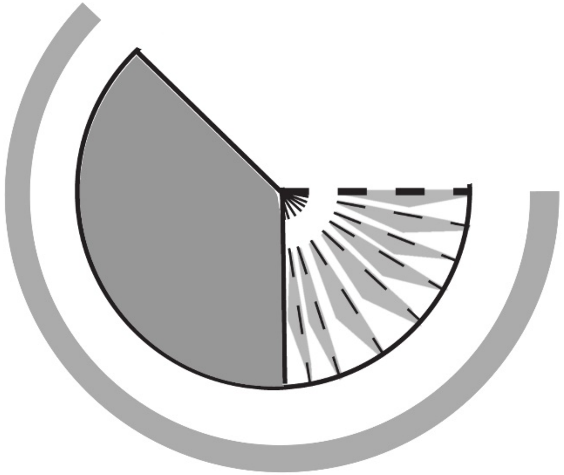
Helio tracker

P.V. integrated shading device

By Shefalika Sukhen Padmanabha



Delft University of Technology

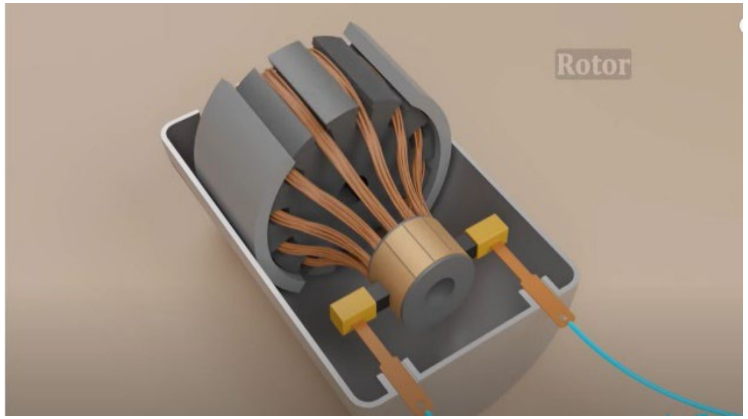
Theme: Sustainable structures

Mentor 1: Prof.dr. Mauro Overend — Field of study: Structural Design
Mentor 2: Dr. Eleonora Brembilla — Field of study: Climate Design
Board of examiner: Dr.ir. MGAD (Maurice) Harteveld

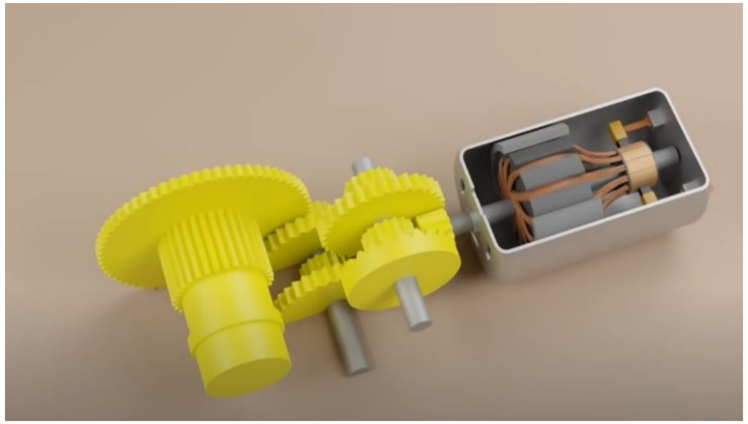
Solar tracking P.V. integrated shading device

Problem

Rotatory Motor



Rotor

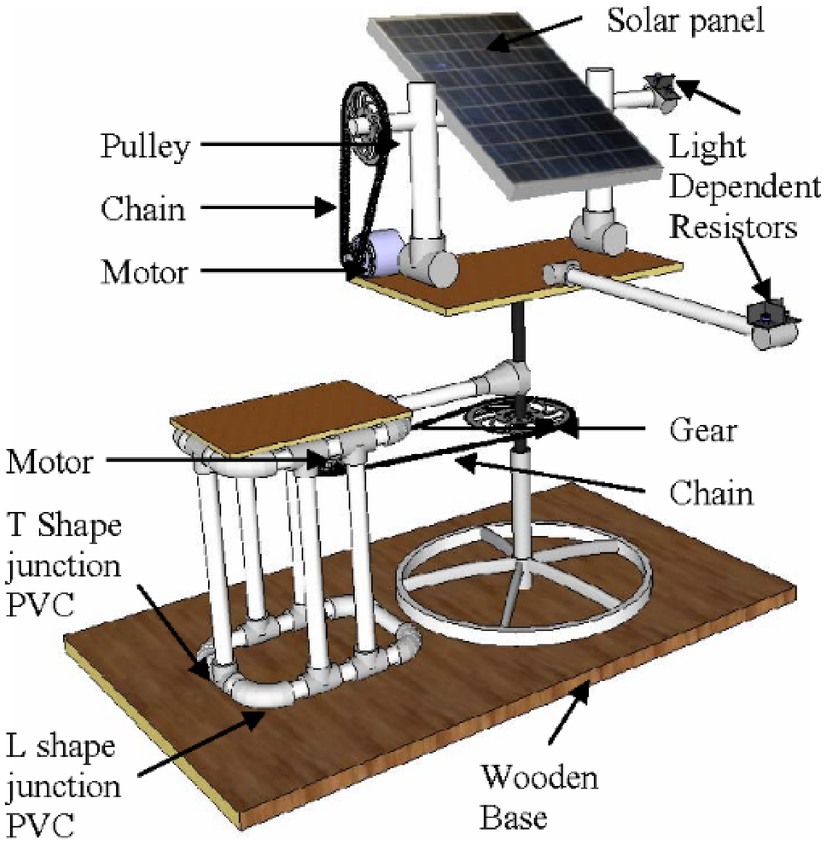


Gear

Source: Jared Owen. (2020, June 10). How does an Electric Motor work? (DC Motor). YouTube. https://www.youtube.com/watch?v=CWulQ1ZSE3c&ab_channel=JaredOwen

Solar tracking device

Used since 1989



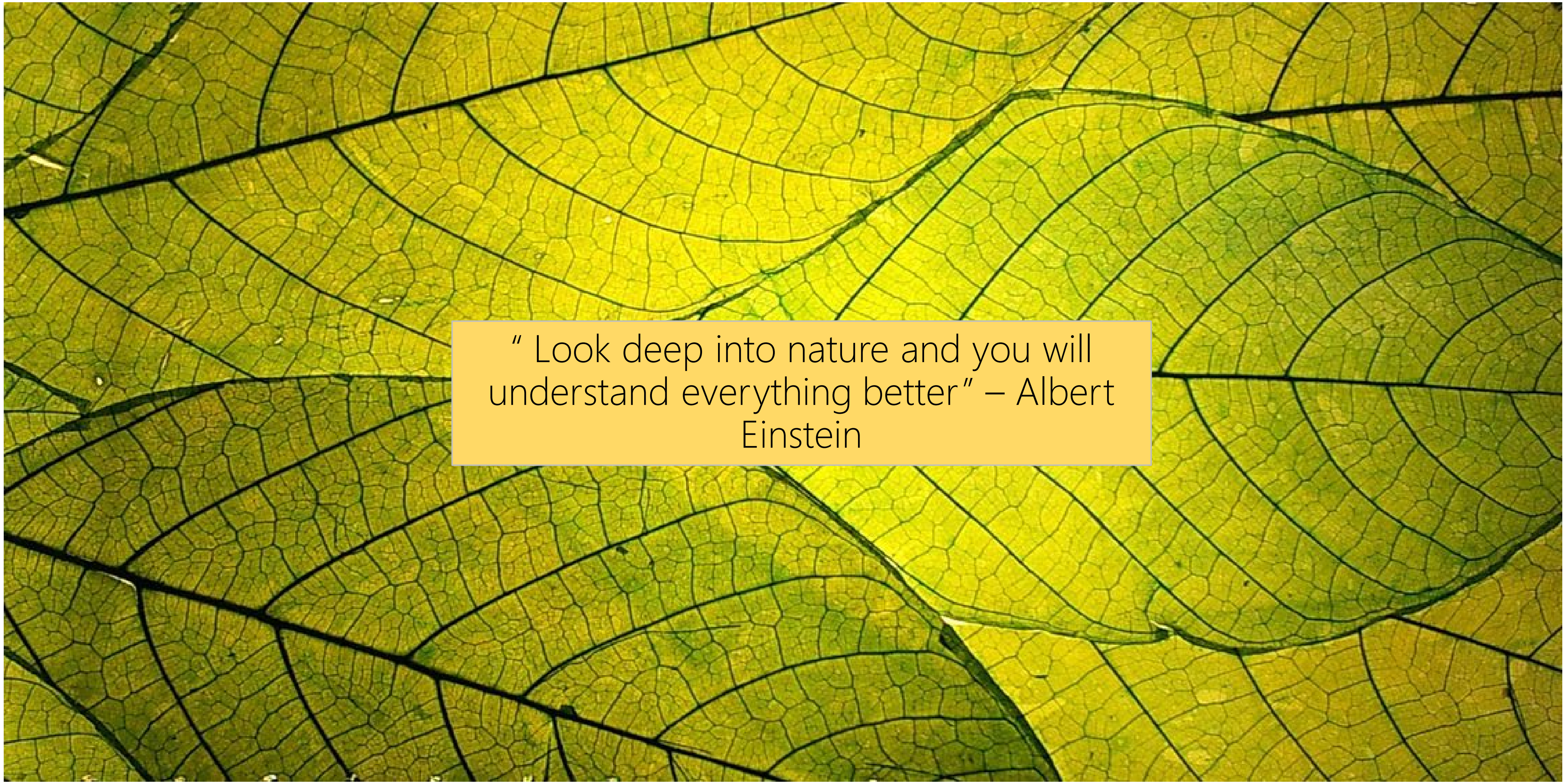
Source:K.E. Kanyarusoke, J. Gryzagoridis, Gr. Oliver. (2015, February). *Active solar tracker* [Image]. Are Solar Tracking Technologies Feasible for Domestic Applications in Rural Tropical Africa? http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-447X2015000100010

Problem

- Solar tracking Rotation system
- Contain multiple gears
- Wear and tear
- Balancing the load of monocrystalline P.V.
- Voluminous rotational system

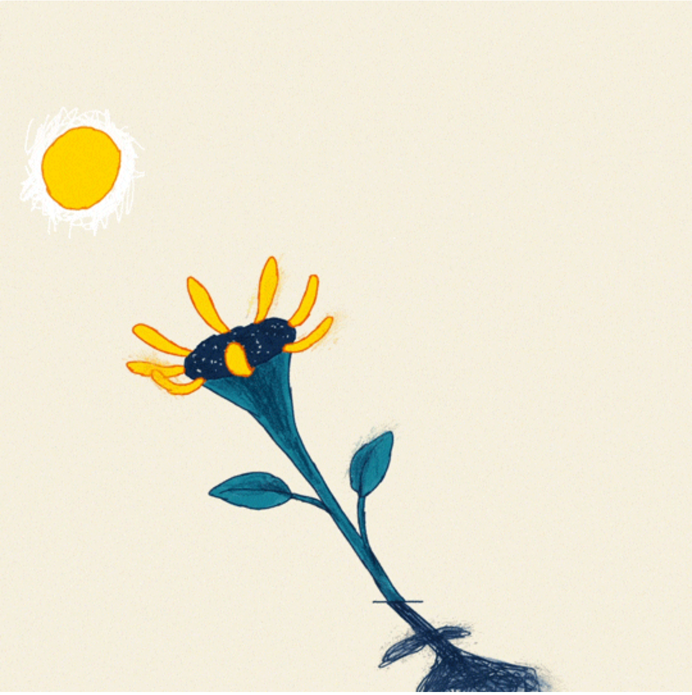
Source: https://doi.org/10.1016/j.apenergy.2019.04.033

How do you solve this problem?



“ Look deep into nature and you will understand everything better” – Albert Einstein

Image Source: Robert Dickinson. (2015). *Every Leaf a Flower* [Image]. https://in.pinterest.com/pin/669840144581489085/



Source: Hoffer, B. (2018). *Sunflower* [GIF].
https://www.google.com/search?q=sunflower%20%20gif%20moving&tbm=isch&hl=en&tbs=rimg:CbydvXINcpxEYYvJ18jiCidm&rlz=1C1CHBF_enIN858IN858&sa=X&ved=0CCMQuIIBahcKEwiAjO7kxb_xAhUAAAAAHQAAAAAQBw&biw=1519&bih=722#imgrc=oe2KtW9KMql3uM&imgdii=gynG0wmy8BW9XM

Heliotropic plants

Heliotropism - It is a response of an organism towards the direction of the sun

Example Sunflowers- follow the sun from east to west to increase the amount of solar radiation falling on it.

Research question

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

Literature study

Tropism in plants

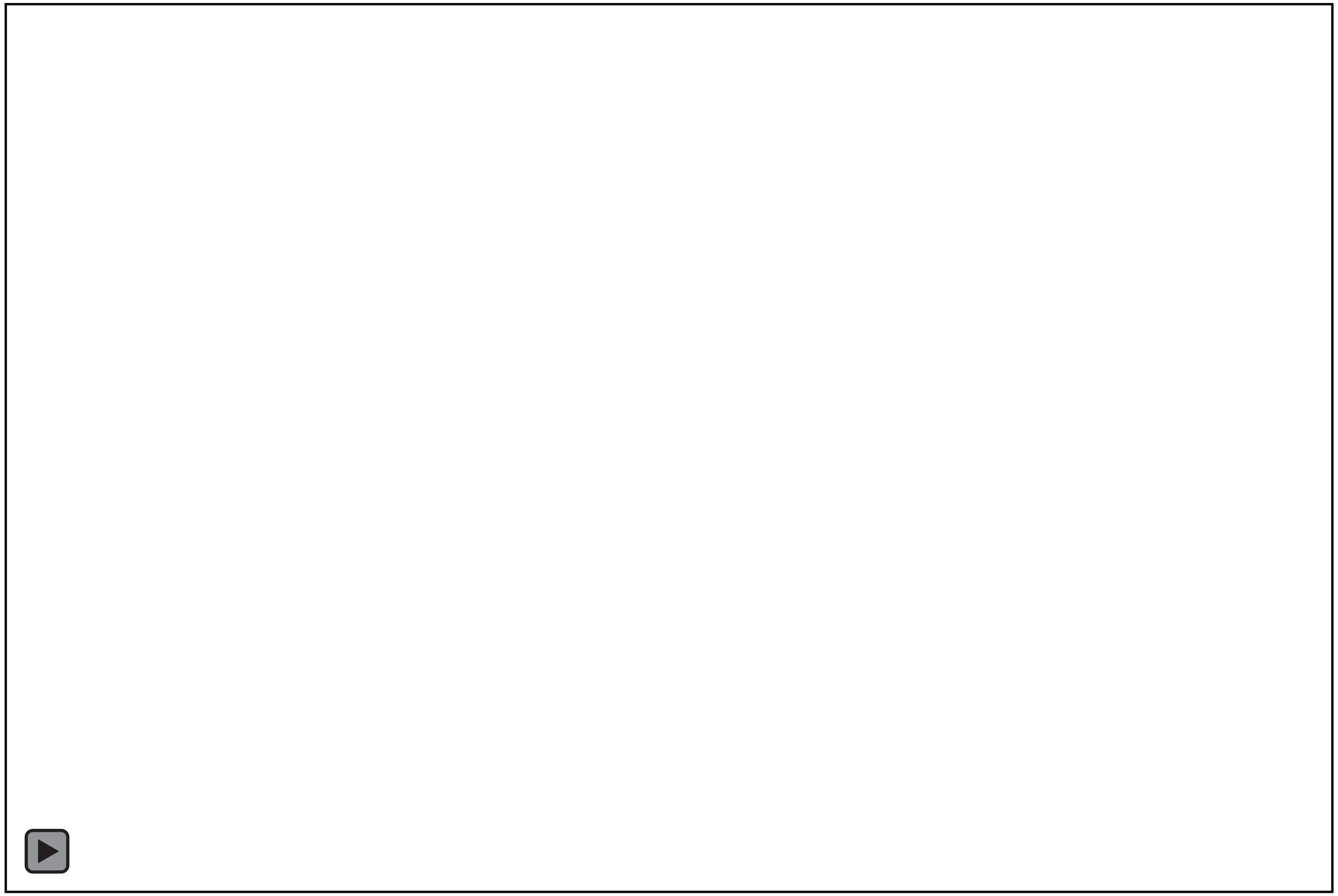
Tropism is an orienting response of an organism to a stimulus

Source: Make a gif. (2013). *Touch-me-not plant (Mimosa pudica) in action*.
https://makeagif.com/gif/touch-me-not-plant-mimosa-pudica-in-action-QjPeDW

Heliotropism – form of tropism.

A positive heliotropism is a response of an organism towards the direction of the sun

How does the sunflower track the sun?



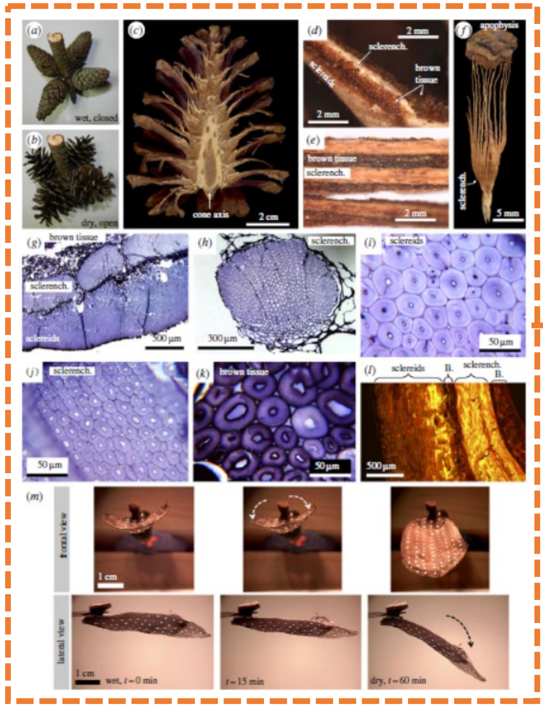
- East to west Morning
- West to east night
- Circadian rhythm
- No sensor in the night
- Stem is responsible for it’s movement

Source: doi:10.1126/science.aaf9793.

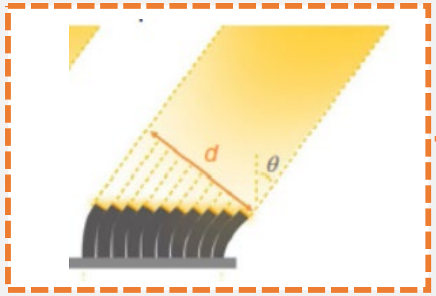
Case Study

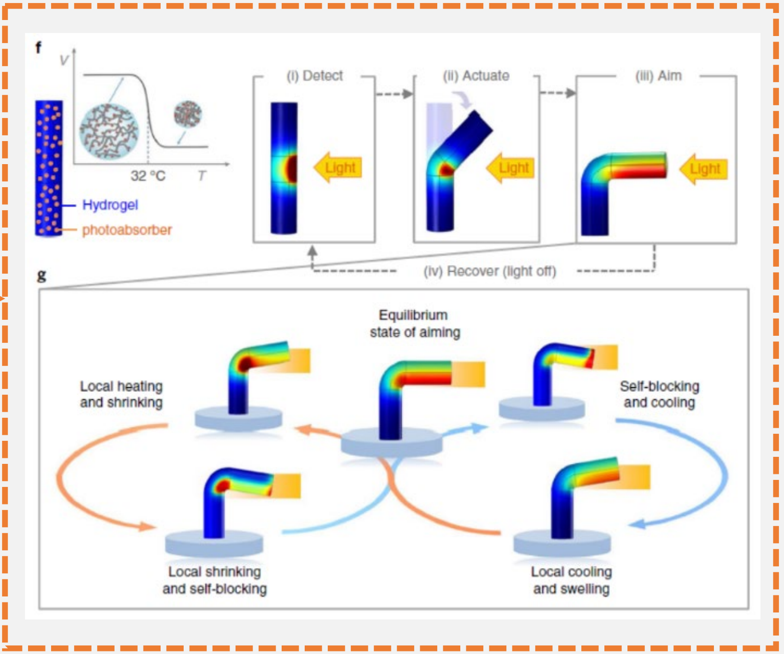
Case study

Hygroscopic pine cones



Nanostructured light responsive polymers





Composition of layers (3 D- printed moisture layer/ stiffness layer)
Calculated blocking force using a load cell
Fluorescent microscope
Gom Armis

Source: http://dx.doi.org/10.1098/rsta.2019.0445

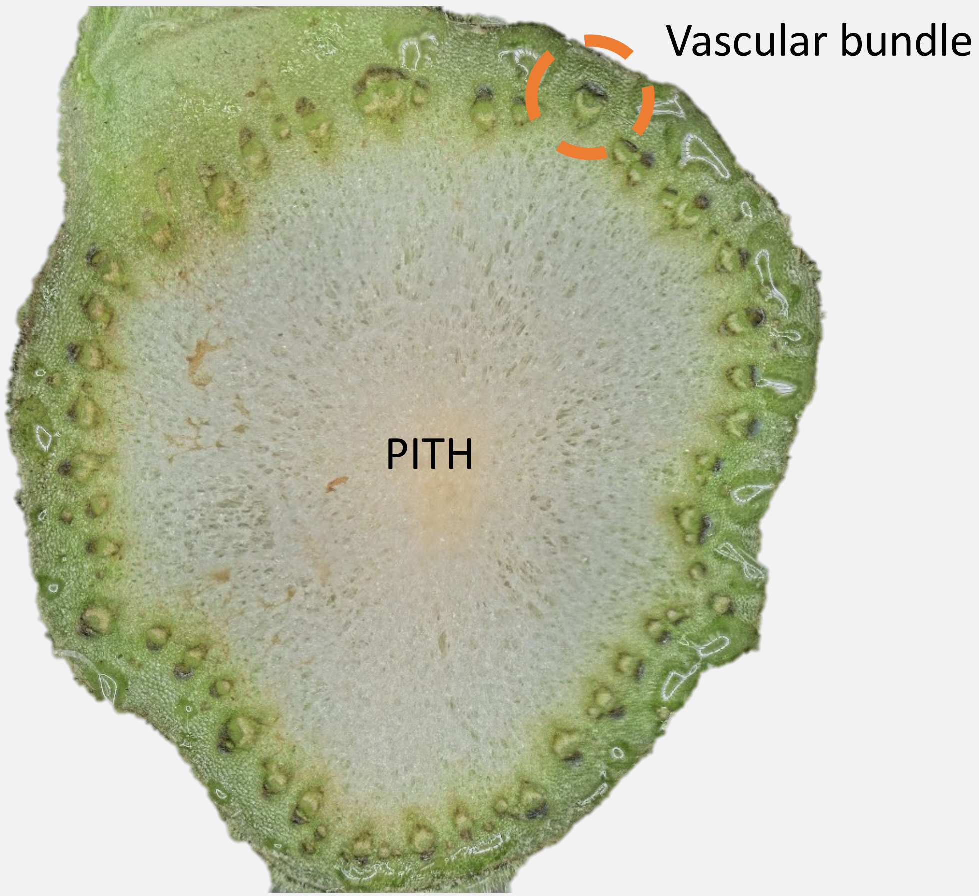
Bends in any direction (poly *N*-isopropylacrylamide)
Bends to any angle
Inbuilt stimuli
Material expands loss stiffness

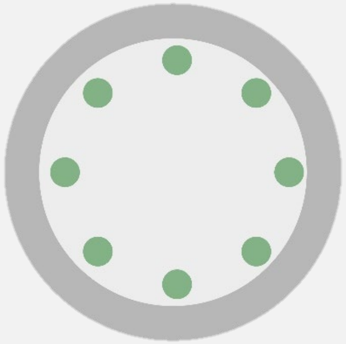
2. https://doi.org/10.1038/s41565-019-0562-3 .

Experimental study using microscope

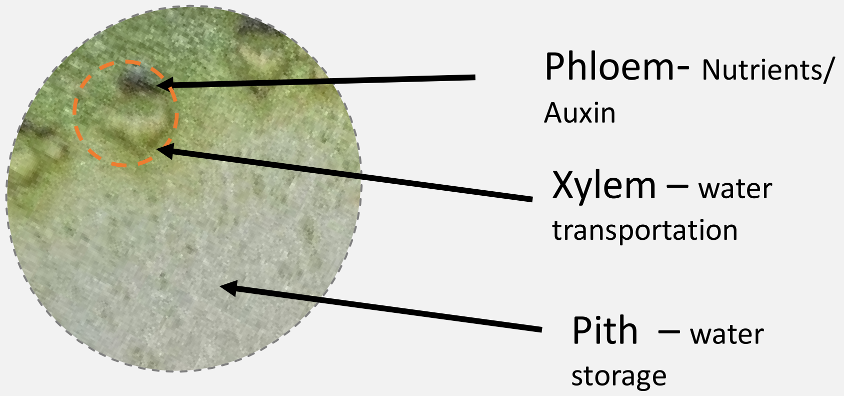
Image Source: Krystal, M. (2000). *How to Collect & Observe Snowflakes Under a Microscope* [Image]. https://stemeducationguide.com/snowflakes-under-microscope-science-activity/

Parts of the stem



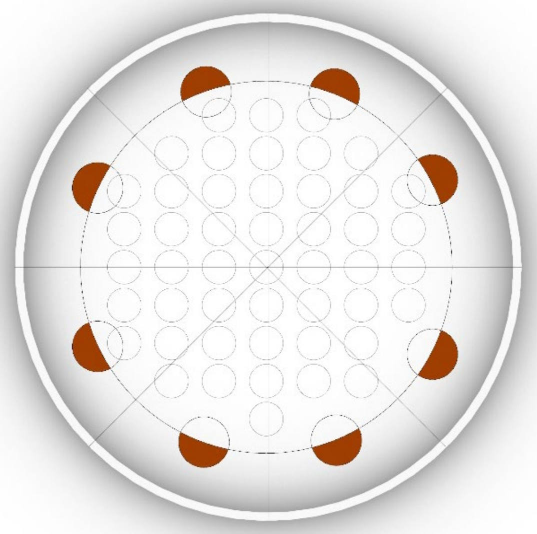


Dicot stem

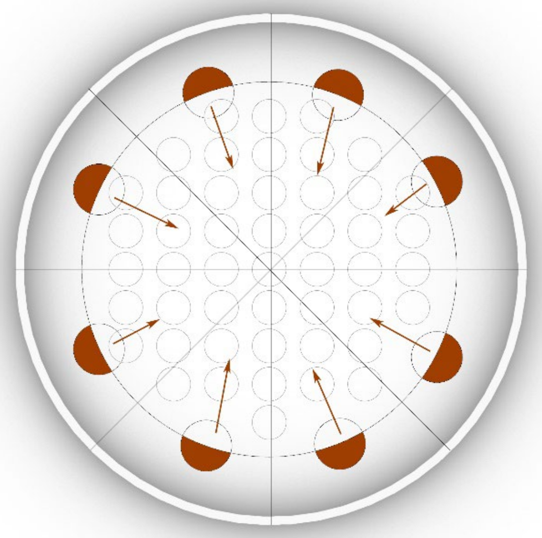


Vascular bundle

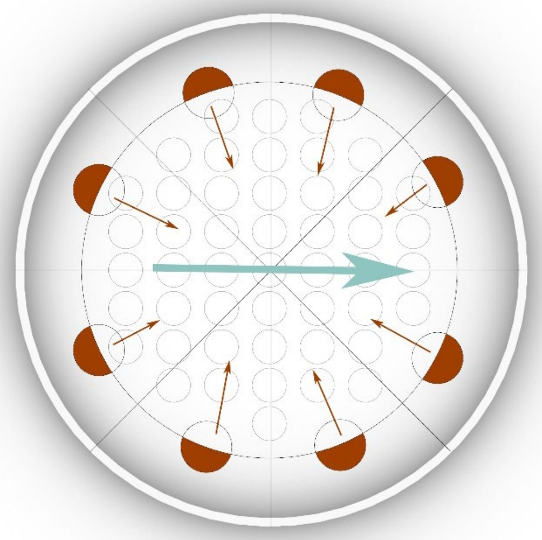
Source: Own work



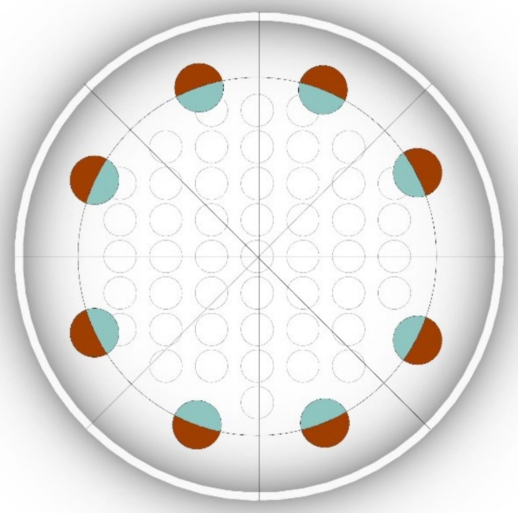
Phloem



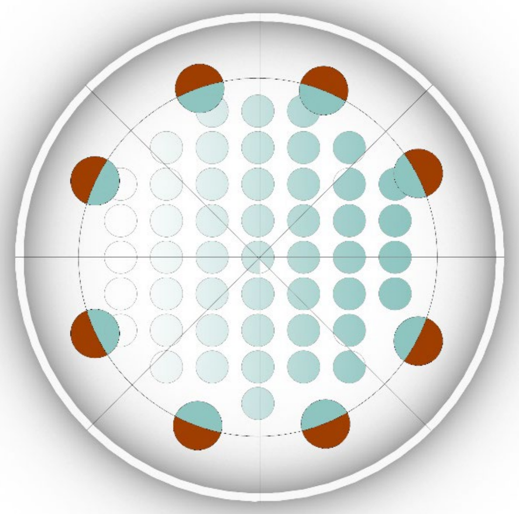
Phloem Releases Auxin



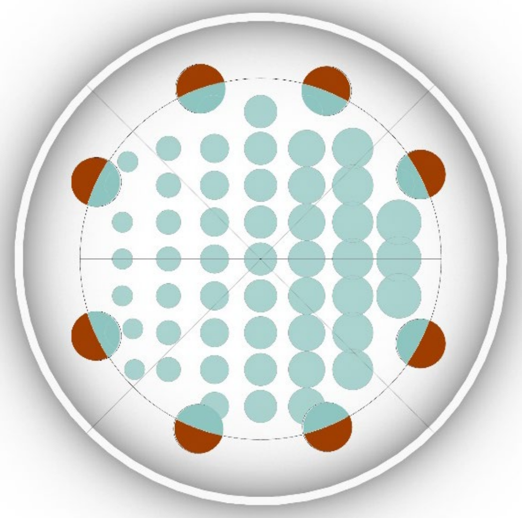
Auxin creates a gradient across pith



Xylem releases water



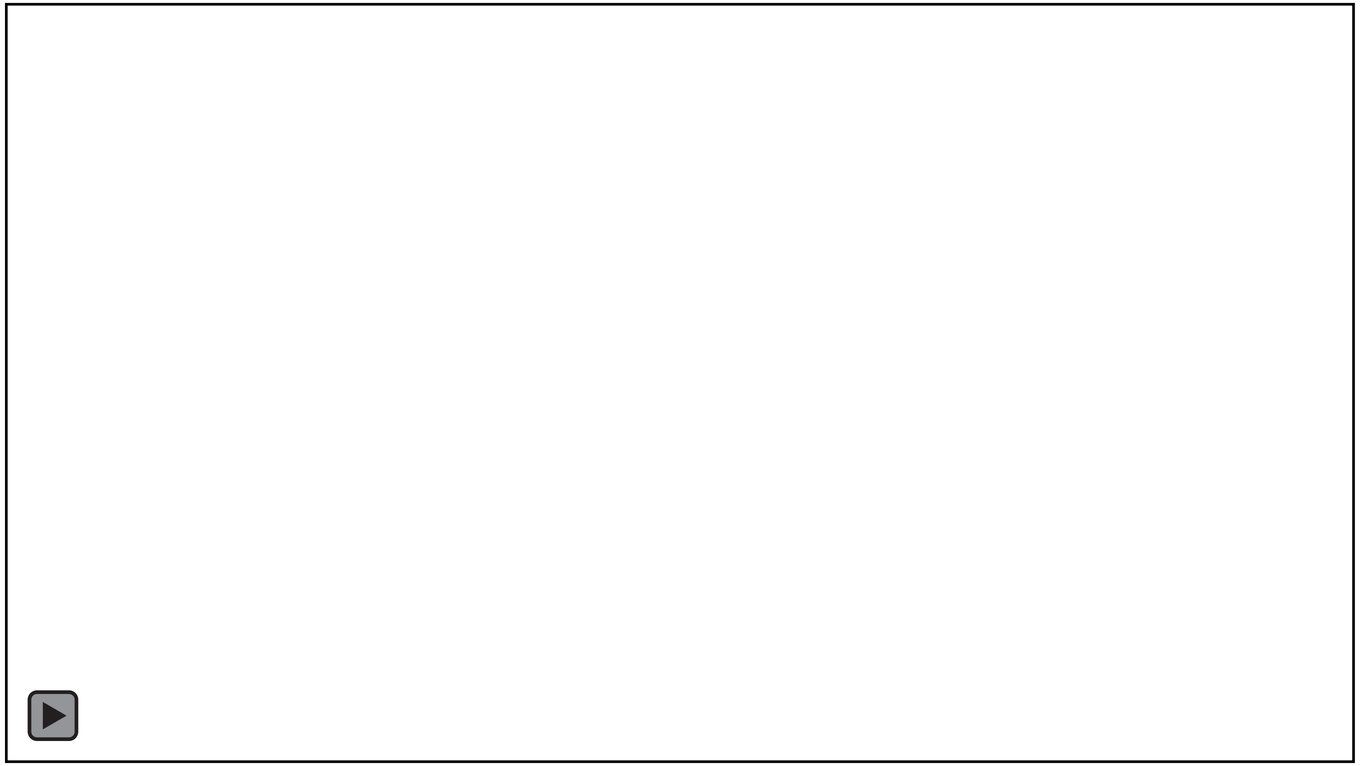
Cells absorb water based on the Auxin



Some cells absorb more water and enlarge

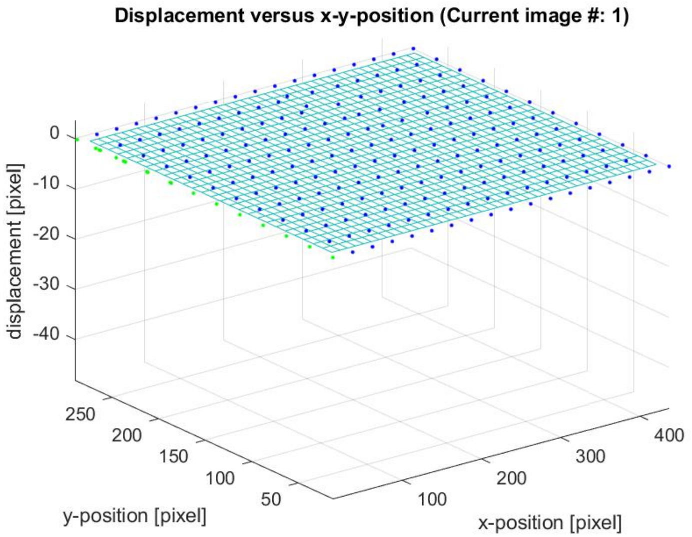
Source: Own work

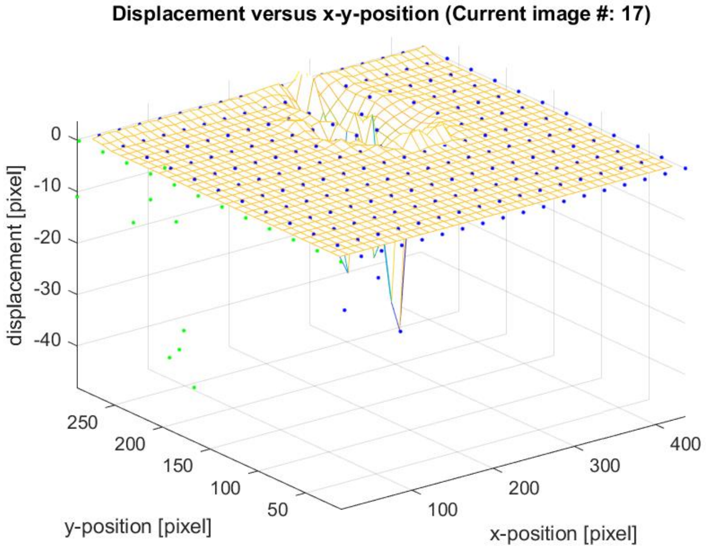
Movement of Sunflower

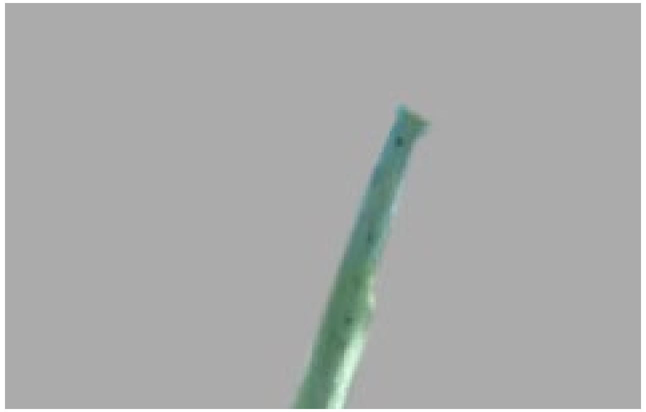


Source: Own work

Mat lab analysis for stem movement

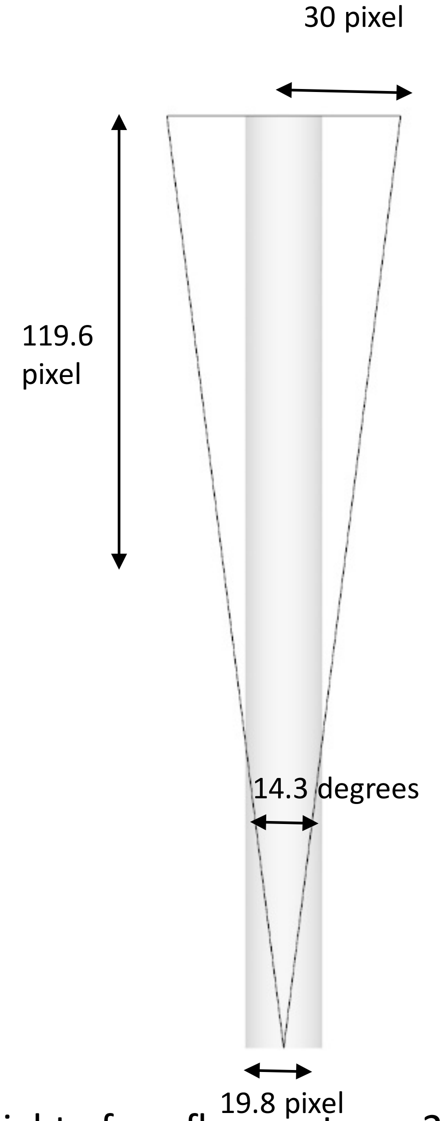






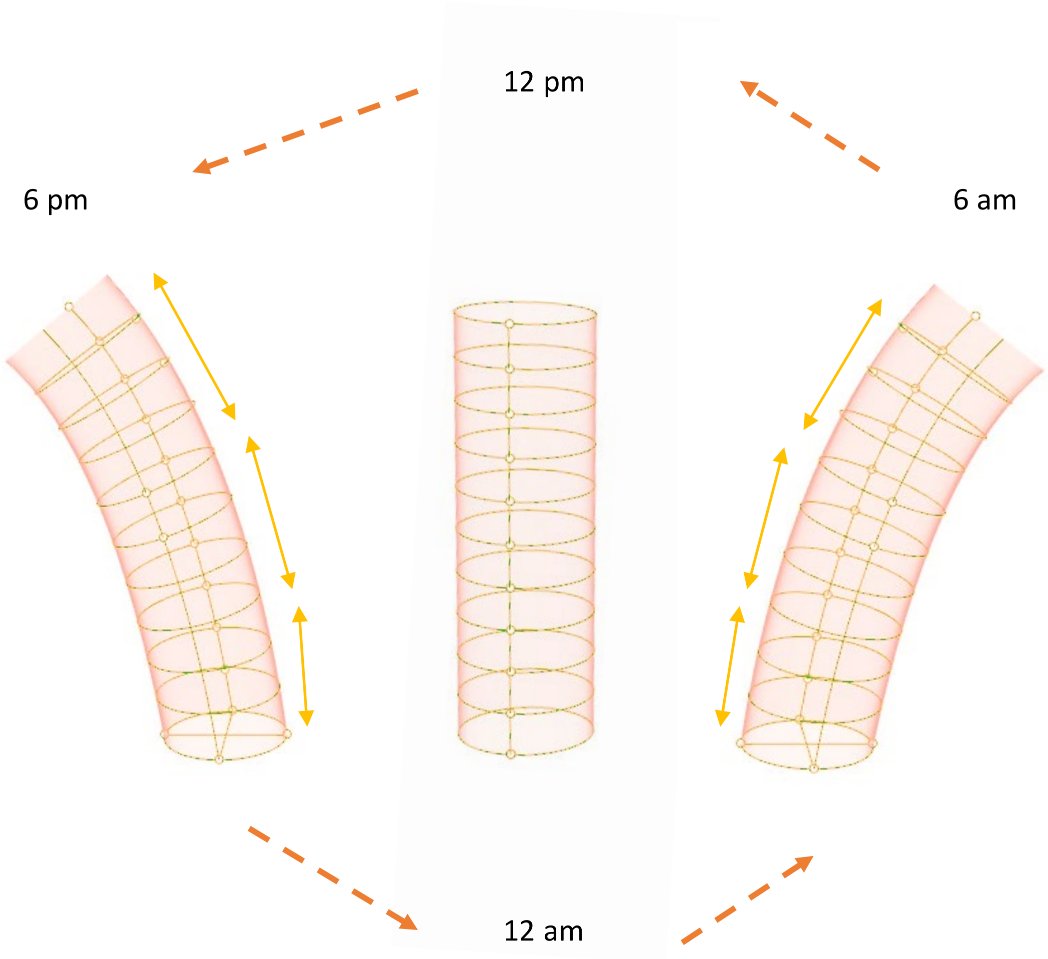
Source: Own work

Angle of movement

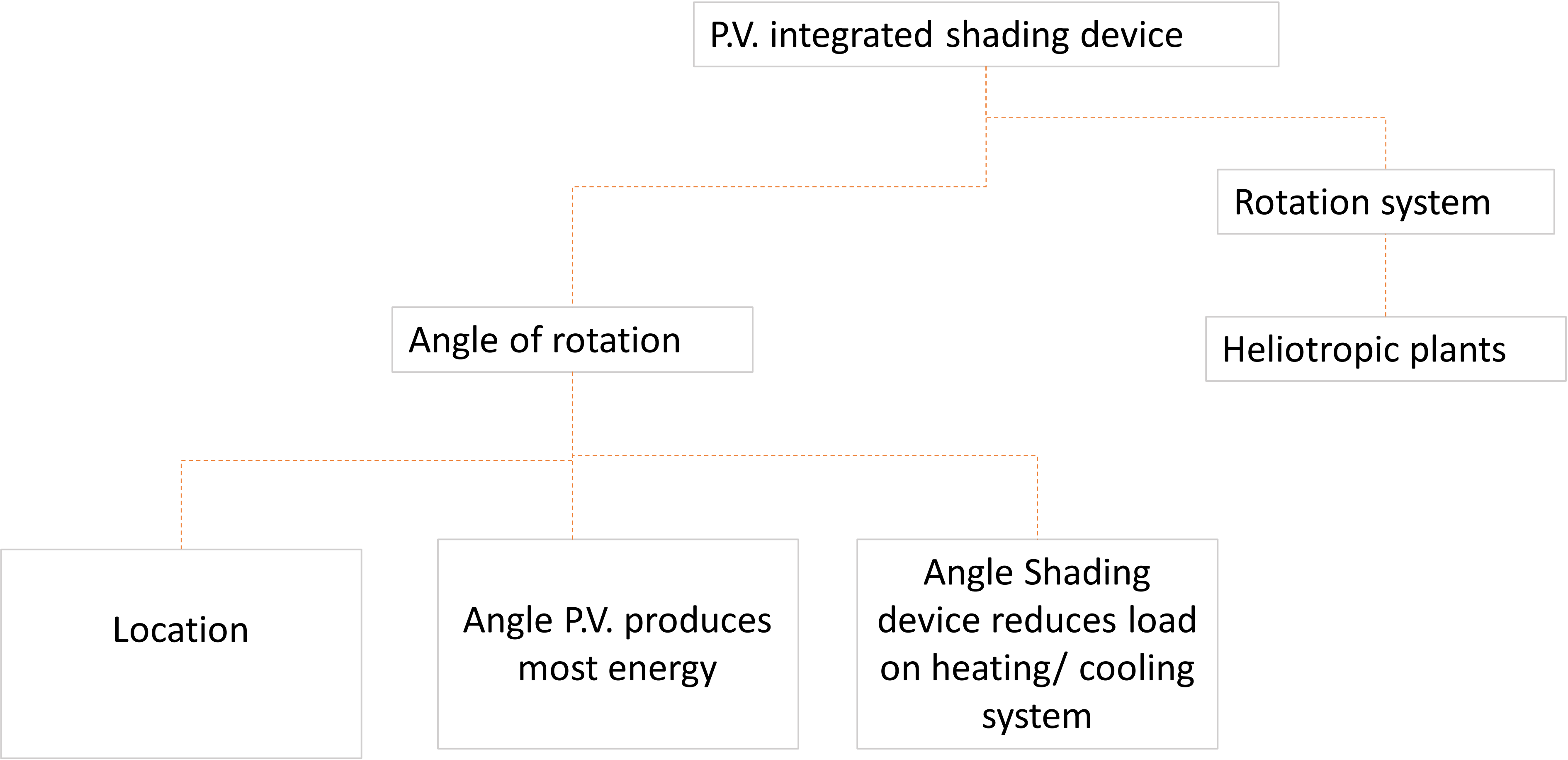


Height of sunflower stem =200 cm
Width of sunflower stem = 2cm

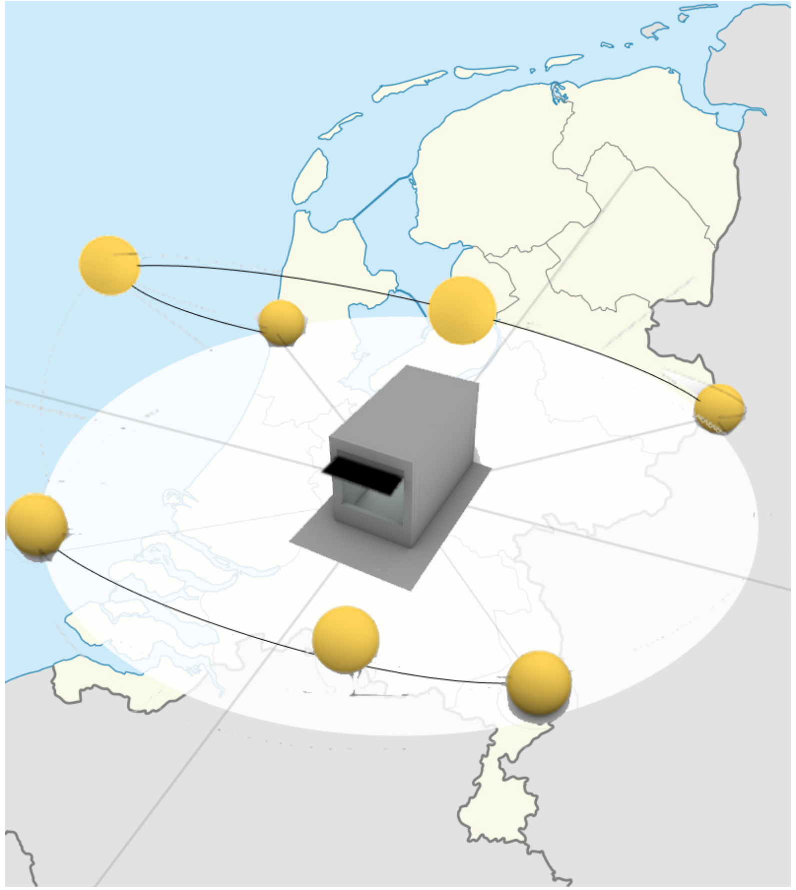
Compression and Tension



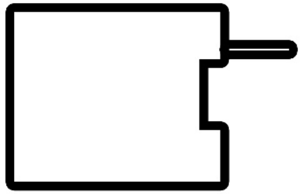
P.V. Integrated shading device


P.V. integrated shading device
Rotation system
Heliotropic plants
Angle of rotation
Location
Angle P.V. produces most energy
Angle Shading device reduces load on heating/ cooling system

Scope



P.V.

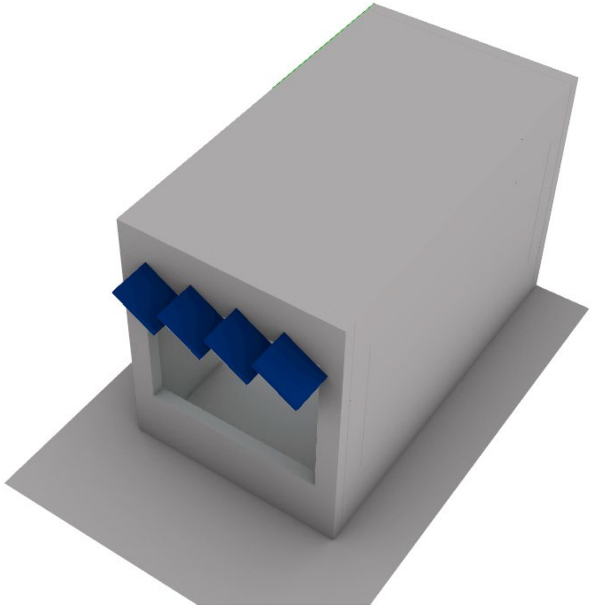


Shading device

- Netherlands
- Summer – higher sun position
- Winter lower sun position

- South facing wall
- Room size – 15m^2
- Window- 2m^2
- Set point temp for cooling is 24 C° and heating is 21 C °.

Shape and Size

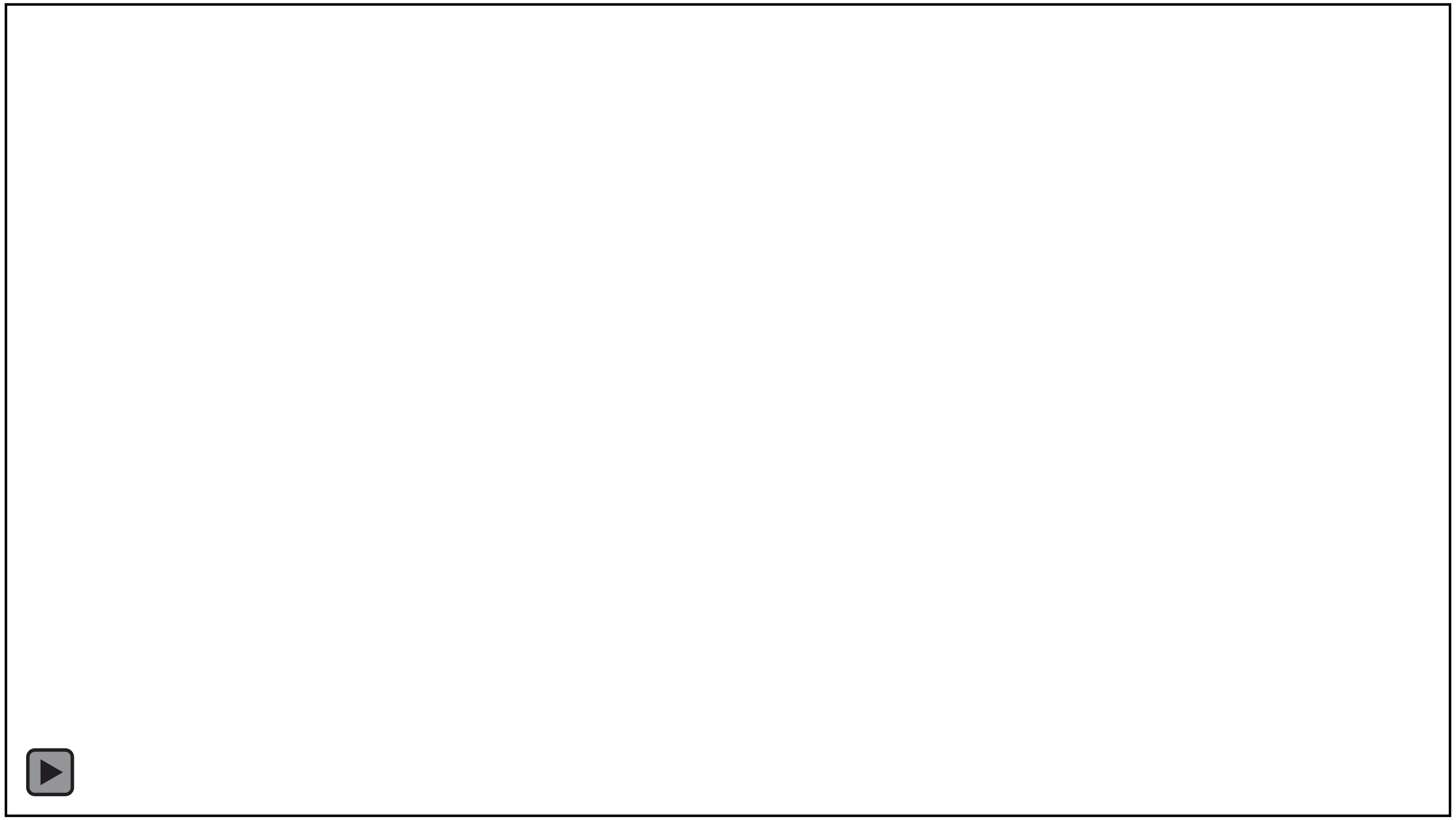


P.V. integrated shading device

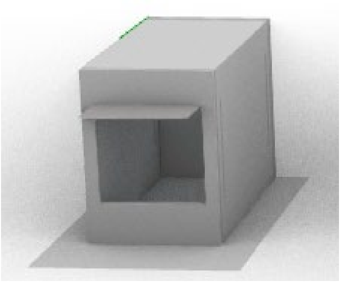
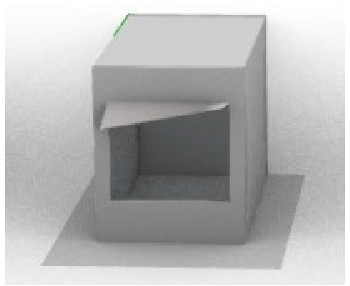
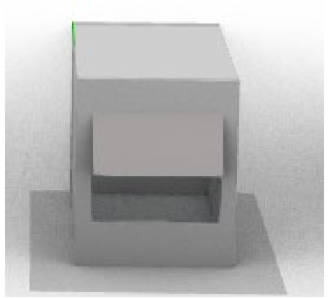
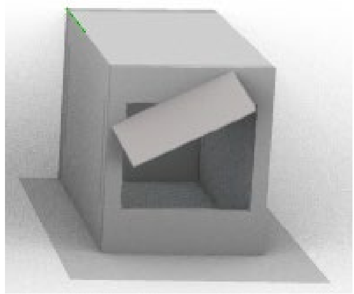
Length / width

Window size
Load on the
rotational system

Types of rotation



Energy used by different rotational systems

	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)	3.74	3.75	3.75	3.76
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)	3.46	3.46	3.45	3.47
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

Best angle for P.V.

Best angle for Shading device

	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°

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

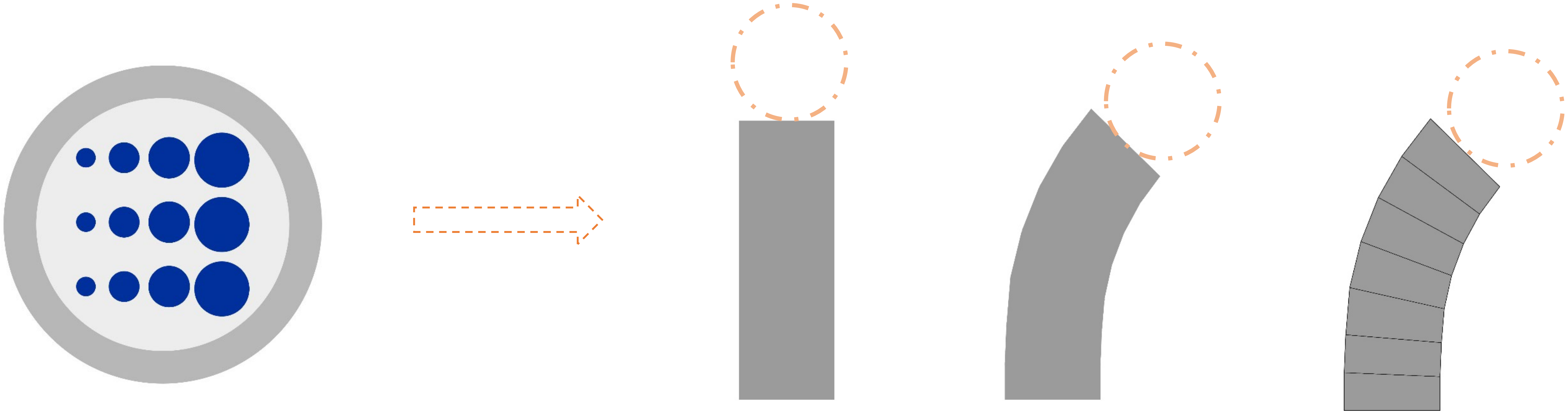
Office- 15m2

Angle for P.V. panel and shading device

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

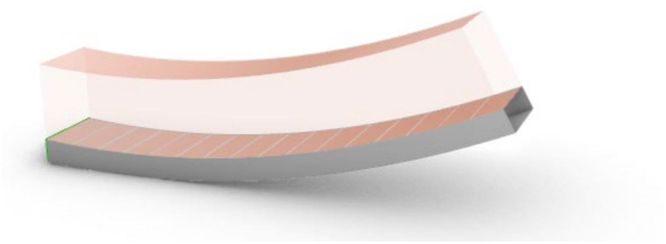
Design of rotational system

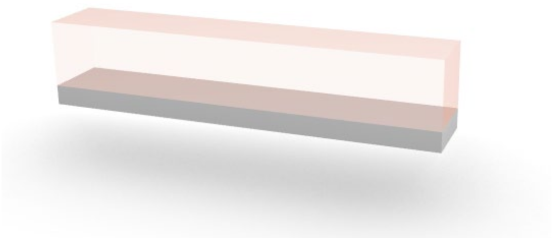
Concept

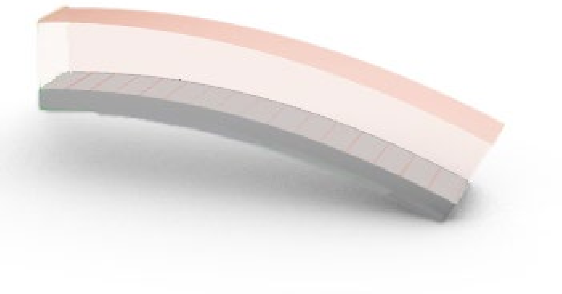


Aim of rotational system : To understand heliotropic movement of plants and incorporate it into a solar tracking P.V. integrated shading device. To check if three is another method for rotation, and to analyse the load it can carry and the energy it can produce with the existing system.

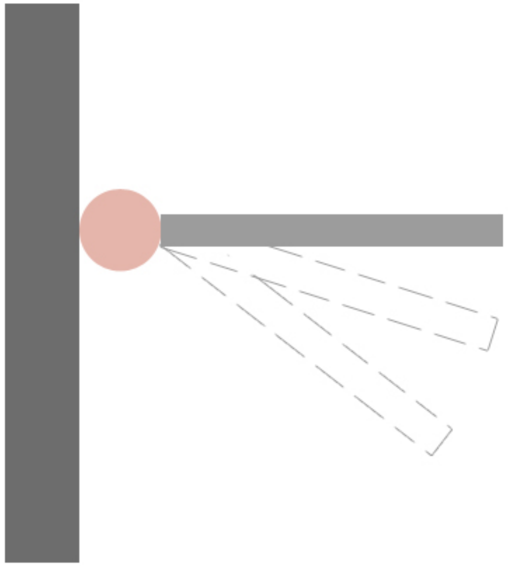
Utilizing compression and tension



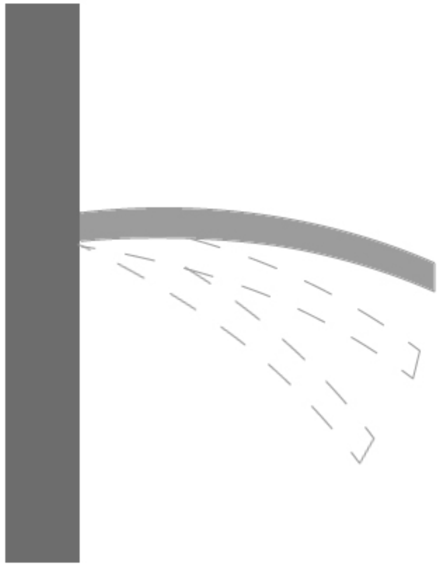




Load transfer

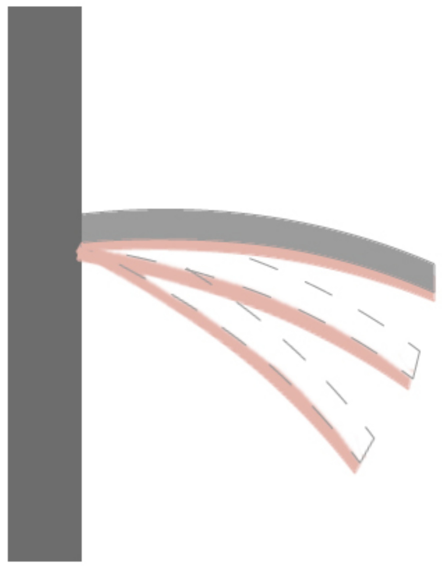


Hinge system

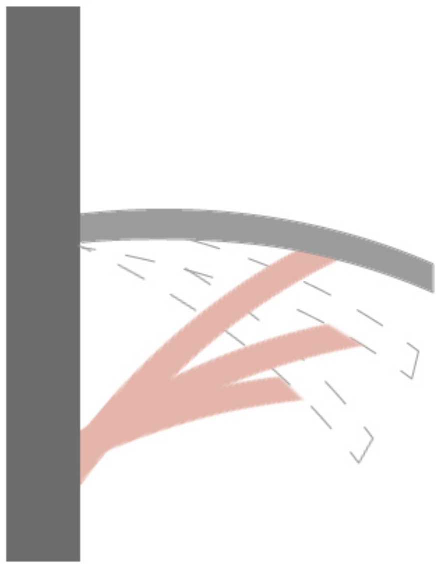


Movement of arm

Types of supports

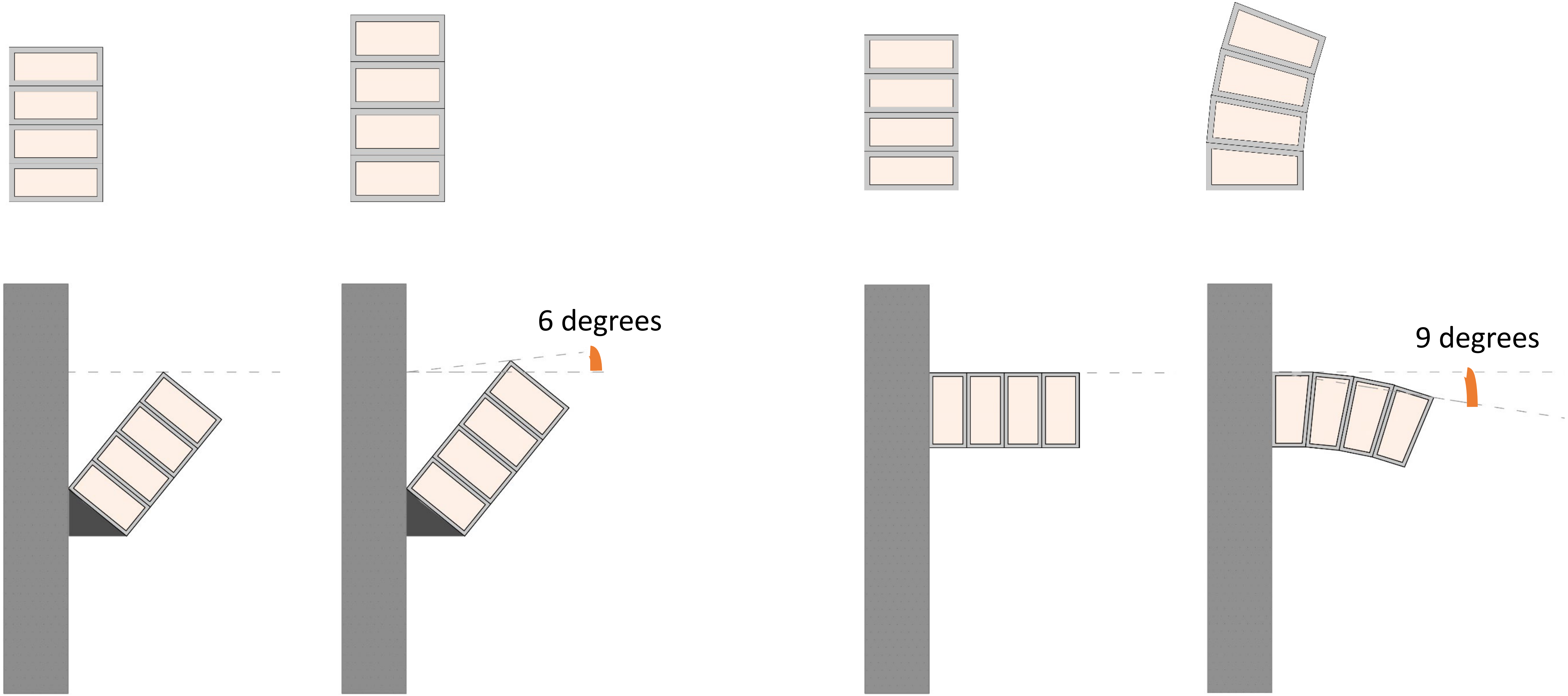


Support below panel



Support at an angle to panel

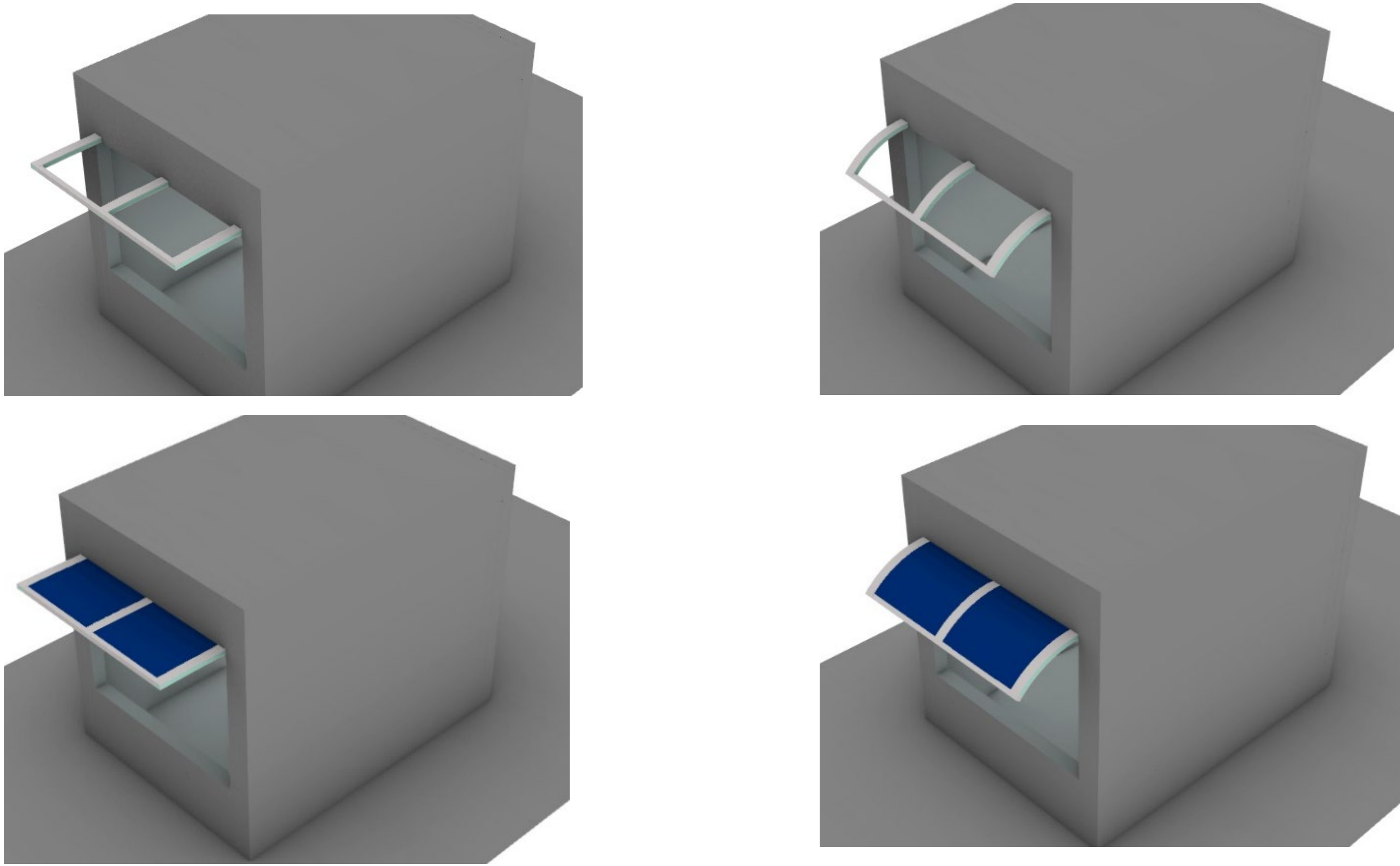
Position of the strut



Mechanism for movement

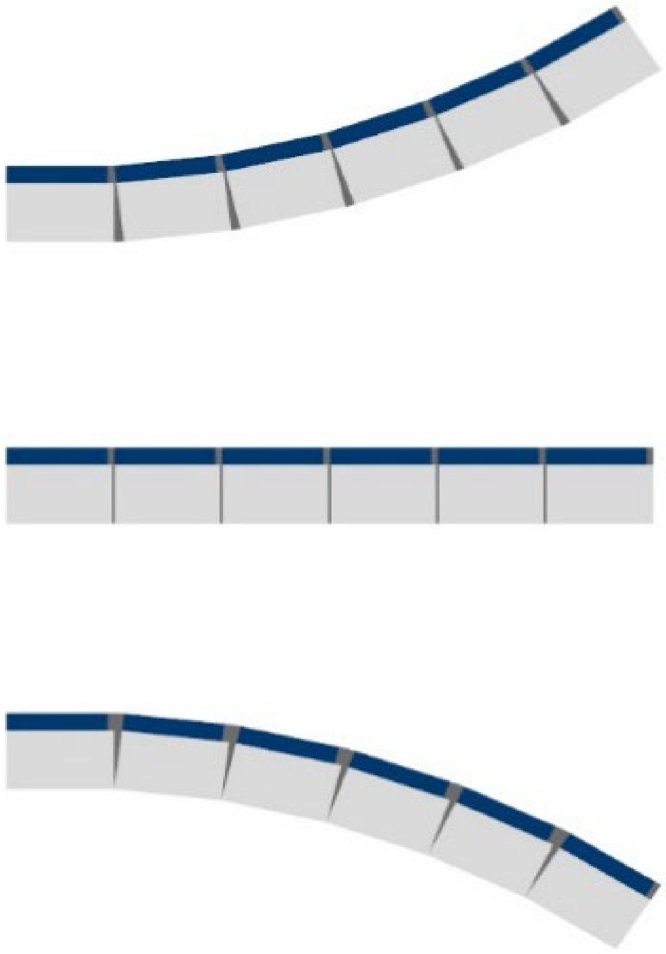
	Hygroscopy	Soft robotics	Piezoelectricity
Control of movement	Difficult to control as the reaction is very dependent on the moisture level	Easy to control But utilizes gears to move	Easy to control **Crystal converts electrical to mechanical**
Precision of movement	Precise up to cm	Precise up to mm	Precise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

Piezo electric struts



Compression and tension

- Piezo electric size – 8mm- blocking force of 750 N
- Strut is broken into smaller segments
- Load distributed on two struts.
- Requires constant electricity to stay in position
- Ball pen mechanism, so that it can stay in place.
- 365*30yrs = 10,950 times



Click pen mechanism

Source:Engineer guy. (2015, September 22). *How a Retractable Ballpoint Pen Works* [Video]. YouTube. https://www.youtube.com/watch?v=MhVw-MHGv4s&ab_channel=engineerguy

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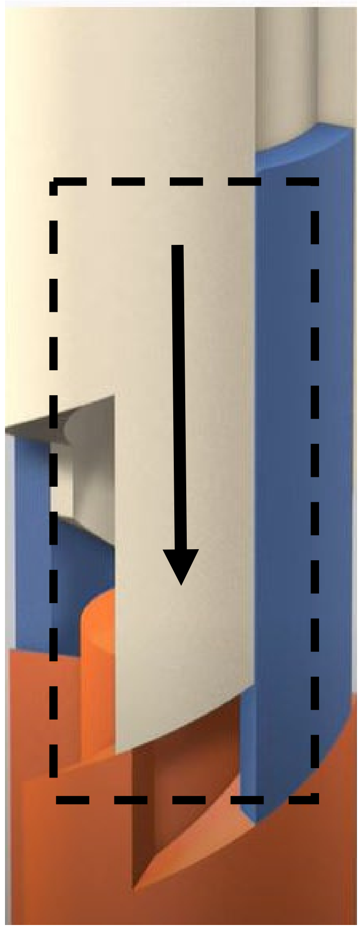
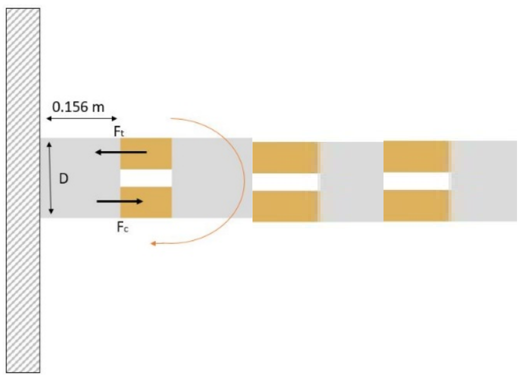
Load transfer in a Click pen



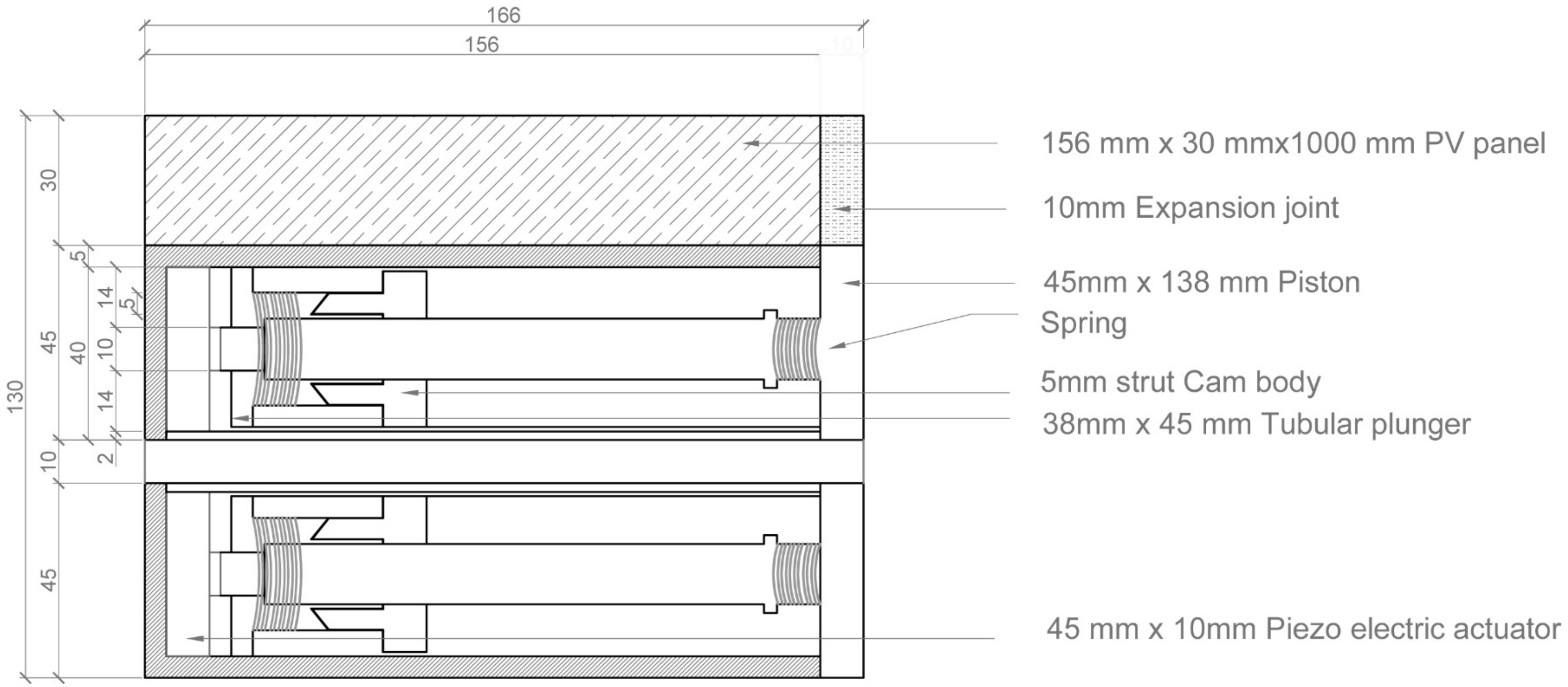
Dimension of module



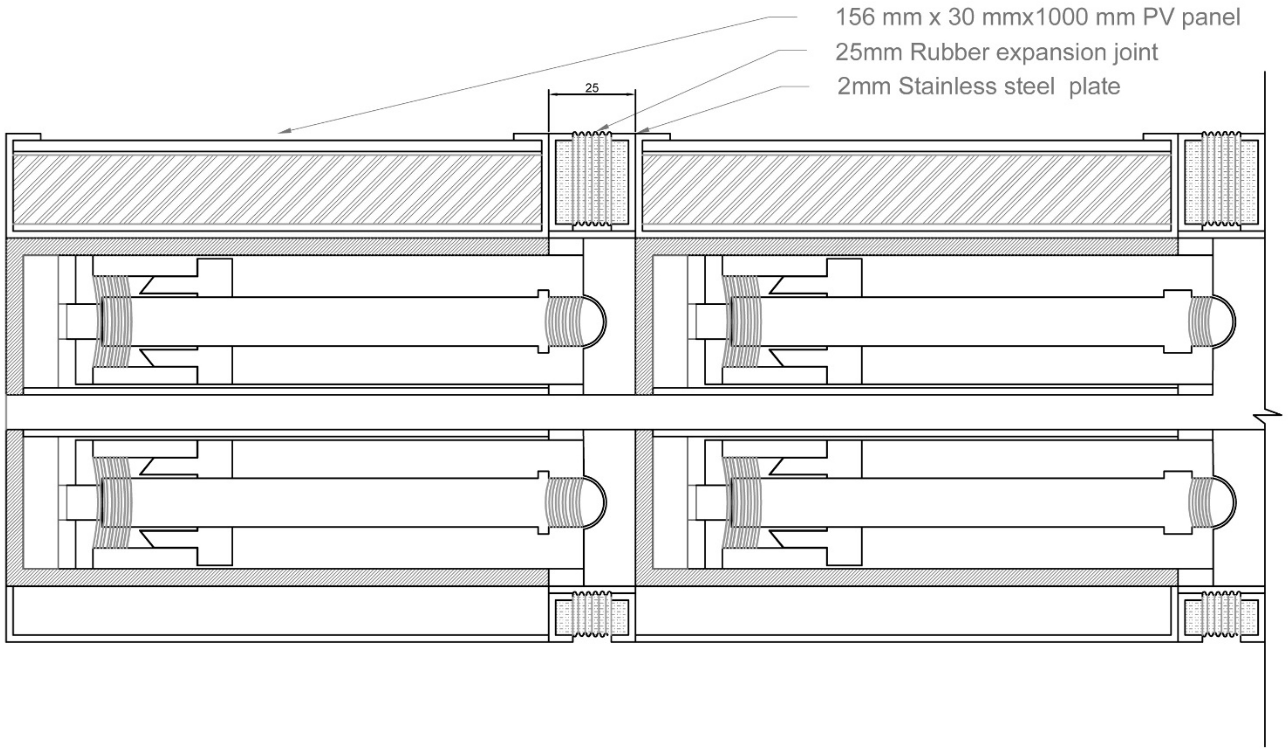
- Ra= 2180 N
- M =1090 Nm
- To move a shading device of one m^2 more than 1090 Nm to move it
- 5 mm strut to counteract the moment
- There are two forces Fc and Ft are the resisting forces as these are the points through which the force is passed. This will help determine the forces in these two struts. (F_c = force in compression)

$M = F_c * d$
F_c = Area * yield strength

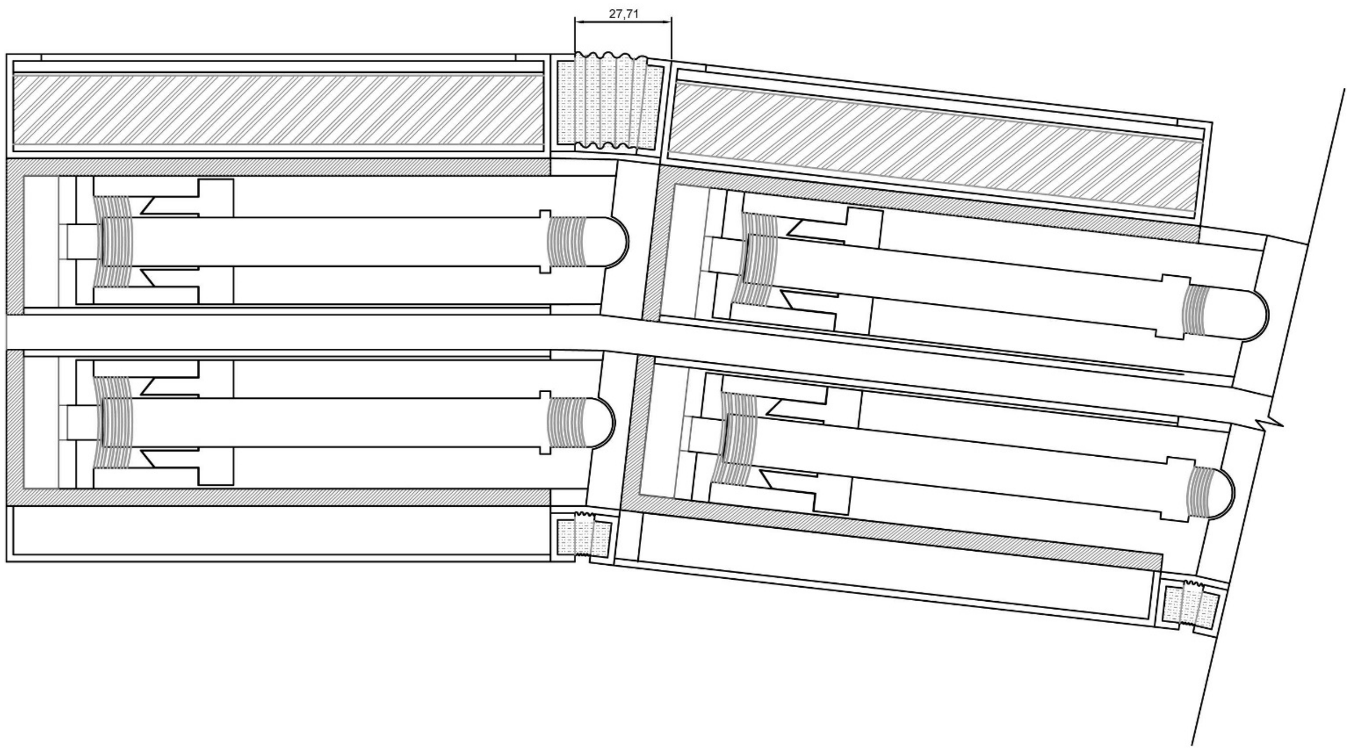
- utilizing a depth of 0.05 for the body of the structure stainless steel will not fail



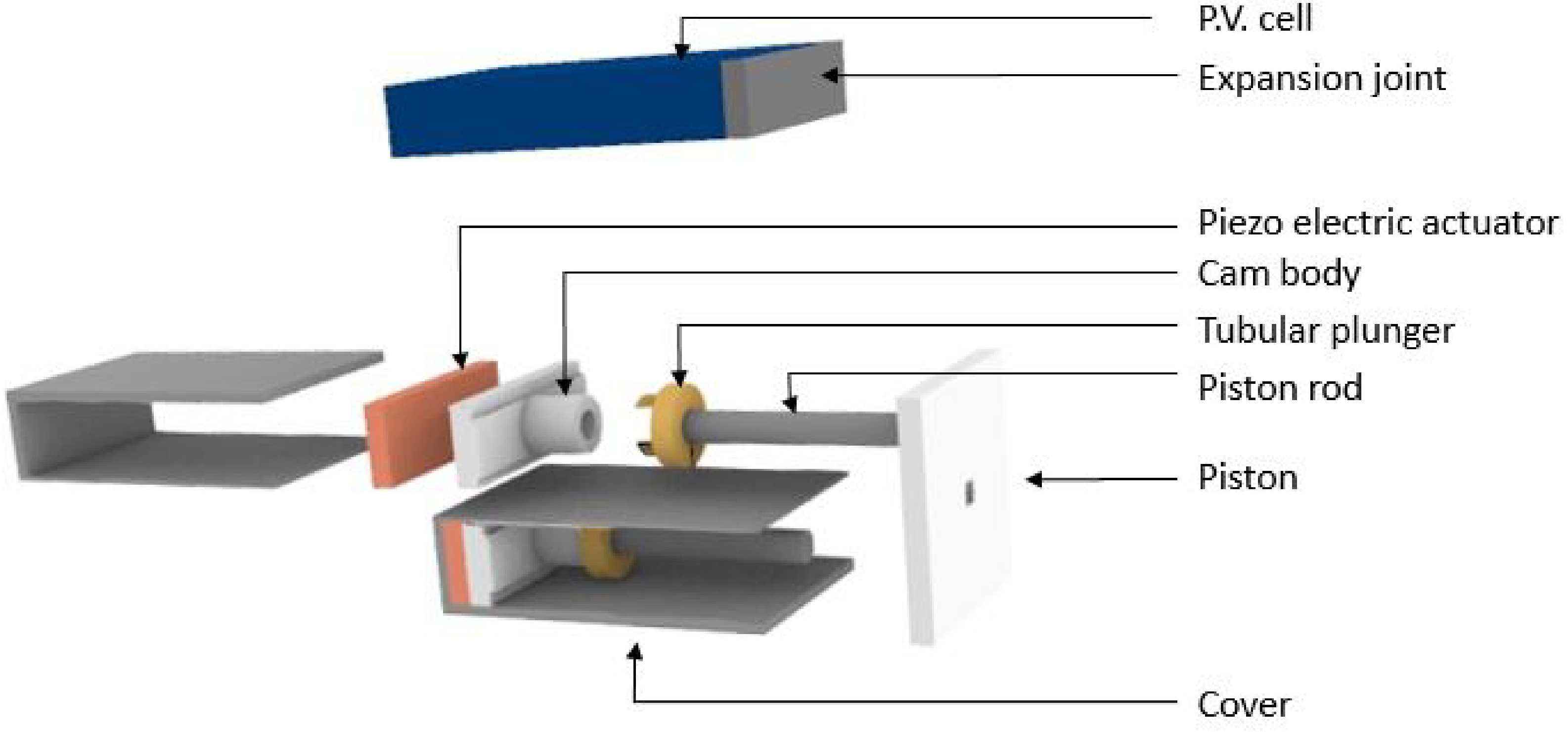
Expansion joint



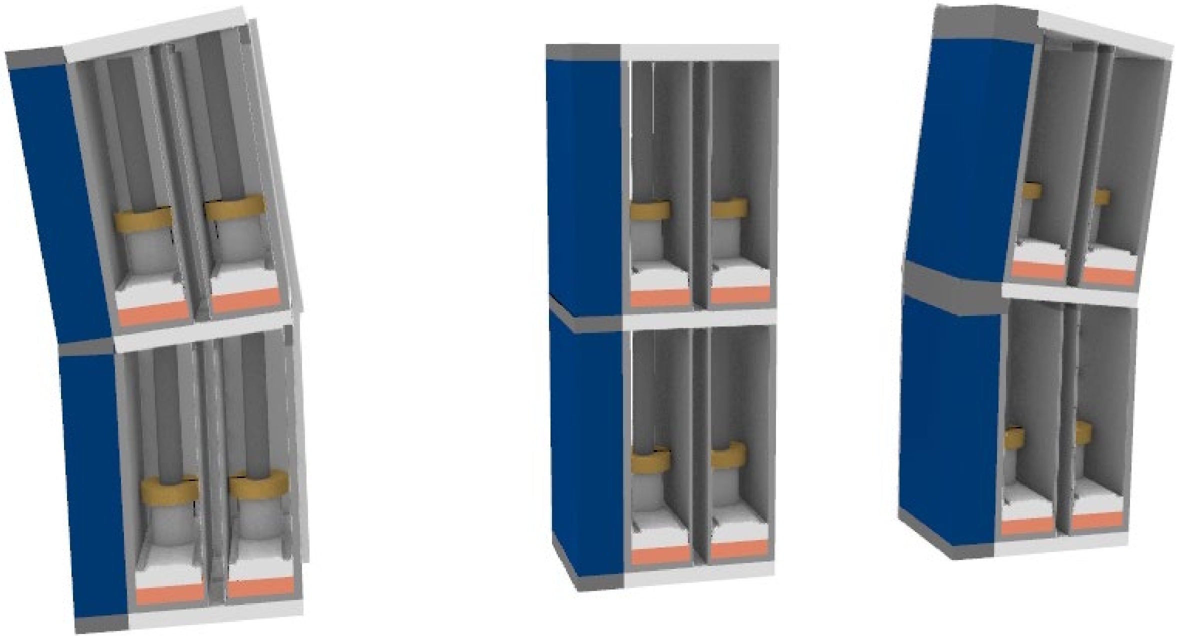
Expansion joint

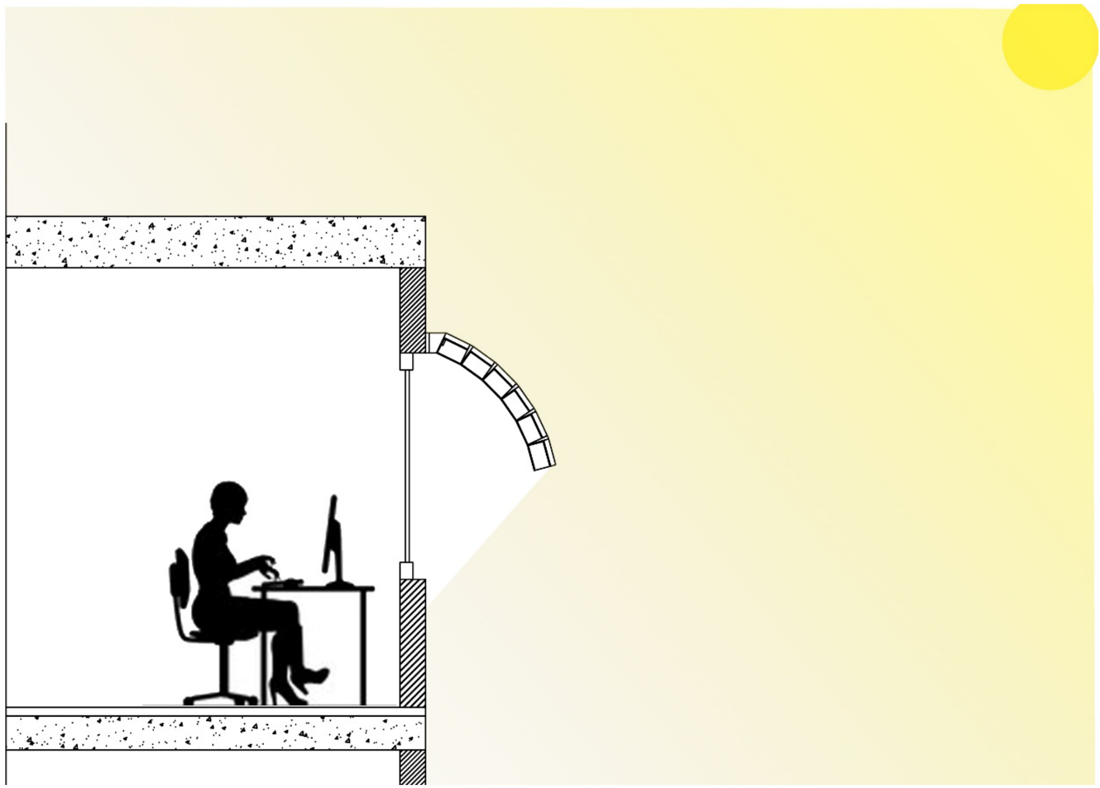


Parts of module

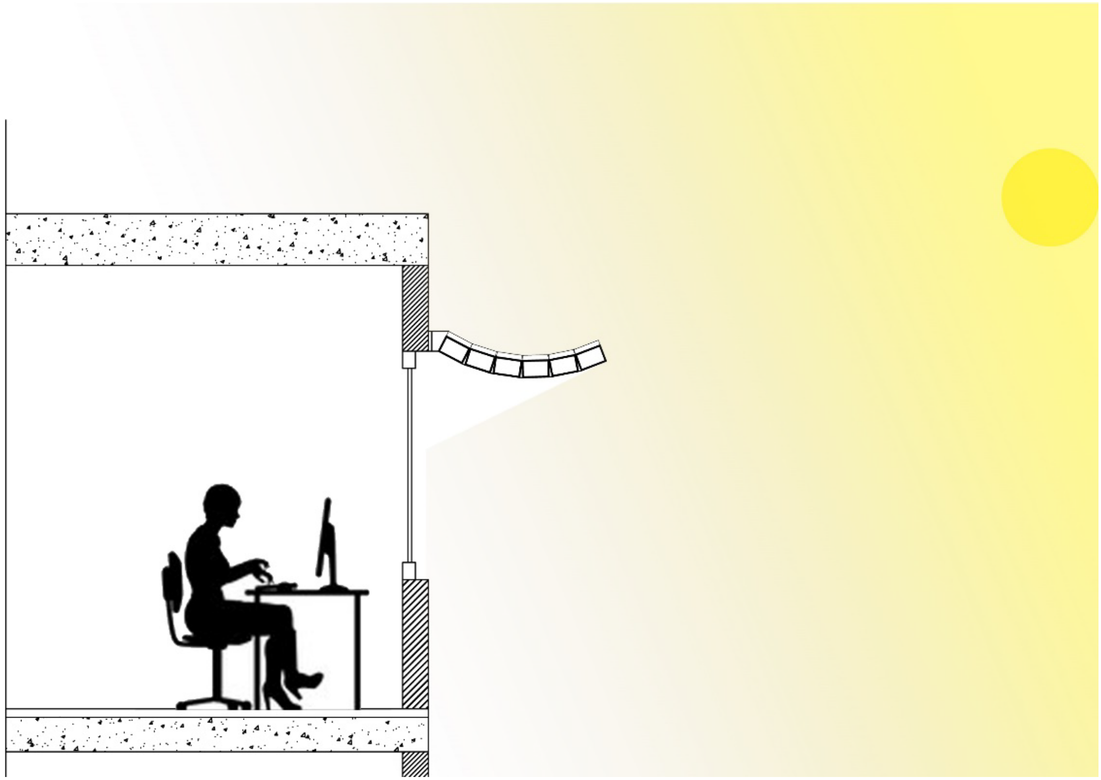


Compression and tension of module



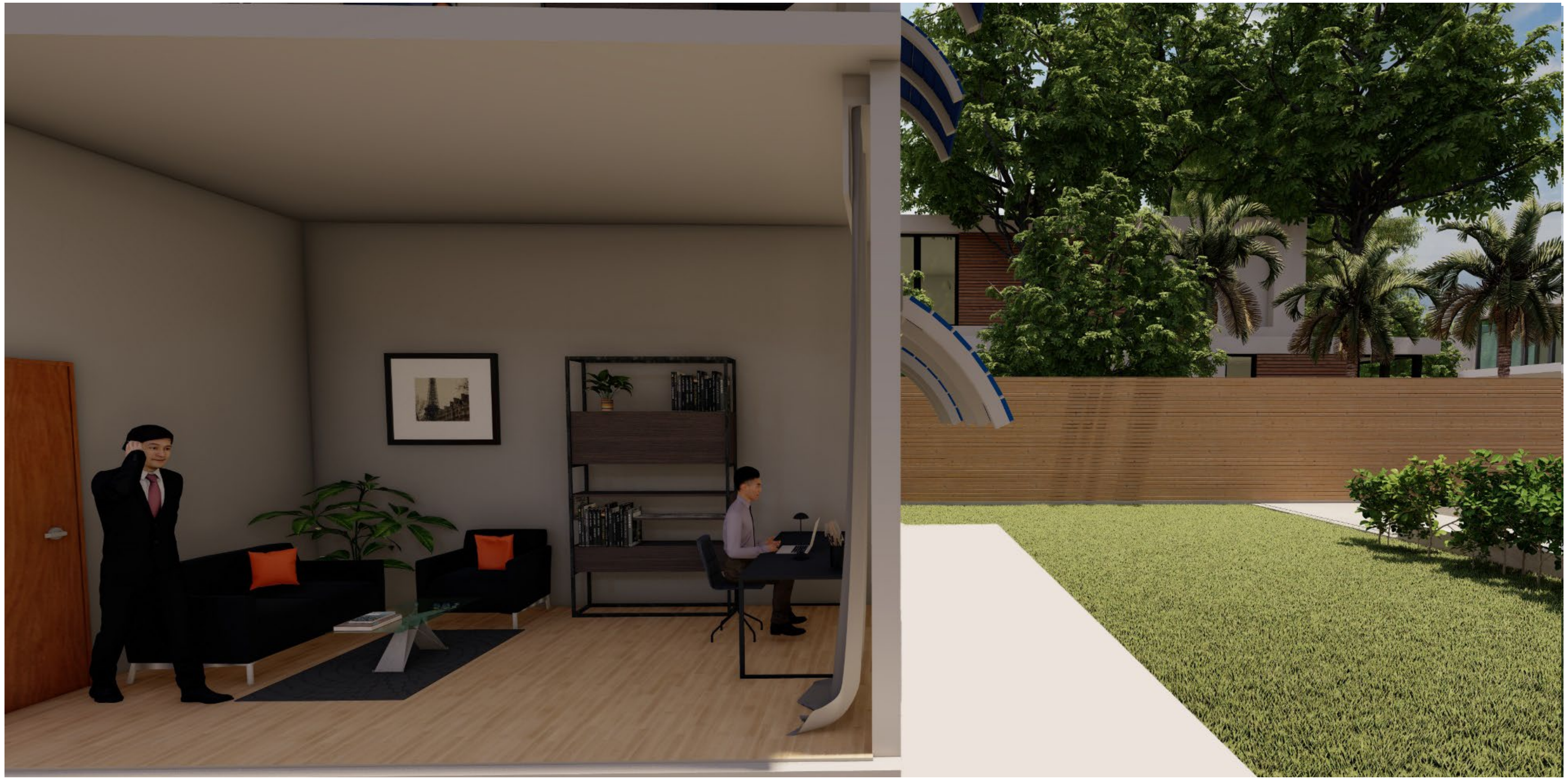


Angle 53 degree



Angle 90 degrees

Winter day



Summer day

Black Mono crystalline panels

Blue Mono crystalline panels

Panel at 71.5 degree

Panel at 53 degree

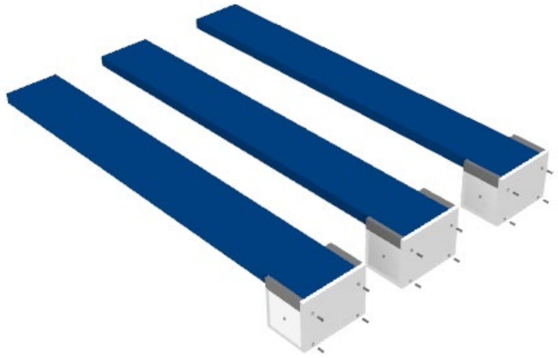
Winter/Spring panel at 90 degree

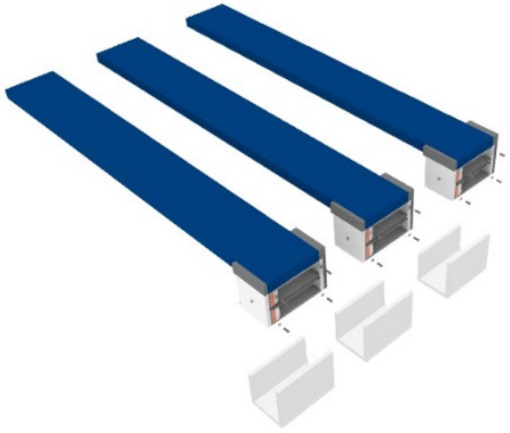
Angle limitation to design

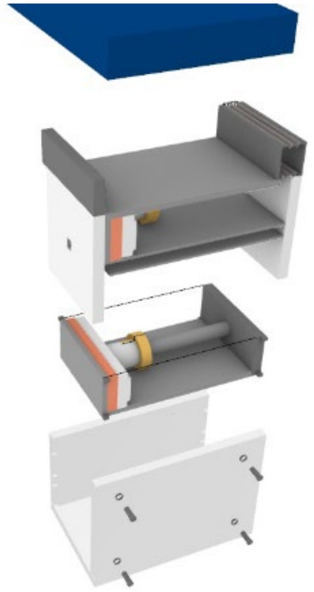
	Spring	Summer	Fall	Winter
South	90°	71.5°	53°	90°
East	90°	53°	90°	90°
West	90°	53°	90°	90°

37°

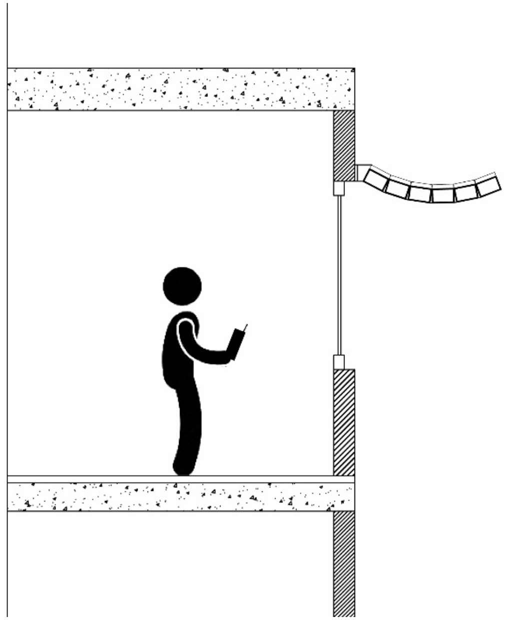
Maintenance



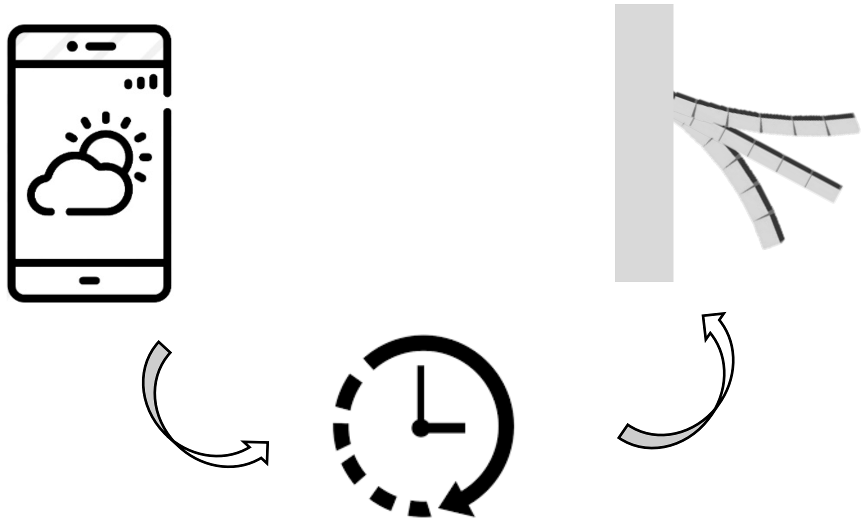




Control

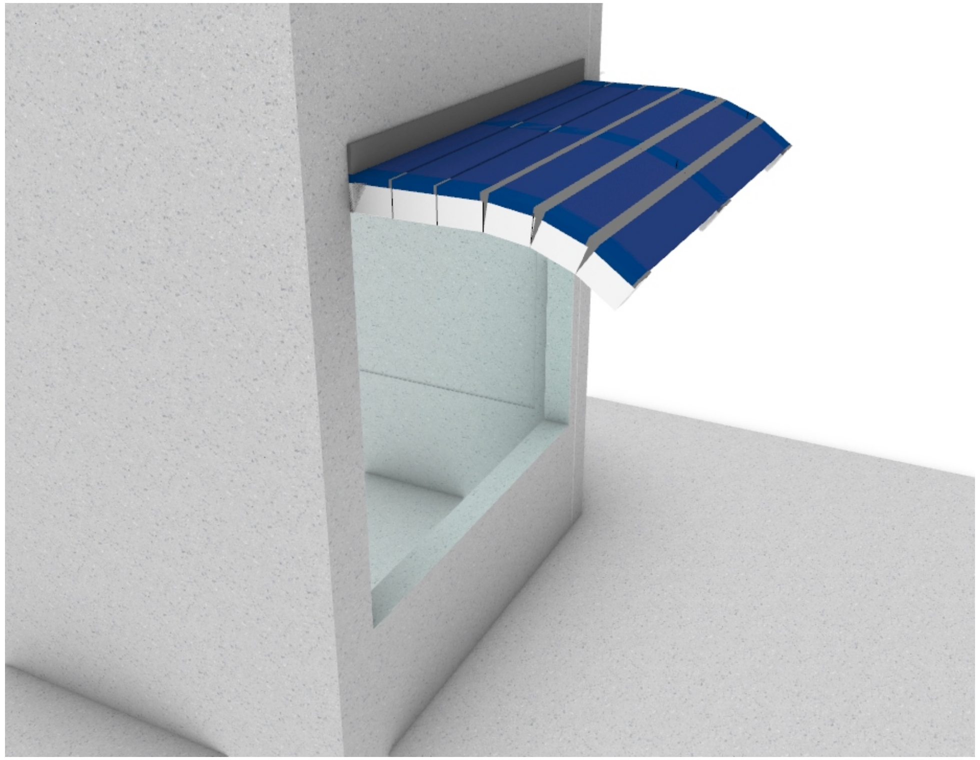


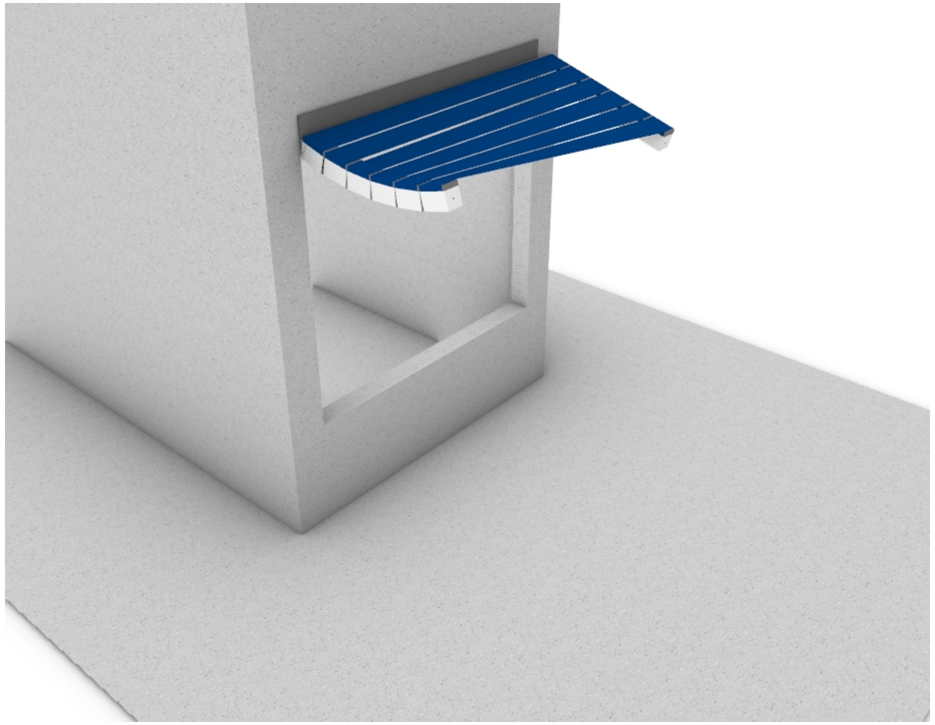
Manual override control



On cloudy day

Advantage





Other applications

Image source: Ankarasolar. (2014). *Building Integrated Photovoltaics (BIPV)* [Image]. http://www.ankarasolar.com.tr/en/products/building-integrated-photovoltaics-bipv-solar-panels/

Energy

Energy generated by P.V. integrated shading device

Netherlands

	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
Total energy produce by P.V. integrated shading device in a year (kW/year)				**204 kW**

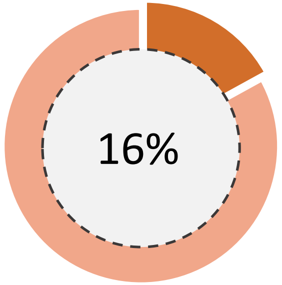
Abu Dhabi

	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 kW**

Moved 4 times a year

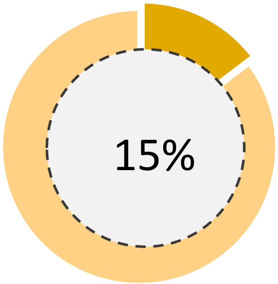
Netherlands

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**
Heating / cooling load	**1,157kW**



Abu Dhabi

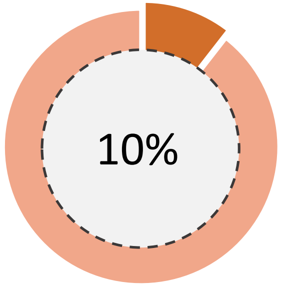
Energy produced by P.V. integrated shading device	+ 784 kW / year
Energy utilized by Piezo actuators	- 0.43 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**777.13 kW / year**
Cooling load	**5067 kW**



Moved twice everyday

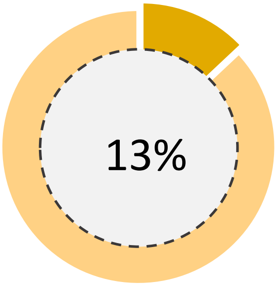
Netherlands

Energy produced by P.V. integrated 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**
Heating / cooling load	**1,157 kW**



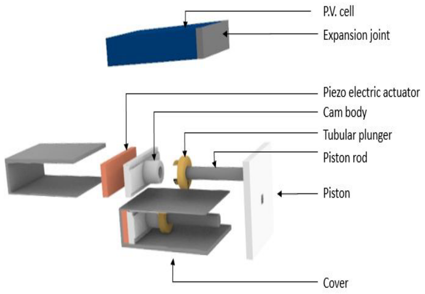
Abu Dhabi

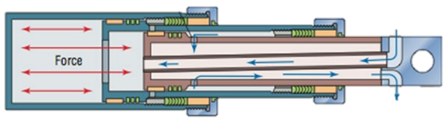
Energy produced by P.V. integrated shading device	+ 784 kW / year
Energy utilized by Piezo actuators	- 0.43 kW/ year
Clock	-3.3 kW/year
Embodied energy	- 3.1389 KW
Total energy produced per year	**698 kW / year**
Cooling load	**5067 kW**

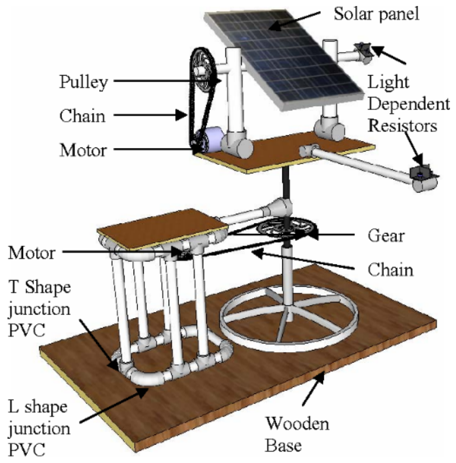


Comparison

	Helio tracker	Telescopic cylinder	Solar tracker
Load	Blocking force 775N	Upto 30 KN	-
Energy per movement	19.5 W	50 W	17.28 Wh
Weight of panel	20 kg	5kg	14 kg
Weight of actuator	3Kg	1-3 Kg	5.64kg
Warranty		2 years	5 year
Material	Stainless steel	Aluminium / stainless steel	Aluminium / stainless steel
Components	Piezo electricity and ball point pen mechanism	Hydraulics	Multiple components and parts
Size	0.016 m3	0.015m3	0.5m3







Limitations

- Not tested, problems in scaling up the ball pen mechanism is unknown.
- Glare not considered
- Winter in Netherlands, it is better to have no shading than a shading at 90 degrees. However if the angle is more than 90 the P.V. panel shades itself.
- 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.
- This device cannot be utilized where straight lines are required. It uses a curvature to rotate.

Future potential

- Analyse in 3D
- The stem shows more possibilities
- Test of mechanisms
- Test the material
- Proto type the product

Look and observe nature to solve complex problems


Small 2m² shading device has the ability to reduce the cooling load by up to 15%

Thank you

	Mechanical rotational system	Heliotropic movement	Soft robotics	Hygroscopy
Mechanism	Electro magnetic motor which uses gears	Pizo electricity and a ball point pen mechanism	The arm	The material itself
Movement	Hinge movement	The structure is utilized to crate the movement	The structure is utilized to crate the movement	The structure is utilized to crate the movement
Material	Metal	Stainless steel	Polymer	Wood fibres
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

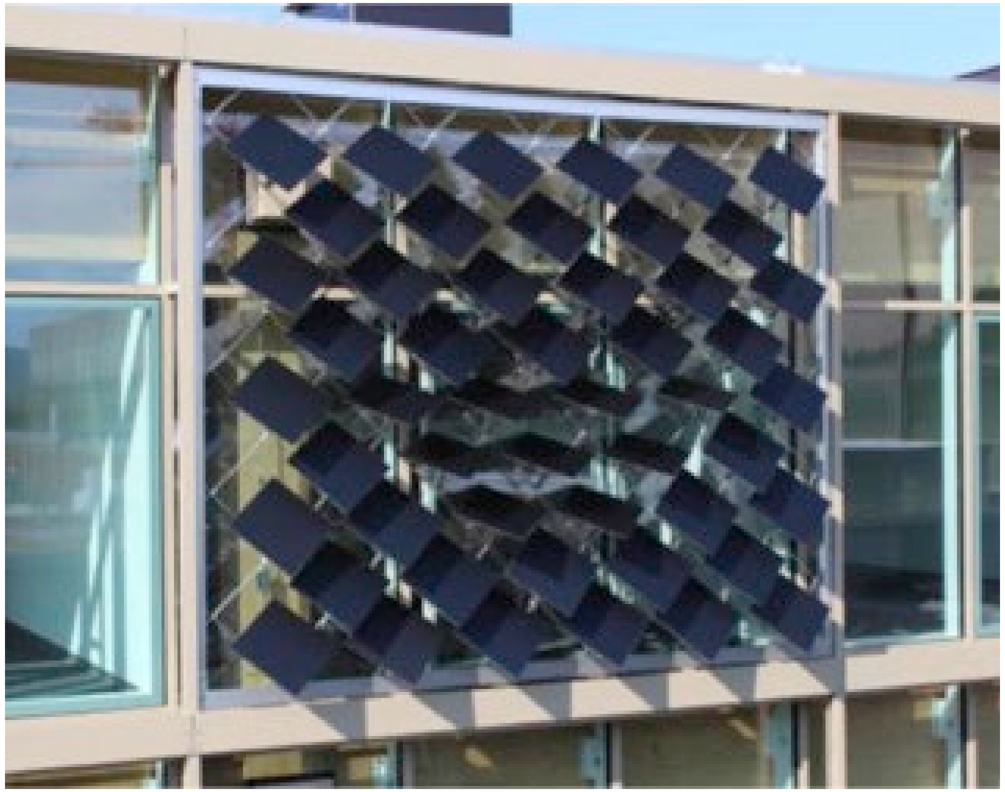
Calculations

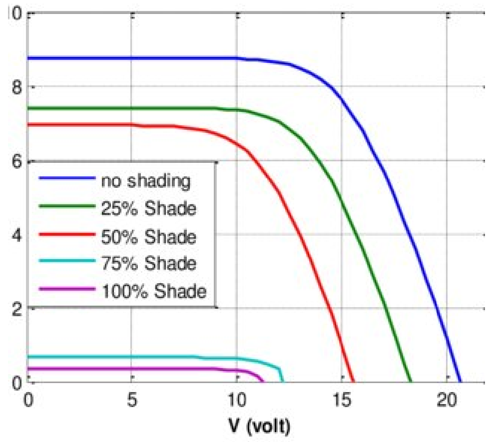
To calculate how much energy this mechanism would require the load on the P.V panel needs to be analysed.
Assuming the P.V. panel to be a cantilever beam the load can be calculated.
Assuming the P.V panel as a Monocrystaline P.V. - (10 kg/m^2) 0.0980665KN/m^2
Polycrystaline P.V. - (8 kg/m^2) 0.0784532 KN/m^2
Thin film- (0.46 kg/m^2) 0.004511059 KN/m^2
Snow load: 0.7 KN per sq/m
Wind Load: 0.102 KN per sq/m
Total load= 0.098 +0.7+1.5 =2.18KN sq/m

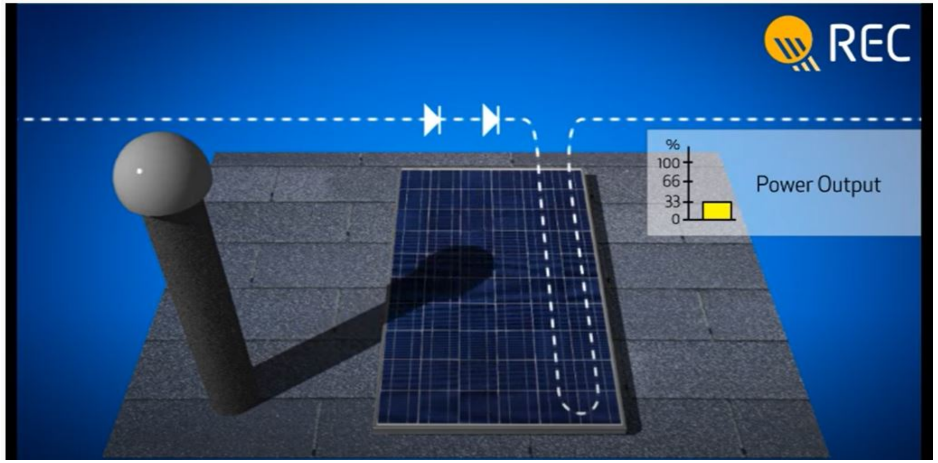
Ra= W*L =2.18*1 = 2.18 KN = 2180 N
M =(WL)/2= (2.18*1)/2 = 1.09KN m= 1090 Nm
This data shows that to move a shading device one requires more than 449Nm to move it

- Blocked force = 775N requires 650 V
- 650V * 0.03 A= 19.5W

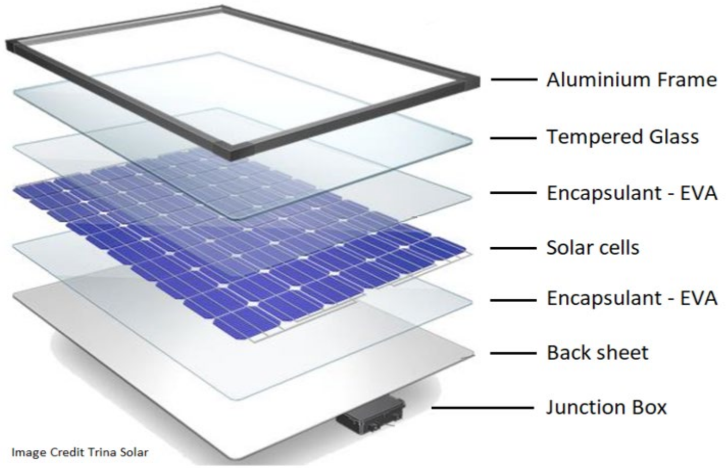
Cannot have smaller segments, As they overlap each other





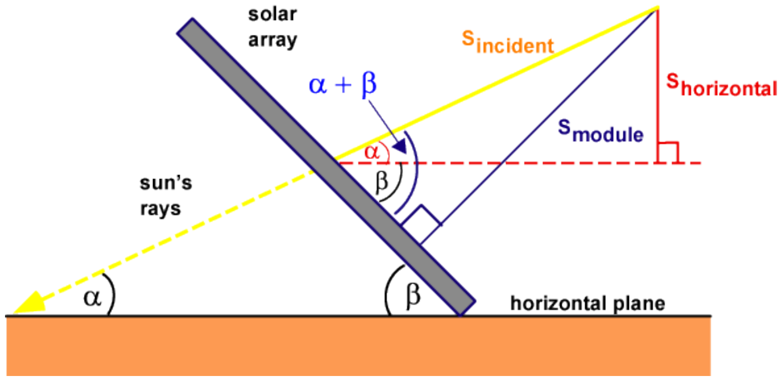


Photovoltaic Panels



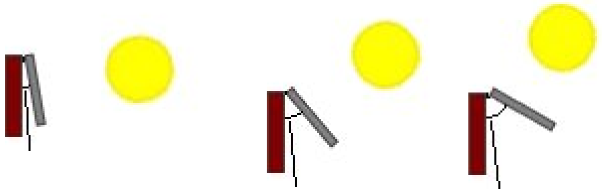
Layers of a P.V. panel

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



Calculating angle of tilt for P.V. Panels

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



Winter
14° angle

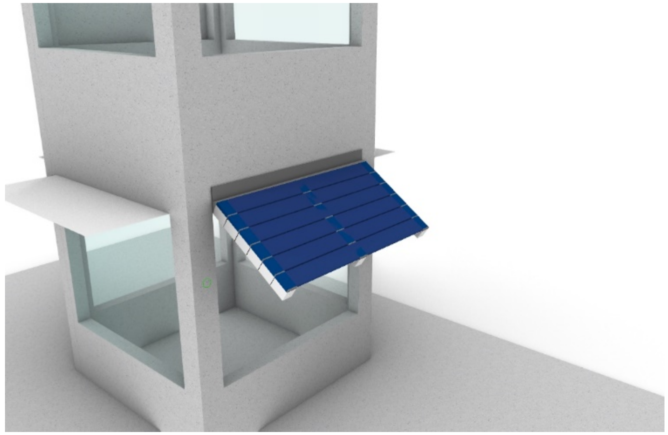
Spring/Autumn
38° angle

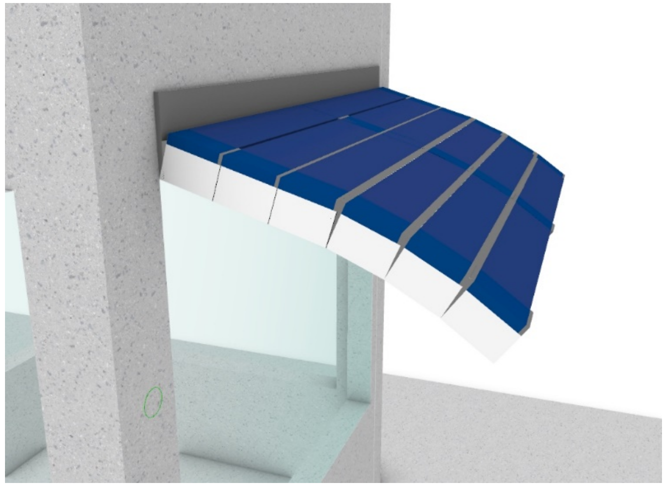
Summer
62° angle

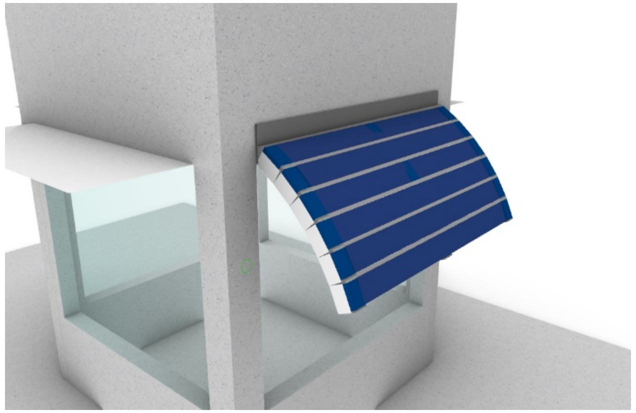
Source: https://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-a-tilted-surface

Range of angle it can perform

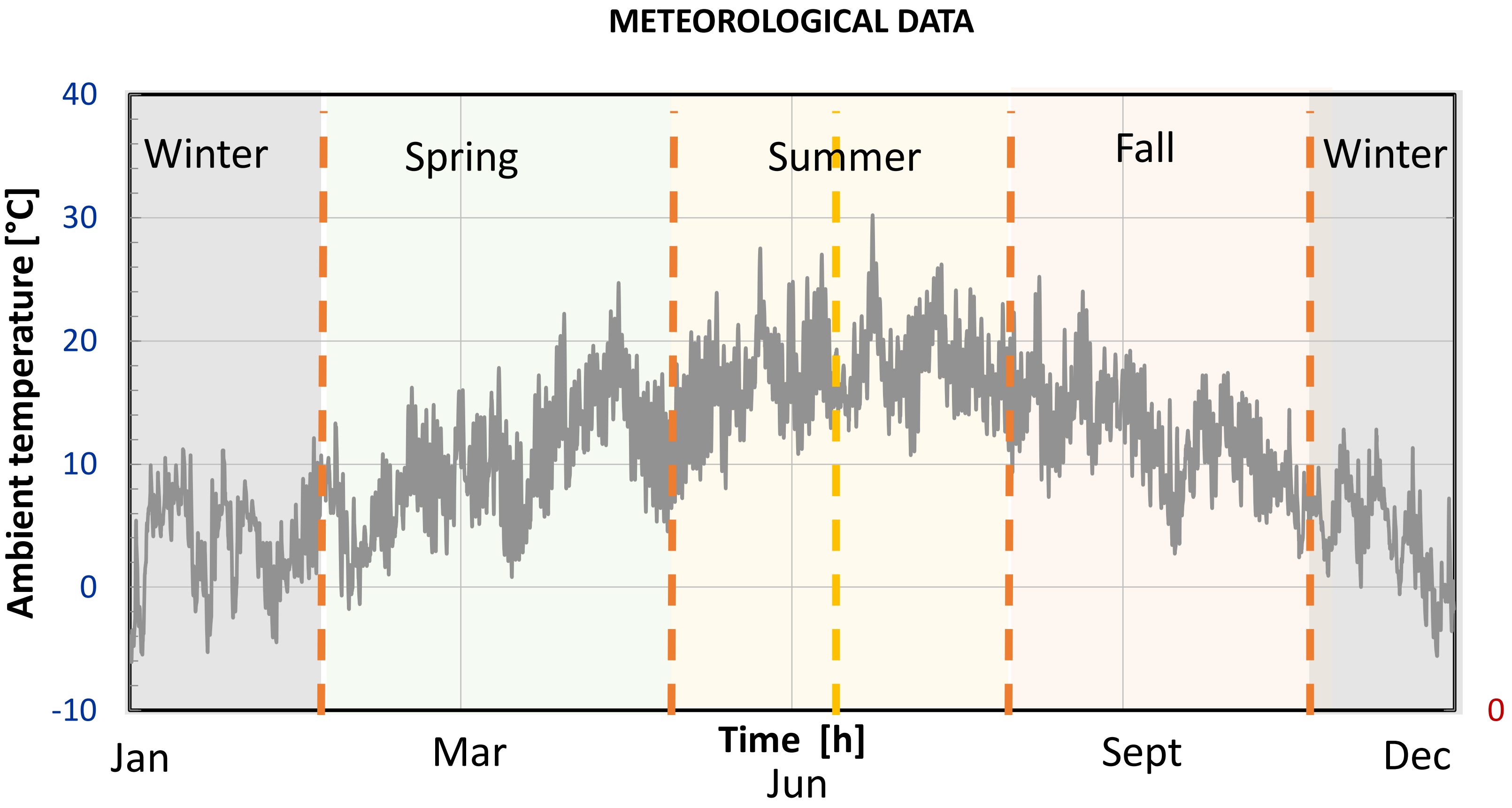
Position 1	3.1 degree
Position 2	6.2
Position 3	9.3
Position 4	12.4
Position 5	15.4
Position 6	18.5







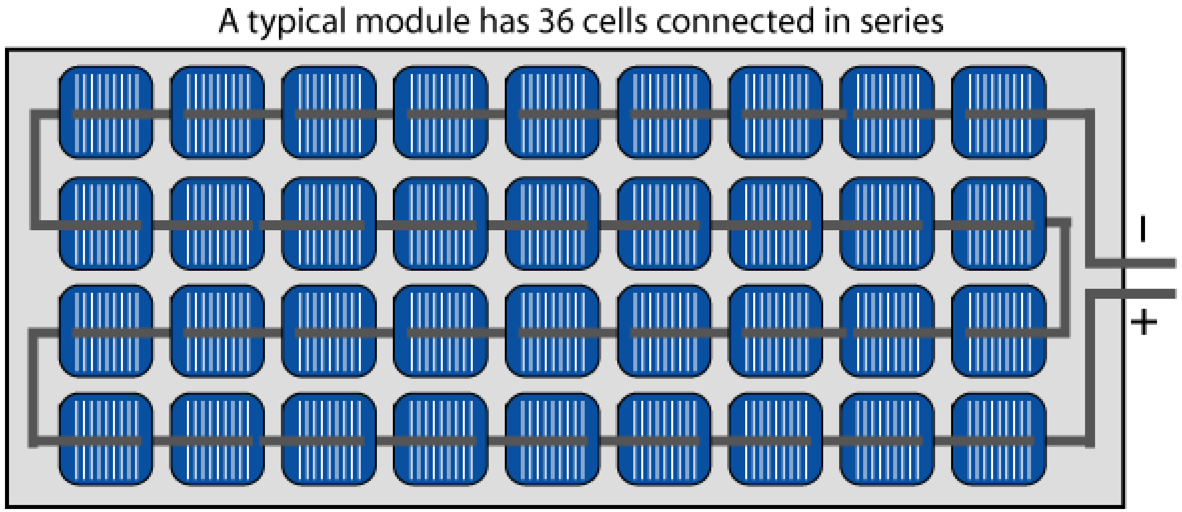
Rotational period



Other factors that affect the cooling load

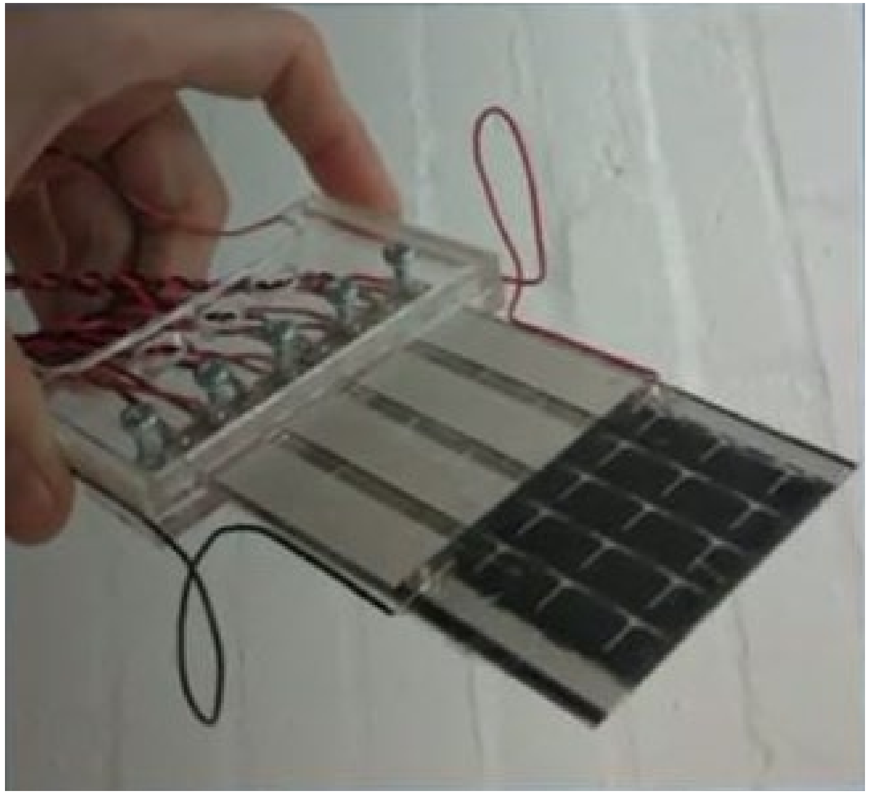
- Moving it up and down- weighed with it energy required to move
- Thermal properties of glass
- Thermal properties of the wall

Can P.V. panels come in strips?



- https://www.pveducation.org/pvcdrom/modules-and-arrays/module-circuit-design

Piezo electric flag



Source: EurekAlert. (2019, February 11). *Researchers develop flags that generate energy from wind and sun*. https://www.eurekalert.org/pub_releases/2019-02/uom-df021119.php#:%7E:text=University%20of%20Manchester-,Scientists%20have%20created%20flags%20that%20can%20generate,using%20wind%20and%20solar%20power.&text=The%20study%2C%20conducted%20by%20researchers,solar%20energies%20using%20inverted%20flags.

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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

$V= \tau * A$

τ= Shear stress

$A= \pi * r^2$ = Area of the piston where the force is transferred.

Since there are 2= A/2

Therefore the formula is:

$V= \tau *(A/2)$

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
$A= *0.075 =0.235\ m^2$
$2180 = \tau*(A/2)$
$2180 = 75*10^6*(A/2)$
If you assume area of the strut as
$A= \pi*r^2$
$A= \pi*0.005^2$
$A= 7.8*10^{-5}$