88525
84	0.002088	0.002426	0.002092	0.001504		5.5744	2.959768	5.566451	12.57747
83	0.002098	0.002418	0.002102	0.001528		5.558784	2.952878	5.551235	12.54876
82	0.002107	0.00241	0.002112	0.001551		5.511246	2.921276	5.506674	12.28304
81	0.002116	0.002402	0.002121	0.001574		5.451684	2.899396	5.443473	12.252
80	0.002124	0.002393	0.00213	0.001597		5.455999	2.850885	5.462928	12.26957
79	0.002132	0.002383	0.002138	0.00162		5.381035	2.858151	5.375409	12.11339
78	0.002139	0.002372	0.002145	0.001642		5.343413	2.847049	5.337393	12.06915
77	0.002146	0.002361	0.002152	0.001663		5.316845	2.828769	5.311568	12.01828
76	0.002151	0.00235	0.002158	0.001684		5.269195	2.792747	5.265118	11.88811
75	0.002157	0.002337	0.002164	0.001704		5.209028	2.773224	5.202734	11.75233
74	0.002161	0.002324	0.002169	0.001724		5.167058	2.745996	5.161984	11.55207
73	0.002165	0.00231	0.002173	0.001744		5.095581	2.728633	5.078609	11.47044
72	0.002168	0.002296	0.002177	0.001763		5.055095	2.701581	5.041082	11.33204
71	0.002171	0.002281	0.00218	0.001781		5.015124	2.678895	5.003237	11.19954
70	0.002174	0.002266	0.002183	0.001799		5.086404	2.682396	5.089272	10.91812
69	0.002175	0.002251	0.002185	0.001817		4.934472	2.643181	4.920523	11.10191
68	0.002177	0.002235	0.002187	0.001834		4.881857	2.613492	4.866551	11.06431
67	0.002178	0.002218	0.002188	0.001851		4.847358	2.594984	4.831974	10.9982
66	0.002178	0.002201	0.002188	0.001867		4.832093	2.589578	4.816658	10.9857
65	0.002177	0.002183	0.002188	0.001883		4.776564	2.56181	4.762727	10.75084
64	0.002176	0.002165	0.002187	0.001898		4.750918	2.546406	4.738333	10.70212
63	0.002175	0.002146	0.002186	0.001912		4.723542	2.526729	4.712235	10.6147
62	0.002172	0.002127	0.002184	0.001926		4.702572	2.515359	4.691089	10.59556
61	0.002169	0.002107	0.002181	0.001939		4.675825	2.496757	4.665887	10.41311
60	0.002166	0.002086	0.002178	0.001952		4.719714	2.511473	4.73038	10.32655
59	0.002162	0.002065	0.002174	0.001964		4.600903	2.453671	4.591545	10.29572
58	0.002157	0.002043	0.00217	0.001976		4.564837	2.429122	4.555701	10.2412
57	0.002152	0.002021	0.002165	0.001987		4.530558	2.413776	4.523285	10.10194
56	0.002147	0.001999	0.00216	0.001998		4.506051	2.402251	4.499053	10.06434
55	0.00214	0.001977	0.002154	0.002008		4.488719	2.393651	4.481768	10.03175
54	0.002134	0.001954	0.002147	0.002018		4.480205	2.390219	4.473291	10.01757
53	0.002126	0.00193	0.00214	0.002026		4.449341	2.375901	4.440635	9.991067
52	0.002118	0.001906	0.002132	0.002035		4.429879	2.370855	4.420066	9.972025
51	0.00211	0.001881	0.002124	0.002042		4.382971	2.336722	4.375703	9.842937
50	0.002101	0.001856	0.002115	0.00205		4.374777	2.293686	4.375347	9.844928
49	0.002091	0.001831	0.002106	0.002056		4.325364	2.30286	4.319938	9.604036
48	0.00208	0.001805	0.002095	0.002062		4.271533	2.268745	4.266586	9.55801
47	0.00207	0.001779	0.002085	0.002067		4.293079	2.263348	4.301603	9.509564

46	0.002058	0.001752	0.002074	0.002072		4.281977	2.258947	4.290739	9.502084
45	0.002046	0.001725	0.002062	0.002076		4.345004	2.261391	4.352022	9.484326
44	0.002034	0.001697	0.002049	0.00208		4.331377	2.256875	4.338212	9.467832
43	0.002021	0.00167	0.002037	0.002083		4.310559	2.248927	4.317555	9.431673
42	0.002008	0.001643	0.002023	0.002085		4.281423	2.238999	4.287384	9.387615
41	0.001994	0.001615	0.00201	0.002087		4.293688	2.234022	4.303849	9.358048
40	0.001979	0.001587	0.001995	0.002088		4.162127	2.178705	4.164588	9.073539
39	0.001964	0.001559	0.00198	0.002089		4.272664	2.231584	4.281356	9.420491
38	0.001949	0.001531	0.001965	0.002089		4.260846	2.222928	4.267774	9.401946
37	0.001933	0.001502	0.001949	0.002088		4.235916	2.20877	4.244833	9.335646
36	0.001916	0.001473	0.001933	0.002087		4.207758	2.186289	4.217221	9.295262
35	0.001899	0.001443	0.001916	0.002085		4.214034	2.161031	4.236817	9.249113
34	0.001882	0.001414	0.001898	0.002083		4.222932	2.155333	4.248538	9.211213
33	0.001864	0.001384	0.00188	0.00208		4.179374	2.136914	4.205555	9.187696
32	0.001845	0.001354	0.001862	0.002076		4.175538	2.129447	4.204534	9.172625
31	0.001826	0.001323	0.001843	0.002072		4.180136	2.128115	4.20815	9.170628
30	0.001806	0.001292	0.001823	0.002067		4.108795	2.136531	4.140023	8.894646
29	0.001786	0.001261	0.001803	0.002061		4.178578	2.122951	4.206108	9.135153
28	0.001766	0.00123	0.001782	0.002055		4.18631	2.121	4.217171	9.115298
27	0.001745	0.001198	0.001762	0.002049		4.198621	2.119024	4.232706	9.099129
26	0.001488	0.000856	0.001503	0.001937		4.257939	2.126743	4.283438	9.448333
25	0.001702	0.001135	0.001718	0.002033		4.190024	2.114407	4.2215	9.159411
24	0.00168	0.001103	0.001696	0.002025		4.20838	2.123423	4.237619	9.316472
23	0.001657	0.001072	0.001673	0.002016		4.215187	2.130222	4.240946	9.347655
22	0.001634	0.001041	0.00165	0.002006		4.189378	2.122402	4.215564	9.326162
21	0.00161	0.001011	0.001626	0.001996		4.195483	2.120538	4.226505	9.312161
20	0.001587	0.00098	0.001602	0.001985		4.076903	2.117398	4.105338	8.784009
19	0.001563	0.000949	0.001578	0.001974		4.234436	2.11988	4.263696	9.338604
18	0.001538	0.000918	0.001553	0.001962		4.223706	2.117829	4.252512	9.350333
17	0.001513	0.000887	0.001528	0.00195		4.248443	2.129848	4.275715	9.478468
16	0.001488	0.000856	0.001503	0.001937		4.257939	2.126743	4.283438	9.448333
15	0.001462	0.000827	0.001477	0.001923		4.296549	2.132632	4.323858	9.458696
14	0.001436	0.000798	0.001451	0.001909		4.289271	2.126979	4.316136	9.444611
13	0.00141	0.000768	0.001425	0.001895		4.280713	2.121634	4.307005	9.416945
12	0.001384	0.00074	0.001398	0.00188		4.294916	2.126583	4.319396	9.52004
11	0.001357	0.000712	0.001371	0.001864		4.3091	2.137653	4.33215	9.638625
10	0.00133	0.000683	0.001343	0.001848		4.249132	2.2098	4.253136	10.48788
9	0.001302	0.000654	0.001315	0.001831		4.353596	2.152153	4.377187	9.850479
8	0.001274	0.000625	0.001287	0.001813		4.376745	2.158186	4.401734	9.837052
7	0.001246	0.000597	0.001258	0.001795		4.373463	2.158278	4.396524	9.824166
6	0.001218	0.000575	0.00123	0.001777		4.375451	2.158231	4.397725	9.809742
5	0.001189	0.000553	0.001201	0.001758		4.393375	2.159368	4.418931	9.794411
4	0.00116	0.00053	0.001172	0.001739		4.409022	2.16489	4.434257	9.805406
3	0.001131	0.000507	0.001142	0.001719		4.510418	2.234967	4.534867	9.968246
2	0.001101	0.000484	0.001112	0.001699		4.713772	2.388882	4.732628	10.39031
1	0.001071	0.000461	0.001082	0.001678		5.597562	2.922235	5.601693	12.49852

The angles that produce the most energy for P.V. and the angle that has the last radiation on the glass.

Angles								
	Mar-21		Jun-21		Sep-21		Dec-21	
	P.V.	Shading	P.V.	Shading	P.V.	Shading	P.V.	Shading
South	66°	20°	90°	25°	66°	20°	38°	20°

Energy produced by the different angles

	Mar-21		Jun-21		Sep-21		Dec-21	
Hours of the day	kW	kW	kW	kW	kW	kW	kW	kW
	66°	20°	90°	25°	66°	70°	38°	70°
1	0	0	0.475807	0.476784	0.400497	0.389838	0	0
2	0	0	0.369825	0.370702	0.196225	0.189684	0	0
3	0	0	0.289809	0.290578	0.028341	0.025721	0	0
4	0	0	0.266529	0.267187	0.000156	0	0	0
5	0	0	0.156218	0.156546	0	0	0	0
6	0	0	0.526612	0.526922	0.216959	0.215486	0	0
7	0	0	0.660846	0.6613	0.622781	0.61971	0	0
8	0	0	0.910701	0.911701	0.785071	0.775097	0	0
9	0.339946	0.321989	1.152314	1.154235	1.104633	1.078313	0	0
10	0.536878	0.511005	1.237884	1.240937	1.174926	1.149718	0.001255	0
11	0.617709	0.590427	1.334592	1.337566	1.209006	1.181237	0.238303	0.227161
12	0.69427	0.664676	1.305397	1.308637	1.262631	1.233596	0.513525	0.497903
13	0.624605	0.593804	1.171032	1.174534	1.206194	1.17611	0.589369	0.57211
14	0.752305	0.719438	1.238773	1.242482	1.282572	1.248957	0.684874	0.665644
15	0.884908	0.846494	1.37215	1.375803	1.410954	1.372226	0.710669	0.693827
16	0.92786	0.885698	1.46689	1.470228	1.512414	1.462726	0.719295	0.703446
17	0.945691	0.906578	1.512198	1.515302	1.464747	1.431937	0.724636	0.710274
18	0.752966	0.724999	1.265054	1.268267	1.186057	1.162996	0.388672	0.375634
19	0.626009	0.600276	1.154809	1.156259	1.033009	1.012235	0.132436	0.123994
20	0.469298	0.450791	1.212387	1.213527	1.05584	1.046355	0.013269	0.010183
21	0.300078	0.286244	1.174487	1.175371	1.023004	1.013668	0	0

22	0.109525	0.100821	1.107264	1.107982	1.051009	1.04327	0	0
23	0	0	0.467451	0.468492	0.431595	0.420739	0	0
24	0	0	0.5681	0.569112	0.504599	0.493758	0	0
Total	8.582048	8.20324	22.39713	22.44045	20.16322	19.74338	4.716303	4.580176

Energy difference

South		PV			Energy for heating/ cooling	
		KWh/m2	KWh	KW	KW	difference
Mar-21	66 °	0.00003	0.00006	0.00072	8.582048	-8.58133
Mar-21	70°	0.000249	0.000498	0.005976	8.20324	-8.19726
Jun-21	90°	0.000445	0.00089	0.01068	22.39713	-22.3864
Jun-21	25°	0.000377	0.000754	0.009048	22.44045	-22.4314
Sep-21	66 °	0.00003	0.00006	0.00072	20.16322	-20.1625
Sep-21	70°	0.000243	0.000486	0.005832	19.74338	-19.7375
Dec-21	38°	0.000088	0.000176	0.002112	4.716303	-4.71419
Dec-21	70°	0.000142	0.000284	0.003408	4.580176	-4.57677

Energy usage without shading device

Mar-21	Jun-21	Sep-21	Dec-21
Without shading			
kW	kW	kW	
0	0.485881	0.45638	0
0	0.377914	0.233235	0
0	0.295452	0.046125	0
0	0.269773	0.002795	0
0	0.155508	0	0
0	0.526683	0.231957	0
0	0.666382	0.64	0
0	0.926702	0.807698	0
0.378972	1.182386	1.150109	0
0.602897	1.280877	1.23229	0.009375
0.715396	1.371056	1.303561	0.307277
0.82261	1.341207	1.383035	0.619834
0.772602	1.208188	1.343295	0.722046
0.911114	1.278614	1.426686	0.823419
1.039818	1.413817	1.544525	0.815887
1.061174	1.508601	1.625344	0.815728
1.051086	1.554131	1.548036	0.802099
0.835189	1.313416	1.252604	0.460066
0.713614	1.17806	1.106717	0.18281
0.544792	1.229355	1.092756	0.038565

0.361994	1.186808	1.062028	0
0.155458	1.116737	1.085192	0
0	0.479537	0.484427	0
0	0.579338	0.560605	0
9.966716	22.92642	21.6194	5.597106

difference between with shading and no shading	1.763476	0.529294	1.876023	1.01693
Energy saved for 3 months	164.0033	49.22434	174.4701	94.57449
Total energy saved (KW)	482.2722			

Energy produced by P.V. at specified angles			
		Energy kWh	Energy for 3 months for a $2m^2$ panel
Mar	90 °	0.025465	56.83788
June	72°	0.040713	90.87142
Sept	90°	0.045655	101.902
Dec	90°	0.023605	52.68636
			302.2976