POLITECNICO
MILANO 1863

School of Architecture, Urban Planning & Construction Engineering

Master of Science in Building and Architectural Engineering (Building Engineering Track)

Application of thin film Photovoltaics to the kinetic shading devices in buildings

Supervisor: Dr. Massimiliano Nastri

Author: Elahe Beyranvand

Academic year: 2019 / 2020

Abstract

This thesis discusses how a kinetic solar shading device can affect the sustainability of a building and how it can control the energy consumption in the building in terms of reducing the cooling loads by decreasing the internal temperature, while providing a comfortable place for the occupants. In this process by the use of digital softwares, the most proper shape for a shading device is gained. A shape which can control the harmful solar radiation while keeping good daylight in the building. This thesis also discusses how the application of thin film photovoltaics as the materials of shading device can improve the performance and reduce the amount of electrical energy consumed in the building, specially the electrical energy required for the shading system to perform. The photovoltaic panels produce enough amount of electricity to activate the actuators for moving the shading device in the way that it becomes adaptable to the surrounding environment. All the analyses have been done for the city of Milan as a case study for the purpose of climatic evaluations. The same system is applicable for any other location all around the world with some small modifications regarding to the control system. At the end there will be a comparison of occupant comfort of the building for the proposed shading device and anormal building without shading device and some existing buildings using kinetic shading devices.

Key words: Passive architecture, kinetic shading device, thin film photovoltaics, solar radiation, occupants comfort

Riassunto

Scopo di questa tesi è quello di valutare come un dispositivo di schermatura solare cinetica possa influenzare la sostenibilità di un edificio e come lo stesso possa controllare il consumo di energia nell'edificio in termini di riduzione dei carichi di raffreddamento, diminuendo la temperatura interna e garantendo un luogo confortevole per gli occupanti. In questo processo, mediante l'ausilio di software digitali, si riesce ad ottenere la forma più appropriata per un dispositivo di ombreggiatura, una forma in grado di controllare la radiazione solare nociva mantenendo un buon livello di illuminazione naturale nell'edificio. Questa tesi verifica anche come l'applicazione del fotovoltaico a film sottile, quale materiale del dispositivo di ombreggiamento, possa migliorare le prestazioni e ridurre la quantità di energia elettrica consumata nell'edificio, specialmente l'energia elettrica richiesta per il funzionamento del sistema di ombreggiamento. I pannelli fotovoltaici producono una quantità di elettricità sufficiente ad attivare gli attuatori che muovono il dispositivo di ombreggiamento in modo che si adatti alle condizioni dell'ambiente circostante. Ai fini delle valutazioni climatiche, tutte le analisi sono state fatte per la città di Milano come caso studio. Lo stesso sistema è utilizzabile in qualsiasi altra località del mondo con alcune piccole modifiche riguardanti il sistema di controllo. La tesi si conclude con un confronto tra il comfort degli occupanti l'edificio con il dispositivo di schermatura proposto, il comfort nello stesso edificio privo del dispositivo di schermatura ed il comfort in alcuni edifici esistenti che già utilizzano dispositivi di schermatura cinetica.

Parole chiave: architettura passiva, dispositivo di schermatura cinetica, fotovoltaico a film sottile, radiazione solare, comfort degli occupanti

Contents

0. Thesis framework

this thesis is consisting of eight chapters, it starts with the aims and reasons that were the inspirations for writing it. The second and third chapter are literature reviews, which in the second chapter it discusses the theory of passive and kinetic architecture and theory related to the photovoltaics, while it reviews the history and the development of these technologies. While the third chapter introduce some existing buildings, which have followed the same goal of being sustainable by using kinetic shading devices or using PV panels in their façade.

The development of the project is discussed in the fourth and fifth chapters. The fourth chapter explains how the device can be adaptable and responsive to it surrounding environment using climatic software, also the technical specifications are introduced in this chapter. And the fifth chapter is about the calculation of the movement of the shading device and the amount of electrical energy that it can produce, and in general it explains the performance of the shading device.

The sixth chapter compares the performance of proposed shading device with the case studies in terms of the occupant comfort. And in the seventh chapter which is the chapter of conclusion, it sums up all the studies and comparisons, and discusses how using the Photovoltaic shading device can be beneficiary for building application.

Finally, in the eighth chapter all the references which have been used in this thesis have been mentioned.

1.Introduction

1.1. The need for a Photovoltaic shading system and the aim of this thesis

In this thesis the aim is to reach a proper thermal comfort for the occupants of the buildings mostly during the summer when the building heats up due to the direct sunlight and outside hot temperature and consequently the indoor temperature increases.

In the past, before the use of new technologies or mechanical coolings, people kept the indoor spaces using natural methods: breeze flowing through windows, water evaporating from fountains or pools, as well as large amounts of stone and earth absorbing daytime heat. These ideas developed over thousands of years as integral parts of the design of houses. Today these are called " passive cooling" (Butters 2002). In which the cooling operation is ensured by the transfer of energy from the space or air abounding the space, to reach a lower temperature or increase the humidity level of the ambient (Al-masued 2004).

Passive cooling is based on the interface of the building and its surroundings. Passive cooling can be an alternative to mechanical cooling that requires complex refrigeration systems. By implementing passive cooling strategies, it is possible to decrease the size of mechanical cooling devices and reduce the cost. Or in some cases eliminate the needs for mechanical cooling systems (Givoni and La Roche 2001).

Passive cooling occurs naturally, by the means of having lower temperature without using any other energy input or mechanical cooling (Al-masued 2011). The location, solar incident radiation and wind are some important factors in passive cooling. By controlling the thermal heat gains during summer with having particular shapes or thermal insulations, it is possible to have a lower temperature during summer (Brown 1985). Shading of wall and roof surfaces are important to reduce summer heat gain, they can reduce the indoor temperature of the building between 5 and 10°c (cook 1989)

Using kinetic shading devices can improve the performance as they can adopt different positions according to climatic requirements. In this way they can reduce the amount of operational energy needed. In this manner using a kinetic shading device, can be very helpful in controlling the amount of sunlight received by the building which can reduce the amount of cooling energy required while providing visual comfort in the meaning of preventing glare. But considering a kinetic shading device, there is still a portion of energy needed to activate an actuator in order to run the system, which can also cause more operational energy, while the aim is to reduce energy consumption. In this case using renewable energies and passive strategies can be very helpful. The photovoltaic panel can be used as a shading device while it provides the needed energy for running the device by converting solar energy to the electricity.

1.2. Study area

Study area is focusing on the theories related to the passive architecture and kinetic shading devices and theories related to photovoltaics.

Duo to scope of research; this research has to narrow down its focus to the environmental adaptivity of the shading device using digital tools and the necessity of providing the required energy for running the device using photovoltaic technology.

2. Theoretical literature review

2.1. Passive and kinetic architecture

Passive Architecture is defined as a climate responsive building that provides comfortable indoor conditions, naturally (Mohd Zaki et al 2008). This aim can be achieved by using different strategies in buildings like; shape, orientation, windows and sun shading systems to control sunlight received by the building and prevent solar radiation or promote ventilation. In this way the amount of required energy for artificial lightening, heating, and cooling, will be reduced. Depending on the type of the building and the design, buildings operational energy can be very different (Buchanan 2005). In order to reduce the costs related to the operational energy it is possible to adopt a sustainable approach, using natural resources, which are known as renewable energies, such as; wind power, solar power and etc (Szokolay 2006). Another way is using more energy efficient equipment (Smith 2005).

Traditional houses all around the world have adopted different strategies to provide more comfortable living space (Mohd Zaki et al 2008). This is already known as " Vernacular Architecture" which is raised from people tradition and culture and highly influenced by climate, and it is very different all around the world. There are informations that people learned from their ancestors about how to build a building with a good energy performance and using local materials. This kind of Architecture has grown because of climatic challenges and cultural expectations. The builders have evolved their architectures for their specific place and climate by making errors and correcting them during the time, and finally gain a rich concept of architecture compatible with their environment. As a result, nowadays it is necessary for Architects and building engineers to see and learn from the past and apply the useful solutions to the new buildings (Elmokadem et al 2018).

Historically moveable structures have always been a great interest for engineers, architects and designers. Kinetic devices have been repeatedly used in Architecture; from traditionally hinged windows, sliding doors and shutters to innovative fully portable dwellings, folding bridges and entirely adaptable structures. The kinetic architecture has been developed during the time. North American tepees, Mongolian yurts and African Berber tents are the early examples of Kinetic Architectural structures. Nomadic architecture was not built to last, it often had to be repaired and replaced. However, the skills and techniques for their construction were passed, advanced and refined from generation to generation. With the advent of sedentism, the creation of settlements and population growth, Architecture needed to be permeant (Zuk and Clark 1970). But gradually the need to add some moveable parts to the building increases. For example, as building's height increased, the need for vertical movements like lifting people and loads increased too, which leads to the creation of the early elevators. During the industrial revelation of the 19th century these and other kinetic devices attached buildings, such as rolling blinds, louvers, foldable shutters, revolving partitions, foldable canopies and collapsible parasols, become commercially popular (Stevenson 2011).

Although, examples of Kinetic Architecture can be traced back to many centuries ago, but the academic research on this topic is quiet recent. This concept began to appear within early modernist Architecture (Stevenson 2011). Kinetic Architecture is a design strategy that is being used for buildings specially for façade design, among different technics and technologies, to have a more climatic responsive building. Which was first represented by William Zuk and Roger H Clark in the early seventies in their book named " Kinetic Architecture". They imagined buildings which are able to change their physical geometries (Bier and Knight 2010).

The kinetic architecture is defined as " The design of buildings with transformative and automatic elements. The building shape is changed to match the people requirements and adapt to environmental conditions" (Elmokadem et al 2018).

Michael Fox (Moloney 2011) defined six category of control systems for kinetics based on the level of complexity:

1) Internal control: They do not have any direct control or mechanism like mechanical hinges.
2) Direct control: They are moved directly by an energy source outside the devices.
3) Indirect control: It depends on the sensor feedback system.
4) Responsive indirect control: It depends on multiple feedback sensors.
5) Ubiquitous responsive indirect control: It has the ability of prediction by using a network of controls with predictive algorithms.
6) Heuristic, responsive indirect control: It depends on algorithmically mediated networks that have a learning capacity.

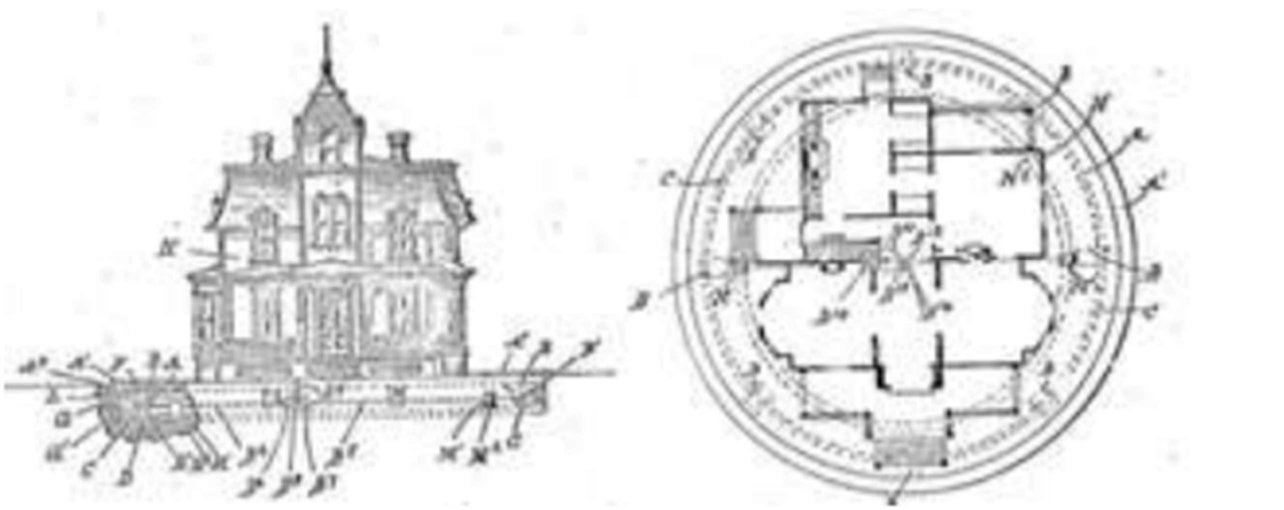


Figure 1: The starting point of Kinetic Architecture, The first design in the kinetic architecture which was never built, the sketches of *Rotary building* by *Thomas Gaynor* in 1908 (Elmokadem et al 2018, Randl 2008)

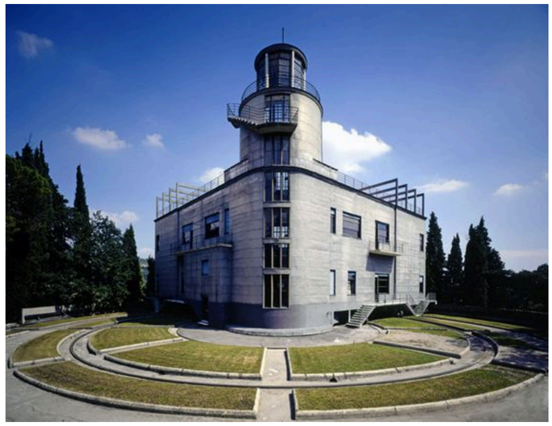


Figure 2: The first building with Kinetic Architecture was *Villa Girasole* where girasole means sunflower designed by *Angelo Invennizzi* in 1935, which follows the sun path (Alter 2017).

The Kinetic Architecture has evolved during time using new technologies and computer, which made it possible to design a building more responsive to the climatic changes. An example is "Institute du Monde Arab" in Paris designed by Jean Nouvel in 1987. The building south façade is a grid of 24×10 m of square bays which simulate the geometry of traditional Arab screens. Each bay contains a central circular shutter set within a grid of smaller shutters, Figure 3 (Elmokadem et al 2018, Moloney 2011)

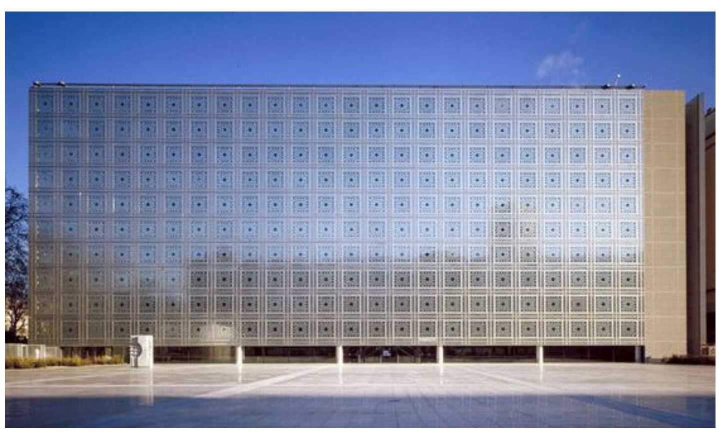


Figure 3*:* an example of a responsive façade to the environment is the southern façade of *Institute du Monde Arab* designed by *Jean Nouvel* in 1987 [www.pinterest.com]

The twenty first century is the real start of Kinetic Architecture because many buildings were built with Kinetic Architecture in this era. Such as Brisbane Airport parking garage designed by Ned Kahn in 2011 and Mercedes-Benz new stadium (Elmokadem et al 2018).

Figure 4: Kinetic façade of *Brisbane Airport parking garage* and its panels which moves by wind, designed by *Ned Kahn* in 2011 (Elmokadem et al 2018).

Figure 5: kinetic roof of *Mercedes-Benz* new stadium, the roof of the stadium opens. and closes as a flower [www.pinterest.com]

A Kinetic Architect system has three main components: kinetic structure systems, kinetic interior, and kinetic façade.

The kinetic structure itself is divided in three categories; embedded kinetic structure (which exist within a larger architectural whole in a fixed location), deployable kinetic structure (which exist in a temporary location and are easily transportable), dynamic kinetic structure (which exist within a larger architectural whole but act independently with respect to control of the larger context).

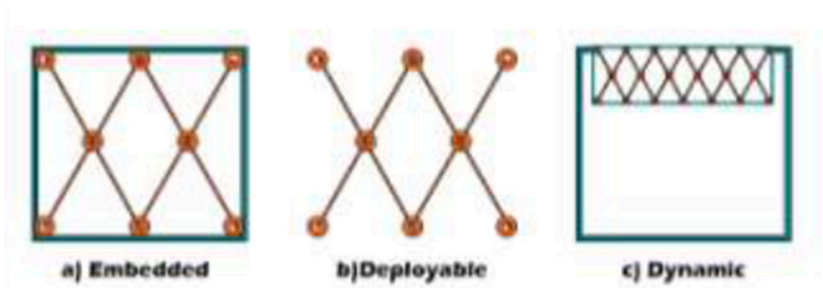


Figure 6: Kinetic structure categories:(a) embedded (b) deployable (c) dynamic (Phocas 2013)

Also, Kinetic interior can be two different categories: transformable space and kinetic wall.

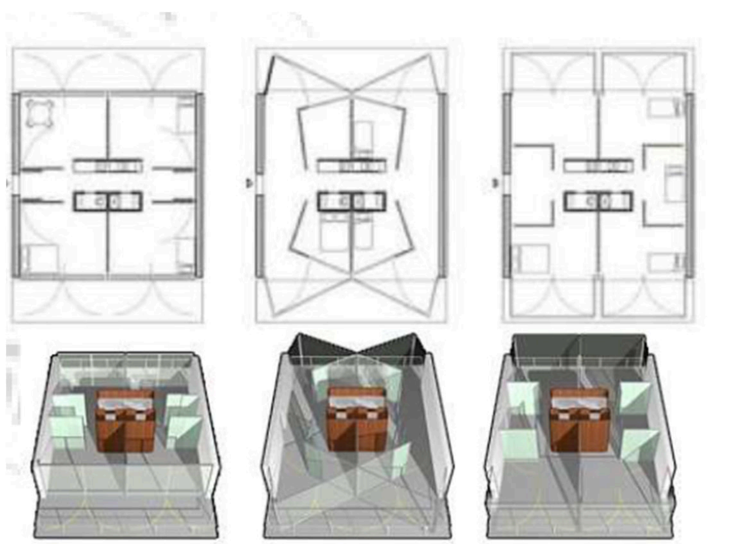


Figure 7: transformable space; different option adapting by *Kalhoefer Korschildgen* (Murray et al 2008)

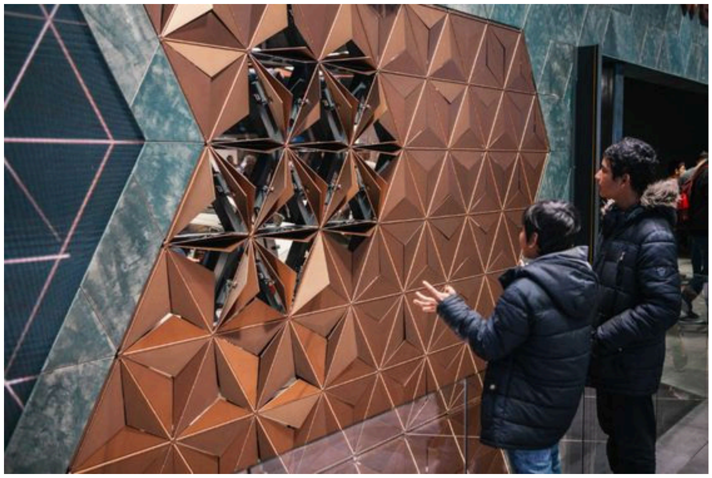


Figure 8: kinetic wall, interactive installation [www.pinterest.com]

A kinetic solar shading device is a part of the façade which According to Ashraf Elmokadem et al;" The concept of kinetic façade is about using geometric transformation to create a motion or a movement in space". There are different types of kinetic façade, but the most common type is based on façade transformations. Geometry transition of kinetic façade are classified in different type of movements: Translation (The motion occurs in vector direction), Rotation (The object is moved around all axis), Scaling (it is an expansion or contraction in size), Motion through material deformation (it depends on changeable material properties, like mass or elasticity).

The operation of the kinetic architectural structures is comparable to the operation of the machine. It usually involves an array of identical components organized within a set of patterns that relate them in order to complete a whole. In the case of kinetic architecture, modularity, is fundamental due to the pragmatic need of movement being transmitted from one element to the next. The ability of modules or components to modify their physical characteristics is dependence to their materials and the ways the parts are connected to each other. The material used in a kinetic device are usually 3 types: rigid, flexible or smart (Stevenson 2011).

Rigid materials such as solid metals, plastics, or timber allow the transmittance of movement through mechanisms, formed by bars or plates linked by hinges or pivoting joints. Rigid Kinetic devices are mainly used within kinetic structures such as foldable or retractable plates, scissor type structure, retractable reciprocal frames and swived diaphragms. A built example of kinetic architectural structure using mainly rigid devices is the Hoberman Arch installed in front of the stage at the 2002 Winter-Olympic-Medals- Plaza in Salt Lake City. The structure comprised 96 interlinked angulated- scissor modules made of sand blasted aluminum profiles and translucent fiber- reinforced covers which moved simultaneously operated by 30ps electric motors Figure 9.

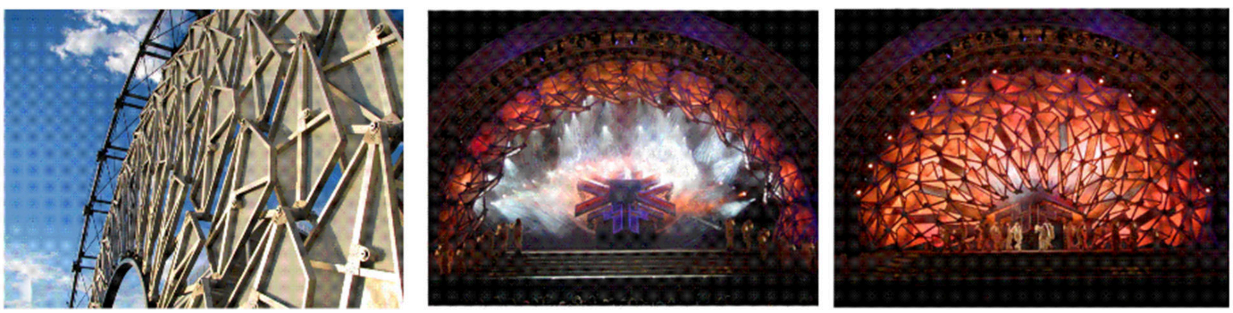


Figure 9: *Hoberman Arch*, an example of kinetic architectural structure using rigid devices, aluminium profile modules moving by electronic motors (Stevenson 2011).

Flexible materials such as textiles or cables allow the transmittance of movement by folding, creasing, bending, stretching and/or inflating. Flexible Kinetic devices can be part of flexible membranes or deformable pneumatic structures. Foldable textile roofs, such as the retractable roof built in 2006 at the Fortress Kufstein, Austria by Kugel + Rei Figure 10, are great examples of kinetic architectural structures that use mainly flexible devices. Combination of rigid and flexible devices can form composite structures such as deployable tensegrity system.

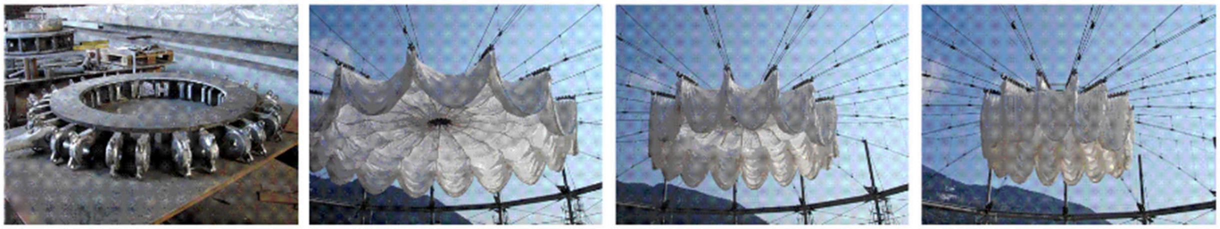


Figure 10: retractable roof of *Fortress Kufstein* which is made of foldable textiles and cables made it possible to open and close. (Stevenson 2011).

smart or intelligent materials transmit movement by changing their physical properties and characteristics. Recent advances in nano technology and bio-mimicry have prompted the emergence of innovative smart materials. These have the extraordinary ability to change their properties (mechanical, electrical, appearance), their structure or composition, and/or their functions in a controlled manner to suit desirable behaviors. Smart devices can be part of responsive surfaces or structures such the (open columns) proposed at the Department of Architecture in Buffalo, USA. These collapsible structures are programmed to drop from the ceiling when co_2 levels are going up in the room where they are placed: as a result, the physical space is reconfigured encouraging people to disperse into smaller groups Figure 11 *(*Stevenson 2011).

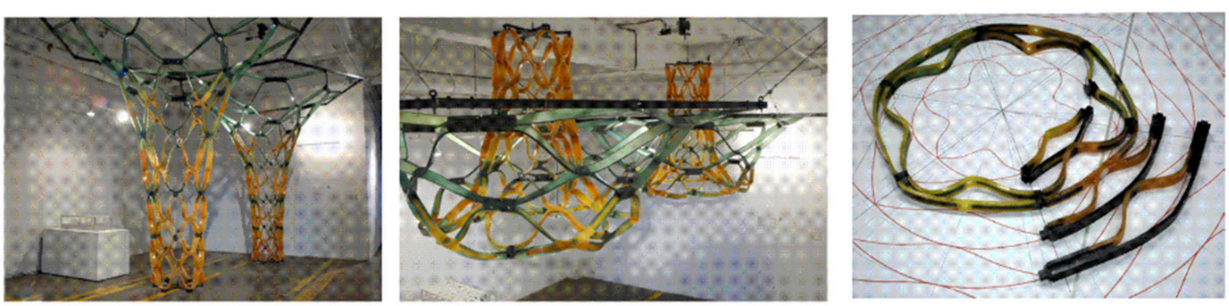


Figure 11: smart materials in open columns proposed at the *Department of Architecture in Buffalo, USA* (Stevenson 2011)

2.2. Renewable energies and photovoltaics

The continuous reduction of fossil fuel resources and their harmful effects on the environment inspired many researchers to look for alternative sources of energy. Renewable energy resources used for electricity generation are: solar, thermal, photovoltaic (PV), wind farm, hydro, bio fuels, wave, tidal, ocean, and geothermal sources. But PV systems are known as the best choice of renewable energies for producing electricity, because of the long-term availability of free solar energy on the earth's crust, while it has no harmful effect on the environment such as carbon emissions, greenhouse gas emissions and climate changes. Solar energy can be easily converted to thermal and electrical energy without causing any negative effect on the environment (Gupta 2020).

Photovoltaic (PV) is a technology option for decarbonization and sustainable energy supply. It can be used almost everywhere in the planet. Solar energy is a source which is abundant and available all around the world, not limited to special region or country. Considering the limitation of energy resources and increasing price of them, PV and other renewable energies are the only solutions for replacing fossil fuel resources and causing the reduction in the future prices.

The cost of PV systems electricity decreased by over 75 % to USD 69/MWh (EUR 60/MWh) between 2009 and 2018. In the most markets the main contribution was the decrease of module prices by over 85%. Because of the continues increase of electricity prices while PV system prices is decreasing, this system is becoming more and more popular and the market develops gradually. Also, the nuclear accident in March 2011 caused a shift in energy investments towards more renewables and PV systems. In 2017, solar energy attracted 58% of all renewable energy investments or USD 161 billion (EUR 140 billion).

PV industry rese again by more than 35% and reached a worldwide production volume of more than 110 GW of PV modules, in 2017. The compound annual growth rate (CAGR) over the last 15 years was above 40%, which nowadays makes PV one of the fastest growing industry. And PV industry has grown from a small group of companies and key players into a global business (Waldau 2018).

PV effect is a process in which PV cells use solar light photons to strike on the doped semiconductor silicone to produce electricity. The PV effect was discovered in 1839, and it was developed to produce power using doped semiconductors in 1954. PV power has been the fastest growing renewable energy technology that grew from 50 MW in 1990 to 177 GW (IEA) in (IEA PVPS TRENDS 2015).

The annual electrical power output of a PV plant depends on the following factors: solar radiation incident on the installation site, inclination and orientation of the PV module, presence of a shading or not, technical performances of the planet components especially modules and inventers.

The solar cell manufacturing technologies are: single cell or monocrystalline, multicell or polycrystalline, bar crystalline silicon, thin film technology.

Monocrystalline and polycrystalline represent the traditional technologies for solar panels and are grouped as crystalline silicon. Monocrystalline PV technology was invented in 1995 and polycrystalline entered the market in 1981. And they are quiet alike in performance and reliability (IRENA 2012).

2.2.1. Thin film technologies

In this technology the PV cell is made of a microscopically thin layer of silicon on a sheet of metal or glass, instead of a thick wafer. They are light weight and flexible made of plastic glazing. Some of them perform slightly better than crystalline modules under low-light conditions. They are also less susceptible to power loss from partial shading of a module (Ramalingam and Indulkar 2017).

Figure 12: Crystalline photovoltaic [source:sharp]

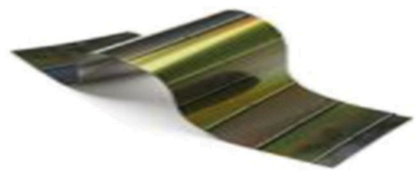


Figure 13: Thin film [source:sikod.com]

Fangyan liu et al defines 3 different categories for solar cells: organic, inorganic and organic-inorganic hybrid. Inorganic PV materials attracted more attention because of the good photoelectric performance, high reliability and lower manufacturing cost (Miles et al 2007). For example, silicon is the second most abundant element in the earth crust, while it is highly stable and not toxic. Silicon solar cells are the most popular one in the PV market (Lee et al 2015) and their power conversion efficiency (PCE) has reached 27.6 % (NREL).In recent years many inorganic materials become more popular because of their high absorption coefficient, low cost and high PCE potentials with absorber layers with micron and even nanometer thickness which makes it easy for thin film production thus it becomes a competitive alternative for silicon solar cells (Poruba et al 2000, Mitchell et al 1977).Among inorganic thin film PV materials, $Cu(In,Ga)Se_2$,(CIGSe) and CdTe with outstanding photoelectric performance have experienced rapid development. And they have achieved high PCE of over 22% (Metzger et al 2019).These materials have the advantages of short energy payback time, light weight, compatibility with substrates compared to the silicon solar cells (Carron et al 2019, Theelen and Daume 2016).But the scarce of In, Ga and Te and the toxicity of Cd restrict the long-term use of these particular PV materials. However Kesterite $Cu_2ZnSn(S, Se)_4$, (CzTsSe), Sb_2Se_3 semiconductors are good alternatives with low cost, less toxicity and they are earth abundant (Chen et al 2013, Zeng et al 2016).

2.2.1.1 $Cu_2ZnSn(S,Se_4)$ solar cells

Despite the fact that CIGSe solar cells, had a good performance, the future development could be restricted because of the scarce reserves of In and Ga. CZTSSe solar cells developed from CIGSe are better alternatives because of the low cost, more abundant and environmentally friendly. They exhibit many similar features as CIGSe in which the In or Ga is replaced by Zn and Sn. The development of CZTSSe solar cells could be inspired by the success of CIGse solar cells (Liu et al 2020).

2.2.1.2. Sb_2Se_3 solar cells

Sb_2Se_3 is a material with good optoelectronic properties and low cost and it has a non toxic composition, which makes it good alternative for CdTe while Cd has toxicity problems and Te is a scarce element. Sb_2Se_3 materials have a peculiar one-dimensional crystal structure that differs considerably from the other conventional absorber materials. These materials are flexible for fabrication and it is possible to create light weight solar cells with them (Liu et al 2020).

2.3. potential of PV panels as a material for kinetic shading device

As mentioned before in the chapter of introduction using kinetic shading devices can be very helpful in controlling energy consumption of a building, but it is clear that in order to create any moving part in a building or activate any system an energy source would be required. This means an extra amount of energy should be added to create the required movement, while the aim was to reduce energy consumption as much as possible. In this case in order to activate a kinetic shading device for required movement an electrical actuator is needed. The use of PV panels as the material of shading device can create enough amount of energy to activate the actuator. Also, it is necessary that the material used in the kinetic shading device is light weight so it can move easily and it will require less energy for movement and prevent any possible dangerous situation in case of breakage of some part of device, also they don’t add to much weight to the total weight of the building. So thin film PV panels are good choice for the material of the kinetic shading devices, as they are lightweight materials, and they can produce the energy required to activate the electric actuator and there is no need to have an extra source of energy to use kinetic shading devices. These type of kinetic shading devices can be applicable to different type of buildings.

3. literature based on case studies

3.1. Al Bahr Tower

The Al Bahr towers are two towers of 25 story. It is located on the North shore of Abu Dhabi island, overlooking the eastern Mangroves and toward Sadiyaat island, and the Persian Gulf beyond. The main aim was to design two towers of to create an outstanding landmark reflecting the region's architectural heritage with the corporate status of the client's organization. It was requested for the design of towers which are contemporary sustainable using modern technologies (Armstrong et al 2013).

The concept of the project was inspired by the traditional Islamic object " Mashrabiya". It is a wooden lattice screen in traditional Islamic architecture and used as a device for achieving privacy and environmental control including natural ventilation, solar control, and glare reduction. The project area is 56000 square meters primarily for office use (bank). The design submitted by architect Abulmajid Karanouh (Aedas) won the competition which offered two 150 meter high circular towers cladded with curtain wall covered with a kinetic shading system, Figure 11a (Attia 2016).

The two towers have a circular envelope cladded with water tight curtain wall. The curtain wall is comprised of unitized panels with a floor to floor height of 4200 mm and variable width of 900-120 mm. From floor to ceiling, the vision area of the curtain wall spans 3100 mm. The curtain wall is separated from the kinetic shading system through a substructure by means of movement joints. The fixation of the substructure movement joints (cantilever struts) is at the first basement, grand floor, and podium levels, thereby allowing them to respond independently from the substructure (Attia 2016).

Figure 14: (a) Northern facade and (b) south facade of *Al Bahr* Towers, with some opened and closed shading devices. coordinates: 248 27' 23" N, 548 24' 4" E; alt: 3m (photo courtesy: Terry Boake).

The dynamic shading system is a screen comprised of a triangulate units such as origami umbrellas. The triangular units act as individual shading devices that unfold to various angles in response to the sun's movement in order to obstruct the direct solar radiation. Each mashrabiya was conceived as a unitized system, cantilevering 2.8 m from the primary structure. the shading device system contains stainless steel supporting frames, aluminum dynamic frames, and fiber glass mesh infill. The folding system transforms the shading screen from a seamless veil into a lattice like pattern to provide shade or light. Each shading device comprises a series of stretched polytetrafluoroethylene (PTFE) panels, so in the case of shading system being closed, the occupants can still see through from inside to the outside Figure 15. In total, each tower has 1049 mashrabiya shading devices, each weighing about 1.5 tonnes. the plan and elevation configuration led to 22 different variations in the mashrabiya geometries, which in itself created a challenge for managing their manufacture and assembly (Attia 2016).

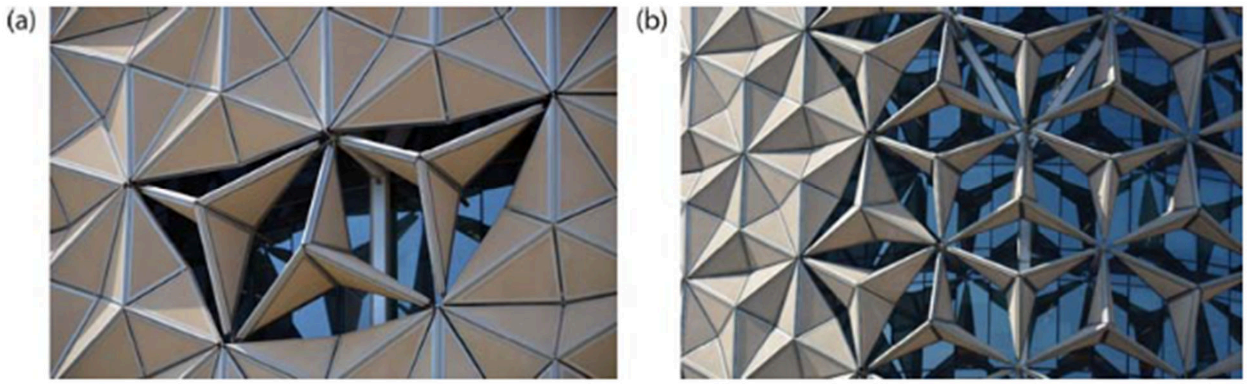


Figure 15: (a) Three fully opened shading devices allowing an open view during non-solar periods and (b) a group of fully opened shading devices. (photo courtesy: Terry Boake).

The shading device is controlled by a computer software which responds to the optimal solar and light conditions. The mashrabiya shading devices are grouped into sectors and they are being open and closed based on the sun's angle. Each shading device comprises a series of stretched PTFE panels and is driven by a linear actuator. The actuator opens or closes the shadings once a day based on the defined sun's position to prevent solar radiation. Figure 16 shows a detailed 3D model of an individual shading device actuator, sleeves, arms, and fabric mesh. The 1049 mashrabiyas are controlled through a central building management system (BMS) that can control each unit individually or in groups. The system is updated every 15 minutes using a light meter and anemometer on the roofs.in the case of whether events the automated program gets overridden power and data transmission is enabled through the strut sleeves, as shown in the Figure 17a. The mashrabiya has a service life of 20 years including the PTFE coated fiber glass fabric and the actuators have a service life of 15 years.

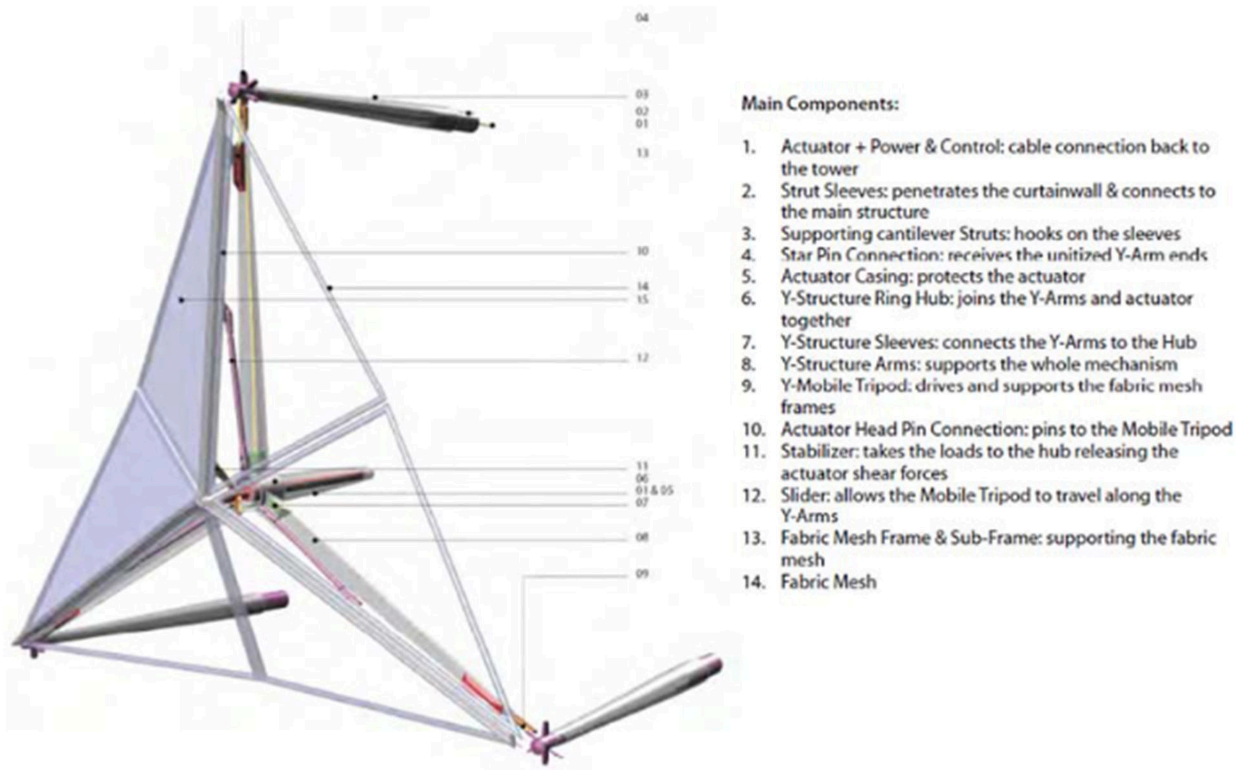


Figure 16: Detailed 3D model of an individual shading device of Albahr tower (photo courtesy: Wood A 2013).

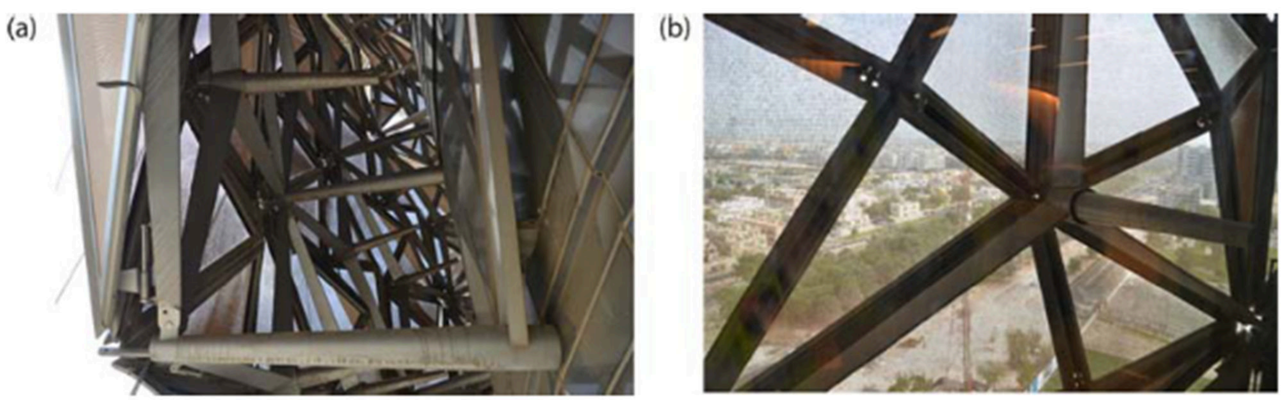


Figure 17: (a) A close view of the mashrabiya and curtain wall where the strut sleeves penetrate the curtain wall and connect to the main structure and (b) a view out when the mashrabiya is open. (photo courtesy: Terry Boake).

Unfortunately, the use of an adaptive façade in this project was meaningless from a sustainable point of view. The use of mashrabiya in Al Bahr project led to missing the huge opportunity to promote adaptive shading systems as a sustainable technology. The client did not consider energy consumption of the occupant satisfaction from the beginning and therefore, the mashrabiya lost its meaning as a sustainable element while acting on the side of being a gadget (Struck et al 2015).

3.2. Simons center at stony brook university

Simon center is the state university of New York designed by Perkins Eastman. In this project an adaptive shading system is applied on the southern façade of the building. The shading system is formed by a Tesselate pattern reflecting the occupant's field which is science and mathematics. The Tesselate pattern forms a combination of geometric shapes like hexagon, circle, square and triangle that shapes into opaque mesh. This kinetic pattern covers 124 square meters of the building façade and provides the building with the functional capability to a dynamic opacity transformation (Hoberman and Schwitter 2008).

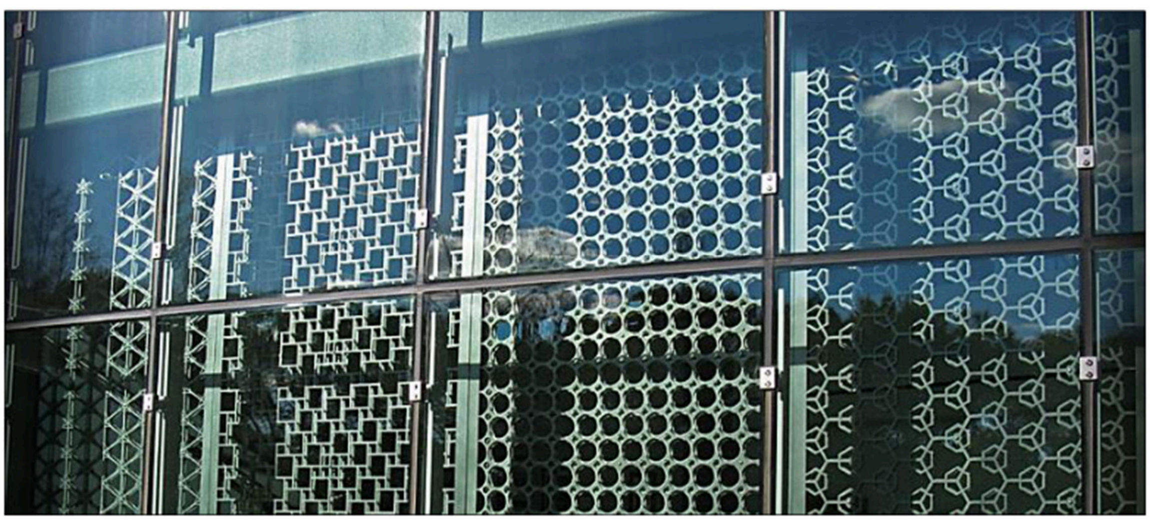


Figure 18 : Tessellate system façade of *Simons center* at *stony brook university*
(Jamil Alkhayyat J 2013)

The design concept is driven from a flower named " Morning Glory" which opens in the morning and closes in the evening when the sunlight is gone (Jamil Alkhayyat J 2013).

Figure 19: Morning Glory flower which opens and closes based on the presence of sunlight (Jamil Alkhayyat J 2013)

Tesselate pattern modules are independent, framed curtains with cribriform patterns that can constantly move and evolve which can dynamically control the light, air flow, ventilation, privacy and sights. This pattern is consisting of couples of overlapping metallic layers which can create an opaque mesh by moving or be open and create more transparent shape. This pattern can dynamically change the façade opacity. Each one of the Tesselate modules has one motor and it is being controlled by a computer (Hoberman and Schwitter 2008).

Figure 20: triangular and rectangular Tessellate pattern *of Simons center at stony brook university* (Jamil Alkhayyat J 2013)

These Tesselate modules has a location-based sensor which responds to the sunlight and weather. For example, in the case of the high sun light the pattern interlock completely to block the excessive sunlight. The sensors are designed to take the maximum advantage of the system in regard to energy efficiency and savings. Pattern opacity can varies from 10% to 85%. also, the moving speed can be adjusted to track the sun or responds to environmental aspects like energy usage, solar gain and daylight levels (Hoberman and Schwitter 2008).

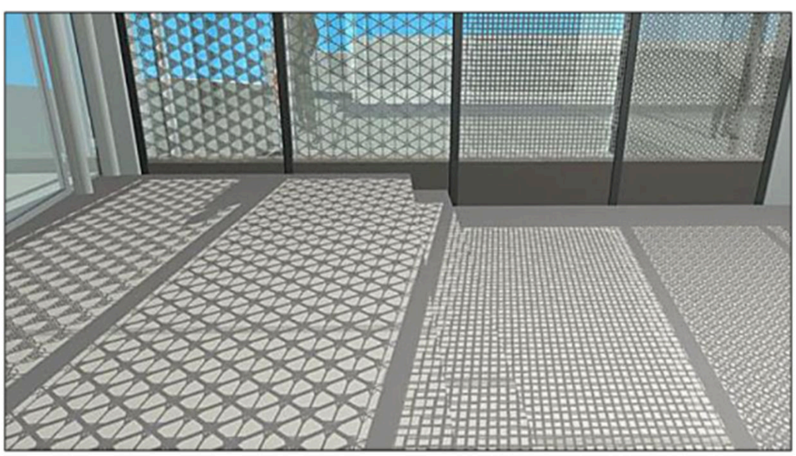


Figure 21: Perforated shades for Tessellate by "The Adaptive Building Initiative" (Jamil Alkhayyat J 2013)

3.3. Helio Trace Center of Architecture

Helio trace center was designed by a team of specialist "Skidmore, Owings, Merrill and Permasteelisa" in New York, Figure 22. The aim of this collaboration was to design a building covered with Kinetic curtain wall system which is responsive to the environmental changes. This system is able to control daylight and glare and can decrease solar heat gain by 81%. Adaptive Building Initiative developed the kinetic shading system for the whole façade, applying its pattern-based strata system. This design responds to the ecological, formal and functional requirements (Hoberman and Schwitter 2008).

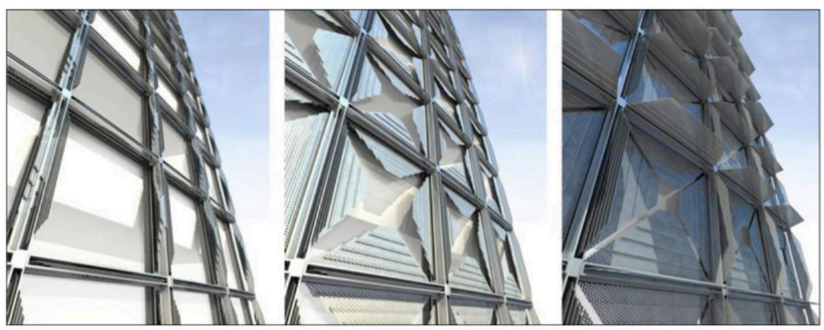
(a)  (b) 

Figure 22: *Helio Trace Center* of Architecture adaptive pattern (a) Tower of *Helio Trace Center* (b) adaptive modules (Hoberman and Schwitter 2008)

The curtain wall is able to track the sun path on the daily and yearly bases. In contrasts with other system mechanisms: this kinetic pattern will expressively develop daylight while decreasing solar heat gain impacts on building residents. The system keeps a good daylight while it eliminates glare, and it decreases peak solar heat gain by 81% on a yearly basis.

This façade technology is applicable to any responsive building geometry by adjusting different panels. It can be placed everywhere in the world by adapting to the location, attributes, orientation and sun path. Kinetic pattern shade on the building façade is linked to a prefabricated, thermally efficient building covering, which enable interior chilled ceiling plates usage that have a lower energy efficiency than other standard air conditioning solutions (Hoberman and Schwitter 2008).

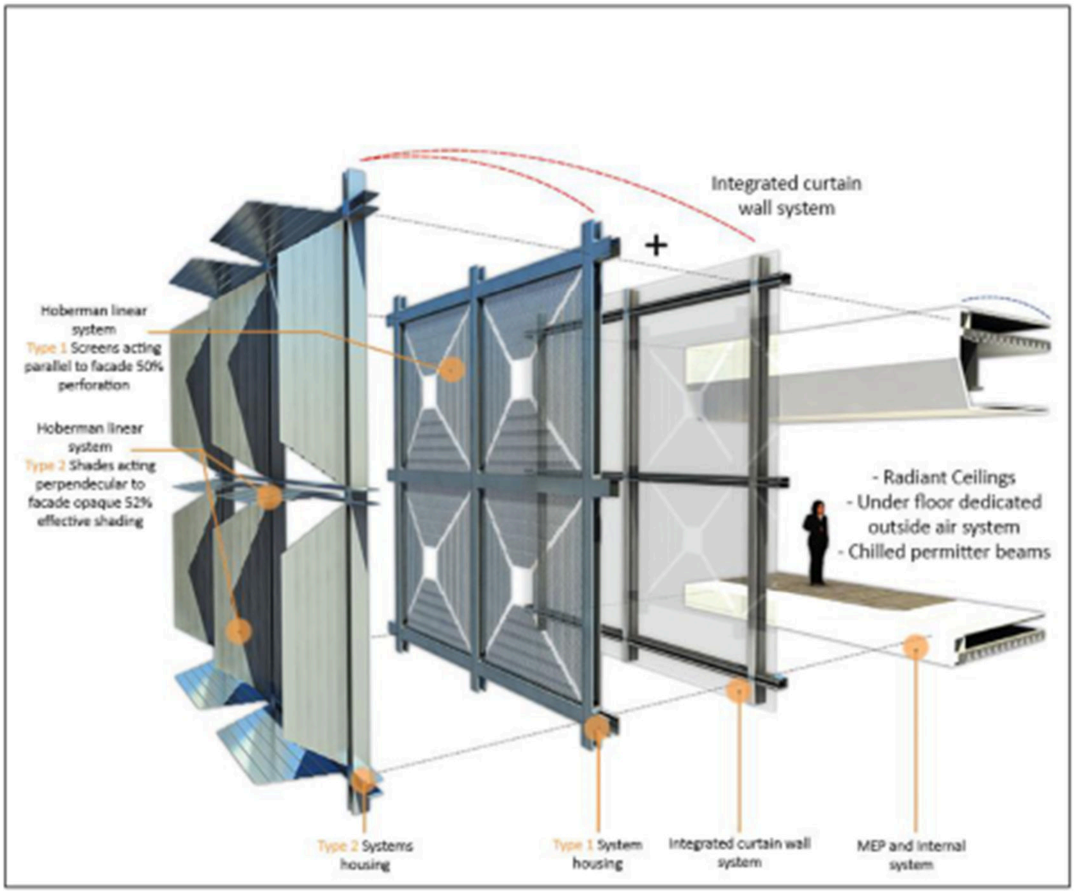


Figure 23: Exploded 3D section for Helio Trace Center window unit, structures and how it performs (Jamil Alkhayyat J 2013)

Hellio Trace maintains the precise balance between shad eand sun. A mobile external sun shade blocks out the rays when required, architects can modify the system to climate sun path and processes schedules. A wide solar analysis has been done on the system with three main objectives: to decrease glare, increase daylighting, and control solar heat gain. Glare studies (at the top), with baseline analysis at its left and enhanced analysis at its right. Daylight levels (at the middle) were adjusted to avoid extreme illumination (at middle left) which can be a reason of glare and to help increasing energy savings, also to provide user comfort. Finally, the problem of high solar gain (at bottom left) was analyzed regarding the systems external shades, all of them together can cut the peak solar gain by an expected 81 percent. The team's parametric analysis calculated the ideal deployment level of every shading system at particular times of day, for every season (Hoberman and Schwitter 2008).

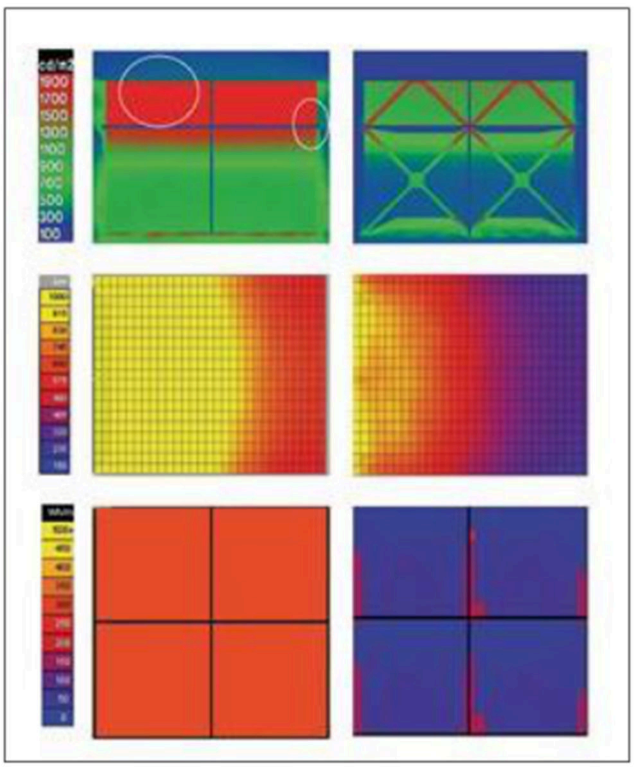


Figure 24: Glare, daylight levels, and solar gain analysis for Helio Trace
(Jamil Alkhayyat J 2013)

3.4. Solar decathlon 2007

In 2007 a team of designer from the Technical university of Darmstadt won the competition of solar decathlon 2007. It was a two-story house, and the aim was to design a house which use the minimum amount of energy while at the same time it provides the maximum amount of comfort. To reach this goal the designers decided that the house should comply with German " Passive House Energy Standard" which requires the annual demand for heating energy to be less than 15 Kwh/m. This requires a highly insulated building envelope. As a result, the East and west walls were constructed as opaque walls, using vacuum insulation panels and North and South walls are glazed. The house was constructed with prefabricated panels which have been transported from Germany to the competition site in Washington DC to be assembled there (Solar decathlon Report 2007).

Figure 25*: Technische Universitat Darmstadt 2007 Solar Decathlon Entry*
[www.solardecathlon.org]

The design team used different strategies to reduce the energy demand of the building while the strategy which is in the interest of this thesis is the use of dynamic louvers on the facades of the building. The facades facing East, West and South are covered with thin film photovoltaic modules to support the energy supply of the house. In order to make sure that the timber-optic of the building is not disturbed the cells are embedded into the lamellae. The necessary deepening's and cable channels are shaped out of the wood. The cables are transmitted to the frame via special side fittings. This provides an optimal integration of the high-tech elements into an approved façade system.

Figure 26: Intelligent facade of automated wood louvers with building integrated Photovoltaics create a continuous facade for TU Darmstadt's 2007 Solar Decathlon House.
(Source: Thun and Velikov, 2013)

The louvers are constructed with oak. On the porch in the south the louver can be opened by folding the two flaps and side them aside. Altogether 9 louver modules can be opened: seven in the south and one in the east and one in the west façade. Additional to these openable louver elements, there are four more louver on the east and west façade which are not openable. The openable louvers consist of two flaps with each 35 lamellae in an oak frame (Solar decathlon Report 2007).

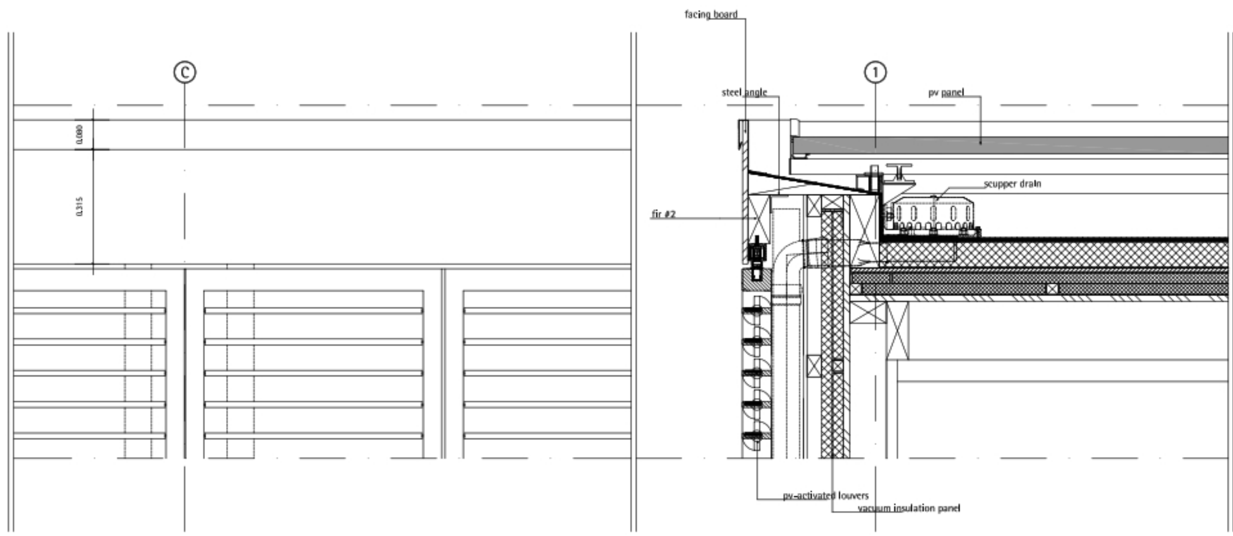


Figure 27: Vertical and horizontal section of the shading system (source: www.solardecathlon.de)

All lamellae can rotate 90° around their center axis. To ensure that the PV surface has always an optimal angle to the sun. the lamellae will be connected to a motor system that rotates them, if it is necessary. the motor system is controlled by a system that calculates the optimal angle with sensors.

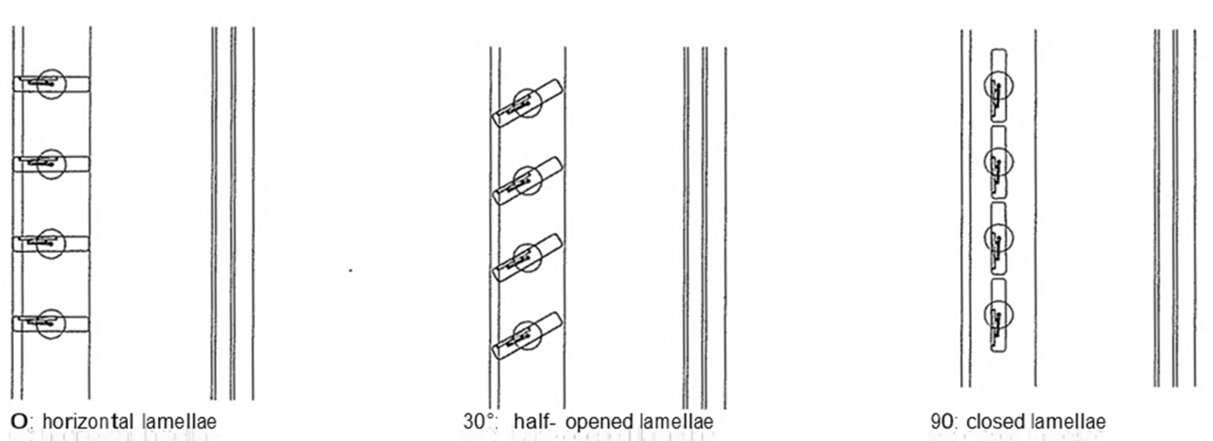


Figure 28: The movement and optimization of the louvers (source: www.solardecathlon.de)

To prevent the self shading of the PV-modules and the loss of energy only 50% of the full depth of each lamellae is activated.

The gained power has to be transported to the electric system of the building. Special fittings and solar cables provide the transportation through the louvers. Every louver is fixed in one point. This fixed point is used to transmit the cable to the building. The louvers are connected parallel to prevent too high voltage at the transmission points. In the building the louver system is connected to an inventor which is a special low voltage device. The inventor is connected to the island system of the building.

The used photovoltaic components are cis-cells produced by the company SCHOTT- Solar. These cells are embedded into a glass-panel and were specially constructed for very small areas such as louvers and shading blinds. They distinguish themselves with their very minimal width of down to only 2cm (around 0.8 inches). This submits the optimal saturation of the lamellae surface, which is necessary to prevent self-shading of the lamellae (Solar decathlon Report 2007).

4.Design process

4.1. Design concept and climate adaptability

The aim of this thesis is to design a kinetic shading device which is made of thin film photovoltaics and can provide the required energy for its movement. It should be possible for the shading system to be applied to different building with all types of façade systems in different locations while it can adapt itself to the required climate.

In order to provide the required electrical energy for the shading system the device must be positioned in the way that it can receive the most solar radiation and as a consequence produce the most possible electrical energy. For normal PV panels there is a defined tilt angle for the whole year for every specific location which is different from the other part of the world according to their latitudinal and longitudinal position. So, it is important to have a kind of inclined shape which can modify its angle based on the location that it is placed in and the angle of solar radiation Figure 29.

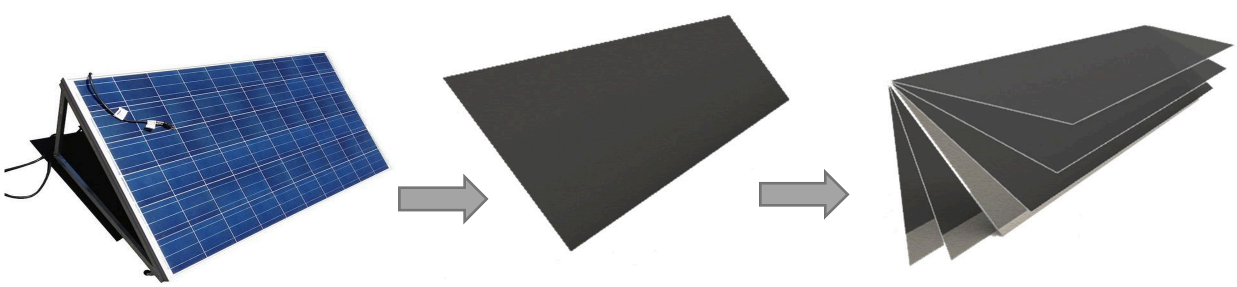


Figure 29: First step of development of the module, moving from a normal shape of a photovoltaic panel to the rotational form of it.

Providing a visual comfort for the occupants is another important aspect which it must be taken into account in the design process. Having too much movement in the façade can cause distraction for the occupants. And also, we have to consider that sometimes the occupants don’t want any obstacle in front of the window which can block their view from the outside. As a result, it is important to avoid any complicated design which requires too much movement, also this can be beneficiary later in industrial production, as it is easier to produce and more economical, and also it will have less maintenance cost. As a consequence, it is better to have a device which can be removed completely from the surface of the window.

In order to start the design process having a climatic sample is necessary, to perform all the climatic analysis on the special location, then it is possible to have the same performance with some modification in different locations. In this thesis the case study climate is the city of Milan, Italy, latitude 45.46° N and longitude 9.19° E. The modelling of the shading device is done by the software of Grasshopper, the plugin of Rhino, and all the climatic analysis are done with Ladybug plugin.

4.1.1. solar radiation analysis

The first step of a designing the shading device is to take the position in which there is the most solar radiation. So, when the shading can perform properly in this position, it means that it can have a good performance also in the other sides of the buildings. Based on the analysis extracted from Ladybug, Figure 30, the best position to apply the shading device is toward south in which there is the most solar radiation.

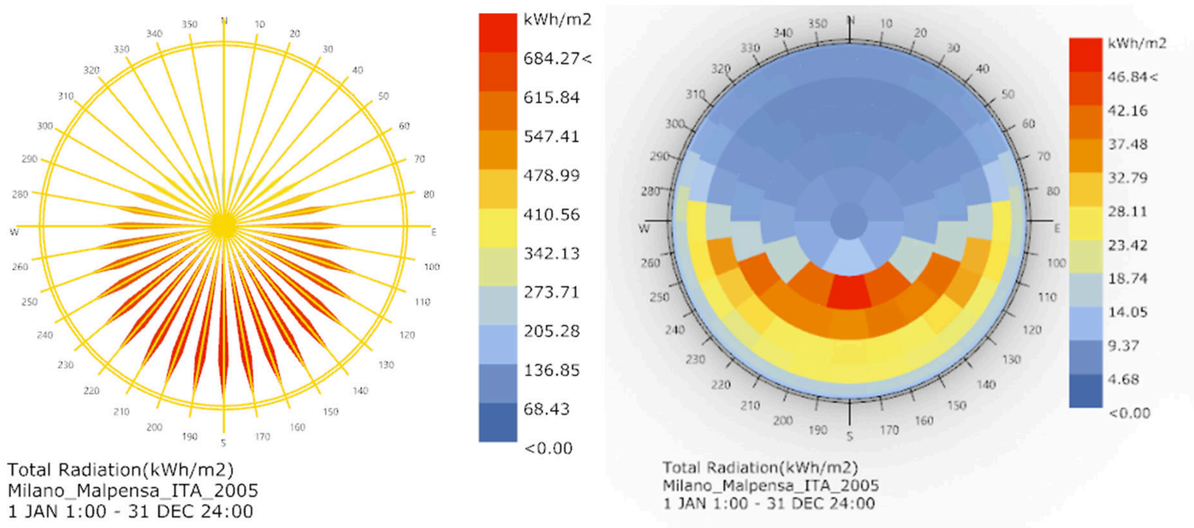


Figure 30: total solar radiation in Milan, radiation rose and sky dome for Milan which it shows the higher values from the south

In order to proceed with the analysis, we consider a box of 3m×4m×3m then we apply the shading device on the southern surface of the shading device. First, we check how much solar radiation do we have on the southern surface of the shoebox without having a shading device, Figure 31.

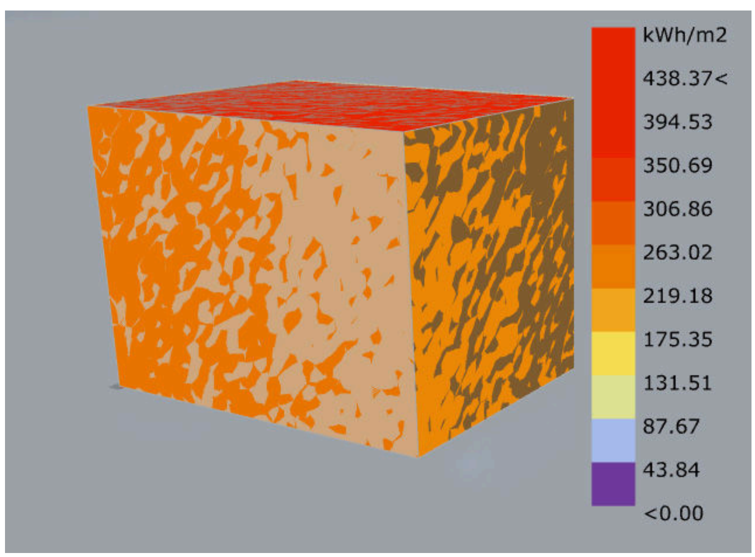


Figure 31: Solar radiation in the summer on the southern façade of the box of 3m×4m×3m without shading

The analyses are done from 21st of June to the 21st of September, the months that we have higher amount of solar radiation specially on the southern façade. These months are important months for the operation of the shading device. As we can see in the Figure 31, we have 306.86 KWh/m2 on the face of the southern façade. In order to reduce the solar radiation, we add an overhang of 0.5m on the top and then another one in the middle in distance of 1.5 m from the base Figure 32.

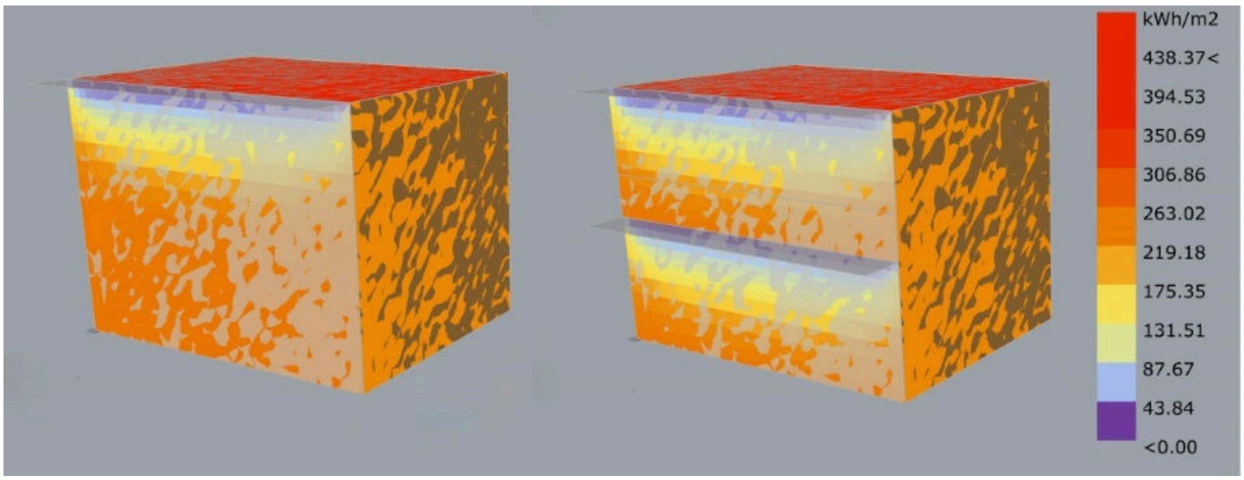


Figure 32: Solar radiation on the southern façade of the box of 3m×4m×3m
(a: with overhang on the top) and (b:with overhang on the top and middle)

It can be seen from Figure 32 that two overhangs are not enough for the southern façade and we should have more overhangs or increase their dimension, while increasing the dimensions can also increase the weight of each module. So, in order to have a southern surface totally shaded it is better to divide the surface in 3 parts and have an overhang every one meter Figure 33.

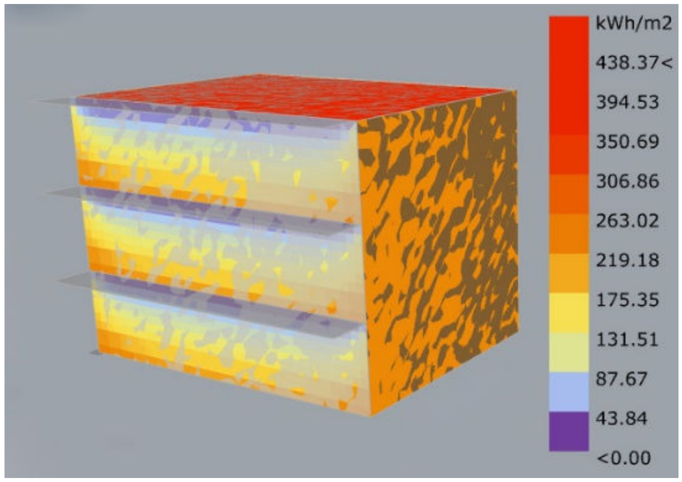


Figure 33: Solar radiation on the southern façade of the box of 3m×4m×3m with 3 overhangs every 1 meter.

The proposed shading device is going to be made of Photovoltaics and we know that sun is not shining perpendicularly on our building, so we need a kind of inclined shape to have the maximum benefits from the sun radiation. The degree of inclination can be different based on the location and also the time of the day. So, the choice is to use a shading device which can change its tilt angle based on the position of the sun.

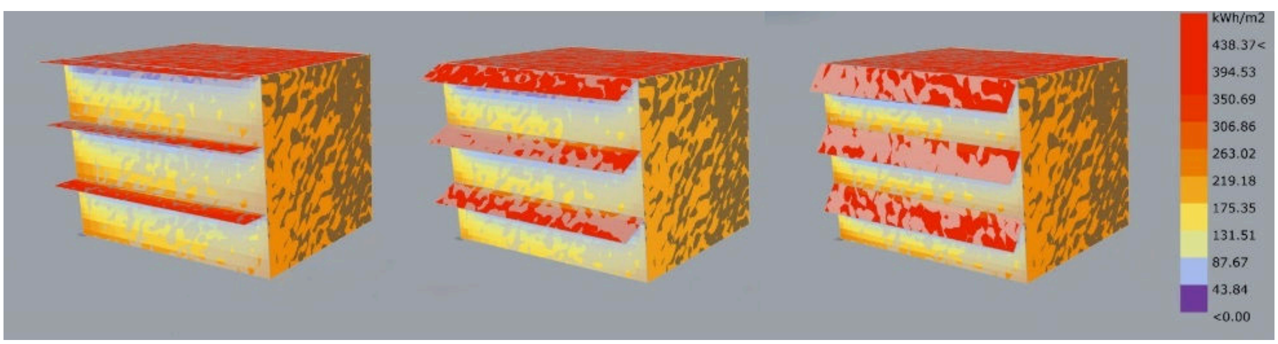


Figure 34: Solar radiation on the southern façade of the shoebox of 3m×4m×3m with inclined overhangs every 1 meters

The overhang can shade almost enough the southern façade even when they are inclined, but there are some parts at the bottom part which still receive some harmful radiation. Considering that these analyses have been done for Milan, we can conclude that this situation can be worst in some other parts of the world with higher amount of radiation, so it is better to add some other parts to the shading device to also cover the bottom parts. In this way it is possible to prevent completely the penetration of the harmful solar radiation. Also, for the possibility of having the whole window closed. It is important to have a kind of shading which can be totally open in winter so we can use the solar radiation to increase the temperature inside the building, or it can be totally closed if the occupants prefer so.

In the new design for each module, we will have one overhang on the top and one on the bottom, so they can be open and close based on the solar radiation angle or the preference of the occupants Figure 35.

Figure 35: single module of the shading device, consist of one overhang on the top and one on the bottom.

We run the solar radiation analysis for the new design to see if it works properly in the required location Figure 36.

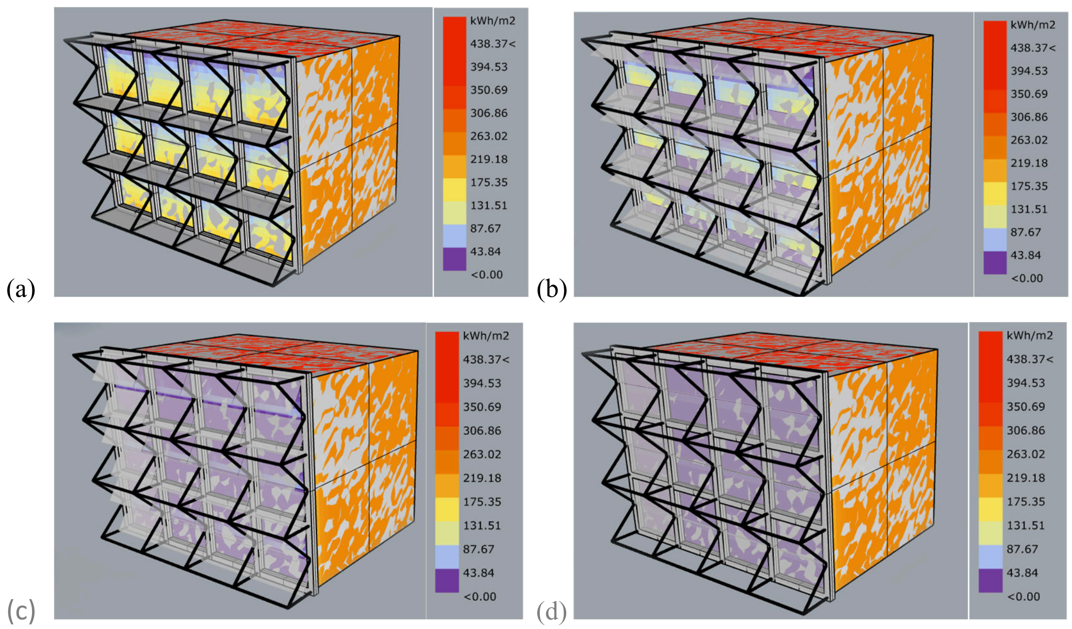


Figure 36: solar radiation received by the southern façade of the box of 3m×4m×3m
(a) completely open position, (b) 15° of rotation, (c) 45° of rotation,
(d) completely closed position

In the Figure 36 we can see that when the shading device is in completely open position, we still have solar radiation at the bottom parts, but with adding another shading at the bottom when it starts to rotate, it reduces the amount of solar radiation that southern façade receives. And when the device is in completely closed position, no radiation can receive to the surface.

4.1.2. daylight analysis

After designing the proper shape for the shading device which shades the façade in the way that it can prevent the excessive solar radiation, it is important to check if we still have enough amount of daylight in the building in the way that no artificial lightening is required during the day. As we can see from the Figure 37, we have enough amount of sun light when the shading device is in the 3 different positions of completely open, 15° of rotation, 45° of rotation. There is only one picture of no daylight and it is for the time when the device is in the completely closed position. And we will have this position only when the occupants want to close it on purpose.

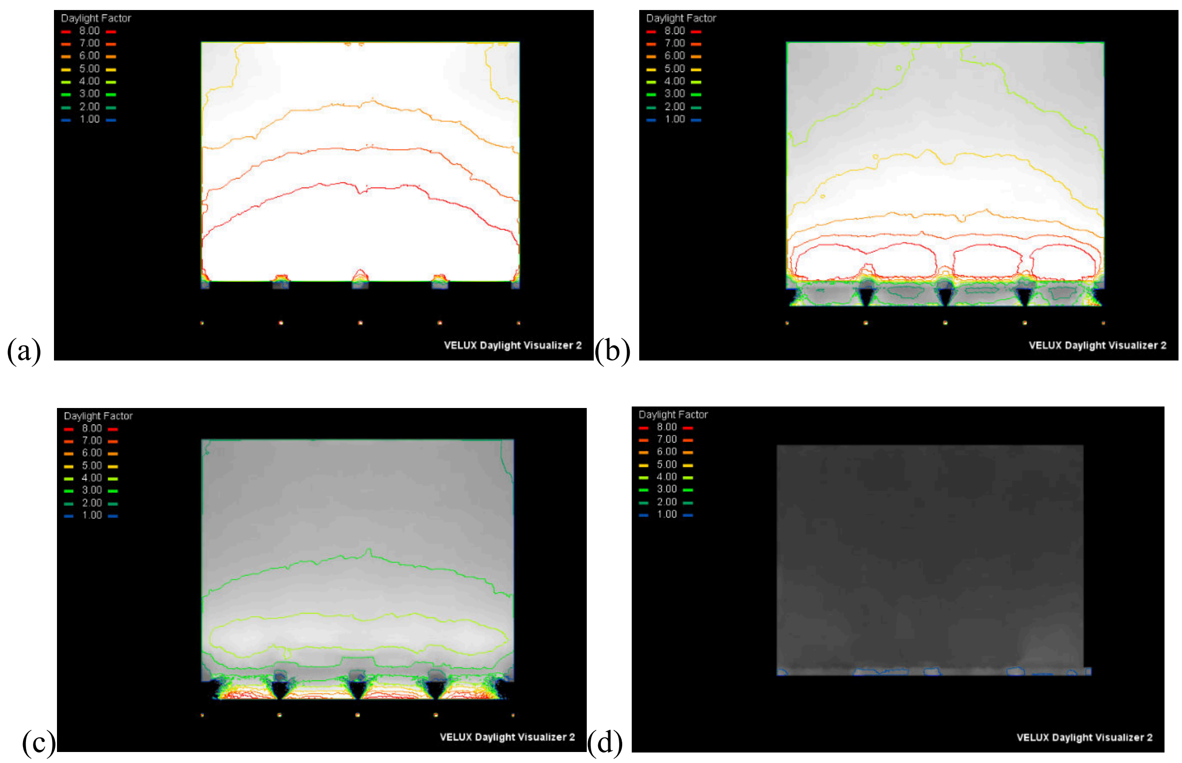


Figure 37: daylight factor for the box of 3m× 4m× 3m (a) completely open (b) 15° of rotation (c) 45° of rotation (d) completely closed.

4.1.3. Internal temperature analysis

In this chapter we analyze the effects of the designed kinetic shading device on the internal temperature of our case study which is a simple box of 4m × 3m × 3m located in Milan, with the help of Honeybee plugin of Rhino software. The first graph Figure 38 shows the values of mean radiant temperatures of the room which has a totally glazed surface on its southern façade. The analysis has been done for the whole year, while our focus is on the summer time where we need to shade more in order to decrease the internal temperature. On the contrary we do not need any movement of the shading device as we need the sun to get in and heats up the space.

In this case while we have no shadings applied on the façade of our room, it can be seen the temperatures during the year vary from 9°c to 41°c and we mostly have this high temperature during spring and summer specifically in the midday around 12 PM and 6 PM. We can see during the winter we have relatively low temperature which supports the pervious idea that we do not need to shade our surface during winter.

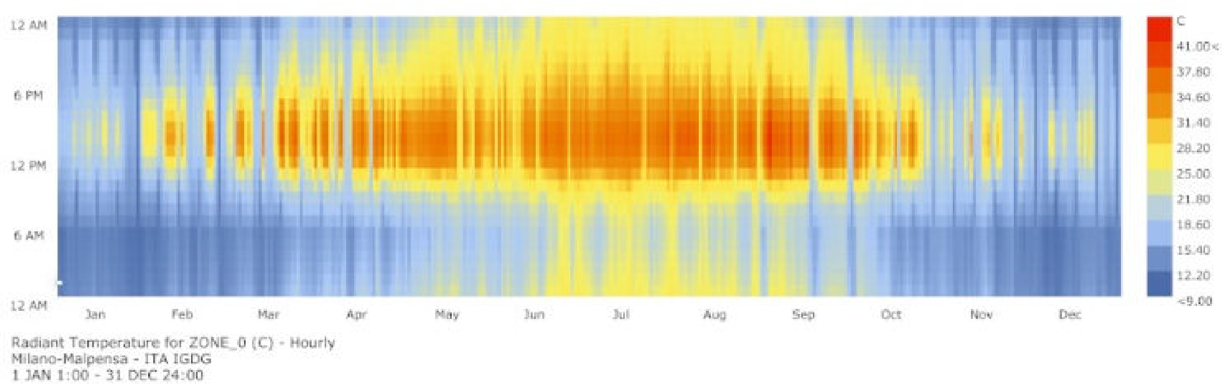


Figure 38: annual mean radiant temperature for the room of 4m× 3m× 3m with the fully glazed southern façade

In the next step we add the shading device to the room as overhangs and run the simulation, to see how having overhangs on the southern façade of the room will affect the internal temperature of the room. Figure 39 shows the results of the analysis.

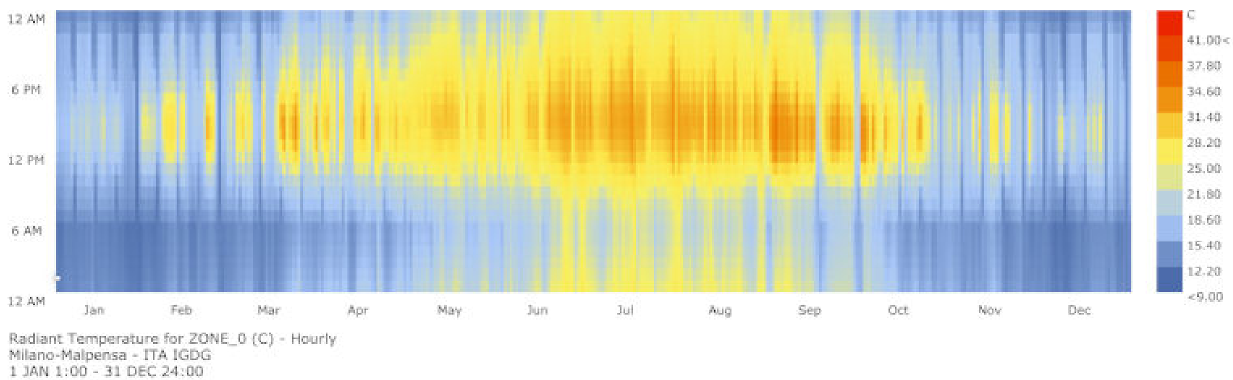


Figure 39*:* annual mean radiant temperature for the room of 4m× 3m× 3m with the fully glazed southern façade and overhangs every 3 meters.

It can be seen from the graph of mean radiant temperature, with simply adding overhangs the temperatures decrease specially during summer. In this case the higher temperature is about 34°c in the beginning of September. 34°c still is a high temperature, but it is significantly low compared to the 41°c in the case of having no shadings on the facade.

Then we start to rotate the shading device to see how it can affect the internal temperature while we provide more shaded area due to the rotation of the overhangs. In this step we run the analysis for 15° of rotation, the results are shown in the Figure 40.

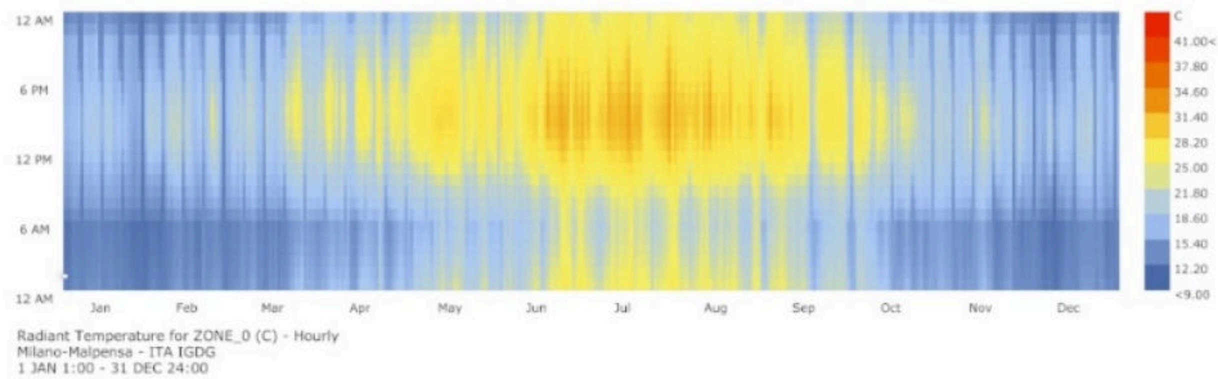


Figure 40: annual mean radiant temperature for the room of 4m× 3m× 3m with the fully glazed southern façade and overhangs 15° of rotation.

The Figure 40 shows the graph of mean radiant temperatures and it can be seen clearly that we have a decrease in the internal temperatures of the room. The highest temperature decreases to 31°c and it exists only in the summer time in the midday.

In the next step we want to try if it is possible to reach a relatively comfortable temperature during the summer in the midday by having higher rotational angle in our shading device. The Figure 41 shows the results of mean radiant temperature for 45° of rotation.

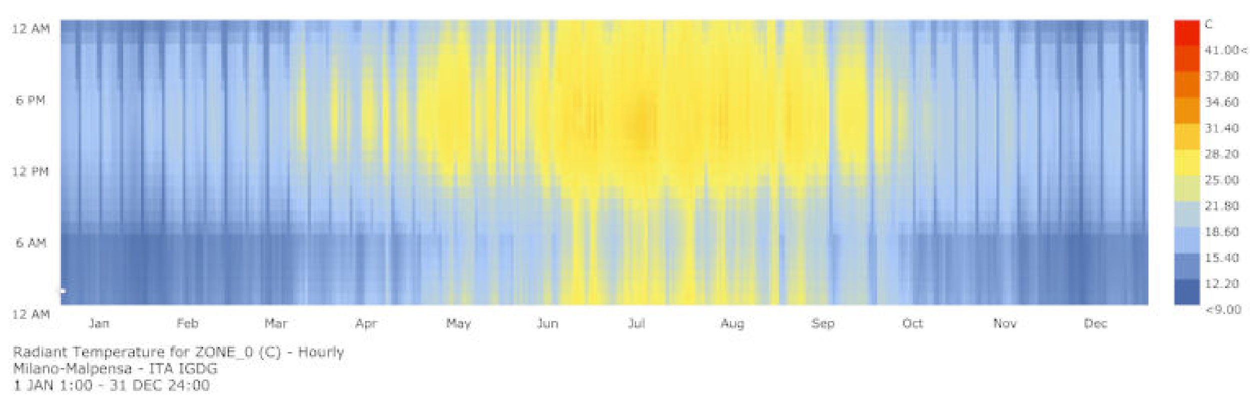


Figure 41: annual mean radiant temperature for the room of 4m× 3m× 3m with the fully glazed southern façade and overhangs 45° of rotation.

From the Figure 41 can be seen that we are mostly in the comfort zone during the summer when we have the rotational angle of 45°. The highest temperature is 28°c which mostly can be seen in the summer in the midday till the afternoon and it is a relatively comfortable temperature.

The next graph Figure 42 shows the values of internal temperature when the device is totally closed.

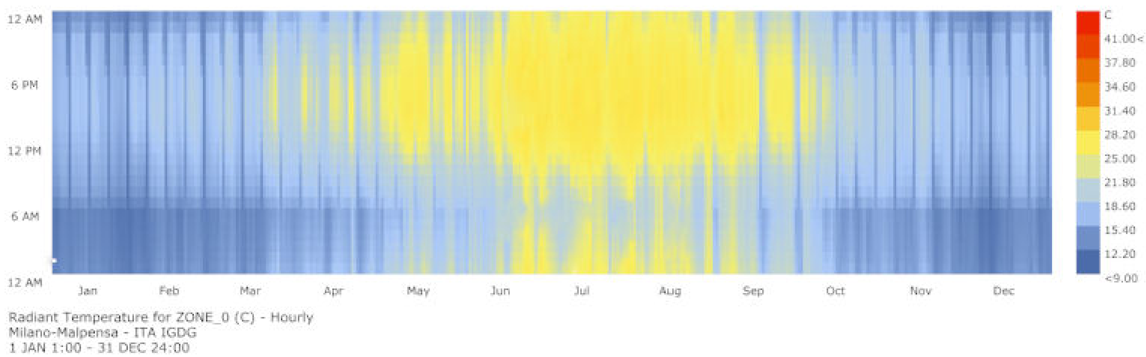


Figure 42: annual mean radiant temperature for the room of 4m× 3m× 3m with the fully glazed southern façade and totally closed shading device.

As it can be seen from the Figure 42, we are in a more comfortable condition when the shading device is in the totally closed position. But this position is not recommended because we also block the sunlight inside the room during the day while it is necessary to have an enough amount of it during the day to avoid artificial lightening, and also when the device is totally closed, it is not in a good position to produce electricity. As we already know this device is made of Photovoltaic panels and the best position is perpendicular to the solar incident angle. But this position is accessible if the occupants of the building prefer to have a closed window sometimes, and they will be able to open and close the shading device manually.

4.2. **Technical specification**

One of the important goals of this design is that to have a shading device which is applicable to different façade systems. The whole structure is light weight, and it can be mounted on window frames on the opaque walls or be connected to the structures of any glazed façade system. The Figure 43 shows a module which is connected to mullions and transoms of a glazed façade. Each module has the dimension of 1m×1m and consist of two kinetic panels which are made of thin film photovoltaics. Each panel has the dimension of 1 m × 0.5 m.

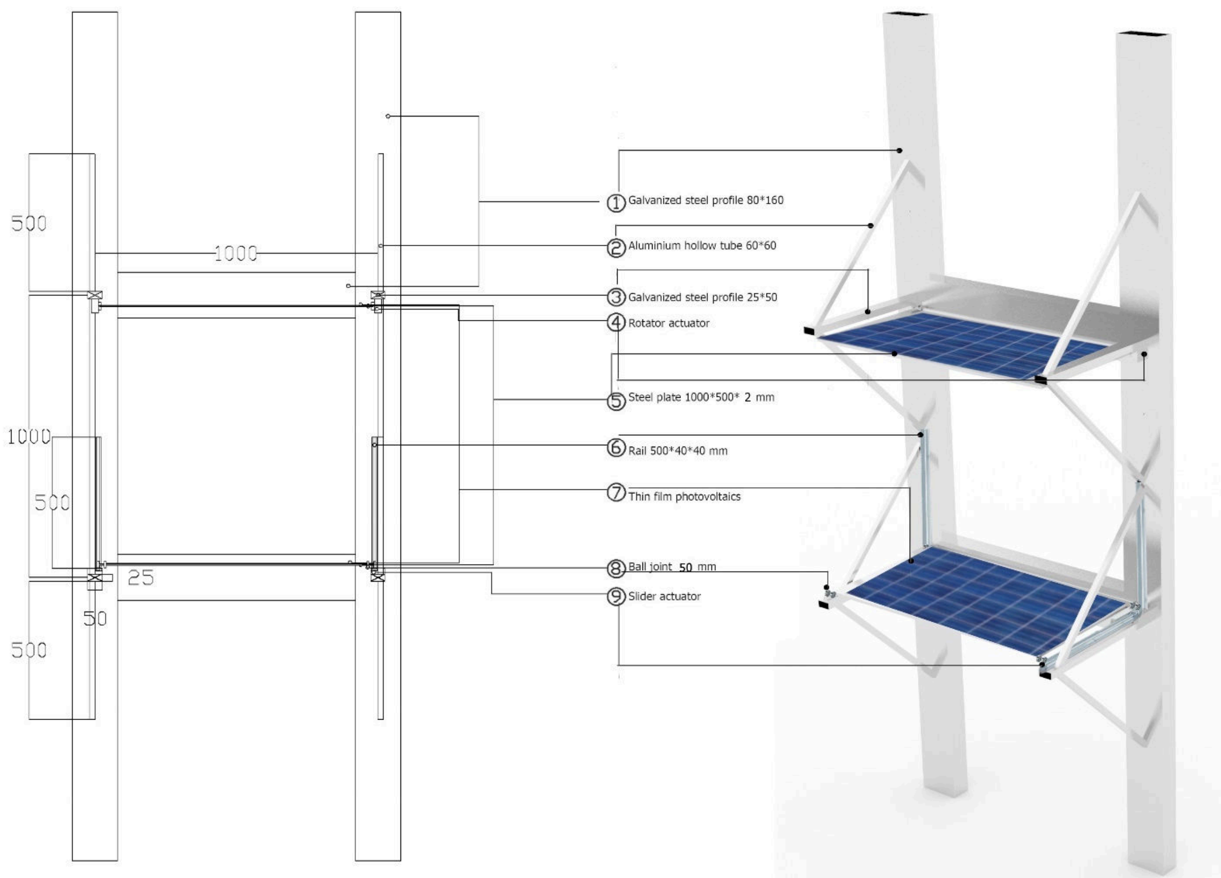


Figure 43: one module of the shading device mounted on a glazed façade with the dimension of 1m × 1m

There are two moveable parts in each module with two different typologies of movement. These moveable parts are the thin film photovoltaic panels which do the shading by being rotated and adopting the required angle based on the solar radiation incident angle and also produce electrical energy for the actuators to operate. The upper panels rotate by using a rotator actuator. It can be rotated for 90° and be totally open at 0° and totally closed at 90°. It can also rotate and adopt any degree between 0° and 90° based on the required degree in the specific location and the specific time of the day and the position of the sun Figure 44.

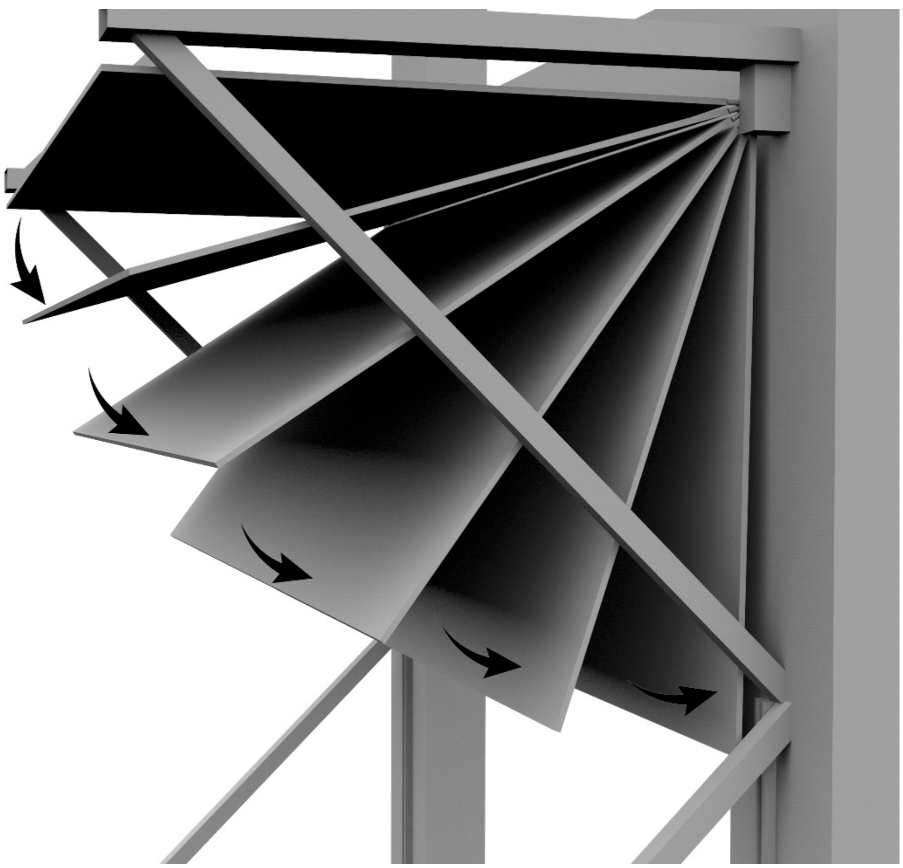


Figure 44: Rotation of upper panel with rotary actuator; rotation from 0˚ open position to 90˚ closed position

The lower panel also rotates but with the help of a slider. As it is necessary to always have the face of the PV panel toward the sun, it is not possible to simply rotate the lower module.it need to move with a slider on two rails so it can always have the same rotational angle as the upper panel. This can be seen more clearly on the Figure 46. The panels move on the slider with the help of two ball joints, one is connected to the panel, one to the slider. The ball joints allow the panels to move along the rail of the slider while they can be rotated at the same time. Also, on the other side of the panel there are two other ball joints, on connected to the panel and one mounted on a vertical rail. When the slider pushes the panel one side of it moves horizontally and rotates and the other side of it moves horizontally and rotates Figure 45.

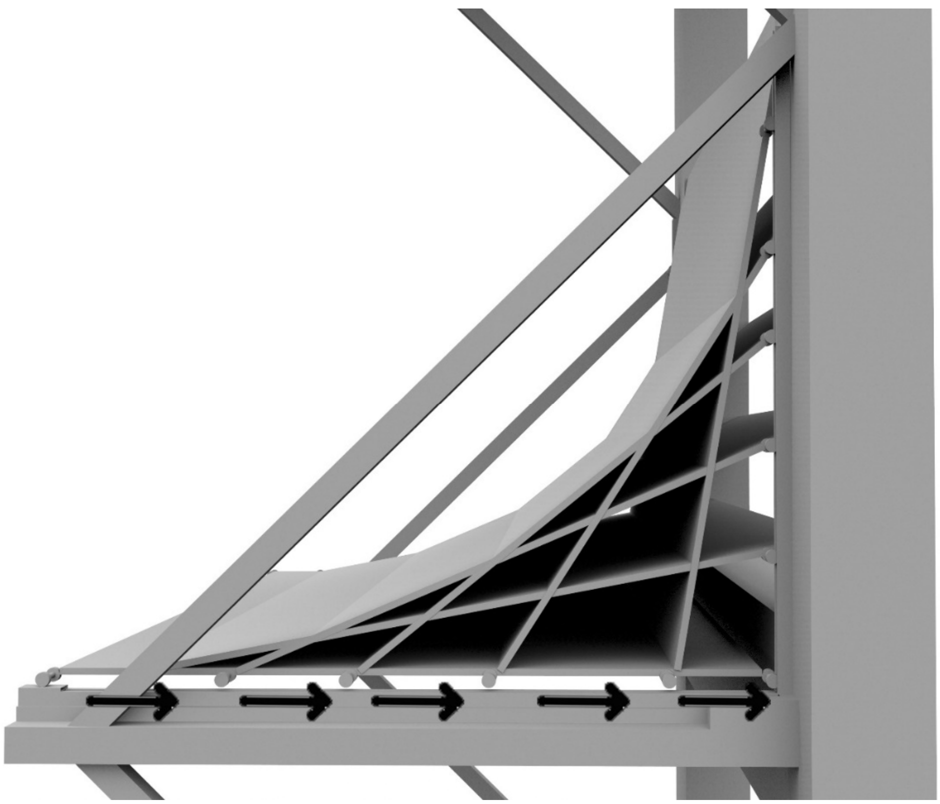


Figure 45: Rotation of the lower panel with the slider actuator; rotation from 0˚ open position to 90˚ closed position

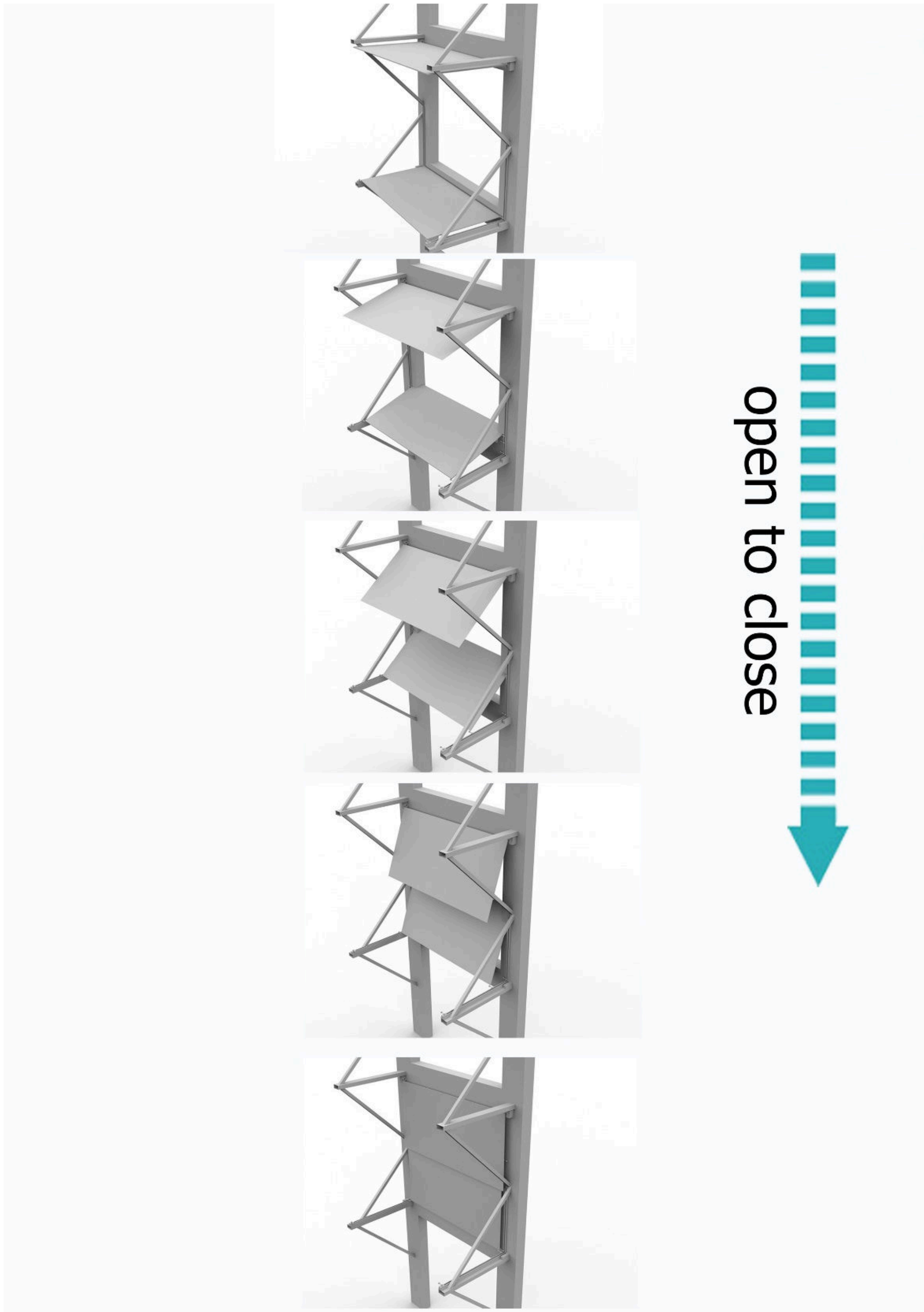


Figure 46: the rotation process of panels one module. Going from completely open to completely closed position

In the Figure 47 all the used components of the shading device can be seen clearly.

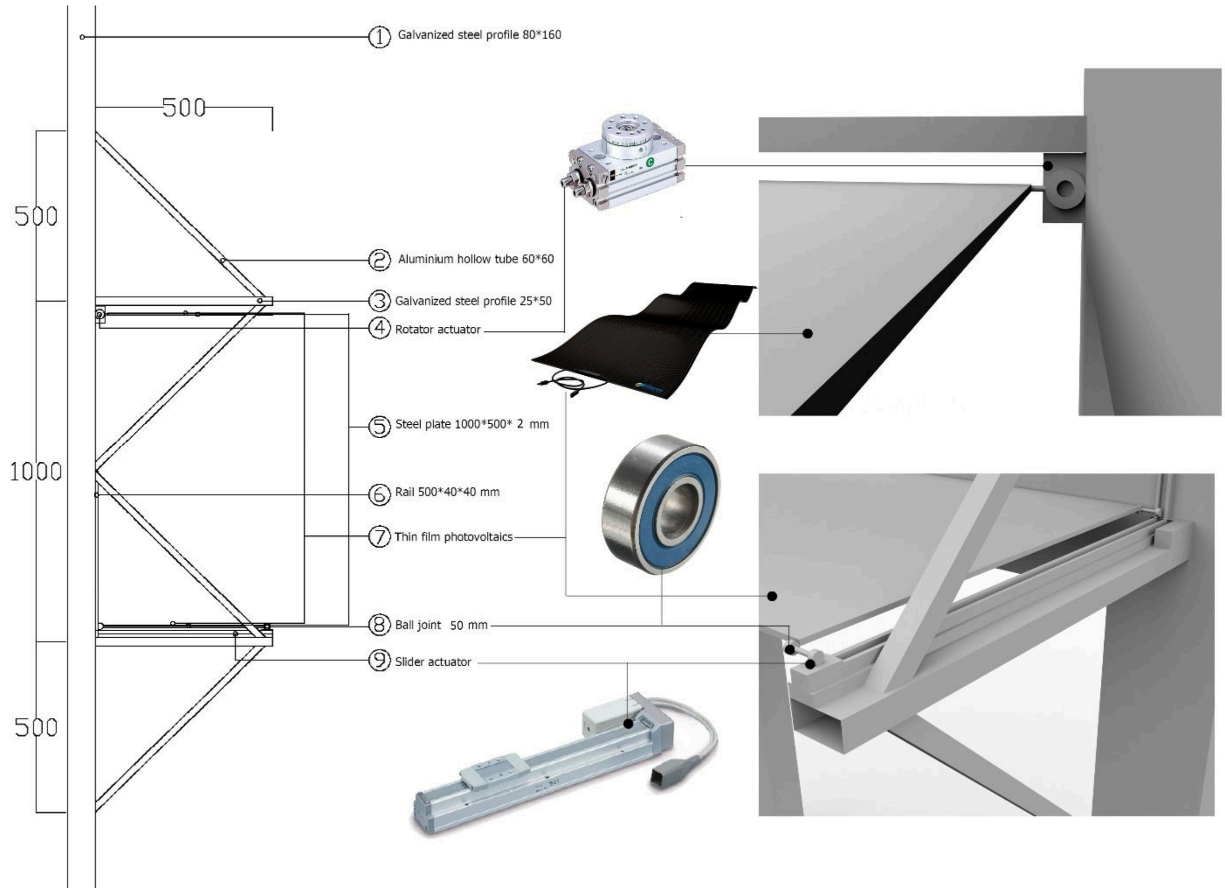


Figure 47: components, details and dimensions of the shading device

4.2.1. Choice of the Photovoltaics

Flex - Flexible CIGS Solar PV modules from Flison company with the Swiss technology

Figure 48: sample of thin film photovoltaic being used in the kinetic shading device [www.flisom.com]

The eFlex is a range of flexible and lightweight CIGS solar PV modules specifically designed for application on buildings and transportation platforms (such as buses, vans and trucks).
The modules can be applied on surfaces with limited load bearing capacity, on curved surfaces, on membranes that need to keep their waterproofing and should not be penetrated, or where aesthetics is critical such as facades and residential roofs. The modules come in different sizes which can be used to cover entire surfaces. The modules are made of high-quality materials which give a lasting performance and are based on a unique technology developed in Switzerland to deliver high performance in targeted applications.

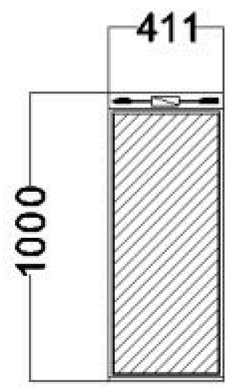
Features

- Ultra-low weight, < 2kg/m2
- Applicable on curved surfaces – bendable on a 20cm radius
- Super thin (<2mm) & aerodynamic
- High energy yield due to shadow tolerance and temperature stability
- Special adhesive option for easy installation on various surfaces
- Beautiful aesthetics - uniform full black design
- Robust and vibration resistant - micro cracks free
- Multiple length options (~1m to ~6m) to meet different needs.
- Low environmental footprint
- Swiss technology made in Europe.

As this thin film material can not tolerate any weight on top of it and it is not strong enough for snow or wind loads it must be applied on another material. In this case we decide to apply it on a steel plate of 1000 mm×500mm×2mm.

eFlex- Flexible CIGS Solar PV modules

Dimensions		
Length	[mm]	1000±2
Width	[mm]	411 ±1
Thickness of module		
without backside adhesive	[mm]	1.5 ± 0.2
with backside adhesive		2.2 ± 0.2
Thickness at J-Box	[mm]	20 ± 1
Weight		
without backside adhesive	[Kg]	0.8
with backside adhesive		1.2



Electrical characteristics at STC [1]			35W
Model number			
Nominal power	Pmpp	[W]	**35**
Tolerance*		[%]	-10/ +10
Voltage at nom. power	Vmpp	[V]	**34.4**
Current at nom. power	Impp	[A]	**1.02**
Open circuit voltage	Voc	[V]	**48.0**
Short circuit current	Isc	[A]	**1.28**
Max. system voltage	IEC	[V]	**1000**
Max. serial fuse rating	I	[A]	**10**

*Average power over all modules shipped to any customer shall be 35W or above. Modules will be sorted into boxes of 5W/10W increments depending on the project size.

Thermal Characteristics			
Temperature coefficient	Voc	[%/°C]	-0.30
Temperature coefficient	Isc	[%/°C]	0.01
Temperature coefficient	Pmpp	[%/°C]	-0.35

Operating Conditions		
Temperature range	[°C]	-40 to +85
Max. mechanical load [2]		2400 Pa, 245 kg/m2

Additional Information	
Cell type	Flexible CIGS on Polyimide
Junction box	Front side including bypass diode, IP68 for box, MC4 type connectors, 400mm long stranded wire 2.5 mm^2
Encapsulation	Fluoropolymer front sheet / plastic back sheet
Customization	Possible on request
Packaging	Shipped rolled on Euro pallets in boxes of 16 pcs without backside adhesive or 14 pcs with backside adhesive – max. 192/ 168 per pallet

Warranty & Certification	
Performance guarantee	10 years on 90% of Pmpp under STC[1] & 20 year on 80% of Pmpp under STC[1]
Warranty	5 years' workmanship after delivery date
Certification	IEC 61215:2016 testing underway; IEC 61730:2016 testing underway
Safety class	II

Figure 49: data sheet and technical specifications of thin film photovoltaics being used in the kinetic device [www.flisom.com]

4.2.2. Choice of the Rotator actuator

For the lower panel in order to operate a rotator is needed, for this purpose we chose a rotary actuator from the SMC company. The choice is a rotary table/ rack and pinion type, MSQ series in size of 70.

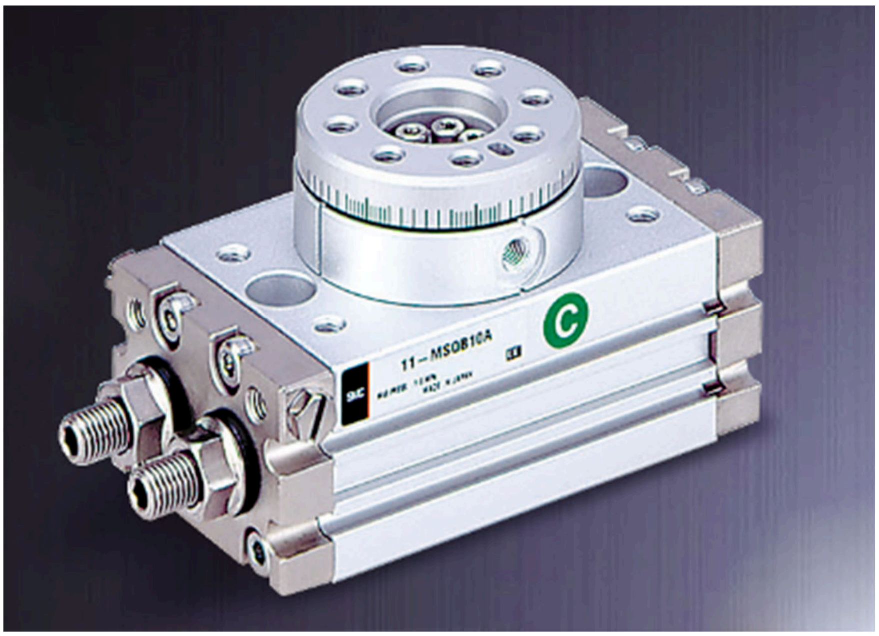


Figure 50: rotary actuator used for the upper panel [www.smcitalia.it]

Weight (g)

Size		10	20	30	50	70	100	200
Basic type	With adjustment bolt	530	990	1290	2080	2880	4090	7580
	With internal shock absorber	540	990	1290	2100	2890	4100	7650
High precision type	With adjustment bolt	560	1090	1410	2240	–		
	With internal shock absorber	570	1090	1410	2260			

Figure 51: sizing of the rotator and weight bearing (unit: gr) [www.smcitalia.it]

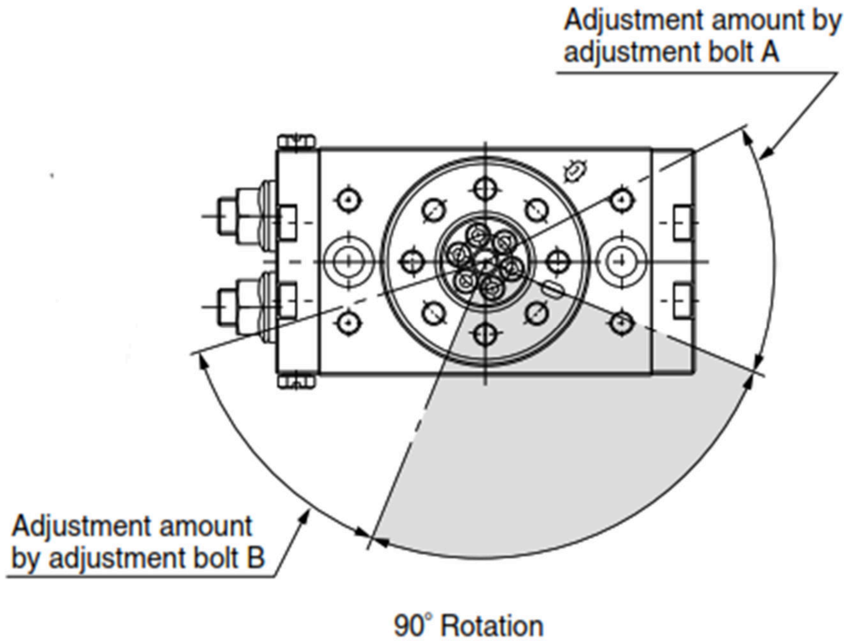


Figure 52: Degree of rotation for the rotary actuator used in the upper panel [www.smcitalia.it]

4.2.2. Choice of the Slider actuator

For the lower panel in order to operate a slider is needed, for this purpose we chose an slider from the SMC company. The choice is a ball screw drive series of LEFS in size of 16 with the parallel motor.

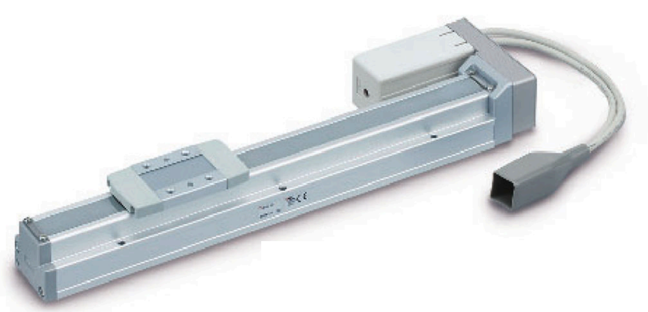


Figure 53: Slider actuator used for the lower panel [www.smcitalia.it]

Servo Motor (24 VDC)

Model			LEFS16A		LEFS25A		
Actuator specifications	Stroke [mm] Note 1)		50 to 500		50 to 800		
	Work load Note 2) [kg]	Horizontal	7	10	5	11	18
		Vertical	2	4	1	2.5	5
	Speed Note 2) [mm/s] Stroke range	Up to 500	1 to 500	1 to 250	2 to 800	2 to 500	1 to 250
		501 to 600	—	—			
		601 to 700	—	—	20 to 630	12 to 420	6 to 230
		701 to 800	—	—	20 to 550	12 to 330	6 to 180
	Max. acceleration/deceleration [mm/s²]		3000				
	Positioning repeatability [mm]	Basic type	±0.02				
		High precision type	±0.015 (Lead H: ±0.02)				
	Lost motion Note 3) [mm]	Basic type	0.1 or less				
		High precision type	0.05 or less				
	Lead [mm]		10	5	20	12	6
	Impact/Vibration resistance [m/s²] Note 4)		50/20				
	Actuation type		Ball screw (LEFS□), Ball screw + Belt (LEFS□R/L)				
	Guide type		Linear guide				
	Operating temperature range [°C]		5 to 40				
	Operating humidity range [%RH]		90 or less (No condensation)				
Electric specifications	Motor size		□28		□42		
	Motor output [W]		30		36		
	Motor type		Servo motor (24 VDC)				
	Encoder		Incremental A/B (800 pulse/rotation)/Z phase				
	Rated voltage [V]		24 VDC ±10 %				
	Power consumption [W] Note 5)		63		102		
	Standby power consumption when operating [W] Note 6)		Horizontal 4/Vertical 9				
	Max. instantaneous power consumption [W] Note 7)		70		113		
Lock unit specifications	Type Note 8)		Non-magnetizing lock				
	Holding force [N]		20	39	47	78	157
	Power consumption [W] Note 9)		2.9		5		
	Rated voltage [V]		24 VDC ±10 %				

Figure 54: motor specification for the lower panel [www.smcitalia.it]

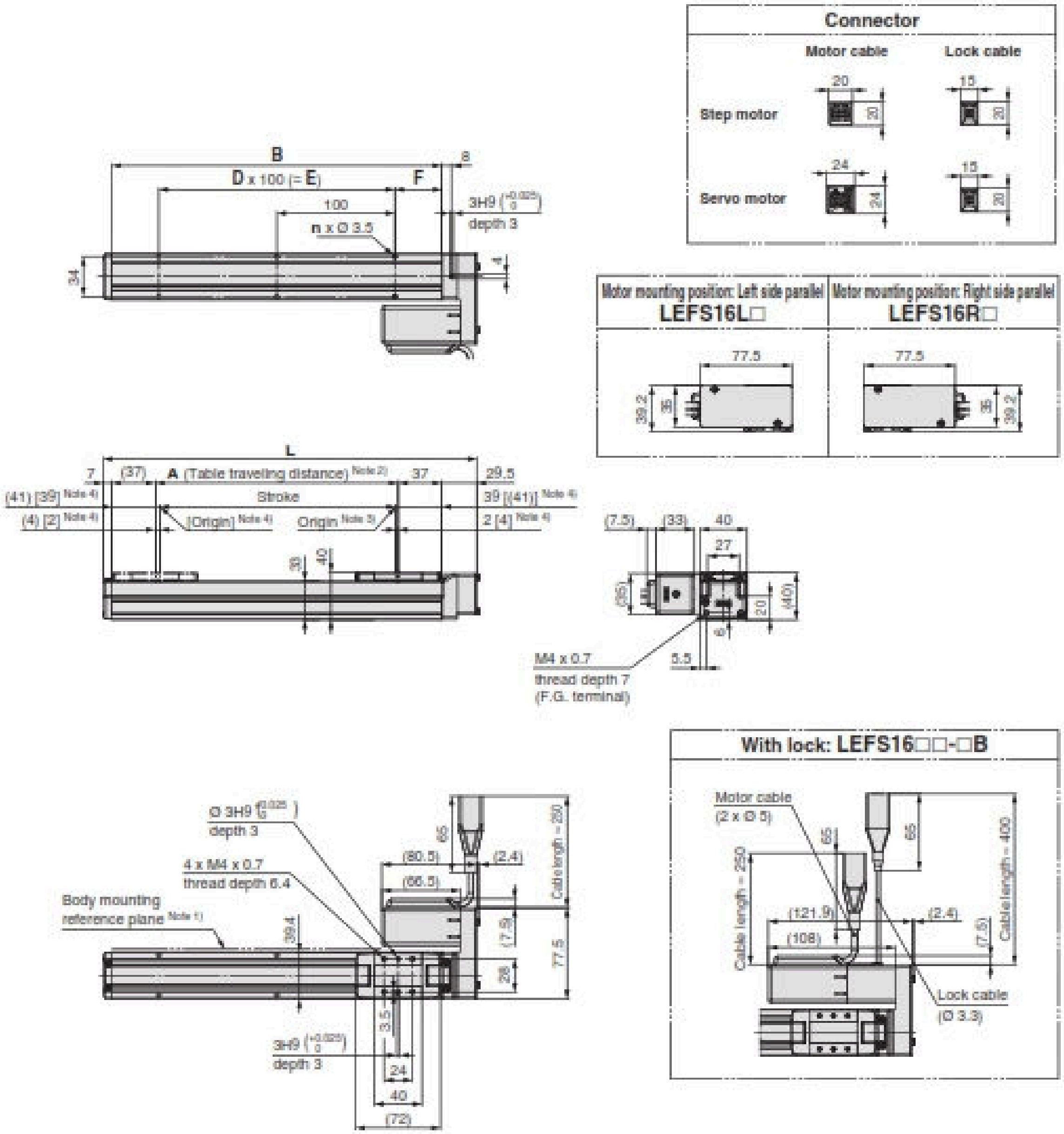


Figure 55: dimension of the slider actuator for the lower panel [www.smcitalia.it]

4.3. **Snow load calculation**

The snow load on the shading device when it is in the completely open position (overhang) should be determined taking into account the local conditions and specific standards related to the built environment. In this case we examine our model for the city of Milan located in Italy and the standard used for this calculation is NTC 2018.

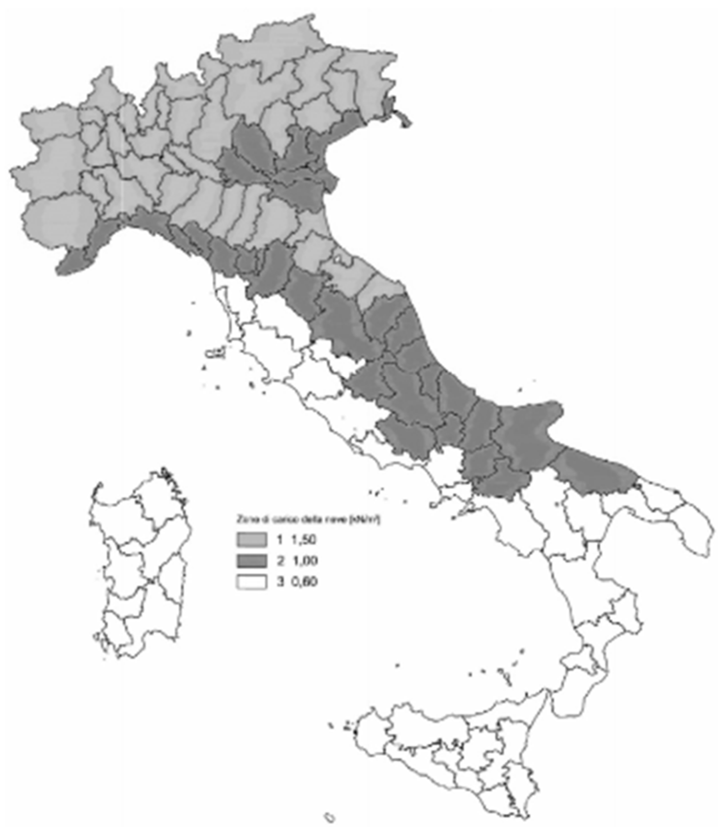


Figure 56: snow load zones (NTC 2018)

The load caused by snow on the covers should be calculated by the following equation in accordance with the NTC 2018 normative:

$$qk = \mu i * qsk \cdot C_E \cdot C_t$$

where:

qk is the snow load on the roof;

μi is the coefficient of the shape that assumes nominal values depending on the angle of inclination of the areas affected by snow – α, which from the following table has been set to μi = 0.8 because the designed surface is flat with an inclination of 1%.

Coefficiente di forma	$0° \leq \alpha \leq 30°$	$30° < \alpha < 60°$	$\alpha \geq 60°$
μ_1	0,8	$0{,}8 \cdot \frac{(60-\alpha)}{30}$	0,0

Figure 57: shape coefficient values (NTC 2018)

qsk is the characteristic value of the snow on the ground. It depends on the local climate conditions and exposure conditions considering the varying of snow precipitation from zone to zone. Milan is part of Zone I – Mediterranean.

Zona I - Mediterranea

Alessandria, Ancona, Asti, Bologna, Cremona, Forlì-Cesena, Lodi, Milano, Modena, Monza Brianza, Novara, Parma, Pavia, Pesaro e Urbino, Piacenza, Ravenna, Reggio Emilia, Rimini, Treviso, Varese:

$$q_{sk} = 1{,}50 \text{ kN/m}^2 \qquad a_s \leq 200 \text{ m}$$
$$q_{sk} = 1{,}35\,[1 + (a_s/602)^2] \text{ kN/m}^2 \qquad a_s > 200 \text{ m} \qquad [3.4.3]$$

Figure 58: zone 1 for snow precipitation and related value of q_{sk} (NTC 2018)

C_E is the exposure factor, in our case is $C_E = 1.0$

Topografia	Descrizione	C_E
Battuta dai venti	Aree pianeggianti non ostruite esposte su tutti i lati, senza costruzioni o alberi più alti	0,9
Normale	Aree in cui non è presente una significativa rimozione di neve sulla costruzione prodotta dal vento, a causa del terreno, altre costruzioni o alberi	1,0
Riparata	Aree in cui la costruzione considerata è sensibilmente più bassa del circostante terreno o circondata da costruzioni o alberi più alti	1,1

Figure 59: C_E values for different classes of topography (NTC 2018)

Ct is the thermal coefficient that can be used to redact the snow load as a result of its melting due to heat loss from the structure itself. In order to consider the higher possible value of snow load this value is considered as Ct = 1.

Therefore:

$$q_k = 0.8 * 1.5\ KN/m^2 \cdot 1 \cdot 1 = 1.2\ KN/m^2$$

As the dimension of each overhang in the shading device is 1000*500 mm we have 0.6 KN of distributed snow load on each overhang.

5. Performance calculations

5.1. Movement calculations

In order to define the performance of the shading device it is necessary to first define how much the shading device needs to be rotated and in what times of the year the rotation is needed. First it is necessary to know the limits of rotation. The first parameter that defines a limit for rotation is the daylight factor, it is necessary to have enough amount of daylight in the building in the way that no artificial lightening is required. We found the limits of rotation with the help of the software Velux Daylight Visualizer, Figure 60.

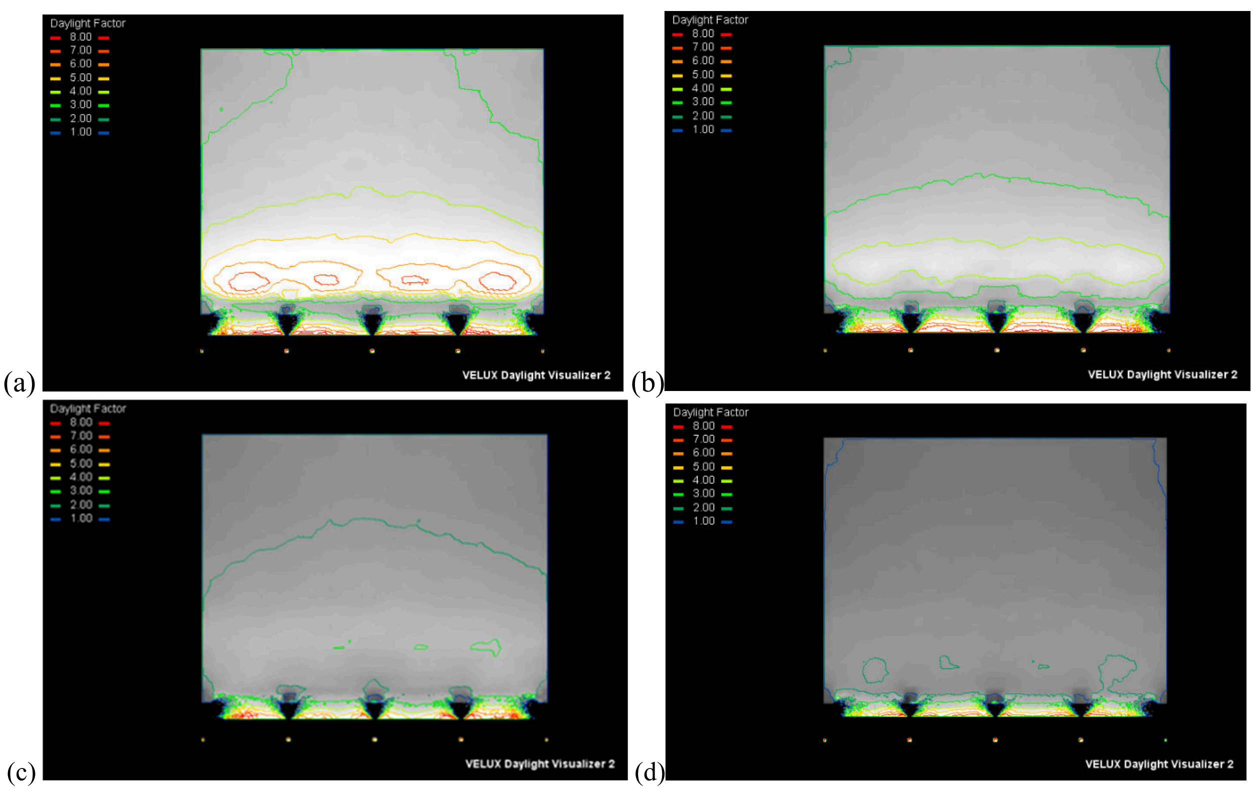
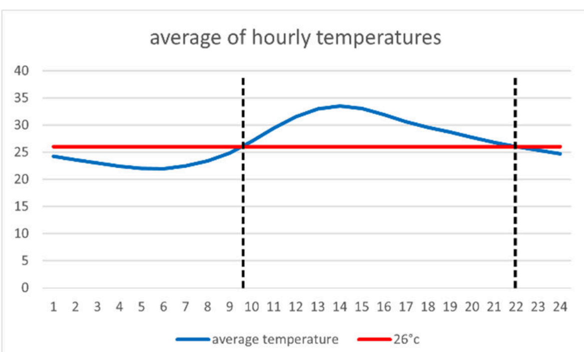


Figure 60: daylight factor for the box of 3m× 4m× 3m (a) 35° of rotation (b) 45° of rotation (c) 50° of rotation (d) 55° of rotation.

The limit for the daylight factor is 2, as we can see from the Figure 60 we reach this limit with 50° of rotation while we still have enough amount of daylight inside the room. And with 55° of rotation, we would not have enough amount of daylight in our area. As a result, in the shading device should rotate at maximum 50°, just in case that the occupants require so, and they want less light inside the room.

The next step is to check in what time of the day there is the need for rotation and how much we need to rotate in each hour. The crucial time of the year that requires the shading device to perform is the summer time, starting from 21th of June until the 21th of September. We need to shade during this time to provide more thermal comfort inside the building. In this case we check the indoor temperature of the room of 3m× 4m× 3m for every single hour of the summer to see in which hours the internal temperature exceeds 26°c, so we will shade to decrease its temperature. And we check with how much rotation we can decrease the internal temperature, taking into account the limit of 50° of rotation. Following graphs show the average internal temperatures of the room for the month of June starting from 21th, which have been extracted from the Honeybee plugin of Rhino software with simulating a room of 3m× 4m× 3m located in Milan as an case study.

(a) 

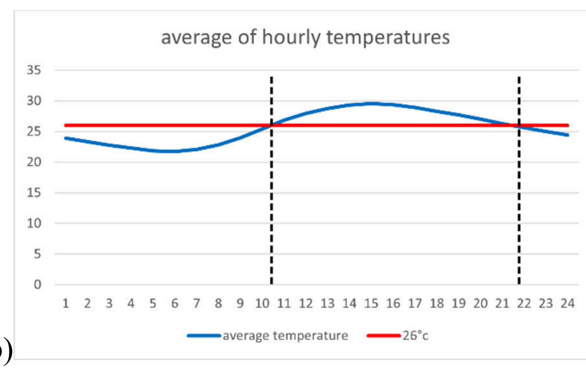
(b) 

Figure 61: average of hourly temperature for the month of June starting from 21th.
(a) without shading (b) with shading 0° of rotation

As it can be seen from Figure 61 it can be seen that with only adding the shading devices as overhangs to the room we are able to simply decrease the temperature about 3°c or 4°c. after having the shading device applied on the façade of the room we have temperatures higher than 26°c starting from 10 AM until usually 21 PM. In some cases we still have higher temperature after 21PM which is obviously not because of presence of sun in the sky. So, if we shade enough during the hot hours of the day it is possible to also have more comfortable temperatures also late at night because we already avoid the space to heats up during the day.

We perform the same analysis for the month of July and the results are shown in the Figure 62.

(a) (b)

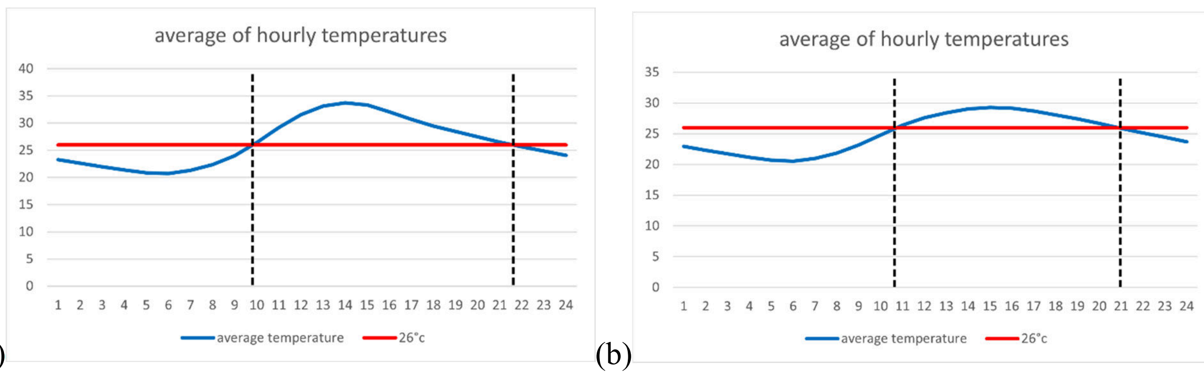


Figure 62: average of hourly temperature for the month of July.(a) without shading (b) with shading 0° of rotation

It can be seen that the situation for the month of July is quiet the same as June, with adding the shading device the average temperatures decrease about 3°c or 4°c, and we have temperatures higher than 26°c starting from 10 AM until 21 PM. Which means that it is necessary to start the rotation from 10 AM.

Following graphs shows the average temperatures for the month of August.

(a) (b)

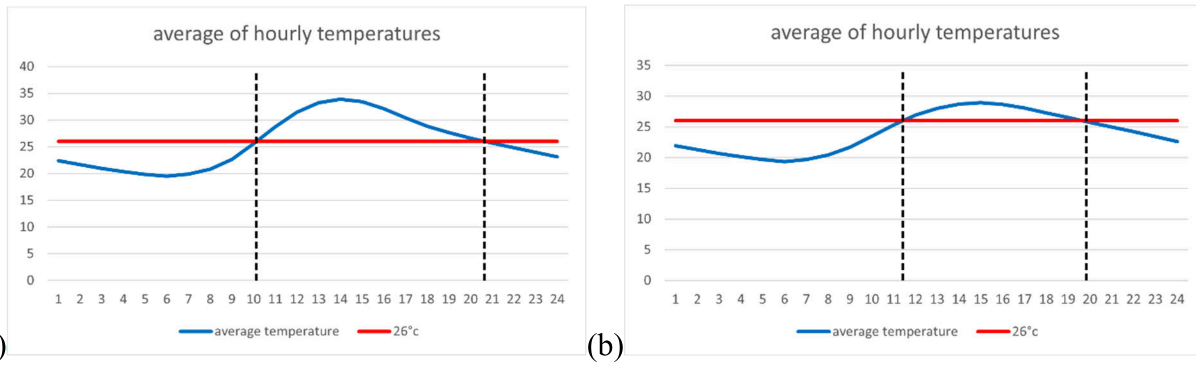


Figure 63:average of hourly temperature for the month of August. (a) without shading (b) with shading 0° of rotation

Figure 63 shows that not only adding the shading system decreases the internal temperatures, but also the time interval which we have temperatures higher than 26°c have been decreases to 11 AM until 20 PM. Consequently, for the month of August it is better to start the rotation from 11 AM.

Following graphs show the average temperatures for the month of September up to the day of 21th.

(a) (b)

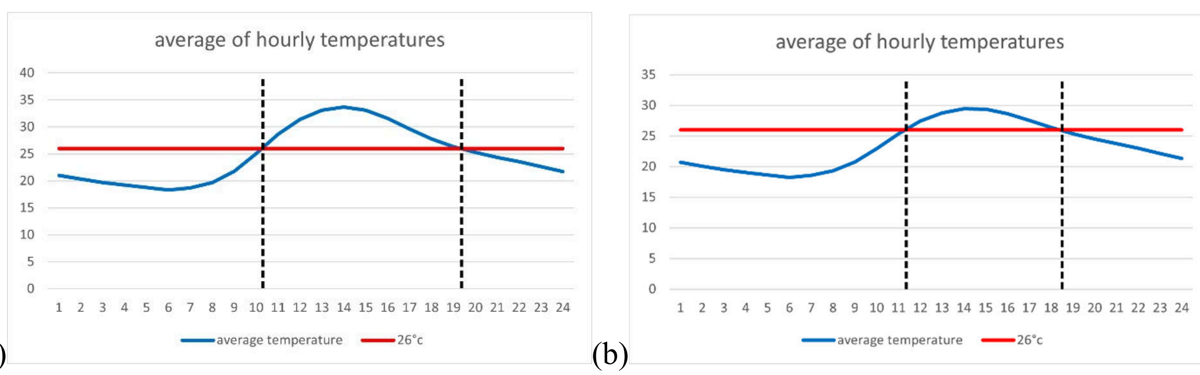


Figure 64: average of hourly temperature for the month of September. (a) without shading (b) with shading 0° of rotation

The same decrease of temperature happens also for the month of September. As in the September we normally have a lower temperature the time interval which temperature exceeds 26°c decreases to 11 AM until 19 PM. So, it is required to start the rotation of panels from 11 AM.

After finding the hours that are necessary to shade the façade, it is crucial to know what the exact rotational angle in each single hour will be. As the shading device is made of photovoltaics the rotational angle should also be compatible with the sun incident angle to produce enough electricity and use the total efficiency of the photovoltaic panels.

The best position for the photovoltaic panels is perpendicular to the sun incident angle. With having the sun altitude for every hours of the year it is easy to calculate the exact position for the photovoltaic panels based on the following formula;

$$\text{Rotational angle} = 90 - \text{sun altitude}$$

It is also important to check if the calculated rotational angle is effective in terms of reducing internal temperatures. Based on the graphs of average temperatures which was shown before the rotation will starts at specific hour for each day. It starts the rotation in the morning from 10 AM or 11 AM and reaches the highest rotational angle when the sun has the highest altitude angle so we have higher temperatures in this case and we need more shading as a result, this happens usually at 13 PM or 14 PM. After that when the sun goes down the device is coming back to its original position. So the device will rotate once a day in the morning and goes up to 50° and return back to its original position in the afternoon. We set the end of the cycle at 7 PM when there is no need for the façade to be shaded. Following table shows the rotational angles for the photovoltaic panels for each hours of the summer. The hours which are not shown in these tables are the hours which the rotational angle is considered equal to zero.

June										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
21	10	24.628934	24.064289	23.767418	23.411852	22.920349	23.833274	53.005391	36.994609	28
	11	26.977477	26.224593	25.832826	25.357231	24.674421	25.149253	61.695339	28.304661	28.304661
	12	28.86176	28.108498	27.757025	27.235121	26.455087	26.292578	67.156464	22.843536	50
	13	30.101037	29.423525	29.127555	28.630633	27.921087	27.216882	66.820905	23.179095	50
	14	31.000841	30.324079	30.04977	29.579415	28.911353	27.88736	60.89461	29.10539	50
	15	31.440805	30.802224	30.516574	30.104621	29.493816	28.273937	52.000316	37.999684	50
	16	31.333212	30.784724	30.507072	30.166906	29.645408	28.316643	41.911456	48.088544	50
	17	30.873464	30.438653	30.202511	29.910558	29.482041	28.092749	31.453447	58.546553	50
	18	30.29422	29.975703	29.7907	29.555852	29.217703	27.792554	21.066142	68.933858	50
	19	29.715708	29.486197	29.358215	29.186307	28.933982	27.487413	11.067303	78.932697	50
22	10	26.43315	25.972394	25.719788	25.421258	25.019363	24.882344	52.968545	37.031455	37.031455
	11	27.68734	27.132995	26.845379	26.496419	26.014175	25.877009	61.665295	28.334705	50
	12	28.70034	28.098447	27.824153	27.426104	26.899146	26.764409	67.142322	22.857678	50
	13	29.413501	28.833093	28.578197	28.163847	27.624997	27.498836	66.829748	23.170252	50
	14	30.007025	29.39008	29.132043	28.715988	28.170956	28.049405	60.919347	29.080653	50
	15	30.27455	29.668679	29.387544	29.004891	28.483345	28.374505	52.032077	37.967923	50
	16	30.105936	29.564763	29.28356	28.954454	28.496495	28.408722	41.945735	48.054265	50
	17	29.575084	29.132315	28.88875	28.602311	28.225096	28.159184	31.487998	58.512002	50
	18	28.886008	28.550928	28.356923	28.125133	27.827508	27.784035	21.099537	68.900463	50
	19	28.115648	27.873368	27.738762	27.571439	27.356834	27.338196	11.098325	78.901675	50
23	10	26.440354	25.899503	25.596758	25.242726	24.81525	24.752069	52.92688	37.07312	37.07312
	11	27.694728	27.068809	26.73121	26.327762	25.826301	25.736762	61.629567	28.370433	45
	12	28.691898	28.016293	27.679933	27.231098	26.68832	26.581864	67.121423	22.878577	50
	13	29.406818	28.73405	28.403365	27.935048	27.378014	27.264302	66.831795	23.168205	50
	14	29.907828	29.202197	28.866882	28.396589	27.837082	27.718689	60.938245	29.061755	50
	15	29.974344	29.292808	28.95004	28.514722	27.984134	27.872639	52.058766	37.941234	50
	16	29.562298	28.947103	28.614798	28.230989	27.76001	27.6635	41.975306	48.024694	50
	17	28.816794	28.289395	27.995683	27.657079	27.259652	27.18062	31.517913	58.482087	50
	18	27.994132	27.569206	27.326017	27.043157	26.718589	26.657579	21.128166	68.871834	50
	19	27.172342	26.842744	26.658131	26.439998	26.191956	26.151662	11.12431	78.87569	50
24	10	25.51904	24.882846	24.523161	24.113163	23.705768	23.628725	52.880468	37.119532	28
	11	26.571876	25.856684	25.453568	24.984428	24.495667	24.389655	61.588219	28.411781	28.411781
	12	27.435086	26.673167	26.255279	25.751061	25.221148	25.100134	67.093801	22.906199	35
	13	28.106789	27.335124	26.91324	26.395232	25.852178	25.723347	66.827023	23.172977	45
	14	28.581904	27.802935	27.38347	26.870272	26.33174	26.201716	60.951244	29.048756	50
	15	28.740256	27.997614	27.592416	27.110784	26.603024	26.480757	52.080316	37.919684	50
	16	28.617674	27.930414	27.54714	27.10779	26.64825	26.538481	42.000101	47.999899	50
	17	28.215748	27.610802	27.271264	26.883378	26.487719	26.39484	31.543125	58.456875	50
	18	27.669929	27.169537	26.887052	26.562657	26.234501	26.15895	21.151969	68.848031	50
	19	27.047797	26.651356	26.429316	26.173306	25.916088	25.859589	11.145205	78.854795	45
25	10	23.871464	23.345828	23.07029	22.774125	22.492059	22.428286	52.82938	37.17062	22
	11	24.675396	24.037377	23.692563	23.318248	22.977356	22.900246	61.541315	28.458685	22
	12	25.353173	24.645874	24.256941	23.817522	23.40349	23.307668	67.059493	22.940507	22.940507
	13	25.847514	25.122872	24.71303	24.245498	23.788341	23.674828	66.815411	23.184589	23.184589
	14	26.206281	25.484476	25.07426	24.598212	24.135128	24.017152	60.95829	29.04171	29.04171
	15	26.392104	25.696046	25.298698	24.838048	24.388011	24.273319	52.096663	37.903337	37.903337
	16	26.376966	25.736272	25.368471	24.942872	24.526305	24.420957	42.020055	47.979945	47.979945
	17	26.164622	25.604536	25.28325	24.907645	24.541709	24.451075	31.563572	58.436428	45
	18	25.849756	25.382038	25.111939	24.791339	24.480095	24.404229	21.170886	68.829114	35
	19	25.43407	25.07101	24.858857	24.601347	24.350564	24.291348	11.160955	78.839045	25
26	10	24.218436	23.670488	23.377756	23.04098	22.619315	22.161591	52.77369	37.22631	28
	11	25.94558	25.293072	24.947767	24.52865	23.976061	23.638325	61.488923	28.511077	28.511077
	12	27.305415	26.615722	26.286041	25.819537	25.215105	24.931	67.018539	22.981461	35
	13	28.242856	27.588871	27.286812	26.816599	26.21213	25.981515	66.796942	23.203058	50
	14	28.968137	28.296578	28.002646	27.54261	26.947673	26.736123	60.959328	29.040672	50
	15	29.286848	28.646289	28.342273	27.926572	27.368256	27.167207	52.10774	37.89226	50
	16	29.157967	28.584084	28.282764	27.924392	27.434253	27.252583	42.035103	47.964897	50
	17	28.720181	28.228676	27.956292	27.635211	27.221279	27.058013	31.57919	58.42081	50
	18	28.11071	27.722837	27.498846	27.232329	26.899332	26.761209	21.184861	68.815139	50
	19	27.410112	27.127315	26.968936	26.773192	26.527601	26.443384	11.171509	78.828491	50
27	10	25.406679	24.787442	24.440772	24.03938	23.581742	23.181115	52.713467	37.286533	28
	11	26.841119	26.153675	25.773387	25.318863	24.772094	24.568878	61.431107	28.568893	28.568893
	12	27.939493	27.218293	26.846323	26.356042	25.770717	25.958858	66.97098	23.02902	45
	13	28.738761	28.035796	27.678783	27.178908	26.588061	26.219428	66.771602	23.228398	50
	14	29.382937	28.652349	28.293578	27.794591	27.20389	27.119187	60.954306	29.045694	50
	15	29.720868	28.999624	28.628069	28.157223	27.592738	27.404597	52.113486	37.886514	50
	16	29.65516	28.98807	28.624768	28.203163	27.697812	27.549238	42.04518	47.95482	50
	17	29.278839	28.701816	28.377986	28.00423	27.57731	27.420845	31.58992	58.41008	50
	18	28.706735	28.245966	27.982527	27.676618	27.334657	27.244192	21.193837	68.806163	50
	19	28.667195	28.285512	28.069055	27.815502	27.534654	27.5053	11.176819	78.823181	50
28	10	26.619841	25.807089	25.364362	24.863725	24.337573	24.536096	52.648783	37.351217	35
	11	28.115779	27.141915	26.587901	25.956203	25.27441	25.227221	61.367933	28.632067	35
	12	29.281507	28.365457	27.83952	27.137986	26.330734	25.895226	66.91686	23.08314	50
	13	30.1334	29.279025	28.80645	28.165904	27.404277	26.510431	66.73938	23.26062	50
	14	30.718327	29.871329	29.421038	28.818047	28.115931	26.945227	60.943173	29.056827	50
	15	30.873776	30.061839	29.622268	29.068986	28.418562	27.09258	52.113837	37.886163	50
	16	30.611993	29.861659	29.440043	28.940027	28.352155	26.944509	42.050224	47.949776	50
	17	30.061332	29.399978	29.021144	28.572459	28.055497	26.620548	31.595702	58.404298	50
	18	29.467765	28.915054	28.59332	28.209007	27.767991	26.324576	21.19776	68.80224	50
	19	28.844207	28.415526	28.167335	27.862951	27.51158	26.069927	11.176838	78.823162	50
29	10	25.847775	25.381638	25.12297	24.809125	24.389194	24.151755	52.579709	37.420291	28
	11	27.172267	26.62089	26.333634	25.977549	25.476609	25.251593	61.299469	28.700531	28.700531
	12	28.228225	27.627918	27.35618	26.954258	26.413933	26.203533	66.856226	23.143774	50
	13	28.952332	28.372246	28.119855	27.703313	27.155508	26.963551	66.700271	23.299729	50
	14	29.530482	28.914159	28.660169	28.243147	27.691438	27.510695	60.925881	29.074119	50
	15	29.726171	29.137992	28.870007	28.495668	27.973793	27.813024	52.108734	37.891266	50
	16	29.550626	29.020629	28.7475	28.424354	27.962724	27.825325	42.050174	47.949826	50
	17	29.048594	28.601179	28.354857	28.064858	27.67642	27.559918	31.596478	58.403522	50
	18	28.340105	28.002417	27.806175	27.569977	27.261284	27.168684	21.196578	68.803422	50
	19	27.560952	27.317892	27.183067	27.013043	26.789316	26.723558	11.171519	78.828481	50

June										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
30	10	25.237898	24.588788	24.230505	23.828751	23.420204	23.315683	52.506316	37.493684	28
	11	26.573454	25.848514	25.44395	24.975145	24.472752	24.34129	61.225781	28.774219	28.774219
	12	27.54104	26.799559	26.396412	25.896178	25.352296	25.207867	66.789128	23.210872	35
	13	28.206105	27.468255	27.067765	26.556143	25.999244	25.849368	66.654269	23.345731	45
	14	28.696452	27.929406	27.520753	27.005088	26.446202	26.294305	60.902385	29.097615	50
	15	28.853225	28.089811	27.676741	27.182745	26.649585	26.505881	52.098116	37.901884	50
	16	28.648789	27.93861	27.543763	27.091365	26.607255	26.477531	42.044969	47.955031	50
	17	28.191088	27.568815	27.218537	26.816952	26.398	26.286216	31.592192	58.407808	50
	18	27.595354	27.096137	26.812612	26.482979	26.138986	26.048738	21.190242	68.809758	50
	19	26.991669	26.618587	26.408268	26.157988	25.89586	25.828182	11.160822	78.839178	45

July										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
1	10	24.051647	23.440527	23.108731	22.740031	22.281658	22.164721	52.428671	37.571329	23
	11	25.672489	24.930111	24.533936	24.078429	23.506181	23.367997	61.146934	28.853066	23
	12	26.880375	26.121871	25.741778	25.248807	24.612047	24.452368	66.715614	23.284386	23.284386
	13	27.697015	27.010677	26.651118	26.1603	25.519515	25.361633	66.601375	23.398625	45
	14	28.382466	27.66196	27.300732	26.814152	26.183884	26.028572	60.87264	29.12736	50
	15	28.727636	28.003914	27.643072	27.189602	26.594961	26.446874	52.081927	37.918073	50
	16	28.600973	27.948493	27.598936	27.203409	26.675483	26.541719	42.034551	47.965449	50
	17	28.082074	27.531615	27.233579	26.882857	26.435074	26.318524	31.582789	58.417211	50
	18	27.299759	26.860941	26.622565	26.326419	25.964197	25.870309	21.178702	68.821298	45
	19	26.416792	26.074346	25.888033	25.660165	25.380221	25.30789	11.144704	78.855296	25
2	10	24.420217	23.724896	23.35017	22.944474	22.500868	22.381071	52.346845	37.653155	23
	11	25.903477	25.098935	24.658568	24.150904	23.589738	23.448765	61.062996	28.937004	23
	12	27.036022	26.197918	25.748538	25.200771	24.578333	24.414666	66.635738	23.364262	23.364262
	13	27.752504	26.97781	26.548103	26.002822	25.370545	25.205234	66.541594	23.458406	45
	14	28.210681	27.420217	26.994839	26.459507	25.839223	25.676284	60.836607	29.163393	45
	15	28.275872	27.481466	27.057837	26.546355	25.952945	25.796539	52.060112	37.939888	45
	16	27.886987	27.147716	26.736355	26.264752	25.714406	25.567981	42.018865	47.981135	47.981135
	17	27.224363	26.567965	26.201351	25.776031	25.299085	25.170596	31.568218	58.431782	35
	18	26.535723	25.993457	25.689779	25.326726	24.925649	24.816653	21.161912	68.838088	15
	19	25.868901	25.446268	25.209344	24.925483	24.607999	24.521281	11.123128	78.876872	0
3	10	24.193881	23.509713	23.13928	22.729529	22.285892	22.169022	52.260904	37.739096	23
	11	25.625666	24.818492	24.371157	23.857049	23.314981	23.18106	60.97403	29.02597	23
	12	26.580896	25.740486	25.283429	24.72637	24.099479	23.936545	66.549554	23.450446	23.450446
	13	27.063729	26.265481	25.818954	25.252735	24.607429	24.440989	66.474931	23.525069	23.525069
	14	27.459288	26.639248	26.191548	25.627181	24.974886	24.806342	60.794248	29.205752	35
	15	27.704995	26.896951	26.459345	25.925726	25.30352	25.137939	52.032616	37.967384	37.967384
	16	27.721611	26.983925	26.570124	26.089405	25.527374	25.375587	41.997855	48.002145	48.002145
	17	27.443345	26.803799	26.444044	26.01822	25.531973	25.400473	31.548428	58.451572	45
	18	26.977462	26.444176	26.142932	25.779263	25.372331	25.261567	21.13983	68.86017	35
	19	26.35911	25.949047	25.716983	25.435473	25.119017	25.032275	11.096058	78.903942	15
4	10	23.452319	22.824129	22.458355	22.060175	21.569575	21.441923	52.170916	37.829084	23
	11	25.176509	24.414908	23.999798	23.534755	22.966556	22.827672	60.880102	29.119898	23
	12	26.540913	25.753969	25.346564	24.827727	24.1662	23.999668	66.457118	23.542882	23.542882
	13	27.453477	26.737742	26.350807	25.830379	25.162272	24.996087	66.401399	23.598601	35
	14	28.111356	27.377862	26.999438	26.491358	25.835509	25.671759	60.745527	29.254473	45
	15	28.338977	27.597287	27.218101	26.742039	26.122638	25.966281	51.99939	38.00061	50
	16	27.998682	27.318002	26.944688	26.520075	25.959581	25.814778	41.971469	48.028531	48.028531
	17	27.310086	26.728349	26.40562	26.023782	25.543343	25.417049	31.523371	58.476629	45
	18	26.604819	26.129274	25.865022	25.538992	25.143654	25.039207	21.112412	68.887588	25
	19	25.984173	25.610587	25.401833	25.147685	24.83718	24.754216	11.063461	78.936539	0
5	10	22.865399	22.399904	22.130005	21.835975	21.401394	21.297725	52.076946	37.923054	23
	11	24.779344	24.168663	23.858255	23.505604	22.989806	22.875387	60.781276	29.218724	23
	12	26.363731	25.688082	25.374869	24.954754	24.349946	24.210155	66.358485	23.641515	23.641515
	13	27.464638	26.848932	26.543188	26.107014	25.485062	25.344236	66.321011	23.678989	45
	14	28.271767	27.633621	27.336609	26.911619	26.303236	26.165731	60.690414	29.309586	50
	15	28.660453	28.028788	27.737162	27.355719	26.79068	26.661874	51.960384	38.039616	50
	16	28.531556	27.982392	27.698438	27.381037	26.886942	26.770835	41.939658	48.060342	50
	17	28.022894	27.587902	27.359173	27.082241	26.671917	26.572279	31.493	58.507	50
	18	27.373367	27.052904	26.882023	26.651284	26.326938	26.248688	21.079621	68.920379	50
	19	26.746202	26.5094	26.38196	26.214463	25.973501	25.916181	11.025305	78.974695	45
6	10	23.332224	22.7727	22.452201	22.101121	21.639123	21.527513	51.979059	38.020941	25
	11	25.386837	24.717822	24.363892	23.95621	23.392346	23.259178	60.677616	29.322384	25
	12	26.9136	26.210279	25.86679	25.412758	24.791397	24.641465	66.253716	23.746284	25
	13	27.885531	27.242849	26.910727	26.449523	25.821582	25.672074	66.233786	23.766214	45
	14	28.583015	27.911852	27.583386	27.130354	26.516523	26.370686	60.62888	29.37112	50
	15	28.903834	28.245121	27.926361	27.516984	26.945213	26.808812	51.915554	38.084446	50
	16	28.807859	28.223144	27.912064	27.561813	27.056571	26.932844	41.902373	48.097627	50
	17	28.291937	27.821747	27.56863	27.264424	26.844598	26.739438	31.457272	58.542728	50
	18	27.644247	27.279801	27.0808	26.822788	26.485339	26.400724	21.041419	68.958581	50
	19	27.458191	27.145912	26.967235	26.75346	26.446608	26.393841	10.981564	79.018436	50
7	10	24.140554	23.38544	22.967995	22.509161	21.982943	21.852397	51.877318	38.122682	29
	11	26.327455	25.331891	24.799368	24.196185	23.487429	23.309851	60.569184	29.430816	29.430816
	12	28.116784	27.051691	26.459625	25.736358	24.885809	24.672073	66.142868	23.857132	35
	13	29.202231	28.289803	27.763445	27.022768	26.07464	25.837847	66.139745	23.860255	50
	14	29.97783	29.079305	28.580257	27.914112	26.993491	26.737732	60.560899	29.439101	50
	15	30.322823	29.459677	28.987649	28.384477	27.592653	27.366899	51.864854	38.135146	50
	16	30.174841	29.399037	28.957296	28.427986	27.742826	27.553413	41.859569	48.140431	50
	17	29.708073	29.026254	28.635182	28.154831	27.565613	27.406153	31.416147	58.583853	50
	18	29.050489	28.474124	28.140147	27.719608	27.222024	27.076536	20.997772	69.002228	50
	19	28.261527	27.805067	27.533149	27.176963	26.711315	26.57501	10.93221	79.06779	50
8	10	24.893584	24.205957	23.81305	23.390984	22.945811	22.829304	51.771784	38.228216	29
	11	26.439197	25.67118	25.241573	24.749271	24.188461	24.046005	60.456042	29.543958	29.543958
	12	27.633155	26.851406	26.4297	25.906698	25.301729	25.143799	66.026002	23.973998	35
	13	28.419481	27.69026	27.284894	26.764999	26.154631	25.996322	66.038914	23.961086	50
	14	29.064589	28.306337	27.897949	27.380318	26.776466	26.619395	60.486452	29.513548	50
	15	29.369056	28.605176	28.199231	27.70918	27.13824	26.989979	51.808245	38.191755	50
	16	29.307976	28.599739	28.206917	27.763749	27.24678	27.110962	41.811203	48.188797	50
	17	28.914565	28.296586	27.952321	27.557123	27.113641	26.99573	31.369585	58.630415	50
	18	28.279134	27.789128	27.515142	27.188772	26.831126	26.736595	20.948649	69.051351	50
	19	27.565442	27.201433	26.997719	26.754605	26.486561	26.416783	10.877221	79.122779	50
9	10	25.693876	25.108857	24.778652	24.410386	23.984396	23.87705	51.662519	38.337481	35
	11	27.097398	26.420993	26.054792	25.629539	25.112808	24.982338	60.33825	29.66175	35
	12	28.176519	27.452708	27.082256	26.616408	26.052299	25.907767	65.90318	24.09682	50
	13	28.89026	28.204497	27.837082	27.357962	26.777921	26.63216	65.93132	24.06868	50
	14	29.437301	28.726881	28.360315	27.883328	27.303478	27.158637	60.405518	29.594482	50
	15	29.716706	29.007168	28.64359	28.195496	27.642388	27.503358	51.745689	38.254311	50
	16	29.633515	28.980988	28.623736	28.22284	27.723966	27.595967	41.757234	48.242766	50
	17	29.133298	28.585189	28.284367	27.934318	27.516827	27.409064	31.317549	58.682451	50
	18	28.475605	28.040196	27.799578	27.507469	27.172543	27.085858	20.894019	69.105981	50
	19	27.744912	27.413923	27.230958	27.011876	26.760913	26.69642	10.816577	79.183423	50

		July								
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
10	10	25.481892	24.948223	24.641481	24.305644	23.892288	23.791359	51.549582	38.450418	35
	11	27.016317	26.375675	26.0307	25.632542	25.118421	24.99239	60.215868	29.784132	35
	12	28.186382	27.495584	27.150828	26.710578	26.150236	26.010413	65.774463	24.225537	50
	13	28.903384	28.272648	27.941207	27.496232	26.929631	26.791899	65.816997	24.183003	50
	14	29.43894	28.78275	28.454263	28.013578	27.451096	27.315384	60.318085	29.681915	50
	15	29.686395	29.014239	28.678963	28.261904	27.721278	27.588899	51.677152	38.322848	50
	16	29.470419	28.857107	28.526466	28.158631	27.671876	27.550149	41.697626	48.302374	50
	17	28.878362	28.365236	28.085223	27.757759	27.34457	27.239008	31.260008	58.739992	50
	18	28.063732	27.662163	27.441721	27.168535	26.83932	26.755696	20.833859	69.166141	50
	19	27.186749	26.881494	26.713414	26.509155	26.262821	26.200578	10.750261	79.249739	50
11	10	25.077291	24.470313	24.133888	23.760705	23.338225	23.233898	51.433029	38.566971	29
	11	26.646713	25.947807	25.569116	25.128375	24.594576	24.460581	60.088955	29.911045	29.911045
	12	27.834916	27.101331	26.723474	26.245727	25.666393	25.51896	65.639914	24.360086	45
	13	28.655487	27.961443	27.587899	27.101916	26.513844	26.365548	65.695978	24.304022	50
	14	29.285564	28.564358	28.189863	27.706788	27.124028	26.977501	60.224142	29.775858	50
	15	29.593052	28.873891	28.502755	28.049141	27.495693	27.355396	51.602601	38.397399	50
	16	29.493575	28.836392	28.476548	28.072469	27.575005	27.446711	41.632343	48.367657	50
	17	29.044164	28.476882	28.164953	27.805269	27.382916	27.272723	31.19693	58.80307	50
	18	28.395679	27.94638	27.697765	27.398112	27.058126	26.970174	20.768142	69.231858	50
	19	27.667052	27.336824	27.153877	26.933818	26.682249	26.617707	10.678257	79.321743	50
12	10	25.966001	25.362526	25.012219	24.618825	24.185173	24.073881	51.312918	38.687082	38.687082
	11	27.219121	26.528018	26.145464	25.702728	25.192038	25.061279	59.957569	30.042431	35
	12	28.307416	27.571499	27.182279	26.701754	26.143728	25.9983	65.499597	24.500403	50
	13	29.08198	28.390689	28.011102	27.524191	26.955128	26.809772	65.568304	24.431696	50
	14	29.726833	29.010073	28.629647	28.14403	27.573618	27.429316	60.123681	29.876319	50
	15	30.039968	29.312257	28.930287	28.466258	27.922037	27.783019	51.522011	38.477989	50
	16	29.890979	29.229011	28.864816	28.452237	27.96809	27.843699	41.561354	48.438646	50
	17	29.407939	28.851753	28.544309	28.185986	27.779499	27.67416	31.128287	58.871713	50
	18	28.749282	28.311002	28.067907	27.7738	27.448963	27.365218	20.69685	69.30315	50
	19	28.043833	27.71316	27.529911	27.309971	27.067358	27.005387	10.600554	79.399446	50
13	10	25.983487	25.368905	25.015677	24.623004	24.185603	24.071774	51.189303	38.810697	38.810697
	11	27.418325	26.705397	26.311641	25.861311	25.345	25.209487	59.821764	30.178236	35
	12	28.475553	27.736857	27.346972	26.867538	26.313632	26.167778	65.353574	24.646426	50
	13	29.143934	28.45862	28.083212	27.603421	27.044785	26.901073	65.434014	24.565986	50
	14	29.689237	28.974246	28.594524	28.113814	27.555903	27.41261	60.016702	29.983298	50
	15	29.915356	29.200118	28.823748	28.369543	27.840037	27.703928	51.435355	38.564645	50
	16	29.784426	29.125499	28.763433	28.356095	27.881686	27.758682	41.484631	48.515369	50
	17	29.367401	28.793649	28.476757	28.113958	27.708388	27.602108	31.054055	58.945945	50
	18	28.711293	28.258956	28.008056	27.709555	27.384176	27.299448	20.619965	69.380035	50
	19	28.549085	28.192579	27.992649	27.754149	27.492786	27.425599	10.517143	79.482857	50
14	10	26.181163	25.456692	25.047963	24.599439	24.086549	23.957846	51.062237	38.937763	38.937763
	11	28.288844	27.466943	26.993251	26.434526	25.754593	25.581047	59.681596	30.318404	45
	12	29.791009	28.951287	28.501211	27.935935	27.237333	27.053997	65.20191	24.79809	50
	13	30.746626	29.981326	29.557316	29.003578	28.327238	28.153531	65.293155	24.706845	50
	14	31.435582	30.657936	30.244742	29.709409	29.052712	28.88492	59.903204	30.096796	50
	15	31.749843	30.982728	30.579881	30.08448	29.472882	29.314356	51.342612	38.657388	50
	16	31.610738	30.911117	30.523797	30.084876	29.540401	29.397364	41.402147	48.597853	50
	17	31.070976	30.477022	30.146735	29.761526	29.301478	29.179694	30.974211	59.025789	50
	18	30.362724	29.887994	29.621994	29.298781	28.924282	28.824892	20.537471	69.462529	50
	19	29.642403	29.264836	29.052572	28.79964	28.507892	28.429864	10.428018	79.571982	50
15	10	26.319227	25.710585	25.36486	24.974288	24.565073	24.457555	50.931771	39.068229	39.068229
	11	27.527712	26.827223	26.439799	25.997545	25.525849	25.401445	59.53712	30.46288	35
	12	28.511209	27.768868	27.366823	26.890421	26.380918	26.244708	65.044668	24.955332	50
	13	29.160859	28.449887	28.055031	27.575332	27.059148	26.922851	65.145774	24.854226	50
	14	29.670423	28.947266	28.553757	28.077672	27.56513	27.429971	59.783192	30.216808	50
	15	29.93721	29.203951	28.808415	28.348015	27.856307	27.726338	51.243766	38.756234	50
	16	29.838244	29.158169	28.781985	28.362075	27.91655	27.798236	41.313881	48.686119	50
	17	29.41217	28.834302	28.513372	28.148949	27.7703	27.670161	30.888737	59.111263	50
	18	28.823326	28.353054	28.09223	27.790411	27.482523	27.401496	20.449356	69.550644	50
	19	28.163959	27.802305	27.601717	27.370353	27.135214	27.073478	10.333176	79.666824	50
16	10	26.907284	26.373854	26.070526	25.738213	25.368118	25.272362	50.797955	39.202045	39.202045
	11	27.9694	27.340389	26.999562	26.612302	26.167052	26.053336	59.388386	30.611614	50
	12	28.780739	28.099568	27.745519	27.312012	26.814162	26.685559	64.881914	25.118086	50
	13	29.258072	28.598239	28.240042	27.786225	27.262472	27.129104	64.991922	25.008078	50
	14	29.575162	28.87709	28.509586	28.04649	27.511094	27.374743	59.656677	30.343323	50
	15	29.595173	28.875093	28.498409	28.048658	27.527056	27.392911	51.138801	38.861199	50
	16	29.153434	28.48194	28.114018	27.706012	27.231782	27.108722	41.219815	48.780185	50
	17	28.406256	27.827267	27.507625	27.142544	26.733361	26.62604	30.797618	59.202382	50
	18	27.524337	27.04741	26.782641	26.469899	26.130126	26.040793	20.355613	69.644387	50
	19	26.611901	26.238756	26.031305	25.789697	25.52889	25.460639	10.232617	79.767383	50
17	10	24.738647	24.239326	23.949721	23.64132	23.255292	23.161812	50.660837	39.339163	30
	11	26.351718	25.743227	25.41763	25.044429	24.542904	24.422111	59.235447	30.764553	30.764553
	12	27.634172	26.980722	26.662108	26.245944	25.693535	25.559233	64.713712	25.286288	45
	13	28.529954	27.925274	27.612886	27.185384	26.62151	26.48715	64.831651	25.168349	50
	14	29.245514	28.599573	28.283342	27.854779	27.291807	27.158345	59.523671	30.476329	50
	15	29.553497	28.912269	28.600906	28.208704	27.677621	27.550765	51.027709	38.972291	50
	16	29.382393	28.820478	28.52109	28.188135	27.719856	27.605365	41.119931	48.880069	50
	17	28.859687	28.399066	28.150954	27.858662	27.469669	27.372993	30.700841	59.299159	50
	18	28.198363	27.845559	27.652723	27.407832	27.09902	27.021953	20.256236	69.743764	50
	19	27.490964	27.236158	27.096776	26.922239	26.698886	26.644072	10.126344	79.873656	50
18	10	24.912416	24.516192	24.287988	24.045369	23.697514	23.615121	50.520463	39.479537	30
	11	26.526671	26.003207	25.735374	25.427311	24.969724	24.865124	59.078353	30.921647	30.921647
	12	27.789348	27.203789	26.93795	26.578762	26.068321	25.950286	64.540127	25.459873	50
	13	28.65613	28.110261	27.842949	27.463024	26.932936	26.813778	64.665018	25.334982	50
	14	29.344806	28.74953	28.475689	28.08983	27.5538	27.434094	59.384192	30.615808	50
	15	29.665964	29.060275	28.782108	28.427473	27.917247	27.801567	50.910483	39.089517	50
	16	29.47719	28.950671	28.678827	28.383325	27.935697	27.83082	41.01422	48.98578	50
	17	28.926888	28.511141	28.2929	28.035132	27.667136	27.578458	30.598396	59.401604	50
	18	28.256225	27.942656	27.775837	27.558746	27.269413	27.199814	20.151221	69.848779	50
	19	27.595502	27.361216	27.23539	27.078222	26.866999	26.816604	10.014363	79.985637	50

						July				
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
19	10	25.083968	24.681808	24.452197	24.206972	23.859388	23.778552	50.376879	39.623121	31
	11	26.662279	26.136989	25.869573	25.56217	25.111311	25.008616	58.917151	31.082849	31.082849
	12	27.894351	27.306527	27.040232	26.682098	26.177337	26.060588	64.361223	25.638777	50
	13	28.71412	28.17656	27.914751	27.539275	27.015136	26.897845	64.492082	25.507918	50
	14	29.382322	28.794021	28.525221	28.143725	27.612351	27.494274	59.23826	30.76174	50
	15	29.679064	29.084789	28.813129	28.464454	27.958476	27.844721	50.78712	39.21288	50
	16	29.474211	28.959154	28.693971	28.404699	27.9626	27.859808	40.902671	49.097329	50
	17	28.911374	28.506476	28.294251	28.04246	27.680601	27.594184	30.490279	59.509721	50
	18	28.1916	27.902902	27.749544	27.544611	27.265493	27.199452	20.040571	69.959429	50
	19	27.530233	27.318011	27.204491	27.058105	26.855871	26.808289	9.896684	80.103316	50
20	10	24.357756	23.792951	23.479882	23.119379	22.760478	22.666207	50.230127	39.769873	25
	11	25.434359	24.768376	24.395078	23.965738	23.544018	23.436523	58.751891	31.248109	25
	12	26.441452	25.724503	25.321357	24.849542	24.368691	24.238245	64.177065	25.822935	25.822935
	13	27.226643	26.520655	26.11816	25.638726	25.147619	25.0146	64.312904	25.687096	35
	14	27.833291	27.123376	26.723922	26.252857	25.767781	25.6354	59.085901	30.914099	45
	15	28.122287	27.420151	27.030131	26.581139	26.125237	26.000563	50.657622	39.342378	50
	16	28.116671	27.470298	27.108	26.699762	26.289268	26.177364	40.78528	49.21472	50
	17	27.880006	27.314095	26.996798	26.638457	26.284092	26.188192	30.376486	59.623514	50
	18	27.441467	26.976612	26.716575	26.420784	26.130151	26.051938	19.924287	70.075713	50
	19	27.348332	26.964476	26.741439	26.488504	26.221902	26.154423	9.773317	80.226683	50
21	10	23.249418	22.730565	22.450066	22.140083	21.852516	21.779858	50.080248	39.919752	25
	11	24.67183	23.996805	23.635555	23.239242	22.870179	22.775209	58.582616	31.417384	25
	12	25.992377	25.180637	24.748059	24.273063	23.83077	23.715601	63.987717	26.012283	25
	13	27.059978	26.22453	25.742447	25.200624	24.696558	24.564262	64.127547	25.872453	25.872453
	14	27.724314	26.95428	26.494752	25.956322	25.419059	25.276426	58.927144	31.072856	31.072856
	15	28.082917	27.38077	26.966171	26.469888	25.977964	25.837706	50.521995	39.478005	45
	16	28.167913	27.52605	27.152301	26.708548	26.26387	26.145434	40.662046	49.337954	50
	17	28.045657	27.480044	27.153973	26.768274	26.37296	26.270239	30.257018	59.742982	50
	18	27.754584	27.286639	27.017808	26.697248	26.361548	26.275444	19.802379	70.197621	50
	19	27.324426	26.971707	26.767925	26.51737	26.251253	26.185453	9.64428	80.35572	50
22	10	24.590017	24.025095	23.707015	23.367009	22.980533	22.884601	49.927284	40.072716	26
	11	25.853589	25.157438	24.775934	24.339535	23.812765	23.683356	58.409374	31.590626	26
	12	26.764207	26.011864	25.622965	25.12864	24.529955	24.379014	63.793244	26.206756	26.206756
	13	27.246158	26.535085	26.1494	25.64044	25.018006	24.862244	63.936077	26.063923	31
	14	27.630057	26.884442	26.495822	25.985888	25.360462	25.204101	58.762022	31.237978	31.237978
	15	27.806048	27.055126	26.667941	26.185358	25.58443	25.433404	50.380247	39.619753	45
	16	27.686242	26.997122	26.617213	26.18621	25.637679	25.49717	40.532971	49.467029	45
	17	27.195136	26.60289	26.272908	25.887716	25.420594	25.299032	30.13188	59.86812	35
	18	26.403752	25.934687	25.671977	25.351236	24.973517	24.874648	19.674856	70.325144	15
	19	25.547915	25.186711	24.983183	24.737657	24.445634	24.368113	9.509589	80.490411	0
23	10	23.0282	22.368846	21.983765	21.550028	21.089226	20.97145	49.771271	40.228729	26
	11	24.823181	24.021927	23.583866	23.093225	22.550016	22.40728	58.232207	31.767793	26
	12	26.302714	25.451513	24.99282	24.426357	23.781168	23.615964	63.593711	26.406289	26.406289
	13	27.333848	26.533596	26.084294	25.51074	24.843703	24.669374	63.738561	26.261439	35
	14	28.083913	27.286287	26.854597	26.300822	25.645121	25.475136	58.590572	31.409428	45
	15	28.463968	27.692168	27.280809	26.77333	26.16408	26.004534	50.232392	39.767608	50
	16	28.450087	27.739197	27.344308	26.892812	26.353664	26.211316	40.398062	49.601938	50
	17	28.108748	27.492153	27.146966	26.745631	26.28602	26.164368	30.001079	59.998921	50
	18	27.519408	27.020973	26.740536	26.404101	26.02974	25.930566	19.541731	70.458269	50
	19	26.835451	26.457076	26.243682	25.988484	25.702625	25.626941	9.369266	80.630734	35
24	10	24.302191	23.671783	23.328335	22.957824	22.550607	22.440041	49.612247	40.387753	26
	11	25.851392	25.100236	24.687017	24.21537	23.682788	23.549433	58.051159	31.948841	26
	12	27.097545	26.307298	25.885357	25.365052	24.763005	24.604983	63.389181	26.610819	26.610819
	13	27.908694	27.167331	26.757821	26.234184	25.618989	25.459167	63.535069	26.464931	45
	14	28.525402	27.773526	27.371597	26.858523	26.25424	26.097302	58.412834	31.587166	50
	15	28.84084	28.090014	27.693405	27.210911	26.640736	26.49277	50.078448	39.921552	50
	16	28.763557	28.070956	27.688421	27.2556	26.745384	26.611876	40.257327	49.742673	50
	17	28.36247	27.768207	27.437933	27.055533	26.621716	26.508254	29.864626	60.135374	50
	18	27.723704	27.254329	26.992171	26.676484	26.327096	26.235977	19.403021	70.596979	50
	19	27.018769	26.670877	26.476343	26.241757	25.980118	25.91228	9.223336	80.776664	45
25	10	23.844904	23.443419	23.21978	22.982903	22.648802	22.567621	49.450246	40.549754	26
	11	25.5282	24.961824	24.672031	24.343667	23.874106	23.767712	57.86627	32.13373	26
	12	26.883851	26.24404	25.947293	25.556216	25.013611	24.886453	63.17972	26.82028	26.82028
	13	27.779706	27.188746	26.895774	26.487485	25.923992	25.794632	63.325674	26.674326	45
	14	28.473098	27.844133	27.550598	27.14254	26.580217	26.452316	58.228853	31.771147	50
	15	28.804646	28.178882	27.888764	27.519087	26.989336	26.867778	49.918435	40.081565	50
	16	28.64889	28.113622	27.836789	27.532763	27.070476	26.961978	40.110781	49.889219	50
	17	28.132401	27.714123	27.493891	27.230381	26.852084	26.762032	29.722537	60.277463	50
	18	27.413962	27.118526	26.96082	26.747282	26.455555	26.386624	19.258747	70.741253	50
	19	26.728746	26.516135	26.401986	26.25084	26.038501	25.988666	9.071826	80.928174	50
26	10	24.106417	23.668592	23.424204	23.164142	22.810705	22.727568	49.285303	40.714697	32
	11	25.80371	25.218258	24.914217	24.566659	24.078733	23.966509	57.677582	32.322418	32.322418
	12	27.141068	26.499587	26.197001	25.796189	25.245811	25.116031	62.96539	27.03461	35
	13	28.029573	27.445111	27.152029	26.741212	26.178962	26.049441	63.110447	26.889553	50
	14	28.769713	28.136984	27.837623	27.423075	26.860047	26.73097	58.038677	31.961323	50
	15	29.08964	28.465261	28.171614	27.795318	27.264933	27.141992	49.752379	40.247621	50
	16	28.947239	28.397854	28.110237	27.791756	27.324204	27.212574	39.95844	50.04156	50
	17	28.431861	27.979672	27.738818	27.454599	27.065483	26.970948	29.574828	60.425172	50
	18	27.700867	27.356201	27.16963	26.930554	26.622397	26.547382	19.108931	70.891069	50
	19	26.891498	26.649492	26.517311	26.349537	26.127596	26.074131	8.914767	81.085233	50
27	10	24.528056	24.066063	23.797919	23.503458	23.105794	23.007142	49.11745	40.88255	32
	11	26.218923	25.636208	25.329528	24.974354	24.473276	24.353896	57.485135	32.514865	32.514865
	12	27.554125	26.915202	26.612748	26.211993	25.662613	25.531387	62.746255	27.253745	45
	13	28.483993	27.892586	27.595003	27.181894	26.622544	26.492623	62.889465	27.110535	50
	14	29.182826	28.553852	28.255458	27.843858	27.28775	27.160165	57.842358	32.157642	50
	15	29.459048	28.837875	28.544769	28.172438	27.651288	27.530153	49.58031	40.41969	50
	16	29.305056	28.745465	28.451586	28.131275	27.670355	27.559232	39.800325	50.199675	50
	17	28.776491	28.313807	28.066533	27.78101	27.398774	27.304855	29.421522	60.578478	50
	18	28.012892	27.675925	27.493374	27.260908	26.964055	26.891909	18.953601	71.046399	50
	19	27.794957	27.523904	27.379674	27.191798	26.945938	26.885601	8.752193	81.247807	50

July										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
28	10	25.210463	24.569102	24.210594	23.821519	23.353504	23.236091	48.946716	41.053284	35
	11	27.446138	26.600201	26.126975	25.59411	24.932723	24.772981	57.288966	32.711034	35
	12	29.118448	28.281116	27.839615	27.275697	26.525862	26.334098	62.52238	27.47762	50
	13	30.19798	29.451662	29.043973	28.504243	27.802703	27.62445	62.662804	27.337196	50
	14	30.988266	30.23651	29.847153	29.329987	28.660738	28.493906	57.63995	32.36005	50
	15	31.359028	30.630959	30.260134	29.7954	29.178941	29.023891	49.402259	40.597741	50
	16	31.255872	30.609589	30.257455	29.858686	29.319927	29.182	39.636461	50.363539	50
	17	30.830438	30.281796	29.977956	29.621759	29.167878	29.050652	29.262644	60.737356	50
	18	30.159975	29.729173	29.488693	29.190465	28.825808	28.730933	18.792786	71.207214	50
	19	29.454467	29.131333	28.950268	28.728107	28.451477	28.379602	8.584139	81.415861	50
29	10	26.091588	25.538499	25.220414	24.86702	24.456973	24.357147	48.773133	41.226867	41.226867
	11	27.556996	26.884806	26.519247	26.102643	25.606588	25.482859	57.089114	32.910886	45
	12	28.659656	27.938509	27.56704	27.110304	26.570143	26.432091	62.293828	27.706172	50
	13	29.399667	28.716048	28.348045	27.879871	27.326392	27.187209	62.430543	27.569457	50
	14	29.969949	29.259777	28.891331	28.42499	27.872979	27.734522	57.431513	32.568487	50
	15	30.233349	29.531169	29.16977	28.734659	28.211922	28.080078	49.218265	40.781735	50
	16	30.127509	29.48115	29.128406	28.740409	28.273233	28.153106	39.466877	50.533123	50
	17	29.648051	29.10276	28.802991	28.462877	28.075128	27.976391	29.098221	60.901779	50
	18	28.945884	28.527419	28.296168	28.020149	27.715762	27.638819	18.626518	71.373482	50
	19	28.183878	27.884027	27.71827	27.521064	27.300838	27.245302	8.410647	81.589353	50
30	10	25.247099	24.767598	24.500969	24.204311	23.927144	23.856429	48.596726	41.403274	33
	11	26.204041	25.638405	25.323909	24.972376	24.634482	24.545567	56.885617	33.114383	33.114383
	12	26.992475	26.378069	26.03889	25.652986	25.278754	25.179221	62.060662	27.939338	35
	13	27.581586	26.957595	26.610152	26.212866	25.82401	25.719736	62.19276	27.80724	45
	14	28.03466	27.40471	27.056918	26.661075	26.273796	26.169802	57.217108	32.782892	50
	15	28.305132	27.694594	27.358544	26.980762	26.612826	26.513731	49.028367	40.971633	50
	16	28.360864	27.801567	27.491168	27.14698	26.814465	26.724903	39.291604	50.708396	50
	17	28.218391	27.722468	27.448092	27.14496	26.858057	26.781513	28.928286	61.071714	50
	18	27.867638	27.470103	27.250086	27.005144	26.773695	26.712306	18.454836	71.545164	50
	19	27.336855	27.060256	26.906815	26.731923	26.563822	26.520022	8.231758	81.768242	50
31	10	26.566093	25.98888	25.665782	25.310949	24.964023	24.872516	48.417524	41.582476	41.582476
	11	27.725251	27.05956	26.699436	26.290535	25.881163	25.771903	56.678509	33.321491	45
	12	28.637072	27.914022	27.529004	27.088077	26.638831	26.52	61.822946	28.177054	50
	13	29.300907	28.552994	28.162224	27.705204	27.237066	27.113832	61.949538	28.050462	50
	14	29.751768	28.996988	28.600796	28.142109	27.671889	27.547864	56.996799	33.003201	50
	15	29.926299	29.199157	28.815827	28.374335	27.92446	27.804749	48.832611	41.167389	50
	16	29.842083	29.163378	28.797447	28.388171	27.976106	27.865932	39.110678	50.889322	50
	17	29.437674	28.857844	28.540255	28.189329	27.839775	27.747837	28.752875	61.247125	50
	18	28.896265	28.436127	28.183319	27.899373	27.621019	27.547519	18.277776	71.722224	50
	19	28.279239	27.943491	27.76001	27.552801	27.348272	27.294791	8.047519	81.952481	50

August										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
1	11	26.261213	25.24699	24.831901	24.360304	23.83066	23.694001	56.467827	33.532173	28
	12	27.725641	26.395339	25.954138	25.454049	24.862365	24.709096	61.580742	28.419258	28.419258
	13	28.70068	27.229252	26.793063	26.295829	25.689162	25.534676	61.700957	28.299043	45
	14	29.331054	27.821065	27.377436	26.882817	26.282056	26.129828	56.770655	33.229345	50
	15	29.450451	28.108877	27.684275	27.205706	26.634664	26.489345	48.631045	41.368955	50
	16	29.087279	28.058698	27.659892	27.216511	26.702182	26.568104	38.924138	51.075862	50
	17	28.406505	27.620278	27.27538	26.894266	26.464945	26.350289	28.572026	61.427974	50
	18	27.527664	26.927532	26.659153	26.355438	26.017659	25.925454	18.095384	71.904616	50
	19	26.654406	26.198843	25.997089	25.76886	25.514725	25.445123	7.857977	82.142023	25
2	11	25.782423	24.757462	24.376417	23.944949	23.437428	23.310958	56.253605	33.746395	28
	12	27.699445	26.294293	25.869677	25.393314	24.798901	24.649516	61.334114	28.665886	28.665886
	13	28.876056	27.327704	26.913791	26.447035	25.841955	25.694259	61.447101	28.552899	45
	14	29.624974	28.0427	27.627489	27.169988	26.57718	26.433887	56.538747	33.461253	50
	15	29.836113	28.441171	28.047881	27.606752	27.046346	26.909837	48.42372	41.57628	50
	16	29.469677	28.432852	28.064267	27.65815	27.159141	27.03327	38.732027	51.267973	50
	17	28.763652	28.002174	27.691334	27.349773	26.94314	26.837828	28.38578	61.61422	50
	18	27.895795	27.337221	27.106863	26.843855	26.533037	26.450053	17.907703	72.092297	50
	19	27.073228	26.669941	26.510109	26.325384	26.101312	26.042386	7.663185	82.336815	50
3	11	26.506264	25.504141	25.089908	24.62043	24.106444	23.975303	56.035879	33.964121	33.964121
	12	28.109253	26.817587	26.373568	25.869518	25.293442	25.144621	61.083125	28.916875	35
	13	29.134262	27.718022	27.278319	26.775983	26.185927	26.034805	61.188055	28.811945	50
	14	29.764295	28.32646	27.885408	27.390096	26.809308	26.661255	56.301148	33.698852	50
	15	29.93326	28.65163	28.227562	27.748384	27.196462	27.054536	48.210692	41.789308	50
	16	29.572957	28.582429	28.187369	27.747575	27.254189	27.125009	38.534392	51.465608	50
	17	28.896833	28.145807	27.812583	27.441628	27.035476	26.927851	28.194184	61.805816	50
	18	28.078719	27.51023	27.254576	26.96379	26.648963	26.564488	17.714784	72.285216	50
	19	27.26932	26.850168	26.664137	26.451189	26.21962	26.157486	7.463197	82.536803	50
4	11	25.952017	24.97591	24.624118	24.221454	23.739945	23.619299	55.814682	34.185318	29
	12	27.622254	26.273789	25.881846	25.440427	24.881718	24.743232	60.827838	29.172162	29.172162
	13	28.72008	27.202408	26.80055	26.352849	25.773857	25.633698	60.923904	29.076096	45
	14	29.405406	27.836347	27.422275	26.973687	26.397015	26.25841	56.057936	33.942064	50
	15	29.501247	28.122271	27.73814	27.310405	26.766686	26.634829	47.992019	42.007981	50
	16	29.072388	28.046699	27.687978	27.293993	26.807348	26.685793	38.331282	51.668718	50
	17	28.297705	27.550004	27.249311	26.919227	26.523382	26.421158	27.997286	62.002714	50
	18	27.383031	26.832787	26.609997	26.355603	26.052757	25.972057	17.516677	72.483323	50
	19	26.518106	26.116926	25.960126	25.779442	25.56077	25.502731	7.25807	82.74193	25

August										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
5	11	24.74043	23.635465	23.19771	22.698769	22.107947	21.949936	55.590048	34.409952	29
	12	26.444896	24.949311	24.455156	23.901562	23.248107	23.083215	60.568316	29.431684	29.431684
	13	27.683532	26.053343	25.564065	25.005134	24.306815	24.129284	60.654734	29.345266	29.345266
	14	28.516566	26.870226	26.388751	25.850128	25.16856	24.994359	55.809189	34.190811	35
	15	28.792857	27.343018	26.892908	26.384019	25.751821	25.588367	47.767765	42.232235	42.232235
	16	28.523154	27.423113	27.006625	26.543439	25.98591	25.839098	38.122751	51.877249	45
	17	27.919747	27.096122	26.743504	26.352166	25.892797	25.768808	27.795138	62.204862	45
	18	27.08407	26.46818	26.202368	25.897785	25.542814	25.445047	17.313439	72.686561	35
	19	26.254799	25.801927	25.610596	25.388259	25.123936	25.05063	7.047865	82.952135	15
6	11	25.410885	24.280008	23.814834	23.283326	22.674675	22.513761	55.362011	34.637989	29
	12	27.144229	25.695904	25.213706	24.663564	23.991426	23.818336	60.304622	29.695378	29.695378
	13	28.311778	26.738073	26.273739	25.739941	25.070658	24.899536	60.380632	29.619368	35
	14	29.063118	27.467646	27.007619	26.492197	25.846172	25.681196	55.554989	34.445011	45
	15	29.299521	27.885515	27.449372	26.95638	26.352501	26.197665	47.537995	42.462005	50
	16	28.977293	27.903613	27.49602	27.044408	26.509185	26.36877	37.908855	52.091145	50
	17	28.269526	27.471176	27.130023	26.751478	26.313631	26.196569	27.587795	62.412205	50
	18	27.310515	26.720198	26.466407	26.175072	25.839397	25.74825	17.105125	72.894875	45
	19	26.701537	26.173345	25.976955	25.722783	25.412171	25.349531	6.832643	83.167357	25
7	11	26.309618	24.992755	24.489565	23.927057	23.286832	23.121385	55.130602	34.869398	34.869398
	12	28.573769	26.754665	26.141022	25.469229	24.682908	24.48429	60.036819	29.963181	35
	13	30.09181	28.251546	27.658788	26.950478	26.056761	25.833201	60.101687	29.898313	50
	14	31.073626	29.271036	28.714626	28.080548	27.248655	27.0221	55.29542	34.70458	50
	15	31.391358	29.828898	29.326702	28.7466	28.015682	27.821836	47.302778	42.697222	50
	16	31.073156	29.901462	29.452653	28.941748	28.311675	28.145209	37.689654	52.310346	50
	17	30.392199	29.52358	29.151265	28.726303	28.210351	28.072982	27.375316	62.624684	50
	18	29.484611	28.835077	28.554191	28.219981	27.816011	27.707929	16.891799	73.108201	50
	19	28.58678	28.10262	27.895907	27.642183	27.334941	27.253306	6.612471	83.387529	50
8	11	26.678851	25.688934	25.253787	24.766361	24.246487	24.111333	54.895855	35.104145	35
	12	28.178906	26.938429	26.478993	25.959359	25.388055	25.238288	59.76497	30.23503	35
	13	29.198052	27.836806	27.385562	26.869557	26.287031	26.134282	59.817987	30.182013	50
	14	29.79907	28.431091	27.979162	27.471355	26.901701	26.753546	55.030569	34.969431	50
	15	29.952773	28.73434	28.299126	27.810322	27.273011	27.133119	47.062185	42.937815	50
	16	29.675669	28.709277	28.301831	27.850885	27.367597	27.239356	37.465213	52.534787	50
	17	29.081857	28.327011	27.978994	27.595282	27.194107	27.086965	27.157761	62.842239	50
	18	28.366403	27.77863	27.502846	27.195187	26.877615	26.791548	16.673523	73.326477	50
	19	27.573292	27.148016	26.951846	26.730333	26.499955	26.438106	6.387416	83.612584	50
9	11	24.534847	24.130894	23.927711	23.706411	23.507168	23.457224	54.657804	35.342196	30
	12	25.289548	24.789019	24.54118	24.268776	24.01618	23.950412	59.489139	30.510861	30.510861
	13	25.787975	25.252312	24.993747	24.705931	24.431253	24.357799	59.529621	30.470379	30.470379
	14	26.183396	25.636751	25.369386	25.0746	24.795172	24.719487	54.760523	35.239477	35.239477
	15	26.372374	25.870872	25.616831	25.333344	25.0676	24.996548	46.816292	43.183708	43.183708
	16	26.45097	26.007944	25.775275	25.514252	25.271475	25.206997	37.235596	52.764404	25
	17	26.408718	26.020946	25.814407	25.584149	25.369163	25.312008	26.935196	63.064804	25
	18	26.158291	25.853332	25.69029	25.506637	25.332194	25.286233	16.450364	73.549636	15
	19	25.735835	25.526603	25.414977	25.283938	25.156033	25.123564	6.15755	83.84245	0
10	11	27.201511	26.271707	25.89151	25.458965	24.984311	24.859385	54.41648	35.58352	35.58352
	12	28.627949	27.387462	26.977024	26.515127	25.986809	25.849762	59.20939	30.79061	45
	13	29.609659	28.21569	27.797094	27.325385	26.775702	26.635869	59.236679	30.763321	50
	14	30.292125	28.841987	28.4031	27.921449	27.365146	27.223378	54.485375	35.514625	50
	15	30.480835	29.182184	28.755781	28.285045	27.752004	27.614576	46.565176	43.434824	50
	16	30.101229	29.119014	28.730942	28.306284	27.836105	27.712691	37.000874	52.999126	50
	17	29.437859	28.698671	28.373296	28.018467	27.636631	27.535312	26.707687	63.292313	50
	18	28.615779	28.060146	27.812526	27.536638	27.244245	27.165523	16.222391	73.777609	50
	19	27.75558	27.36046	27.18863	26.994875	26.78719	26.731637	5.922946	84.077054	50
11	11	26.34537	25.400331	25.052753	24.659993	24.19682	24.078167	54.171916	35.828084	35
	12	27.737461	26.411611	26.021669	25.590709	25.057077	24.922247	58.925785	31.074215	35
	13	28.840011	27.342541	26.947522	26.511783	25.960057	25.825068	58.939252	31.060748	45
	14	29.622232	28.077947	27.675906	27.241752	26.691555	26.55857	54.205215	35.794785	50
	15	29.833855	28.472203	28.090892	27.670778	27.148666	27.021283	46.308919	43.691081	50
	16	29.496189	28.483874	28.126009	27.739128	27.274958	27.157771	36.761118	53.238882	50
	17	28.790044	28.054962	27.757634	27.437242	27.064393	26.967723	26.475305	63.524695	50
	18	27.939327	27.396788	27.175517	26.929495	26.647803	26.572712	15.989676	74.010324	50
	19	27.059262	26.676215	26.527118	26.359298	26.163161	26.1113	5.683679	84.316321	50
12	11	26.439419	25.462896	25.068467	24.627217	24.145786	24.020599	53.924146	36.075854	35
	12	27.980349	26.711745	26.290822	25.817356	25.274667	25.134135	58.63839	31.36161	35
	13	29.011985	27.599976	27.176211	26.697606	26.134767	25.990952	58.637432	31.362568	50
	14	29.711497	28.249433	27.809773	27.325327	26.760451	26.616328	53.920139	36.079861	50
	15	29.883788	28.588667	28.172113	27.70651	27.169535	27.032296	46.047604	43.952396	50
	16	29.566962	28.576051	28.189923	27.76389	27.284983	27.16038	36.516406	53.483594	50
	17	28.905013	28.164849	27.843527	27.489043	27.100969	26.998846	26.238123	63.761877	50
	18	28.047389	27.511883	27.279088	27.013005	26.722079	26.645214	15.752294	74.247706	50
	19	27.230781	26.847863	26.68595	26.498478	26.290996	26.236413	5.439828	84.560172	50
13	11	25.797312	24.769448	24.327764	23.824499	23.278655	23.133828	53.673203	36.326797	31
	12	27.346485	26.028736	25.558361	25.022094	24.414286	24.251253	58.347268	31.652732	31.652732
	13	28.41036	26.975198	26.514703	25.986228	25.371831	25.210655	58.33131	31.66869	35
	14	29.099189	27.641499	27.179267	26.660123	26.059922	25.902027	53.630243	36.369757	50
	15	29.276035	27.97552	27.531903	27.032967	26.46798	26.319009	45.781317	44.218683	50
	16	28.931917	27.921287	27.510282	27.055287	26.553964	26.420262	36.266814	53.733186	50
	17	28.31814	27.537833	27.186768	26.799282	26.382903	26.270315	25.996217	64.003783	50
	18	27.472135	26.891105	26.627495	26.328083	26.007519	25.920699	15.510322	74.489678	50
	19	27.051991	26.548683	26.339918	26.070733	25.808711	25.735236	5.191474	84.808526	45
14	11	25.477618	24.183835	23.689218	23.149744	22.532243	22.375348	53.419119	36.580881	31
	12	28.139597	26.293981	25.681061	25.022467	24.242458	24.050591	58.052484	31.947516	31.947516
	13	29.871202	27.99653	27.419462	26.739981	25.862735	25.64954	58.020979	31.979021	45
	14	30.924939	29.097961	28.561192	27.957607	27.153842	26.945412	53.335624	36.664376	50
	15	31.198846	29.629745	29.146797	28.597003	27.894268	27.713802	45.510147	44.489853	50
	16	30.826051	29.643808	29.203218	28.707022	28.099735	27.941427	36.012423	53.987577	50
	17	30.054621	29.17117	28.799944	28.380686	27.884912	27.753654	25.749665	64.250335	50
	18	29.088542	28.437764	28.161517	27.834158	27.451164	27.349362	15.26384	74.73616	50
	19	28.214492	27.724975	27.520533	27.278176	26.990367	26.912942	4.938699	85.061301	50

August										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
15	11	24.974839	24.181406	23.800481	23.389905	23.010713	22.912943	53.16193	36.83807	32
	12	26.203067	25.239466	24.811313	24.329616	23.85737	23.733999	57.754103	32.245897	32.245897
	13	27.072584	26.039368	25.601372	25.104428	24.603474	24.467449	57.70653	32.29347	32.29347
	14	27.635636	26.60571	26.172426	25.67999	25.182069	25.046852	53.036382	36.963618	36.963618
	15	27.781872	26.861551	26.453674	25.991191	25.523041	25.396867	45.234184	44.765816	44.765816
	16	27.675651	26.895171	26.518159	26.094691	25.67128	25.555457	35.753319	54.246681	45
	17	27.343526	26.701031	26.376482	26.012438	25.651787	25.552311	25.498549	64.501451	45
	18	26.834982	26.34067	26.088651	25.801198	25.514895	25.436282	15.01293	74.98707	35
	19	26.241427	25.892543	25.716014	25.509229	25.298977	25.240765	4.681589	85.318411	15
16	11	26.370494	25.431496	25.018432	24.550299	24.068539	23.937751	52.901668	37.098332	35
	12	27.672829	26.467049	26.015604	25.506189	24.962422	24.816207	57.452191	32.547809	35
	13	28.561111	27.23038	26.772032	26.254536	25.688284	25.53781	57.388058	32.611942	45
	14	29.099903	27.752093	27.293197	26.781936	26.222731	26.075107	52.732618	37.267382	50
	15	29.226527	28.020475	27.583736	27.094437	26.564474	26.424656	44.953523	45.046477	50
	16	28.981955	28.015185	27.603698	27.149611	26.668861	26.539927	35.489586	54.510414	50
	17	28.407433	27.654489	27.305084	26.919803	26.520935	26.41318	25.242952	64.757048	50
	18	27.649183	27.079967	26.812833	26.5119	26.202629	26.119215	14.757677	75.242323	50
	19	26.845319	26.437598	26.249264	26.034652	25.811514	25.751553	4.420231	85.579769	45
17	11	25.914237	24.92333	24.492767	24.019933	23.537476	23.413939	52.63837	37.36163	32
	12	27.517225	26.243436	25.77045	25.244863	24.678132	24.528134	57.146812	32.853188	32.853188
	13	28.607198	27.203488	26.736094	26.207056	25.617445	25.462693	57.065657	32.934343	45
	14	29.243745	27.833283	27.366637	26.847053	26.268914	26.116718	52.424434	37.575566	50
	15	29.405342	28.149853	27.700425	27.200922	26.656399	26.512924	44.668258	45.331742	50
	16	29.10696	28.115618	27.698292	27.24089	26.754511	26.624051	35.221313	54.778687	50
	17	28.467005	27.706002	27.357227	26.97478	26.576516	26.469049	24.982961	65.017039	50
	18	27.703946	27.122288	26.851622	26.549672	26.238816	26.154751	14.498169	75.501831	50
	19	26.874233	26.457751	26.267735	26.052507	25.828192	25.767804	4.154715	85.845285	45
18	11	25.674224	24.755362	24.33565	23.869445	23.414933	23.299706	52.372069	37.627931	33
	12	27.019534	25.862875	25.40413	24.886958	24.347671	24.204241	56.838034	33.161966	33.161966
	13	27.938077	26.673325	26.211588	25.682423	25.118589	24.968913	56.739419	33.260581	35
	14	28.55896	27.26511	26.794511	26.26505	25.698894	25.546792	52.111933	37.888067	45
	15	28.689664	27.530992	27.079171	26.572005	26.037674	25.893651	44.378488	45.621512	45.621512
	16	28.404749	27.472017	27.056199	26.593816	26.115368	25.985445	34.948592	55.051408	50
	17	27.897331	27.149134	26.790744	26.393126	25.990034	25.879748	24.718664	65.281336	45
	18	27.19022	26.62085	26.344913	26.03308	25.718222	25.63263	14.234493	75.765507	45
	19	26.464511	26.054783	25.858366	25.63303	25.402015	25.339162	3.885133	86.114867	25
19	11	25.659531	24.749581	24.322792	23.855463	23.405316	23.290527	52.102802	37.897198	33
	12	27.021236	25.87638	25.407725	24.88676	24.351203	24.206491	56.525922	33.474078	33.474078
	13	28.034875	26.790862	26.326539	25.798581	25.241924	25.092668	56.40944	33.59056	35
	14	28.684379	27.441955	26.981875	26.4647	25.916566	25.768982	51.79522	38.20478	45
	15	28.858555	27.753068	27.313924	26.822352	26.309656	26.171878	44.084312	45.915688	50
	16	28.621744	27.734822	27.335575	26.891604	26.435974	26.312751	34.671517	55.328483	50
	17	28.096226	27.40081	27.067476	26.696333	26.321449	26.220335	24.450151	65.549849	50
	18	27.467898	26.929561	26.667672	26.372681	26.077746	25.998399	13.966742	76.033258	50
	19	26.735236	26.354654	26.172636	25.96396	25.751404	25.694462	3.611578	86.388422	35
20	11	25.442102	24.610569	24.208872	23.7601	23.331335	23.220503	51.830606	38.169394	33
	12	26.69025	25.666018	25.219053	24.716029	24.209115	24.073638	56.210544	33.789456	33.789456
	13	27.534294	26.437183	25.988084	25.475685	24.954402	24.813882	56.075815	33.924185	33.924185
	14	28.073255	26.974306	26.52958	26.025971	25.508455	25.368941	51.474401	38.525599	45
	15	28.268971	27.265475	26.838188	26.355798	25.863118	25.728514	43.785832	46.214168	46.214168
	16	28.036673	27.224194	26.841931	26.412231	25.97965	25.861589	34.390183	55.609817	45
	17	27.609512	26.960409	26.638373	26.275707	25.914633	25.816265	24.177517	65.822483	45
	18	26.985665	26.480111	26.226643	25.938386	25.652467	25.57542	13.69501	76.30499	35
	19	26.569166	26.160913	25.939048	25.702467	25.485621	25.422042	3.334146	86.665854	25
21	11	23.329998	22.880103	22.650761	22.396855	22.163133	22.103786	51.555517	38.444483	34
	12	24.408721	23.81999	23.533039	23.219244	22.930486	22.855837	55.891969	34.108031	34.108031
	13	25.450335	24.735538	24.397153	24.030675	23.694366	23.606144	55.738639	34.261361	34.261361
	14	26.268946	25.524918	25.158341	24.762522	24.399653	24.304162	51.149583	38.850417	38.850417
	15	26.754583	26.10103	25.768238	25.375795	25.009233	24.913458	43.483152	46.516848	46.516848
	16	26.992336	26.421146	26.13688	25.822442	25.498733	25.408567	34.104687	55.895313	35
	17	26.962493	26.492627	26.249324	25.993296	25.752661	25.687437	23.900857	66.099143	35
	18	26.699655	26.315709	26.119153	25.918281	25.731054	25.680355	13.419391	76.580609	35
	19	26.219638	25.922224	25.773874	25.610939	25.448032	25.403797	3.052936	86.947064	15
22	11	25.40511	24.412129	24.050241	23.656757	23.206839	23.095383	51.277573	38.722427	34
	12	27.231463	25.854211	25.446105	24.999558	24.45416	24.318551	55.570263	34.429737	34.429737
	13	28.402159	26.869009	26.462432	26.014335	25.448222	25.310023	55.398007	34.601993	45
	14	29.116506	27.544674	27.130344	26.685507	26.126298	25.989723	50.820873	39.179127	50
	15	29.213006	27.83906	27.452659	27.029217	26.506407	26.377833	43.176376	46.823624	50
	16	28.743973	27.727865	27.371343	26.986385	26.525835	26.409001	33.815131	56.184869	50
	17	27.932301	27.18589	26.886607	26.565751	26.195166	26.098587	23.620268	66.379732	50
	18	26.935961	26.389609	26.169799	25.925829	25.647893	25.57458	13.139985	76.860015	35
	19	25.945481	25.547653	25.394391	25.222471	25.02278	24.969924	2.768046	87.231954	0
23	11	24.142158	23.091306	22.6433	22.137603	21.602138	21.462361	50.996813	39.003187	34
	12	26.057061	24.630165	24.113711	23.547069	22.962451	22.813372	55.245496	34.754504	34.754504
	13	27.325274	25.786634	25.270235	24.684537	24.028633	23.859554	55.054015	34.945985	34.945985
	14	28.143106	26.60867	26.101657	25.529078	24.884328	24.71454	50.488381	39.511619	39.511619
	15	28.352298	27.020231	26.550162	26.017707	25.419155	25.262254	42.865612	47.134388	47.134388
	16	28.105777	27.073906	26.64712	26.170501	25.644533	25.503366	33.521616	56.478384	45
	17	27.533049	26.742108	26.384697	25.986447	25.555687	25.437682	23.335849	66.664151	35
	18	26.750769	26.16025	25.890261	25.580518	25.245748	25.154112	12.856889	77.143111	25
	19	25.867973	25.45596	25.272971	25.055781	24.810564	24.74444	2.479578	87.520422	0
24	11	24.278081	23.222646	22.839032	22.410528	21.900544	21.770209	50.713278	39.286722	35
	12	26.367116	24.868653	24.422553	23.938666	23.364484	23.225771	54.917738	35.082262	35.082262
	13	27.727299	26.099694	25.659284	25.171053	24.555695	24.405592	54.70676	35.29324	35.29324
	14	28.604069	26.962096	26.523296	26.046061	25.441302	25.293775	50.152215	39.847785	45
	15	28.839775	27.411189	27.004975	26.555985	25.996661	25.857493	42.550968	47.449032	47.449032
	16	28.474514	27.415739	27.043303	26.639334	26.152828	26.027899	33.224245	56.775755	50
	17	27.757437	26.980729	26.670021	26.335617	25.946483	25.843791	23.047702	66.952298	45
	18	26.824281	26.265439	26.042805	25.793328	25.504412	25.427682	12.570207	77.429793	35
	19	25.920886	25.519036	25.366295	25.192066	24.983066	24.927002	2.187635	87.812365	0

August										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
25	11	24.039748	23.0181	22.661608	22.24648	21.766529	21.642632	50.427006	39.572994	35
	12	26.033725	24.527928	24.090157	23.617367	23.069323	22.937734	54.587058	35.412942	35.412942
	13	27.287337	25.6244	25.173478	24.67892	24.054235	23.90512	54.356339	35.643661	35.643661
	14	28.032696	26.351944	25.9011	25.414464	24.792045	24.640787	49.812487	40.187513	40.187513
	15	28.159188	26.698942	26.28841	25.836349	25.259263	25.117354	42.232553	47.767447	47.767447
	16	27.72048	26.640753	26.267424	25.86241	25.358833	25.230067	32.923125	57.076875	35
	17	26.914949	26.128386	25.819203	25.484089	25.076588	24.969224	22.755931	67.244069	25
	18	25.895685	25.317488	25.090517	24.834702	24.525401	24.443705	12.280041	77.719959	0
	19	24.863455	24.443907	24.284862	24.100506	23.871247	23.810908	1.892323	88.107677	0
26	11	24.920705	23.892371	23.532947	23.14585	22.690898	22.579524	50.138041	39.861959	35
	12	26.804035	25.364585	24.941162	24.482253	23.922762	23.78948	54.253527	35.746473	35.746473
	13	28.061117	26.476577	26.053707	25.591277	25.004432	24.864299	54.002847	35.997153	35.997153
	14	28.865406	27.251298	26.825586	26.372167	25.794331	25.65496	49.469307	40.530693	45
	15	29.005152	27.600382	27.210325	26.785298	26.253062	26.123542	41.91048	48.08952	50
	16	28.515585	27.491502	27.140266	26.762179	26.302545	26.187328	32.618362	57.381638	50
	17	27.735411	26.990769	26.699477	26.388022	26.021918	25.927588	22.46064	67.53936	50
	18	26.825816	26.282471	26.069361	25.833028	25.559974	25.489093	11.986497	78.013503	35
	19	25.948564	25.561255	25.417331	25.255049	25.061258	25.011233	1.593747	88.406253	0
27	11	25.658644	24.616309	24.193202	23.72198	23.204491	23.066445	49.846425	40.153575	36
	12	27.168389	25.802399	25.345969	24.836058	24.245701	24.089796	53.917218	36.082782	36.082782
	13	28.227155	26.718938	26.267893	25.761891	25.161237	25.004964	53.646384	36.353616	36.353616
	14	28.857766	27.333957	26.883114	26.389758	25.807445	25.656516	49.122788	40.877212	45
	15	28.960996	27.624638	27.202474	26.736333	26.196247	26.056097	41.58486	48.41514	50
	16	28.604003	27.584719	27.193414	26.769193	26.293399	26.167012	32.310067	57.689933	50
	17	27.905823	27.140054	26.812423	26.459963	26.076917	25.973672	22.161936	67.838064	50
	18	27.04553	26.476112	26.229775	25.958682	25.668985	25.590614	11.689681	78.310319	35
	19	26.494927	25.986854	25.813572	25.592682	25.334121	25.270571	1.292015	88.707985	15
28	11	26.562427	25.39753	24.877959	24.317907	23.765868	23.621418	49.5522	40.4478	36
	12	28.237867	26.736455	26.105316	25.42728	24.748556	24.57053	53.578201	36.421799	36.421799
	13	29.295165	27.793194	27.17451	26.429551	25.65881	25.456298	53.287045	36.712955	45
	14	29.941089	28.482004	27.913429	27.235952	26.438366	26.218645	48.773041	41.226959	50
	15	30.075789	28.808108	28.285812	27.681826	26.998017	26.796154	41.255809	48.744191	50
	16	29.863233	28.849811	28.380226	27.845784	27.266142	27.098791	31.998349	58.001651	50
	17	29.369435	28.564248	28.163969	27.710743	27.235102	27.099262	21.859928	68.140072	50
	18	28.64325	28.018151	27.698291	27.333413	26.956043	26.849995	11.389701	78.610299	50
	19	27.753254	27.293649	27.062094	26.792273	26.502097	26.418478	0.987238	89.012762	50
29	11	23.023144	22.806681	22.699334	22.57176	22.447214	22.417157	49.255413	40.744587	36
	12	23.515605	23.216611	23.073137	22.913999	22.765823	22.728863	53.236551	36.763449	36.763449
	13	23.907337	23.526967	23.353265	23.167756	22.998949	22.955891	52.92493	37.07507	37.07507
	14	24.120035	23.730235	23.541048	23.344979	23.170329	23.126524	48.42018	41.57982	41.57982
	15	24.225859	23.855101	23.666519	23.468392	23.29661	23.25405	40.92344	49.07656	49.07656
	16	24.240034	23.900224	23.721329	23.530291	23.368692	23.329134	31.683321	58.316679	45
	17	24.051298	23.774649	23.626238	23.465118	23.329537	23.297181	21.554727	68.445273	35
	18	23.701743	23.495401	23.386723	23.268946	23.168125	23.144901	11.086669	78.913331	25
	19	23.21802	23.094493	23.034272	22.963694	22.900042	22.886716	0.679527	89.320473	15
30	11	22.388975	21.525298	21.108075	20.675865	20.274665	20.171896	48.956108	41.043892	37
	12	24.06489	22.985015	22.538582	22.041252	21.530596	21.392133	52.89234	37.10766	37.10766
	13	25.235922	23.98222	23.486865	22.972544	22.480781	22.348201	52.560136	37.439864	37.439864
	14	25.990469	24.724671	24.208127	23.63458	23.106655	22.973551	48.064319	41.935681	41.935681
	15	26.31878	25.178928	24.691458	24.136464	23.580709	23.441976	40.58787	49.41213	49.41213
	16	26.185137	25.258035	24.820027	24.32324	23.808443	23.675846	31.365097	58.634903	45
	17	25.854204	25.093872	24.711843	24.280601	23.831285	23.711615	21.246443	68.753557	35
	18	25.255479	24.650712	24.342445	23.991193	23.624681	23.530639	10.780695	79.219305	25
	19	24.443423	24.011152	23.793342	23.534717	23.270263	23.205597	0.368993	89.631007	15
31	11	24.164097	22.453703	21.912244	21.42184	20.872263	20.729026	48.654333	41.345667	37
	12	26.574252	24.165219	23.531227	23.004628	22.382557	22.221014	52.545643	37.454357	37.454357
	13	28.109168	25.416006	24.74625	24.154754	23.470962	23.308536	52.192763	37.807237	37.807237
	14	28.960105	26.291467	25.626378	25.045334	24.334441	24.158019	47.705571	42.294429	42.294429
	15	29.032387	26.730224	26.117998	25.578144	24.916282	24.74811	40.249216	49.750784	49.750784
	16	28.39751	26.678583	26.146422	25.663125	25.088064	24.940796	31.043791	58.956209	45
	17	27.478926	26.254404	25.828622	25.415945	24.941942	24.819061	20.93519	69.06481	35
	18	26.423088	25.543239	25.227884	24.907201	24.54206	24.447404	10.471892	79.528108	25
	19	25.365407	24.735901	24.519775	24.293458	24.028009	23.959691	0.055752	89.944248	15

					September					
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
	11	28.478387	26.208291	24.918665	24.45889	23.950186	23.798335	56.467827	33.532173	33.532173
	12	30.705202	27.831657	26.171259	25.656664	25.068316	24.90891	61.580742	28.419258	35
	13	32.141362	28.973785	27.120847	26.611167	26.015971	25.870199	61.700957	28.299043	50
	14	32.879031	29.699068	27.854732	27.343508	26.751009	26.606003	56.770655	33.229345	50
1	15	32.681355	29.834317	28.211504	27.730232	27.179408	27.041662	48.631045	41.368955	50
	16	31.59911	29.388355	28.137314	27.709644	27.232242	27.108536	38.924138	51.075862	50
	17	30.074012	28.53647	27.671425	27.322795	26.944331	26.844536	28.572026	61.427974	50
	18	28.514686	27.524408	26.94572	26.703021	26.439761	26.378731	18.095384	71.904616	50
	19	27.261288	26.597759	26.202889	26.056007	25.889661	25.86441	7.857977	82.142023	45
	11	28.650794	26.255814	24.895253	24.419796	23.897231	23.741051	56.253605	33.746395	33.746395
	12	31.06284	28.030683	26.275415	25.733242	25.116133	24.948952	61.334114	28.665886	35
	13	32.561812	29.222485	27.267702	26.729127	26.103337	25.950062	61.447101	28.552899	50
	14	33.390221	29.960928	28.014295	27.471837	26.847535	26.694199	56.538747	33.461253	50
2	15	33.220002	30.073888	28.362272	27.852156	27.271079	27.125015	48.42372	41.57628	50
	16	31.947825	29.5536	28.238261	27.787172	27.286122	27.155396	38.732027	51.267973	50
	17	30.20558	28.577684	27.679399	27.319341	26.928399	26.824889	28.38578	61.61422	50
	18	28.549441	27.491419	26.883045	26.627366	26.350893	26.285875	17.907703	72.092297	50
	19	27.236262	26.508437	26.082422	25.92012	25.74012	25.7108	7.663185	82.336815	35
	11	27.125638	25.329675	24.331871	23.844731	23.362093	23.232852	56.035879	33.964121	28
	12	29.014493	26.806388	25.539013	24.98365	24.40452	24.252669	61.083125	28.916875	28.916875
	13	30.263203	27.852512	26.458103	25.899307	25.301625	25.150784	61.188055	28.811945	35
	14	30.930031	28.526639	27.144128	26.587502	25.996363	25.843571	56.301148	33.698852	45
3	15	30.847225	28.708265	27.487739	26.962136	26.410987	26.266618	48.210692	41.789308	50
	16	30.087986	28.392749	27.436261	26.969926	26.489241	26.361634	38.534392	51.465608	50
	17	28.988326	27.762634	27.072772	26.684995	26.292757	26.188684	28.194184	61.805816	50
	18	27.831107	26.98864	26.501516	26.212136	25.920154	25.847464	17.714784	72.285216	45
	19	26.766657	26.196057	25.860714	25.671815	25.475595	25.433209	7.463197	82.536803	25
	11	27.583373	25.565511	24.42893	23.92315	23.410186	23.264603	55.814682	34.185318	29
	12	29.671164	27.156417	25.706664	25.138303	24.531476	24.365895	60.827838	29.172162	29.172162
	13	31.045853	28.295327	26.696284	26.134225	25.518043	25.358864	60.923904	29.076096	45
	14	31.775387	29.034029	27.449874	26.890777	26.28313	26.124615	56.057936	33.942064	50
4	15	31.656222	29.217987	27.81991	27.289716	26.721528	26.570796	47.992019	42.007981	50
	16	30.689429	28.792538	27.716916	27.250317	26.75977	26.627792	38.331282	51.668718	50
	17	29.389246	28.047219	27.290273	26.911055	26.519089	26.413913	27.997286	62.002714	50
	18	28.017905	27.135749	26.622227	26.353591	26.07347	26.004894	17.516677	72.483323	50
	19	26.883287	26.283708	25.927924	25.755559	25.570026	25.532798	7.25807	82.74193	25
	11	27.650174	25.910274	24.936635	24.455169	23.971724	23.838266	55.590048	34.409952	34.409952
	12	29.45211	27.284407	26.053554	25.517854	24.962463	24.813896	60.568316	29.431684	35
	13	30.587641	28.218467	26.861676	26.327826	25.762697	25.618216	60.654734	29.345266	45
	14	31.179781	28.814198	27.464298	26.931391	26.370211	26.225543	55.809189	34.190811	50
5	15	31.06925	28.953847	27.755424	27.246608	26.718031	26.57936	47.767765	42.232235	50
	16	30.274396	28.598755	27.659812	27.20661	26.744477	26.621372	38.122751	51.877249	50
	17	29.099444	27.903764	27.236934	26.867423	26.495902	26.397747	27.795138	62.204862	50
	18	27.87368	27.070632	26.610679	26.343125	26.073325	26.007099	17.313439	72.686561	50
	19	26.822595	26.272524	25.95261	25.777297	25.596083	25.556892	7.047865	82.952135	25
	11	27.675056	25.810624	24.751982	24.235416	23.706361	23.553707	55.362011	34.637989	29
	12	29.616718	27.245953	25.889515	25.328221	24.733441	24.568179	60.304622	29.695378	29.695378
	13	30.906016	28.286533	26.776242	26.217961	25.616053	25.457262	60.380632	29.619368	45
	14	31.522704	28.903293	27.39901	26.842583	26.248074	26.090543	55.554989	34.445011	50
6	15	31.172368	28.881304	27.573695	27.052216	26.501752	26.354913	47.537995	42.462005	50
	16	30.183014	28.374607	27.353022	26.887624	26.405599	26.27535	37.908855	52.091145	50
	17	28.868605	27.573178	26.843546	26.459449	26.068359	25.962659	27.587795	62.412205	50
	18	27.612707	26.731774	26.220044	25.935342	25.646165	25.573348	17.105125	72.894875	35
	19	27.004381	26.27154	25.870071	25.646961	25.399336	25.349905	6.832643	83.167357	25
	11	27.11565	24.536979	23.211298	22.615484	22.016523	21.845065	55.130602	34.869398	29
	12	29.78551	26.334539	24.416611	23.67744	22.927557	22.725628	60.036819	29.963181	29.963181
	13	31.37093	27.914741	25.532706	24.696538	23.840181	23.6212	60.101687	29.898313	29.898313
	14	32.084409	28.918994	26.47072	25.555951	24.618063	24.377942	55.29542	34.70458	34.70458
7	15	31.85821	29.120159	26.97975	26.033996	25.072095	24.822066	47.302778	42.697222	42.697222
	16	30.770012	28.611481	26.864219	25.954269	25.040203	24.800032	37.689654	52.310346	35
	17	29.339427	27.743834	26.249637	25.431098	24.619244	24.405093	27.375316	62.624684	35
	18	27.925428	26.584849	25.318595	24.633507	23.959285	23.787517	16.891799	73.108201	25
	19	26.50654	25.323025	24.283796	23.746939	23.215912	23.08868	6.612471	83.387529	15
	11	26.344578	24.503012	23.467006	22.968642	22.468137	22.32236	54.895855	35.104145	30
	12	28.105669	25.865064	24.531999	23.929434	23.335708	23.183807	59.76497	30.23503	30.23503
	13	29.20054	26.777165	25.325969	24.713938	24.066155	23.899473	59.817987	30.182013	30.182013
	14	29.743709	27.341804	25.91693	25.31159	24.668414	24.498651	55.030569	34.969431	34.969431
8	15	29.641395	27.493016	26.23005	25.66007	25.054276	24.891531	47.062185	42.937815	42.937815
	16	28.88781	27.186409	26.192005	25.686793	25.154752	25.009835	37.465213	52.534787	35
	17	27.855852	26.608132	25.878435	25.456218	25.013996	24.893313	27.157761	62.842239	25
	18	26.70362	25.835542	25.309113	24.98742	24.646194	24.558419	16.673523	73.326477	15
	19	25.632117	25.030607	24.653681	24.431496	24.190125	24.133693	6.387416	83.612584	0
	11	27.424196	25.356491	24.193314	23.709873	23.219044	23.083217	54.657804	35.342196	35.342196
	12	29.473926	26.881278	25.3725	24.808277	24.205661	24.044688	59.489139	30.510861	30.510861
	13	30.719212	27.874105	26.202361	25.635608	25.012178	24.853434	59.529621	30.470379	35
	14	31.282026	28.447087	26.788221	26.224668	25.605912	25.445009	54.760523	35.239477	43
9	15	31.021889	28.5022	27.038556	26.504622	25.926511	25.773159	46.816292	43.183708	43.183708
	16	29.971677	27.997951	26.861726	26.390305	25.889596	25.754357	37.235596	52.764404	43
	17	28.514595	27.120946	26.31918	25.935788	25.533962	25.425189	26.935196	63.064804	35
	18	27.009005	26.073456	25.514706	25.235695	24.941012	24.867688	16.450364	73.549636	25
	19	25.680423	25.040547	24.648545	24.467284	24.265494	24.223943	6.15755	83.84245	0
	11	25.7825	24.043294	23.113386	22.632342	22.131097	21.985237	54.41648	35.58352	30
	12	27.47092	25.314727	24.050206	23.474967	22.925593	22.780794	59.20939	30.79061	30.79061
	13	28.552476	26.213639	24.808056	24.19857	23.572725	23.415571	59.236679	30.763321	30.763321
	14	29.089299	26.771851	25.390048	24.772864	24.134084	23.964327	54.485375	35.514625	35.514625
10	15	28.956717	26.904632	25.690452	25.110811	24.502827	24.339296	46.565176	43.434824	43.434824
	16	28.260098	26.633544	25.676234	25.162131	24.623165	24.476602	37.000874	52.999126	25
	17	27.251802	26.060652	25.357108	24.929743	24.484635	24.365008	26.707687	63.292313	25
	18	26.143732	25.3022	24.78716	24.456806	24.115308	24.028025	16.222391	73.777609	15
	19	25.044789	24.461617	24.087614	23.855475	23.607196	23.547974	5.922946	84.077054	0

September										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
11	11	25.117452	23.279495	22.275305	21.711673	21.160846	21.010032	54.171916	35.828084	31
	12	27.102359	24.818764	23.491587	22.898777	22.288295	22.116218	58.925785	31.074215	31.074215
	13	28.39619	25.973236	24.498822	23.846654	23.208006	23.049108	58.939252	31.060748	31.060748
	14	29.037334	26.67182	25.240548	24.600563	23.928381	23.755048	54.205215	35.794785	35.794785
	15	28.89774	26.815277	25.566232	24.967341	24.338595	24.169484	46.308919	43.691081	43.691081
	16	28.104976	26.446313	25.455242	24.913522	24.359738	24.209168	36.761118	53.238882	25
	17	27.016637	25.79175	25.053206	24.601947	24.147089	24.023662	26.475305	63.524695	15
	18	25.91334	25.054028	24.516418	24.17151	23.818549	23.726539	15.989676	74.010324	0
	19	24.965493	24.359846	23.95779	23.70723	23.446468	23.385334	5.683679	84.316321	0
12	11	25.975435	24.097448	23.081597	22.603112	22.103696	21.956877	53.924146	36.075854	31
	12	27.961329	25.65683	24.301555	23.726354	23.16599	23.020145	58.63839	31.36161	31.36161
	13	29.283631	26.789163	25.297451	24.699166	24.070097	23.909858	58.637432	31.362568	31.362568
	14	29.935284	27.478485	26.022195	25.432009	24.807906	24.644727	53.920139	36.079861	36.079861
	15	29.848489	27.672373	26.396211	25.846425	25.263819	25.108776	46.047604	43.952396	43.952396
	16	29.115831	27.389238	26.385073	25.896085	25.385578	25.246659	36.516406	53.483594	35
	17	28.003383	26.762947	26.040609	25.64173	25.227712	25.114875	26.238123	63.761877	35
	18	26.815428	25.976394	25.470119	25.178797	24.870428	24.792101	15.752294	74.247706	15
	19	25.768763	25.193198	24.834415	24.638775	24.423219	24.374451	5.439828	84.560172	0
13	11	25.408503	23.797483	22.897175	22.371482	21.863971	21.729187	53.673203	36.326797	31
	12	27.18941	25.268759	24.143143	23.556673	22.98285	22.826035	58.347268	31.652732	31.652732
	13	28.315746	26.289049	25.082192	24.485899	23.878864	23.723682	58.33131	31.66869	31.66869
	14	28.865966	26.894448	25.7301	25.15331	24.56401	24.407196	53.630243	36.369757	35
	15	28.820109	27.068988	26.046672	25.510352	24.96509	24.818871	45.781317	44.218683	35
	16	28.252602	26.842377	26.025314	25.550589	25.069966	24.940862	36.266814	53.733186	35
	17	27.331834	26.302857	25.705741	25.318863	24.925857	24.822337	25.996217	64.003783	25
	18	26.356021	25.642491	25.214881	24.924223	24.627122	24.553105	15.510322	74.489678	15
	19	25.662169	25.084437	24.738617	24.516021	24.278274	24.224985	5.191474	84.808526	0
14	11	25.834252	22.978547	21.496736	20.943975	20.36837	20.195732	53.419119	36.580881	31
	12	29.117127	25.08357	22.898647	22.206707	21.481547	21.283046	58.052484	31.947516	31.947516
	13	31.187598	26.931277	24.212343	23.431433	22.602875	22.393162	58.020979	31.979021	31.979021
	14	32.103692	28.301644	25.339245	24.484126	23.578537	23.350391	53.335624	36.664376	36.664376
	15	31.941507	28.753465	26.042325	25.164761	24.242068	24.005473	45.510147	44.489853	44.489853
	16	30.8832	28.398762	26.153638	25.309658	24.435975	24.207846	36.012423	53.987577	35
	17	29.389441	27.564016	25.704668	24.949026	24.180034	23.977832	25.749665	64.250335	25
	18	27.77631	26.302219	24.774524	24.165019	23.5472	23.394247	15.26384	74.73616	25
	19	26.221173	24.921107	23.678542	23.21229	22.73515	22.628772	4.938699	85.061301	15
15	11	25.021525	22.722037	21.409407	20.887518	20.374151	20.229453	53.16193	36.83807	32
	12	27.568389	24.66989	22.967156	22.366069	21.713129	21.530711	57.754103	32.245897	32.245897
	13	29.087096	25.995846	24.032865	23.39709	22.762828	22.600932	57.70653	32.29347	32.29347
	14	29.804785	26.780342	24.864437	24.203617	23.502787	23.333695	53.036382	36.963618	36.963618
	15	29.637501	26.975182	25.30685	24.685743	24.007754	23.832248	45.234184	44.765816	44.765816
	16	28.667528	26.57211	25.26416	24.710011	24.118661	23.957236	35.753319	54.246681	25
	17	27.237352	25.739196	24.790874	24.338022	23.861349	23.728314	25.498549	64.501451	15
	18	25.765422	24.7441	24.056465	23.715538	23.352421	23.262751	15.01293	74.98707	0
	19	24.550957	23.800115	23.259439	23.014093	22.754128	22.698662	4.681589	85.318411	0
16	11	18.771359	18.588353	18.487582	18.398348	18.31398	18.294376	52.901668	37.098332	32
	12	19.348978	19.075863	18.937621	18.822532	18.718895	18.69478	57.452191	32.547809	32.547809
	13	19.97105	19.590389	19.390177	19.220774	19.070989	19.03944	57.388058	32.611942	32.611942
	14	20.549066	20.11427	19.883539	19.683252	19.502303	19.460974	52.732618	37.267382	37.267382
	15	21.00392	20.562073	20.32686	20.115101	19.922532	19.877453	44.953523	45.046477	45.046477
	16	21.247603	20.832369	20.610927	20.405814	20.21874	20.174694	35.489586	54.510414	35
	17	21.241963	20.892559	20.706431	20.530955	20.368428	20.331173	25.242952	64.757048	25
	18	20.960012	20.69989	20.562024	20.430424	20.304727	20.277768	14.757677	75.242323	15
	19	20.411479	20.242404	20.151445	20.062702	19.976606	19.959484	4.420231	85.579769	0
17	11	18.880657	18.637453	18.510915	18.388243	18.276312	18.248481	52.63837	37.36163	32
	12	19.673462	19.236375	19.023989	18.855713	18.709798	18.673557	57.146812	32.853188	32.853188
	13	20.500139	19.87077	19.548746	19.305869	19.094888	19.048578	57.065657	32.934343	32.934343
	14	21.136873	20.449224	20.092598	19.809433	19.55801	19.498525	52.424434	37.575566	37.575566
	15	21.60827	20.928835	20.575628	20.277868	20.012476	19.948305	44.668258	45.331742	45.331742
	16	21.81966	21.207367	20.888316	20.606505	20.353079	20.292095	35.221313	54.778687	35
	17	21.80601	21.29436	21.025105	20.780246	20.557939	20.505335	24.982961	65.017039	25
	18	21.561845	21.151976	20.937983	20.741493	20.560868	20.519385	14.498169	75.501831	15
	19	21.048831	20.747568	20.596398	20.452966	20.318437	20.28902	4.154715	85.845285	0
18	11	20.857527	19.970864	19.532432	19.237162	18.984736	18.922284	52.372069	37.627931	33
	12	22.486778	21.207304	20.529717	20.101043	19.717877	19.621084	56.838034	33.161966	33.161966
	13	23.62894	22.274177	21.429694	20.908936	20.436818	20.317669	56.739419	33.260581	33.260581
	14	24.366307	22.96081	22.198076	21.66442	21.137365	21.003406	52.111933	37.888067	37.888067
	15	24.666635	23.321946	22.659562	22.22957	21.760076	21.622719	44.378488	45.621512	45.621512
	16	24.543487	23.385777	22.835398	22.46692	22.110631	22.010608	34.948592	55.051408	35
	17	24.111396	23.192748	22.777247	22.485074	22.213113	22.141657	24.718664	65.281336	25
	18	23.490966	22.835812	22.547179	22.342289	22.151064	22.099841	14.234493	75.765507	15
	19	22.853874	22.395824	22.171272	22.016506	21.863112	21.81929	3.885133	86.114867	0
19	11	23.906093	21.904143	20.823992	20.328099	19.864472	19.738019	52.102802	37.897198	33
	12	26.219656	23.676273	22.245808	21.606575	20.977459	20.812538	56.525922	33.474078	33.474078
	13	27.765939	25.067353	23.409995	22.794008	22.123682	21.940881	56.40944	33.59056	33.59056
	14	28.570515	25.977756	24.341151	23.676361	23.030471	22.866281	51.79522	38.20478	38.20478
	15	28.597104	26.32408	24.893029	24.26222	23.61729	23.456861	44.084312	45.915688	45.915688
	16	27.892798	26.110492	24.98559	24.426798	23.839206	23.691049	34.671517	55.328483	25
	17	26.865879	25.557891	24.71898	24.253313	23.757892	23.635467	24.450151	65.549849	15
	18	25.67644	24.76559	24.144955	23.791163	23.424766	23.343308	13.966742	76.033258	0
	19	24.605955	23.945661	23.472309	23.22959	22.987229	22.940569	3.611578	86.388422	0
20	11	24.59294	22.648618	21.580842	21.078929	20.609253	20.483395	51.830606	38.169394	33
	12	26.747187	24.373326	22.960205	22.320794	21.693279	21.530846	56.210544	33.789456	33.789456
	13	28.066484	25.570324	24.010095	23.355548	22.682966	22.501924	56.075815	33.924185	33.924185
	14	28.693569	26.272312	24.760894	24.099489	23.425896	23.255484	51.474401	38.525599	38.525599
	15	28.542687	26.441403	25.136899	24.52657	23.882764	23.716345	43.785832	46.214168	46.214168
	16	27.838871	26.180516	25.151752	24.613961	24.047922	23.893499	34.390183	55.609817	25
	17	26.828077	25.610492	24.843645	24.397474	23.93142	23.802656	24.177517	65.822483	15
	18	25.689232	24.841074	24.276669	23.941609	23.579376	23.482907	13.69501	76.30499	0
	19	24.747927	24.057474	23.594516	23.331316	23.035047	22.962023	3.334146	86.665854	0

September										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
21	11	24.770729	21.950938	20.466792	19.932576	19.383677	19.220131	51.555517	38.444483	34
	12	28.412425	24.387422	22.191741	21.504983	20.797434	20.605544	55.891969	34.108031	34.108031
	13	30.769481	26.488968	23.753405	22.982577	22.169229	21.966803	55.738639	34.261361	34.261361
	14	31.852817	28.032828	25.090067	24.253189	23.363821	23.144474	51.149583	38.850417	38.850417
	15	31.838817	28.635795	26.011383	25.15247	24.244399	24.016362	43.483152	46.516848	46.516848
	16	30.824992	28.358233	26.270526	25.454907	24.604896	24.389415	34.104687	55.895313	35
	17	29.3705	27.584023	25.940567	25.225088	24.490714	24.305302	23.900857	66.099143	25
	18	27.89651	26.56147	25.189142	24.615296	24.027183	23.890022	13.419391	76.580609	25
	19	26.65579	25.4548	24.317338	23.876987	23.419462	23.325599	3.052936	86.947064	15

In these tables the angles which are highlighted with green are the angles which are compatible with the previous calculations regarding to the internal temperatures. In this case not only we have the best position for the photovoltaic panels, but also, we have the internal temperature lower than 26°c.

The angles which are highlighted in red are the angles higher than 50°. As previously discussed, it is better not to have a rotational angle higher than 50°, because we won't have enough sunlight inside the place. We can see from the tables this happens mostly in the afternoon when sunset is gradually happening, as a result we will have a very low value for sun altitude and consequently high value for rotational angle. While we know during sunset our photovoltaic panels would not produce a considerable amount of electricity. So, in the case of having the rotational angle higher than 50° we stop at 50 and based on the previous calculations we follow the angle wich is more suitable for the internal temperature.

The angles which are highlighted in orange shows the angles in which the rotational angle is lower than the required angle for having the temperature lower than 26°c. This happens mostly in middays when we have the highest temperatures during the day, and it is crucial to shade enough the space. As the priority in this design is to provide a more comfortable space for the occupants rather than producing electricity, we adopt the angle which helps us the most to decrease the temperature.

The angles which are highlighted in yellow, are the angle related to the sunrise time when the sun altitude is very low, so the rotation angle will be higher than what is really necessary. In these hours the photovoltaic panels would not have the highest efficiency and considering that it is only necessary to close and open the shading device only once a day. We will choose a lower value for rotation which is the closest one to the calculated angle.

Finally, by defining the patterns of rotation for each day of summer and giving it to an internal control system it is possible to adopt the best position for our shading system.

5.2. Electrical calculations

5.2.1. Required electricity

Each module of the proposed shading device is consisted of two different panels. These two panels have different way of rotation. The upper panel moves by the help of a rotary actuator and the lower panel moves by the help of a slider actuator. These actuators need specific amount of electricity to perform the defined pattern of movement. For calculating the required amount of electricity for each one of the panels, it is necessary to know how much power is required to move the panels with their specific weight in the defined direction and pattern. These calculations have been done separately for each panels and at the end the values of upper and lower panels have been sum up together and that will be the final value of required electricity for each module to perform in the correct manner.

5.2.1.1. Lower panel

Figure 65 shows the lower panel of the shading device. In order to move it to be closed, for example in this case to move the panel from point «B» to the «Goal» position in «t» seconds the linear speed diagram in point «B» will be Figure 66.

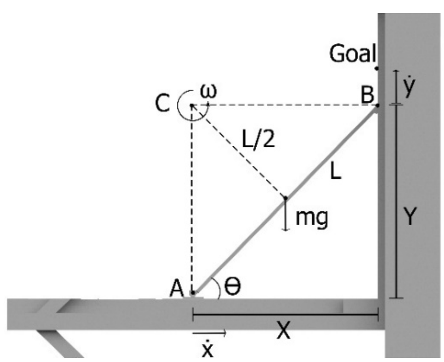


Figure 65: relation of the rotational degree and displacement of the lower panels, how to move from point «B» and reach the goal point.

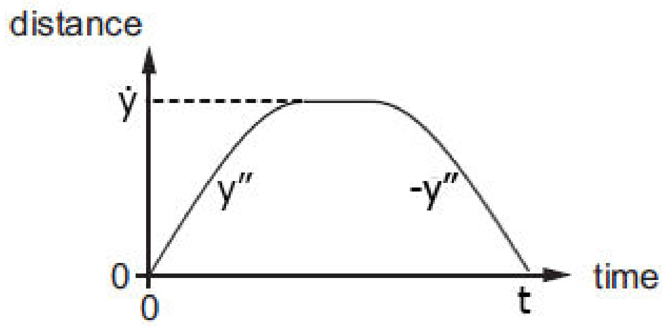


Figure 66:linear speed diagram of point «B», the variation of the distance with respect to the time.

As the actuator introduce the force in point «A» we have to define «y» as a function of «x».

$$\dot{y} = \frac{l}{tan\theta}\dot{x}\eta$$

Where;

η is power transmission efficiency coefficient according to the roller friction

If we define the angular velocity « ω » as the function of «x» and «y», we will have;

$$\omega_c = \dot{y}.l\,.cos\theta$$

$$\omega_c = \dot{x}.l\,.sin\theta$$

The moment of inertia of the panel for the point c will be ;

$$I_c = \frac{ml^2}{12} + m\left(\frac{l}{2}\right)^2 = \frac{ml^2}{12} + \frac{ml^2}{4} = \frac{4ml^2}{12} = \frac{ml^2}{3}$$

$$I_c = \frac{ml^2}{3}$$

Knowing that;

$$\tau_c = I_c.\alpha_c$$

Where;

τ_c is the torsion of point «c»

$I_c.\alpha_c$ is the angular acceleration

By knowing $\omega_c = \dot{y}.l.cos\theta$ the graph for ω_c as a function of time will be;

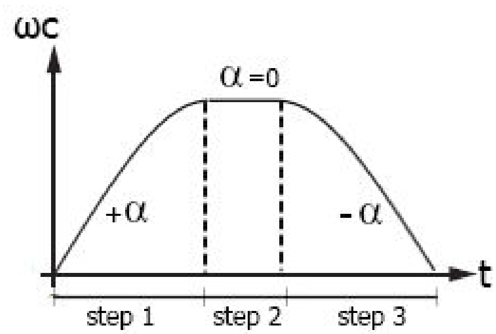


Figure 67: variation of angular velocity «ω_c» with respect to the time

The forces applied on the panel are shown in the Figure 68.

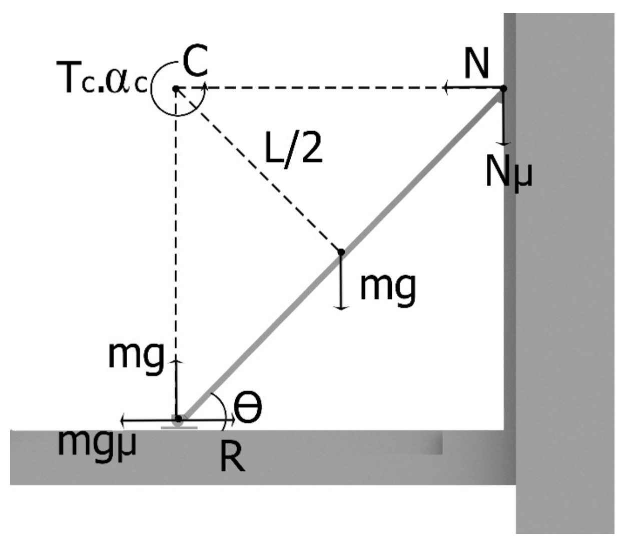


Figure 68: forces applied on the lower panel in order to move the panel from pint «B» and reach the goal point.

Where N will be;

$$N = mg\frac{cos\theta}{2(sin\theta + \mu cos\theta)}$$

In order to calculate the total force required to move the panel, it is necessary to calculate the forces in different steps as shown in Figure 67.

Step 1&3:

$$\tau_c = I_c.\alpha_c = \frac{ml^2}{3}.\alpha_c \qquad \begin{cases}\tau_c > 0 & if \quad \alpha > 0 \\ \tau_c < 0 & if \quad \alpha < 0\end{cases}$$

$$\mathrm{F}.l.sin\theta - mg.\mu.l.sin\theta - mg\frac{l}{2} - N.\mu.l.cos\theta = \tau_c$$

Where μ is coefficient of static surface friction

$$\mathrm{F}.l.sin\theta - mg.\mu.l.sin\theta - mg\frac{l}{2} - mg.\mu.\frac{cos\theta}{2(sin\theta + \mu\, cos\theta)}.cos\theta = \tau_c$$

$$\mathrm{F}.l.sin\theta = \tau_c + mg.l\left[\mu.sin\theta + \mu.\frac{cos^2\theta}{2(sin\theta + \mu\, cos\theta)} + \frac{1}{2}\right]$$

$$\mathrm{F} = \frac{\tau_c}{l.sin\theta} + \frac{mg}{sin\theta}\left[\mu.sin\theta + \mu.\frac{cos^2\theta}{2(sin\theta + \mu\, cos\theta)} + \frac{1}{2}\right]$$

$$\mathrm{F} = \frac{\tau_c}{l.sin\theta} + mg\left[\mu + \mu.cot\theta\frac{cos\theta}{2(sin\theta + \mu\, cos\theta)} + \frac{1}{2\, sin\theta}\right]$$

Step 2 $\alpha = 0$ constant ω $\tau_c = 0$

$$F = mg\left[\mu \,.\left(1 + cot\theta \ \frac{cos\theta}{2(sin\theta + \mu \ cos\theta)}\right) + \frac{1}{2 \ sin\theta}\right]$$

In order to calculate the required forces and electrical energy to move the lower panel we perform the calculation for a sample day, in this case 21 of June, and the same principal is applicable for the other days of the year.

June										
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
21	10	24.628934	24.064289	23.767418	23.411852	22.920349	23.833274	53.005391	36.994609	28
	11	26.977477	26.224593	25.832826	25.357231	24.674421	25.149253	61.695339	28.304661	28.304661
	12	28.86176	28.108498	27.757025	27.235121	26.455087	26.292578	67.156464	22.843536	50
	13	30.101037	29.423525	29.127555	28.630633	27.921087	27.216882	66.820905	23.179095	50
	14	31.000841	30.324079	30.04977	29.579415	28.911353	27.88736	60.89461	29.10539	50
	15	31.440805	30.802224	30.516574	30.104621	29.493816	28.273937	52.000316	37.999684	50
	16	31.333212	30.784724	30.507072	30.166906	29.645408	28.316643	41.911456	48.088544	50
	17	30.873464	30.438653	30.202511	29.910558	29.482041	28.092749	31.453447	58.546553	50
	18	30.29422	29.975703	29.7907	29.555852	29.217703	27.792554	21.066142	68.933858	50
	19	29.715708	29.486197	29.358215	29.186307	28.933982	27.487413	11.067303	78.932697	50

Figure 69: rotatonal angles for 21 of june for each hour of the day from 10 AM to 19 PM.

Figure 69 shows the rotational angles for the 21 of June. It can be seen that starting from 10 AM in the morning, the panel starts to rotate and reaches 50° at 12 AM then returns to 0° at 8 PM. As we are calculating the forces for the time when the shading is closing, we should consider t= 2hr. the return process is happening due to gravitational forces and with a hydraulic clamping system is possible to control the movement.

For this purpose we have already defined 3 steps to calculate the forces:

Step 1: First step happens when the panel starts to rotate. Considerin Figure 65 we have the following formulas and values:

$$\mathrm{F} = \frac{\tau_c}{l.sin\theta} + mg\left[\mu \,.\left(1 + cot\theta \ \frac{cos\theta}{2(sin\theta + \mu \ cos\theta)}\right) + \frac{1}{2 \ sin\theta}\right]$$

Where:

$l = 0.5 \ m$

$\mu = 0.14$ for steel

$m =$ is the weight of the panel.

This panel is made of steel plate of 1m×0.5m×0.002m which has the weight of 7.85 kg and a PV panel which has the weight of 1.2 kg. so;

$$m = 7.85kg + 1.2\ kg = 9.05\ \text{kg}$$

$$I_c = \frac{ml^2}{3} = \frac{7.85kg\ .(0.5m)^2}{3} = 0.65\ \text{kg}.m^2$$

in order to calculate α_c, first we need to obtain ω_c for all required rotational degree. Then the value of α_c is equal to the slope of the graph $\omega_c - t$ of Figure 67.

ẏ	l	Θ°	Θ [Rad]	cosΘ	sinΘ	ω_c
0	0.5	0	0	1	0	0
0.234626	0.5	28	0.488444	0.883064	0.469253	0.103595
0.353413	0.5	45	0.785	0.707388	0.706825	0.125
0.38288	0.5	50	0.872222	0.643126	0.76576	0.12312

Figure 70: values of angular velocity for different Θ

having the values of α_c and I_c , now we can obtain the values of τ_c which is equal to:

$$\tau_c = I_c.\alpha_c$$

αc	I_c	τ_c
0	0.65	0
0.103595	0.65	0.067337
0.016054	0.65	0.010435
-0.00047	0.65	-0.00031

Figure 71: values of torsion of point c for different angular acceleration α_c

So we have:

τ_c	l [m]	cosΘ	sinΘ	cotΘ	m [kg]	g [kg.m/s2]	μ	F [N]
0	0.5	1	0	∞	9.05	9.8	0.14	0
0.003525	0.5	0.883064	0.469253	1.881851	9.05	9.8	0.14	124.3342
0.100722	0.5	0.707388	0.706825	1.000797	9.05	9.8	0.14	151.8996
-0.00031	0.5	0.643126	0.76576	0.839854	9.05	9.8	0.14	74.24393

Figure 72: required load to move the panel to each desired rotational angle

The movement for each panel happens with two actuators, so the calculated forces should be divided by two, in order to find the electricity consumption for each actuator. For this purpose, we use the graph of currents with respect to loads which is already provided by the manufacturer. We mark the required loads on the graph to see how much current is required to move the panels, Figure 73.

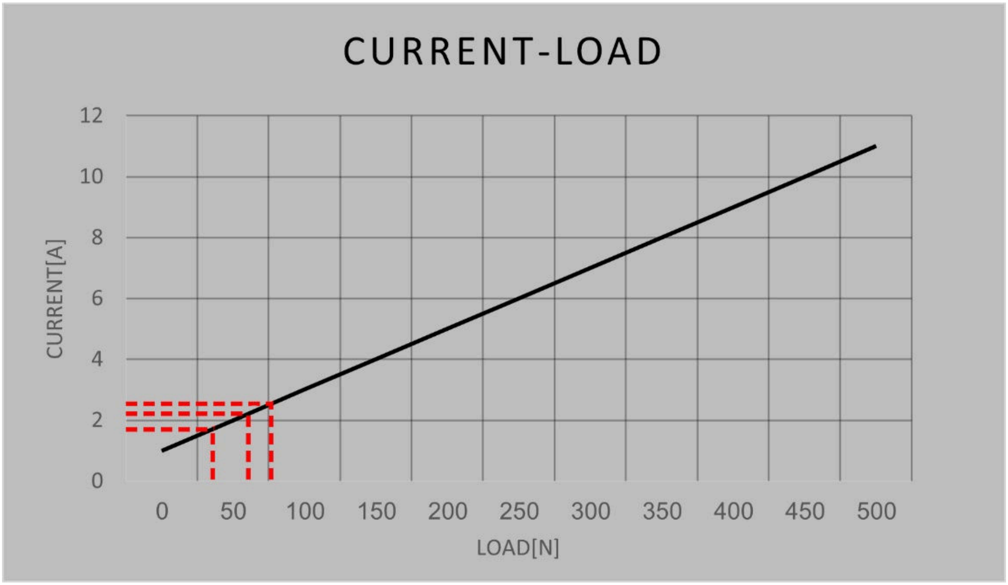


Figure 73: required current [A] corresponding to the applied load [N]

Plotting each value of current we can have the required electrical energy using the following formula;

W=V.I

V [v]	I [A]	W [W]
24	2.3	55.2
24	2.1	50.4
24	1.8	43.2
		148.8

Figure 74:electricity power [w] required, with respect to the required current [A] to move the panel in one day

One slider actuator will use 148.8 W of electricity, this value for two sliders of a panel will be equal to 297.6 W.

5.2.1.2. Upper panel

The upper panel has two types of movements: one movement for closing and one for opening the shading device. The closing movement includes a rotation from up to down. This rotation happens with the help of gravitational force. In this case it is only necessary to have a hydraulic clamping system to allow the movements happen slowly. This characteristic has been already provided by the chosen actuator. But for opening the panel which includes the rotation from down to up. And it is the amount of energy that needs to be calculated in order to be provided by electrical sources.

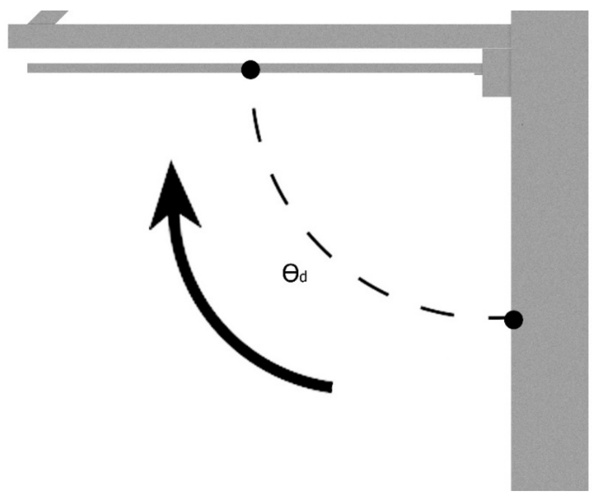


Figure 75: Rotation of the upper panel to reach the desired position with the angle of Θ_d

Where Θ_d is the desired angle to reach the goal position.

In this case we are using "computed torque control" which is a kind of PID control system.

$$\tau = M(\ddot{\theta}_d + K_p\theta_d + K_i\int \theta_e \, dt + K_d\,\dot{\theta}_e) + \tilde{h}(\theta.\dot{\theta})$$

Where:

τ is the required torsion that DC motor should provide.

M is the weight of the panel

$\ddot{\theta}_d$ is the second derivative of θ_d with respect to the time (acceleration)

K_p is the weight coefficient of the proportional control part

θ_e is the error parameter

$\theta_e = \theta_d - \theta(t)$

K_i is the weight coefficient of integral part

K_d is the weight coefficient of derivative part

$\dot{\theta}_e$ first derivative of error with respect to the time

$\tilde{h}(\theta.\dot{\theta})$ is the sum of all the required torsions to compensate with friction and gravitational forces;

$$\tilde{h}(\theta.\dot{\theta}) = C(\theta.\dot{\theta})\dot{\theta}(t) + g(\theta)$$

in this formula the friction part can be ignored due to lubrication and it will have a very low quantity. And the formula will be:

$$\tilde{h}(\theta.\dot{\theta}) = g(\theta) = mgl\frac{\sin\theta(t)}{2}$$

Considering the21 of June, The values for $\tilde{h}(\theta.\dot{\theta})$ will be;

t [h]	Θ(t)	Θ(t) [Rad]	sin Θ(t)	m[kg]	g [kg.m/s2]	l [m]	$\tilde{h}(\theta.\dot{\theta})$
19	0	0	0	9.05	9.8	0.5	0
19.5	25	0.436111	0.422418	9.05	9.8	0.5	9.366058
20	50	0.872222	0.76576	9.05	9.8	0.5	16.97881

Figure 76: values of torsions «$\tilde{h}(\theta.\dot{\theta})$» for the required rotational angles «Θ(t)» in different times «t»

So we have:

$$\tau = M(\ddot{\theta}_d + K_p\theta_e + K_i \int \theta_e \, dt + K_d \, \dot{\theta}_e) + \tilde{h}(\theta . \dot{\theta})$$

Θe°	Θe [Rad]	m [kg]	g [kg.m/s2]	$\ddot{\theta}_d$	K_p	K_i	K_d	t [h]	$\dot{\theta}_e$	$\tilde{h}(\theta.\dot{\theta})$	τ
50	0.87222	9.05	9.8	0	1	1	1	19	0	0	77.35739
25	0.43611	9.05	9.8	0	1	1	1	19.5	-0.21806	9.366058	38.68303
0	0	9.05	9.8	0	1	1	1	20	-0.21806	16.97881	12.32875

Figure 77: values of the required loads to rotate the panel
in each degree «Θ(t)» at different times« t »

The movement for each panel happens with two actuators, so the calculated forces should be divided by two, in order to find the electricity consumption for each actuator. For this purpose we use the graph of currents with respect to loads which is already provided by the manufacturer. We mark the required loads on the graph to see how much current is required to move the panels, Figure 78.

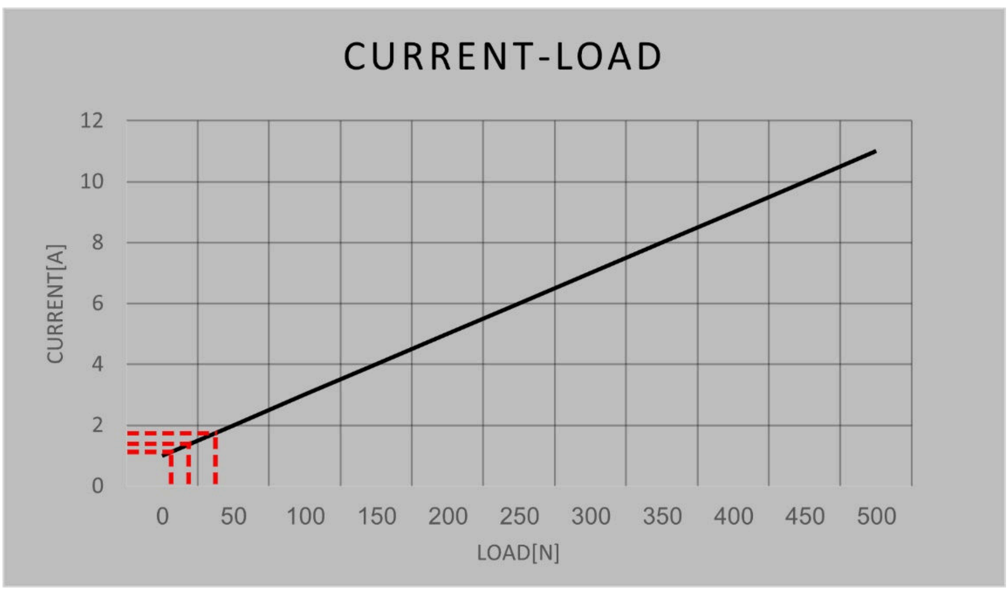


Figure 78: required current [A] corresponding to the applied load [N]

Plotting each value of current we can have the required electrical energy using the following formula;

$$W=V.I$$

V [v]	I [A]	W [w]
24	1.6	38.4
24	1.7	40.8
24	1.9	45.6
		124.8

Figure 79: electricity power [w] required, with respect to the required current [A] to move the panel in one day

One slider actuator will use 124.8 W of electricity, this value for two sliders of a panel will be equal to 249.6W.

In total each module needs 547.2 W of electricity to do the required movement in a day.

5.2.2. Produced electricity

Inorder to calculate the electricity produced by our Photovoltaic panels we used the softwares "Ladybug" and "Honeybee". With this softwares it is possible to gain the huorly values of produced electricity for the target location. Considering the rotation of the panels we have the specific result for each degree of rotation in each hour of the day. In this case we are getting the results for 21of june.

		June								
days	hours	0° Rotation	15° Rotation	25° Rotation	35° Rotation	45° Rotation	50° Rotation	sun altitude	rotation angle	adopted rotational angle
21	10	24.628934	24.064289	23.767418	23.411852	22.920349	23.833274	53.005391	36.994609	28
	11	26.977477	26.224593	25.832826	25.357231	24.674421	25.149253	61.695339	28.304661	28.304661
	12	28.86176	28.108498	27.757025	27.235121	26.455087	26.292578	67.156464	22.843536	50
	13	30.101037	29.423525	29.127555	28.630633	27.921087	27.216882	66.820905	23.179095	50
	14	31.000841	30.324079	30.04977	29.579415	28.911353	27.88736	60.89461	29.10539	50
	15	31.440805	30.802224	30.516574	30.104621	29.493816	28.273937	52.000316	37.999684	50
	16	31.333212	30.784724	30.507072	30.166906	29.645408	28.316643	41.911456	48.088544	50
	17	30.873464	30.438653	30.202511	29.910558	29.482041	28.092749	31.453447	58.546553	50
	18	30.29422	29.975703	29.7907	29.555852	29.217703	27.792554	21.066142	68.933858	50
	19	29.715708	29.486197	29.358215	29.186307	28.933982	27.487413	11.067303	78.932697	50

Figure 80 :rotatonal angles for 21 of june for each hour of the day from 10 AM to 19 PM.

taking into account the rotational degree of the PV panels in the 21of June, Figure 80 shows the value of produced electricity for each hour of the day.

month	day	hour	produced electricity
june	21	1	0
june	21	2	0
june	21	3	0
june	21	4	0
june	21	5	1.03E-06
june	21	6	0.001226
june	21	7	0.010892
june	21	8	0.023479
june	21	9	0.037346
june	21	10	0.050934
june	21	11	0.06218
june	21	12	0.068248
june	21	13	0.070109
june	21	14	0.066994
june	21	15	0.059971
june	21	16	0.048529
june	21	17	0.034666
june	21	18	0.021344
june	21	19	0.008788
june	21	20	0.000792
june	21	21	8.90E-07
june	21	22	0
june	21	23	0
june	21	24	0
Total produced electricity [KW]			0.565499921

Figure 81:electricity power produced by one module[kwh] for 21 of June.

It can be seen from Figure 81 that our photovoltaic panels produce higher amount of electricity compared to required electricity in a day.

month	power produced [kwh]
january	2.467082678
february	3.888317432
march	7.713940523
april	11.18044102
may	14.50733939
june	15.01625032
july	15.61224823
august	12.78565189
september	9.022617118
october	5.493642928
november	2.388239894
december	1.804349076
annual power	101.8801205

Figure 82: monthly and annual power produced by one module.

Considering that in some months of the year, no rotation is needed, the power produced by the panels can be stored in the batteries for further used in other months or for usage of occupants control.

6. Comparison of the proposed shading device with case studies

In this chapter we are comparing the performance of the proposed shading device compared to the two of the case studies that we have introduced before in chapter 3, Al Bahr tower and Solar decathlon 2007, in terms of PMV (predicted mean vote) which represent the comfort condition in the building and percentage of the occupant satisfaction. Al Bahr tower has been chosen because it is a well known sample of building with a good adaptive kinetic shading system and Solar decathlon have been chosen because it is more similar sample in terms of system and performance to the proposed project. The analysis has been done for the summer time as it is the most critical time of the year the performance of the shading device matters. These analyses have been done with the help of softwares Ladybug and Honeybee.

6.1.1 Simple model without any shading

First, we analyze the simple model which is a box of 3m× 4m× 3m fully glazed on the southern façade without any shading applied on it. The analysis has been done for the summer in city of Milan. Figure 83 shows the result of PMV comfort analysis during the summer we have only 32.34% of comfortable hours in our case study room.

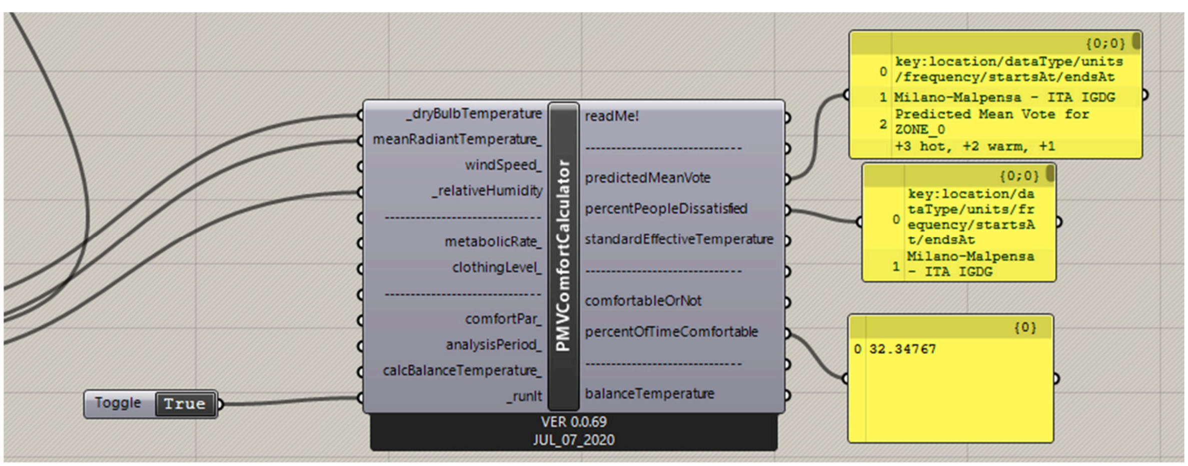


Figure 83: percentage of the comfortable hours in the summer for the simple model without shading

Figure 84 shows the percentage of dissatisfied occupants of the building for all hours of summer which shows a relatively high values, while at some point we see the percentages are very low, which are related to the night time while we have very high percentages during the day.

Figure 84: percentage of dissatisfied people for the summer in the simple model without shading

Figure 85 represent PMV comfort situation for all hours of summer which shows that with a fully glazed façade we have hot conditions inside our analyzed model.

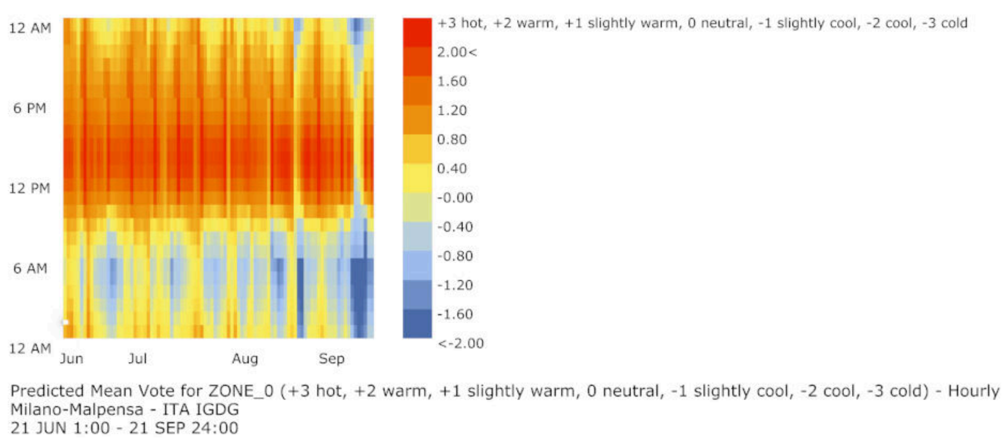


Figure 85: PMV comfort for the summer in the simple model without shading

6.1.2. Proposed shading device

In this part we add the designed shading to the southern façade of our model to see how the application of shading device will change the comfort of the occupants of the building and how it will change with different position of our device. Figure 86 shows that with simply adding the shading device without applying any rotation to it the percentage of comfortable hours from 32.34 will increase to 37.36.

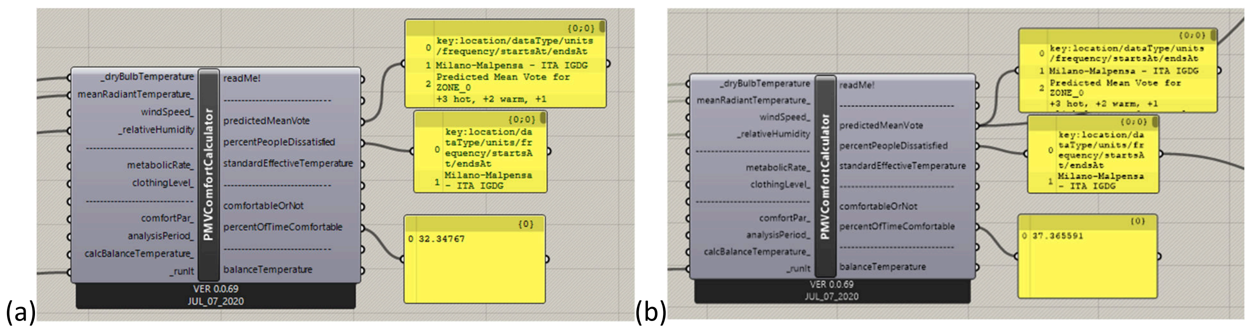


Figure 86: percentage of the comfortable hours in the summer. (a) simple model (b)model with shadings as overhangs

It can be seen from Figure 87 the percentage of comfortable hours in the analyzed model will increase when we gradually close the shading device. This value reach 60% of comfortable hours in the whole summer when the shading device is completely closed and the glazed surface is completely shaded.

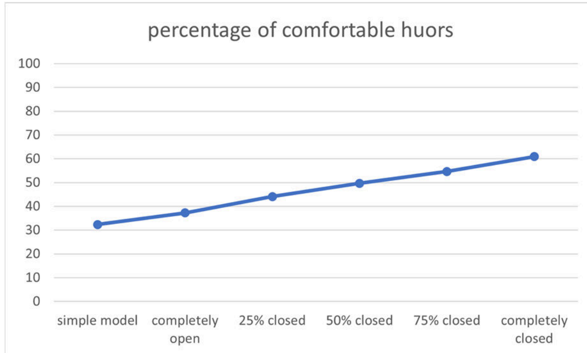


Figure 87: percentage of the comfortable hours in the summer for different opening percentages of the proposed shading device, starting from the model without shading, then adding the shading and gradually closing it, which shows the increase of comfortable hours by closing the device.

Figure 88 shows that with simply adding the shading device to the southern façade as an overhang without applying any degree of rotation we have a significant decrease of people dissatisfaction inside the building.

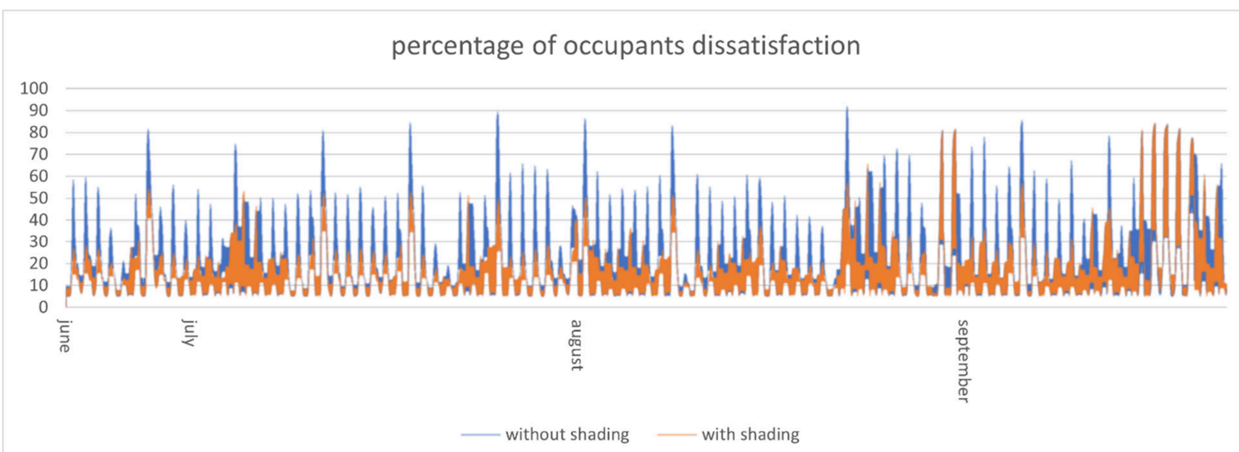


Figure 88: percentage of dissatisfied people for the summer comparing simple model without shading and with shadings as overhangs

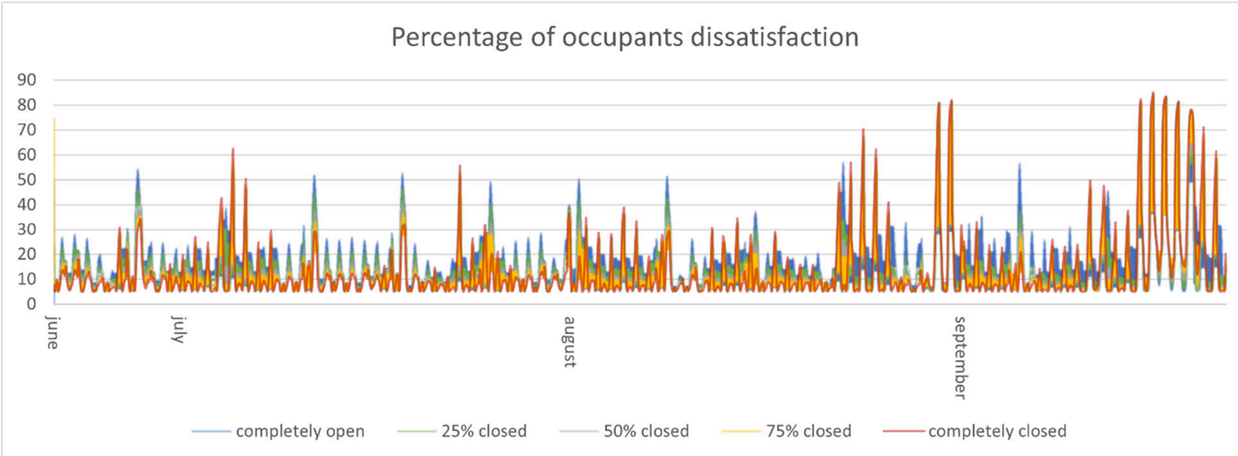


Figure 89: percentage of dissatisfied people for the summer comparing different percentage of shading device openings

From Figure 89 it can be seen with gradually closing the shading device and avoiding the solar radiation to heat up the space the percentage of people dissatisfaction will decrease little by little during the summer time. and we will have the lowest value of people dissatisfaction when the device is completely closed.

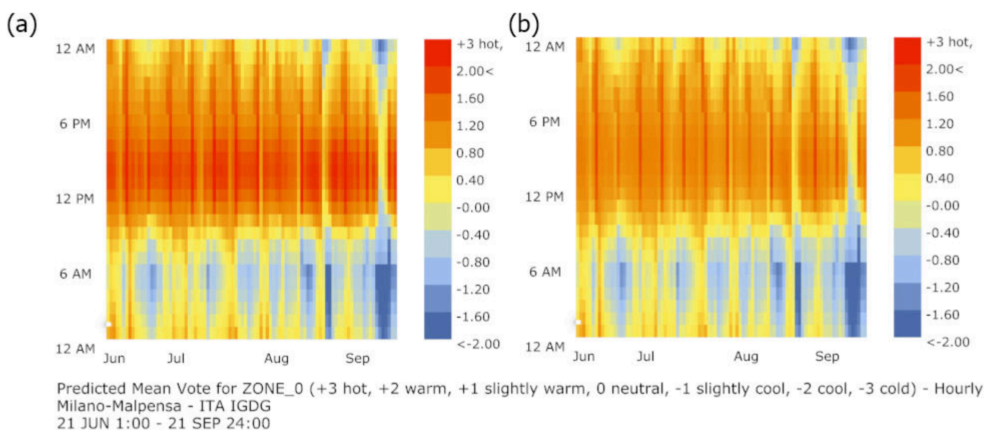


Figure 90: PMV comfort for the summer in the (a) simple model without shading (b) with overhangs

Comparing the PMV graphs represented in the Figure 90 , it can be clearly seen that adding a shading device will make the place more comfortable during the summer.

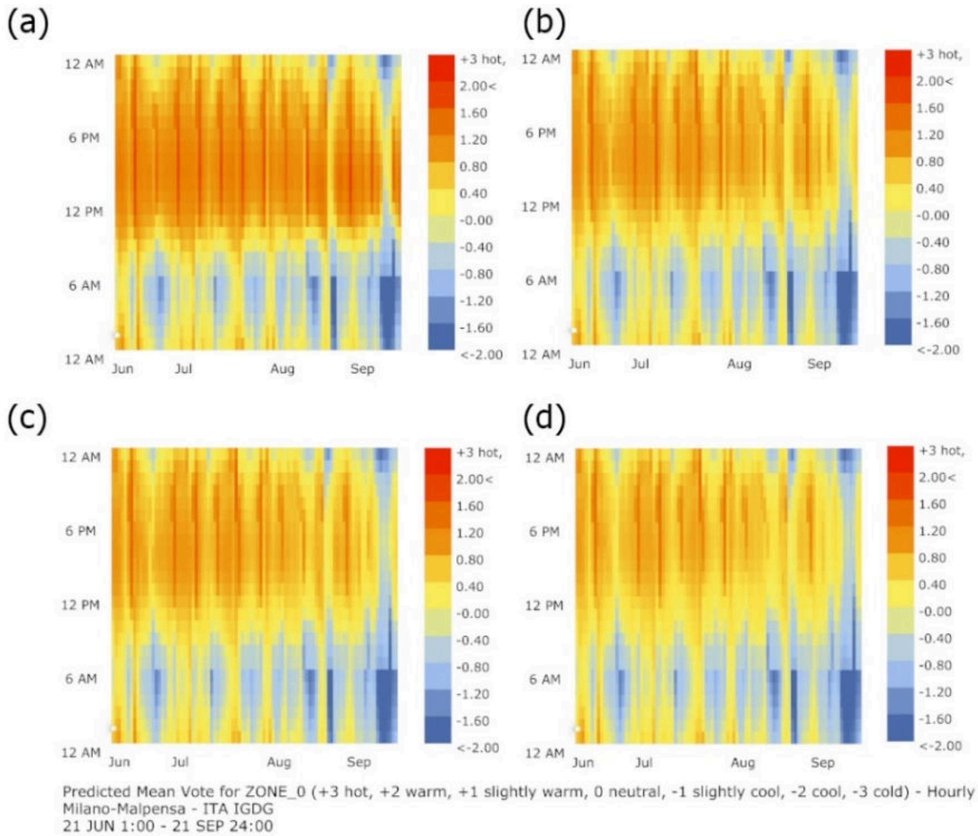
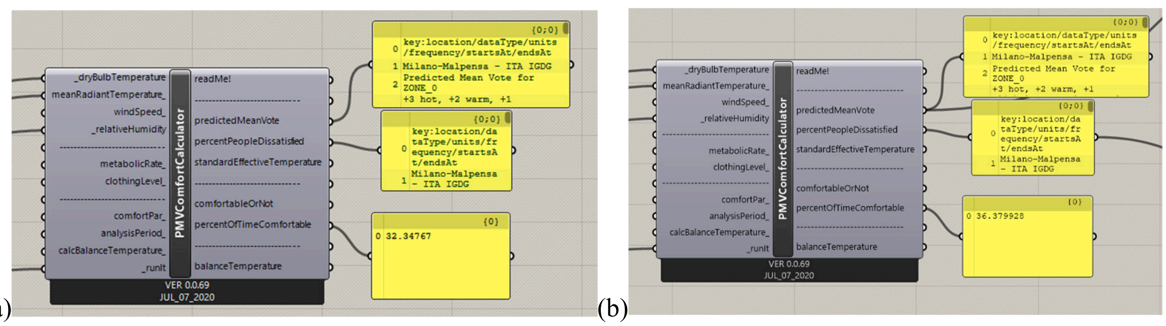


Figure 91: PMV comfort for the summer in the (a) 25% closed (b) 50% closed (c) 75% closed (d) completely closed

As represented in the Figure 91 which shows the values of PMV comforts for the analyzed model for different percentages of opening of the shading device, It can be seen that the gradually closing the shading device during the summer will provide more comfortable place for the occupants of the building. And the more comfortable situation will be reached when the device is completely closed and the glazed surface is shaded completely.

6.1.3. Al Bahr tower

In this part we add the shadings of Albahr tower to the southern façade of our model to see how the application of shading device will change the comfort of the occupants of the building and how it will change with different position. Figure 92 shows that with simply adding the shading device, the percentage of comfortable hours from 32.34 will increase to 36.37 and it is lower than our proposed shading device, which is 37.36.



(a) (b)

Figure 92: percentage of the comfortable hours in the summer. (a) simple model (b)model with shadings as overhangs

It can be seen from Figure 93 the percentage of comfortable hours in the analyzed model will increase when we gradually close the shading device. This value reach 60% of comfortable hours in whole summer when the shading device is completely closed and the glazed surface is completely shaded. But the percentages are generally lower than our proposed shading device. They only have the equal percentage of comfortable hours when both system are completely closed.

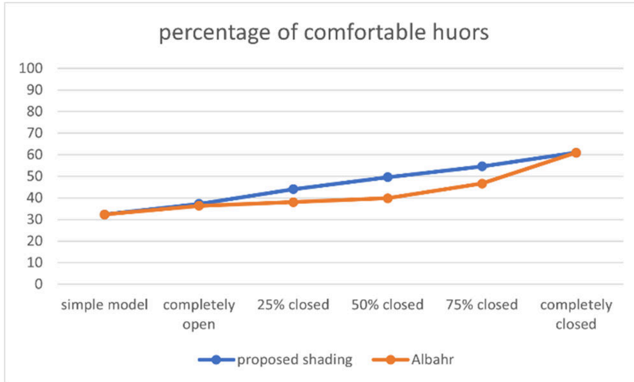


Figure 93: percentage of the comfortable hours in the summer for different opening percentages of Albahr tower compared to the proposed shading device, starting from the model without shading, then adding the shading and gradually closing it, which shows the increase of comfortable hours by closing the device.

Figure 94 shows that with adding the shading device to the southern façade we have a significant decrease of people dissatisfaction inside the building.

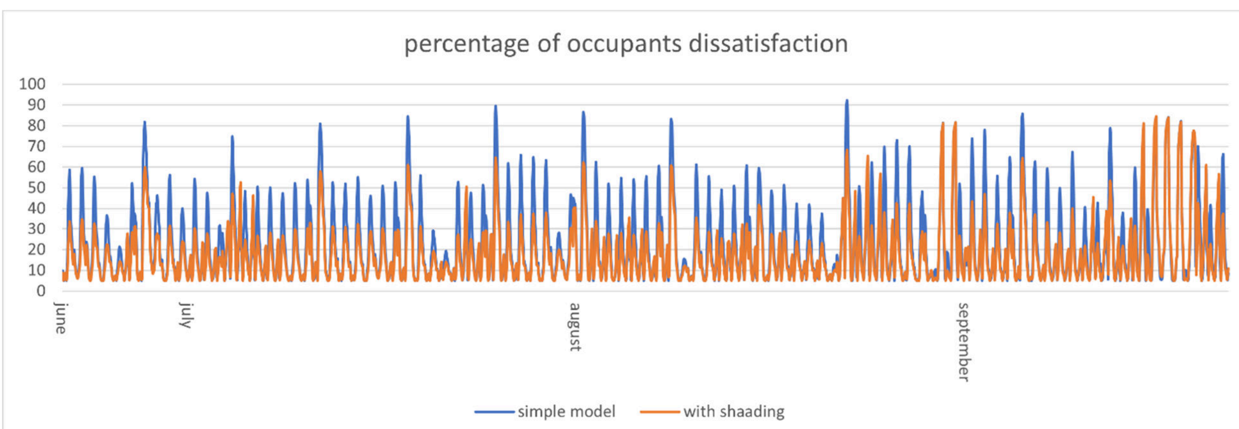


Figure 94: percentage of dissatisfied people for the summer comparing simple model without shading and with shadings

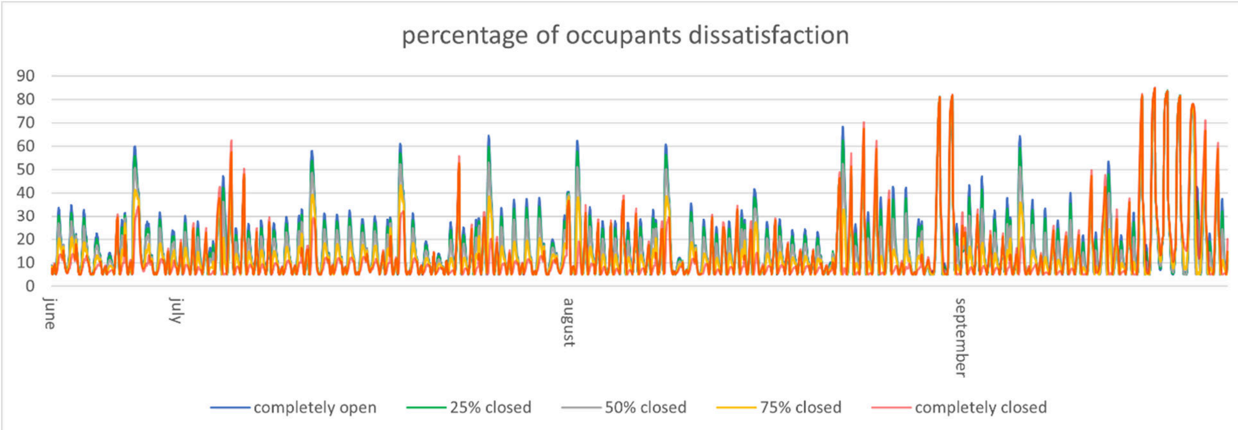


Figure 95: percentage of dissatisfied people for the summer comparing different percentage of shading device openings

From Figure 95 it can be seen with gradually closing the shading device and avoiding the solar radiation to heat up the space the percentage of people dissatisfaction will decrease little by little during the summer. and we will have the lowest value of people dissatisfaction when the device is completely closed.

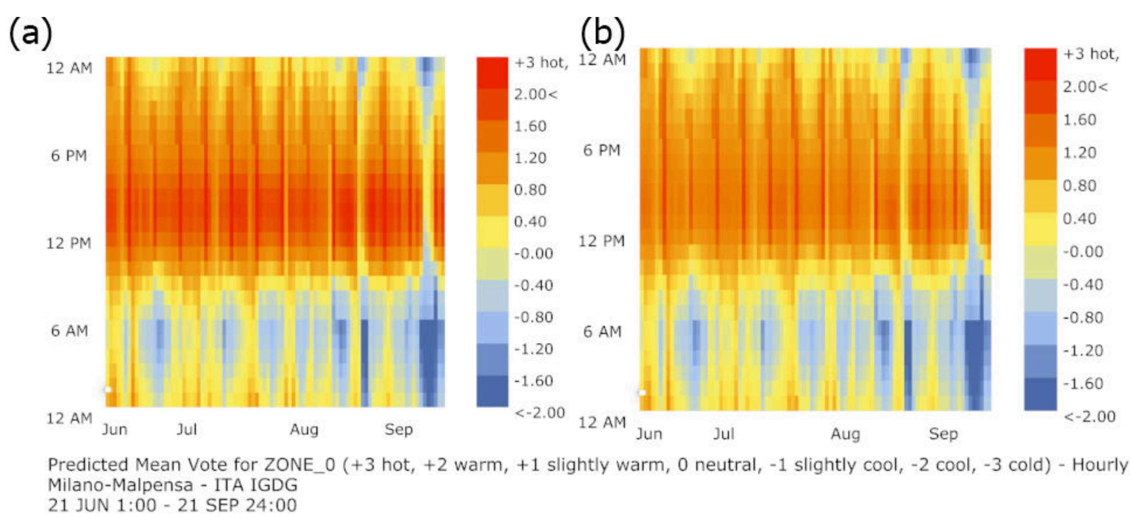


Figure 96: PMV comfort for the summer in the (a) simple model without shading (b) with shadings

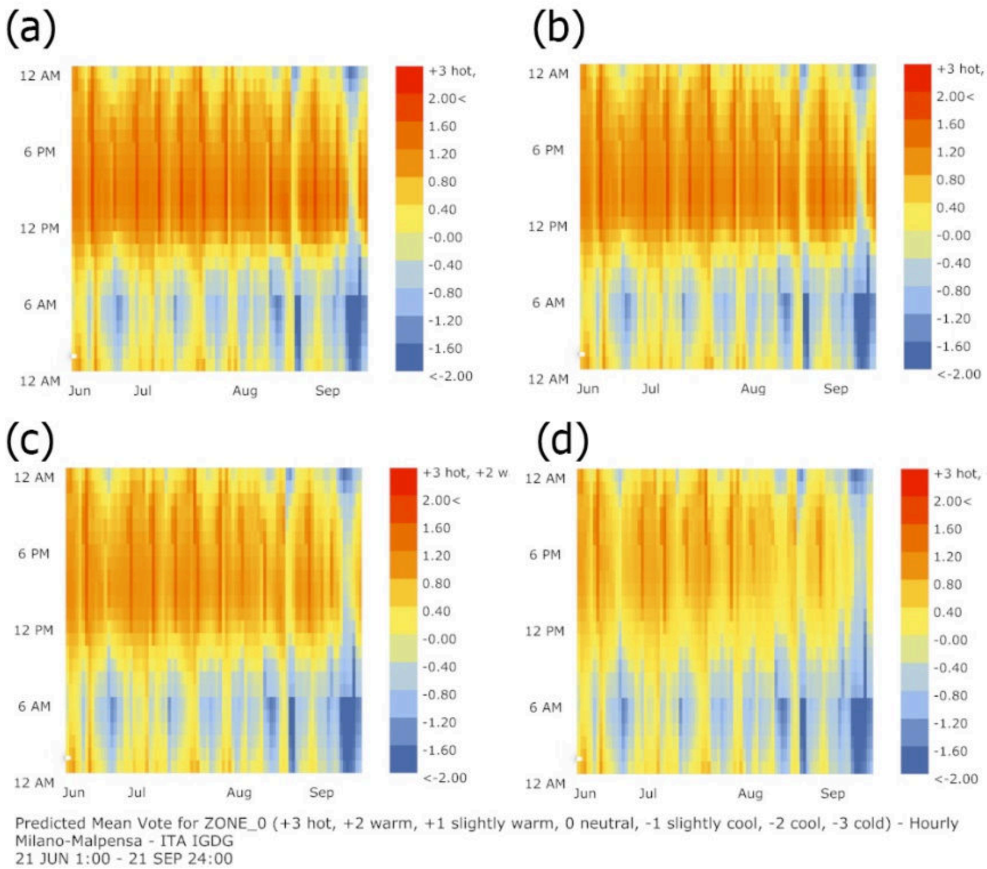


Figure 97: PMV comfort for the summer in the (a) 25% closed (b) 50% closed (c) 75% closed (d) completely closed

As represented in the Figure 97 which shows the values of PMV comforts for the shading of Albahr tower applied to the case study model for different percentages of opening, It can be seen that the gradually closing the shading device during the summer will provide more comfortable place for the occupants of the building. And the more comfortable situation will be reached when the device is completely closed and the glazed surface is shaded completely. But the except the completely closed position which has the exact same result of our proposed model the other opening positions of Albahr tower are less comfortable than the proposed shading device.

6.1.4. Solar decathlon 2007

In this part we add the shading of Solar decathlon 2007 to the southern façade of our model to see how the application of shading device will change the comfort of the occupants of the building and how it will change with different positions. Figure 98 shows that with simply adding the shading device without applying any rotation to it the percentage of comfortable hours from 32.34 will increase to 44.71.

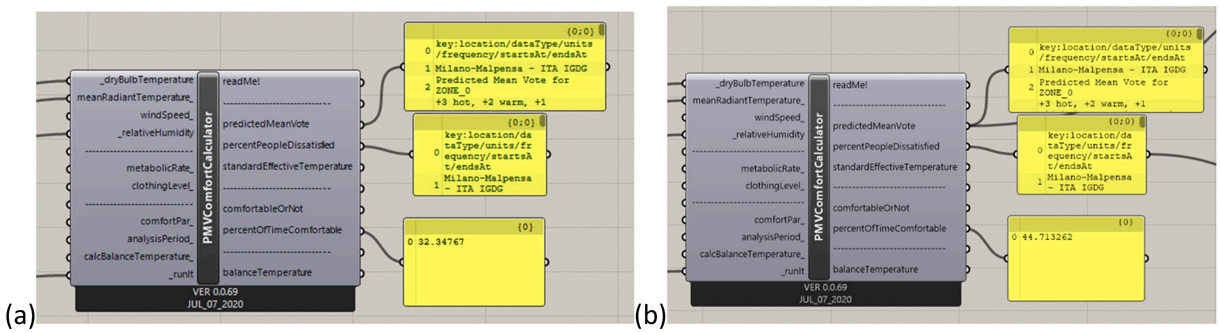


Figure 98: percentage of the comfortable hours in the summer. (a) simple model (b)model with shadings as overhangs

It can be seen from Figure 99 the percentage of comfortable hours in the analyzed model will increase when we gradually close the shading device. This value reach 60% of comfortable hours in whole summer when the shading device is completely closed and the glazed surface is completely shaded. This graph shows that the shading system of solar decathlon is performing better than the proposed shading device during the summer. But this system has also some other disadvantages; because it is not possible to remove the shadings from the surface of the window it causes visual discomfort, also this amount of shadings will also creates unnecessary shadows during the winter and increase the heating loads of the building. As it can be seen from the Figure 100, Despite of the good performance in the summer it creates an uncomfortable place in the winter.

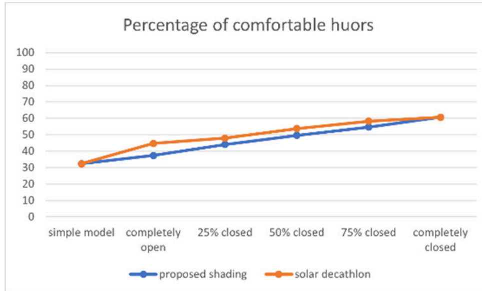


Figure 99: percentage of the comfortable hours in the summer for different opening percentages of Solar decathlon 2007 compared to the proposed shading device, starting from the model without shading, then adding the shading and gradually closing it, which shows the increase of comfortable hours by closing the device.

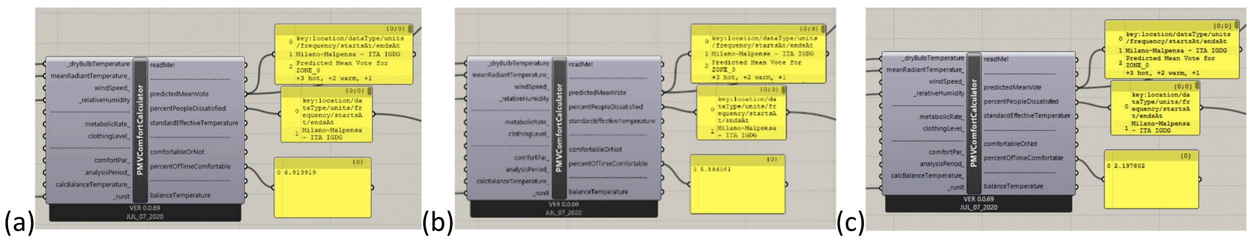


Figure 100 : percentage of the comfortable hours in the winter. (a) simple model without shading (b) model with proposed shading (c) solar decathlon shadings

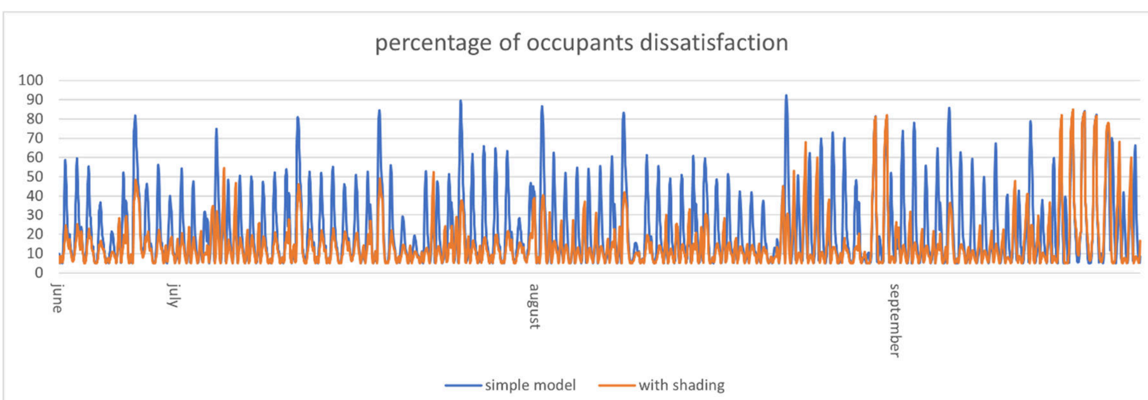


Figure 101: percentage of dissatisfied people for the summer comparing simple model withoutshading and with shadings

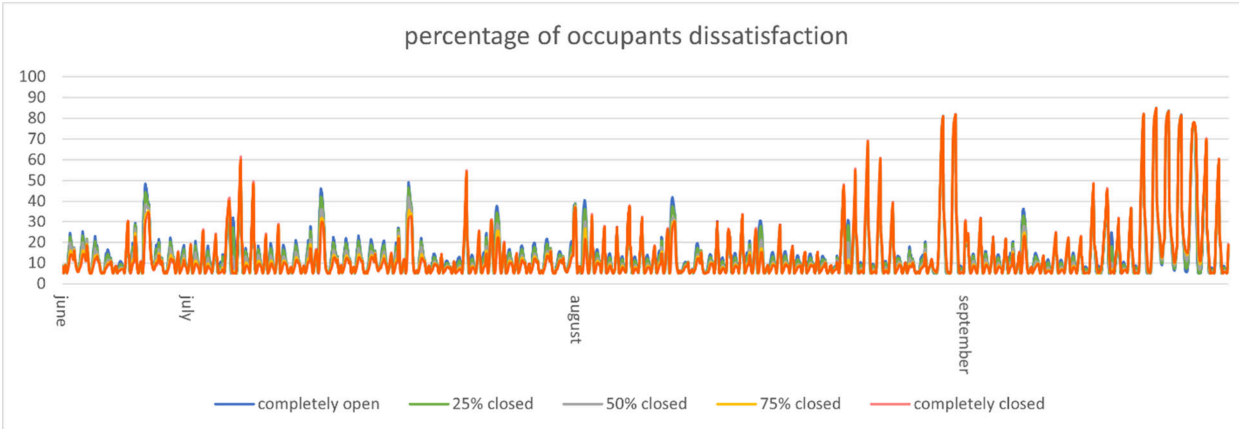


Figure 102: percentage of dissatisfied people for the summer comparing different percentage of shading device openings

From Figure 102 it can be seen with gradually closing the shading device and avoiding the solar radiation to heat up the space the percentage of people dissatisfaction will decrease little by little during the summer time. and we will have the lowest value of people dissatisfaction when the device is completely closed.

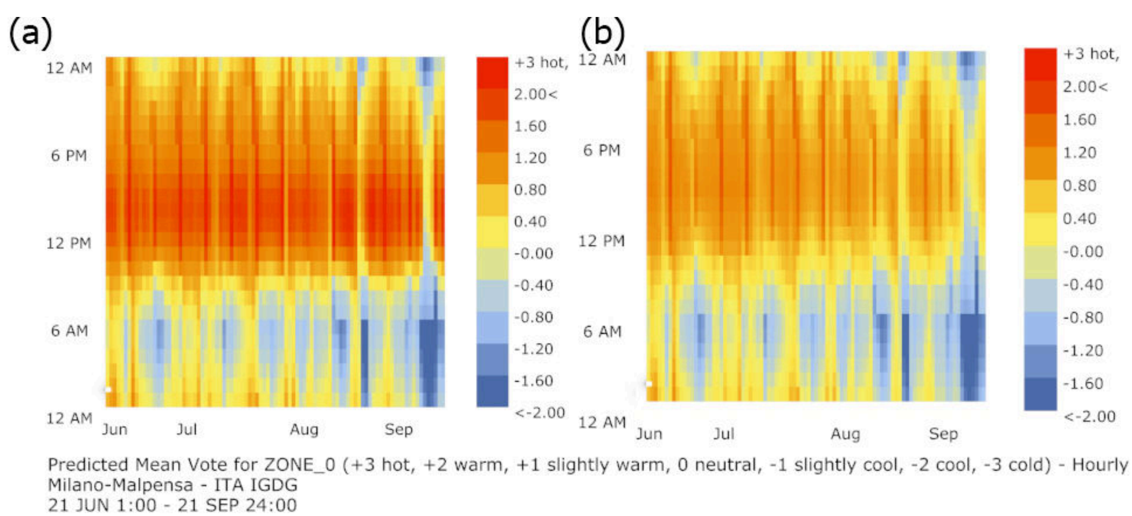


Figure 103: PMV comfort for the summer in the (a) simple model without shading (b) with shadings

Comparing the PMV graphs represented in the Figure 103, it can be clearly seen that adding a shading device will make the place more comfortable during the summer.

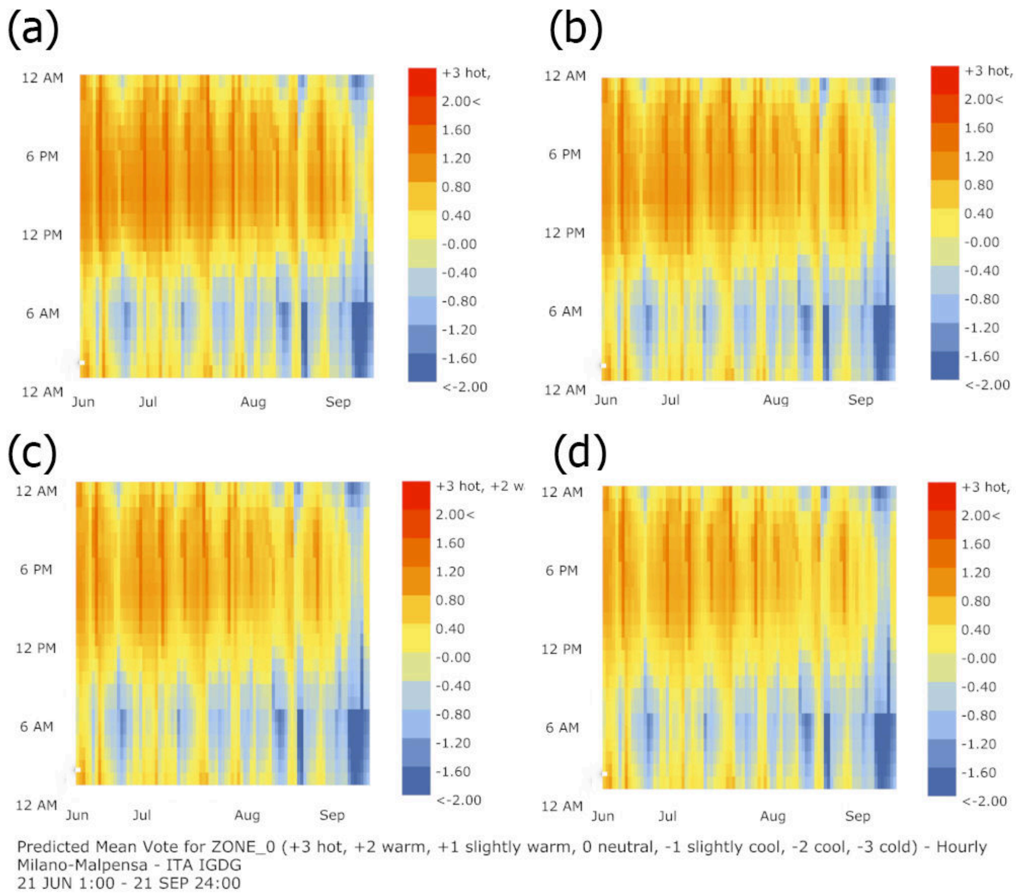


Figure 104: PMV comfort for the summer in the (a) 25% closed (b) 50% closed (c) 75% closed (d) completely closed

As represented in the Figure 104 which shows the values of PMV comforts for the analyzed model for different percentages of opening of the shading device, It can be seen that the gradually closing the shading device during the summer will provide more comfortable place for the occupants of the building. And the more comfortable situation will be reached when the device is completely closed and the glazed surface is shaded completely.

7. Conclusion

The aim of this thesis was to design a shading system which can help to reduce the energy consumption in a building. As previously discussed in the second chapter shading devices can be beneficial in reducing cooling loads of a building during summer, specially kinetic shading devices can perform much better than the normal shadings, due to the ability to shade when it is required.

In this thesis with the help of climatic softwares such as Ladybug and Honeybee and Velux daylight visualizer, a shading device was designed which is completely climatic responsive. With the help of this softwares the most proper shape was reached which is able to shade enough during the summer and consequently reduce the internal temperature, while keeping the good amount of daylight inside the building. It was really important not to over shade the façade both for having a good daylight and not shading the façade during the winter which can increase heating loads.

Performing the comparison in chapter 6, with a normal building without shading and with a very famous example of kinetic façade "Albahr tower" and also " solar decathlon 2007", it was possible to see that, we could gain the goal of the thesis. With this design we could reach a space which is more comfortable during the summer compared to the other examples while it does not shade the façade during the winter and let the sun to come inside the building and heats up the space. As mentioned before this shading keeps a good daylight inside the building, while visual comfort of the occupants have been also considered. As the device can be completely open.

This device moves by the help of electric actuator. The novel aspect of this device was being made of photovoltaic panels to produce the electricity required for the movement, so in this way there was no need to consume more electrical energy in order to have comfortable space inside. As it can be seen in the second section of chapter 5, this device is able to produce all the required energy for its movement.

8.References

Al-musaed A (2004) Intelligent sustainable strategies upon passive bioclimatic houses . Arkitektskole in Aarhus, Denmark

Almusaed A (2011) Biophilic and Bioclimatic Architecture, Denmark

Alter L (2017) “Villa Girasole: Rotating House Follows the Sun,” treehugger.com, Dec. 15, [Online] .Available : www.treehugger.com/corporate- responsibility/1935-villa-girasole-rotating-housefollows-the-sun.html

Armstrong A, Buffoni G, Eames D, James R, Lang L, Lyle J, et al. (2013) The Al Bahar Towers: Multidisciplinary design for Middle East high-rise. Arup J;2:90– 95.

Attia, Sh. (2016). Evaluation of adaptive facades: The case study of Al Bahr Towers in the UAE. QScience Connect, Shaping Qatar’s Sustainable Built Environment, 2.

Bier H, Knight T (2010) “Digitally-driven architecture”, Footprint: Delft School of Design journal, (6).

Buchanan, P. (2005). Ten shades of green: architecture and the natural world. New York: The Architectural League. Chartered Institute of Building Services Engineers (CIBSE) Code for Interior Lighting, (1994).

Butters C (2002) Architects in the time and space, understanding sustainability. UIA Congress,Berlin

Brown GZ (1985) Sun, wind and light: architectural design strategies. Wiley, pp 65- 67

Carron R, Nishiwaki S, Feurer T, Hertwig R, Avancini E, Löckinger J, Yang S.C, Buecheler S, Tiwari A.N(2019) Advanced Alkali Treatments for High-Efficiency $Cu(In,Ga)Se_2$ Solar Cells on Flexible Substrates, Advanced Energy Mater 9.

Chen S, Walsh A, Gong X.G (2013) Classification of Lattice Defects in the Kesterite Cu_2ZnSnS_4 and $Cu_2ZnSnSe_4$ Earth-Abundant Solar Cell Absorbers, Advanced Materials 25, 1522.

Cook J (ed) (1989) Passive cooling. MIT Press, Cambridge

Elmokadem A, Ekram M, Waseef A, Nashaat B. (2018). Kinetic architecture: Concepts, history and applications. International journal of science and research (IJSR), 7(4): 750-758.

Gupta S. K, Gupta S (2020) The role of nanofluids in solar thermal energy: A review of recent advances, materials today: proceedings.

Givoni B, La Roche P (2001) Radiant cooling systems for developing countries. Accepted forISES 2001, Adelaide Australia

Hoberman C, Schwitter C. (2008) Adaptive Building Initiative, NY, US

IEA, World Energy Statistics and Balances 2018. 2018a, Paris: OECD/IEA

IEA PVPS TRENDS (2015) in photovoltaic applications—executive summary, Report IEA-PVPST 1-27, October 2015.

Istrian Regional Energy Agency (IRENA), (2012), Photovoltaic systems.

Jamil Alkhayyat J (2013) Design strategy for adaptive kinetic patterns: creating a generative design for dynamic solar shading systems, University of Salford

Lee Y,Park C, Balaji N, Lee Y.J, Ai Dao V (2015) High-efficiency Silicon Solar Cells: A Review, Israel journal of chemistry.

Liu F, Zeng Q, Li J, Hao X, Ho-Baillie A, J (2020) Tang, M. A. Green, Emerging inorganic compound thin film photovoltaic materials: Progress, challenges and strategies, Materials today.

Metzger W. K, Grover S, Lu D, Colegrove E, Moseley J, Perkins C. L, Li X, Mallick R, Zhang W, Malik R, Kephart J, Jiang C.S, Kuciauskas D, Albin D. S, Al-Jassim M. M, Xiong G, Gloeckler M, (2019) Exceeding 20% efficiency with in situ group V doping in polycrystalline CdTe solar cells,Nature Energy volume 4, 837–845

Miles R.W, Zoppi G, Forbes I, (2007) Materials Today 10 : 20-27

Mitchell k, Fahrenbruch A.L , Bube R. H (1977) Photovoltaic determination of optical absorption coefficient in CdTeJournal of Applied Physics 48, 829

Mohd Zaki W. R, Nawawi A. H, Ahmad S. S. (2008). Energy Savings Benefit from Passive Architecture. Journal of sustainable development, 1(3): 51-63.

Moloney J (2011) Designing kinetics for architectural facades: state change, Taylor & Francis, New York .

Murray S, Whibley S, Ramírez-Lovering D (2008) Re Housing. RMIT Publishing, Melbourne.

NREL, "Best Research-Cell Efficiency Chart" https://www.nrel.gov/pv/cellefficiency.html.

Phocas M.C (2013) "Initiations and Future Directions in the Development of Kinetic Structures for Earthquake Resistance," J of Archit Eng Tech, 10 (2).

Poruba A, Fejfar A, Remeš *Z,* Špringer J, Vaněček M, Kočka J (2000) Optical absorption and light scattering in microcrystalline silicon thin films and solar cells, Journal of Applied Physics ,Volume 88, Issue 1

Ramalingam K, Indulkar C (2017) Distributed Generation Systems: Design, Operation and Grid Integration, Chapter 3, Solar Energy and Photovoltaic Technology.

Randl C (2008) Revolving architecture: a history of buildings that rotate, Swivel, and Pivot. USA: Princeton Architectural Press, New York, P 75.

Smith, P. F. (2005). Architecture in a climate of change: a guide to sustainable design (2nd ed.). Oxford; Boston: Elsevier/Architectural Press.

Solar decathlon Report 2007 available at: www.solardecathlon.de

Struck C, Almeida M, Silva S, Mateus R, Lemarchand P (2015) Adaptive facade systems – Review of performance requirements, design approaches, use cases and market needs. Adv Build Skins; 1254– 1262, (Economic Forum,2015).

Stevenson C. M. (2011). Morphological Principles of Current Kinetic Architectural Structures. Liverpool School of Architecture

Szokolay S. V. (2006). Proceedings from the International Symposium on Sustainable Energy & Environment (ISEESEE): Passive Climate Control in Warm-humid Region, Kuala Lumpur.

Theelen M, Daume F, (2016) Stability of $Cu(In,Ga)Se_2$ solar cells: A literature review Solar Energy 133, 586-627.

Thun G, Velikov K (2013) Responsive Building Envelopes, Characteristics and Evolving

Waldau J. A (2018) PV Status Report

Wood A (2013) Best Tall Buildings: The 2010 CTBUH Reference Guide. New York, NY: Routledge.

Zeng K, Xue D.J,Tang J (2016) Antimony selenide thin-film solar cells,Semiconductor Science and Technology. 31,

Zhai Z.J, Previtali J.M (2010) Ancient vernacular architecture: characteristics categorization and energy performance evaluation, Energy and Buildings, 42 , pp. 357-365

Zuk, W, Clark, R.(1970), Kinetic Architecture. Van Nostrand Reinhold, New York .