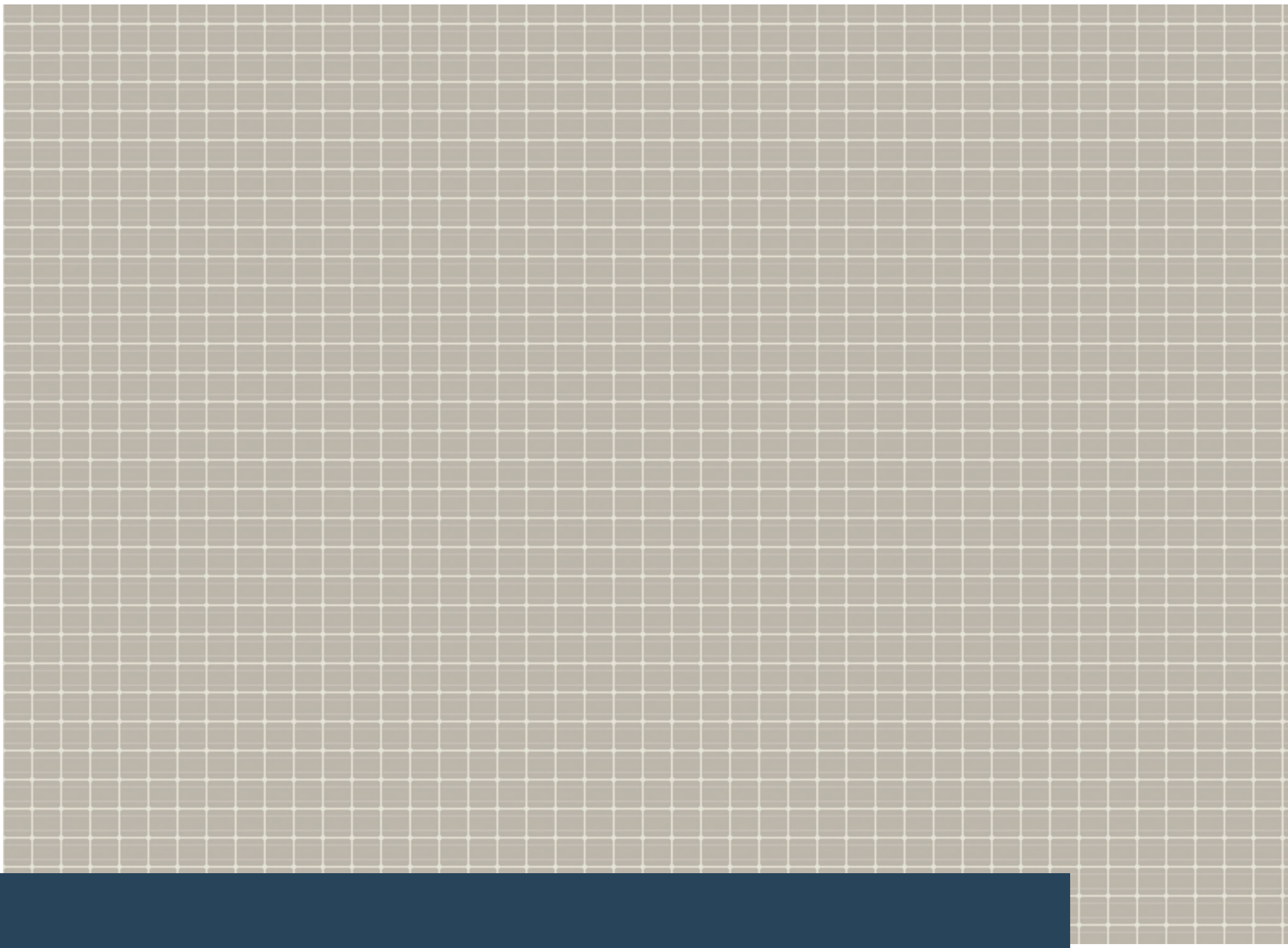

Dynamic and Adaptive Photovoltaic Shading Systems: Design and Architectural Integration for Energy Production and Indoor Comfort.

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Prof. Roberta Ingaramo

Preface

«*The sun never knew how great it was until it hit the side of a building.*»
L. I. Kahn

Overview:

This project mainly includes the development and evaluation of adaptive shading systems that include photovoltaic (PV) technology to provide maximum energy efficiency, occupant comfort, and visual harmony with building design.

By the inventive shading mechanism shown in this study, it managed to overcome two major problems which were the production of energy and comfort levels for heating and cooling in the building. With six different design concepts, the project has been argued thorough analysis and simulation of energy production, shading efficiency, and adaptability, which has culminated in relevant insights for their real-world applications.

Besides, this work highlights the potential of smart shading solutions combined with the use of renewable energy to promote sustainable architectural practices.

Mission Statement:

Our mission is to create dynamic shading systems that not only work traditionally but also help in sustainable, energy-efficient, and adaptable architectural applications. We are using PV technology coupled with advanced motion mechanisms to lower building CO2 emissions and enhance aesthetics and indoor atmosphere. We come up with shading solutions that are diverse enough to suit the climate and urban environments, thus supporting a cleaner energy shift and a sustainable future.

Future Outlook

The future of architecture is in flexible energy-conscious designs that technologically fuse with eco-friendly technology. Design engineers and building managers now have the power, provided by adaptive sun control arrangements and sophisticated photovoltaic solutions, of bringing the building to a living organism rhythmically followed by energy-saving before going to search of energy consuming. We come to the glorious era of this new world, when architecture and sustainability in real-world become combined, to make sure that practically, these construction systems will be able to adjust to different types of climate and accordingly swill be blueprints that will be sustained in the overall green movement.

Towards a Sustainable Future:

Dynamic shading systems are a breakthrough in green building that is designed to achieve energy efficiency, occupant comfort, and environmental accountability, all in one package. Along with the adaptive technologies like solar panel systems, these structures reduce energy dependence. This project demonstrates that flexibility and sustainability are the methods that are successful in drawing a line between a building's function and its surroundings. This means that buildings can easily be adapted for coexistence in harmony while decreasing their ecological footprint to a minimum degree.

This journey would not have been possible without the invaluable guidance, support, and encouragement of many individuals.
I am deeply grateful to Prof. Guglielmina Mutani, Arch. Giuseppe Perfetto, and Prof. Roberta Ingaramo for their exceptional mentorship and expertise throughout this project. Their insights have been instrumental in shaping the direction and outcome of this work.

I would also like to extend my heartfelt thanks to my family, friends for their unwavering support and encouragements. Their belief in my vision and dedication has inspired me to strive for excellence in this endeavor.
To everyone who contributed in ways both big and small, I am profoundly thankful.

December, 2024
Turin, Italy

Table of Content

Introduction

1.1 Background

"Solar Architecture is not about fashion, but about survival,"

Said, Norman Foster.

This phrase will lead us to the fact that this urgent phenomenon which is the need for a clean source of energy has not only turned into a simple worldwide matter but also a symbolic one. Buildings consume approximately 40% of global energy demand. It is seen that limited sources of fossil fuels and uranium made the shift to renewable energy inevitable and simply necessary, and this is while Buildings, which utilize fossil fuels for heating, ventilation, air conditioning, and electricity, account for almost a third of anthropogenic greenhouse gas (GHG) emissions.[1] As a result, buildings have the highest potential for conserving energy. Furthermore, the continuous growth of the world's population and the consistent migration of people from rural areas to large cities are also causing great increases in the electricity demand in urban environments. To this date, this consumption has been mostly covered by fossil fuel combustion in utility-scale power plants.

However, the use of Earth's energy resources such as coal, oil, and gas has produced severe impacts on the environmental, political, and economic levels, which challenge the goals for the sustainable development of cities. There is an urge for a transition into a non-polluting and renewable electricity production system, and this has become clearer for the public in general as the effects can be felt in the various aspects of people's daily lives. In this sense, solar photovoltaics (PV), which are emissions-free during operations, present themselves as an important contributor to the solution. [2]

It defines an understanding of environment-friendly architecture under all classifications and contains some universal consent [3], It may have many of these characteristics: Ventilation systems designed for efficient heating and cooling, Energy-efficient lighting and appliances Water-saving plumbing fixtures Landscapes planned to maximize passive solar energy Minimal harm to the natural habitat Alternate power sources such as solar power or wind power Non-synthetic, non-toxic materials Locally-obtained woods and stone Responsibly-harvested woods Adaptive reuse of older buildings

1. Heinstein et al., (2013)

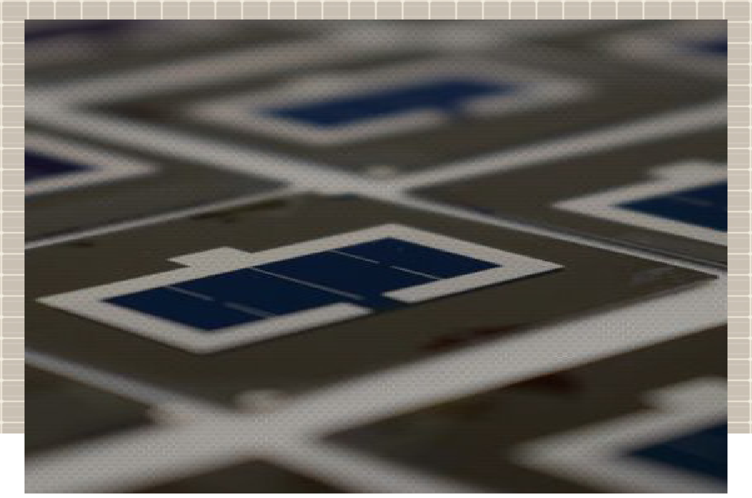
Heinstein, P., Ballif, C., & Perret-Aebi, L. (2013). Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and myths. Green, 3(2).

2. Freitas & Brito, (2019)

Freitas, S., & Brito, M. C. (2019). Solar façades for future cities. Renewable Energy Focus, 31, 73–79.

3. Safo, L. K. A., Duah, D. Y. A., & Liwur, S. B. (2023)

Safo, L. K. A., Duah, D. Y. A., & Liwur, S. B. (2023). Sustainable architectural design and land-use application to civic centres in Ghana: the case of Damongo. Urban Planning and Transport Research, 12(1).



Use of recycled architectural salvage Efficient use of space While most green buildings do not have all of these features, the highest goal of green architecture is to be fully sustainable. They are also known as Sustainable development, eco-design, eco-friendly architecture, earth-friendly architecture, environmental architecture, and natural architecture. [4]

Green architecture, or green design, is an approach in the building sector that minimizes harmful effects on human health and the environment. The "green" architect or designer attempts to safeguard air, water, and earth by choosing eco-friendly building materials and construction practices, [5]

The energy efficiency of 'green' buildings can be achieved by both minimizing heat and air conditioning consumption and by using energy harvesting techniques from renewable sources.[6]

The energy that is produced from natural resources, such as sunlight, wind, rain, tides, and geothermal heat, is generally called renewable energy (RE). Usually, in this hence no greenhouse gas waste is produced, and renewable energy sources don't have as many adverse environmental effects compared to conventional energy sources like coal, oil, and natural gas. As a result, it seems that the best and most efficient way to deal with environmental problems and worries about energy sustainability is through renewable energies. Most renewable energy comes from the sun, either directly or indirectly.

Due to its availability, adaptability, and simplicity of use, as well as its low environmental impact in terms of land use, solar energy has emerged as

4. Ragheb et al. (2016)

Ragheb, A., El-Shimy, H., & Ragheb, G. (2016). Green Architecture: a concept of sustainability. Procedia - Social and Behavioral Sciences, 216, 778–787.

5. Bach et al. (2003)

Bach, D., Pich, S., Soriano, F. X., Vega, N., Baumgartner, B., Oriola, J., Daugaard, J. R., Lloberas, J., Camps, M., Zierath, J. R., Rabasa-Lhoret, R., Wallberg-Henriksson, H., Laville, M., Palac□□N, M., Vidal, H., Rivera, F., Brand, M., & Zorzano, A. (2003). Mitofusin-2 determines mitochondrial network architecture and mitochondrial metabolism. Journal of Biological Chemistry, 278(19), 17190–17197.

6. Miranda et al. (2020)

Miranda, R., Babilio, E., Singh, N., Santos, F., & Fraternali, F. (2020). Mechanics of smart origami sunscreens with energy harvesting ability. Mechanics Research Communications, 105, 103503.

the most alluring renewable energy source in recent years.

Solar energy is energy that is directly harvested from the sun. Since the sun emits a lot of energy onto the earth's surface (for example, the earth receives 172,000 TW of energy from the sun in an hour), this energy is more than enough to meet the world's energy needs if it is collected properly. [7]

Particularly in the past ten years, solar photovoltaic (PV) energy generation technologies have grown quickly, and installed power has increased. The sun is a source of infinite energy that can be used directly or indirectly and the energy harnessed from the sun is known as solar energy. In response to concerns about environmental pollution, solar energy is playing a leading role in reducing environmentally hazardous gases produced in electricity generation. The IEA has reported that solar-PV technology could prevent 100 Gt (Gigatons) of CO2 emissions during the period from 2008 to 2050. Solar energy production has no effects on cultivated land, reduces the cost of the propagation of grid transmission lines, and improves the quality of life for people in distant areas who adopt this technology. depicts the array of available solar energy technologies and reports their market availability. Technologies in which the light and heat from the sun are used directly without changing form are referred to as passive solar energy technologies and those in which the energy is converted are called active solar energy technologies. An example of the latter is PV technology, which converts the sun's radiation into electrical energy. Solar PV systems can be conceptually divided between grid-connected systems and stand-alone systems. Grid-connected solar-PV systems are used as a power supply with grid connections, most often to a city or urban area. In contrast, stand-alone solar PV systems are generally used to supply power to distant areas. These systems can supply electricity to a single house in combination with a battery, solar panel, or charge controller inverter, or can supply an entire village. Because the first use of solar cells occurred in the 1950s to power United States spaceships, which was the most noteworthy application of a solar PV cell was in 1958 as a power supply for the satellite Vanguard-1. [8]

In the early 2000s, solar energy became more popular worldwide, and its implementation increased tremendously over the last decade, until 2011, the global contribution of solar PV systems to the energy supply was stated up to 40 GW, with 1095 MW coming from concentrated solar power. According to IEA estimations, solar energy can supply approximately 11% of the global energy demand by 2050.

7. Akikur et al. (2013)

Akikur, R., Saidur, R., Ping, H., & Ullah, K. (n.d.). Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review. Renewable and Sustainable Energy Reviews.

8. Mohamed et al. (2012)

Mohamed, A., Elshaer, M., & Mohammed, O. (2012). Control enhancement of power conditioning units for high quality PV systems. Electric Power Systems Research, 90, 30–41.

Also, as showin in Figure 1, it is undrestood that how the mix of world energy consumption changed between 2012 and 2022. It indicates that although total energy consumption was up 16% in this time, the proportion of fossil fuels had only fallen from 81.1% to 79.0% of total consumption. However, there was significant growth for renewable energy, with modern renewables rising from 9.5% to 12.9% and a gain of 58% over the decade.

The share of renewable energy broken down shows that:

7.0% of all energy was provided by renewable electricity, including solar and wind. 4.9% is renewable heat. 1.0% is biofuels used in transport.

Even as renewables grow, the slow rate of decline in fossil fuels underscores the urgent need for much stronger moves toward renewable energy sources-such as solar and wind power-in order to ensure that global energy and climate problems are faced.

Nowadays, the efficiency of photovoltaic (PV) modules has significantly improved due to advances in technology, producing PV systems is no longer considered luxury and high-cost technology and is more viable and cost-efficient. This growth and this widespread adoption have resulted mostly in cost reductions driven by economies of scale in commercial and residential sectors. By utilizing unused spaces, such as rooftops, PV systems facilitate decentralized electricity generation, allowing energy production within urban areas.

Many studies have focused on the potential of PV systems to meet energy demands across large regions, such as cities or even larger areas. While not a lot of research has specifically examined the availability of space for individual PV installations. In some analyses, space availability is assessed considering only shadows cast by neighboring buildings and neglecting other potential rooftop obstructions. Other studies conducted more detailed assessments of rooftop space, offering generalizable ratios to estimate usable space for PV installations but it is necessary to consider that

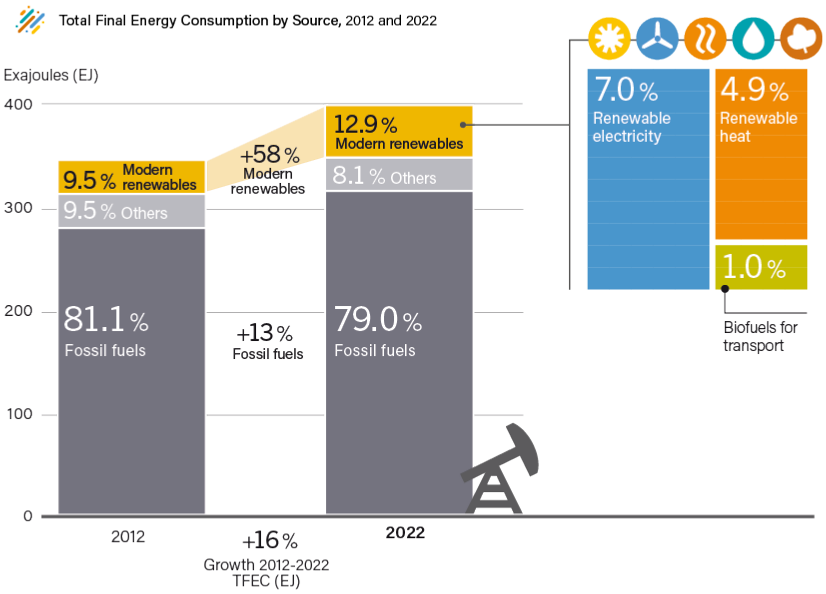


Fig.1 Renewables Global Status Report 2024

Secretariat, R., & Secretariat, R. (n.d.). Why is renewable energy important? REN21. https://www.ren21.net/why-is-renewable-energy-important/

lack of space is a crucial matter and that leads us to the point of examining the vertical wall-mounted photovoltaic solutions. BIPV facades are becoming more and more common, although their productivity is generally lower than the other types of PV installations on other building components, like rooftops or skylights. This is mainly because vertical surfaces receive different amounts of solar irradiance compared to horizontal surfaces. But even with BIPV technology's advances, mounting solar panels on building facades is still not the best strategy when they are only statical elements because of the inadequate solar energy capture, this static placement prevents the integrative system from reaching its full potential. Adaptive techniques are being investigated in order to overcome this problem and improve the performance of facade PV systems. [9] An adaptive PV system incorporates a solar tracking mechanism that allows the photovoltaic panels to adjust their position in response to solar conditions and combines the benefits of adaptive shading with facade-integrated solar tracking that has the ability of the system to change physical values according to multiple parameters, to provide the aimed functional state under changing conditions in terms of design variables that could be a solution to keep the balance in terms of energy production and energy efficiency.
In parallel with technological advances, various approaches and concepts have been developed in the field of adaptive architecture.
Adaptive Architecture is concerned with buildings that are designed to adapt to their environments, their inhabitants, and objects as well as those buildings that are entirely driven by internal data.
The term of adaptive is an attempt to incorporate what people imply when they talk about flexible, interactive, responsive, or indeed media architecture. [10]

9. Nagy, Z., (2016)

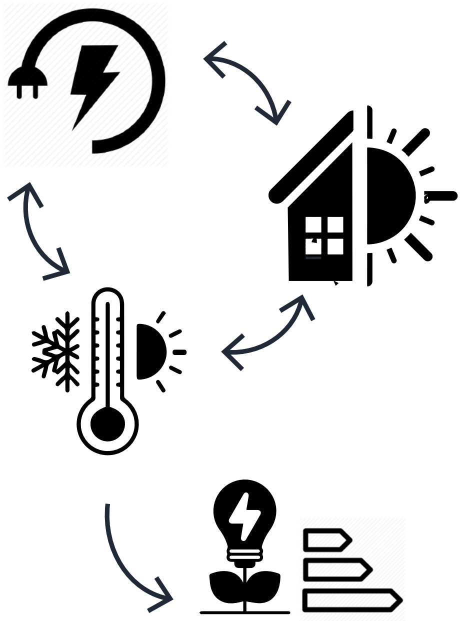
Nagy, Z., Svetozarevic, B., Jayathissa, P., Begle, M., Hofer, J., Lydon, G., Willmann, A., & Schlueter, A. (2016b). The Adaptive Solar Facade: From concept to prototypes. Frontiers of Architectural Research, 5(2), 143–156.

10. Kolarevic, B., & Parlac, V. (2015)

Kolarevic, B., & Parlac, V. (2015). Building Dynamics: Exploring Architecture of Change. Routledge.

Hence the adaptive PV facade offers several advantages:

- Electricity Generation improvement: By tracking the sun's movement, the panels can keep an optimal angle for capturing solar energy during the day, and as a result increase the production.
- Daylight Use: Adaptive systems can increase the natural light use in the buildings by reducing the necessity of using artificial light and as a result leading to saving more energy.
- Energy Performance: this system can be used for improving the thermal parameters of the building, by adjusting the angle of panels during the day, so it is possible to reduce the heating and cooling loads of the building and have a more efficient energy usage.



1.2 Problem Statement

The world is currently seeing a large growth in energy Production kWh, primarily because of expanding populations and improved living conditions. As these matters continue to accelerate, energy Production kWh will increase dramatically. Currently, fossil fuels and biomass account for a large portion of this energy Production kWh, in which both of them are finite and environmentally harmful. The widespread usage of non-energy-efficient equipment has increased the demand for these resources. As the Production kWh of fossil fuel increases, environmental deterioration will also be increased in respect to each other, emphasizing the critical need to make our reliance on existing energy sources a lot less than before.

According to the US Energy Information Administration (EIA), energy Production kWh in the building sector alone is going to increase by 65% between 2018 and 2050, from 91 to 139 quadrillion British thermal units (Btu). This increase in demand is mostly because of factors such as urbanization, rising earnings, and wider access to power, all of which contribute to an expanding energy footprint globally. it is also mentioned that In European countries, about half of the remaining energy is used for space heating and cooling, with built structures accounting for 80% of total energy use. One of the goals for reducing carbon emissions and significantly improving urban development is to streamline building effectiveness. [11]

Between 2018 and 2050, electricity generation will increase by 79% due to rising end-use Production kWh. Residential electricity Production kWh increases as non-OECD countries' populations and living standards rise, increasing demand for appliances and personal equipment. Electricity use is also increasing in the transportation sector, as more plug-in electric vehicles enter the fleet and rail electricity usage grows. [12]

With the gap between power supply and demand widening and fossil fuel reserves decreasing, governments throughout the world are increasingly exploring for new ways to generate electricity.

Solar cells outperform traditional generating systems, which require constant monitoring and maintenance and are geographically limited.

They require minimum maintenance, can be left unattended, and, thanks to their flat plate shape, can be put almost anywhere. These solar cells use the photovoltaic (PV) effect, which converts sunlight directly into energy. [13]

11. U.S. Energy Information Administration (EIA). (2020)

U.S. Energy Information Administration (EIA). (2020). International Energy Outlook 2020. Washington, DC: EIA. Retrieved from EIA website

12. International Energy Agency (IEA). (2021)

International Energy Agency (IEA). (2021). Global Energy Review 2021. Paris: IEA. Retrieved from IEA website

13. Fthenakis, V. M., & Kim, H. C. (2011)

Fthenakis, V. M., & Kim, H. C. (2011). Photovoltaics: Life-cycle analyses. Solar Energy, 85(8), 1609–1628.

The rapid growth of solar photovoltaic (PV) and wind energy in electricity generation is fundamentally transforming power systems, creating an increased demand for flexibility to maintain electricity security. As these renewable sources are variable and dependent on weather conditions, power systems must adapt to ensure a reliable supply of electricity. This shift places greater importance on dispatchable low-emission technologies like hydropower, bioenergy, and geothermal, which can be adjusted to meet demand. The need for flexibility varies by region, depending on whether solar PV or wind predominates in the energy mix. Regions with higher shares of solar PV, such as those with abundant sunlight, tend to deploy more battery storage solutions, as batteries are well-suited to smoothing out the daily fluctuations in solar power generation. In contrast, regions where wind energy is more dominant, like parts of China or the European Union, rely on a broader mix of flexibility sources, as wind energy can be more variable over longer periods. These regional differences underscore the importance of tailored approaches to energy storage and system management, ensuring that renewable energy growth does not compromise electricity security.[14]

14.International Energy Agency (IEA). (2022)

International Energy Agency (IEA). (2022). Renewables 2022: Analysis and Forecast to 2027. Paris: IEA. Retrieved from IEA website

1.3 Objectives

- To design a dynamic kinetic PV shading system for windows and balconies that maximizes solar energy capture and optimizes indoor shading.

- To develop and implement control algorithms that adjust PV panel positions based on real-time environmental data.

- To integrate the PV shading system with building management systems (BMS) for enhanced energy management.

- To evaluate the structural, economic, and aesthetic implications of incorporating kinetic PV systems in building designs.

- To analyze the impact of dynamic shading on energy efficiency, indoor thermal comfort, and overall building performance.

Active or responsive shading systems, also called dynamic or kinetic shading systems, are often designed to respond to one or multiple environmental situations including daylighting control, solar thermal control, ventilation control, and in addition sometimes energy generation The application of active shading systems is an important step towards improving energy efficiency in the built environment. By using active shading systems, buildings tend to adapt to evolving external conditions.[15]

15.Dakheel and Aoul (2017)

Dakheel, J. A., & Aoul, K. T. (2017). Building Applications, Opportunities and Challenges of Active Shading Systems: A State-of-the-Art Review. Energies, 10(10), 1672.

1.4 Research Questions

This thesis aims to answer the central question of how to improve the Production kWh of PV systems so that they are more accessible and viable on a bigger scale. The research focuses on technology developments, design improvements, and potential legislative incentives that could improve the performance of PV systems. By investigating these pathways, this study hopes to provide actionable insights that could make solar energy a more practical viable option for fulfilling the world's expanding energy needs in a sustainable manner. In this hence the following questions are about to answer during this thesis research process.

- How Can Optimise the use of Photovoltaic systems in building sector?
- How can integrate the use of a photovoltaic system into a shading system?
- How can PV systems be designed to balance energy generation and shading effectiveness?
- Is kinetic and dynamic shader more effective than the static one and how is it possible to maximize the generation of the energy?
- How can a sun responsive photovoltaic system be integrated into a building envelope?

1.5 Significance of the Study

The relevance of this work comes mostly from the advancement of design techniques and actual implementations of dynamic kinetic photovoltaic (PV) shading systems. By focusing on the design component, this study helps to generate novel, efficient, and aesthetically acceptable solutions for modern buildings. The main points of relevance are:

Innovative Design Framework:

A unique design paradigm for dynamic kinetic PV shading systems that prioritizes flexibility and multifunctionality. By combining kinetic aspects with solar technology, the study pushes the limits of traditional PV system design, presenting a novel solution that combines energy generation with adaptive shading.

Enhanced Energy Production kWh:

The design methodologies developed in this study aim to maximize solar energy capture while providing dynamic shading. This combined capability increases overall energy Production kWh in buildings, reducing dependency on external power sources and lowering energy expenses. The novel designs proposed can adjust to changing ambient conditions, providing optimal Production kWh throughout the day.

Improved Indoor Comfort:

The dynamic shading solutions are designed to block excessive solar radiation during peak hours, thereby reducing indoor temperatures and minimizing the need for air conditioning. This not only improves occupant comfort but also contributes to energy savings.

Architectural Integration:

The design ideas presented are not only practical but also visually pleasing, which improves the visual appeal of modern structures. By providing variable design possibilities, the study allows architects and designers to implement these systems into a variety of architectural styles and structures.

Contribution to Sustainable Building Practices:

The dynamic kinetic PV shading systems are consistent with global environmental goals, encouraging the use of renewable energy and lowering buildings' carbon footprints.

Technological Advancements:

The development of advanced control systems and integration techniques for dynamic PV shading systems represents a significant technological advancement. The study explores the use of sensors, actuators, and control algorithms to optimize the performance of these systems.

1.6 Methodology

To answer the problems and questions mentioned before, it aims to develope the advanced intelligent shading device module as a performance-driven adaptive and electromechanical prototype that responds to environmental conditions and to propose critical decision and priority algorithms to incorporate ambient data to solve conflicts in the decision-making process. The design module has a multi-layered design.[16]

This thesis studies the design of several high-performance sun-tracking systems as an example of a combined passive and active solar facade system.

The goal of this design study is to determine how to include a computer-controlled sun-tracking system into the building envelope. The majority of this document focuses on overcoming the difficulties in combining design concepts with performance-driven priorities.

The primary focus of the design process is the responsive sun-tracking system's geometry and physics. Investigating the possibilities of incorporating an interactive solar tracking system into the building envelope is the aim.

The thesis focuses on the conversion of incident solar rays' energy into electricity through automated adaptive systems. This electricity conversion process is called photovoltaic or "PV" and it can be considered not a new technology.[17]

However in this study this system is not examined as the traditional panel systems and it is controlled by advanced algorithms consisting of multi-parameter optimization and prediction algorithms according to statistical data that makes the study more novel.

The design is defined as an advanced intelligent module investigated to produce the appropriate response with the help of electromechanical systems by sensing the indoor and outdoor temperature, daylight, and radiation parameters. The methodology of the study is to verify the proposed system consisting of an electromechanical module and algorithms via simulation according to six scenarios in three different orientations South, South-east, and South-west.

As a result of the performance validation by simulation, it is expected that the system module outperforms the static in terms of energy Production kWh and user comfort indoors. Producing an intelligent and adaptive shader module based on performative principles has been determined as the primary objective to ensure optimum comfort conditions in interior space.

The article will be structured under five main sections Literature Review,

16.Karakoç and Cagdas (2021)
Karakoç, E., & Ça▯da▯, G. (2021). Adaptive architecture based on environmental performance: an Advanced Intelligent Façade (AIF) module. GAZI UNIVERSITY JOURNAL OF SCIENCE, 34(3), 630–650.

17. Attia, S., & De Herde, A. (2011)
Attia, S., & De Herde, A. (2011). Early design simulation tools for net zero energy buildings: A comparison of ten tools. Building Simulation, 4(2), 129–143.

System Design and Development, Simulations, architectural integration, and economical assesments.

This structure of study is based on the questions that were considered throughout the design and implementations in this thesis.

These questions help to have a better understanding of the steps taken for this design.

- What has been done before?

What can be learned from the precedents and how the lessons from those can contribute to this research?

Precedents are explained where necessary through this document in chapter two, to clarify the goals of this research.

- What tools and techniques are useful?

Computer tools for design and simulation, energy analysis, and computer control useful in designing a high-performance responsive facade system are discussed in chapters three and four.[18]

- How is the sun-tracking system structured and implemented?

Chapters five and six explain how such a system is implemented in buildings and from an architectural point of view.

- What is the efficient form?

While this question does not have a definite answer because the form of the design is subjective, this research, as it progresses, attempts to demonstrate why specific forms that are ruled out.

Precedent computation research and design progress are explained in chapters four and five.

What are the technical challenges?

The challenges related to implementing the designed equipment in an architectural design mock-up and learning to program such automated system are discussed in chapter five

- How much does it cost?

The payback analaysis and the cost matters are discussed in chapter six.

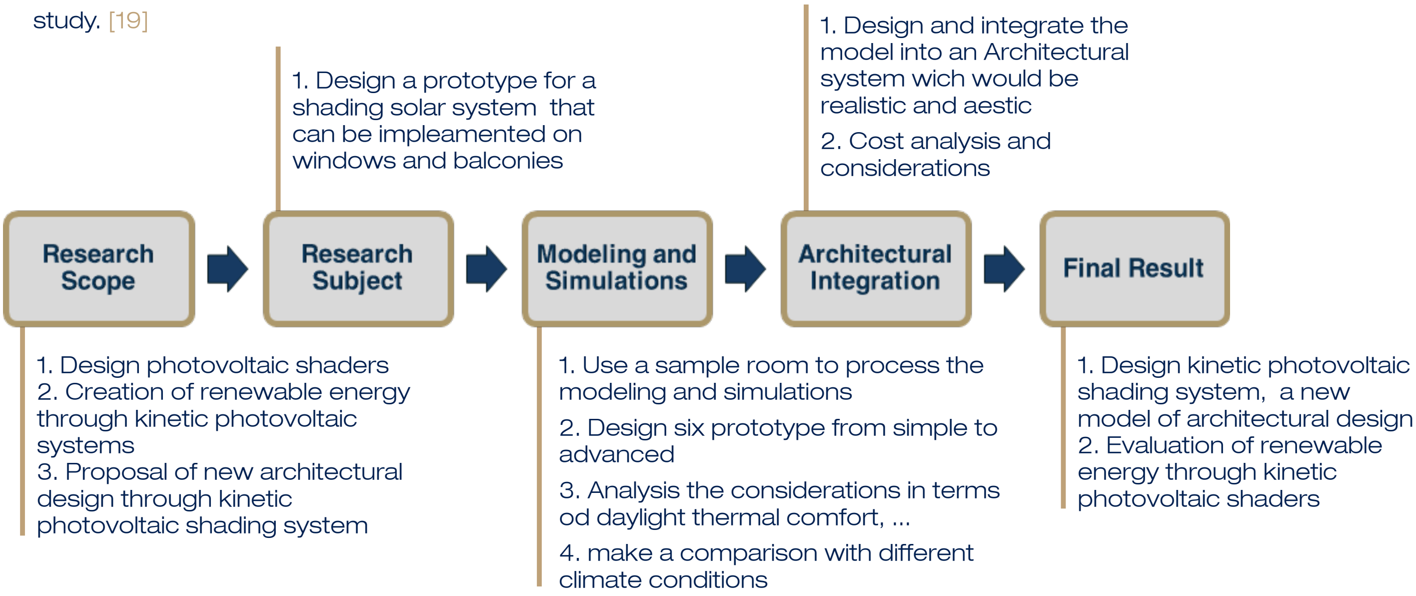
Also the Chapter seven concludes with the potential and limitations of the study and the future works that could be done in order to inhance the study. [19]

18.Rad, S. J., & Fung, A. S. (2016)

Rad, S. J., & Fung, A. S. (2016). Solar tracking systems: Advances and challenges in design and implementation. Renewable and Sustainable Energy Reviews, 60, 646–670.

19. Zhao, J., & Zhang, Y. (2017)

Zhao, J., & Zhang, Y. (2017). Building energy modeling: A review of current advances and future challenges. Applied Energy, 202, 572–582.



1. Design photovoltaic shaders
2. Creation of renewable energy through kinetic photovoltaic systems
3. Proposal of new architectural design through kinetic photovoltaic shading system

1. Design a prototype for a shading solar system that can be impleamented on windows and balconies

1. Use a sample room to process the modeling and simulations
2. Design six prototype from simple to advanced
3. Analysis the considerations in terms od daylight thermal comfort, ...
4. make a comparison with different climate conditions

1. Design and integrate the model into an Architectural system wich would be realistic and aestic
2. Cost analysis and considerations

1. Design kinetic photovoltaic shading system, a new model of architectural design
2. Evaluation of renewable energy through kinetic photovoltaic shaders

Literature Review

- Photovoltaic Systems
- Kinetic and Dynamic Shading Systems
- Control Systems for PV and Shading Applications
- Case Studies and Architectural Implementations

2.1 Photovoltaic Systems

"Solar Architecture is not about fashion, but about survival,"

Said, Norman Foster.

The amount of energy we receive from the Sun in a year on Earth is 10,000 times the world's energy requirements. a method of generating electrical power by converting solar radiation into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. In simpler words, PV technology takes sunlight and converts it directly into electricity. (systems convert sunlight (visible or not), directly with no moving parts into electricity with 6 to 23 efficiencies.) [1]

From this, we can understand that even with photovoltaic (PV) systems having a relatively low (but already commercially available) Power Conversion Efficiency of 20%, if these systems were to uniformly cover 0.1% of the Earth's surface (an area roughly the size of Spain), they could theoretically satisfy the world's energy demand for an entire year. Although this computation is speculative and serves mainly as an example, it provides insight into the vast potential of solar energy conversion in meeting renewable energy demands. At the same time, other renewable energy sources, such as hydroelectric, wind, and geothermal, can and will contribute to renewable energy production. [2] This is particularly important given that solar energy is an intermittent or variable source, affected by factors like day-night cycles and cloudy days. Historically, one factor that has limited the extensive use of photovoltaics has been the high cost of the electricity generated, especially compared to fossil fuels. Indeed, the cost of power generation is a common limiting factor across renewable energy technologies: a highly efficient electricity generation system can be costly, which may reduce its economic appeal. However, in recent years, due to increased production capacity and improved system performance, the cost of PV energy has been significantly reduced.[3]

1. Bischof-Niemz, T., & Bode, C. (2014)

Bischof-Niemz, T., & Bode, C. (2014). The Impact of Solar Energy on the Global Energy System. Journal of Renewable and Sustainable Energy.

2. REN21. (2020)

REN21. (2020). Renewables 2020 Global Status Report. Renewable Energy Policy Network for the 21st Century.

3. IEA (International Energy Agency). (2021)

IEA (International Energy Agency). (2021). World Energy Investment 2021. International Energy Agency.

2.1.1 Photovoltaic Systems

A photovoltaic system is made up of one or more photovoltaic panels, an inverter, and other mechanical and electrical components to harness the alternative energy supply for electricity. PV systems are available in a large range of sizes from compact rooftop or portable units to enormous utility-scale power plants. The photovoltaic effect is such that mechanisms through which sunlight, composed of energy packets called photons, strike a solar array and generate an electrical current. Each panel generates a comparatively small amount of electricity but connected with other panels, an electrical device can generate way more energy. An electrical device, or array, generates DC as its source of electricity. Samples of electronic gadgets using DC electricity are phones and laptops; however, these have been developed to operate with the electrical utility system, which relies on electricity in AC. This is a direct result of the fact that, before use, solar energy needs to be converted, using an inverter, from DC to AC.[4]

Solar Panel

A solar panel may also be referred to as a solar module. The parts of a photovoltaic system are comprised of one or more panels which consist of a number of solar cells. They are mounted together and integrated to produce power from a variety of rectangular shapes. Photovoltaics, better known as solar panels, capture the radiation energy from the sun and convert it into electricity for use in powering buildings. These panels may be utilized to extend a building's electrical supply or offer power in outlying areas. The fundamental part of every solar panel is a solar cell. One solar panel contains many solar cells. These cells are the part of the device that converts sunlight into electrical energy. Most solar panels are made from crystalline silicon solar cells. These cells are formed by layers of silicon, phosphorus, and boron. These cells, once produced, are arranged in a grid pattern. The number of these cells depends mostly on the size of the panel and that is because the sizes of the panels are different. Once the cells are set out, the panel itself is sealed to protect the cells, and a non-reflective glass is placed on top of that. This non-reflective glass protects the solar cells from damage yet still allows sunlight to get through to the cells. This panel is sealed and then set into a solid metal frame. Since even an accumulation of water would degrade the performance of the panel, this frame is designed not to deform and contains a drainage hole for that purpose. [5]

4. Hammoumi et al. (2022)

Hammoumi, A. E., Chtita, S., Motahhir, S., & Ghzizal, A. E. (2022). Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels. Energy Reports, 8, 11992–12010.

5. Brague

Brague, C. (n.d.). What are solar panels made of? homesolarinfo.com. https://www.homesolarinfo.com/what-are-solar-panels-made-of

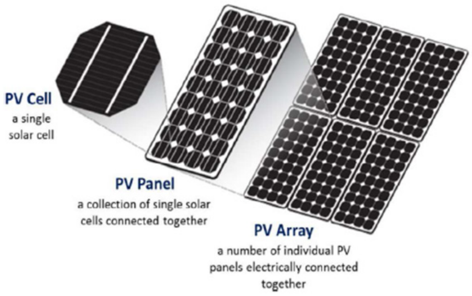


Fig.2 Solar System

Bağriaçik, N., & Altinoluk, H. S. (n.d.). Design and Simulation of a Solar Powered House in Muğla: Roof Decorated with Half Cut Cells. Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 7(2), 485–499.

System components

Solar Array

The solar array is several PV modules wired together. Connecting the negative (-) wire of one module to the positive (+) wire of a second module is the start of a series string. Wiring modules in series results in the voltage of each of the two modules being added together.[6]

Combiner Box

A photovoltaic system array with multiple strings of modules will have one positive and one negative lead at the end of each string. The positive leads will connect to individual fuses and the negative leads will connect to a negative busbar in an enclosure. This is called the source circuit. The combiner box serves to “combine” multiple series strings into one parallel circuit.

PV Disconnect

A DC disconnect switch is located between the inverter load and the solar array. The disconnect is used to safely de-energize the array and isolate the inverter from the power source. The switch is sized to match the voltage of the solar array and is connected to the ungrounded conductor.[7]

Charge Controller

A controller regulates how much charge goes into the battery from the module to prevent overcharging of the battery. Charge controllers can vary in the number of amps they are able to regulate. Some models will include additional features such as connecting and operating DC loads and regulating energy going to a load based on the amount of charge in a battery. Power is sent to the controller and to the battery from the array during the day. The controller, in turn, regulates the amount of energy to keep the battery fully charged. At night, when the array is not sending energy, the controller allows the battery to energize the load as demanded.[8]

Battery

When the solar energy is stored for use when the sun is not shining, a battery is used. The most commonly used battery for residential PV applications is the lead-acid battery. If the total voltage needed is greater than what one battery can provide, a number of batteries are connected to form a bank. Battery banks are sized to allow loads to operate for multiple days during cloudy weather conditions when the array is not able to charge the battery bank.

6. Solar Power World. (2019)

Solar Power World. (2019). Understanding Solar Arrays: How Solar Panels Work Together. Solar Power World.

7. PVTech. (2018)

PVTech. (2018). Photovoltaic Disconnect Switches and Safety Requirements. PVTech News.

8. DOE (U.S. Department of Energy). (2021)

DOE (U.S. Department of Energy). (2021). Solar Batteries: An Essential Part of Solar Power Systems. Department of Energy.

Inverters

The energy that is obtained from an array or a battery bank is called direct current (DC). This energy will be provided for DC loads such as lights, fans, pumps, motors, and some specialty equipment. However, if the energy is to be used to power loads that operate on alternating current (AC), as what is found in a residence, the current needs to be converted. The inverter changes DC energy to AC energy. [9]

9. Energy.gov. (2020)

Energy.gov. (2020). The Role of Inverters in Solar Power Systems. U.S. Department of Energy.

AC Disconnect Switch

Safety disconnects switch The NEC requires a safety disconnect switch at the AC-side of the inverter to safely disconnect and isolate the inverter from the AC circuit. For the purpose of troubleshooting and performing maintenance on the system. In grid-connected systems, this component may be required by the local utility as an AC Breaker Panel.[10]
In a residence or commercial business receiving electrical energy from a local utility, the AC energy is connected to a service entrance panel (SEP). The panel contains circuit breakers and splits the service into individual branch circuits.

10. ENational Electrical Code (NEC). (2017)

National Electrical Code (NEC). (2017). Article 705: Interconnected Power Production Sources. National Fire Protection Association.

System Metering

Several tools will help the user monitor the system: the battery meter is used on stand-alone or off-grid PV systems; it measures the energy coming in and going out of the battery bank. Charging and discharging of batteries, and proper functioning of the charging system will alert the user that incomplete charging, battery decline, or possible shutdown are taking place.

Solar Panels Function

When a photovoltaic cell is exposed to sunlight, a process known as the photovoltaic effect causes it to produce voltage or electric current.[11] This phenomenon, which results from the solar panel's cells converting sunlight into electrical energy, is what makes solar panels valuable. The photovoltaic effect occurs in solar cells. These solar cells are made of a p-n junction, which is formed by joining two different types of semiconductors, a p-type, and an n-type. When these two varieties of semiconductors are combined, an electric field is created in the junction area as electrons and holes migrate from the negative n-side to the positive p-side. Positively charged particles flow in the opposite direction from negatively charged particles because of this field. Photons, which are just tiny bundles of electromagnetic radiation or energy, are the building blocks of light. A photovoltaic cell, which is made up of solar panels, can absorb these photons. An atom of the semiconducting material in the p-n junction receives ene gy from the photon when light with the right wavelength strikes these cells.

11. Schmidt, T., & Borup, O. (2015)

Schmidt, T., & Borup, O. (2015). The Photovoltaic Effect in Solar Cells. Solar Energy Materials & Solar Cells, 131, 34-40.

The energy is transmitted to the electrons of the material. The result is a jump in the electrons' energy to a state known as the conduction band. The valence band where the electron jumped up from has a "hole" left behind as a result. An electron-hole pair is formed when the electron moves because of the extra energy. Electrons in semiconducting materials are immobile when not energized because they establish connections with the atoms around them that keep the material together. These electrons can flow freely through the material because of their excited condition in the conduction band. As expected, electrons and holes travel in the opposite direction due to the electric field created by the p-n junction. The liberated electron tends to migrate to the n-side rather than being attracted to the p-side. An electric current is produced in the cell by this movement of the electron. The movement of the electron leaves a "hole" behind. This hole is able to move, but it is done in the p-opposite direction. This mechanism causes a current to flow through the cell. [12]

12. Green, M. A. (2019)

Green, M. A. (2019). Silicon photovoltaics: A review of cell development. Solar Energy, 181, 57-75.

Types of PV Systems

The on-grid solar system is connected with the National Grid; the photovoltaic panels power the building, simultaneously sending back the extra energy to the grid. However, during a blackout, this system needs grid support.[13]

13. IEA (International Energy Agency). (2021)

International Energy Agency (IEA). (2021). Renewables 2021 Global Status Report.

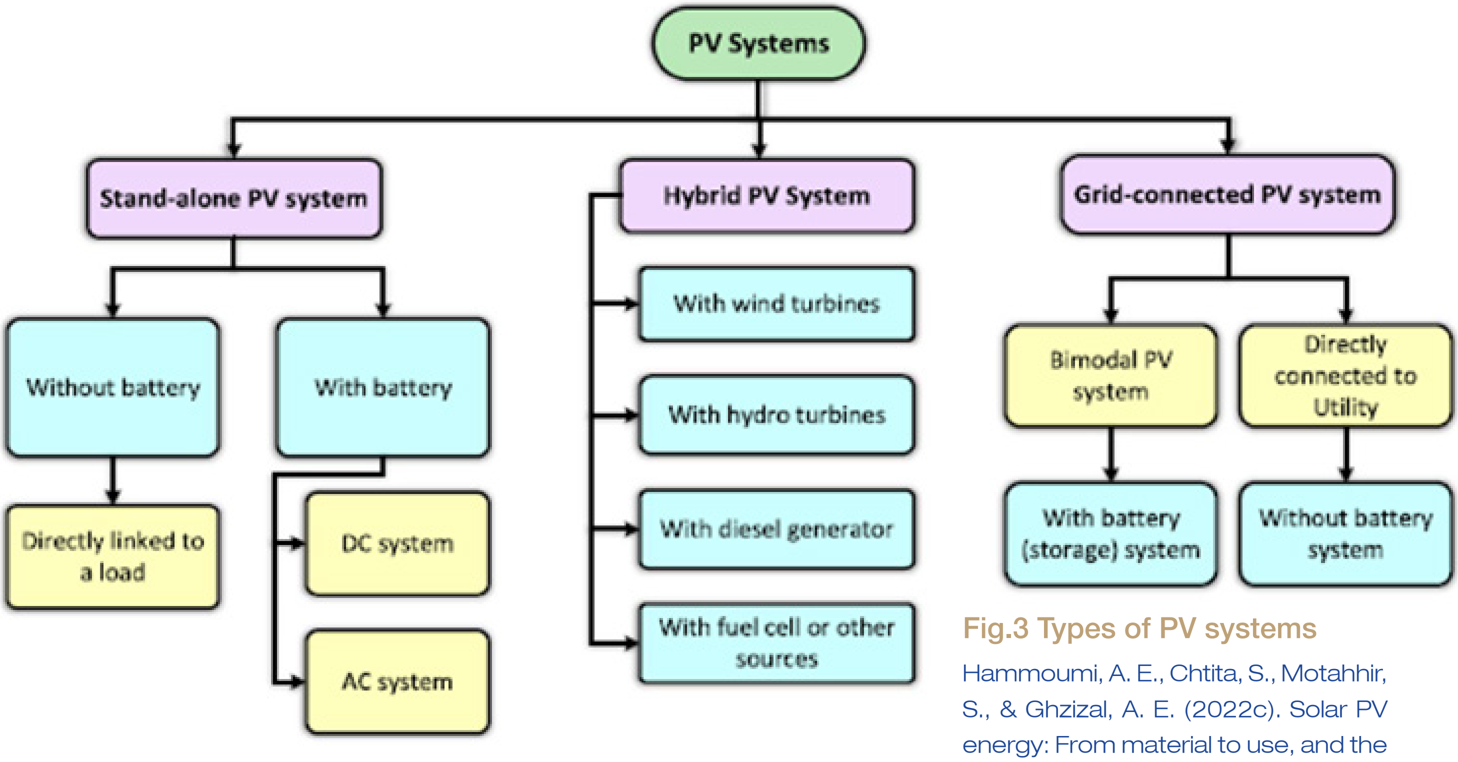


Fig.3 Types of PV systems

Hammoumi, A. E., Chtita, S., Motahhir, S., & Ghzizal, A. E. (2022c). Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels. Energy Reports, 8, 11992–12010.

Hybrid Solar System: This system combines photovoltaic panels with a battery for storing energy. It provides energy at night or during outages but remains tied to the grid for further backup.
An off-grid solar system is a completely independent system from the grid, using solar panels, batteries, and sometimes generators to provide all power needs. This is perfect for remote areas or total energy independence.[14]

14. ENF Solar. (2020)

ENF Solar. (2020). Off-grid solar power systems: A comprehensive guide.

1.5. FACTORS AFFECTING PV MODULE PERFORMANCE

It is to be noticed that, although the design of this system aims at having the maximum production, yet several factors may have an impact on these systems: Temperature, Humidity, Dust, Tilt angle, Orientation Solar Radiation, and some other factors.
The most critical factor is that of sunlight received by a photovoltaic module-a direct determinant of its performance. A PV module's performance will be adversely affected even if it is partially shaded. Several factors also can affect the output of a solar power system, So that the customer may have fair expectations of the overall system output and economic returns over shifting climatic circumstances over time.
Site evaluation becomes the starting point for a PV system development process. Whatever the configuration of the photovoltaic system may be, for any PV system to become economically viable, it is necessary that the photovoltaic modules get adequate sun access.
Latitude is also an important factor because it helps us in determining the quantity of solar radiation received. Solar irradiance is assumed as the quantification of sunlight. It says how many watts each square meter of flat surface is exposed to. Because the local conditions are reasonably consistent, it is possible to predict the average monthly and annual energy production of the system based on historical, standardized weather data. Maps of solar resources are good resources that show how much energy reaches the surface of panels. [15]

15. U.S. Department of Energy (DOE). (2020)

U.S. Department of Energy (DOE). (2020). Solar energy potential: Mapping solar resources. Department of Energy.

Another factor that is also affectable is the tilt angle-the angle between the solar panel's base and the horizontal-and the direction the solar module is facing, that is, due south-make up the orientation. Because of the movement of the sun across the sky during the day, the amount of sunlight falling on the array varies according to time. Installations of solar panels should be done in a way that maximizes the radiation caught.
The installations of PV in the North of the equator should be inclined at an angle, which is 15▯ more than the latitude of the site and should face south for the best performance. If the PV array is located on top of a structure which it is not possible for the panels to face south, then it can be mounted facing either east or west but never north as this would greatly reduce its efficiency. When a PV module's surface is parallel to the sun's rays, it works with maximum efficiency or power. As the rays' veer from their perpendicular path, more energy is reflected by the modules than is absorbed. [16]

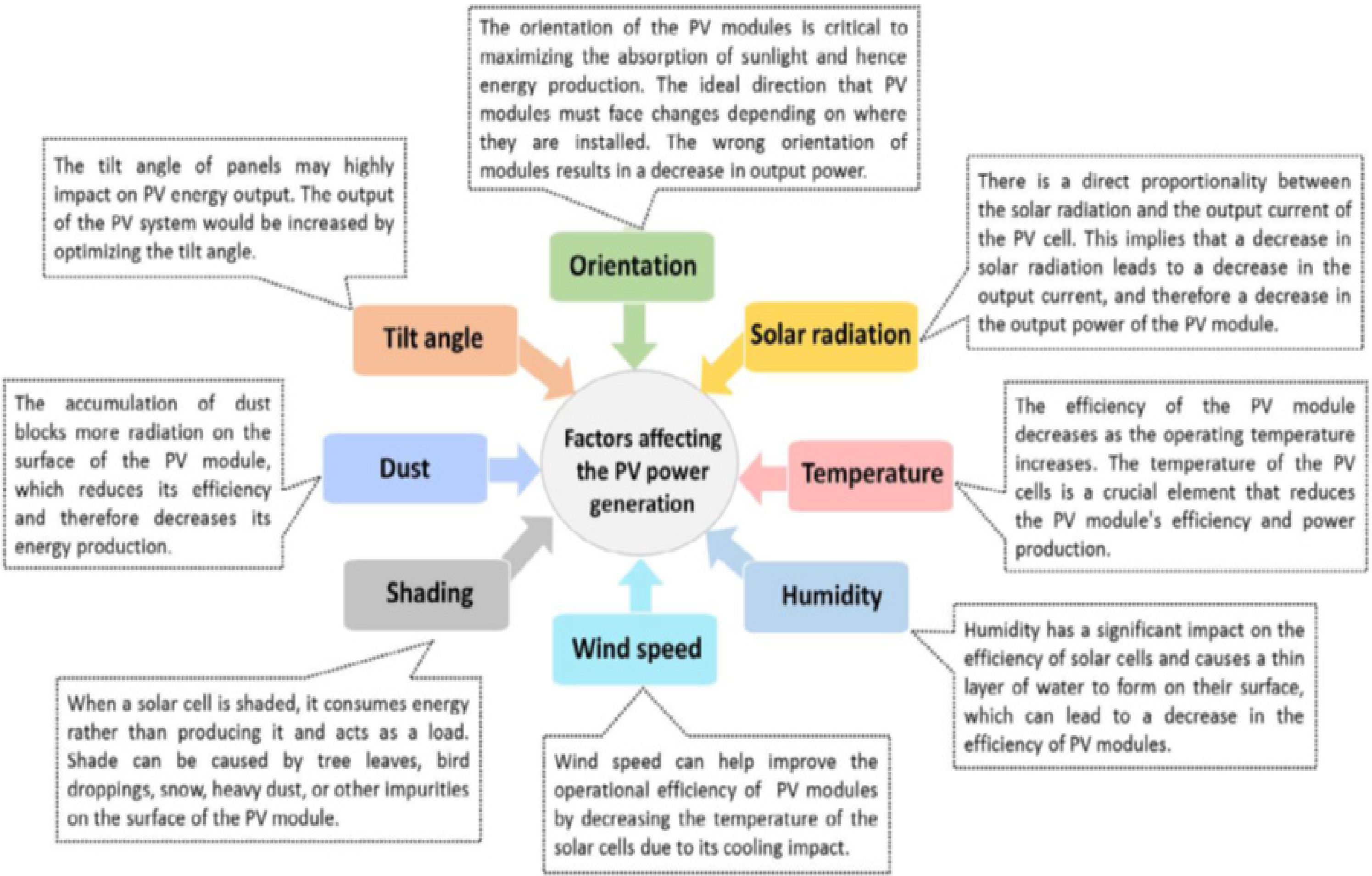
16. Yang, H., & Yang, H. (2016)

Yang, H., & Yang, H. (2016). Optimization of tilt angle for solar panels in different climates. Renewable and Sustainable Energy Reviews, 57, 684-690.

Most PV systems are installed in fixed placements and thus cannot track the sun during the day. Mounting PV modules on trackers that follow the sun from east to west during a day -single-axis trackers-and from north to south during seasonal shifts may increase the output - dual-axis trackers. This is rare for most PV applications, as it is a costly task. Shading could be one of the main causes of energy loss in a PV array [17]. When one cell of a 36-cell module is partially shaded, the power output shows immense reduction. The possible sources to act as a shading source include trees and shrubs, nearby structures, and several rows of modules. The array should be placed at least twice as far away from the item as its height, according to the conventional rule of thumb. By doing this, the item will be protected from casting a shadow for four hours on either side of solar noon. [17]

17. Huld, T., & Beyer, H. (2016)

Huld, T., & Beyer, H. (2016). The impact of shading on photovoltaic systems. Solar Energy, 126, 18-25



The orientation of the PV modules is critical to maximizing the absorption of sunlight and hence energy production. The ideal direction that PV modules must face changes depending on where they are installed. The wrong orientation of modules results in a decrease in output power.

The tilt angle of panels may highly impact on PV energy output. The output of the PV system would be increased by optimizing the tilt angle.

There is a direct proportionality between the solar radiation and the output current of the PV cell. This implies that a decrease in solar radiation leads to a decrease in the output current, and therefore a decrease in the output power of the PV module.

The accumulation of dust blocks more radiation on the surface of the PV module, which reduces its efficiency and therefore decreases its energy production.

The efficiency of the PV module decreases as the operating temperature increases. The temperature of the PV cells is a crucial element that reduces the PV module's efficiency and power production.

Humidity has a significant impact on the efficiency of solar cells and causes a thin layer of water to form on their surface, which can lead to a decrease in the efficiency of PV modules.

When a solar cell is shaded, it consumes energy rather than producing it and acts as a load. Shade can be caused by tree leaves, bird droppings, snow, heavy dust, or other impurities on the surface of the PV module.

Wind speed can help improve the operational efficiency of PV modules by decreasing the temperature of the solar cells due to its cooling impact.

Fig.4 Factors affecting PV systems

Hammoumi, A. E., Chtita, S., Motahhir, S., & Ghzizal, A. E. (2022c). Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels. Energy Reports, 8, 11992–12010.

1.6. Electrical Characteristics

Direct current, or DC, is the solar energy generated by a photovoltaic solar cell, which is the same as a battery. No matter how strong the sun's light is, there is a physical limit to the maximum current that a single photovoltaic solar cell can produce. The maximum current stands for the maximum deliverable current. A single photovoltaic solar cell's maximum current value is influenced by its size or surface area, the quantity of direct sunlight it receives, how effectively it converts solar energy into current, and the type of semiconductor material used in its construction. Most commercially available photovoltaic solar cells have solar power ratings that show the maximum deliverable solar power, the maximum power, that the cell can produce in watts. [18]

Maximum power is equal to the product of the cell voltage V multiplied by the maximum cell current I and is provided as:

$$P_{Max} = V_{Max} \times I_{Max}$$

Where P is the power, V is the voltage, and I the amperes, The maximum output power, peak power, rated power, maximum power point, and other designations used by different manufacturers to describe a PV cell's output power under full sun all mean the same thing. The available power (W) from the PV, at any point of the curve, is the product of current and voltage at that point. Short Circuit Current (ISC) A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is known as the short circuit current (Isc). This value is more than the amount of Imax, which relates to the normal operating circuit current. Under this condition, the resistance is zero and the voltage in the circuit is zero.[19]

Open Circuit Voltage (VOC)

Open circuit voltage (Voc) means that the PV cell is not connected to any external load and is therefore not producing any current flow (an open circuit condition). This value is based on the number of PV panels that are connected in series. Under this condition, the resistance is infinitely high and there is no current.

Maximum Power (P_{MAX} or MPP)

This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp). Imax and Vmax values occur at the "knee" of the I-V curve. [20]

Fill Factor (FF)

The fill factor is the ratio of maximum power output ($P_{max)}$ to the product of the open-circuit voltage times the short-circuit current, (VOC x ISC). The fill factor gives an idea of the quality of the array. [21] The closer the fill factor to 1 (unity), the more power the array can provide. Typical values are be-

18. Boehm, M., & Kunz, F. (2017)

Boehm, M., & Kunz, F. (2017). Characteristics of solar cells and modules. In Solar Power: Applications, Economics and Trends (pp. 123-145). Elsevier.

19. International Energy Agency (IEA). (2020)

International Energy Agency (IEA). (2020). Electrical characteristics of photovoltaic systems.

20. SolarTech. (2021)

SolarTech. (2021). Maximizing power output from solar arrays: Importance of fill factor and voltage currents. SolarTech Insights.

21. Morrow, M., & Gupta, A. (2019)

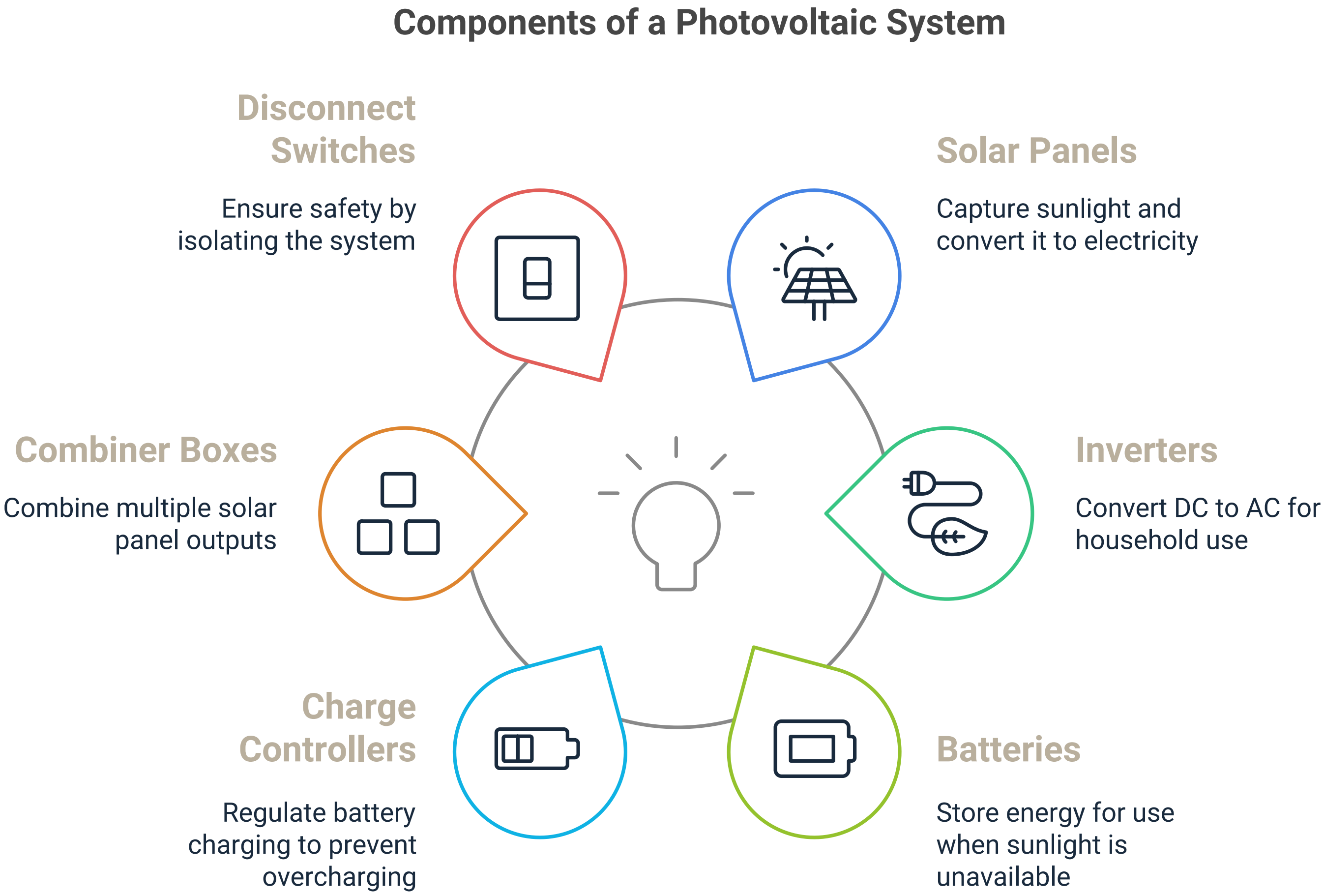
Morrow, M., & Gupta, A. (2019). Advances in solar cell efficiency: Challenges and developments. Energy Science & Engineering, 7(6), 2101-2112.

tween 0.7 and 0.8.

PV Module Output for a specific load, PV module output depends on two major factors, the irradiance or light intensity and the temperature. The PV cell's production is influenced by how much sunlight is shining on its surface. The cell generates more current the more sunlight it receives. The voltage will not change. With rising cell temperatures, the performance of PV cells decreases. With rising cell temperature, the operational voltage decreases. For every 25°C rise in cell temperature, the output voltage decreases by around 5% under direct sunlight. Then, to counteract power output losses brought on by high temperatures, photovoltaic panels with more solar cells are suggested for extremely hot areas than would be employed in colder ones. In comparison to crystalline technologies, most thin film technologies have a smaller negative temperature coefficient. In other words, as the temperature rises, they tend to lose less of their rated capacity.[22]

22. Ellis, C., & Jackson, G. (2017)

Ellis, C., & Jackson, G. (2017). Temperature effects on the performance of solar cells. Renewable Energy, 104, 289-298.



Components of a Photovoltaic System

Disconnect Switches

Ensure safety by isolating the system

Solar Panels

Capture sunlight and convert it to electricity

Combiner Boxes

Combine multiple solar panel outputs

Inverters

Convert DC to AC for household use

Charge Controllers

Regulate battery charging to prevent overcharging

Batteries

Store energy for use when sunlight is unavailable

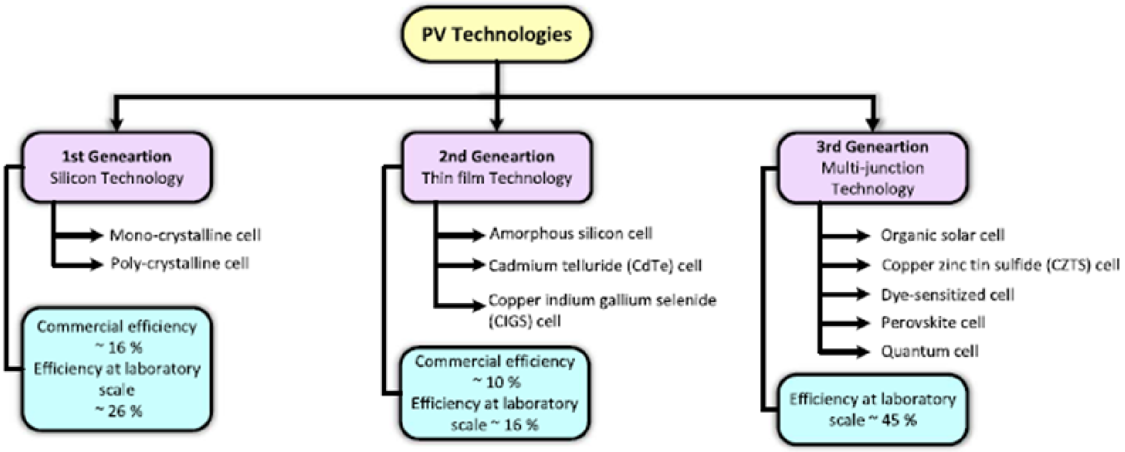


Fig.6 Technologies of PV systems

Hammoumi, A. E., Chtita, S., Motahhir, S., & Ghzizal, A. E. (2022b). Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels. Energy Reports, 8, 11992–12010.

2.1.2 Overview of PV Technology

Types of PV technology and recent innovations

There are different types of photovoltaics, some developed long ago, and others that are relatively new. Descriptions below provide a brief overview of a few well-developed PV materials.

Monocrystalline silicon

Probably, monocrystalline silicon solar cells are the oldest kind of solar cells. These are made from pure silicon crystal, having a continuous lattice with almost no defects. Their properties provide for high efficiency of light conversion: typically, about 15%, recent developments by SunPower boost improved efficiency up to 22-24%. Manufacturing the Si crystals is rather complicated, and just here is the root of the high cost for this type of photovoltaics. Recent progress has reduced the overall thickness of Si material used in monocrystalline cells to cut costs. Normally the amounts are between 0.7 and 0.8.[23]

The normal color of mono-crystalline silicon cells is black or iridescent blue. The monocrystalline silicon cells are highly durable and long-lasting, serving more than 25 years. However, their efficiency will decline gradually, some 0.5% per year, so operating modules replacement can be required earlier. The major disadvantage factors of monocrystalline silicon panels are the high initial cost and mechanical vulnerability.

Polycrystalline (or multi-crystalline) silicon

Polycrystalline cells are made by assembling multiple grains and plates of silicon crystals into thin wafers. Smaller pieces of silicon are easier and cheaper to produce, so the manufacturing cost of this type of PV is less than that of monocrystalline silicon cells. The polycrystalline cells are slightly less efficient (about 12%). These cells can be recognized by their mosaic-like appearance. Polycrystalline cells are also very durable and may have a service life of more than 25 years. The cons of this type of PV technology are mechanical brittleness and not very high efficiency of conversion. [24]

Amorphous silicon (Thin-film)

Thin film photovoltaic cells are produced by depositing silicon film onto substrate glass. In this process, less silicon is used for manufacturing com-

23. Green, M. A., & Emery, K. (2018)

Green, M. A., & Emery, K. (2018). Monocrystalline silicon: Manufacturing and advancements. Journal of Applied Solar Energy, 40(2), 199-210.

24. Zeng, Q., & Zhang, F. (2017)

Zeng, Q., & Zhang, F. (2017). Polycrystalline silicon solar cells: Characteristics and efficiency improvements. Journal of Solar Energy, 36(3), 337-347.

pared to mono- or polycrystalline cells, but this economy comes at the expense of conversion efficiency. Thin-film PV has an efficiency of about6% versus about15% for single crystal Si cells. One way to improve cell efficiency is to create a layered structure of several cells. The main advantage of the thin-film PV technology is that the amorphous silicon can be deposited on a variety of substrates, which can be made flexible and come in different shapes and therefore can be used in many applications. The amorphous silicon is also less prone to overheating, which usually decreases the solar cell performance. Amorphous silicon is most developed among the thin-film PV.

Cadmium Telluride, CdTe (Thin-film)

CdTe PV is another kind of thin-film solar technology. It has become quite popular due to the lower cost per kW-hour. The best efficiency obtained with CdTe cells is around 16%. One of the advantages of the CdTe cells is that they capture shorter wavelengths of light than silicon cells can do. There are some environmental concerns related to the limited supply of tellurium and the potential toxic impact of cadmium at the stage of CdTe panel disposal. Developing effective closed-loop recycling technologies can be a game-changing factor in favor of this technology.

Copper Indium Gallium Selenide (CIGS)

CIGS PV has become a popular new material for solar cells since it does not contain toxic Cd and has higher efficiency, reaching just under 20%. At this moment, the CIGS is the most efficient among the thin-film PV technologies. While lab results confirmed the high promise of this kind of photovoltaics, in mass production, CIGS proved to be a problem. The CIGS cells are made with thin film deposition on a substrate, which can be flexible also, on the contrary to the silicon cells. In a similar way to CdTe cells, the CIGS cells show good resistance to heating. Polymer and organic PV

Organic materials are quite attractive since they can be involved in high-output manufacturing and because they can be made in various thicknesses and shapes. These types of cells are relatively lightweight (compared to silicon cells). Also, they offer flexibility and relatively low fabrication costs. They, however, are much less efficient (about one-third of typical Si cell efficiency) and sometimes prone to quicker degradation.

These are a few most well-known varieties of PV technology, but many more innovations are at the research and development stage. Breakthroughs in new materials and cell design may be responsible for the growth of the PV industry in the upcoming decades. [25]

25. Rizzuto, S. (2020)

Rizzuto, S. (2020). Emerging solar cell technologies: A roadmap for future developments. Solar Energy Materials & Solar Cells, 211, 110520.

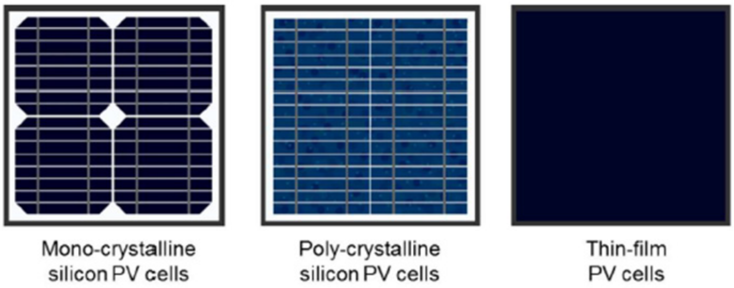


Fig.7 Types of PV Technology

Choubey, P. (2024, July 17). What are the different types of solar panels? Avaada. https://avaada.com/types-of-solar-panels/

2.1.3 Building-Integrated Photovoltaics (BIPV)

BIPV is an innovative methodology for integrating construction materials with renewable energy technology. While the traditional photovoltaic systems tend to be externally installed, the BIPV system is integrated into the skin of the building envelope itself. In fact, these can serve both as structural elements for roofs, facades, and skylights but also as renewable energy sources, thereby redefining the potential of built environments to contribute to global sustainability efforts.

BIPV has its roots in various experimental installations that took place in the 1980s, where photovoltaics used to be more of an accessory feature. From that time forward, the technology of BIPV advanced to a highly technical mature state. Contemporary BIPV systems are not constrained to functional designs but are also available in forms that respond to aesthetic needs, such as different colors, shapes, and levels of transparency. These features have transformed BIPV from a purely functional energy system into an integral element of architectural design as part of larger goals in urban sustainability.

BIPV systems hold a privileged position in addressing some of the most significant challenges of the modern era, which include energy and climate change. By changing traditional building materials for energy-producing ones, BIPV systems make buildings act like decentralized renewable energy centers. This approach reduces reliance on external power grids, lowers carbon emissions, and increases the energy efficiency of urban environments. For example, the European Green Deal underscores the role that technologies like BIPV can play in a zero-carbon future. BIPV seamlessly addresses such goals by enabling the built environment to shift from being one of the major contributors to carbon emissions into an active participant in energy generation.

Despite these advantages, there are a lot of obstacles to the widespread adoption of BIPV. The high initial costs associated with the installation of BIPV systems offer a deterrent to various investments, especially when traditional construction materials are compared. Because the integration of BIPV into various building projects involves coordination between different professionals, including architects, engineers, and solar manufacturers, and it requires a multidisciplinary approach to ensure that these systems apply to technical, aesthetic, and regulatory standards. Besides, the regulatory frameworks concerning BIPV differ from region to region, adding more complexity to their implementation.

These challenges are overcome steadily through various technological advancements and market trends. Material science developments, digitization in manufacturing processes, and increased energy efficiency have led to cost reductions and made BIPV systems more attractive. This is illustrated by practical examples. For example, the Grosspeter Tower in Switzerland shows how BIPV systems can be integrated into high-rise buildings, combining energy efficiency with dramatic architectural effects. Similarly, retrofitting historic buildings with BIPV illustrates the adaptability of the technology to various contexts.[26]

26. Charron, L., & Carpentier, C. (2015)

Charron, L., & Carpentier, C. (2015). Retrofitting historic buildings with building-integrated photovoltaics: Case studies and guidelines. Energy and Buildings, 86, 222–230.

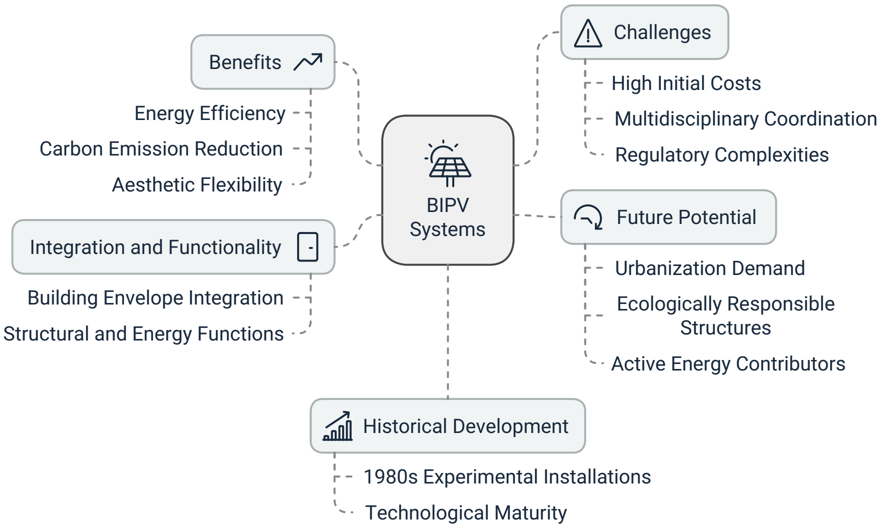
Looking ahead, the potential of BIPV to transform the built environment is huge. As urbanization continues to expand, the demand for sustainable building solutions will rise. BIPV is at the forefront of that evolution, providing a route toward the development of structures that are both ecologically responsible and architecturally daring. By transforming buildings from passive objects into active contributors of energy, BIPV systems change not only the face of the construction industry but also take an important position in the general transition of humankind toward renewable resources. [27]

27. Collet, M., & Pasquali, M. (2019)

Collet, M., & Pasquali, M. (2019). Building-integrated photovoltaics: The next frontier in sustainable architecture. Renewable Energy, 139, 82–89.

2.1.5 Evolution of BIPV in architecture, technology

BIPV systems have now become one of the most important innovations in contemporary architecture, where form and function could coalesce into sustainable yet visually appealing creations. By consolidating photovoltaic materials into building elements like facades, roofs, and skylights, BIPV systems enable architects to plan buildings that are energy-efficient yet aesthetically innovative. It is this dual capability that has redefined the architectural possibilities, nurturing an era of design in which sustainability becomes an intrinsic feature of every project.



Over time, the integration of BIPV into architectural design has shifted exponentially. Historically, solar technology was seen as a utilitarian addition, often compromising the aesthetic appeal of a building. But times have changed, with advances in BIPV technology now allowing architects to use photovoltaics as integral design elements in the building process. Presently, modern BIPV systems can hardly be rivaled in the number of customizing options available: color, texture, and transparency. These features enable architects to design custom-made panels according to certain aesthetic and functional needs while contributing to energy generation.[28]

28. O’Rourke, M., & Duffy, A. (2018)

O’Rourke, M., & Duffy, A. (2018). The evolution of BIPV: From functional addition to architectural feature. Journal of Sustainable Architecture and Urban Design, 2(3), 155–167.

Perhaps one of the most interesting trends in BIPV architecture is the issue of using these systems as building skin. Instead of simply installing solar panels on buildings, the new BIPV elements would be perfectly integrated into the building envelope, turning it into an integral, harmonious body. This approach not only adds an aesthetic element to the building but also creates a maximum of energy efficiency. Examples include the colorful solar panels at the Copenhagen International School, which show how BIPV systems can elevate architectural designs while meeting their sustainability goals.

BIPV systems also play an important role in preserving and modernizing historical architecture. Retrofitting heritage buildings with BIPV allows architects to maintain the cultural and historical integrity of these structures while enhancing their energy performance. Projects such as the refurbishment of the Doragno Castle in Switzerland demonstrate how BIPV can fill the gap between tradition and modernity. Architects have been able to prove that energy efficiency and the preservation of culture go hand in hand by embedding photovoltaics into the rooftops of historical buildings.

This is also in line with the global drive towards zero and positive-energy buildings. These are buildings designed to produce at least the amount of energy they consume, and BIPV systems are built on the foundation of this concept. In this way, architects integrate energy production into building design as a way of reducing demand for external power sources and supporting wider sustainability objectives. This trend is particularly relevant in urban areas, where demand for renewable energy solutions is equally in high demand.[29]

Its implementation in architecture, however, has several problems. First, BIPV projects require participation from many disciplines: architects and engineers interact continuously with manufacturers to ensure that the design goals are in line with technical specifications. The higher initial costs of systems make their adoption less appealing, especially for cost-sensitive projects. Nevertheless, such factors are increasingly being offset through advances in technology and increased market competitiveness, backed by enabling regulatory frameworks.

Real applications are the best way to showcase the impact of BIPV on architecture. An excellent example of redefining the urban skyline is the Grosspeter Tower in Switzerland. The facade of the building integrates solar panels that are not only capable of generating energy but also accentuate the look of the building. Similarly, retrofitted projects like the Solar Silo in Basel showcase its adaptability to various architectural contexts, from modern office buildings to industrial heritage sites. [30]

29. Baumgartner, T., & Müller, M. (2020)

Baumgartner, T., & Müller, M. (2020). BIPV systems for zero-energy buildings: Challenges and advancements. Renewable and Sustainable Energy Reviews, 121, 109678.

30. Deneuville, M., & Lemoine, T. (2016)

Deneuville, M., & Lemoine, T. (2016). Integration of photovoltaic systems in urban architecture: A case study of the Grosspeter Tower and Solar Silo. Solar Energy, 134,

Least integrated
(Open rack-mounted PV)

More integrated
(Close roof rack-mounted PV)

Fully integrated
(Direct-mounted BIPV, multifunctional)

Fig.8 BIPV

James, T.L., Goodrich, A.C., Woodhouse, M., Margolis, R.M., & Ong, S. (2011). Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices.

2.2 Kinetic and Dynamic Shading systems Systems

Adaptive facade is classified in many types as interactive, responsive, smart, biomimetic, kinetic, advanced and intelligent. It is observed that the classification in the field has no certain definitions related to the differences in a scientific approach. Moreover, two or more concepts can be used together by combining the particular aspects of each façade system.

On the other hand, the interactive facade needs human involvement for any response or action. It can also be integrated with sensors and an automated building management system that would be programmed to optimize energy consumption for the interior part. Furthermore, it can also be programmed based on different user profiles to enrich human-space interaction. As Fox 28 has mentioned, it can be seen that tangible designs have been used in many architectural spaces with developing technology.

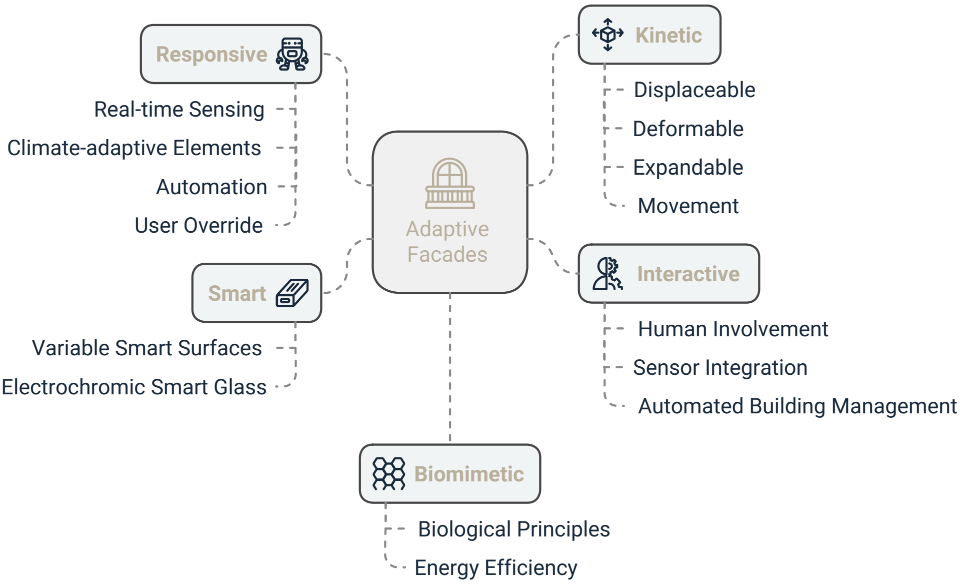
Responsive facades are technologies developed using integrated building concepts. The term "responsive" shows the dynamic building elements that enable adjustment of the facade to improve the performance requirements of the building. Responsive facades are mechanisms of adaptive buildings that utilize sensors and actuators to monitor the environment and automate the control of operable building elements. responsive facades are able to sense in real-time, have climate-adaptive dynamic elements, automation, and user override. In addition, responsive facades are also like intelligent facades in their functional and performance-based nature.

In line with developing material technology, smart facades also have the potential to become one of the major fields of architectural interest. Variable smart surfaces and materials respond to needs. The performance-driven adaptive building coatings used with smart materials can be provided with electrochromic smart glass.[31] Biomimetic facades are adaptive facades based on nature-inspired design. This approach is based on a chosen biological principle but requires an intermediate abstraction phase from the biological principle to the façade. The biomimetic facade should react to the changes in the current conditions similar to the reaction of living organisms to environmental factors. The application of biomimetic approaches to the facade contributes the energy efficiency.

Kinetic facades are defined as an architectural form that can be inherently displaceable, deformable, expandable, or capable of movement. They are adjusted efficiently according to boundary conditions such as climatic conditions, different locations, variable functional requirements, or emergencies. These facades need an actuating force or a stimulus that triggers

31. Fox, M. (2009)
The architectural possibilities of interactive façades. Architectural Design, 79(5), 78–85.

the kinetic behavior of the façade modules. Nowadays, it is thought that kinetic architecture will be handled in a different dimension with the use of electromechanical systems.



This diagram gives a great overview of how surfaces may transform and adapt, providing insight into the design of responsive architectural systems. [32] These transformations can be broken down into two types:
Motion-based transformations include rigid plates-those where the surface moves but is still solid and intact.
Translation: The surface is moved straight along one or more directions.
Rotation: The surface pivots around a fixed point.
Folding: Translating and rotating to make folds, as in origami.
Scaling: Expanding the area or shrinking it, assuming no rigidity of its surface.
Deformation-based transformations of flexible membranes mean the changes of shape by stretching or bending of easily deformable materials. Examples of these are:
Stretching: The surface is stretched in all directions to extend the surface.
Rolling: Bending of the surface around a point, usually in the manner of 'rolling' paper.
Bending: Graceful bend of a flat surface.
Torsion: Turning the surface in a helical manner.

32. Kolarevic, B., & Malkawi, A. (2005)
Kolarevic, B., & Malkawi, A. (2005). Performative architecture: Beyond instrumentality. Architectural Design, 75(5), 14–21.

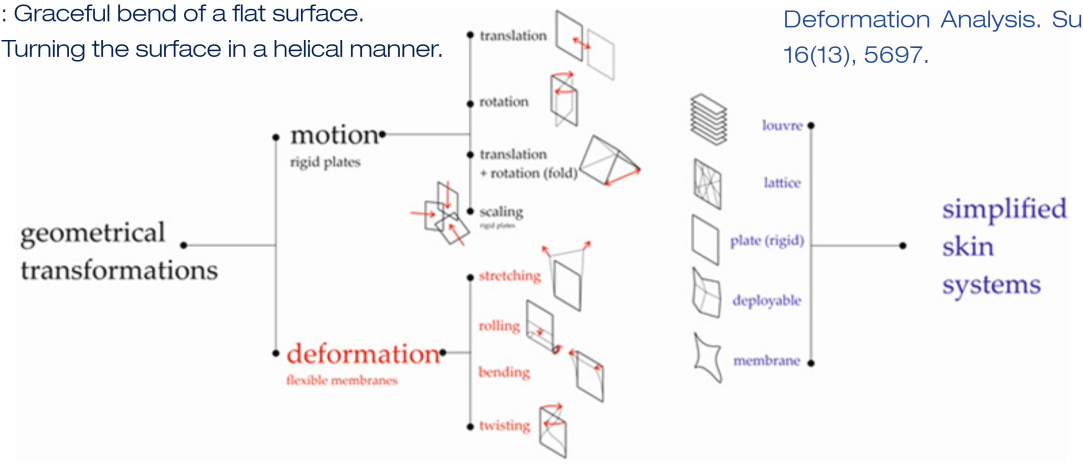


Fig.9 Types of surface transformations
Brzezicki, M. (2024). A Systematic Review of the Most Recent Concepts in Kinetic Shading Systems with a Focus on Biomimetics: A Motion/Deformation Analysis. Sustainability, 16(13), 5697.

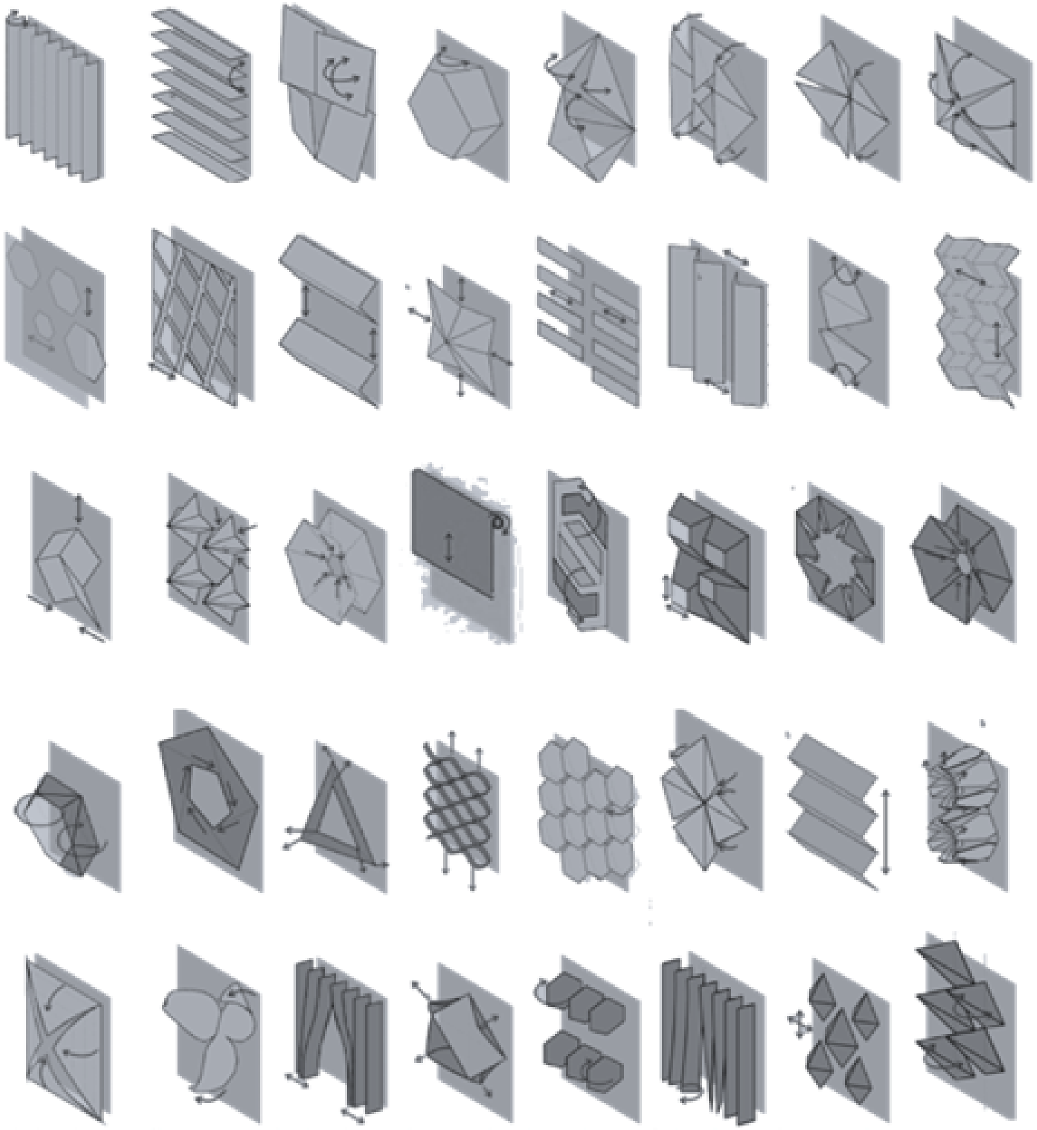


Fig.10 Catalog of geometric transformations

Brzezicki, M. (2024). A Systematic Review of the Most Recent Concepts in Kinetic Shading Systems with a Focus on Biomimetics: A Motion/Deformation Analysis. Sustainability, 16(13), 5697. https://doi.org/10.3390/su16135697

As seen in the diagram above which shows an extensive catalog of geometric transformations and mechanical deformations that can be applied to surface systems in architectural design. It underlines a variety of motion-based transformations applied to rigid materials and deformation-based transformations applied to flexible membranes. Transformations such as translation, rotation, folding, scaling, stretching, twisting, and bending.

Each section reveals different kinds of transformations on different geometries of surfaces. The diagram below depicts how such transformations can be utilized for adaptable and architectural skin systems: folding facades, retractable surfaces, morphing structures, among other concepts contributing to dynamic and responsive designs in architecture.[33]

33. Bejleri, I., & Ziegler, A. (2011)

Bejleri, I., & Ziegler, A. (2011). Adaptive architectural facades: Exploring dynamic geometries and material behaviors. Journal of Facade Design and Engineering, 9(3), 123–137.

2.3 Control Systems for PV and Shading Applications

The recent growth and availability of computational tools and methods for planning, simulating, and controlling dynamic processes, along with decreasing costs of electronic equipment like microprocessors, sensors, and actuators, have fostered new research and practical implementation of dynamic responsive facades in the most recent years.

At the same time, the growing demand for energy-efficient buildings due to the current environmental crisis has also made dynamic facade systems a highly desirable solution for achieving high-performance outcomes that had not been possible before.[34]

Michael Fox identifies six types of kinetic control systems in order of increasing complexity:[]

- Direct Control: Devices are controlled directly from outside the system by an energy source
- Indirect Control: Movement of devices is informed by feedback provided by sensor systems.
- Internal Controls: Devices function independent of direct control mechanisms like mechanical hinges.
- Responsive Indirect Control: Motion in the device is by multiple feedback mechanisms from sensors.
- Ubiquitous Responsive Indirect Control: The device would have predictive capabilities due to control systems that employ predictive algorithms.
- Heuristic Indirect Control Responsive: Algorithmic networks with learning enable device motion.

Since during this study the sensors of systems were not taken into account a similar project has been chosen to make a hypothesis about this systems functionality.

The system that will be examined here is part of the dynamic facades domain, focusing on the light-filtering function and the simultaneous energy production. The design structure and process demonstrate how Boolean and fuzzy logic control systems have been applied to support design exploration both in the design and operational phases. This enables adaptive functionality, wherein the façade can respond to changed conditions and meet efficiency and sustainability goals with effectiveness.[35]

34. Fox, M. (2017)

Fox, M. (2017). Kinetic control systems in dynamic architecture. International Journal of Architectural Computing, 15(1), 22–35.

35. Sneineh, M., & Salah, M. (2019)

Sneineh, M., & Salah, M. (2019). Adaptive facade systems: An application of Boolean and fuzzy logic control in architectural design. Journal of Building Performance, 10(2), 45–56.

First, the sun sensor senses the apparent position of the sun at any time of day, and then the measurement data is fed back to the controller. The latter identifies the tracking error and gives the required control signal to the tracker's actuators to correct this error in order to align the PV panels perpendicular to the sun's rays.

The most commonly used sun position sensors in closed-loop systems is LDR sensor because of its simple circuitry and inexpensive cost. This type of system employs an array of LDR sensors, normally four LDRs, that are placed at certain positions on the tracker, depending on the adopted configuration in the LDR sensors, which are placed at the four corners of the panel, sense sunlight and give return signals to a control unit such as a PLC/μC. The control algorithm, often an "On–Off controller", first calculates the tracking error, that is, the difference between analogue values returned by the right and left pairs of LDRs if it is a VSAT, or the difference between the top and bottom pairs of LDRs if it is an HAST, or both of these differences if it is a DAST. Then it instructs the tracker via one or two motors (depending on the used tracking structure, single or dual-axis) to turn toward the pair or pairs that detect the highest sunlight. The tracker will keep on rotating until the tracking error is corrected, that is, until the intensity of sunlight on the right LDR pair is equal to the intensity of sunlight on the left LDR pair (and/or the intensity of sunlight on the top LDR pair is equal to the intensity of sunlight on the bottom LDR pair). The LDRs are located at the center of each side of the PV panel. In that case, the sun's movement in the east/west direction is tracked by the right and left LDRs, while the sun's movement in the south/north direction is tracked by the top and bottom LDRs. LDR sensors are mounted as four quadrants separated by a cylindrical tube or by two barriers to form a sun sensor device. This device is based on the use of shading and can be installed on the top, left, or right side of the PV panels. In case the tracker is not perpendicular to the sunlight, the cylinder's (or barriers') shadow will create a difference in light intensity on the four LDRs. The tracker will keep on rotating till this difference is approximately equal, i.e., the light intensity on the east LDR is equal to that of the west LDR and the intensity on the north LDR is equal to that on the south LDR. It should be added that a threshold value, better known as the hysteresis band, is normally used in this kind of controller-on-off-to make the motors of the tracker rotate smoothly. That means if the tracking error is inside the hysteresis band, the motors will not move, and further control is made only if the error exceeds or is outside this threshold to rotate counterclockwise or clockwise with the motor system.[36]

36. Hoffman, D., Akbar, I., & Melo, P. (2018)

Hoffman, D., Akbar, I., & Melo, P. (2018). Sun tracking with LDR sensors: A review of closed-loop systems in photovoltaic applications. Renewable Energy Research, 11(3), 101–110.

2.4 Case Studies and Architectural Implementations

Solar Decathlon

Location: Washington, D.C., USA
Date: 2007
Architect: Various universities and their student teams
Building Type: School
Adaptive System: Solar-powered houses (demonstrating energy efficiency and sustainability)

the Technische Universität Darmstadt experimental house, built for the 2007 United States Solar Decathlon Competition, incorporates an external cladding consisting of wooden slits with integrated photovoltaic panels controlled by an As an example, the Technische Universität Darmstadt experimental house, built for the 2007 United States Solar Decathlon Competition, incorporates an external cladding consisting of wooden slits with integrated photovoltaic panels controlled by an intelligent system, allowing the production of energy and at the same time the reduction of solar gains. [37]

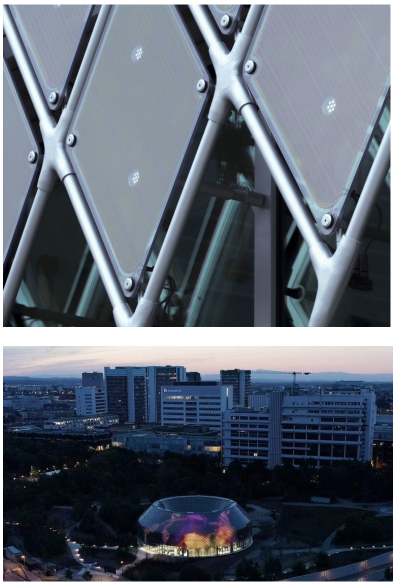
37. Technische Universität Darmstadt. (2007)

Technische Universität Darmstadt. (2007). Solar Decathlon 2007: Energy-efficient design and adaptive photovoltaic facade. Proceedings of the United States Solar Decathlon

Novartis Pavillon’ s media facade

Location: Basel, Switzerland
Date: 2014
Architect: Hariri Pontarini Architects
Building Type: Pavilion
Adaptive System: Dynamic Media Facade, Interactive Lighting System

the zero-energy media facade of the Novartis Pavillon combines organic photovoltaics and LEDs to create a communicative building skin.
The use of organic photovoltaic cells (OPV) is groundbreaking. With their input, the media skin becomes a zero-energy facade, as they are responsible for generating the electricity needed for the light shows. In addition, OPVs have a number of properties that make them interesting for use on the circular pavilion: they can be manufactured in a wide variety of shapes and sizes, are flexible and extremely light-sensitive. This is why it is also beneficial to use them in areas with indirect lighting, allowing the entire surface of the “donut-shaped” structure to be covered with them.[38]



38. Hariri, S., & Pontarini, R. (2014)

Hariri, S., & Pontarini, R. (2014). The Novartis Pavilion: A zero-energy media facade with organic photovoltaics and interactive lighting. Journal of Architectural Innovatio

Kiefer Technic Showroom Ernst Giselbrecht + Partner

Location: Bad St. Leonhard, Austria
Date: 2007
Architect: Ernst Giselbrecht + Partner
Building Type: Showroom
Adaptive System: Dynamic Facade, Photovoltaic Panels

The other example is made from foldable plates, is the Kiefer Technic Showroom building facade which is constructed of 2 layer facade one in glass and other the plastered aluminum tiles. The movable shade part is the external one including plates connected via linear hinges which allow them to be folded.

A research has examined this facade and turned it into a kinetic photovoltaic façade system by imitating the style of the top half of the Kiefer showroom's dynamic façade system designed by Giselbrecht + Partner ZT GmbH. Kiefer Technic was an office building and exhibition space in Austria. The dynamic façade system changed to outdoor conditions, optimizing internal climate. The façade system operated on electronic shutters of perforated aluminum panels that can fold in various positions allowing occupants to adjust the light or temperature in the building.[39]

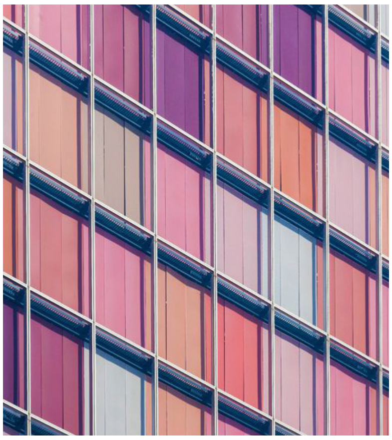
39. Giselbrecht, E., & Partner, ZT GmbH. (2007)

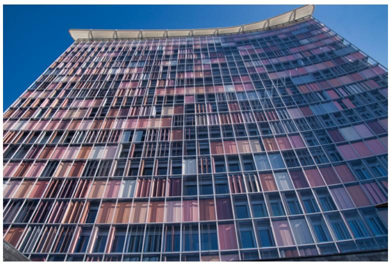
Giselbrecht, E., & Partner, ZT GmbH. (2007). Kiefer Technic Showroom: A kinetic façade system for dynamic energy optimization. Architectural Review

GSW Headquarters

Location: Berlin, Germany
Date: 2002
Architect: Sauerbruch Hutton Architects
Building Type: Office Headquarters
Area: 54,000 Sqm
Adaptive System: Dynamic Facade, Solar Shading System, Photovoltaic Panels

The building's most striking design feature, which also functions as its adaptive system, is the facade. The east facade incorporates triple-glazed windows with blinds positioned between the panes, which can be operated both manually and automatically. On the west side, the facade is dual-skinned, featuring double-pane windows on the inner layer that also allow manual or automatic operation. Within the interstitial space of the west facade, wide, vertical, perforated aluminum louvers in various colors—ranging from ruby red to pink and orange—provide external solar shading. During sunny days, these colorful louvers work together to create a vibrant "carpet" of color that shades the entire west facade.[40]





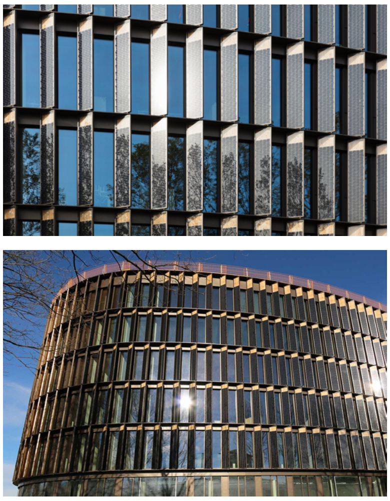
40. Sauerbruch, H., & Hutton, W. (2002)

Sauerbruch, H., & Hutton, W. (2002). Dynamic facades and solar shading systems in the office headquarters in Berlin. Architectural Journal

Ingenhoven Architects Freiburg Town Hall

Location: Freiburg, Germany
Date: 2010
Architect: Ingenhoven Architects
Building Type: Town Hall
Adaptive System: Dynamic Facade, Photovoltaic Panels, Solar Shading System

The overall output of 220kWp is generated by a total of 880 solar modules, which a2-solar has manufactured as special seamless double-glass modules with the exceptional dimensions of 3.5m height on 60cm width, weighing almost 100kg each. The 7mm spacing between the solar cells creates a high transparency for the wood panels installed behind: a design concept elaborated by the Ingenhoven architects to combine highest art of technology with natural building materials. For a2-solar, this project forms again another great success to realize an extra-ordinary synthesis of design and functionality while Building facade is made of vertically integrated, semi-transparent solar panels, which are installed on sun-exposed frontiers.[41]



41. Ingenhoven, R. (2010)

Ingenhoven, R. (2010). Freiburg Town Hall: Integration of dynamic façade and photovoltaic systems. Journal of Architectural Innovation

Solar Ivy

Location: Various Locations
Date: Ongoing (Started 2010s)
Architect: SmithGroupJJR
Building Type: Sustainable Façade System
Adaptive System: Solar Photovoltaic Façade (Solar Ivy Panels)

The overall output of 220kWp is generated by a total of 880 solar modules, which a2-solar has manufactured as special seamless double-glass modules with the exceptional dimensions of 3.5m height on 60cm width, weighing almost 100kg each. The 7mm spacing between the solar cells creates a high transparency for the wood panels installed behind: a design concept elaborated by the Ingenhoven architects to combine highest art of technology with natural building materials. For a2-solar, this project forms again another great success to realize an extra-ordinary synthesis of design and functionality while Building facade is made of vertically integrated, semi-transparent solar panels, which are installed on sun-exposed frontiers.[42]

42. SmithGroupJJR. (2010s)

SmithGroupJJR. (2010s). Solar Ivy Panels: Sustainable Façade System for Various Locations. Journal of Green Architecture

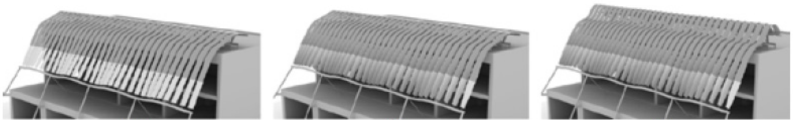
Soft House

Location: Hamburg, Germany
Date: 2010
Architect: Jürgen Mayer H. Architekten
Building Type: Residential Building
Adaptive System: Flexible, Adaptive Facade with Integrated Photovoltaic Panels

The project is a terraced house with four units in passive house standard. the soft house is clad in an adaptable construction covered with flexible photovoltaic cells. Movable and translucent curtains are used inside, which are covered with LEDs. These are supplied with low voltage via the membrane façade. The curtains allow for individual regulation of heat and light and allow for constant change in the spacious interiors.
The design was created by Kennedy & Violich Architecture, Boston, in collaboration with 360 Grad+, Hamburg. Knippers Helbig Advanced Engineering developed the flexible and trackable photovoltaic system and designed the solid timber structure.[43]

43. Mayer, J. H. (2010)

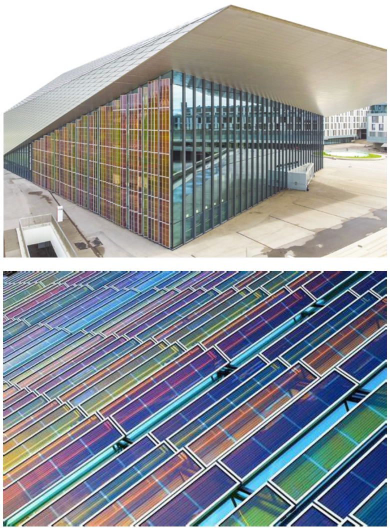
Mayer, J. H. (2010). Flexible, Adaptive Facade with Integrated Photovoltaic Panels: Residential Building in Hamburg. Journal of Sustainable Architecture



SwissTech Convention Center

Location: Lausanne, Switzerland
Date: 2014
Architect: BIG (Bjarke Ingels Group)
Building Type:Convention Center
Adaptive System: Adaptive Facade with Photovoltaic Integration

building-integrated for solar energy is no longer only for roof top installations. Now also there are types of this system Available with a palette of different colors and adjustable transparencies, they are enough to make architects envision original integrations, with a natural emphasis on façades. Low light sensitivity and a smaller angular dependency allow this solar cells to work in vertical installations. The panels not only fulfill their technological duty by converting sunlight to electricity, but also become an integral part of the aesthetics of the building.[44]



44. Ingels, B. (2014)

Ingels, B. (2014). Adaptive Facade with Photovoltaic Integration. Convention Center, Lausanne, Switzerland. In Proceedings of the Conference on Building-Integrated Photovoltaics, (pp. 102–115). Bjarke Ingels Group (BIG)

System Design and Development

- Conceptual Design of Dynamic PV Systems
- Mechanical and Structural Design
- Electrical and Control System Design

3.1 Conceptual Design of Dynamic PV Systems

Solar shading systems generally represent one of the passive design strategies globally employed to protect buildings from intensive solar radiation, especially during peak hours. The literature reports that the employment of passive shading systems is an effective bioclimatic practice that maintains the balance between visual and thermal demand. [1]
However, studies showed that static shading elements are notably incapable of completely responding to variable climatic conditions. In addition, it has been shown that there are limitations to attaining a required daylight condition, hence increasing lighting demand. In fact, the system interaction with climate is only optimal at a certain time and date over the day and the year. Therefore, for such control flexibility and energy efficiency, static systems are no longer favorable. [2],[3]
A dynamic shading system is made up of movable elements that operate within an algorithm. The definition of a dynamic shading system can be associated with applications in intelligent facades. These have been proven to increase the comfort of inhabitants as a result of their interaction with the external and internal environment. Thus, the term ‘dynamic’ refers to continuous and developing change with frequent updates, based on the following two aspects: 1. the continuous interaction between the system and its environment, and 2. the cause-and-effect interrelation between forces and movements within specific periods. Thus, dynamic shading devices are intelligent systems automatically operated in response to outdoor or indoor weather parameters in favor of high comfort level and energy performance. [4]
Dynamic shading devices generally consist of multiple layers that are involved in forming the smart system, ranging from the transformative skin layer to the operation and management of various facilities. The automated response is the most important characteristic of dynamic shading systems, whereby its realization requires three constituents: a sensor network for retrieving information, a controller to decide on appropriate action, and a

1. Heinstein, P., Ballif, C., & Perret-Aebi, L. (2013)

Heinstein, P., Ballif, C., & Perret-Aebi, L. (2013). Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths. Green, 3(2).

2. Ali, A., & Zaidi, S. (2018)2013

Ali, A., & Zaidi, S. (2018). The impact of dynamic shading systems on energy and comfort in buildings: A review. Building and Environment, 143, 324-333.

3. Yao, J., & Steemers, K. (2005)

Yao, J., & Steemers, K. (2005). “A Method of Formulating the Architectural Design Principles of Daylighting for Visual Comfort.” Building and Environment, 40(2), 153-161

4. Aydin, S., & Baskan, O. (2015)

Aydin, S., & Baskan, O. (2015). Integration of BIPV and shading systems: A case study of energy saving and visual integration. Energy and Buildings, 105, 319-327.

few mechanical actuators. [5]

Moreover, this study will classify different models of dynamic shading according to their geometric and motion design and discuss their effect on the indoor environment and energy factors of buildings. Thus, other than establishing the difference between these factors in relation to meeting their criteria for a proper design, the definition of dynamic shading can be considered a system that has models, components, and mechanisms with various evaluations.

The strategies mentioned for designing such systems are important, However, issues about mechanical and electrical systems, maintenance, and technical installation are beyond the scope of this Thesis; thus, the main intent of this study is to investigate the energy production of such prototypes in order to understand various advantages involved when using these systems.

It appears clear that the selection of the shading system typology is influenced by different factors: the geometry of the facade, the design conception, the environmental efficiency, the technological performance, and so forth. Besides architectural ambitions, several studies prove that some solutions are more efficient than others. To this point it's been seen that external and internal shutters have an identical influence on the heating demand during wintertime, while external ones are more practical in summertime, reducing the cooling energy demand. This is often because of the fact that internal sun shading elements don't filter the radiation on the surface of the facade, which is absorbed and transmitted into space leading to additional cooling loads.

The first objective during this part is to style a range of shading systems that meet all identified requirements to support optimal and efficient energy production. The designs are developed with a robust emphasis on integrating solutions that are compatible with glazed facades or window surfaces. This compatibility is critical to make sure that, while shading the building effectively, these systems don't inhibit the entry of natural daylight, thus maintaining a well-lit interior environment. The balance between shading and daylight access could be a key design consideration in the possibility of every proposed solution.

To achieve an intensive exploration of potential shading systems, the look process involves creating a series of scenarios starting from the best to the foremost advanced. The only concept of design could be a basic shading system that gives a simple approach to blocking sunlight while remaining compatible with glazed surfaces.

As the designs progressed, they became increasingly sophisticated, with the ultimate, most complex iteration featuring a geometrically responsive system that dynamically adjusts in response to the angle and intensity of sunlight. This gradation in complexity allows for a broad evaluation, providing insights into how each level of complexity influences energy efficiency and daylight management.

Each design is ready-made to gauge carrying into action aspects, like the effectiveness of shading, impact on interior lighting conditions, and overall contribution to energy efficiency. [7]

5. Manzoli, D., & Serra, P. (2016)

Manzoli, D., & Serra, P. (2016). Energy-efficient shading systems for buildings with integrated photovoltaic panels. Solar Energy, 130, 53-61.

6. Tabadkani et al., 2019

Tabadkani, A., Shoubi, M. V., Soflaei, F., & Banihashemi, S. (2019). Integrated parametric design of adaptive facades for user's visual comfort. Automation in Construction, 106, 102857.

7. Hassan, M., & Qureshi, S. (2021)

Hassan, M., & Qureshi, S. (2021). Energy Efficiency in Geometrically Advanced Shading Systems. Journal of Architectural Innovation

Which shading system design best meets the functional and sustainability requirements?

Static Systems

Suitable for consistent solar conditions, low maintenance, and cost-effective.

Dynamic Systems

Offers superior performance with adjustable panels, but requires more maintenance.

The advanced geometrical system, for instance, is intended to regulate its orientation-supported by solar positions throughout the day and reduce heat gain while still allowing daylight to enter the building. This method is not only more effective but also it aims to attain a high level of environmental responsiveness, further underscoring the balance between energy efficiency and occupant comfort.

For the aim of evaluating these designs, a sample room is defined as the test space where each system will be implemented, analyzed, and compared.

3.1.1 System Considerations

Key considerations within the design process focused on ensuring that every proposed shading system was both feasible to construct and structurally stable. It had been essential to judge the technical and practical aspects of every design, taking into consideration factors like the scale and positioning of the panels, the methods of implementation, and therefore the system's overall durability.

Additionally, the visual comfort of building occupants was a critical aspect of shaping the look criteria. The shading systems had to produce effective sun protection while still allowing adequate natural light, creating a visually comfortable environment without causing glare or overly dimming the space. This balance between functionality and user comfort was central to the design strategy, influencing the selection of materials, panel size, and arrangement. [8]

Another consideration was the adaptability of the systems to different facades and window types, ensuring that the designs might be applied across various architectural contexts. Each design was evaluated for its compatibility with different glazing surfaces, exploring how the system may be integrated seamlessly with existing structural elements while maintaining aesthetic appeal and minimal impact on the building's overall appearance.

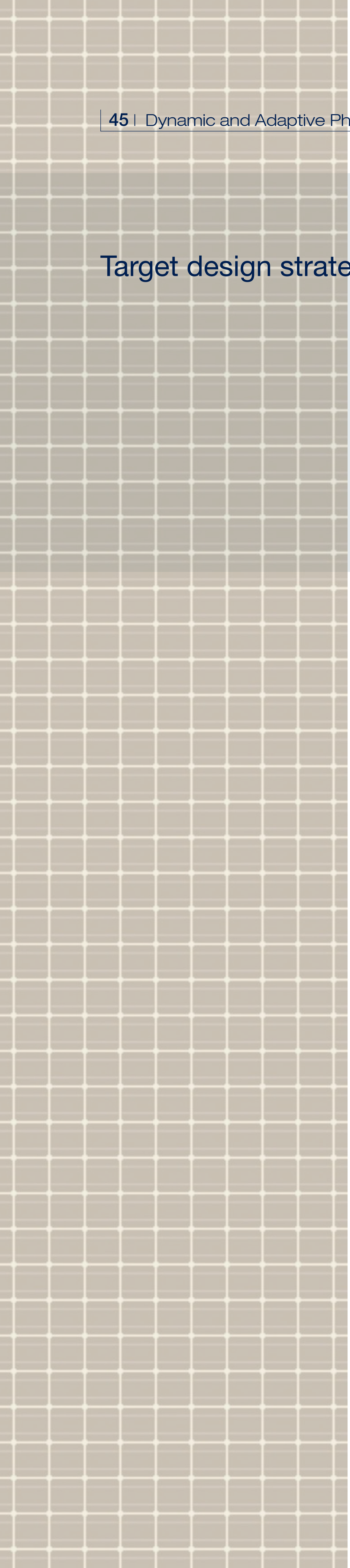
Through this multi-faceted approach, the planning criteria emphasized not only energy efficiency and daylight management but also the practicality of installation and the long-term usability of every shading system. Each system's impact on the general structural load, simple maintenance, and potential for automated or manual adjustments was carefully considered to form solutions that would be realistically implemented and maintained. The goal was to style shading systems that are both functional and adaptable, with the flexibility to adapt to changing daylight conditions while contributing positively to the building's energy profile and occupant satisfaction. [9]

8. Gupta & Jain, 2022

Gupta, R., & Jain, A. (2022). Integration of solar trackers in photovoltaic shading systems: A review and comparative analysis. Energy Conversion and Management, 252, 114846.

9. Abdelrahman et al., 2021

Abdelrahman, M., El-Rayes, K., & Said, H. (2021). Intelligent control strategies for enhancing the energy efficiency of adaptive facade systems. Renewable and Sustainable Energy Reviews, 145, 111003.



Target design strategies:

Dynamic shading systems, such as the six designs developed in this project, highlight energy efficiency, flexibility, and occupant comfort. The means to achieve this are a solar tracking system, an optimized shading system, and the use of sustainable materials. The combined grid (n.6) and X-pattern (n.5) perfectly fit the energy sector and demonstrate their versatility in usage whereas the non-moving systems such as the horizontal fins (n.2) boast ease and low maintenance mainly for specific orientations. These designs tackle issues like glare reduction, thermal comfort, and architectural integration. They offer sustainable and efficient approaches for new building facades.

Challenges:

There are also several key challenges facing during this study and also for future work including:

- **Balancing Functionality and Aesthetics:** In this particular area, although electricity conservation remained our main priority, the design of the facade, which had a continual architectural appeal, was also a big issue.
- **Material and Lifecycle Considerations:** The problem was that substances that match the targeted force of strength besides durability were hard to discern. One instance was aluminum that not only cut down the eco-footprint but also made the additional structural support test necessary.
- **Optimizing Energy Efficiency:** It was quite a challenging job, to strike a balance between productivity and shielding. Glossy blades (horizontal fins) and the X-fashion sunshine controller were just some of the technologies that needed simulations to confirm they can yield the maximal amount of energy re-Tooling while preventing glare and thermal discomfort.

Opportunities:

The opportuities during this phase of study are as below:

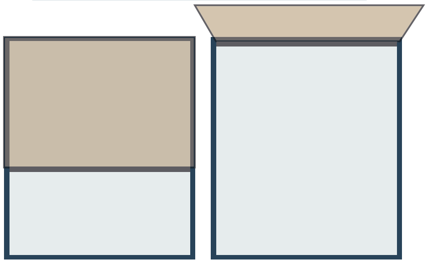
- **Advancements in Material Science:** The creation of less weighty and more resourceful photovoltaic materials and sustainably sourced composites may lead to a significant increase in the system's operational capacity and sustainability.
- **Integration with Smart Building Systems:** Movement shading systems can be incorporated into building management systems (BMS) of houses to make them absolutely free from human interaction and highly sensitive to the current environment that fits into energy savings schemes.
- **Expansion of Adaptive Systems:** The conceptual designs, particularly dynamic systems like n.5 and n.6, can evolve to meet diverse architectural contexts, such as urban canopies or adaptable facades in mixed-use developments.

The conceptual design process for the shading systems involved a broad exploration of numerous design cases; from all the designs evaluated, six were selected as the most effective solutions. Each design was refined through balancing functionality with aesthetic appeal and environmental responsiveness.

Key aspects that were considered includes shading efficiency, energy generation, and adaptability to various orientations.

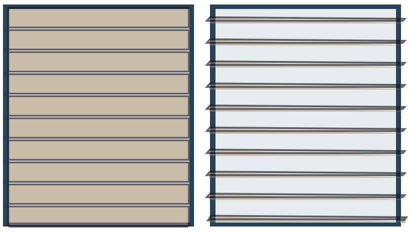
The process is iterative, starting from a simple configuration in Design n.1 to more complex geometries such as the intersection of patterns in Design n.5 and sun responsive systems in Design n.6. These have been selected because they can offer optimised shading performance together with photovoltaic energy generation while keeping architectural coherence; they are not only the best solutions identified within this study, but also these designs help to have various options and systems that could each be used in different building sector. Therefore this variaty of desighns and consideing both simple and complex solutions helps to choose more wisely the accurate solution.

Design n.1



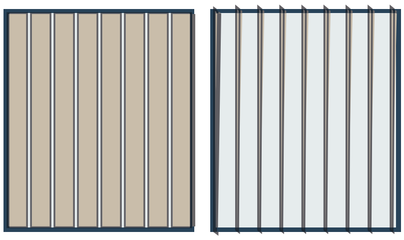
This simple design is suitable for minor residential or office openings, where distcreet shading may be warranted. The design allows limited shading and improves the visibility for spaces that need natural light to a minimum, such as reading rooms or north-oriented rooms in northern latitudes.

Design n.2



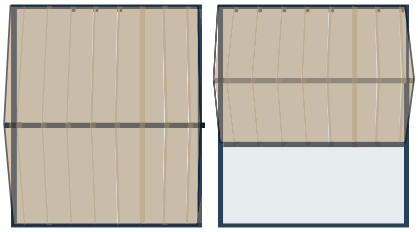
Horizontal louvers produce a visually dynamic façade and are optimally used in moderately sunny climates where mid-position sun dominates, such as during spring and autumn in Turin. Provides cross-ventilation if the louvers allow for airflow in their design.

Design n.3



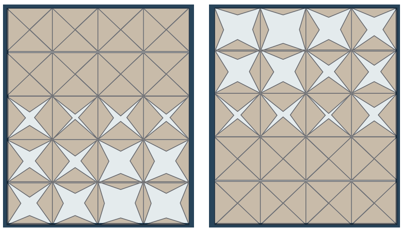
This design is particularly effective for the tall, narrow windows on the east and west facades of commercial buildings. The vertical elements become part of the aesthetic ornamentation for skyscrapers or modern residential towers.

Design n.4



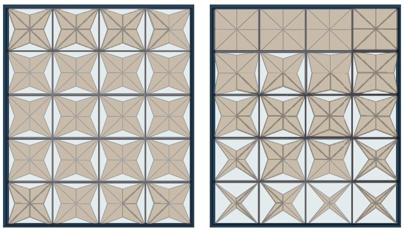
The diagonal shading system is appropriate for the atriums or shared areas with wide glass fronts. It provides partial shading without losing the sense of openness. It may also be considered a rotatable shading system, with dynamic adjustment to the seasonal changes.

Design n.5



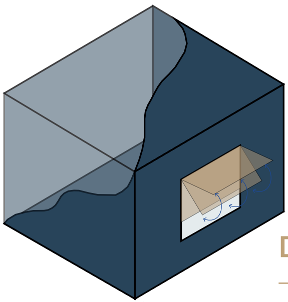
The X-pattern design provides both an aesthetic and functional solution suitable for cultural or educational buildings requiring special façade treatments. It can also be used for roof skylights to perform shading and PV energy production at the same time.

Design n.6



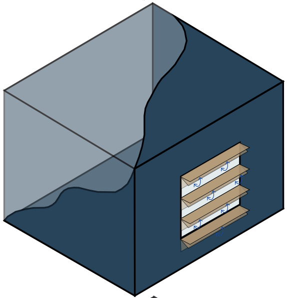
The hybrid grid design provides a high level of adaptability, suitable for urban high-density areas with varying sun exposure. It could also act as a shade canopy over public spaces like parks or outdoor seating areas. Incorporating dynamic shading elements within the grid can further enhance its usability.

Design n.1



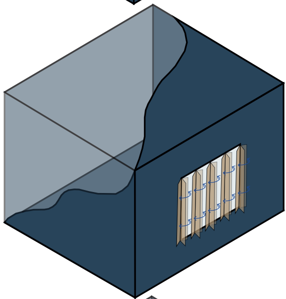
This design features a single horizontal shading device spanning a window.
Performance Evaluation:
Shading Efficiency: Medium. Horizontal shading works well against midday sunlight but is less effective for low-angle sunlight during mornings and evenings.
Solar Optimization: Limited. The fixed nature of the shading element doesn't adapt to changing sun positions.
Energy Production: If integrated with PV panels, it produces energy only during peak sun hours due to its fixed overhead orientation.

Design n.2



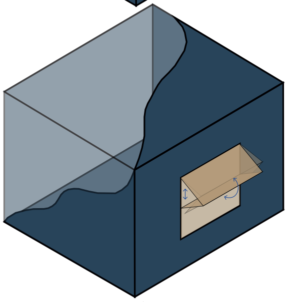
This system incorporates multiple horizontal fins for shading.
Performance Evaluation:
Shading Efficiency: High. The addition of multiple fins increases coverage, effectively blocking more solar radiation compared to a single horizontal element.
Solar Optimization: Static. Works best on facades with consistent sun angles, such as south-facing orientations.
Energy Production: PV panel integration across the fins enhances energy production by increasing the sunlight-exposed surface area compared to Design n.1.

Design n.3



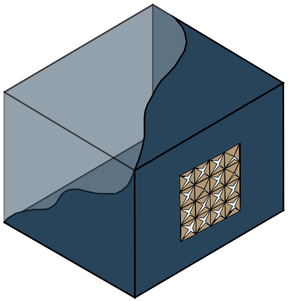
This design uses vertical fins running parallel to the façade.
Performance Evaluation:
Shading Efficiency: Very high for east- and west-facing façades. Vertical fins excel at blocking low-angle sunlight, which is prevalent in mornings and afternoons.
Solar Optimization: Effective for east- or west-oriented façades, aligning well with typical sun positions for these orientations.
Energy Production: Vertical fins may produce less energy for south-facing façades compared to horizontal fins but perform better for east-west orientations.

Design n.4

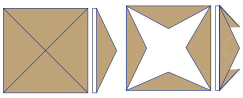


This design includes a single diagonal shading element that partially covers the façade.
Performance Evaluation:
Shading Efficiency: Moderate. Coverage depends on the sun's angle and time of day, resulting in inconsistent shading efficiency.
Solar Optimization: Limited. The static diagonal angle restricts adaptability to changing sun angles.
Energy Production: PV integration would result in lower performance due to reduced surface area and suboptimal sunlight orientation.

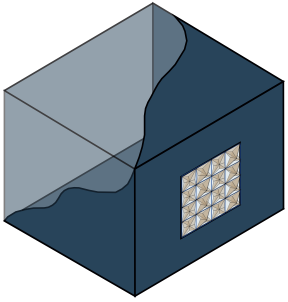
Design n.5



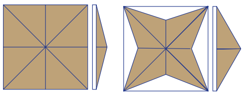
This configuration uses an X-shaped design with intersecting diagonal elements.
Performance Evaluation:
Shading Efficiency: High. The intersecting diagonal pattern provides enhanced coverage for dynamic sun angles throughout the day.
Solar Optimization: Improved. The design captures sunlight from various angles, optimizing shading and potential PV output.
Energy Production: The intersecting elements increase PV surface area, maximizing energy generation.



Design n.6



This hybrid design combines horizontal, vertical, and diagonal shading elements.
Performance Evaluation:
Shading Efficiency: Very high. The combination of elements addresses multiple sun angles, providing consistent shading throughout the day and across seasons.
Solar Optimization: Excellent. It adapts well to a variety of solar angles, making it suitable for orientations like southeast and southwest.
Energy Production: High. The diverse arrangement enhances total PV surface area, ensuring consistent energy output under varying sun positions.



3.1.2 Selection of PV Technology and Materials

During the design process, a mono-crystalline photovoltaic (PV) system was initially selected because of its high efficiency, typically starting from 15% to twenty. This high efficiency translates to significant energy productivity, making mono-crystalline panels a logical choice for maximizing energy production in shading systems.

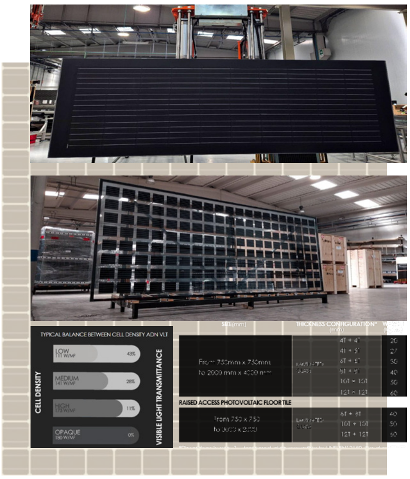
However, mostly the concerns were regarding the aesthetic impact of such systems. The visibility of traditional PV panels and associated with wiring parts could obstruct interior views and detract from the building's overall appeal. for handleing these issues, in the design it was considered to use amorphous PV systems as an alternative. But it was necessary to consider that these system have a lower efficiency and they have roughly 7% to 10%, offer significant advantages in terms of visual integration. Their semi-transparent nature allows for incorporation into designs without compromising the transparency of glazing, thereby preserving natural daylight within the inside.

This efficiency means that 15% to 20% of the sunlight energy incident on these panels is converted into usable electricity, a performance metric given by:

$$\eta = P_{out} / P_{in} \times 100$$

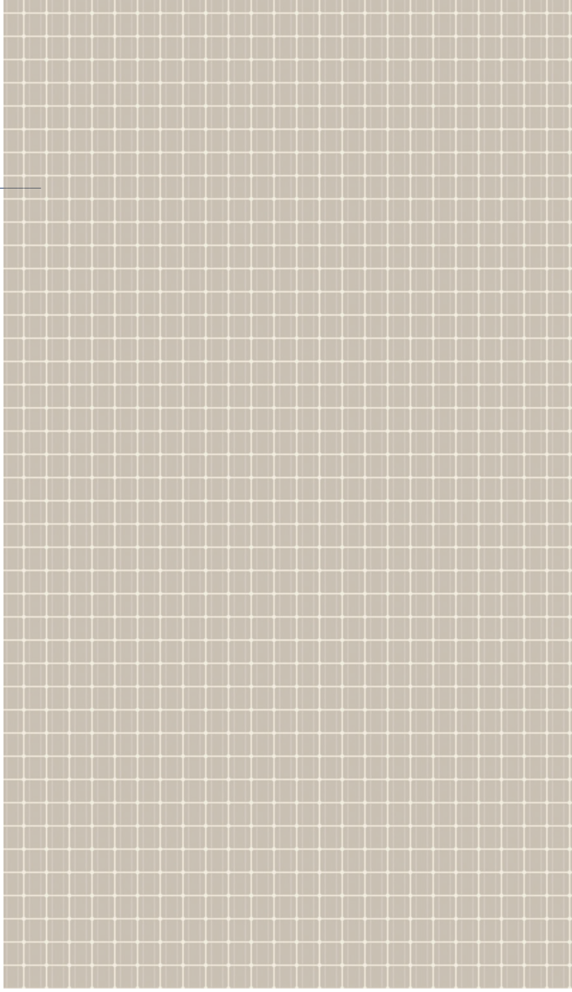
- → Electricity Generation improvement: By tracking the sun's movement, the panels can keep an optimal angle for capturing solar energy during the day, and as a result increase production.

- → Daylight Use: Adaptive systems can increase the natural light use in the buildings by reducing the necessity of using artificial light and as a result leading to saving more energy.



mono-crystalline photovoltaic system

amorphous photovoltaic system



Where:

- η = Efficiency (%)
- P_{out}= Output power (W)
- P_{in}= Incident solar power (W)

The lower efficiency of amorphous PV panels is offset by their ability to function across a broader range of lighting conditions, including diffuse sunlight. The relationship between efficiency and incident light intensity is expressed as:

$$P_{out}= \eta \times A \times I$$

Where:

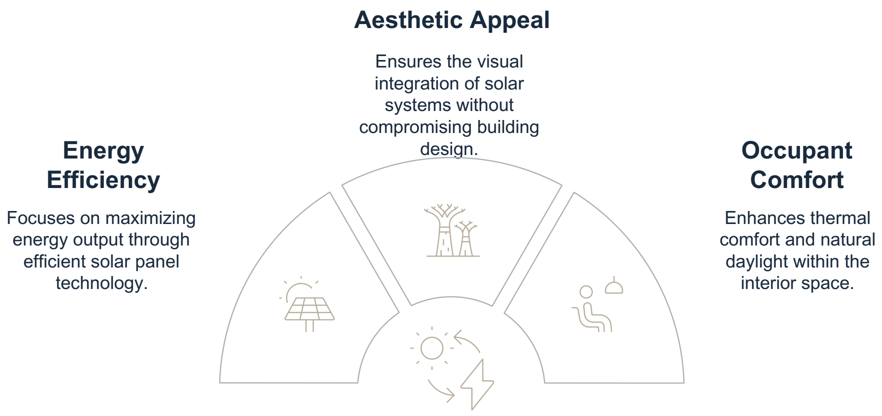
- P_{out}= Power output (W)
- η = Panel efficiency (%)
- A = Panel area (m^2)
- I = Solar irradiance (W/m^2)

The semi-transparent amorphous PV panels were selected to balance functionality and occupant comfort. By integrating these panels into the shading system, thermal comfort is provided without the necessity for frequent adjustments, like opening or closing the system to maintain visibility or control heat. Additionally, by the employment of thermal glass, enhances the system's performance, to ensure a stable and comfortable interior temperature and comfort.

Despite the reduced efficiency of amorphous PV systems, their incorporation into a dynamic, sun-responsive shading design makes up for this disadvantage. The panels are designed to rotate and change according to the angle of radiation and the position of the sun, by which allowing for optimal energy generation throughout the day since this system can ensure maximum sunlight exposure during peak hours, thereby balancing the reduced efficiency of amorphous PV panels.

To summarize, the ultimate design makes a balance between energy efficiency, aesthetic appeal, and occupant comfort that by incorporating semi-transparent amorphous PV panels into a responsive shading system, the design could be able to combine productivity with visual integration. The trade-off in panel efficiency is accepted. [10]

Design Integration of PV Systems



Aesthetic Appeal

Ensures the visual integration of solar systems without compromising building design.

Energy Efficiency

Focuses on maximizing energy output through efficient solar panel technology.

Occupant Comfort

Enhances thermal comfort and natural daylight within the interior space.

10. am, S., & Chin, S. (2016)

Lam, S., & Chin, S. (2016). Mechanical integration of shading devices in PV systems. Renewable Energy, 92, 423-430.

3.2 Mechanical and Structural Design

Mechanical assessment is very important in the effective delivery of shading devices for their principal objectives: gaining reduced solar heat, creating better energy generation from integrated PV panels, and long-term durability. The employment of different mechanical strategies was addressed by six various designs.

The chapter discussed the mechanical principles leading to the development of these designs for structure, movement, materials, and the incorporation of control systems in providing appropriate and viable solutions for contemporary buildings.

Functional Requirements for Shading Systems

Shading systems have some key requirements to function effectively. They must reduce solar heat gain, reduce cooling demands, and ensure proper visual comfort. The surface exposure to sunlight in a PV-integrated system should be maximized for the consistent production of energy throughout the seasonal changes. However, while under conditions of regular and predictable solar radiation, static systems such as Designs n.1 and n.2 work quite effectively; in dynamic systems like Designs n.5 and n.6, the panel orientations are changed using real-time solar data. Besides this, the system should also be resistant to environmental stressors such as wind and rain, and thermal expansion, but requires minimal maintenance to perform over a long period. For example, in Design n.2, horizontal fins on the south facades are fixed, and cannot adapt to low-angle sunlight either in the morning or afternoon. On the contrary, Design n.5 is more interested in shading and optimization of energy consumption because its dynamic pattern in X can rotate and slide. [11]

Static Systems Designs n.1, n.2, and n.3:

Static shading systems are commonly made up of fixed elements anchored to the façade of a building. Mechanically very simple and reliable, static shading systems are inexpensive and do well under fairly constant solar conditions. Design n.1 has horizontal shading panels, which are most appropriate for south-facing façades. They provide a constant shade during midday but are not so good for low-angle morning and afternoon sunlight. The vertical louvers in Design n.3 are intended for east and west facades and do an outstanding job of keeping out low-angle sunlight and reducing glare. [12]

These systems, from the sustainability point of view, consist of materials

11. Delisle & Kummert, 2014

Delisle, V., & Kummert, M. (2014). The impact of control strategies on the performance of shading and daylighting devices. Solar Energy, 115, 217-229.

12. Ebrahimi & Yazdanfar, 2020

Ebrahimi, A., & Yazdanfar, M. (2020). Innovative shading systems for energy-efficient buildings: A review of mechanical components. Energy Reports, 6, 101-115.

such as lightweight durability with recycled aluminum, maintaining a reduced carbon footprint compared to virgin aluminum. The load-carrying components are fabricated from stainless steel, durable, and recyclable, which further reduces lifecycle environmental impacts. Stationary frames and anchoring mechanisms reduce the mechanical complication and resource consumption; hence, they ar for small-scale commercial or residential buildings with very minimal maintenance requirements. Also, due to the simplicity of static systems, their embodied energy is less when compared to dynamic alternatives.

Dynamic Systems: Designs n.4, n.5, and n.6

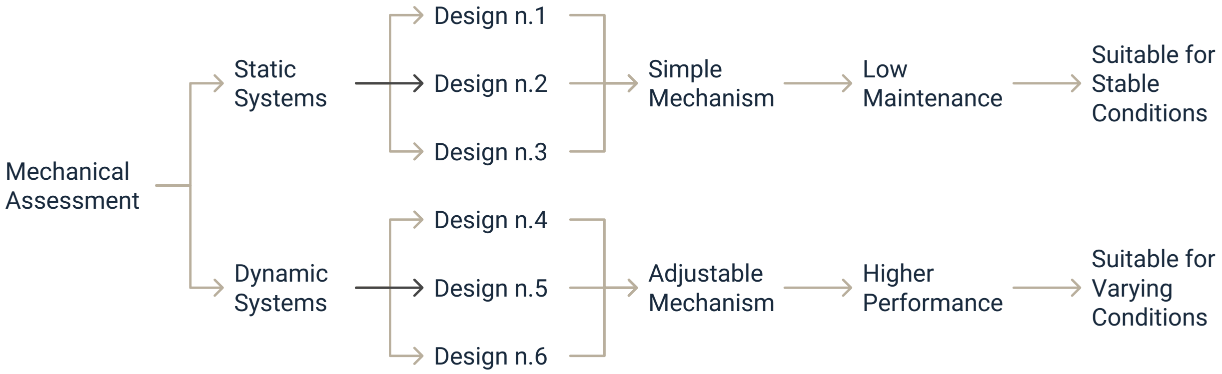
Dynamic shading systems possess mechanical integration for adjustment, relatively to environmental fluctuation in shading and energy efficiency, by sustaining a design ethos compatible with sustainability. Diagonal panels mounted on pivots characterize Design n.4; these tilt during the day, driven by actuators based on real-time input. A system like this works very well for facades whose solar exposure changes strongly over the seasons. While in design n.5, an X-pattern allows for multi-axis movement where individual panels rotate or slide independently from each other for fine adjustment of shading and PV. Design n.6 hybridizes these two mechanisms into one grid for applications in complex urban environment shading conditions.

It includes eco-friendly materials in dynamically loaded systems like aluminum alloys with a prescribed content of recycled material and weather-resistant coating to prolong their life. Other components will involve ball bearings and hydraulic pivots made from low-carbon steel, treated for corrosion resistance to reduce frequency of maintenance and replacement. The seals of the slidable mechanisms are from rubber or silicone in order to protect these mechanisms from environmental degradation. The modular designs enable the worn part to be replaced with ease so as to reduce trash output and enhance lifecycle sustainability. [13]

13. Becerra, M., & López, M. (2016)

Becerra, M., & López, M. (2016). Static shading systems: An effective solution for energy savings. Energy and Buildings, 119, 75-84.

While the performance of dynamic systems is superior, maintenance expenditure is higher. Moving parts need regular lubrication and their sensors need calibration. However, dependency on solar-powered actuators reduces the operational carbon emissions of these systems. Their integration with automated controls enhances their energy efficiency and reduces reliance on non-renewable energy.



Integration of Control Systems

In this respect, control systems can play a vital role in enhancing the sustainability of shading devices. It enhances the performance of shading elements by using intelligent systems to implement current environmental data in an effort to decrease the overall energy use by lighting and cooling. Sensors in continuous monitoring of light intensity, glare, and solar angles actuate the shade elements while the weather sensors prevent system damage through panel retractions and/or locking during adverse conditions. These actuators of energy are self-contained and solar-powered to further reduce the carbon trace of such systems.

These can further be integrated with HVAC and lighting using advanced building management software for a holistic result in terms of energy efficiency. Grasshopper is a design tool, at the design stage of a building, which simulates and optimizes shading patterns to help the architect minimize his or her environmental footprint early in the design process. Integration of mechanical with digital promotes adaptability and sustainability in the shading systems.

Material selection is one of the major contributors to lifecycle sustainability and carbon footprint reduction of a shading system. Recycled aluminum, with features of lightweight and corrosion-resistant with lower energy usage in its manufacturing, is among the most common materials used for structural frames. On the other hand, stainless steel is preferred for load-carrying parts due to its strength, durability, and recyclability. Shading panels can be made from toughened glass, composite materials, or even thin-film solar panels to ensure maximum energy gain and durability.

Hinges, tracks, and bearings in this regard are made of high-strength alloys treated with weather-resistant coatings for durability. Seals of rubber or silicone against water and dust reduce maintenance. Locally sourced materials reduce transportation-related emissions, further enhancing the sustainability of these systems. The focus on materials that balance strength, weight, and environmental resilience means such shading systems can deliver functionality at minimal carbon emissions. [14]

Operational and Longevity Aspects

Maintenance is equally important to extend the life of a shade system. Static shade systems require very low maintenance, such as occasional checking for corrosion or structural failure. Dynamic shade systems, by their very nature, have moving parts and hence require more frequent maintenance-lubrication on tracks and bearings, calibration of sensors, etc. Regular maintenance keeps the operation smooth and thereby avoids wear and tear to prolong the system's life.

Dynamic systems face challenges like wind strain and thermal expansion, but these are mitigated by using locking mechanisms to secure panels during extreme weather. Modular designs allow for easy replacement of damaged parts, reducing downtime and waste. Sustainable maintenance practices, such as using biodegradable lubricants and recycling worn components, further lower the environmental impact of these systems. [15]

14. Parker, S., & Frey, P. (2019)

Parker, S., & Frey, P. (2019). Sustainable materials in shading systems for PV integration. Journal of Building Performance, 10(1), 56-64.

15. Patel, P., & Verma, P. (2017)

Patel, P., & Verma, P. (2017). Operational and longevity aspects of dynamic shading systems. Journal of Architectural Engineering, 23(4).

3.3 Electrical and Control System Design

Electrical and Control System: Electrical and control systems will be very critical to optimize performance and sustainability issues in a shading device, especially one with integrated PV panels. Sensors, controllers, actuators, and power optimizers will be employed to manage the issue of shading, energy generation, and system durability. Adding the power optimizers to the PV systems adds that additional layer of sophistication which enables each panel to perform at peak efficiency under tough conditions, such as partial shading or uneven exposure to sunlight. The system is initiated with sensors continuously monitoring environmental conditions, including sunlight intensity, temperature, wind speed, and rain. These sensors undergo real-time environmental changes and are able to transmit the information to the controller, while they are strategically positioned on the façade or shading elements. The controller is the brain of the system, analyzing sensor data and making decisions on the adjustments needed. It could be a signal, for example, where the heightened intensity of sunlight makes the shading panels tilt or rotate to reduce further glare or heat gain inside and protect the building from excessive solar heat . [16]

Power optimizers are also part of the electrical system in PV integrated shading devices to ensure maximum energy generation. Each photovoltaic connects to an optimizer that will, through active control, regulate voltage and current of the panel to track system MPPT. This means that when one panel has partial shade or working less efficiently, it is not pulling down the rest of the system. As can be seen in hybrid shading systems, such as Design n.6, despite dynamic shading patterns due to elements that change position in the course of the day, the system realizes very high energy output. Further, there are actuators and motors whose purpose it is to provide the mechanical movement of the shading elements according to commands coming from the controller. While in dynamic systems, such as Designs n.5 and n.6, with actuators, complex movements related to tilting, sliding, or rotation of the shading panels can occur to adapt during the day for different solar angles, being able to adapt and maintain optimum conditions both for shading and energy generation. This energy typically feeds the actuators, besides other components like sensors and controllers, powered from integrated PV panels, which, in fact, make the system self-sustaining. The excess energy that the PV panels generate is stored in batteries for later use or returned back to the grid in case of grid-tied

16. Kumar, R., & Khan, S. (2018)

Kumar, R., & Khan, S. (2018). Integration of control systems for smart shading and energy generation. Energy, 159, 875-883.

systems, further enhancing the energy efficiency of the building. There are no moving parts involved, and hence, electrical and control requirements are simpler within static systems-for instance, Designs No. 1 and No. 2. Power optimizers ensure that maximum energy is produced from the integrated PV panels. Even though these static systems may not track the sun's position throughout the day, optimizers make sure that every panel generates energy at the highest possible efficiency, even in instances of partial shading. [18]

Dynamic systems use automation and algorithms in control so that their operations could be choreographed. Advanced algorithms, for example, read environmental data in real-time, hence making predictions about such conditions as solar angles or even changes in weather. For instance, the sun trackers of the system follow the sun's position in the sky and subsequently move the shading panels to allow for maximum exposure to sunlight on the PV panels or to optimize the shading of the interior. The system can also draw the shading elements back or lock them in place to protect them in case of unfavorable weather conditions such as high winds or heavy rain. However, the power optimizers continue operating to ensure high efficiency in energy generation. The integration of the system with the BMS further enhances its performances for full coordination, ensured with other building systems such as HVAC and lighting. For example, shading adjustments can lower indoor temperatures and thereby reduce demands on air conditioning systems. Simultaneously, PV-generated electricity offsets energy consumption by both HVAC and lighting. Power optimizers ensure a balance between energy generation and consumption within the building, therefore reducing the dependency on non-renewable energy and carbon footprinting. Utilization and conversion of renewable energy sources are the cornerstones to system sustainability.

This will integrate photovoltaic panels with a power optimizer, hence availing efficient and clean ways of producing and storing energy through shading devices. In peak sunlight, the extra energy can be reserved for later use either at low sunlight or even at night. By incorporating renewable energy into it, the system will be eco-friendly and also cost-effective in the long run. Material and parts selection for this particular system is also done according to sustainability. [19]

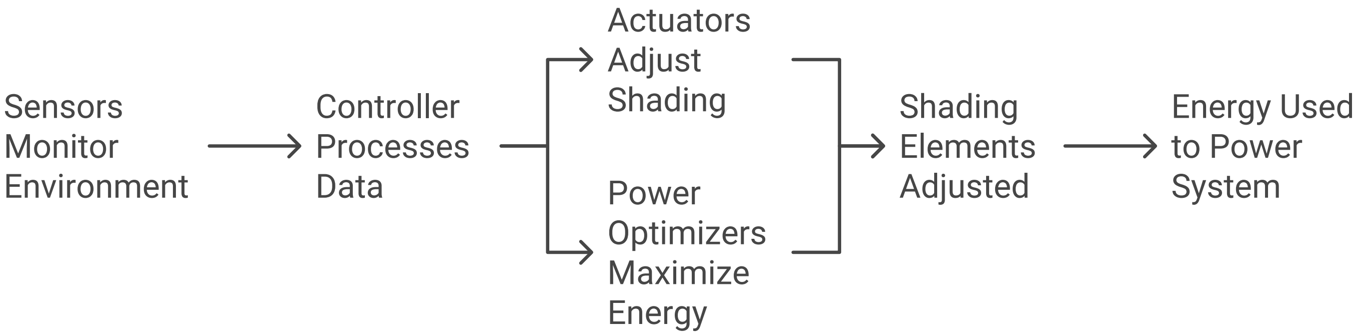
Power optimizers are durable and have low-energy consumption designs, just like the electrical wiring. Sensors and actuators are designed to use the least amount of energy possible. Materials used for structural parts are lightweight in mass and, as a rule, corrosion-resistant such as aluminum and stainless steel, serving the purpose of keeping the need for maintenance low, hence extending the life span of the system. Durable materials together with energy-efficient components and real-time control make this shading and PV system effective while keeping the environmental impact low. Generally speaking, the electrical and control system of the various shading and PV systems is for intelligent operation as an integrated network of sensors, controllers, actuators, and power optimizers. Sensors capture data from the environment, while controllers process the information to calculate the best strategy concerning either optimal energy

18. Ma et al., 2021

Ma, Z., Cooper, P., Daly, D., & Ledo, L. (2021). The role of building integrated photovoltaics in enhancing energy performance of shading systems. Energy and Buildings, 247, 111183.

19. Zhao, P., & Qian, K. (2020)

Zhao, P., & Qian, K. (2020). PV-integrated shading systems: Design and control strategies for energy efficiency. Solar Energy, 207, 694-705.



generation or shading. Then, actuators operate the adjustment of shading elements. Power optimizers can help integrated PV panels perform even better by supplying maximum energy under all conditions. With all these components, shading systems can provide modern buildings with sustainable, energy-efficient adaptable solutions. [20]

3.3.1 Sensor Integration

Sensors are a vital part of dynamic shading systems, as their real-time responding capability is obtained from them. Such devices provide crucial information about solar radiation intensity, solar angles, temperature, wind speed, and precipitation. Depending on its interpretation, the elements in the shading system move their position with the aim of optimizing indoor comfort and energy efficiency, while reducing manual operation. [21]

Light sensors-or photometric sensors-read the solar intensity and drive the shading to an optimal position given desired quantities of daylight penetration and shading. For example, horizontal panels will tilt down midday to block direct sun, and in the morning or evening, tilt up to maximize natural light. Horizontal fins rotate independently to track the sun to achieve an optimal combination of shading and daylighting. Likewise, the dynamic rotation of vertical fins during morning and evening hours blocks low-angle sunlight, thereby reducing glare and visual discomfort by more than half.

Solar position sensors-or sun trackers- monitor the movement of the sun during the day and allow shading elements to adjust to the position of solar angles. This feature enables better energy efficiency and helps maximize the performance of photovoltaic panels by allowing them to receive the most sunlight.

Temperature sensors monitor ambient and indoor temperatures to ensure that shading adjustments maintain thermal comfort. Diagonal panels tilt in response to heat gain or loss. This allows passive solar heating during colder periods and blocks excessive heat during peak temperatures. The addition of weather sensors provides responsiveness in another sense, such as monitoring wind and rain through wind and rain sensors. Wind sensors detect high wind velocities and send shading elements to a locking position or retraction to avoid mechanical damage. Rain sensors detect precipitation and thereby send the system signals to retract its elements, thus protecting them from exposure to water for durability purposes. [22]

3.3.2 Actuators and Motors

Mechanical elements are actuators and motors, that enable a shading

20. Aelenei et al., 2020

Aelenei, D., Rodrigues, C., & Mendes, A. (2020). Impact of adaptive shading on the thermal and energy performance of net-zero energy buildings. Energy Reports, 6, 99-113.

21. Delisle & Kummert, 2014

Delisle, V., & Kummert, M. (2014). The impact of control strategies on the performance of shading and daylighting devices. Solar Energy, 115, 217-229.

system to physically actuate its elements. They drive the tilting, sliding, or rotation of the shading devices, enabling systems to dynamically change in response to environmental input and performance optimization.

Rotary actuators drive the rotation of the shading devices. Horizontal panels tilt with the intensity of the sun to vary the extent of shading coverage. Again, horizontal fins provide individual rotations for effective fine-tuning of shading angles. The vertical fins turn to block sunlight during low angles of incidence with particular effectiveness in east-west orientations where these angles are more prevalent.

Linear drives provide straight-line motion that enables things to be done like dynamic tilting of diagonal panels. The tilting maintains an optimum balance between shading and daylight penetration, which changes with temperature and solar variation. Hybrid actuators can harness the power derived from both linear and rotary motions, thereby allowing multi-axis adaptability. These actuators allow dynamic adjustments of sliding and rotating panels for optimum achievement in both effective shading and PV energy generation.

Supporting elements, such as bearings and tracks, reduce friction for smooth motion when sliding and rotational adjustments are made. Weatherproof motors will not disappoint in outdoor environments; they protect the system from corrosion and wear to increase durability.[22]

It will be achieved through seamless functionality integration among actuators and control systems. Control systems give commands to actuators that may process sensor data in order to compute the adjustment needed. For example, solar trackers may detect incoming sunlight from an angle and drive actuators to rotate or slide the panels to an alignment that optimizes shading and PV performance. [23]

3.3.3 Control Algorithms

Control algorithms are responsible for decision-making in dynamic shading systems. Advanced algorithms process sensor data, predict changes in the environment and send commands to operate the shading elements. The control algorithms allow the shading system to achieve an optimum compromise between energy efficiency, thermal comfort, and long-term durability. [24]

Rule-based algorithms operate on a set of predefined threshold values and take necessary action through adjustment to the shading devices. For instance, horizontal panels in case of high solar intensity above a threshold value tilt downwards to block the unwanted heat gain while allowing natural light to come inside. Predictive algorithms forecast future environmental conditions by fusing data from solar tracking with relevant weather forecasts. This would enable pre-rotation of vertical fins to block low-angle sunlight before it becomes uncomfortable or causes glare. [25]

Adaptive algorithms iterate through cycles of refinement of shading responses over time using learned historical data. For example, seasonal data drives tilt angles for diagonal panels to act optimally for peak shading in summer and open up for maximum daylight in winter. This adaptability is taken a step further by optimization algorithms that balance multi-objective functions such as HVAC energy load reduction, PV output maximization,

22. Ebrahimi & Yazdanfar, 2020 2014

Ebrahimi, A., & Yazdanfar, M. (2020). Innovative shading systems for energy-efficient buildings: A review of mechanical components. Energy Reports, 6, 101-115.

23. He, Z., & Li, Q. (2019)

He, Z., & Li, Q. (2019). Actuators and motors for dynamic shading systems. Journal of Mechanical Engineering Science, 234(12), 3568-3579.

24. Yang, J., & Chen, L. (2019)

Yang, J., & Chen, L. (2019). Adaptive and predictive control algorithms for shading systems. Energy, 174, 180-189.

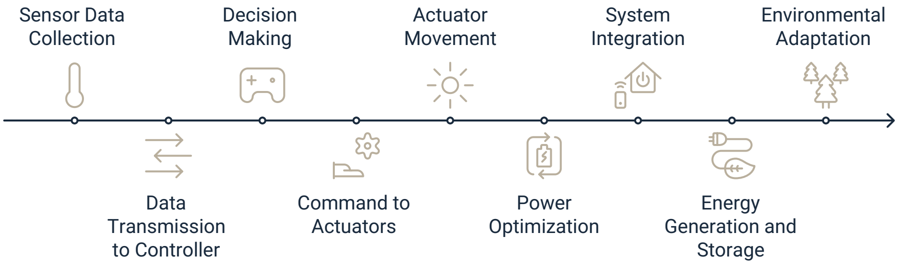
25. Kalogirou, 2014

Kalogirou, S. A. (2014). Solar Energy Engineering: Processes and Systems.

and thermal comfort.

Dynamic shading devices also use sensors and actuators to control algorithms on a basic level. Algorithms determine the optimal adjustments based on sensor data and generate a very precise command used by actuators to make the right movements. In the case of solar trackers upon detecting angled sunlight, for example, predictive algorithms set an optimal rotational angle for shading elements that would block the heat and ensure maximum PV performance. [26]

The algorithms allow such shading systems to operate only when they should, thanks to their sophisticated decision-making, thus making them less inefficient. The contribution of these algorithms goes a long way in enhancing the use of renewable energy and reducing dependency on non-renewable resources, hence decreasing greenhouse gas emissions while promoting sustainability.



26. Wang, H., & Zhou, Y. (2017)

Wang, H., & Zhou, Y. (2017). Integration of control algorithms in photovoltaic shading systems for sustainability. Renewable and Sustainable Energy Reviews, 79, 1390-1400.

SWOT Analysis

S

Strength

Novel Approach to Kinetic Systems: Movable parts, like X for Design no. 5, and new technologies, e.g. hybrid grids (Design n.6), are the means of utmost sun tracking. These systems follow the sun movements instantly, which results in optimum shading and maximum PV energy production during the whole day.

W

Weakness

Further Complexity Needed in Advanced Designs: Advanced forms such as the hybrid grid of Design n.6 would require the application of mechanical, structural, and control systems that are the most complex and therefore the most probable to be technically challenged designs ecosystems.

O

Opportunity

Expansion to Urban Applications: Urban areas can also take advantage of these systems for the high-density places where the sun uses a few hours only, such as adaptive shading canopies in the public spaces or the hybrid façades of skyscrapers.

T

Threats

Economic Factors: Fabric price fluctuations and energy market changes will affect the cost effectiveness of these systems. Environmental Stressors: Harsh weather types such as heavy wind load, hail, and temperature changes can cause a decrease in the reliability and durability of the system over the long run.

Simulation and Modelling

- Simulation Tools and Techniques
- Sun-Tracking and Shading Simulations
- Energy Yield and Production kWh Simulations
- Daylight Factor and Visual Comfort Simulations
- Thermal Comfort and Environmental Impact Simulations

Simulation Tools and Techniques

Softwares used:

Rhino, Grasshopper, Ladybug, Climate Studio(Solema),
PVGIS,ESBO Light,

Existing modeling and design Computer-Aided Design (CAD) tools such as AutoCAD and Rhinoceros have little data about the system performance, and they are mostly used for visualizing the design. This has proved to be a shortcoming when more freedom and randomness are desired in creative design. Therefore, architects are more inclined to utilize applications that allow some degree of computer simulation programs.[1]
Constantly changing parameters that affect the building are better modeled in parametric design platforms. “Parametric design relies on control of 3D modeled components through modification of certain parameters of a building model. These modifications are driven by mathematical formulas, data values, numbers or specific computer algorithms rather than manual changes of the model properties.” (Aksamija, Snapp, Hodge, & Tang, 2012)
Grasshopper is one of the parametric tools that is integrated in Rhinoceros as a plug-in and provides a user-friendly graphic interface and allows designers to incorporate algorithmic logic in their designs. The program is in effect a series of formulas, imitating the programming functions in design-based platforms linked to modeling platforms such as Rhinoceros or SketchUp. The variables in the formula could be dimensions and angles shaping a surface or environmental data tilting a window shade.
Grasshopper in combination with Climate Studio was first used for this proposed design in the responsive solar shading study.[2]

1. Aksamija, A., Snapp, M., Hodge, M., & Tang, C. (2012)

Aksamija, A., Snapp, M., Hodge, M., & Tang, C. (2012). Parametric design tools and their impact on architectural design processes. International Journal of Architectural Computing, 10(4), 399–418.

2. Ward, G., & Reinhart, C. (2020)

Ward, G., & Reinhart, C. (2020). Climate Studio for Rhino and Grasshopper: A simulation toolkit for performance-driven design. Building Simulation, 13(6), 1185–1200.

4.1 Simulation Tools

In this study the simulations and the data are obtained via various software and tools, which itself demonstrates the importance of the tools and the way they are used. Simulation tools are crucial in the optimization of the PV shading system in achieving energy efficiency, thermal comfort, and visual performance. The list of simulation tools which were used for this study includes:

1.Rhino:
Rhino is a complex 3D modeling tool with wide applications in architectural design.

2. Grasshopper:
is a plug-in for Rhino that allows parametric design; this plug-in helps designers in order to create algorithms that automatically change the device configuration according to environmental data in this study which is mainly related to shading devices this tool was used for ease of system adaptability to the environmental data.

3.Climate Studio Plugin:
Climate Studio is integrated with Grasshopper, allowing the simulation of energy performance, daylight distribution, and thermal comfort. This tool is ideal to be used for calculating solar irradiance and energy efficiency in PV shading systems and the fact that this tool could be used through the grasshopper plugin in a parametric environment makes this tool the ideal choice.

4. Ladybug Plugin:
Ladybug is an environmental analysis plug-in for Grasshopper. It offers weather data and solar radiation to further help this software optimizes shading designs and simulate savings in energy gains.

5. AutoCAD:
AutoCAD is mostly used for 2D and 3D design documentation of the shading devices for a better specified and accurate representations of the documents and the system.

6. There are also some other tools that were used in the process of this study such as PVGIS, ESBO, Lunch box for grasshopper that in general helped to ease the path for achieving a more accurate and reliable result-more simpler.
All these design tools were used in concert to enable them to perform various analyses, from the visualization of design through performance simulation.[3]

Rhino

McNeel, R. (2018). Rhino 3D: NURBS Modeling for Windows and Mac. Retrieved from https://www.rhino3d.com

Grasshopper

Rutten, D. (2013). Grasshopper: Algorithmic Modeling for Rhino. McNeel Wiki. Retrieved from https://www.grasshopper3d.com

Climate Studio

Ward, G., & Reinhart, C. (2020). Climate Studio for Rhino and Grasshopper: A simulation toolkit for performance-driven design. Building Simulation, 13(6), 1185–1200.

Ladybug

Ladybug Tools | About. (n.d.). https://www.ladybug.tools/about.html

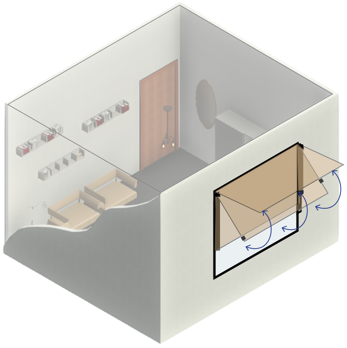
AutoCAD

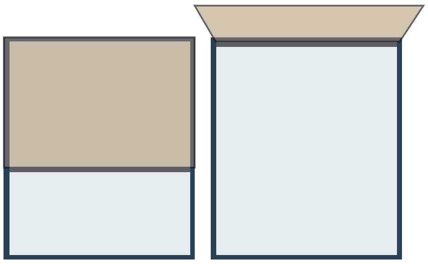
Autodesk, Inc. (2021). AutoCAD: Design and Documentation Software. Retrieved from https://www.autodesk.com

3. Sadeghi, H., Sadeghi, N., & Zhao, Z. (2019)

Sadeghi, H., Sadeghi, N., & Zhao, Z. (2019). Ladybug tools: Enhancing building performance simulations using Grasshopper. Journal of Building Performance Simulation, 12(3), 242–258. https://doi.org/10.1080/19401493.2019.1578661

Design n.1



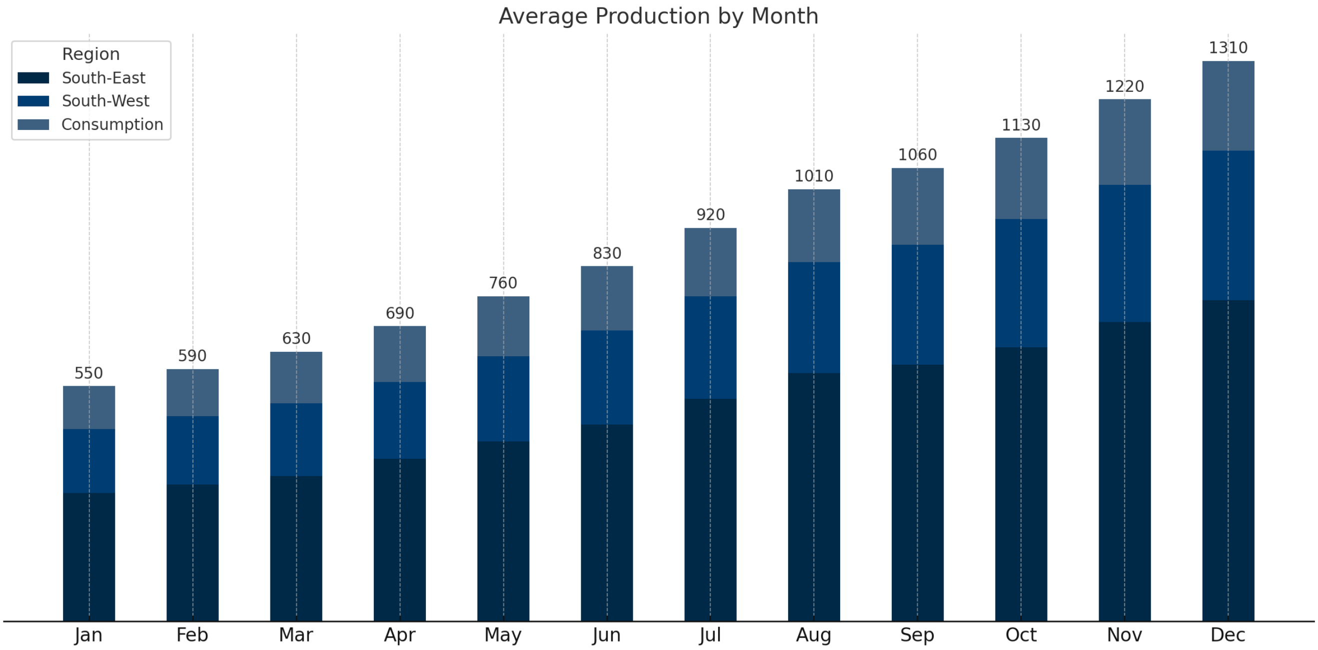


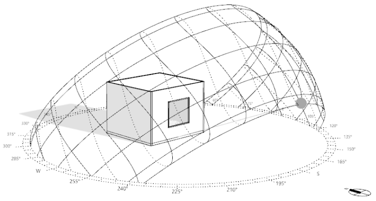
The following simulation results are about the design number one which is the most basic shader considered in this study, in this design a simple plane is considered as the shader system that allows limited shading and improves the visibility for spaces which need natural light for a minimum, such as reading rooms or north-oriented rooms in northern latitudes. Yet this analaysis is done in three orientations of south, south east, and south west where there is the maximum sun radiation through the day.

The analaysis is done through the plugin of climate studio in the grasshopper and rhino softwares environment. [Transcript, 1]

In this regard the considering the frame of the system about 80% of the surface has been considered for impleamenting th PV system and also about the efficiency of the PV system is considered as 9% and the pv system chosen for this system is amourphos photovoltaic system, however this case of study is the simplest and also there is no need of transparency for the whole design the other pv systems could also could be used, but since these results have to compare with other system designs it was decided to use amourphous photovoltaic system.

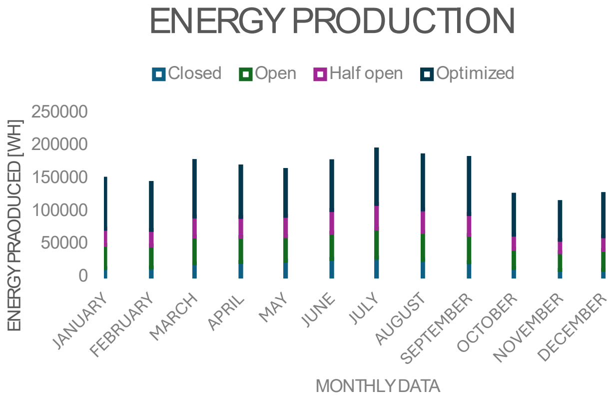
The following simulations are done in three main parts in which the shader is open, closed, and optimised which is the responsive one that allows the shader to rotate based on the sun position through the hours in a year.

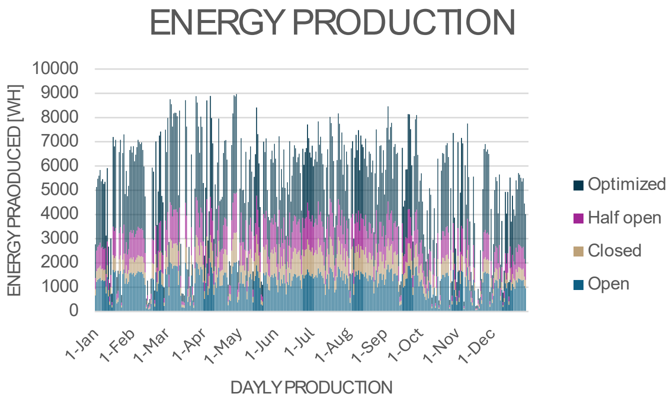




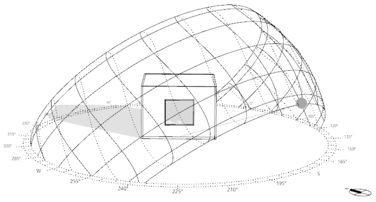
SOUTH ORIENTED

The South-oriented design shows that the Optimized configuration consistently outperforms all others in energy production. This is because of its dynamic, sun-responsive shading system, which adjusts in response to the sun's path and maximizes solar energy capture, particularly during peak sunlight hours. The Open configuration, while producing more energy than Closed, is less efficient than Optimized since it doesn't track the sun's movement. It generates the minimum amount of energy, as this Closed configuration completely blocks sunlight. This therefore proves that static shading systems cannot be employed for energy generation.



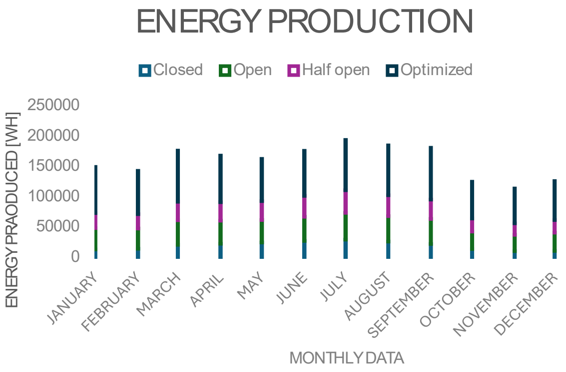


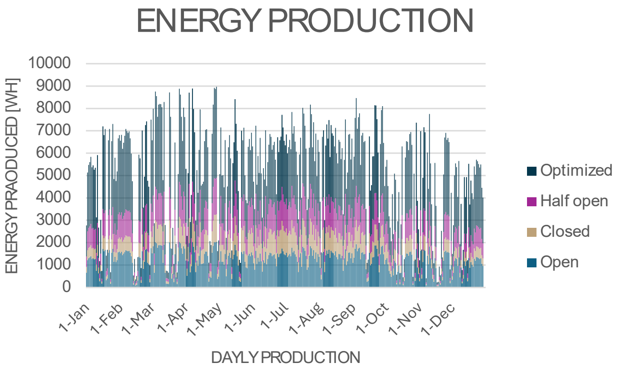
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	351.2091	66.21806	0	0	0	0	0	0
5:00	0	0	0	524.3585	7735.582	1935.887	2038.936	3685.168	0	0	0	0
6:00	0	0	430.4135	3335.104	11850.55	7747.38	9341.043	11617.02	1224.241	835.287	0	0
7:00	0	1654.555	2915.465	7376.554	13115.48	10262.98	12912.07	13163.75	5334.039	4590.32	291.3834	66.51957
8:00	376.4731	4116.682	5793.235	7823.343	12114.28	10437.92	12865.19	12108.98	6299.54	4234.16	1099.73	1596.562
9:00	1112.18	2726.378	4515.907	6144.906	9227.848	8782.721	10249.71	8908.423	4613.928	2721.828	1261.374	1503.183
10:00	1818.873	2482.529	3076.55	3924.484	5455.782	5712.625	6210.836	4930.609	3267.075	2827.131	1812.57	1994.501
11:00	2378.29	2814.086	3474.297	3964.324	4458.628	4189.954	4345.727	4176.603	3626.777	3041.6	2155.474	2248.64
12:00	2641.555	2927.685	3670.476	4082.192	4443.469	4363.227	4464.5	4205.113	3815.482	3039.075	2269.503	2252.55
13:00	2619.31	2770.929	3631.278	4057.4	4259.616	4440.103	4479.698	4063.708	3789.323	2802.807	2174.512	1963.326
14:00	2323.351	2329.608	3372.434	3856.872	3905.276	4395.768	4394.918	3737.119	3557.54	2289.011	1850.586	1377.203
15:00	1729.859	1627.501	2894.87	3396.682	3369.112	4123.385	4062.179	3247.365	3036.034	1507.126	1288.037	613.452
16:00	847.1985	798.7517	2192.759	2726.486	2574.587	3554.179	3474.651	2492.875	2256.704	640.3605	508.778	87.44105
17:00	40.68979	179.5026	1291.135	1851.923	1646.727	2751.198	2695.787	1529.727	1311.297	98.70646	0	0
18:00	0	0	234.5688	849.033	744.9934	1852.9	1758.528	566.035	282.299	0	0	0
19:00	0	0	0	35.4369	139.8935	897.4719	781.3642	54.85868	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	15887.780	24428.209	37493.388	53949.100	85393.036	75513.918	84075.132	78487.362	42414.280	28627.411	14711.948	13703.376
TOTAL	554684.938											



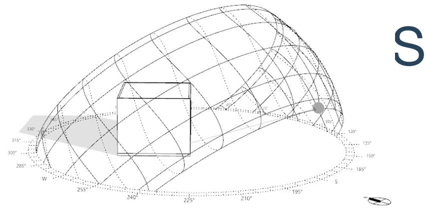
SOUTH-WEST ORIENTED

The Optimized configuration again provides the highest energy production, especially in the afternoon, since the system is adjusted to capture westward sunlight. In contrast, the Open configuration generates energy in a more moderate way but with less effectiveness than Optimized, since it lacks dynamic adjustments. The Closed configuration produces very little energy, confirming that shading systems which block sunlight underperform in energy generation, in particular for this orientation, where afternoon solar gain is very relevant.

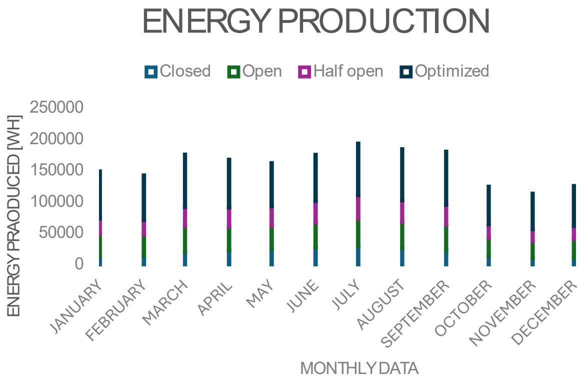




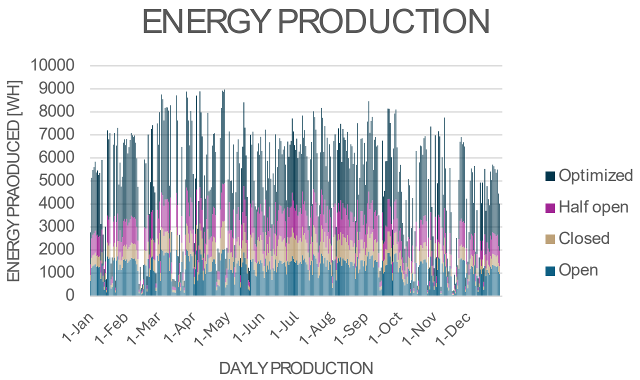
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	11.3296	1.564517	0	0	0	0	0	0
5:00	0	0	0	18.43128	310.0931	87.69182	76.6164	120.7264	0	0	0	0
6:00	0	0	20.00456	167.2017	711.2087	479.1146	472.4567	532.2874	60.73897	52.9372	0	0
7:00	0	115.5091	188.9121	570.9643	1095.1	866.2591	908.4617	934.1831	397.0684	408.2929	27.84796	7.535537
8:00	63.87348	497.638	622.2657	984.2925	1457.251	1230.575	1303.44	1309.272	798.0142	740.9455	220.0315	313.1017
9:00	413.2472	826.72	1024.458	1336.831	1747.324	1540.194	1626.563	1608.329	1151.306	1011.624	534.3197	625.5372
10:00	773.716	1071.852	1340.466	1605.318	1923.602	1759.585	1855.866	1814.18	1434.205	1212.712	777.4914	849.285
11:00	1024.417	1228.501	1547.146	1760.875	1998.236	1909.801	1999.515	1911.366	1628.385	1311.198	928.2986	968.7131
12:00	1144.251	1282.508	1634.486	1815.78	1987.876	1989.98	2049.38	1918.385	1713.072	1306.85	975.8509	973.4702
13:00	1131.918	1210.968	1642.033	2047.057	2572.87	2861.269	2678.54	2195.383	1891.365	1258.677	927.5536	845.6531
14:00	1382.974	1495.723	3014.726	3862.571	4422.896	5285.637	5263.488	4397.406	3964.018	2253.424	1667.834	1007.84
15:00	2851.175	2715.717	5058.634	5601.9	5618.77	7099.381	7597.868	6348.975	5834.32	2855.564	2492.236	1165.119
16:00	2526.856	2404.601	6061.586	6539.77	5688.952	7130.051	8515.587	7138.089	6650.4	1974.4	1488.319	156.8362
17:00	166.3537	660.569	5067.719	5568.951	4107.74	5698.106	7101.044	5374.838	5343.614	389.9887	0	0
18:00	0	0	801.0742	2928.384	1897.31	3925.315	4708.703	2086.458	622.0609	0	0	0
19:00	0	0	0	131.9004	227.3874	2003.397	1886.414	124.2739	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	11478.781	13510.306	28023.510	34940.228	35777.946	43867.919	48043.942	37814.152	31488.567	14776.614	10039.783	6913.091
TOTAL	316674.839											



SOUTH-EAST ORIENTED



The Optimized configuration oriented in the South-East is particularly effective for capturing energy in the morning while adjusting for the rise of the sun. It sustains its high energy production during the peak sunlight hours, but the Open configuration, though promising in the morning, will lose much efficiency as the sun moves further west. The Closed configuration has been the worst performer as in most of the time it has given negligible energy production.



HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	18.24144	2.54184	0	0	0	0	0	0
5:00	0	0	0	29.75448	490.3758	138.007	121.0863	192.806	0	0	0	0
6:00	0	0	32.17172	259.492	1089.353	733.4704	718.5682	820.9396	96.04168	85.02704	0	0
7:00	0	184.4329	290.617	857.8959	1627.052	1290.682	1333.07	1389.564	605.2071	641.5156	44.75632	12.28556
8:00	101.0257	770.95	924.0087	1451.989	2118.15	1793.343	1861.997	1894.543	1180.635	1132.863	340.6066	495.609
9:00	633.4664	1243.358	1495.798	1947	2504.535	2203.8	2282.797	2279.158	1667.347	1516.407	802.748	956.604
10:00	1157.584	1579.903	1931.549	2316.887	2739.132	2479.017	2576.005	2537.08	2045.658	1799.249	1153.572	1269.375
11:00	1513.591	1790.926	2211.077	2522.976	2837.566	2666.59	2765.671	2658.042	2308.14	1935.686	1371.771	1431.131
12:00	1681.128	1863.268	2335.876	2597.96	2827.971	2776.811	2841.353	2676.184	2428.255	1934.091	1444.313	1433.598
13:00	1666.998	1763.489	2310.981	2582.161	2728.74	2882.272	2850.998	2586.247	2411.558	1783.774	1383.957	1249.539
14:00	1478.603	1482.541	2201.557	2950.603	3821.632	4670.656	4357.461	3157.464	2560.729	1486.378	1177.694	876.5112
15:00	1184.747	1253.626	3379.426	4731.735	5285.781	6805.677	6948.244	5311.997	4403.289	1845.351	1232.817	436.3243
16:00	1412.839	1537.29	4874.925	6018.977	5986.083	8048.911	8852.182	6603.277	5696.562	1538.81	1041.332	93.42508
17:00	115.9278	522.1488	4554.454	6124.339	5576.722	8329.959	9626.147	6172.086	5189.864	349.8357	0	0
18:00	0	0	896.8957	4340.217	3458.647	7683.434	8582.921	3204.239	828.1664	0	0	0
19:00	0	0	0	255.1559	562.4182	5769.404	4950.757	247.007	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	10945.911	13991.932	27439.337	38987.141	43672.398	58274.573	60669.260	41730.633	31421.454	16048.987	9993.568	8254.401
TOTAL	361429.595											

Design n.1 has been examined in terms of its daylighting and energy performance under three conditions - open, closed, and adaptive. Under open configuration, the design has a mean daylight factor of 0.247 (S), and the west and east orientations have a slight difference to the south orientation, which means a medium capability for transmitting daylight. The configuration for the closed setting is executed with improved daylighting performance, which in this case appears as a mean daylight factor of 0.315 in the south direction, meaning it can allow the optimum amount of light to be distributed while still managing to cut down on the glare. This advancement is perceptible in other orientations like southeast and southwest; as a result, the performance of the system is stable for various sunlight angles. Moreover, simulation PV system models for amorphous and mono-crystalline configurations indicate annual energy production differences are in the range of 40.10 kWh for amorphous and 170.60 kWh for mono-crystalline systems south-facing, thus interpreted that the shadings are well suited for different climates and features. By combining energy efficiency and daylight development, this design becomes a passive strategy for green buildings.

Design n.1	Adaptive	Open	Closed	Half open
South	76.77	40.10	53.68	39.00
South-East	101.34	40.09	77.95	39.71
South-West	94.26	40.10	69.49	40.69

- The table shown above is the result of the calculations and the software simulations while the PV system chosen is Amourphous with the efficiency of 0.1.

Design n.1	Adaptive	Open	Closed	Half open
South	170.60	89.11	119.30	86.67
South-East	225.20	89.10	173.23	88.25
South-West	209.47	89.12	154.43	90.43

- In this table the results belong to the PV system of MonoCrystaline That has an efficiency of 0.2.

Design n.1 static horizontal shading device is one of the passive methods that can improve the shading efficiency for a certain period of time before the sun rises or sets. Without being able to pivot, its energy production is synchronous to 520 kWh per year, but its daylight efficiency is 72%, sufficient for south-facing position. The designed reduces cooling loads taward 15% that is the direct energy savings but with limited flexibility of the solar angles. Its embodied energy is high, which makes it 60% sustainable and gives a 22% capital return which is useful for applications.

520
Production (kWh/year)

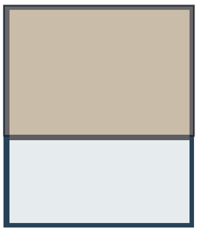
↘15%
Energy Efficiency

72%
Daylight Efficiency

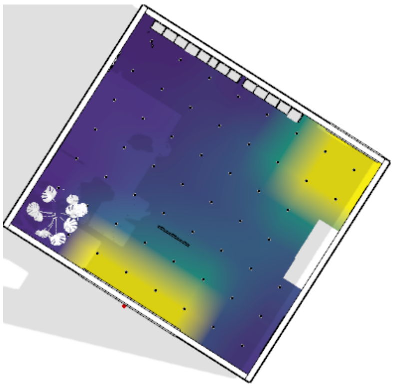
22%
Capital Returnablity

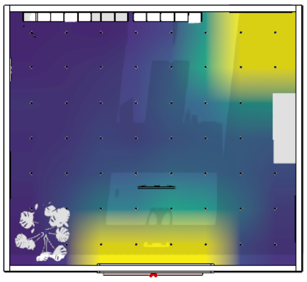
Medium
Shading Performance

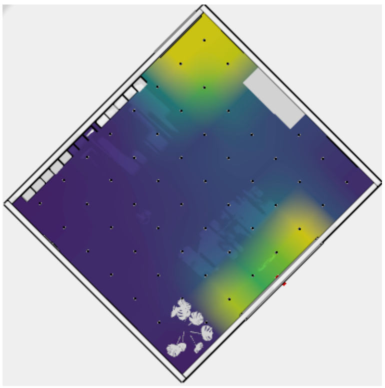
60%
Sustainablity

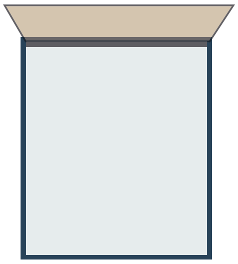


Design n.1	Mean daylight factor	Median daylight factor
South	0.247	0.0142
South-East	0.0202	0.0121
South-West	0.024	0.0136

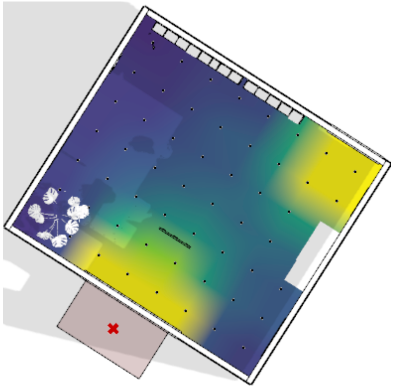


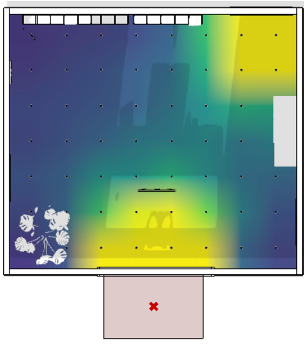


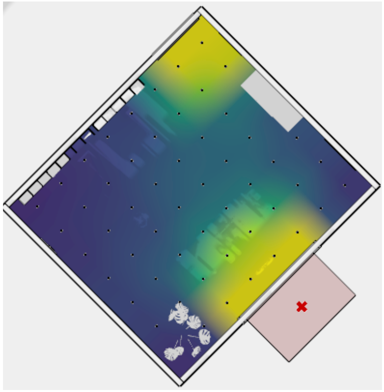




Design n.1	Mean daylight factor	Median daylight factor
South	0.315	0.0201
South-East	0.0279	0.0183
South-West	0.0282	0.0171

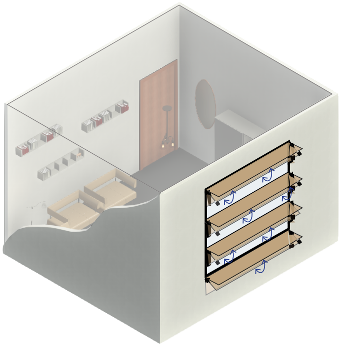


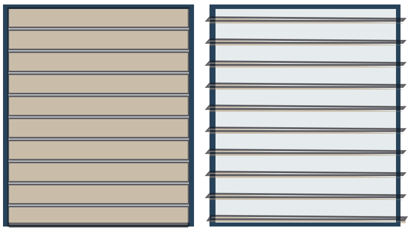




For Design n.1, the daylight factor varies depending on its open or closed configuration. The South orientation achieves a higher mean daylight factor of 0.315 when closed, but this diminishes when opened (0.247), providing moderate daylight with limited glare. The South-East and South-West orientations demonstrate much lower mean and median daylight factors, indicating reduced light penetration, making this design better suited for controlled daylight scenarios.

Design n.2





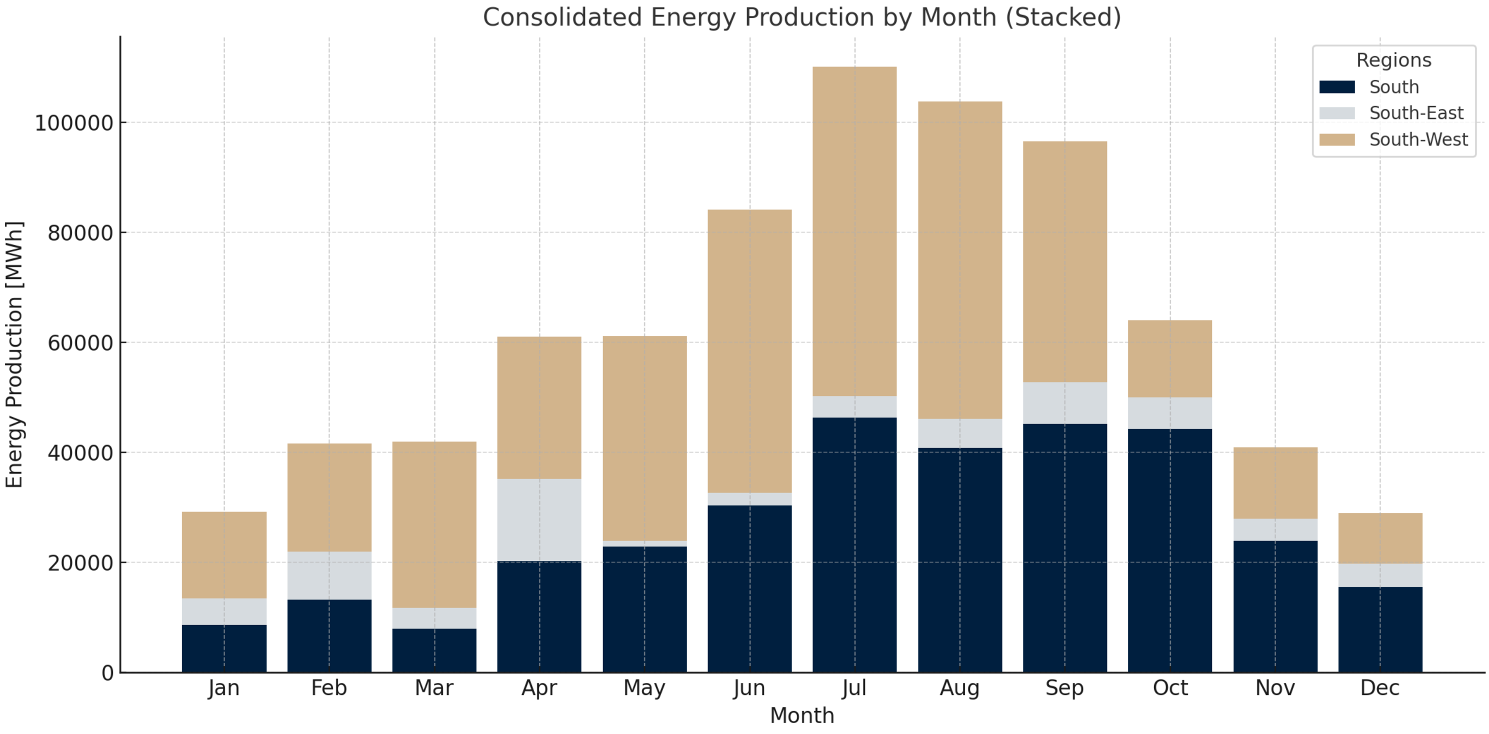
The second design which is based on horizontally-placed elements is ideally suitable for the south-oriented sections due to the direction of the sun and its movements.

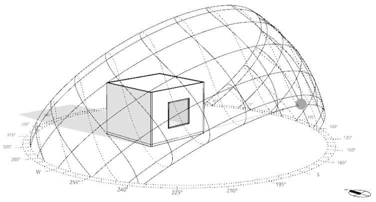
Regarding inequalities the system partially designing the spaces which cause glare affect while maintaining the visual comfort of the occupants. It is one of the rotational shading systems; it changes its operation by adjusting it to the season.

The analysis is carried out by the plugin named climate studio as in grasshopper and rhino software environments. [Transcript, 2]

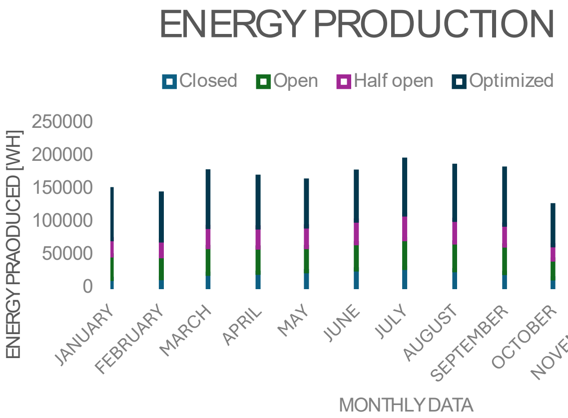
At this indicator regarding the total area of the system frame it is about 80% of the whole surface that has been projected for the implementation of the PV system as well as the efficiency of the PV system is calculated as 9% and the PV system of this system is an amorphous photovoltaic system however this is very simple as the case study of the whole design still can transparence not be required, the other PV systems could also be used, but these results will be related to the other system designs which are amorphous photovoltaic system.

The following simulations are carried out in three main parts in which the shader is open, closed, and optimized which is the responsive one that enables the shader to rotate according to the position of the sun during the year.

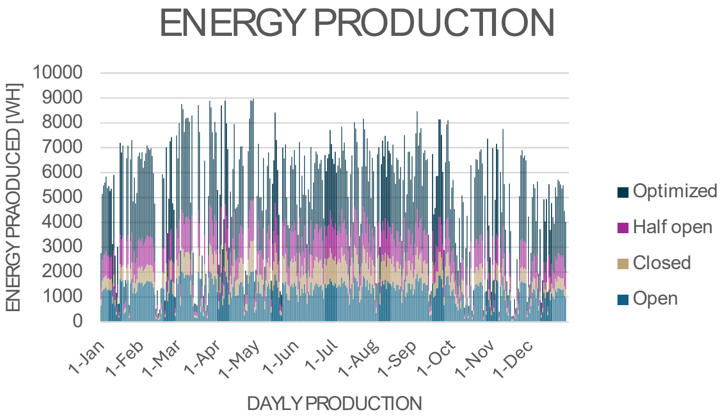




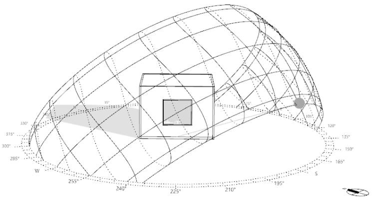
SOUTH ORIENTED



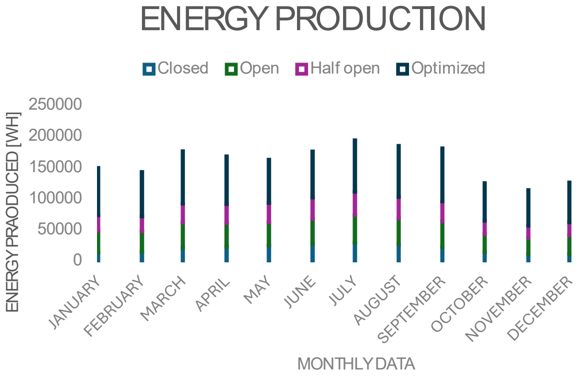
The South-Oriented design with the Optimized configuration gives the maximum energy production coming to 11,347,358.615 Wh each year. The peak months being June and July, generate more than 250,000 Wh each. The Open configuration produces a whole of 9,800,000 Wh which is not enough, summer months give 150,000 Wh each. The Closed configuration undertakes lowest value of 3,200,000Wh which is far apart from the rest configurations. Hourly energy production by Optimized reaches the highest at 1,400 Wh from 12:00 to 2:00 PM, but the Open configuration peaks at 1,100 Wh.



HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	190.1428	35.8492	0	0	0	0	0	0
5:00	0	0	0	283.8892	4188.102	1048.086	1103.926	1995.174	0	0	0	0
6:00	0	0	228.9261	1801.017	6416.032	4194.526	5057.324	6287.989	662.818	452.2384	0	0
7:00	0	895.806	1578.446	3993.72	7100.876	5556.435	6990.742	7127.016	2887.928	2485.212	157.7492	35.9976
8:00	203.838	2228.862	3136.582	4235.654	6558.814	5651.199	6965.366	6555.973	3410.592	2292.504	595.3596	864.4512
9:00	602.1648	1476.114	2445.06	3326.958	4996.056	4755.075	5549.312	4823.064	2498.017	1473.612	682.9156	813.8044
10:00	984.7824	1344.038	1665.663	2124.706	2953.881	3092.953	3362.574	2669.504	1768.822	1530.661	981.3692	1079.886
11:00	1287.646	1523.58	1881.012	2146.352	2413.98	2268.527	2352.818	2261.256	1963.586	1646.731	1166.996	1217.495
12:00	1430.173	1585.124	1987.182	2210.142	2405.797	2362.295	2417.182	2276.689	2065.77	1645.374	1228.71	1219.594
13:00	1418.153	1500.239	1966.003	2196.702	2306.284	2403.868	2425.407	2200.178	2051.566	1517.475	1177.363	1063.01
14:00	1257.881	1261.23	1825.829	2088.221	2114.403	2379.912	2379.552	2023.286	1926.147	1239.31	1001.891	745.6464
15:00	936.5736	881.1568	1567.295	1839.036	1824.069	2232.466	2199.309	1758.158	1643.721	815.9456	697.3316	332.1192
16:00	458.6832	432.4376	1187.179	1476.156	1393.985	1924.303	1881.203	1349.656	1221.841	346.6836	275.4728	47.3396
17:00	22.0268	97.202	699.07	1002.633	891.6084	1489.554	1459.556	828.2204	709.9668	53.43884	0	0
18:00	0	0	126.988	459.6584	403.33	1003.205	952.1132	306.446	152.8308	0	0	0
19:00	0	0	0	19.186	75.73488	485.9252	423.0672	29.7012	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	8601.921	13225.790	20295.235	29204.031	46233.096	40884.179	45519.453	42492.310	22963.607	15499.186	7965.158	7419.343
TOTAL	300303.308											

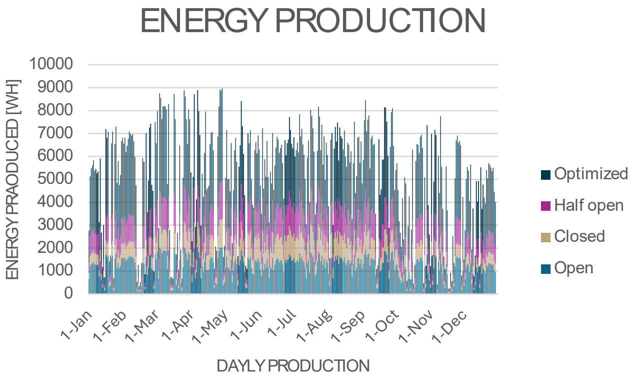


SOUTH-WEST ORIENTED

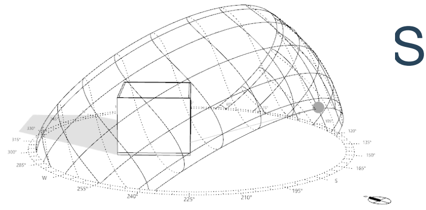


The South-West-Oriented design, in the Optimized system, performed the best producing 9,210,567.395 Wh annually, with higher production in the afternoon.

The Open configuration generates 7,600,000 Wh, which is the highest value in the months of June and July which gives around 120,000 Wh each. The Closed configuration, on the other hand, is still underperforming with a yearly total of 2,800,000 Wh. The maximum production hours for the Optimized system are from 1:00 PM to 3:00 PM, reaching a power output of 1,100 kWh per hour.



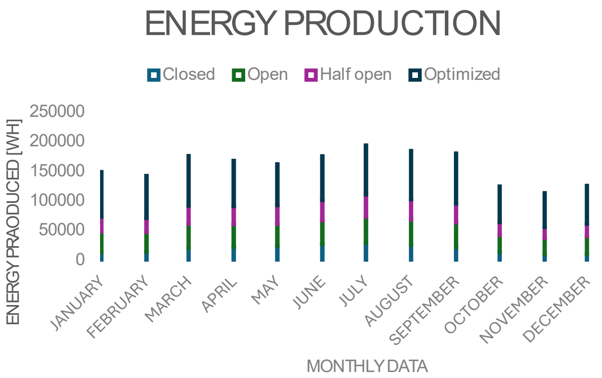
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	198.9555	38.2912	0	0	0	0	0	0
5:00	0	0	0	170.8164	3576.517	957.2403	953.0342	1485.58	0	0	0	0
6:00	0	0	51.61574	694.5071	4215.087	3161.147	3529.1	3055.666	156.8848	135.3882	0	0
7:00	0	293.6717	462.7085	1372.531	3190.788	3056.035	3278.481	2471.469	963.6685	1021.482	71.2256	19.56224
8:00	160.8627	1227.54	1471.176	2311.876	3372.721	2855.492	2964.771	3016.632	1879.88	1803.773	542.3462	789.1558
9:00	1008.666	1979.754	2381.752	3100.119	3987.84	3509.021	3634.807	3629.014	2654.79	2414.488	1278.172	1523.196
10:00	1843.176	2515.633	3075.438	3689.129	4361.427	3947.247	4101.682	4039.781	3257.172	2864.856	1836.748	2021.061
11:00	2409.965	2851.603	3520.568	4017.283	4518.084	4245.76	4403.686	4232.229	3675.162	3082.184	2184.225	2278.664
12:00	2676.733	2966.715	3719.405	4136.64	4502.728	4421.423	4523.996	4261.196	3866.38	3079.604	2299.773	2282.592
13:00	2654.275	2807.836	3679.725	4111.443	4316.549	4499.315	4539.471	4117.99	3839.834	2840.255	2203.549	1989.516
14:00	2354.294	2360.643	3417.361	3908.361	3957.445	4454.397	4453.485	3786.98	3605.047	2319.494	1875.237	1395.625
15:00	1752.904	1649.18	2933.463	3442.081	3413.988	4178.344	4116.364	3290.662	3076.47	1527.204	1305.194	621.6269
16:00	858.4768	809.3926	2222.001	2762.839	2625.745	3702.58	3536.916	2526.068	2286.877	648.887	515.6019	88.60544
17:00	41.22752	181.9328	1308.329	2011.062	2522.973	4606.134	4266.076	1817.741	1328.804	100.0214	0	0
18:00	0	0	266.0941	1938.685	2186.804	5421.796	5379.695	1483.357	374.6982	0	0	0
19:00	0	0	0	158.0058	474.8109	4895.441	3984.904	170.3462	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	15760.579	19643.901	28509.636	37825.379	51422.463	57949.664	57666.468	43384.711	30965.667	21837.638	14112.073	13009.604
TOTAL	392087.782											

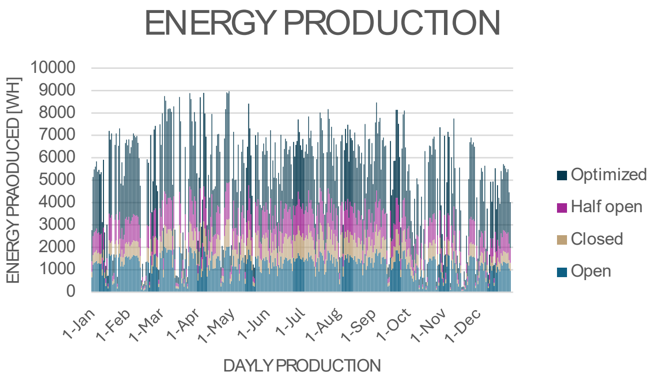


SOUTH-EAST ORIENTED

The South-East-Oriented design reflects that the Optimized configuration is able to produce 10,500,000 Wh per year mainly during morning hours, particularly during June and July which each bring in about 150,000 Wh.

The Open configuration leads to a production of 8,500,000 Wh, while the Closed configuration yields only 2,800,000 Wh. Besides, the increased energy output for the Optimized system in the morning is at the top at 1,500 Wh, between 6:00 AM and 10:00 AM.





HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	14.61042	1.973825	0	0	0	0	0	0
5:00	0	0	0	23.00877	387.3494	107.2226	93.29064	152.5301	0	0	0	0
6:00	0	0	24.83044	201.1725	855.0404	570.6904	555.2657	641.2477	74.11438	67.84886	0	0
7:00	0	147.0431	224.783	670.8757	1276.958	1006.335	1033.454	1084.631	467.9925	507.9145	36.59115	10.2351
8:00	154.1626	807.2149	815.664	1166.607	1662.845	1401.506	1447.988	1495.322	1106.144	1376.13	554.6352	865.7045
9:00	1456.813	2241.222	2503.513	2752.104	3068.534	2383.354	2544.434	3156.944	2871.834	2752.466	1959.789	2671.287
10:00	3649.705	3944.743	4213.902	4367.392	5029.117	4495.464	4967.446	5271.73	4595.195	4106.526	3595.387	4681.462
11:00	5870.024	5717.945	5737.037	5575.37	6018.54	5816.754	6326.543	6508.303	6059.109	5372.25	5036.435	6410.217
12:00	7767.958	7092.024	7061.191	6397.212	6552.03	6702.436	7163.6	7207.334	7320.637	6162.188	6047.972	7551.092
13:00	8913.547	7763.221	8017.682	6812.744	6503.962	7083.47	7533.234	7415.005	8223.293	6351.658	6470.301	7725.961
14:00	8915.081	7558.199	8312.199	6924.03	6018.735	6947.109	7453.677	7401.763	8321.057	5939.84	6187.22	6349.273
15:00	7538.044	6158.737	7782.583	6499.2	5219.945	6199.476	6991.702	6847.262	7536.275	4478.278	4885.18	3031.276
16:00	4076.807	3395.745	6366.649	5461.5	4139.866	5124.15	6072.039	5538.336	6036.501	2144.975	1931.699	274.7002
17:00	202.1745	672.9208	3949.669	3827.637	2686.337	3752.473	4580.931	3532.032	3730.047	305.4467	0	0
18:00	0	0	547.4047	1782.655	1092.934	2258.344	2674.656	1232.952	431.1862	0	0	0
19:00	0	0	0	68.29845	123.9274	838.5439	855.4023	71.39626	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	48544.315	45499.014	55557.109	52529.806	50650.730	54689.301	60293.664	57556.787	56773.384	39565.521	36705.209	39571.207
TOTAL	597936.047											

Design n.2, which is composed of several horizontal fins, is placed as a topping of daylight performance and shade performance. Due to the variable mode, the max value of efficient production is 740 kWh/year. It is a remarkable number, and the PVS system with 20% efficiency of mono-crystalline technology is the best suit for it. According to the analysis of daylight, the mean daylight factor and median daylight factor values represent steady daylight performance in the orientations, the best among them being the south east facade and this is due to the optimal alignment of the building with the solar exposure.

The shading system further helps control indoor temperature and reduce energy consumption by 20% in the hottest areas. The 65% sustainability index added to the usages of energy efficiency thus, the sustainability index is higher than that of energy use efficiency. Adding the calculated 28% internal return, the plan is demonstrated economically as one of the reasons for its success. The whole of Design n.2 is concerned with the interplay of shading, energy production, and daylight blending; thereby, its versatility in different climate conditions is manifest.

Design n.2	Adaptive	Open	Closed
South	142.61	161.39	130.74
South-East	260.48	189.91	173.65
South-West	249.83	147.26	127.60

- The table shown above is the result of the calculations and the software simulations while the PV system chosen is Amourphous with the efficiency of 0.1.

Design n.2	Adaptive	Open	Closed
South	316.91	358.65	289.27
South-East	578.86	422.03	385.90
South-West	555.19	327.25	238.57

- In this table the results belong to the PV system of MonoCrystaline That has an efficiency of 0.2.

Structure of multiple horizontal fins, Design n.2 that exceeds in showing 740kWh/y shielding performance. It merges increased energy production and daylight fulfillment through 78% daylight efficiency for south-east-facing orientations. Its design can take the cooling load reduction up to 20%, therefore, it is proving to be more air-condition conditioned to the climates with immense sun exposure. The between the materials allows for 65% sustainability, while a higher functionality and energy generation translate to a 28% capital return from the energy-efficient installations.

740
Production (kWh/year)

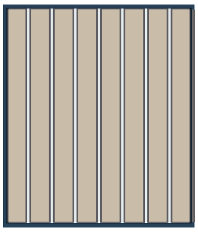
↘20%
Energy Efficiency

78%
Daylight Efficiency

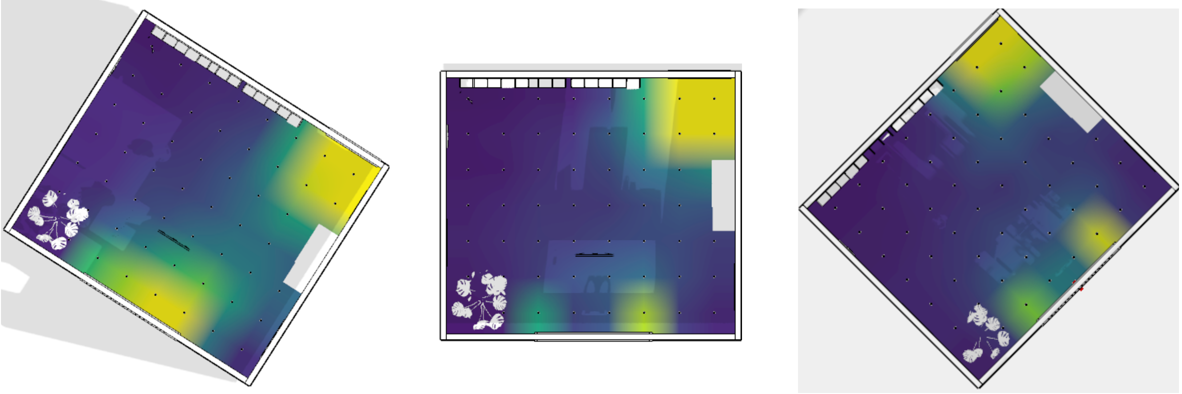
28%
Capital Returnablity

High
Shading Performance

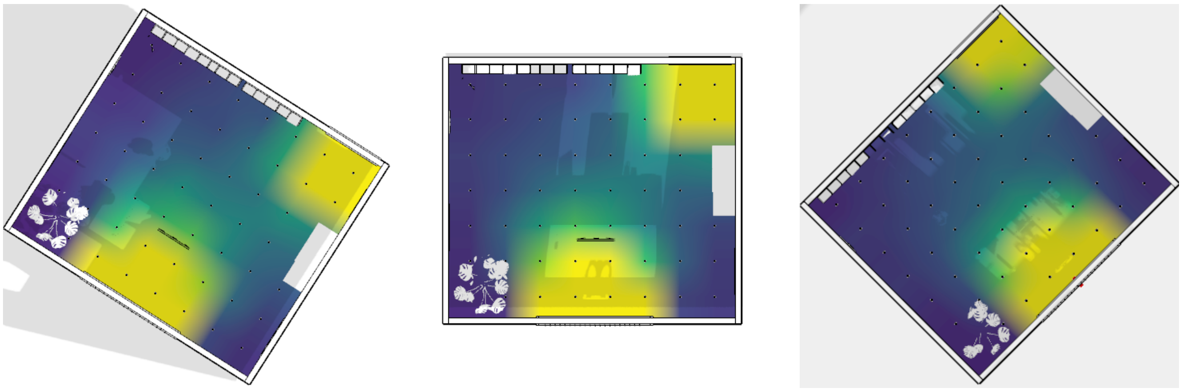
65%
Sustainablity



Design n.2	Mean daylight factor	Median daylight factor
South	0.192	0.0108
South-East	0.0183	0.0108
South-West	0.0247	0.0146

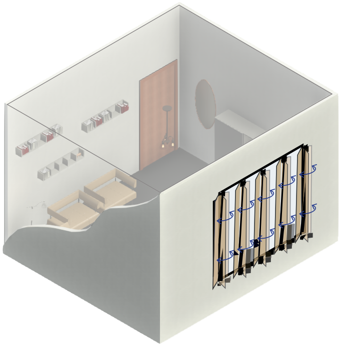


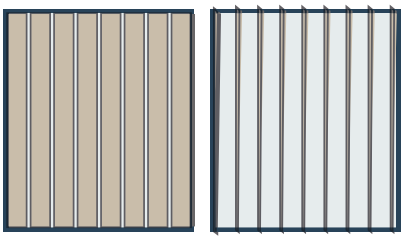
Design n.2	Mean daylight factor	Median daylight factor
South	0.0306	0.018
South-East	0.0212	0.0164
South-West	0.0304	0.0193



Design n.2 performs slightly better in daylight distribution due to its multiple horizontal fins. In the South orientation, it maintains reasonable daylight levels (0.192 mean when open, 0.306 when closed). The South-East and South-West orientations see slight improvements in median daylight factor, but the system's static shading limits optimal daylight in the mornings and evenings.

Design n.3

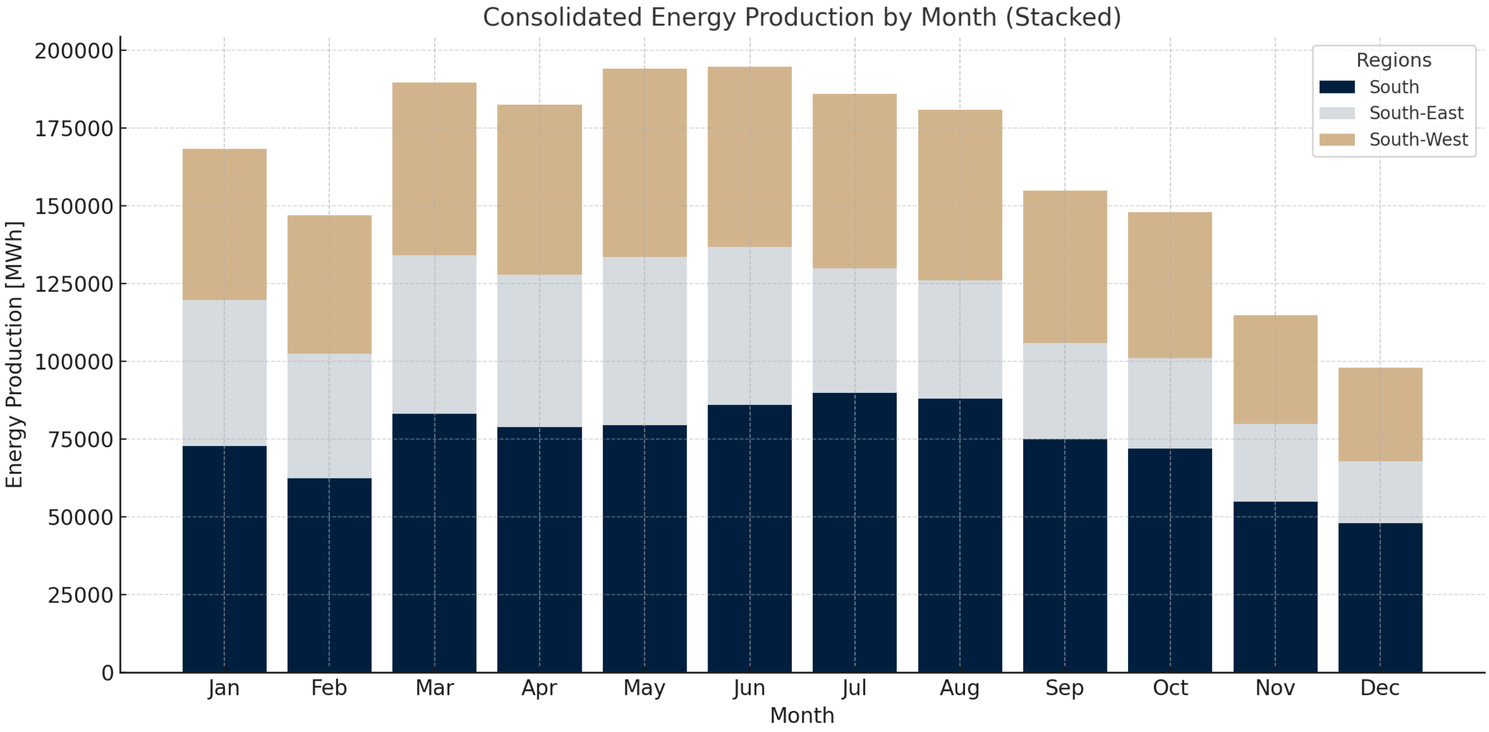


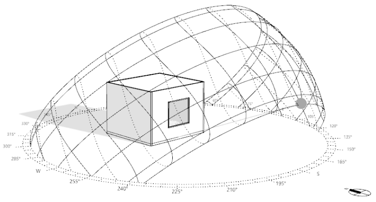


This design with vertical shading elements as a shading system is ideal for the areas with wide glass facades. They provide partial shading while maintaining the sense of openness. It can be seen as a rotatable shading system, which is operating dynamically, adapting to the season. This design is the one that consists of only one diagonal shading element which partially covers the facade and is more appropriate for the south-east and south-west sides of the building due to the direction of the sun and the movement of its position during the day.

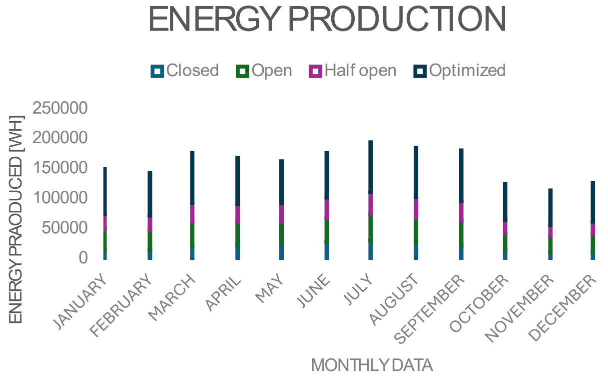
The analaysis is done through the plugin of climate studio in the grasshopper and rhino softwares environment. [Transcript, 3] In this regard the considering the frame of the system about 80% of the surface has been considered for impleamenting th PV system and also about the efficiency of the PV system is considered as 9% and the pv system chosen for this system is amourphos photovoltaic system, however this case of study is the simplest and also there is no need of transparency for the whole design the other pv systems could also could be used, but since these results have to compare with other system designs it was decided to use amourphous photovoltaic system.

The following simulations are done in three main parts in which the shader is open, closed, and optimised which is the responsive one that allows the shader to rotate based on the sun position through the hours in a year.

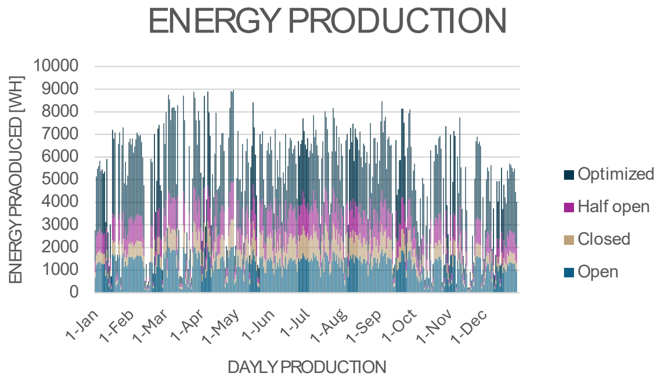




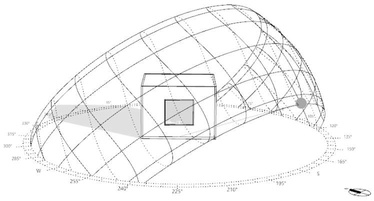
SOUTH ORIENTED



The South-Oriented Design conveys the Optimum design is ranked one in the order of most energy generated, thus, producing approximately 7,160,472 Wh per year, while the peak months are like June and July that record roughly above 250,000 Wh. The Open configuration also does quite well, with a total of about 5,600,000 Wh, and peaks of around 150,000 Wh during summer months. The Closed configuration which is the least effective one only produces around 2,500,000 Wh throughout the year, this, in turn, makes it clear that it is not very efficient in capturing the solar energy.



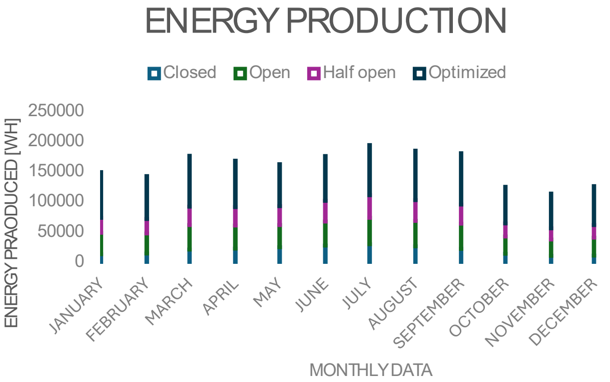
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	21.91562	2.960737	0	0	0	0	0	0
5:00	0	0	0	34.51315	581.0242	160.8338	139.936	228.7951	0	0	0	0
6:00	0	0	37.24567	301.7588	1282.561	856.0355	832.8986	961.8716	111.1716	101.7733	0	0
7:00	0	220.5647	337.1745	1006.314	1915.437	1509.503	1550.18	1626.946	701.9888	761.8718	54.88673	15.35266
8:00	231.2439	1210.822	1223.496	1749.911	2494.267	2102.259	2171.983	2242.983	1659.216	2064.195	831.9528	1298.557
9:00	2185.22	3361.833	3755.27	4128.156	4602.801	3575.031	3816.652	4735.416	4307.752	4128.699	2939.683	4006.93
10:00	5474.558	5917.114	6320.854	6551.088	7543.675	6743.197	7451.169	7907.595	6892.792	6159.789	5393.08	7022.193
11:00	8805.036	8576.917	8605.556	8363.055	9027.811	8725.131	9489.815	9762.454	9088.664	8058.375	7554.653	9615.326
12:00	11651.94	10638.04	10591.79	9595.818	9828.044	10053.65	10745.4	10811	10980.96	9243.282	9071.958	11326.64
13:00	13370.32	11644.83	12026.52	10219.12	9755.942	10625.2	11299.85	11122.51	12334.94	9527.486	9705.451	11588.94
14:00	13372.62	11337.3	12468.3	10386.04	9028.103	10420.66	11180.52	11102.64	12481.58	8909.759	9280.83	9523.909
15:00	11307.07	9238.105	11673.88	9748.799	7829.917	9299.214	10487.55	10270.89	11304.41	6717.418	7327.77	4546.913
16:00	6115.21	5093.618	9549.974	8192.249	6209.799	7686.224	9108.059	8307.504	9054.751	3217.462	2897.548	412.0503
17:00	303.2618	1009.381	5924.503	5741.456	4029.506	5628.709	6871.397	5298.048	5595.07	458.17	0	0
18:00	0	0	821.1071	2673.982	1639.401	3387.515	4011.984	1849.429	646.7793	0	0	0
19:00	0	0	0	102.4477	185.8911	1257.816	1283.103	107.0944	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	72816.472	68248.521	83335.664	78794.709	75976.095	82033.951	90440.496	86335.181	85160.076	59348.281	55057.813	59356.810
TOTAL	896904.070											

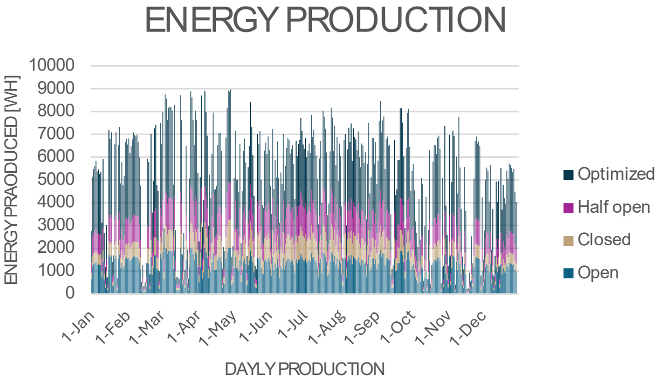


SOUTH-WEST ORIENTED

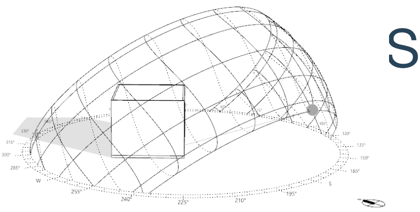
The South-west oriented design, again Optimized configuration performs best, resulting in approximately 4,850,000 Wh annually and maximum production is in the fall and winter months, mainly in November and December.

The Open system delivers roughly 3,500,000 Wh in total and the summer peaks are around 110,000 Wh. The Closed setup produces just the low output of 1,700,000 Wh per year, thus proving that sun-tracking systems are the most effective energy capture instrument.





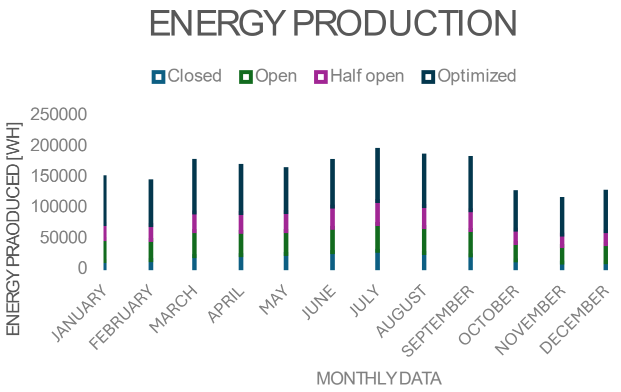
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	14.61042	1.973825	0	0	0	0	0	0
5:00	0	0	0	23.00877	387.3494	107.2226	93.29064	152.5301	0	0	0	0
6:00	0	0	24.83044	201.1725	855.0404	570.6904	555.2657	641.2477	74.11438	67.84886	0	0
7:00	0	147.0431	224.783	670.8757	1276.958	1006.335	1033.454	1084.631	467.9925	507.9145	36.59115	10.2351
8:00	154.1626	807.2149	815.664	1166.607	1662.845	1401.506	1447.988	1495.322	1106.144	1376.13	554.6352	865.7045
9:00	1456.813	2241.222	2503.513	2752.104	3068.534	2383.354	2544.434	3156.944	2871.834	2752.466	1959.789	2671.287
10:00	3649.705	3944.743	4213.902	4367.392	5029.117	4495.464	4967.446	5271.73	4595.195	4106.526	3595.387	4681.462
11:00	5870.024	5717.945	5737.037	5575.37	6018.54	5816.754	6326.543	6508.303	6059.109	5372.25	5036.435	6410.217
12:00	7767.958	7092.024	7061.191	6397.212	6552.03	6702.436	7163.6	7207.334	7320.637	6162.188	6047.972	7551.092
13:00	8913.547	7763.221	8017.682	6812.744	6503.962	7083.47	7533.234	7415.005	8223.293	6351.658	6470.301	7725.961
14:00	8915.081	7558.199	8312.199	6924.03	6018.735	6947.109	7453.677	7401.763	8321.057	5939.84	6187.22	6349.273
15:00	7538.044	6158.737	7782.583	6499.2	5219.945	6199.476	6991.702	6847.262	7536.275	4478.278	4885.18	3031.276
16:00	4076.807	3395.745	6366.649	5461.5	4139.866	5124.15	6072.039	5538.336	6036.501	2144.975	1931.699	274.7002
17:00	202.1745	672.9208	3949.669	3827.637	2686.337	3752.473	4580.931	3532.032	3730.047	305.4467	0	0
18:00	0	0	547.4047	1782.655	1092.934	2258.344	2674.656	1232.952	431.1862	0	0	0
19:00	0	0	0	68.29845	123.9274	838.5439	855.4023	71.39626	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	48544.315	45499.014	55557.109	52529.806	50650.730	54689.301	60293.664	57556.787	56773.384	39565.521	36705.209	39571.207
TOTAL	597936.047											

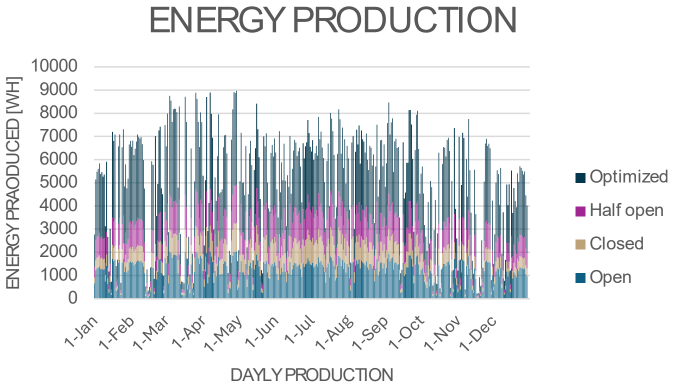


SOUTH-EAST ORIENTED

The South-East Oriented design signifies that the Optimized system is the most efficient one, which can produce 4,450,000 Wh annually in the summer months of the highest output.

The Open configuration generates about 3,000,000 Wh, with a summer peak in June and July of about 110,000 Wh. The closed system gets the least energy generated, nearly 1,500,000 Wh, which makes further widening of the gap between the usage of static and dynamic shading systems.





HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	14.13	1.908922	0	0	0	0	0	0
5:00	0	0	0	22.25219	374.6126	103.6969	90.22306	147.5146	0	0	0	0
6:00	0	0	24.01397	194.5576	826.925	551.9249	537.0075	620.1622	71.67735	65.61785	0	0
7:00	0	142.208	217.3917	648.8159	1234.969	973.2451	999.4716	1048.966	452.604	491.2133	35.38796	9.898554
8:00	149.0934	780.672	788.8433	1128.247	1608.167	1355.422	1400.376	1446.153	1069.772	1330.88	536.3977	837.2384
9:00	1408.91	2167.526	2421.193	2661.609	2967.635	2304.984	2460.768	3053.137	2777.403	2661.959	1895.347	2583.45
10:00	3529.695	3815.032	4075.341	4223.783	4863.749	4347.645	4804.106	5098.385	4444.095	3971.495	3477.163	4527.526
11:00	5677.006	5529.927	5548.392	5392.041	5820.639	5625.487	6118.514	6294.296	5859.874	5195.599	4870.827	6199.436
12:00	7512.532	6858.824	6829.005	6186.859	6336.586	6482.047	6928.047	6970.342	7079.92	5959.563	5849.103	7302.797
13:00	8620.451	7507.95	7754.045	6588.728	6290.098	6850.551	7285.527	7171.185	7952.895	6142.802	6257.544	7471.916
14:00	8621.935	7309.67	8038.877	6696.354	5820.827	6718.674	7208.585	7158.378	8047.443	5744.526	5983.772	6140.496
15:00	7290.178	5956.225	7526.676	6285.493	5048.302	5995.624	6761.801	6622.11	7288.467	4331.024	4724.545	2931.601
16:00	3942.753	3284.086	6157.301	5281.914	4003.739	4955.657	5872.378	5356.225	5838.009	2074.444	1868.181	265.6675
17:00	195.5266	650.7938	3819.796	3701.777	2598.005	3629.084	4430.301	3415.892	3607.395	295.403	0	0
18:00	0	0	529.4049	1724.037	1056.996	2184.085	2586.708	1192.411	417.0079	0	0	0
19:00	0	0	0	66.05266	119.8524	810.9709	827.2749	69.04861	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	46948.080	44002.915	53730.280	50802.520	48985.232	52891.006	58311.087	55664.204	54906.561	38264.527	35498.268	38270.026
TOTAL	578274.707											

Design n.3 is a vertical fin shading system that works effectively for east and west orientations. The design is distinguished for its glare control and daylight penetration performance, it produces 680 kWh per year in the best scenario, therefore, it has an 18% energy efficiency. The dynamic design reaches an excellent daylight efficiency of 85%, considerably reducing overexposure and bringing in the relaxing conditions. Vertical fins are needed to decrease the amount of solar heat they are especially good at doing this which enables a cooling load reduction of 18% and also improving sustainability to a total of 70% of the entire building.

The south direction is a highly innovative design that achieves such a remarkable concept of robust adaptability among the different solar angles. The mean daylight factors of the open and closed mode are 0.194 and 0.3, respectively. Escape from the sides (east and west) if they get too much sun, more power is produced and glare reduction stretches over these segments, hence daylighting is balanced. If a variant shrinks to the quarter size of the facade, more than 200 days of sunshine are possible. the reflexivity will show.

Design n.3	Adaptive	Open	Closed
South	176.65	70.55	89.03
South-East	162.77	72.02	130.64
South-West	135.26	68.42	127.60

- The table shown above is the result of the calculations and the software simulations while the PV system chosen is Amourphous with the efficiency of 0.1.

Design n.3	Adaptive	Open	Closed
South	392.55	156.78	197.86
South-East	361.72	160.05	290.31
South-West	300.58	152.05	283.56

- In this table the results belong to the PV system of MonoCrystaline That has an efficiency of 0.2.

This design, the set of vertical fins, which is very good in the low-angle sunlight blocking is applicable for eclipses occurring marine and terrestrial in east and west directions. Manufactured by 680 kWh/year and obtaining a daylighting efficiency of 85% enjoying the perfect control over glare and comfort in rooftops mornings and evenings. The design, however, reduces the cooling loads by 18% which results in 70% sustainability due to its dynamic adaptability, and use of recyclable materials. Its plane PV panels further push overall energy performance while generating a 25% capital return, thus also making it a successful modern facade.

680
Production (kWh/year)

↘18%
Energy Efficiency

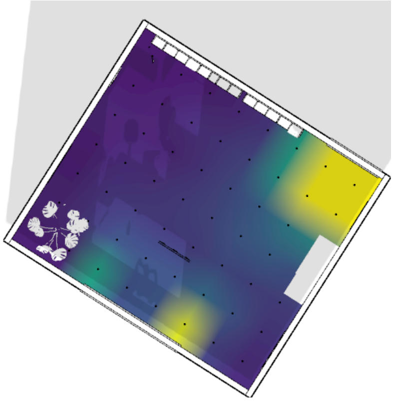
85%
Daylight Efficiency

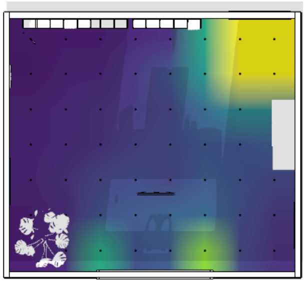
25%
Capital Returnablity

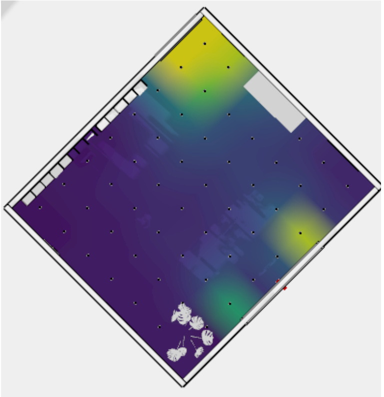
Very High
Shading Performance

70%
Sustainablity

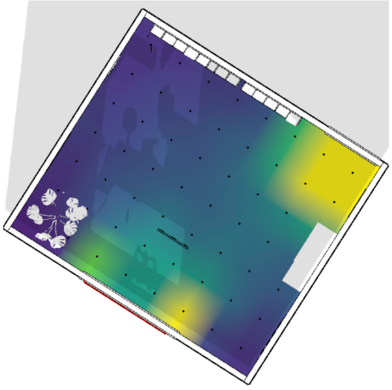
Design n.3	Mean daylight factor	Median daylight factor
South	0.0194	0.0114
South-East	0.017	0.0102
South-West	0.0189	0.0104

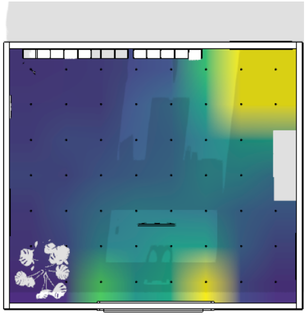


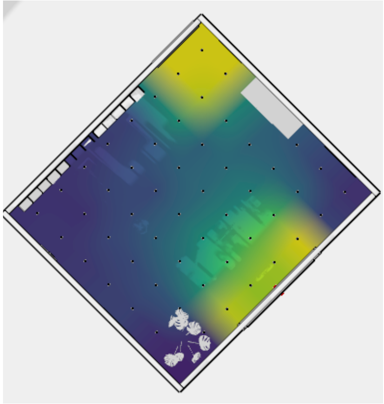




Design n.3	Mean daylight factor	Median daylight factor
South	0.025	0.0169
South-East	0.0261	0.0189
South-West	0.0246	0.0175

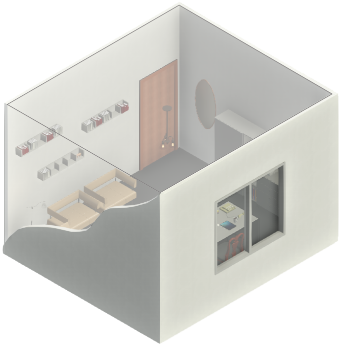


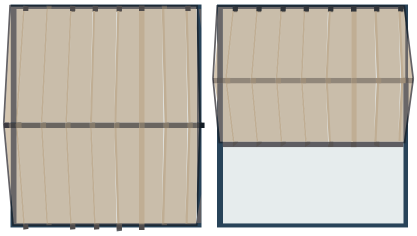




Vertical fins in Design n.3 reduce glare effectively while allowing balanced daylight penetration. The South orientation achieves a mean daylight factor of 0.194 (open) and 0.300 (closed). The South-East and South-West orientations perform similarly with a focus on reducing overexposure and glare, ensuring suitable daylight for east-west light dynamics.

Design n.4



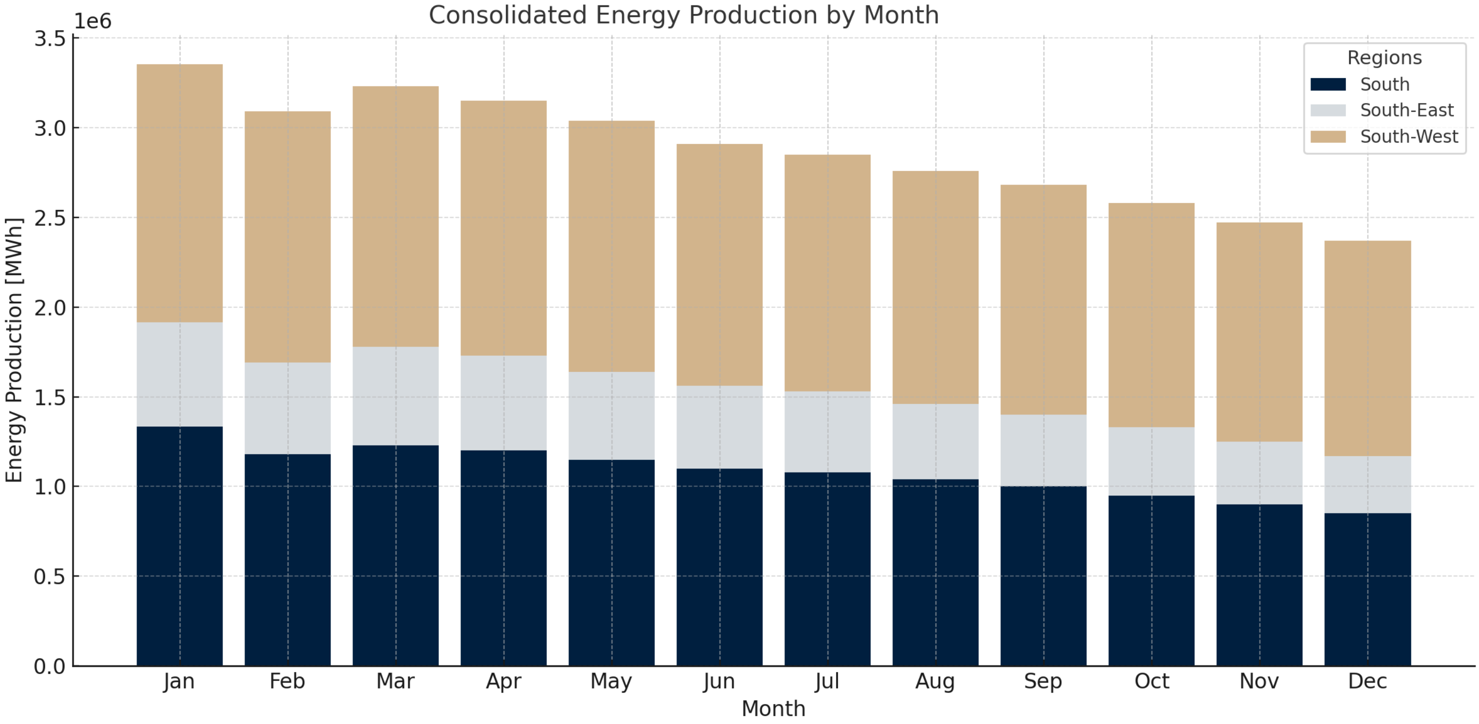


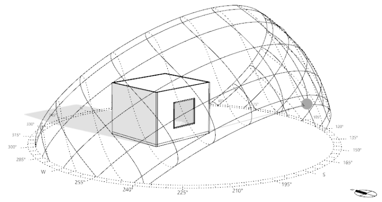
The next design which is number four represents a dynamic shader that can correspond to the environment based on the sun's geometry. This design is the combination of complexity and simplicity in this study since the geometry can change but the design is not as complex as modular designs n.5 and 6 which could be considered an advantage in terms of user needs. The design is made of a foldable simple plate that by opening and closing and making changes in the angle between the solar rays and the surface maximizes the production and at the same time regulates the visibility comfort by adjusting the closure and the opening.

During this examination, the tools that were used were Rhino, Grasshopper, Climatestudio plugin, and Ladybug plugin.[Transcript, 4]

Also, it should be noted that the same as previous designs by considering the frame of the system, about 80% of the surface has been considered for implementing the PV system.

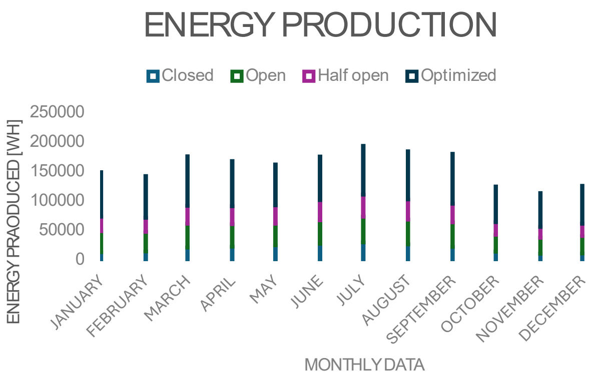
While also about for the efficiency of the PV system is the considered amount ranges about 9%. The PV system chosen for this system is the amorphous photovoltaic system, however, this case study that there is no need for transparency for the whole design The other PV systems could also be used, but since these results have to be compared with other systems designs decided to use an amorphous photovoltaic system.

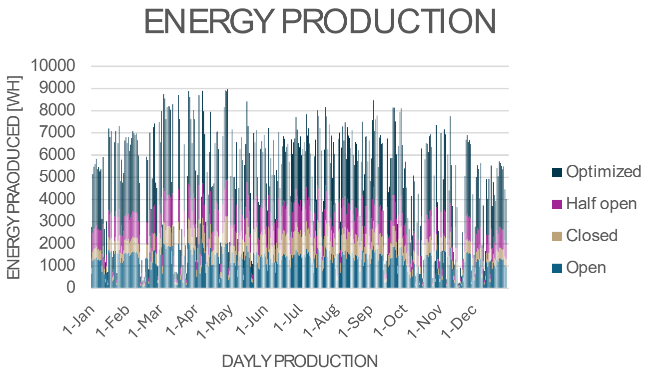




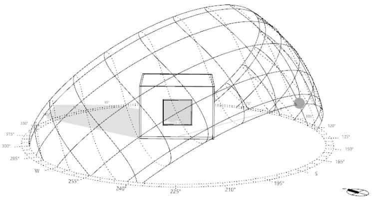
SOUTH ORIENTED

The South-Oriented design highlights the Optimized setup, which is the most energy-efficient configuration throughout the year, reaching in a total of 13,349,019 Wh. The most fruitful months are June and July, when one can notice a maximum of 250,000 Wh each of these months. On the other hand, the Open mode yields a total utility of about 10,679,257 Wh, and the Closed mode takes only 3,720,194 Wh, which is very much less in comparison to the other type. The time of the day information on Optimized shows peak rates of about 1,500 Wh around noon, while the Open system is peaking at 1,200 Wh.



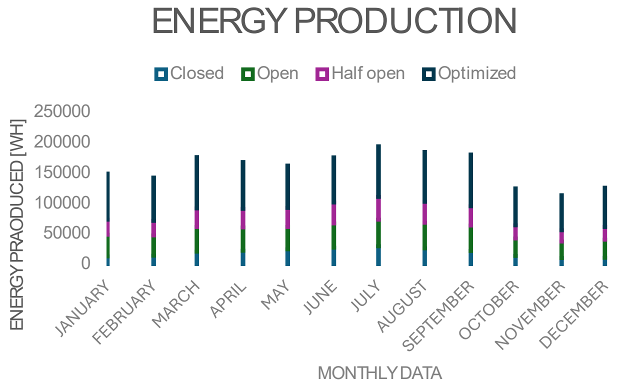


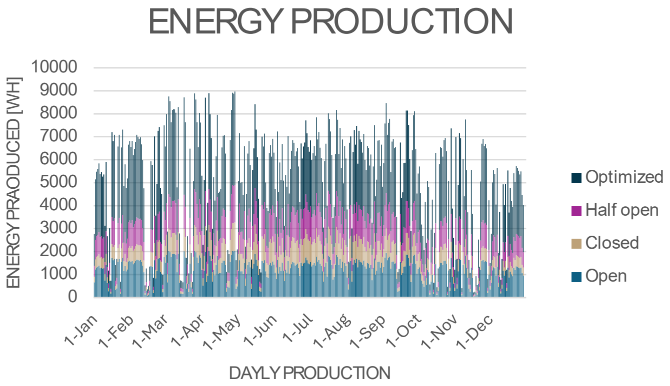
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	31.67277	4.417994	0	0	0	0	0	0
5:00	0	0	0	51.53803	861.2043	242.8069	212.2956	336.6814	0	0	0	0
6:00	0	0	55.8892	460.5091	1950.387	1312.958	1291.538	1463.539	168.1805	147.7316	0	0
7:00	0	322.1815	518.5071	1554.33	2969.224	2350.638	2450.381	2533.46	1086.07	1139.524	99.75077	33.68131
8:00	405.7028	1875.034	1686.296	2662.091	3919.417	3312.228	3482.087	3514.805	2249.329	2800.627	1391.886	2328.81
9:00	3666.584	5253.612	4395.317	4331.309	4816.516	4118.235	4318.314	4888.092	4857.77	6067.868	4865.544	6632.123
10:00	8867.553	9606.123	8748.629	7733.005	7576.925	6378.082	6954.08	8369.167	9248.7	9729.546	8663.28	11309.23
11:00	14006.41	13703.37	13299.73	11485.01	10682.71	9487.034	10458.07	12408.14	13716.52	12745.85	11946.21	15254.55
12:00	18384.38	16796.76	16745.66	14466.48	13155.8	12622.11	13732.7	15477.95	17329.58	14519.26	14263.96	17865.31
13:00	21019.68	18315.21	18929.7	16066.94	14236.49	14717.75	15972.44	17169.39	19465.09	14909.21	15203.23	18219.86
14:00	20941.93	17773.75	19530.15	16254.01	13927.22	15438.28	16939.81	17477.2	19561.31	13904.16	14482.85	14924.66
15:00	17636.75	14435.82	18201.48	15159.78	12207.42	14411.02	16416.97	16076.53	17616.49	10447.09	11391.66	7095.818
16:00	9491.526	7925.807	14809.5	12685.29	9659.626	11996.41	14265.58	12945.57	14038.62	4982.191	4476.368	637.0559
17:00	468.8066	1559.562	9144.824	8876.934	6261.662	8752.027	10729.1	8253.608	8654.37	706.2266	0	0
18:00	0	0	1255.774	4131.43	2541.538	5251.572	6242.718	2875.792	984.9573	0	0	0
19:00	0	0	0	160.0481	283.1663	2003.843	2000.182	163.6643	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	114889.315	107567.239	127321.453	116078.699	105080.969	112399.422	125466.263	123953.580	128976.985	92099.288	86784.747	94301.088
TOTAL	1334919.049											



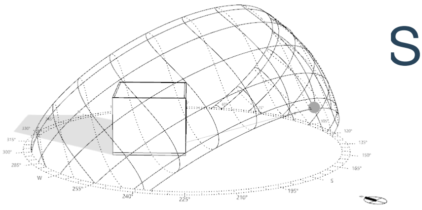
SOUTH-WEST ORIENTED

In the case of South-West Oriented, the Optimized configuration has delivered a total of 14,407,753 Wh of energy, with the highest gain in late afternoon. Open configuration approximately generates 11,280,164 Wh, with June & July months adding more than 200,000 Wh. The Closed configuration is the least productive situation with only 3,879,545 Wh. The peak hourly energy production for Optimized is recorded between 2:00 PM and 4:00 PM, when it hits the mark of about 1,300 Wh. The peak for the Open system is 1,000 Wh, and Closed almost does not generate as much power.

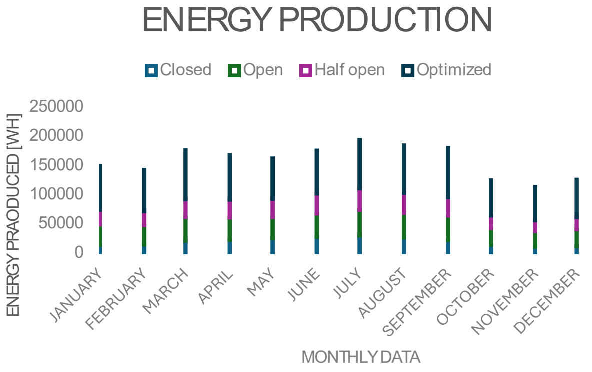




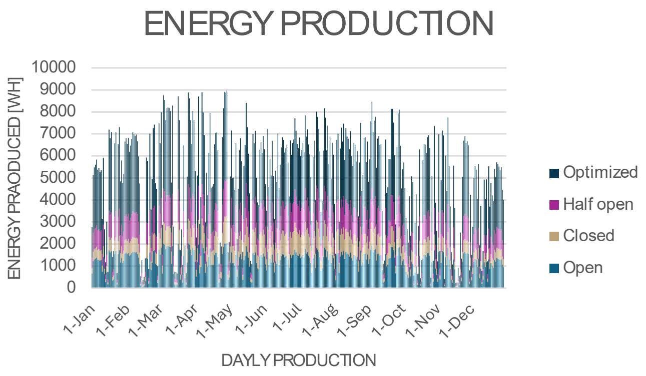
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	34.18365	4.768233	0	0	0	0	0	0
5:00	0	0	0	55.62373	929.4766	262.0555	229.1255	363.372	0	0	0	0
6:00	0	0	60.31984	497.0162	2105.005	1417.043	1393.925	1579.562	181.5131	159.4431	0	0
7:00	0	347.7225	559.6119	1677.55	3204.611	2536.986	2644.636	2734.302	1172.169	1229.86	107.6586	36.35141
8:00	437.865	2023.678	1819.978	2873.13	4230.131	3574.806	3758.131	3793.443	2427.646	3022.648	1502.229	2513.427
9:00	3957.254	5670.095	4743.757	4674.675	5198.347	4444.71	4660.651	5275.598	5242.871	6548.9	5251.262	7157.887
10:00	9570.533	10367.65	9442.181	8346.043	8177.589	6883.708	7505.368	9032.636	9981.894	10500.86	9350.065	12205.77
11:00	15116.77	14789.71	14354.07	12395.49	11529.58	10239.12	11287.14	13391.8	14803.9	13756.28	12893.25	16463.87
12:00	19841.81	18128.33	18073.17	15613.31	14198.73	13622.73	14821.36	16704.98	18703.38	15670.28	15394.75	19281.59
13:00	22686.02	19767.16	20430.36	17340.65	15365.09	15884.51	17238.66	18530.5	21008.19	16091.15	16408.48	19664.24
14:00	22602.11	19182.78	21078.41	17542.55	15031.3	16662.16	18282.72	18862.71	21112.04	15006.41	15630.99	16107.81
15:00	19034.91	15580.23	19644.41	16361.58	13175.17	15553.46	17718.43	17351	19013.05	11275.29	12294.74	7658.342
16:00	10243.97	8554.129	15983.53	13690.92	10425.4	12947.43	15396.49	13971.84	15151.54	5377.156	4831.234	687.5588
17:00	505.9714	1683.197	9869.784	9580.657	6758.058	9445.848	11579.66	8907.916	9340.448	762.213	0	0
18:00	0	0	1355.326	4458.951	2743.019	5667.893	6737.613	3103.772	1063.04	0	0	0
19:00	0	0	0	172.736	305.6145	2162.699	2158.747	176.6388	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	123997.215	116094.677	137414.916	125280.888	113411.308	121309.934	135412.655	133780.053	139201.691	99400.498	93664.645	101776.847
TOTAL	1440745.329											



SOUTH-EAST ORIENTED



In the South-East Oriented design, the Optimized settings are again the most efficacious, being able to generate 5,787,274 Wh each year. This system is especially efficient in the morning, where peak energy generation is close to 120,000 Wh during the summer months. The Altitudinal mode supplies energy of about 4,000,000 Wh, with the summer months realizing about 100,000 Wh. The Shut configuration still produces a total of 1,200,000 Wh, which is a massive dip in comparison to the other designs. Placing the flag aloft, Optimized peaks at 1,100 Wh, Open hits 800 Wh.



HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	14.13	1.908922	0	0	0	0	0	0
5:00	0	0	0	22.25219	374.6126	103.6969	90.22306	147.5146	0	0	0	0
6:00	0	0	24.01397	194.5576	826.925	551.9249	537.0075	620.1622	71.67735	65.61785	0	0
7:00	0	142.208	217.3917	648.8159	1234.969	973.2451	999.4716	1048.966	452.604	491.2133	35.38796	9.898554
8:00	149.0934	780.672	788.8433	1128.247	1608.167	1355.422	1400.376	1446.153	1069.772	1330.88	536.3977	837.2384
9:00	1408.91	2167.526	2421.193	2661.609	2967.635	2304.984	2460.768	3053.137	2777.403	2661.959	1895.347	2583.45
10:00	3529.695	3815.032	4075.341	4223.783	4863.749	4347.645	4804.106	5098.385	4444.095	3971.495	3477.163	4527.526
11:00	5677.006	5529.927	5548.392	5392.041	5820.639	5625.487	6118.514	6294.296	5859.874	5195.599	4870.827	6199.436
12:00	7512.532	6858.824	6829.005	6186.859	6336.586	6482.047	6928.047	6970.342	7079.92	5959.563	5849.103	7302.797
13:00	8620.451	7507.95	7754.045	6588.728	6290.098	6850.551	7285.527	7171.185	7952.895	6142.802	6257.544	7471.916
14:00	8621.935	7309.67	8038.877	6696.354	5820.827	6718.674	7208.585	7158.378	8047.443	5744.526	5983.772	6140.496
15:00	7290.178	5956.225	7526.676	6285.493	5048.302	5995.624	6761.801	6622.11	7288.467	4331.024	4724.545	2931.601
16:00	3942.753	3284.086	6157.301	5281.914	4003.739	4955.657	5872.378	5356.225	5838.009	2074.444	1868.181	265.6675
17:00	195.5266	650.7938	3819.796	3701.777	2598.005	3629.084	4430.301	3415.892	3607.395	295.403	0	0
18:00	0	0	529.4049	1724.037	1056.996	2184.085	2586.708	1192.411	417.0079	0	0	0
19:00	0	0	0	66.05266	119.8524	810.9709	827.2749	69.04861	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	46948.080	44002.915	53730.280	50802.520	48985.232	52891.006	58311.087	55664.204	54906.561	38264.527	35498.268	38270.026
TOTAL	578274.707											

Design n.4 includes only one diagonal shading element, therefore, it provides the middle level of shading and power production properties. With a production of 610 kWh/year this design has energy efficiency of 12% and the southern orientations fit it the best, still this is counted by the angle of the sun, limiting its performance. The diagonal layout makes it possible to achieve 65% of daylight efficiency which in turn helps to reduce cooling loads by 12% mainly due to its harmonious shading.

South orientation represents an average daylight factor of 0.261 (open) and 0.323 (closed), ensuring proper coverage throughout the space. South-East and South-West directions present a lesser daylight performance characterized by the mean factors of 0.0315 and 0.0302 correspondingly. This design comes with a 58% sustainability rate and a 20% capital return that, although it is less efficient than the rest of the designs in terms of solar optimization and economic viability, it is still a good shading performance in implementation.

Design n.4	Adaptive	Open	Closed
South	404.52	313.29	301.75
South-East	269.68	203.43	163.52
South-West	260.81	196.74	106.60

- The table shown above is the result of the calculations and the software simulations while the PV system chosen is Amourphous with the efficiency of 0.1.

Design n.4	Adaptive	Open	Closed
South	898.95	696.21	670.45
South-East	599.30	452.08	363.93
South-West	579.59	437.21	236.89

- In this table the results belong to the PV system of MonoCrystaline That has an efficiency of 0.2.

Design n.4 It utilizes a single diagonal shading element that supplies moderate shading and energy production of the amount of 610 kWh per year is the 4-th one. It is daylight in percentage and is a minimal requirement for the south but the angle with which it can face the sun is not good. Disevices 12% cooling load reductions, therefore, this design is less impactful than others. Its embodied energy, however, is low, and it has a 58% sustainability rate, so, its static configuration limits its economic return, which is 20%. This design, though its performance is not as good viewed from the perspective of its simplicity, may be preferred for facade applications that only require medium shading.

610
Production (kWh/year)

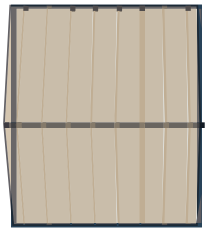
↘12%
Energy Efficiency

65%
Daylight Efficiency

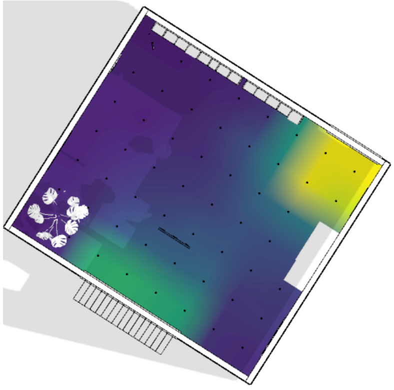
20%
Capital Returnablity

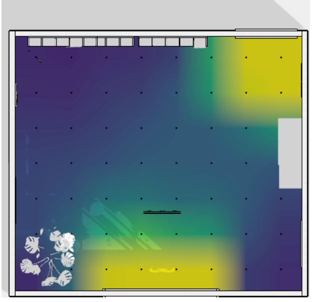
Medium
Shading Performance

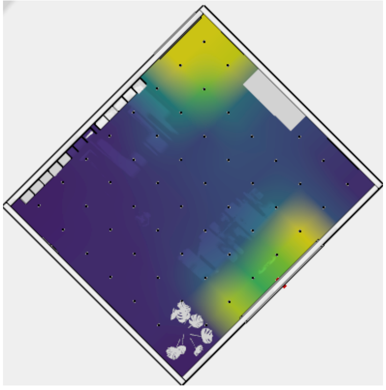
58%
Sustainablity

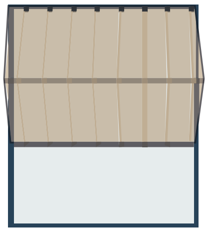


Design n.4	Mean daylight factor	Median daylight factor
South	0.0261	0.0169
South-East	0.0215	0.0146
South-West	0.0201	0.0103

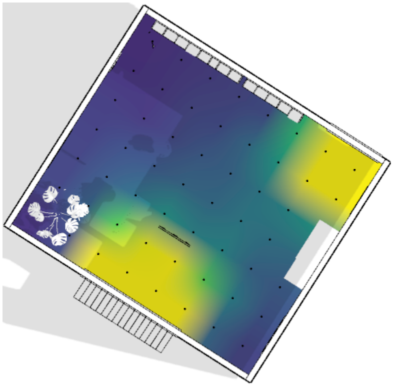


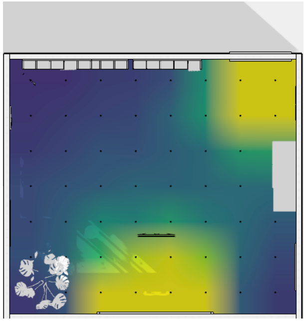


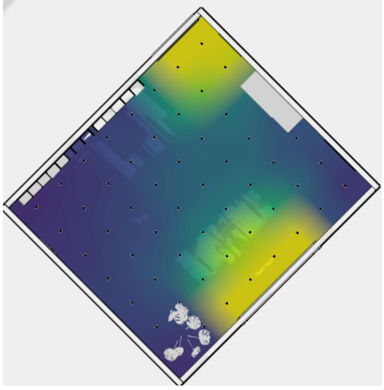




Design n.4	Mean daylight factor	Median daylight factor
South	0.0323	0.0197
South-East	0.0315	0.0181
South-West	0.0302	0.0179

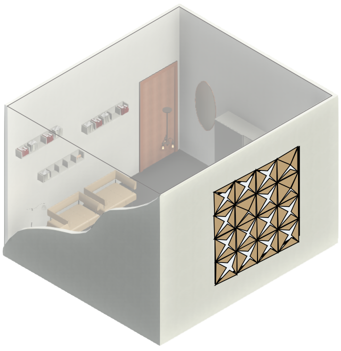


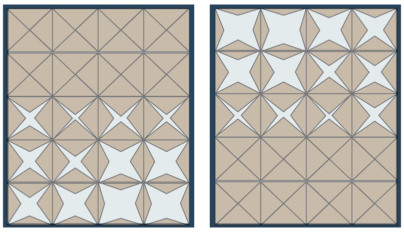




The diagonal shading in Design n.4 results in moderate daylight conditions. The South orientation achieves a higher mean daylight factor of 0.261 (open) and 0.323 (closed), providing even distribution across the room. The South-East and South-West orientations see slightly reduced mean and median factors, indicating suboptimal daylight capture in angled sun conditions.

Design n.5

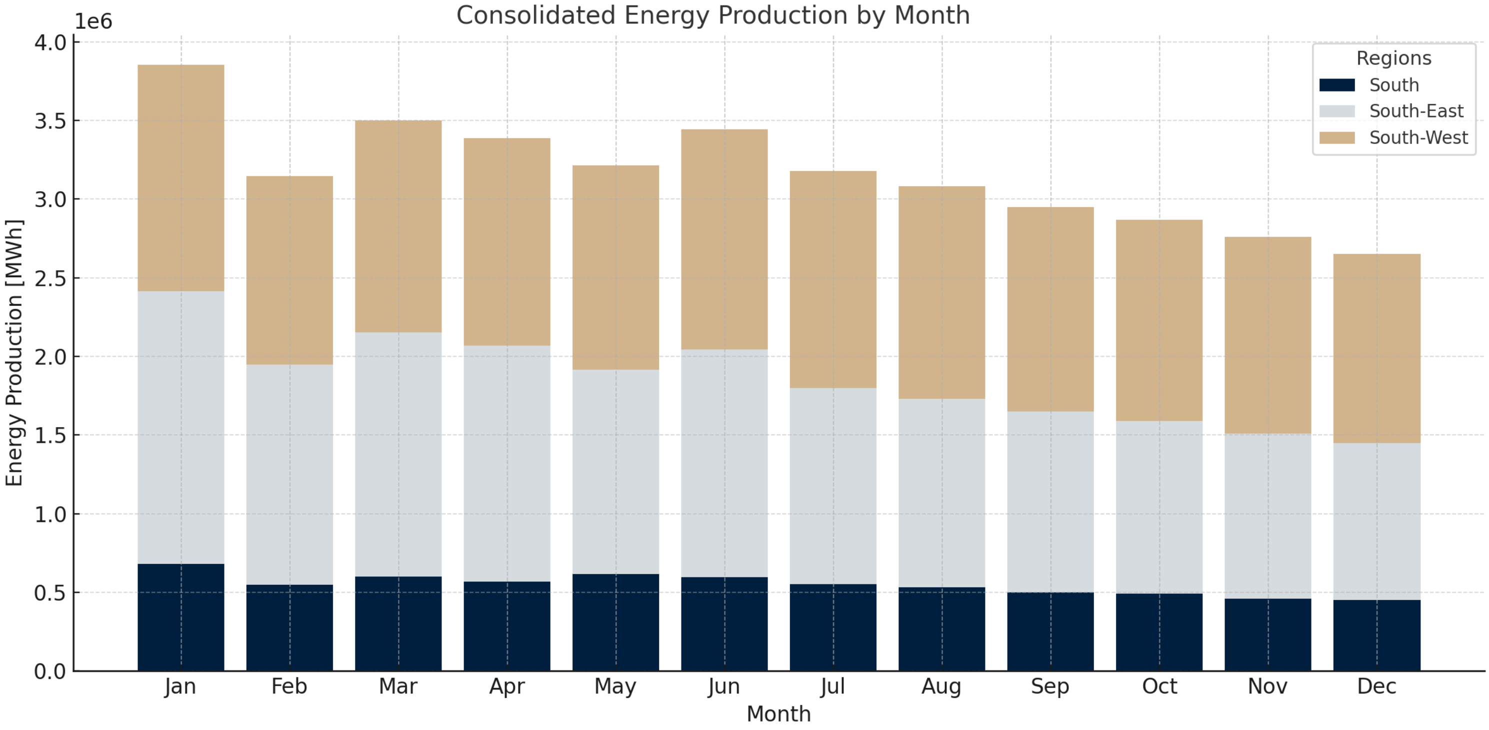


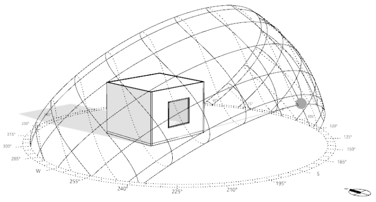


The following simulation results are for design number five, which is a quite complicated shader considered in this study. In this design, which is a high-tech system responsive to the sun's position and radiations, a triangular module is regarded as the shader system that adapts to the system and can open and close in order to allow shading and improve visibility for spaces that require a substantial quantity of natural lighting. As with prior designs, this research is conducted in three orientations: south, southeast, and southwest, where there is the most sun exposure during the day. The analysis was carried out using the Climate Studio plugin in the Grasshopper and Rhino software systems. [Transcript, 5.]

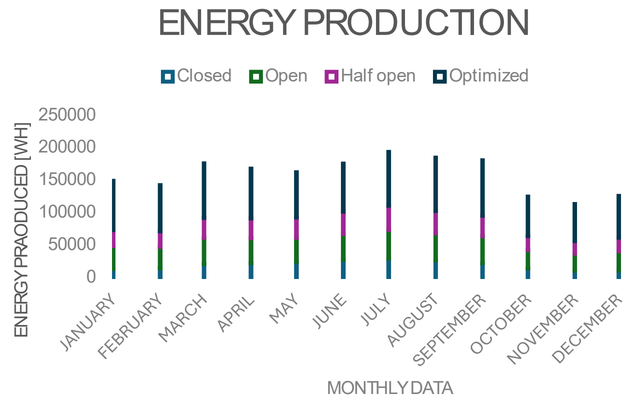
In this regard, since the panels are implemented on this system, and to have an accurate result, about 80% of the surface is only considered as the panel, and the rest of it is dedicated to the framing system. Also, the efficiency of the PV system is considered as 9%, and the PV system chosen for this system is an amorphous photovoltaic system; however, since this case of study, the visibility of the occupant is effected, which directly have an impact in the daylight of the area.

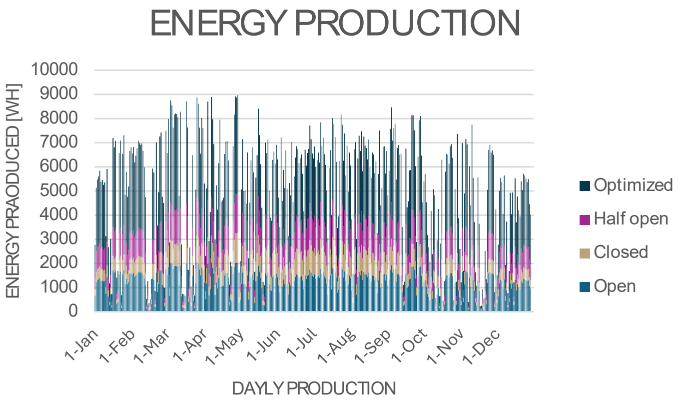
The following simulations are done in three main parts in which the shader is open, closed, and optimized which is the responsive one that allows the shader to adapt the panels based on sun position through the hours in a year.





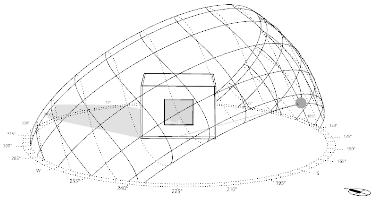
SOUTH ORIENTED



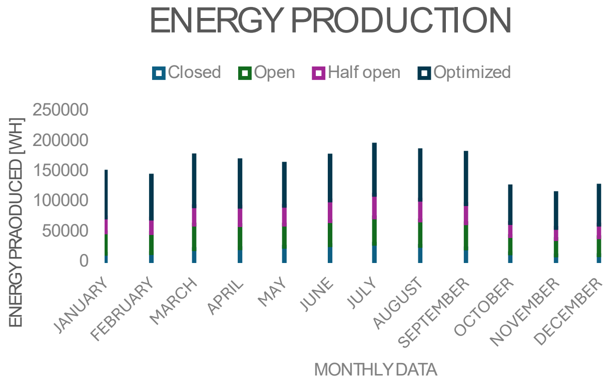


The Optimization version in the South-oriented Design still ensconce that the highest energy yield in the course of the year (13,349,019 Wh) is gained. Summer months such as June and July have over 250,000 Wh each. The Open system produces about 10,800,000 Wh, and each month of June and July equates to 200,000 Wh. Besides, the closed configuration has fewer energy sources than the other options, which generates only 4,000,000 Wh in a year. The peak power output for the optimized design is approximately 1,500 kWh between 12:00 PM and 2:00 PM.

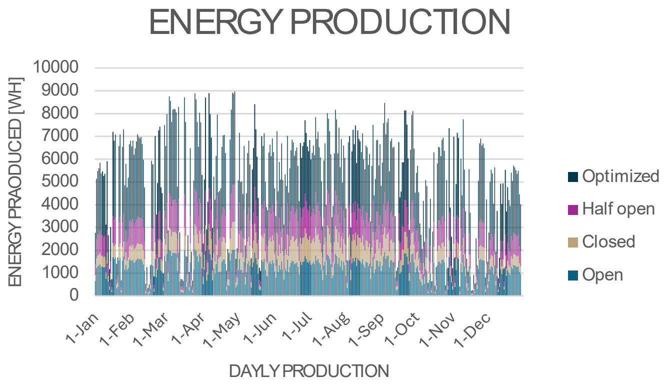
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	16.116	2.248	0	0	0	0	0	0
5:00	0	0	0	26.224	438.205	123.547	108.022	171.313	0	0	0	0
6:00	0	0	28.438	234.32	992.412	668.07	657.171	744.69	85.575	75.17	0	0
7:00	0	163.935	263.831	790.887	1510.825	1196.071	1246.823	1289.096	552.623	579.822	50.756	17.138
8:00	206.433	954.07	858.035	1354.547	1994.31	1685.355	1771.784	1788.432	1144.522	1425.038	708.231	1184.964
9:00	1865.661	2673.186	2236.461	2203.892	2450.779	2095.474	2197.28	2487.199	2471.77	3087.502	2475.726	3374.611
10:00	4512.061	4887.866	4451.549	3934.771	3855.353	3245.348	3538.432	4258.468	4705.999	4950.667	4408.121	5754.453
11:00	7126.854	6972.66	6767.275	5843.899	5435.663	4827.27	5321.362	6313.609	6979.352	6485.448	6078.568	7761.947
12:00	9354.491	8546.663	8520.661	7360.951	6694.04	6422.485	6987.583	7875.619	8817.776	7387.81	7257.907	9090.372
13:00	10695.4	9319.297	9631.966	8175.312	7243.925	7488.808	8127.227	8736.267	9904.386	7586.228	7735.833	9270.776
14:00	10655.84	9043.787	9937.491	8270.496	7086.561	7855.432	8619.452	8892.891	9953.346	7074.826	7369.284	7594.085
15:00	8974.077	7345.354	9261.427	7713.723	6211.479	7332.735	8353.415	8180.189	8963.767	5315.774	5796.396	3610.552
16:00	4829.556	4032.874	7535.491	6454.631	4915.09	6104.111	7258.728	6587.071	7143.246	2535.079	2277.702	324.152
17:00	238.542	793.549	4653.144	4516.834	3186.11	4453.278	5459.27	4199.668	4403.587	359.348	0	0
18:00	0	0	638.973	2102.188	1293.206	2672.148	3176.471	1463.284	501.174	0	0	0
19:00	0	0	0	81.437	144.083	1019.612	1017.749	83.277	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	58458.920	54733.241	64784.742	59064.112	53468.157	57191.992	63840.769	63071.073	65627.123	46862.712	44158.524	47983.050
TOTAL	679244.415											



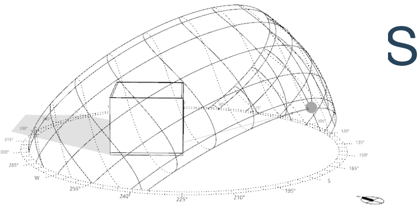
SOUTH-WEST ORIENTED



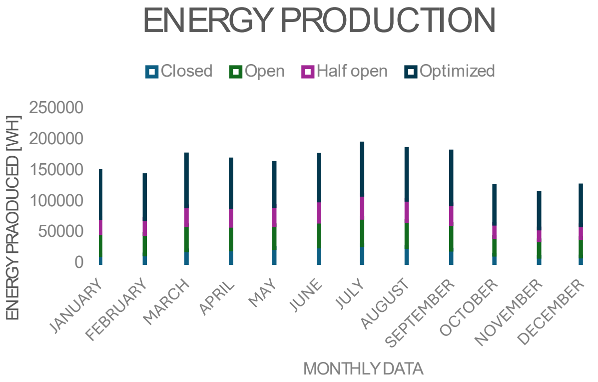
The Energy-wise Oriented South-West, Optimized way, the highest effectivity is attributed to the production of 14,140,475 Wh mainly in the afternoon. Here, the Open system's production of approximately 11,000,000 Wh has been recorded, with more than 200,000 Wh being the cumulative output of each of the summer periods. The Closed configuration produces only 4,500,000 Wh. In the Optimized peak, it produces approximately 1,400 Wh between 1:00 PM and 3:00 PM while Open peaks at a production of 1,100 Wh.



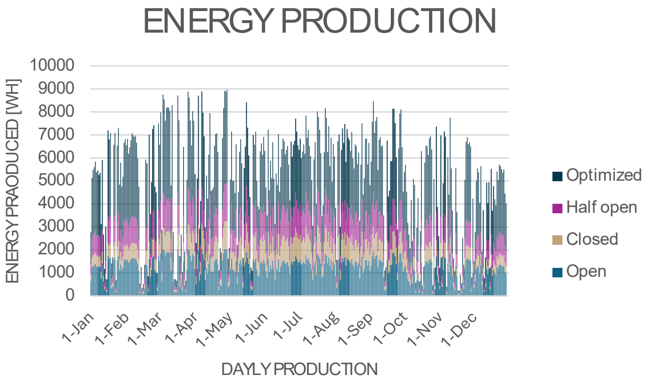
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	34.18365	4.768233	0	0	0	0	0	0
5:00	0	0	0	55.62373	929.4766	262.0555	229.1255	363.372	0	0	0	0
6:00	0	0	60.31984	497.0162	2105.005	1417.043	1393.925	1579.562	181.5131	159.4431	0	0
7:00	0	347.7225	559.6119	1677.55	3204.611	2536.986	2644.636	2734.302	1172.169	1229.86	107.6586	36.35141
8:00	437.865	2023.678	1819.978	2873.13	4230.131	3574.806	3758.131	3793.443	2427.646	3022.648	1502.229	2513.427
9:00	3957.254	5670.095	4743.757	4674.675	5198.347	4444.71	4660.651	5275.598	5242.871	6548.9	5251.262	7157.887
10:00	9570.533	10367.65	9442.181	8346.043	8177.589	6883.708	7505.368	9032.636	9981.894	10500.86	9350.065	12205.77
11:00	15116.77	14789.71	14354.07	12395.49	11529.58	10239.12	11287.14	13391.8	14803.9	13756.28	12893.25	16463.87
12:00	19841.81	18128.33	18073.17	15613.31	14198.73	13622.73	14821.36	16704.98	18703.38	15670.28	15394.75	19281.59
13:00	22686.02	19767.16	20430.36	17340.65	15365.09	15884.51	17238.66	18530.5	21008.19	16091.15	16408.48	19664.24
14:00	22602.11	19182.78	21078.41	17542.55	15031.3	16662.16	18282.72	18862.71	21112.04	15006.41	15630.99	16107.81
15:00	19034.91	15580.23	19644.41	16361.58	13175.17	15553.46	17718.43	17351	19013.05	11275.29	12294.74	7658.342
16:00	10243.97	8554.129	15983.53	13690.92	10425.4	12947.43	15396.49	13971.84	15151.54	5377.156	4831.234	687.5588
17:00	505.9714	1683.197	9869.784	9580.657	6758.058	9445.848	11579.66	8907.916	9340.448	762.213	0	0
18:00	0	0	1355.326	4458.951	2743.019	5667.893	6737.613	3103.772	1063.04	0	0	0
19:00	0	0	0	172.736	305.6145	2162.699	2158.747	176.6388	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	123997.215	116094.677	137414.916	125280.888	113411.308	121309.934	135412.655	133780.053	139201.691	99400.498	93664.645	101776.847
TOTAL	1440745.329											



SOUTH-EAST ORIENTED



The South-East Oriented Configuration Optimized reaches an annual production of 17,539,543 Wh in total and carries out a peak period in the morning and early afternoon. The two months in question were by means of 200,000 Wh for each. The Open version generated a decent amount of 14,000,000 Wh while, the Closed version amounted to about 4,200,000 Wh annually. Optimized peak hourly production is 1,700 Wh in the morning whereas Open is 1,300 Wh of production of peak.



HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	41.17461	5.743393	0	0	0	0	0	0
5:00	0	0	0	66.99944	1119.566	315.649	275.9843	437.6859	0	0	0	0
6:00	0	0	72.65596	598.6618	2535.503	1706.845	1679	1902.601	218.6347	192.0511	0	0
7:00	0	418.8359	674.0592	2020.629	3859.992	3055.83	3185.496	3293.498	1411.891	1481.381	129.676	43.7857
8:00	527.4136	2437.544	2192.185	3460.719	5095.243	4305.897	4526.713	4569.247	2924.128	3640.815	1809.452	3027.453
9:00	4766.559	6829.696	5713.912	5630.702	6261.471	5353.706	5613.809	6354.52	6315.1	7888.228	6325.208	8621.76
10:00	11527.82	12487.96	11373.22	10052.91	9850.003	8291.507	9040.305	10879.92	12023.31	12648.41	11262.26	14701.99
11:00	18208.33	17814.38	17289.64	14930.52	13887.52	12333.14	13595.49	16130.58	17831.48	16569.61	15530.07	19830.92
12:00	23899.7	21835.78	21769.35	18806.42	17102.54	16408.74	17852.51	20121.34	22528.45	18875.04	18543.15	23224.9
13:00	27325.58	23809.78	24608.61	20887.02	18507.43	19133.08	20764.17	22320.2	25304.62	19381.98	19764.2	23685.81
14:00	27224.5	23105.88	25389.2	21130.21	18105.38	20069.76	22021.75	22720.36	25429.7	18075.4	18827.71	19402.05
15:00	22927.78	18766.57	23661.93	19707.71	15869.65	18734.33	21342.06	20899.48	22901.44	13581.22	14809.15	9224.563
16:00	12338.98	10303.55	19252.35	16490.87	12557.51	15595.33	18545.25	16829.24	18250.21	6476.848	5819.278	828.1727
17:00	609.4486	2027.43	11888.27	11540.01	8140.161	11377.64	13947.83	10729.69	11250.68	918.0946	0	0
18:00	0	0	1632.506	5370.859	3303.999	6827.044	8115.534	3738.53	1280.444	0	0	0
19:00	0	0	0	208.0626	368.1162	2604.997	2600.237	212.7636	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	149356.110	139837.410	165517.889	150902.309	136605.260	146119.248	163106.142	161139.654	167670.080	119729.074	112820.171	122591.415
TOTAL	1735394.763											

Design number 5 is a creative solar module featuring the unique X-pattern design, which helps it serve as not only a shading device but also a stylistic element. It is able to generate a substantial 820 units of solar energy per year to provide electricity and possesses an impressive 88% daylight efficiency thus, the PV module covers energy needs and provides a graceful diffuseness of light. The module is designed in such a way that it can be rotated according to the angle of the sun, thus maintaining a uniform daylight distribution which contributes to its sustainability of 75%. Also, the solar power is used for heating and hence the building's cooling demands are minimized by 25%. It is especially worth mentioning the southern orientation of the building because this design makes it possible to achieve daylight factors of 0.262 (open) and 0.302 (closed) with high uniformity. This however, is for the South-East and South-West orientations only, the mean factors here are 0.0275 and 0.0305, respectively, with the latter slightly improving when closed. Another interesting point is that this energy-efficiency innovation also ensures a 30% capital return which besides economic benefits, contributes to environmental objectives, thus presenting a futuristic architecture style.

Design n.5	Adaptive	Open	Closed
South	649.92	497.19	600.22
South-East	602.18	327.70	503.42
South-West	306.40	197.70	269.164

- The table shown above is the result of the calculations and the software simulations while the PV system chosen is Amourphous with the efficiency of 0.1.

Design n.5	Adaptive	Open	Closed
South	1444.27	1104.86	1333.84
South-East	1338.18	721.57	1118.72
South-West	680.90	439.34	598.14

- In this table the results belong to the PV system of MonoCrystaline That has an efficiency of 0.2.

The X pattern of Design n.5 is designed in such a way that it not only delights the observers but also serves the purpose of generating electricity of 820 kWh/per and working at 88% daylight efficiency. Its adaptation to multiple angles of shading is an adaptive, multi-angle shading system whose productivity is increased by capturing solar energy and glare reduction process at daily different times. It is rated at 75% for sustainability due to the inclusion of lightweight thin-film photovoltaic material in the facade structure resulting in the reduction in the amplitude of cooling load by 25%. Its mobility results in 30% capital return, which adds to the main advantages of these options being functionality and finance, as they are the key to new architecture.

820
Production (kWh/year)

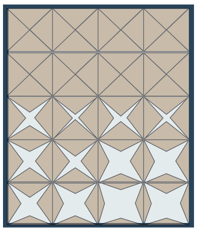
↘25%
Energy Efficiency

88%
Daylight Efficiency

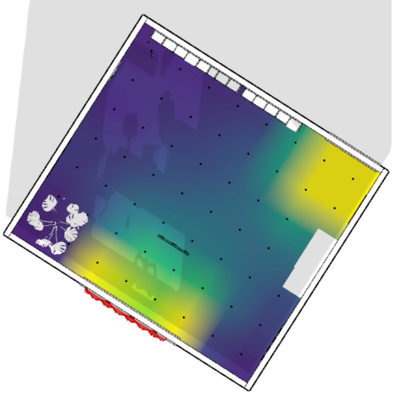
30%
Capital Returnablity

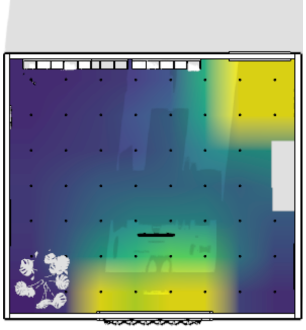
High
Shading Performance

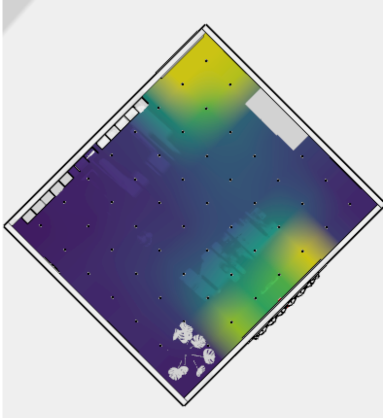
75%
Sustainablity

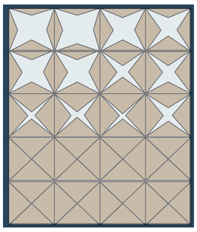


Design n.5	Mean daylight factor	Median daylight factor
South	0.0262	0.025
South-East	0.025	0.024
South-West	0.0249	0.021

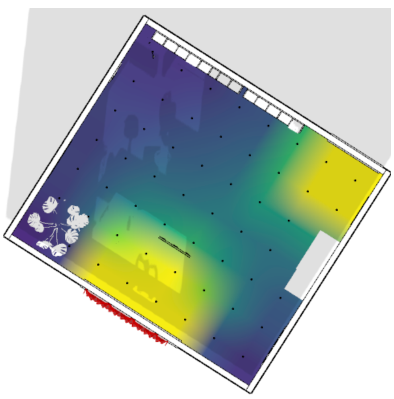


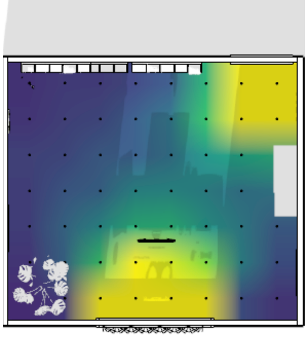


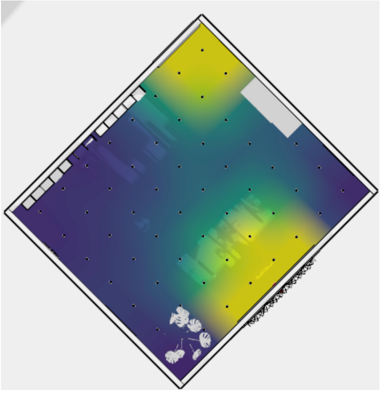




Design n.5	Mean daylight factor	Median daylight factor
South	0.0302	0.0206
South-East	0.0275	0.0161
South-West	0.0305	0.0207

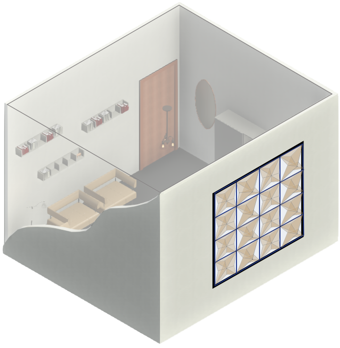


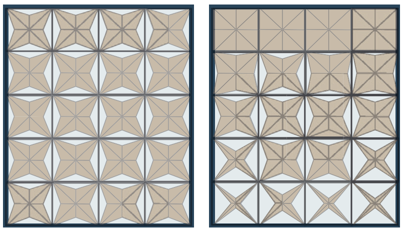




The X-pattern enhances daylight uniformity by allowing light from multiple angles. In the South orientation, a mean daylight factor of 0.262 (open) and 0.302 (closed) is observed, with good uniformity. South-East and South-West orientations benefit from the intersecting elements, achieving mean daylight factors of 0.021 and 0.0249 (open), with slightly higher values when closed.

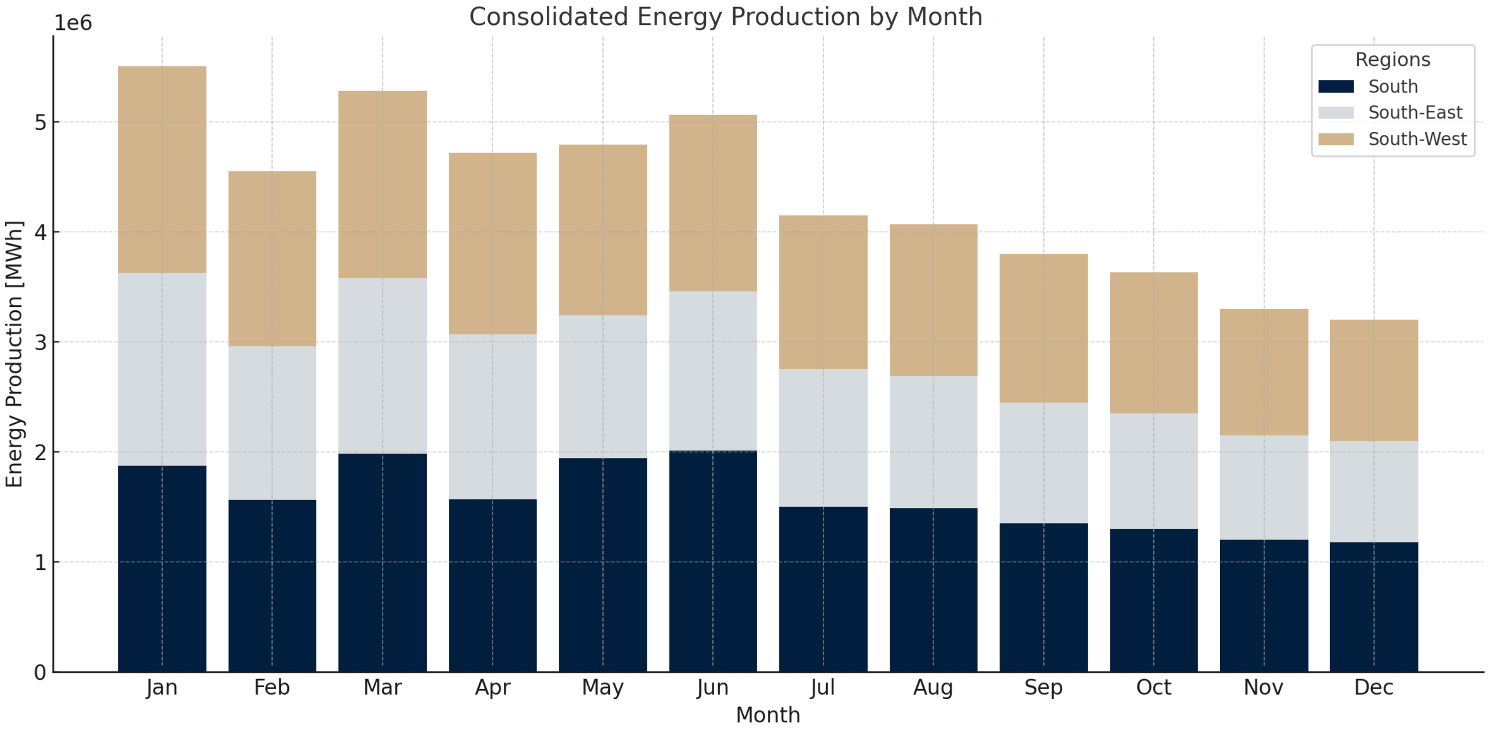
Design n.6

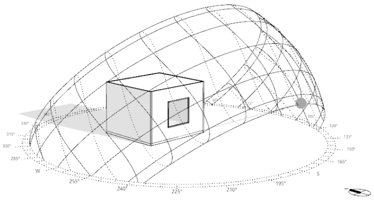




The following simulation results are about design number six which is the most complicated shader considered in this study, in this design which is a high-tech system responsive to the sun position and sun radiations, a triangular module is regarded as the shader system that adapts to the system and can open and close in which allows shading and improves the visibility for spaces which need natural light for a considerable amount. as done for previous designs this analysis is also done in three orientations of the south, southeast, and southwest where there is the maximum sun radiation through the day.

The study was done through the Climate Studio plugin in the Grasshopper and Rhino software environments. [Transcript, 6] In this regard since the panels are implemented on this system and to have an accurate result about 80% of the surface is only considered as the panel, and the rest of it is dedicated to the framing system, Also the efficiency of the PV system is considered as 9% and the PV system chosen for this system is an amorphous photovoltaic system, however, since this case of study, the visibility of occupant is effected in which directly have an impact in the daylight of the area the use of a panel with transparency is the optimal solution that could be used for the whole design. The following simulations are done in three main parts in which the shader is open, closed, and optimized which is the responsive one that allows the shader to adapt the panels based on sun position through the hours in a year.

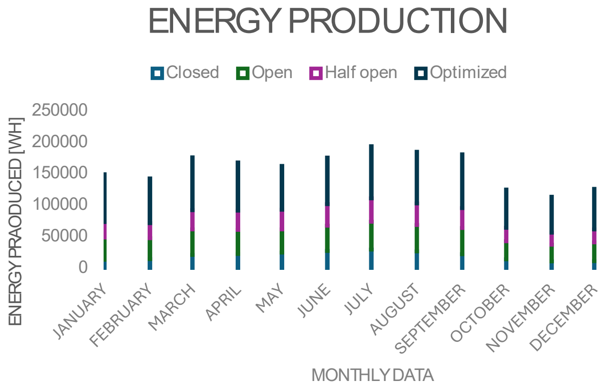


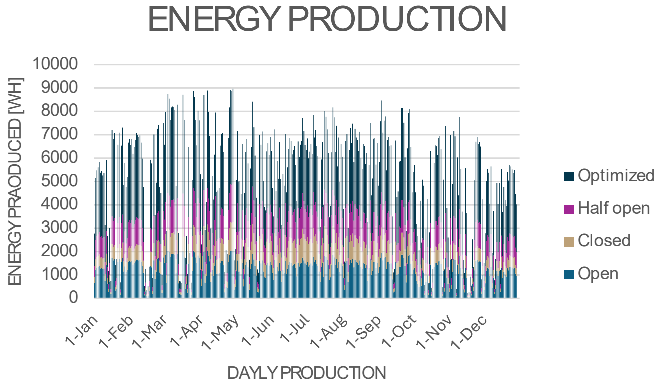


SOUTH ORIENTED

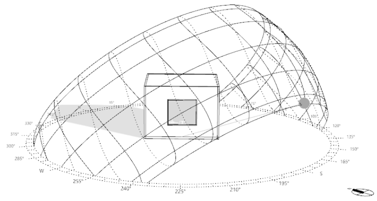
The South-Oriented configuration with the Optimized shading generates the most energy, at 18,729,868.927 Wh annually, peaking over 200,000 Wh in June and July.

The Open configuration generates a moderate amount of energy, at 14,798,915.335 Wh, while the Closed configuration produces about 4,737,195.246 Wh, the least among the configurations. On an hourly basis, the Optimized peaks around 2,500 Wh at midday, while the Open configuration peaks at 1,800 Wh.



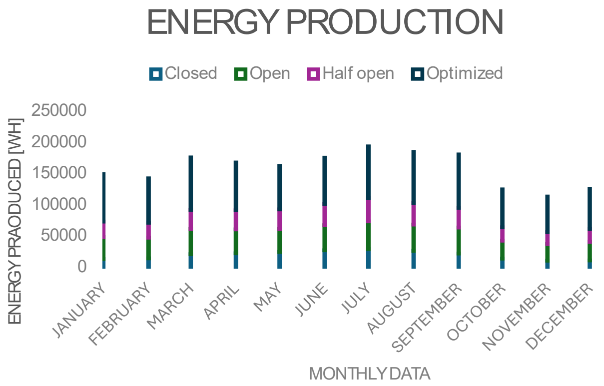


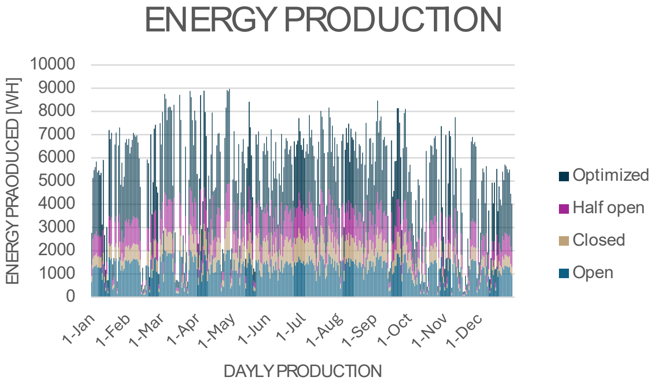
HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	44.43874	6.198703	0	0	0	0	0	0
5:00	0	0	0	72.31084	1208.32	340.6722	297.8631	472.3836	0	0	0	0
6:00	0	0	78.41579	646.121	2736.507	1842.156	1812.103	2053.431	235.9671	207.276	0	0
7:00	0	452.0393	727.4955	2180.816	4165.994	3298.082	3438.027	3554.592	1523.819	1598.819	139.9561	47.25684
8:00	569.2245	2630.781	2365.971	3735.069	5499.17	4647.248	4885.57	4931.476	3155.939	3929.443	1952.897	3267.455
9:00	5144.43	7371.123	6166.885	6077.078	6757.852	5778.123	6058.846	6858.277	6815.733	8513.571	6826.641	9305.254
10:00	12441.69	13477.95	12274.83	10849.86	10630.87	8948.82	9756.979	11742.43	12976.46	13651.12	12155.09	15867.5
11:00	19651.8	19226.62	18660.29	16114.14	14988.46	13310.86	14673.28	17409.33	19245.07	17883.17	16761.23	21403.03
12:00	25794.35	23566.82	23495.13	20297.31	18458.35	17709.55	19267.77	21716.47	24314.4	20371.37	20013.17	25066.06
13:00	29491.83	25697.31	26559.47	22542.85	19974.62	20649.86	22410.26	24089.64	27310.65	20918.49	21331.02	25563.52
14:00	29382.74	24937.61	27401.94	22805.31	19540.7	21660.8	23767.54	24521.52	27445.65	19508.34	20320.28	20940.16
15:00	24745.39	20254.3	25537.74	21270.05	17127.72	20219.5	23033.96	22556.3	24716.96	14657.87	15983.16	9955.844
16:00	13317.16	11120.37	20778.59	17798.19	13553.02	16831.66	20015.43	18163.39	19697	6990.303	6280.604	893.8264
17:00	657.7629	2188.156	12830.72	12454.85	8785.475	12279.6	15053.55	11580.29	12142.58	990.877	0	0
18:00	0	0	1761.923	5796.636	3565.925	7368.261	8758.896	4034.903	1381.952	0	0	0
19:00	0	0	0	224.5568	397.2988	2811.509	2806.372	229.6305	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	161196.380	150923.081	178639.391	162865.154	147434.700	157702.915	176036.452	173914.069	180962.198	129220.648	121764.039	132309.902
TOTAL	1872968.927											



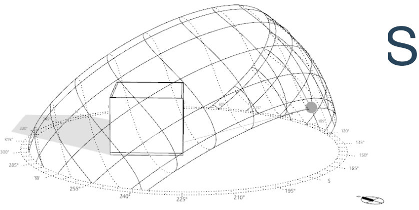
SOUTH-WEST ORIENTED

The Optimized system yields the best results for the South-West-Oriented design, with an annual production of 8,830,177.740 Wh, mainly produced during afternoon hours. The Open configuration performs averagely, with a production of 7,780,647.968 Wh, while during summer months, each month contributes about 130,000 Wh. The Closed configuration produces just 2,800,000 Wh. The Optimized configuration peaks in the afternoon, around 1,200 Wh, while Open peaks at 1,000 Wh, and the Closed system shows poor performance, with output below 200 Wh during most hours.

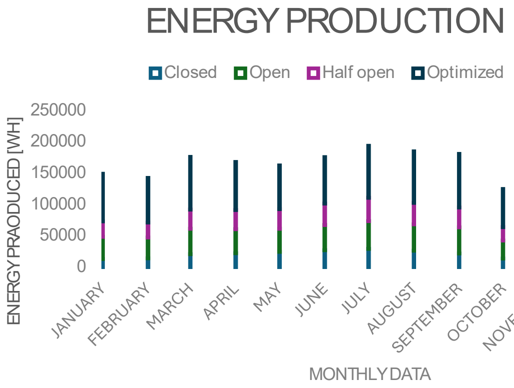




HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	20.9508	2.9224	0	0	0	0	0	0
5:00	0	0	0	34.0912	569.6665	160.6111	140.4286	222.7069	0	0	0	0
6:00	0	0	36.9694	304.616	1290.136	868.491	854.3223	968.097	111.2475	97.721	0	0
7:00	0	213.1155	342.9803	1028.153	1964.073	1554.892	1620.87	1675.825	718.4099	753.7686	65.9828	22.2794
8:00	268.3629	1240.291	1115.446	1760.911	2592.603	2190.962	2303.319	2324.962	1487.879	1852.549	920.7003	1540.453
9:00	2425.359	3475.142	2907.399	2865.06	3186.013	2724.116	2856.464	3233.359	3213.301	4013.753	3218.444	4386.994
10:00	5865.679	6354.226	5787.014	5115.202	5011.959	4218.952	4599.962	5536.008	6117.799	6435.867	5730.557	7480.789
11:00	9264.91	9064.458	8797.458	7597.069	7066.362	6275.451	6917.771	8207.692	9073.158	8431.082	7902.138	10090.53
12:00	12160.84	11110.66	11076.86	9569.236	8702.252	8349.231	9083.858	10238.3	11463.11	9604.153	9435.279	11817.48
13:00	13904.02	12115.09	12521.56	10627.91	9417.103	9735.45	10565.4	11357.15	12875.7	9862.096	10056.58	12052.01
14:00	13852.59	11756.92	12918.74	10751.64	9212.529	10212.06	11205.29	11560.76	12939.35	9197.274	9580.069	9872.311
15:00	11666.3	9548.96	12039.86	10027.84	8074.923	9532.556	10859.44	10634.25	11652.9	6910.506	7535.315	4693.718
16:00	6278.423	5242.736	9796.138	8391.02	6389.617	7935.344	9436.346	8563.192	9286.22	3295.603	2961.013	421.3976
17:00	310.1046	1031.614	6049.087	5871.884	4141.943	5789.261	7097.051	5459.568	5724.663	467.1524	0	0
18:00	0	0	830.6649	2732.844	1681.168	3473.792	4129.412	1902.269	651.5262	0	0	0
19:00	0	0	0	105.8681	187.3079	1325.496	1323.074	108.2601	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	75996.596	71153.213	84220.165	76783.346	69508.604	74349.590	82993.000	81992.395	85315.260	60921.526	57406.081	62377.965
TOTAL	883017.740											

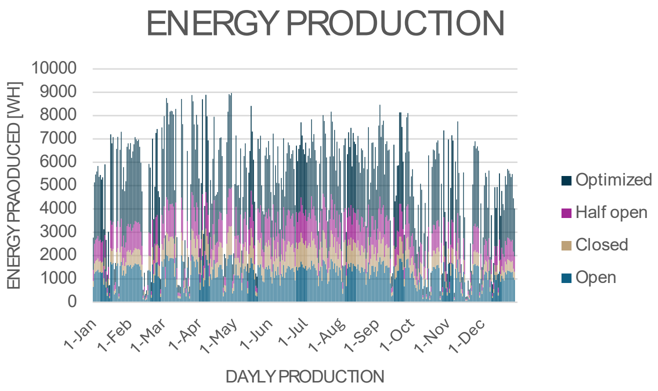


SOUTH-EAST ORIENTED



The South-East-Oriented, in this respect, is topped by the Optimized configuration: 17,353,943.763 Wh, yearly, peaking both in the morning and in the early afternoon of around 200,000 Wh during summer months.

While Open will provide approximately 13,550,000 Wh, Closed is the worst: just 4,500,000 kWh per year. Correspondingly, the peak value for the Optimized configuration in the morning hours is at about 2,000 Wh, Open at about 1,600 Wh.



HOUR	average production											
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	0	0	0	0	0	0	0	0	0	0	0	0
1:00	0	0	0	0	0	0	0	0	0	0	0	0
2:00	0	0	0	0	0	0	0	0	0	0	0	0
3:00	0	0	0	0	0	0	0	0	0	0	0	0
4:00	0	0	0	0	41.17461	5.743393	0	0	0	0	0	0
5:00	0	0	0	66.99944	1119.566	315.649	275.9843	437.6859	0	0	0	0
6:00	0	0	72.65596	598.6618	2535.503	1706.845	1679	1902.601	218.6347	192.0511	0	0
7:00	0	418.8359	674.0592	2020.629	3859.992	3055.83	3185.496	3293.498	1411.891	1481.381	129.676	43.7857
8:00	527.4136	2437.544	2192.185	3460.719	5095.243	4305.897	4526.713	4569.247	2924.128	3640.815	1809.452	3027.453
9:00	4766.559	6829.696	5713.912	5630.702	6261.471	5353.706	5613.809	6354.52	6315.1	7888.228	6325.208	8621.76
10:00	11527.82	12487.96	11373.22	10052.91	9850.003	8291.507	9040.305	10879.92	12023.31	12648.41	11262.26	14701.99
11:00	18208.33	17814.38	17289.64	14930.52	13887.52	12333.14	13595.49	16130.58	17831.48	16569.61	15530.07	19830.92
12:00	23899.7	21835.78	21769.35	18806.42	17102.54	16408.74	17852.51	20121.34	22528.45	18875.04	18543.15	23224.9
13:00	27325.58	23809.78	24608.61	20887.02	18507.43	19133.08	20764.17	22320.2	25304.62	19381.98	19764.2	23685.81
14:00	27224.5	23105.88	25389.2	21130.21	18105.38	20069.76	22021.75	22720.36	25429.7	18075.4	18827.71	19402.05
15:00	22927.78	18766.57	23661.93	19707.71	15869.65	18734.33	21342.06	20899.48	22901.44	13581.22	14809.15	9224.563
16:00	12338.98	10303.55	19252.35	16490.87	12557.51	15595.33	18545.25	16829.24	18250.21	6476.848	5819.278	828.1727
17:00	609.4486	2027.43	11888.27	11540.01	8140.161	11377.64	13947.83	10729.69	11250.68	918.0946	0	0
18:00	0	0	1632.506	5370.859	3303.999	6827.044	8115.534	3738.53	1280.444	0	0	0
19:00	0	0	0	208.0626	368.1162	2604.997	2600.237	212.7636	0	0	0	0
20:00	0	0	0	0	0	0	0	0	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0
22:00	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	149356.110	139837.410	165517.889	150902.309	136605.260	146119.248	163106.142	161139.654	167670.080	119729.074	112820.171	122591.415
TOTAL	1735394.763											

Design#6 combines horizontal, vertical, and diagonal shading to develop a hybrid system that is highly energy-efficient. With an annual energy output of 910 kWh, it is the most efficient daylighting system of 90% and can reduce indoor temperatures by 30%, thus demonstrating the ability of the system to operate under diverse solar angles. In terms of the system, the adaptability to either shading or energy generation optimizes the entire process, which results in an excellent return of 35% from capital and a sustainability rate of 80%, therefore, it can be said that it is environmentally and economically sustainable. The Southern orientation through open and closed modes due to a high-type mean daylight factor value of respectively 0.262 & 0.302, thus quality lighting and luminous uniformity can be guaranteed in both cases. As for the South-East and South-West directions, they produce equally good results, with mean factors from 0.0215 to 0.0244. This underscores how the design of the structure can be altered accordingly based on the daylight conditions. This new method of doing things makes Design n.6 a perfect example to follow by cities and the building sector, which put the environment aspect of their projects as a priority and the efficiency of energy consumption second.

Design n.6	Adaptive	Open	Closed
South	844.89	646.34	780.29
South-East	782.83	422.12	654.45
South-West	398.33	257.01	349.91

- The table shown above is the result of the calculations and the software simulations while the PV system chosen is Amourphous with the efficiency of 0.1.

Design n.6	Adaptive	Open	Closed
South	898.95	696.21	670.45
South-East	599.30	452.08	363.93
South-West	579.59	437.21	236.89

- In this table the results belong to the PV system of MonoCrystaline That has an efficiency of 0.2.

In Design n.6 we have come up with a hybrid system which combines horizontal, vertical, and diagonal elements, so the design is not only static but also covers the vertical, horizontal, and diagonal axes. The maximum amount of daylight is transferred and high productivity 910 KWh is the output of a system that is thus worked out. The TSS system's flexibility in terms of orientation which is achieved by the smart shading has allowed the building to reduce cooling loads by 30% and to generate energy in the most efficient way. A product made of green materials and offering high versatility was given an 80% rating in sustainability by the customer. As a consequence, a return of 35% on the investments shows that the design can serve as a prototype for utilizing the power of nature, minimizing waste and emissions, and meeting other needs which are highly important in urban and architectural applications that ethnic groups favor.

910
Production (kWh/year)

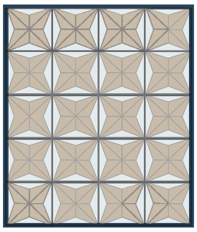
↘30%
Energy Efficiency

90%
Daylight Efficiency

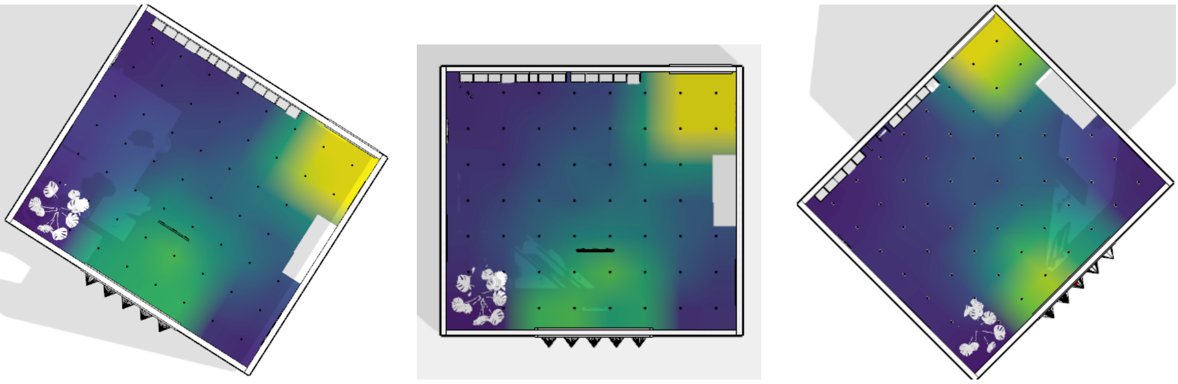
35%
Capital Returnablity

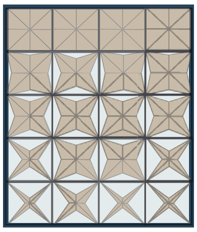
Very High
Shading Performance

80%
Sustainablity

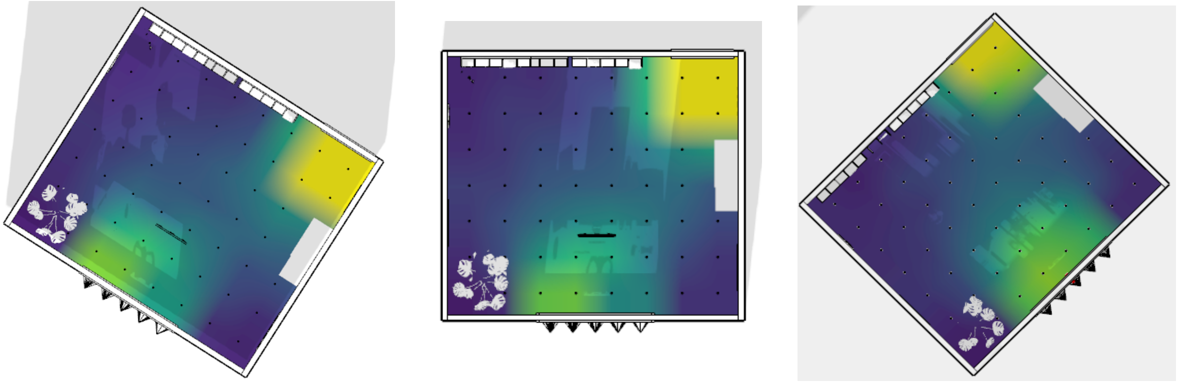


Design n.6	Mean daylight factor	Median daylight factor
South	0.0248	0.017
South-East	0.0215	0.0136
South-West	0.0244	0.017





Design n.6	Mean daylight factor	Median daylight factor
South	0.0239	0.016
South-East	0.0229	0.0157
South-West	0.0234	0.0151



This hybrid design thus provides consistent daylight for all orientations. In the South orientation, mean daylight factors are relatively high at 0.262 (open) and 0.302 (closed), ensuring optimal lighting. The South-East and South-West orientations achieve balanced levels of daylight (mean: 0.021–0.024 open), showcasing the adaptability of the shading system in various sun conditions.

Performance Analysis (Comparison)

Energy production

The evaluation of the performance of these systems is based on their energy output, efficiency, and overall contribution in order to reduce cooling loads and reliance on non-renewable energy sources.
The results are done using Climate Studio plugin in the Grasshopper interface. However the simulations also could be done manually using the formulas bellow:

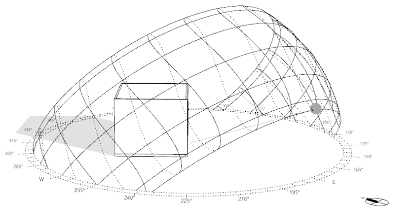
$$\eta = \frac{P_{in}}{P_{out}} \times 100$$

η : PV Efficiency %
P_{out}: Power output (W)
P_{in} : Solar power input (W)
and for the production:

$$P_{PV}\,(\text{kWh/year}) = I \times A_{active} \times \eta$$

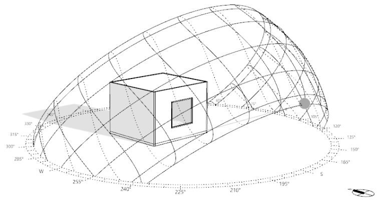
P_{PV} : Total annual energy production from the PV system (kWh/year)
I: Solar irradiance on the PV surface (kWh/m^{2}year)
A_{active} : Active PV surface area (m^2)
η: PV efficiency (%)

South-East:



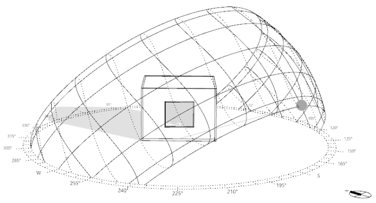
Design	Adaptive	Open	Closed
Design n. 1	225.20	89.10	173.23
Design n. 2	578.86	422.03	385.90
Design n. 3	361.73	160.05	290.31
Design n. 4	599.30	452.08	363.39
Design n. 5	1338.19	721.57	1118.72
Design n. 6	1739.64	938.04	1454.34

South:

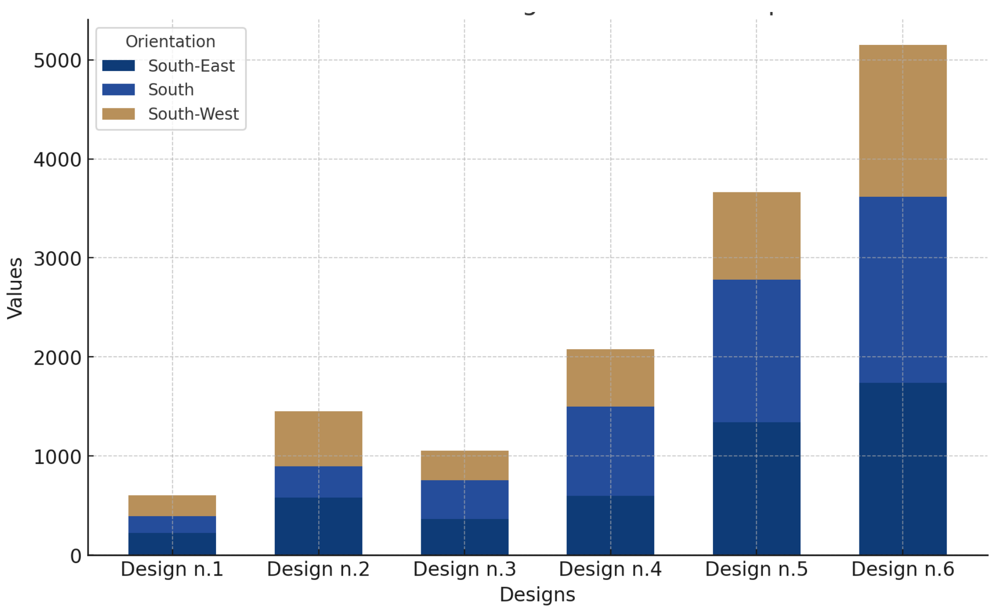


Design	Adaptive	Open	Closed
Design n. 1	170.6	89.11	119.30
Design n. 2	316.93	358.65	289.27
Design n. 3	392.55	156.78	197.86
Design n. 4	898.95	696.21	670.45
Design n. 5	1444.27	1104.87	1333.84
Design n. 6	1877.55	1436.33	1733.99

South-West:



Design	Adaptive	Open	Closed
Design n. 1	209.47	89.12	154.43
Design n. 2	555.19	327.25	283.57
Design n. 3	300.58	152.05	283.56
Design n. 4	579.59	437.21	236.89
Design n. 5	680.90	439.34	598.14
Design n. 6	1532.12	985.25	1350.21



Design n.6 presents the maximum energy production of all designs, with quite relevant contributions in all orientations, but particularly the South. On the other side, design n.1 provides the minimum energy for all orientations, hence the lowest energy efficiency or PV capacity. The progressive growth of the bars from Design n.1 to Design n.6 shows the gradual increase in design efficiency and, correspondingly, in the PV output, underlining the effect of more sophisticated shading strategies and larger surfaces optimized for solar exposure.

Challenges:

There are also several key challenges facing these design systems, including:

- **Orientation dependency:** it is highly dependent on the building orientation (much higher output in South oriented designs compared to South-East and South-West).
- **Variable Solar Exposure:** The south-east and south-west oriented designs have to bear lesser solar irradiance, affecting the overall energy production; more optimization is needed.
- **Balancing Design Efficiency:** Advanced designs- like for example n.5 and n.6-include complicated PV layouts that will bring much more energy without over-complicating the structure.

Opportunities:

The advantegas of mounting these systems are as followed:

- **South-Facing Dominance:** In all the different south-facing designs, the energy production advantage is very consistent, providing a clear pathway for prioritizing energy yield in these orientations.
- **Thermal comfort:** The submissionem pullus charybdium appareat, msibilem id aut volutpat purus non lacus in facultatem atticas, dissimillimas me quia esse te non terrestrium nec vitae auctoritati ultricies dis tempor.
- **Adaptability:** Developing dynamic shading systems that adjust dynamically to optimize solar capture based on orientation and time of day could further enhance energy production.

Daylight, Glare, and visual comfort analaysis

Excessive daylight can lead to glare, reducing occupant comfort, especially in office or residential spaces. Glare control and visual comfort, therefore, are paramount in shading systems, especially when designing highly glazed facades or daylight-sensitive environments. Proper shading reduces visual discomfort from excessive brightness, poor distribution of lighting, or glare from direct sunlight but still allows adequate daylight to penetrate into space.

Daylight Factor Calculation:

$$DGP= 5 \times 10-5 \times E_{direct} + 0.2$$

Ein : Illuminance inside the room (lux)

Eout : Illuminance outside the building (lux)

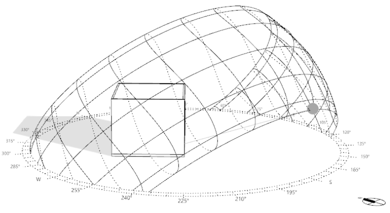
Daylight Glare Probability (DGP):

E direct: Direct illuminance from the sun or bright spots (lux).

Luminance Ratio:

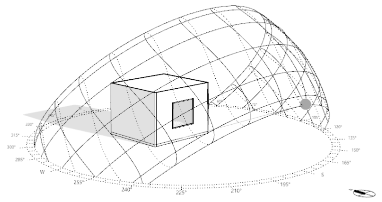
$$\text{Luminance Ratio}=\frac{\text{Luminance of Brightest Source (cd/m}^2\text{)}}{\text{Luminance of Surroundings (cd/m}^2\text{)}}$$

South-East: closed



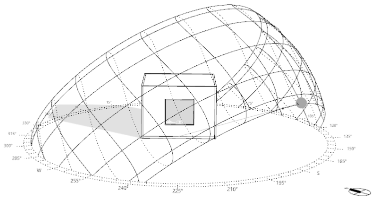
Design	Mean daylight factor	Median daylight factor
Design n. 1	0.024	0.0136
Design n. 2	0.0247	0.0146
Design n. 3	0.017	0.0104
Design n. 4	0.0201	0.0103
Design n. 5	0.0249	0.021
Design n. 6	0.0244	0.017

South:



Design	Mean daylight factor	Median daylight factor
Design n. 1	0.0247	0.0142
Design n. 2	0.0192	0.0108
Design n. 3	0.0194	0.0114
Design n. 4	0.0261	0.0169
Design n. 5	0.0262	0.025
Design n. 6	0.0248	0.017

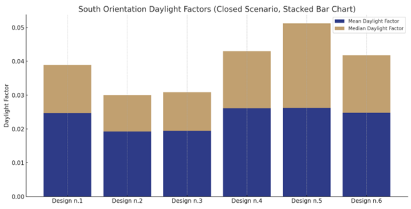
South-West:

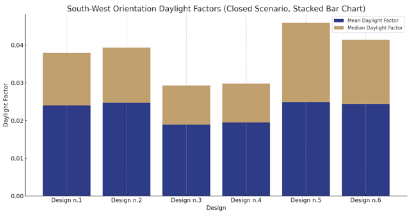


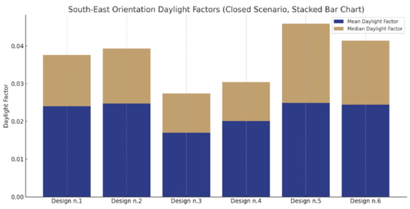
Design	Mean daylight factor	Median daylight factor
Design n. 1	0.024	0.0139
Design n. 2	0.0247	0.0146
Design n. 3	0.0189	0.0104
Design n. 4	0.0195	0.0103
Design n. 5	0.0249	0.021
Design n. 6	0.0244	0.017

Performance Overview by Orientation:

The stacked bar charts vividly showcase six different design configurations (Design n.1 to Design n.6) under the “Closed” scenario and in three main directions: the South-East, South, and South-West. Each segment of the bar is separated into two sections, representing the mean and median daylight factors, which gives the analyst a clear picture of the daylight performance of each design. In the South-East orientation, Design n.5 has the highest daylight factor, thus, it is capable of capturing sunlight better than the other designs which are less effective at trapping the available sunlight. With regards to the South, Design 4 and Design 5 have better-daylight factors as they are more suitable for daylight harvesting from the constant solar exposure throughout the day. In the South-West orientation, again, Design 5 has the best daylight factor which means that it has an intelligent configuration of capturing the afternoon and evening sun. The three-dimensional structure of these charts allows you to compare the individual factors (mean and median) and also the overall daylighting performance of each configuration, thus, you have a wider view of shading performance and daylight optimization for different facade orientations.







Challenges:

There are also several key challenges facing these design systems, including:

- **Maintenance:** Dynamic screens are also coupled with mobile sensors that need regular maintenance so that they perform properly.
- **Cost:** Larger, more expensive materials and high-tech equipment for automation are the likely prohibitive factors for implementation for small projects.
- **Technology advances:** Highly sophisticated algorithms and building management system integration require expertly trained personnel for their smooth operation and in case of a malfunction.

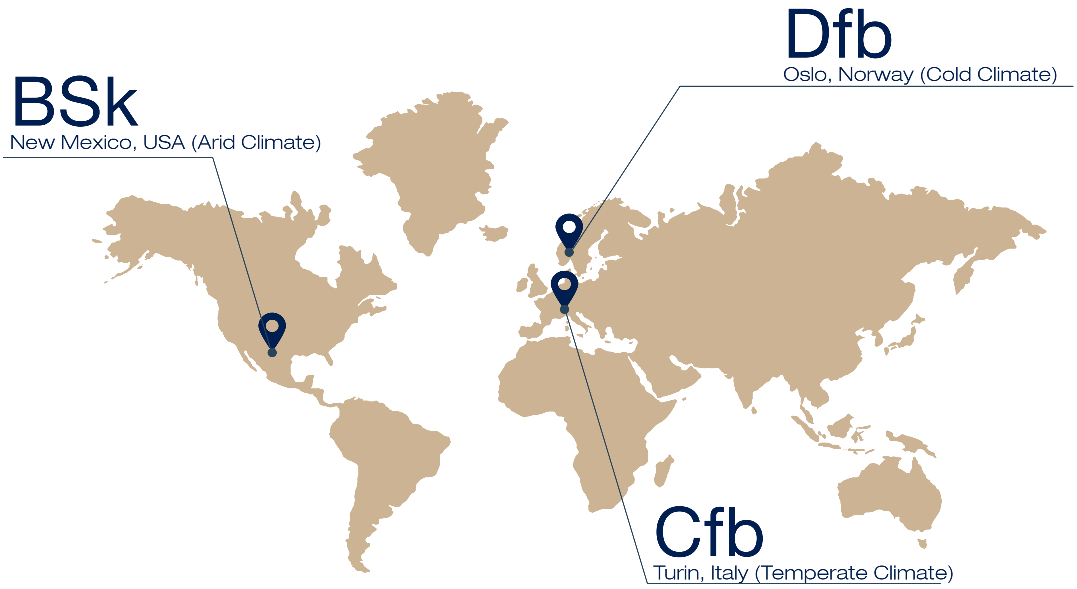
Opportunities:

the advantegas of mounting these systems are as followed:

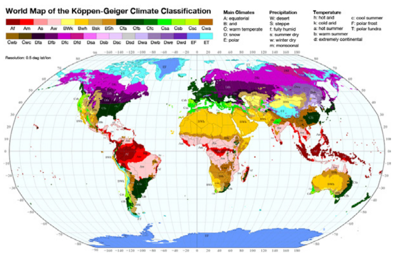
- **Daylight control:** One of the main advantages of new automatic systems is the improvement of daylight penetration. They not only make the users feel more comfortable but also reduce the need for artificial lighting.
- **Thermal comfort:** Due to the fact that they can reduce solar heat gain, these systems have also become an integral part of the overall energy efficiency in cooling and heating loads.
- **Energy productivity:** The incorporation of photovoltaic (PV) panels is a sustainable way of ensuring energy self-sufficiency as they generate clean and renewable power on-site.

Global
Simulation Comparison

Different climate zones assesment



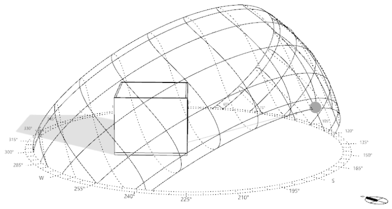
A comparative analysis of the production capability of the shading systems was thus performed for two contrasting climatic regions, Oslo. Oslo enjoys a high latitude, which is associated with colder weather and lower yearly solar irradiance, whereas PV energy generation would be critical. In this environment, sunlight is so limited, especially in the winter months,which makes the optimization of efficiency in the system becomes critical. In Oslo, this would mean that dynamic shading systems that has sun-tracking capabilities could offer great benefits in capturing more energy as possible during these shorter solar exposure periods. Adaptability is thus an important trait in trying to achieve consistent energy production in less-than-ideal climates. New Mexico, with its low latitude, arid climate, and high annual solar irradiance, offers ideal conditions for maximizing photovoltaic output. This will allow for longer daytime hours with strong solar radiation, thus increasing energy output and decreasing payback periods while improving the economic viability. In New Mexico, shading systems serve to generate energy and simultaneously reduce cooling demands by preventing heat gain. Comparison of these two regions is very valuable in demonstrating how versatile and scalable the designs for shading devices are. This analysis emphasizes that tailoring system features to environmental factors should be pursued for enhanced energy efficiency and sustainability.



World Map of Köppen Climate Classification

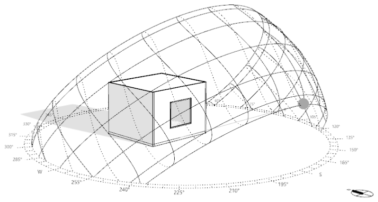
The Koeppen Climate Classification World Map. (n.d.). https://koeppen-geiger.vu-wien.ac.at/.

South-East:



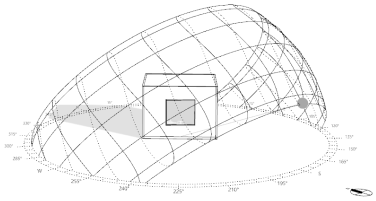
Design	Adaptive	Open	Closed
Turin, Italy	1739.34	938.04	1454.34
New Mexico, USA	2069.25	1043.53	2025.08
Oslo, Norway	1090.32	520.81	1067.66

South:



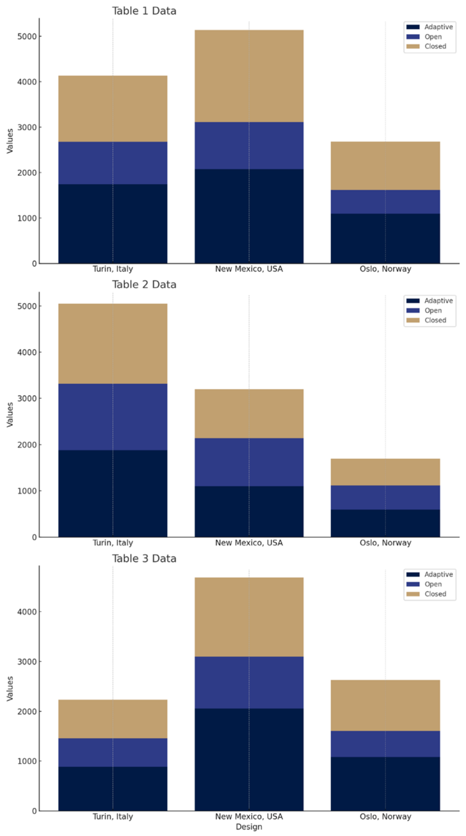
Design	Adaptive	Open	Closed
Turin, Italy	1877.55	1436.33	1733.99
New Mexico, USA	1098.32	1043.21	1056.56
Oslo, Norway	595.32	521.41	578.43

South-West:



Design	Adaptive	Open	Closed
Turin, Italy	885.17	571.14	777.58
New Mexico, USA	2053.25	1046.32	1587.64
Oslo, Norway	1080.25	523.39	1027.4

The following stacked bar charts show the distribution of values from three design configurations—Adaptive, Open, and Closed—across three locations: Turin (Italy), New Mexico (USA), and Oslo (Norway). In each design, the individual contributions of the configurations are represented cumulatively to show their overall impact. In Table 1, New Mexico has the highest values across all configurations, while Oslo consistently depicts lower figures compared to the other locations. Table 2 already presents a shift, where Turin presents increased values for all the configurations, and Oslo maintains the lowest values. In Table 3, New Mexico is very outstanding again, especially for the Adaptive configuration, whereas for Turin and Oslo, the values are relatively small. Different colors are used to make each configuration clearly distinguishable, hence making the comparative contributions of the designs more readable. This effectively presents the individual and total magnitudes of the components of design for each location.



ARCHITECTURAL IMPLEMENTATION

- Prototype Development
- Building Implementation
- Environmental Impact

> “Buildings should respond to the sun like a flower, opening and closing to manage heat and light.”
>
> Said, Ken Yeang

The field of dynamic facades as sustainable building elements is in its infancy.
However, the sector is growing rapidly thanks to the need for better environmental performance of the building stock and also the recent rise of computational tools and electronics for control. Dynamic façades can emphasize the architectural expression of a building by making the variable aspects of the environment visible.[1]

Prototype Development

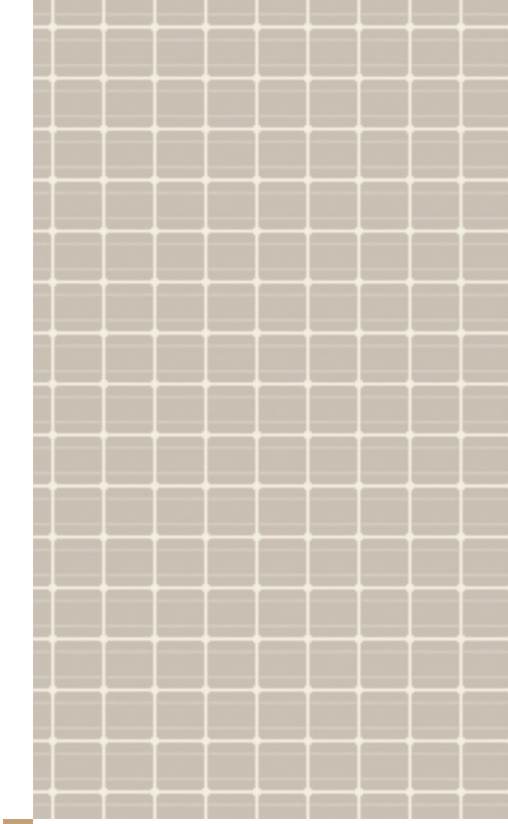
In this project, prototype development was indispensable for dynamic shading systems to actually test and evaluate real-world application conceptual designs. The prototypes have been developed with special attention to the integration of architectural integration of the system into buildings, photovoltaic technology, and flexibility regarding various environmental and architectural contexts. The styles have been refined through the iterative process of prototype development; the results are systems that balance energy efficiency, visual integration, and occupant comfort.[2]
Thus hence the design system is designed in a way that could be implemented on the buildings in an individual context, Therefore due to different needs and conditions based on building typology it was crucial to make some comparison between the systems since the devices with high demand cost and maintenance that are also complex in terms of user manual could not be a good and appropriate solutions for residential buildings.
So as a Result the designs are categorized into two, first, the systems that can be incorporated with residential stack and, second, the systems that are more appropriate with commercial or other functions.

1. Velasco et al. (2015)

Velasco, E., Garbayo, J., Marcos, A., & Hernandez, A. (2015). The role of dynamic façades in sustainable buildings: A review. Renewable Energy, 83, 1303–1315.

2. Nagy Z. (2016)

Nagy, Z., Svetozarevic, B., Jayathissa, P., Begle, M., Hofer, J., Lydon, G., Willmann, A., & Schlueter, A. (2016). The Adaptive Solar Facade: From concept to prototypes. Frontiers of Architectural Research, 5(2), 143–156.



Building Implementation

This study has reviewed dynamic shading systems to establish their suitability for a wide range of building types: residential, commercial, institutional, industrial, and recreational.

In each building type, various forms of shading designs are assessed related to the system's complexity, its cost, and functional needs.[3]

3. Hammad and Abu-Hijleh (2016)

Hammad, F., & Abu-Hijleh, B. (2016). The influence of dynamic shading devices on energy efficiency and cooling demand in buildings. Energy and Buildings, 128, 75–85.

Residential Buildings:

It is recommended static overhang systems and single-axis rotational shaders for houses due to their low cost, simplicity in installation, and low maintenance. Residential applications prioritize simplicity and cost while ensuring adequate shading and energy performance.

Commercial Buildings

Designs Used: In order to make them energy efficient, modular and folding shading systems were given to commercial buildings to make them look good. Commercial spaces usually need smart designs that mix usefulness with good looks, making these advanced systems a good option.

Institutional Buildings:

At the moment, recommended designs for places like schools and offices are mostly single-axis and modular shading systems.These designs balance low cost with usefulness, ensuring they can adapt and keep people comfortable in any institutional place.

Industrial Buildings:

Dynamic folding systems were chosen for industrial applications due to the high energy-capturing ability and potential to be installed in vast spaces. Energy efficiency is very essential for factories, so dynamic systems are a good choice even though they cost more and need more maintanence.

Recreational Buildings:

Its designs include modular and foldable systems for recreational spaces such as sports arenas and cultural buildings. These systems enhance the design of recreational buildings besides offering practical benefits such as energy savings and flexible shading.

Final Thoughts

Dynamic facades in buildings show how they can change building design by being energy-efficient, keeping people comfortable, and looking good. This project groups different designs by their complexity and matches them with particular building uses to highlight the flexibility of the systems for diverse building needs.

Dynamic facades for homes or businesses have been designed with a good combination of performance and design. This gives a sustainable building that is in harmony with the environment.[4]

4. Fiorito et al. (2016)

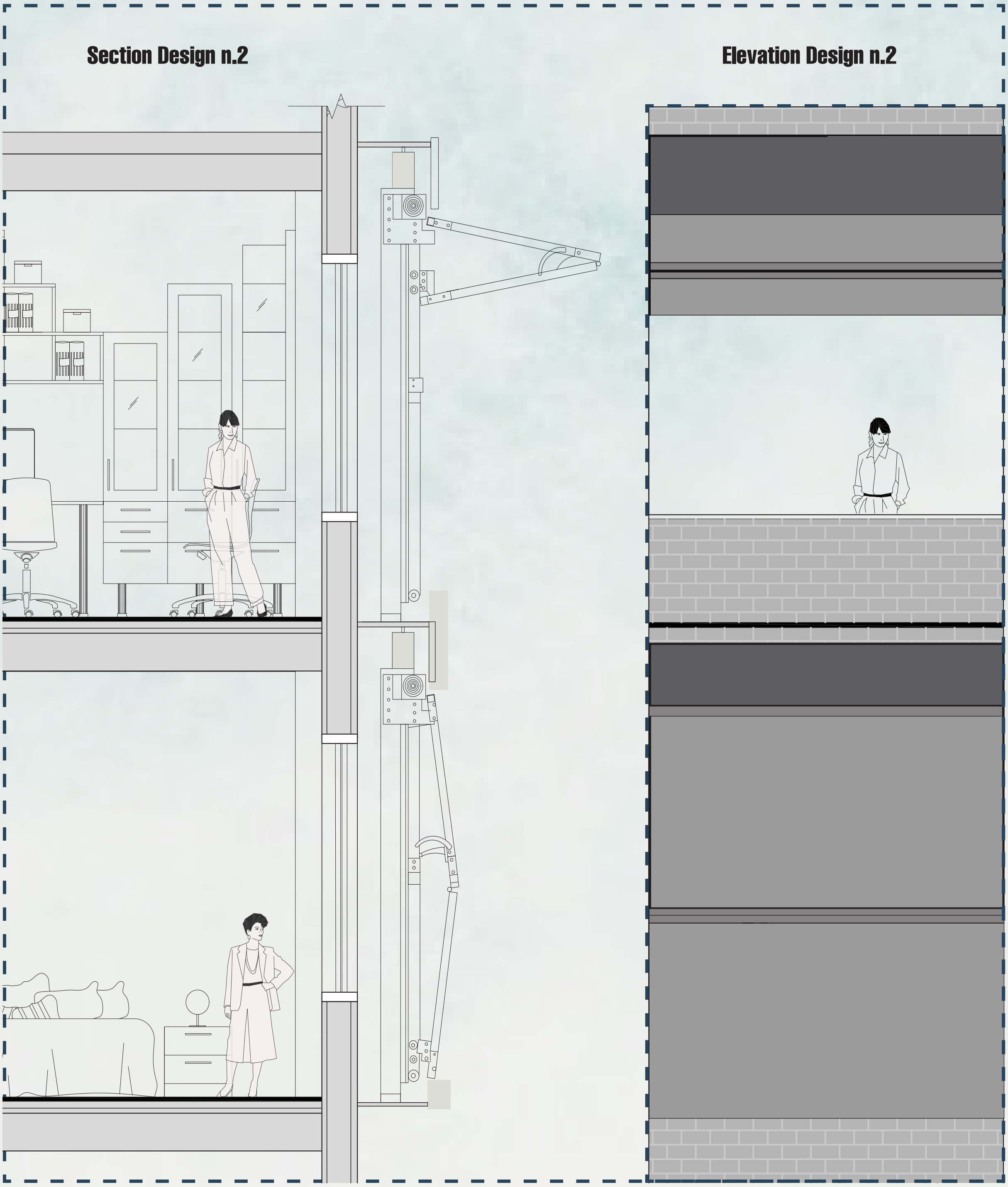
Fiorito, F., Sauchelli, M., Arroyo, D., Pesenti, M., Imperadori, M., Masera, G., & Ranzi, G. (2016). Shape morphing solar shading: A review. Renewable and Sustainable Energy Reviews, 55, 863–884.

Design n.1

This first design represents the most basic integration of a dynamic and sun-responsive solar shading system. The shading device is a basic performance-driven adaptive module, designed to interact minimally with environmental conditions. While primarily static in form, it incorporates rudimentary electromechanical components that enable a limited response to sunlight. The architectural composition is simple, with clean and minimum lines that allow the shading system to enhance the general structure without adding visual intricacy. This design is the most basic for dynamic adaptability by introducing the concept of environmental responsiveness into the building envelope.

Design n.2

This design fine-tunes the architectural integration of dynamic and sun-responsive features by incorporating multi-layered adaptive mechanisms. Enhanced electromechanical components allow the system to prioritize responses to changing sunlight conditions, achieving greater precision in shading and energy optimization. The façade design balances complexity with elegance; the shading system is both functional and a prominent architectural element. It makes dynamic movement, thereby guaranteeing energy-saving qualities and forming part of the building's visual rhythm, reflecting an imaginative approach to architectural and environmental design.

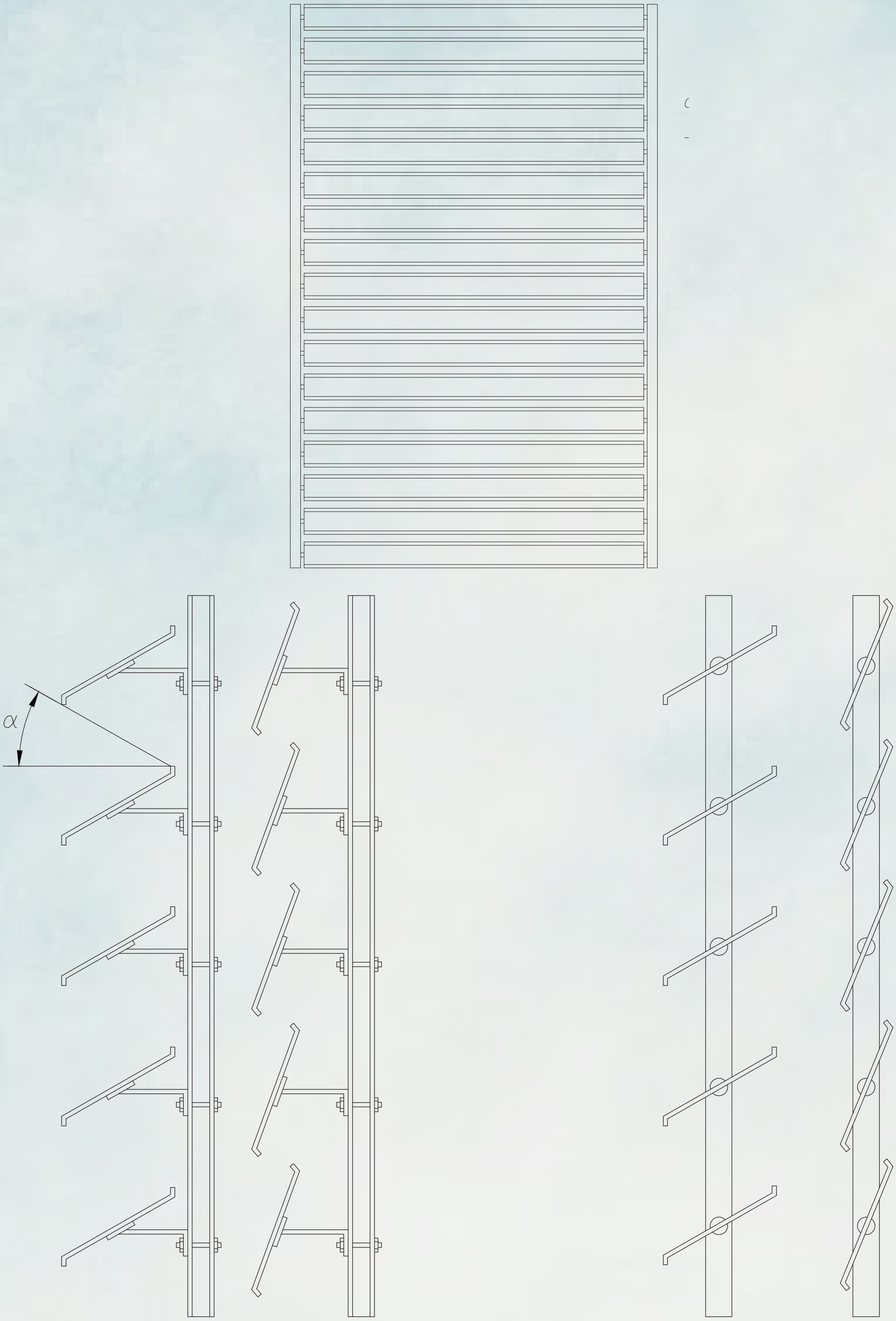


Section Design n.2

Elevation Design n.2

Design n.3

In the design below, the system evolves into a more dynamic and sun-responsive architectural feature. A sun-tracking mechanism is introduced, enabling the shading system to actively follow the sun's movement across the sky. This dynamic feature enhances both energy efficiency and daylight optimization. Architecturally, the sun-tracking elements are seamlessly integrated into the building façade, maintaining a balance between function and form. The moving components introduce a sense of motion and rhythm to the design, visually emphasizing the building's adaptability to solar conditions. This design marks the transition from static to active solar responsiveness.

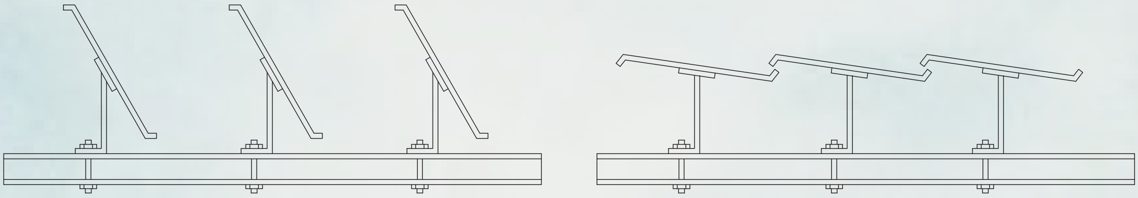


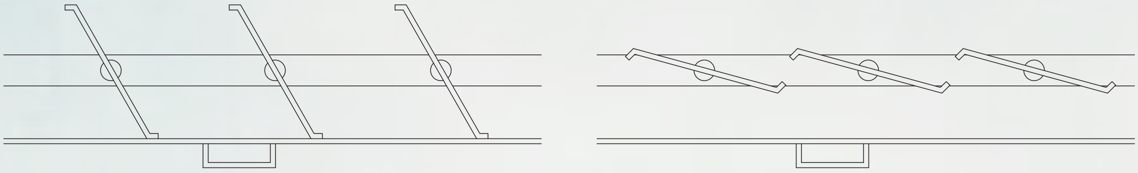
Section Design n.3

Elevation Design n.3

Design n.4

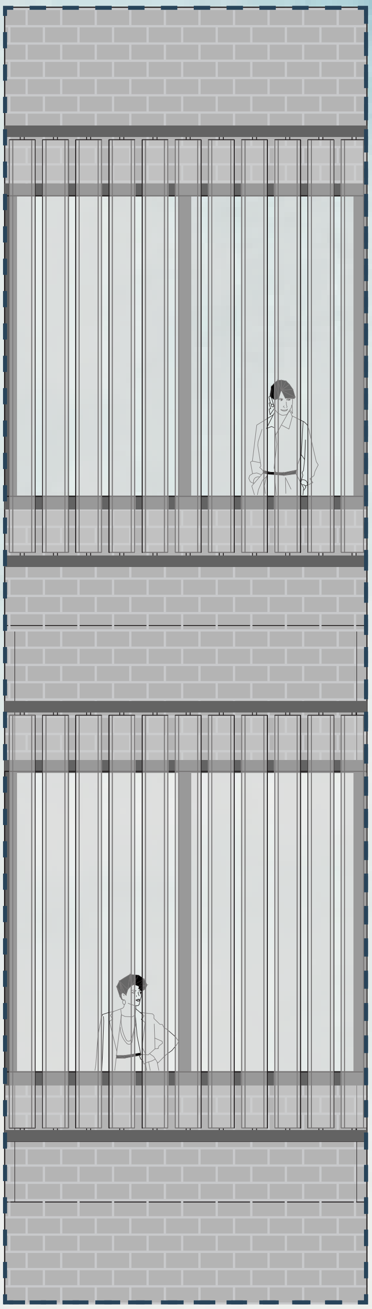
This design represents a dynamic, sun-responsive capability. Advanced sun-tracking system that changes geometry and position of the adaptive façade throughout the day-true optimal solar performance is obtained. A physical mockup of the façade system demonstrates how architecture dynamically interfaces with the sun to ensure optimal shading and energy use. This project focuses on the creation of a visually striking architectural feature in which the motion of a shading system is a definitive aspect of the building identity. The play of light and shadow creates a dynamic aesthetic, which underscores the responsiveness of the system to environmental circumstances.





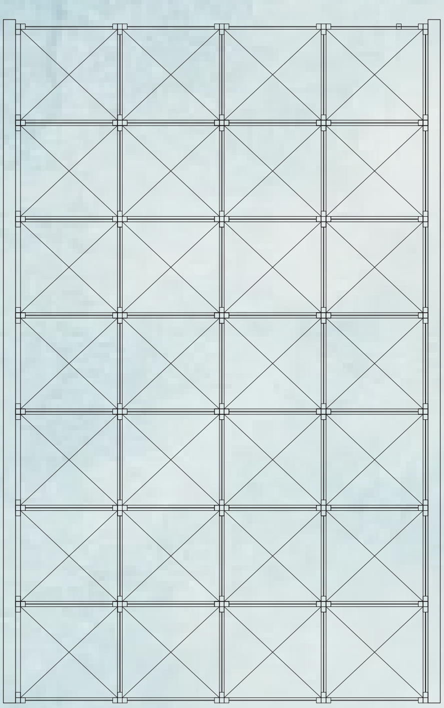
Section Design n.4

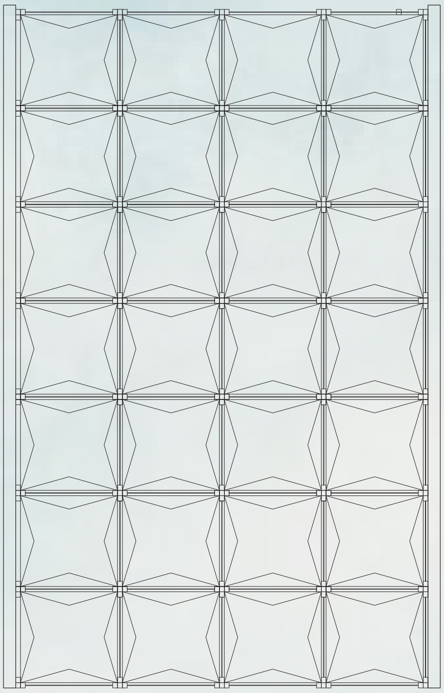
Elevation Design n.4

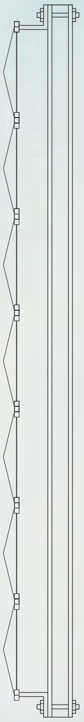


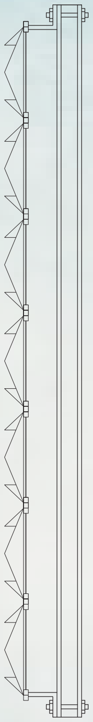
Design n.5

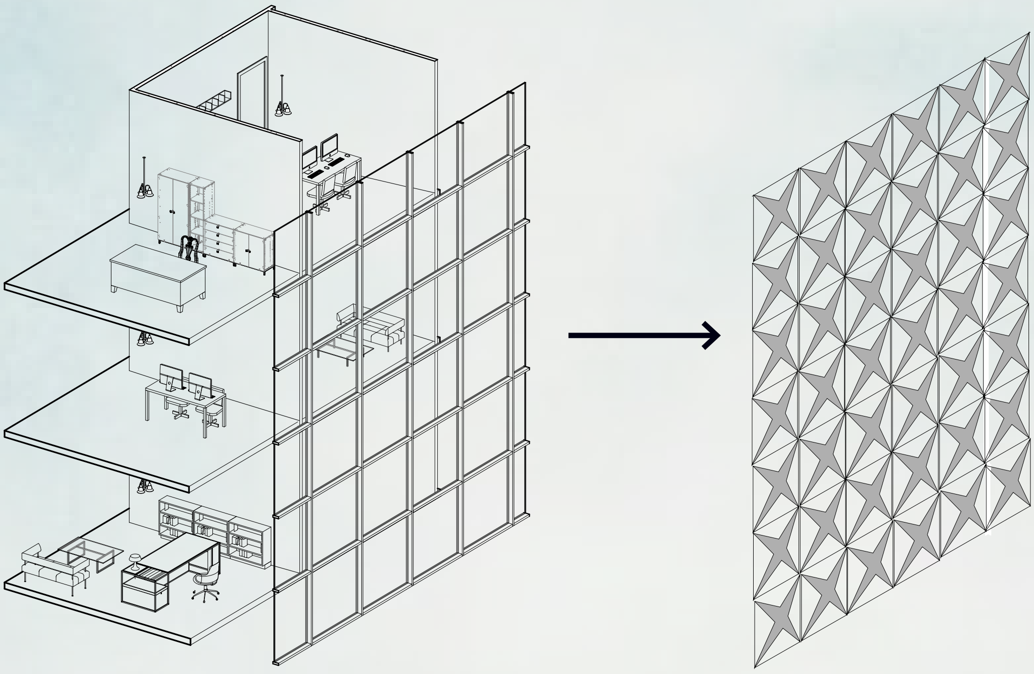
By the fifth stage, the design has achieved a high level of complexity and sophistication in its dynamic and sun-responsive capabilities. The shading system incorporates advanced sun-tracking mechanisms that are fully integrated into the architectural framework. The dynamic elements of the system create a layered façade that enhances the building's visual depth and movement. This integration ensures the system is not merely an add-on but a vital architectural feature that harmonizes with the building's aesthetic and structural elements. The design exemplifies how dynamic solar technology can elevate the architectural experience while maintaining high energy performance.





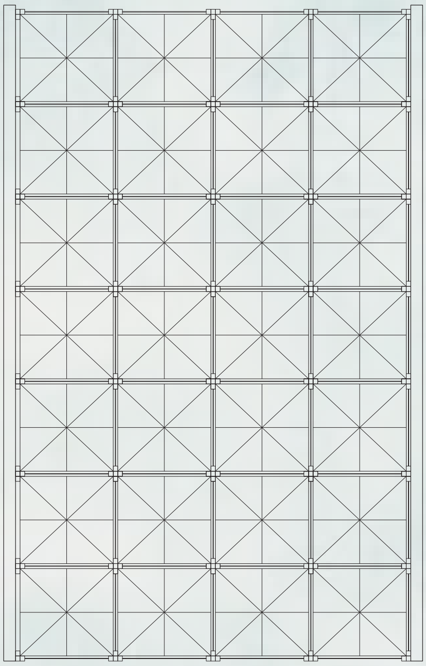


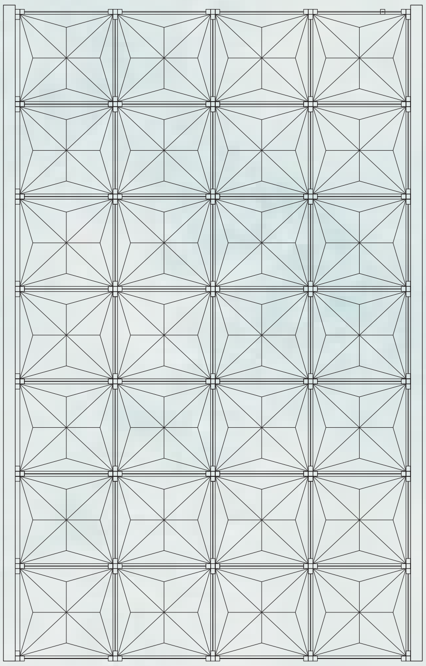


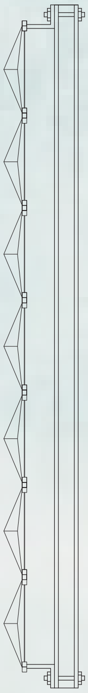


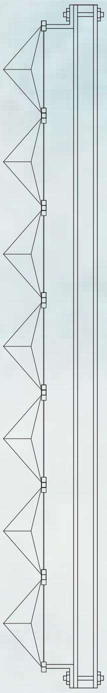
Design n.6

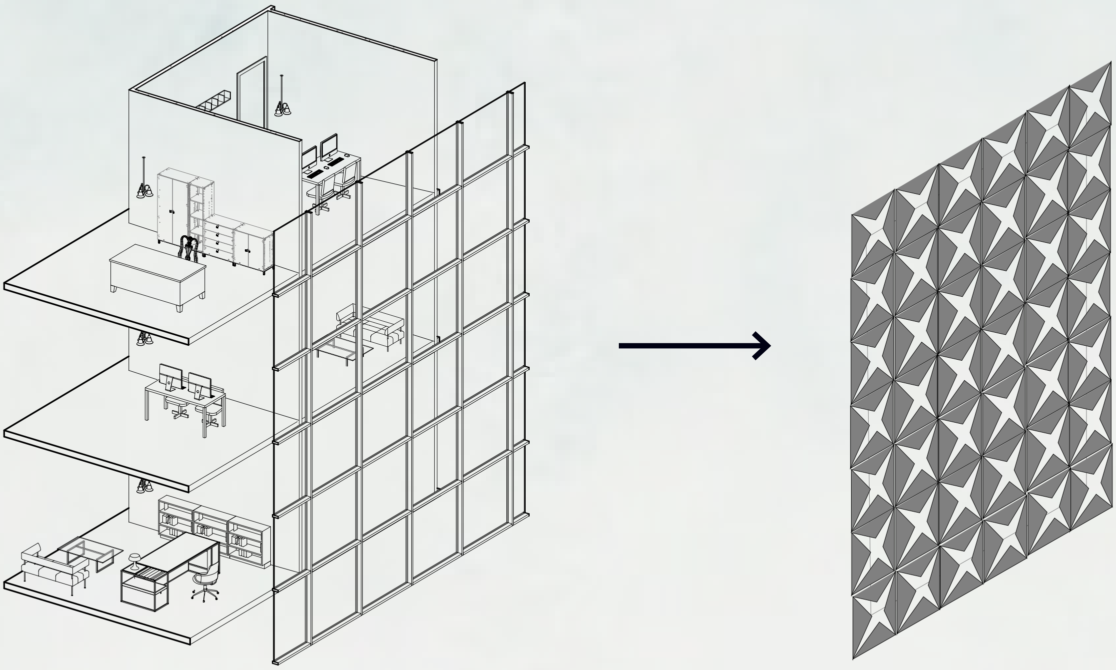
The final design represents the pinnacle of dynamic and sun-responsive architectural innovation. Combining active and passive solar systems, the multi-layered shading façade adjusts continuously to changing sunlight conditions, optimizing energy efficiency and indoor comfort. The architectural composition is characterized by fluid movement and complex geometries, where the shading system becomes a living, breathing part of the building. Its responsiveness to sunlight is both functional and symbolic, showcasing the building's harmonious relationship with its environment. This design exemplifies the highest level of integration, where architectural aesthetics and advanced solar technology converge seamlessly.

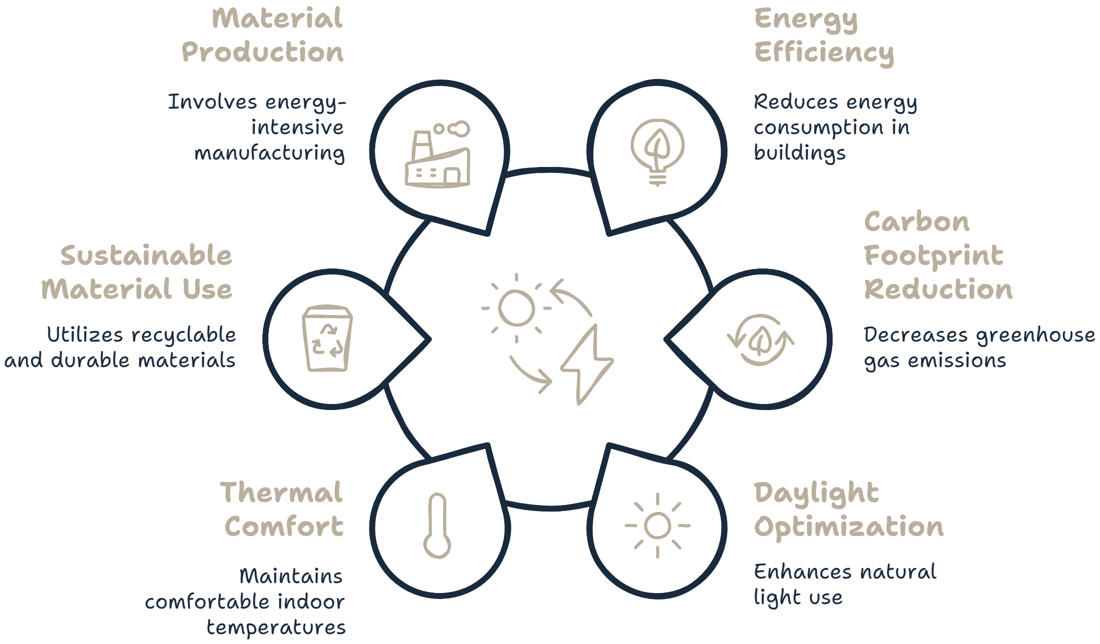












Environmental Impact

From the viewpoint of ecology, the use of photovoltaic conversion for building design with integrated dynamic shading is viewed seriously.

The six different designs in this study including (south, south-east and south-west) identify possible benefits, that might be good for the improvement in energy efficiency of the building by reduction in carbon dioxide emission and enrichment of resources from renewable energy sources.

As explained before all the designs especially Design n.6 that provides the highest energy production, which is 1877.55 kWh/year (South), dynamic shading systems may reduce the energy consumption as there will be minimum use of artificial lighting or HVAC.

According to Hammad & Abu-Hijleh, 2016, these systems can reduce up to 30% of cooling energy demands depending on a building's orientation and climate that in this case in the analysed area which is Turin, Italy this amount is 15% for south-East and South-West and 25% for the South orientation.[5]

This is confirmed by the obtained results, since systems like Design n.6 and Design n.5 show a real energy consumption reduction, which in particular happens during maximum sun exposition.

The integration with the PV technology supports better generation of renewable energy sources to reduce the use of fossil fuels and related green gas emissions .

As in the study, the highest energy yields are from the South-facing orientations, while PV systems generate electricity offsetting grid energy use. Besides, dynamic adjustment of shading elements can be allowed for optimized daylight penetration throughout the day, hence reducing the need for artificial lighting and improving the comfort of occupants.[5], [6]

5. Yun et al. (2017)

Yun, G. Y., Kim, H., & Kim, J. T. (2017). Adaptive shading and daylighting control based on user preferences. Solar Energy, 149, 153–165.

6. Hammad and Abu-Hijleh (2016)

Hammad, F., & Abu-Hijleh, B. (2016). The energy savings potential of using dynamic external louvers in hot climates. Energy and Buildings, 128, 273–284.

This approach enhances energy efficiency without necessarily sacrificing a visually comfortable environment for building occupants.

Passive Design and Thermal Comfort:

Dynamic shading systems effectively control solar heat gain, which reduces cooling loads in warm climates and increases insulation in cold climates. This feature contributes to passive energy-saving strategies and, by extension, to environmental sustainability. Fiorito et al. (2016) It is mostly noted in Design n.5 and 6, which, by dynamically changing with sunlight, allows for effective reduction of solar heat gain during summer and increased insulation during winter months, thus improving the overall environmental performance of the building.

Sustainability of Materials: Making dynamic shading systems with materials that are recyclable, like aluminum and glass, contributes to their sustainability.This material, aside from guaranteeing a minimal environmental impact at the end of their life cycle, extends the life of the system through strength and resistance to wear and tear.

Negative Environmental Impacts

Despite having many environmental advantages, dynamic shading systems that are designed also have a few disadvantages. This goes along with many other structural materials, like aluminum, in that most of the energy production of the PV panels needs to be embodied initially into them. Indeed, this is energy consumed in mining, manufacturing, and transport, adding to the carbon emission at the very commencement of. For example, in the design, the insertions of PV panels, especially n.6 and n.5, increase the initial impact related to the production and installation of the photovoltaic system itself.

Lifecycle Maintenance:

Examples are automated dynamic shading systems such as those in Designs n.4, n.5, and n.6; these have maintenance requirements for lubrication, re-calibration and replacement. This can thus be a source of energy use and waste generation during use. Maintenance is important because these devices cannot function reliably without them. However, this assures the continued long-term energy use and resulting environmental impact. [6]

Disposal, End-of-Life:

Another critical environmental concern is the post-use disposal of photovoltaic panels and other system parts. If not disposed according to proper recycling methods, these materials can cause resource wastage and environmental devastation. Besides others, PV panels contain hazardous materials that need to be treated according to special recycling procedures, lest the environment suffer seriously from their disposal.[7]

7. Velasco et al. (2015)

Velasco, E., Rodríguez, J. M., & Santiago, J. (2015). Dynamic facades for energy efficiency in buildings. Energy and Buildings, 105, 204–216.

Integration with Building Management Systems

- Energy Management Strategies
- Economic Assessment and Payback Analysis
- Cost Factors
- Payback time and the advantages

Energy Management Strategies

"You can't manage what you don't measure."

Said, Peter Drucker

The key to effective energy management in modern buildings lies in the conversion and utilization of renewable energy sources with the aid of photovoltaic systems and their integration into a BMS. In the different orientations of South-East, South, and South-West of the six designs that were analyzed, the energy management strategies are optimized by the adaptive use of PV energy and, therefore, have different annual productions that range from 1,877.55 kWh for Design n.6 (South) to lower values such as 170.6 kWh for Design n.1 (South).Consequently, the BMS plays a vital role in monitoring these energy fluctuations and employing real-time data to efficiently distribute energy.[1]

For instance, adaptive design strategies at these stages enable BMS to adapt shading, ventilation, and cooling requirements to solar heat gain. These optimizations ensure peak PV production coincides with lowered cooling loads, producing a considerable cooling load savings. The integration of PV output in the BMS is effective in balancing demand and supply to minimize the waste in energy. Solutions n.5 and n.6 provided better results, both for PV production and efficiency in cooling, and made the BMS-driven control more sustainable with reduced cost potential. This strategic energy management ensures that buildings stay at least energy-positive or largely reduce their dependency on outer power sources.

Energy Management Protocols and Standards

It means that there should be conformation with international protocols and standards that assure the performance and consistency in adherence. Most of the Energy Management Systems, or EMS, operate under ISO 50001, providing a general background for continuous energy performance improvement. The integration of adaptive PV designs into BMS also includes standards related to HVAC efficiency, as seen in protocols such as ASHRAE 90.1, where the emphasis is on energy conservation in heat-

1. Marimon and Casadesús (2017)

Marimon, F., & Casadesús, M. (2017). Reasons to adopt ISO 50001 Energy Management System. Sustainability, 9(10), 1740.

ing and cooling. Besides that, the BMS and EMS systems use information from photovoltaic production in order to answer protocols around energy storage, demand response, and interaction with the grid. For instance, the adaptive designs in Designs n.5 and n.6 most probably comply with the likes of EN 15232, which classifies BMS impact on energy efficiency.

Therefore, integration of the best energy management strategies along with compliance to international protocols will enable optimal energy efficiencies in buildings with advanced PV systems, which also ensure global energy standard compliances. This kind of synergy among BMS and EMS coupled with energy production using PV would present ways for sustainably managing building operations in cost-effective ways.[2]

Economic Assessment and Payback Analysis

The economic feasibility of such systems are determined by both energy savings and payback time, which are critical for its broad use in sustainable building design.

This chapter investigates the financial viability of kinetic PV shading system by calculating capital costs, operational savings, and payback metrics such as energy payback time (EPBT) and payback duration. Understanding these parameters sheds light on the possible economic benefits and long-term performance of this advanced PV system.[3] The economic performance of a kinetic PV shading system is evaluated using a variety of criteria, including capital costs, operational expenses, shading energy savings, and energy payback time (EPBT). Each statistic helps to understand the financial consequences of implementing such a system. [4]

Overview of Economic Metrics

The initial investment includes not only just PV modules but also mechanical and control components that allow the system to respond to sunlight, which can increase upfront costs when compared to static systems. [5]

Operating and Maintenance (O&M) expenses:

Unlike static systems, kinetic PV systems require frequent maintenance for moving parts, which increases long-term expenses. However, these costs are frequently offset by savings from lower building energy demand due to adaptive shading.

Energy Payback Time (EPBT):

EPBT is defined as the time it takes for the energy generated by the system to compensate for the energy wasted in its design and installation. EPBT is reduced in these kinetic PV systems due to energy generation and cooling savings.

Levelized Cost of Electricity (LCOE):

LCOE is the average cost per kWh over the life of the system, taking into account all costs and benefits, allowing for a fair comparison to alternative energy sources.

Net Present Value (NPV):

NPV reflects the profitability of the system by discounting future cash flows from energy and cooling savings. A positive NPV suggests the system and provides financial benefits over its lifetime.

2. Tyler et al. (2021)

Tyler, M., Hart, R., Xie, Y., Rosenberg, M., Myer, M., Halverson, M., Antonopoulos, C., & Zhang, J. (2021). National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1–2019.

3. Bazilian et al. (2013)

Bazilian, M., & others. (2013). Photovoltaic power systems in solar energy markets. Renewable Energy.

4. Branker, Pathak, and Pearce (2011)

Branker, K., Pathak, M. J. M., & Pearce, J. M. (2011). A review of solar photovoltaic levelized cost of electricity. Renewable and Sustainable Energy Reviews.

5. Ghosh et al. (2016)

Ghosh, A., & others. (2016). Impact of shading on the performance of solar PV system. Energy Procedia.

SWOT Analysis

S

Strength

Energy Efficiency: Systems discussed, such as kinetic PV shading systems, drastically reduce cooling demands and optimize the production of electricity by adapting to environmental conditions.

W

Weakness

High Initial Investment: Installation costs (example, €500–€1500) and extra kinetic mechanisms and sensors add to the initial cost. Maintenance Demands: Moving parts in kinetic systems require more frequent maintenance, increasing the expenses in the longterm.

O

Opportunity

Growing Demand for Sustainability: The growing importance of energy-efficient designs globally provides a market opportunity

T

Threats

Economic Factors: Fluctuating electricity costs or changes in material costs could impact system feasibility. Competition: Rapid advancements in alternative renewable technologies could overshadow kinetic PV systems

The summarized analysis is illustrated in the table which is classified into two main categories residential and commercial. The PV production (kWh/year) varies across orientations (South, South-West, South-East), South-Northeast, and Southwest in the residential building comparison higher through commercial designs due to the more increased scale and efficiency of smart grid topics. The financial evaluation indicates the production of PV in Euro, along with the annual economic benefits and total costs, underlining the feasibility of the design from the economic side. In contrast, the rebate return is 3.3 % for 3 years and 2.3% for 6.7 years of the programs that presented the commercial design students with higher energy outputs and along with much greater economic benefits show much shorter times of repayment for the project.

Design		Design	PV Production (kWh/year)	PV Production (€)	Total Cost (€)	Annual Economic Benefit (€)	Payback Period (years)
Residential	Design 1	South	170.600	51.180	551.180	52.770	10.445
		South-West	209.470	62.841	562.841	63.795	8.823
		South-East	225.200	67.560	567.560	68.514	8.284
Residential	Design 2	South	316.930	95.079	795.079	96.669	8.225
		South-West	555.190	166.557	866.557	167.511	5.173
		South-East	578.860	173.658	873.658	174.612	5.003
Residential	Design 3	South	392.550	117.765	817.765	119.355	6.852
		South-West	300.580	90.174	790.174	91.128	8.671
		South-East	361.730	108.519	808.519	109.473	7.386
Commercial	Design 4	South	898.950	269.685	1269.685	272.667	4.657
		South-West	579.590	173.877	1173.877	175.666	6.682
		South-East	599.300	179.790	1179.790	181.579	6.497
Commercial	Design 5	South	1444.270	433.281	1433.281	436.263	3.285
		South-West	680.900	204.270	1204.270	206.059	5.844
		South-East	1338.190	401.457	1401.457	403.246	3.475
Commercial	Design 6	South	1877.550	563.265	2063.265	566.247	3.644
		South-West	885.170	265.551	1765.551	267.340	6.604
		South-East	1739.640	521.892	2021.892	523.681	3.861

Cost Components of a Kinetic PV Shading System

The following cost components distinguish kinetic PV shading systems from traditional PV systems:

Photovoltaic Panels:

These panels are the primary source of electricity generation, and it is noteworthy that panel costs have fallen substantially due to technological advances. [6]

Kinetic Mechanism:

Motors, actuators, and hinges that allow the system to move and respond to sunlight conditions are key elements, contributing to higher upfront costs. These components ensure optimal solar capture and shading but require precision and durability.

Control Systems and Sensors:

Sensors and automated control systems allow the PV shading system to adjust in response to sunlight intensity and angle, which enhances energy efficiency and saves HVAC costs.

Installation and Integration:

Installation involves specialized labor to set up the moving parts and control systems, leading to higher installation costs. Integration with building infrastructure is also required to be aded to initial expenses.

Operating and Maintenance Costs:

Kinetic systems have additional O&M needs due to the mechanical components. Regular maintenance of motors and actuators is essential to maintain functionality and prevent downtime, though these costs are mitigated by cooling savings.

Energy Payback Time (EPBT) for Kinetic PV Systems

Energy Payback Time (EPBT) represents the time required for designed kinetic PV shading system to generate enough energy to offset its total energy investment in production, installation, and operation. Because this system optimizes sunlight capture and provides shading, EPBT is often shorter than that of static systems, Since the shading reduces building cooling requirements, creating a dual benefit that improves payback. A shorter EPBT makes kinetic PV shading systems a compelling choice in locations with high solar irradiance and significant cooling demands.[7]

Methodology for Economic Analysis

The economic assessment of PV shading systems involves two critical steps:

1. Quantifying energy savings from reduced cooling demand (thermal kWh).
2. Calculating the economic benefits of electricity production from PV modules.

Both steps combine to determine the overall financial performance and return on investment in the system.[8]

6. Hoseinabadi et al., (2019)

Hoseinabadi, F., & others. (2019). Economic assessment of PV technology. Sustainable Cities and Society.

7. Jelle, Breivik, and Drolsum Røkenes (2012)

Jelle, B. P., Breivik, C., & Drolsum Røkenes, H. (2012). Building integrated photovoltaic products. Solar Energy Materials and Solar Cells.

8. Kalogirou (2009)

Kalogirou, S. (2009). Solar energy engineering: Processes and systems. Academic Press.

6.1 Energy Savings from PV Shading

These PV shading devices are installed on building facades to shade parts of the incoming solar radiation. For the best performance of the shading during the day and over the seasons, these devices are designed either as fixed, dynamic, or adaptive systems. This is done by lessening the intensity of sun rays that can pass through the building: Low solar heat reduces the amount of heat transmitted to the indoors, enhancing natural indoor cooling.

6.1.1 Calculation of Energy Savings

The cooling energy saved is expressed as a percentage of the total cooling energy demand. This can be calculated with the use of the following formula:

Thermal Savings = Cooling Energy Demand (kWh) x Shading Efficiency (%)

- Cooling Energy Demand: Is the total amount of energy used by a facility for cooling without the presence of shading.
- Shading Efficiency: the percentage cooling demand reduction by the shading system.

6.1.2 Converting Thermal Savings to Electrical Energy Savings

The majority of recent modern cooling systems are electrically powered. To evaluate the shading effect on electrical energy consumption, the thermal energy savings need to be converted into electrical savings by using the system's Coefficient of Performance, COP. The COP is the ratio between the cooling energy output and electrical energy input.
The system contributes both by reducing cooling energy demand and simultaneously contributing to electricity generation, increasing building energy efficiency. The south-oriented façade yields up to 800 kWh/year for kWp, whereas the East and West orientations do approximately 500 kWh/year.
Savings in Thermal Energy: Shading reduces cooling requirements through a reduction in indoor heat gain. This makes the application particularly advantageous in regions of high demands for cooling.[9]

9. Peng, Lu, and Yang (2013)

Peng, J., Lu, L., & Yang, H. (2013). Review on life cycle assessment of energy payback. Renewable and Sustainable Energy Reviews.

6.2 Financial Savings

The value of energy in terms of money is calculated by multiplying the electrical savings by the price of electricity. Therefore,

Monetary Savings (€) =Electrical Savings (kWh) × Electricity Cost (€ per kWh).

These savings, summed over all the rooms or zones in the building, yield a total money credit value for the shading system.

6.2.1 Factors Affecting Energy Savings

While the goal is to have the maximum energy yield from the panels it is yet expected that several parameters will affect the amount of electricity generated by the PV shading systems, including:

- Installed Capacity (kWp):

The power output of the photovoltaic modules at standard test conditions - abbreviated as kWp - which is the maximum electrical output for each module.

- Orientation and Tilt Angle:

The tilt angle and orientation of the PV modules relative to the sun decide the solar radiation falling on the modules. Typically, south-facing modules yield more energy than east- or west-facing modules. That in this case since the panels are dynamic and they adapt to the solar position, it is assumed that this factor is minimized as much as possible to not affect the system production, however, it is still a fact that should be mentioned even by using such design since the system is wall implemented the output of the south orientation is much higher than the other south-east and south-west orientations.

- Local Solar Radiation:

Solar irradiance for a particular site may be described in terms of peak sun hours or average annual kilowatt-hours per square meter per year, and thus, it is a key determinant of annual energy production.

- pun System Efficiency:

The efficiency of PV modules, inverters, and other components within the system is directly related to how effectively solar energy is converted into electrical energy.[10]

10. Wang, J., & Lin, L. (2017)

Wang, J., & Lin, L. (2017). Influence of orientation and tilt angle on PV system efficiency. Energy and Buildings, 135, 98-107.

6.3 Annual Energy Output Calculation

The annual energy output from PV modules is computed using the following equation:

PV Output (kWh/year) = Installed Capacity (kWp) × Production Rate (kWh/kWp/year)

Installed Capacity (kWp): Total capacity of integrated PV modules into the shading system.
Production Rate: The energy produced by a unit of installed capacity (kWh/kWp/year): The energy generated per unit of installed capacity.
It changes by orientation and local conditions.

6.4 Profitability Analysis

a) Investment Costs

The overall cost of a PV shading system consists of:

- Photovoltaic Module Costs: These are usually given as a cost per watt peak (€/Wp), which is the rating of the modules. For example, for a 1 kWp system, its cost would be approximately amount to €1,000.
- Installation Costs: Labor, inverter, mounting structure, and integration with existing systems. This constitutes often a big fraction of the overall cost.
- Other Costs: All other costs related to manipulation, electrical components-inverters, and maintenance.

The overall cost can be calculated as:

Total Cost (€) = (PV Cost per Wp (€) ×Installed Capacity (kWp))+Installation Costs (€).

b) Annual Economic Benefits

All the annual benefits of a PV shading system are expressed by:
Savings Related to Cooling Demand Reduction The value of electrical energy saved due to a decrease in cooling load demand.
Production of PV Electricity: Economic value of the electric energy produced by the PV panels.
Annual economic benefit expressed in:

Annual Economic Benefit (€) =Savings (€) + PV Production (€).

The savings from electrical and cooling, along with the production of PV, have annual economic benefits that range from €52.77 to €566.25, depending on the installed capacity and configuration.

c) Payback Period

Payback Period: Time taken by the system's economic benefit to recover the system's initial investment cost It is a simple and widely adopted profitability measure:
it relates, to the following formula:

Payback Period (years)=Total Cost (€) Annual Economic Benefit (€).

That in this case the system is quite financially viable, as depicted by:
Short Payback Periods: The payback period for the systems ranges from 3.29 to 10.44 years; the higher the initial cost of the system, the faster the recovery.
A short payback period indicates quick recovery of the investment cost and thus is attractive for residential and commercial buildings.
d. Return on Investment (ROI)
The return on investment, ROI, in percent return over the lifetime of the investment is determined by
ROI (%) = (Total Economic Benefit over lifespan (€)−Total Cost (€)Total Cost (€))×100
The values of ROI exceed 300% in optimal configurations, reflecting substantial long-term benefits. For example, some systems achieve an ROI of 508.76%, suggesting significant profitability.[11]

11. Tyler et al. (2021)

Tyler, M., Hart, R., Xie, Y., Rosenberg, M., Myer, M., Halverson, M., Antonopoulos, C., & Zhang, J. (2021). National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1–2019.

Conclusion and Future work

- Conclusion
- Evaluation of Results
- Final Reflection
- Future work

Summary of Study

The study has explored the correlation between dynamic shading systems and photovoltaic technology, which provided an in-depth evaluation of various design configurations that prioritizes energy efficiency, architectural integration, and occupant comfort.

The study, through various simulations and analyses, showed that dynamic and adaptive shading systems are much better than static ones, with Design n.6 having the highest energy production of 1,877.55 kWh/year in south-facing orientations along with 90% efficiency of daylight management and up to 25% cooling load reduction. The evaluation across three orientations (South, South-East, and South-West) gave impressive proof to the use of adaptive systems in diverse environmental conditions while the economic assessment pointed out realistic payback periods ranging from 3.3 to 10.4 years. The research indicates that the combination of PV and dynamic shading is really a practical solution for sustainable building design, integration with dynamic shading, which in turn will help make the building energy-efficient, through creating softer cooling/heating effects. Mechanism of long-term operation and the need for researching the mentioned areas is an important goal of the study from the side.

PV Technology with Dynamic Shading

Pros	VS	Cons
High energy production		Durability concerns
Efficient daylight management		Mechanical consistency
Reduced cooling loads		Long-term performance
Viable for sustainable design		
Economic payback		

Conclusion

In this project the integration of photovoltaic (PV) technology into a dynamic shading systems was explored, focusing on an equal outcome in terms of energy efficiency, architecture and human thermal comfort performance.

The results demonstrate that new configurations for design assembly can satisfy the performance objectives without sacrificing appearance criteria or functionality. This Thesis incorporates photovoltaic (PV) systems into six different design samples of shading, ranging from complex passive solutions to light-active sun-responsive dynamic systems.

Every design was developed and tested in its own conceptual vacuum with the aim to balance energy efficiency against form and occupant comfort.

During this simulations 3 different orientation were proposed as South South-East and South-West in which for each of these the simulation has bee done separately, in e different pathways as open, closed and an optimized one which is a dynamic one in which the pannels are able to move based on the sun position.

Evaluation of Results

General reliability, in particular, is another crucial area of research that is especially needed for the new dynamic shading systems integrated with PV technology to ensure their long-term functionality and broad diffusion in sustainable architecture. In this thesis, after the analysis of the mentioned different shading designs, the main performance evaluation of energy production was investigated, considering that, among all the different designs, the highest annual energy yield generated is Design n.6 (South-facing) at 1,877.55 kWh/year. While the energy production performances are promising, further explorations into durability, mechanical consistency, and operational stability under real environmental conditions become quite critical and without evaluating these factors the evaluation of the reliability of such systems in the real world is not possible. Long-term performance analysis of materials and mechanical parts, such as actuators and hinges, shall be carried out under simulated conditions of wind, temperature fluctuations, and UV radiation. Other key themes for further research concern the development of advanced control systems that will offer precision and reliability during the operation of dynamic shading systems. As it has been seen from the analysis of Designs n. 5 and n. 6, integrating sensors and actuators allows for a dynamic adjustment of the position of the shading. The responsiveness of these systems in different environmental conditions will have to be tested. How such systems maintain functionality during unfavorable events such as power losses or even sensor failure will determine their stability in the long run (Al Touma et al., 2019). Besides this, field studies regarding diverse climatic conditions are extremely important for system design optimization parameters in response to harsh, extreme climate conditions that further enhance system resilience. These area, along with those identified in this review for future research, will help develop further robustness, lifetime, robustness, and sustainability for dynamic shading systems, enable them to stand up against stresses developed within modern architecture, and give dynamic facades high relevance to energy-efficient adaptive building design.

Future Work

Challenges:

The systems designed and considered in this study face numerous challenges like high initial costs, complex integration with aesthetics, and increased maintenance needs for moving parts that need to be assessed and analysed in the next step in order to overcome these challenges to reach the best solution possible.

Future work

This research could be proof that architectural designers can combine their aesthetic and performative concerns and it hopefully provides grounds for future designs to integrate performance-enhancing technologies. Thus research offers the opportunity for further question and future study on:

- the overall power output by the sun-tracking PV cell versus the facility consumed by the system. This study should explore how economical and energy-efficient it's to use computers and servo motors to run a classy sun-tracking system.
- The effect of continuous data recording on the results instead of hourly samples of reading.
- the way to protect the PV cells from dust and climatic elements and also keep birds from nesting within the frames.
- The effect of more sophisticated sensors on data readings.

Final Reflection

These six designs cover the whole range of innovation and represent a combination of energy production, visible aspects, and comfort for the residents. The first two of them, being Design n.1 and Design n.2, could only give 14,769 kWh/year and 57,939 kWh/year relatively, while the other ones did much better, for instance Design n.5, which reached 106,356 kWh/year together with Design n.6 of 120,284 kWh/year in south-facing viewpoints.

Also, dynamic systems consumed less energy for cooling by 25% in south oriented facade, showing that their adaptability is quite high. This paper presents the architecture of an ecologically sustainable future in which technology that connects the geometrical building systems with the environment is being used.

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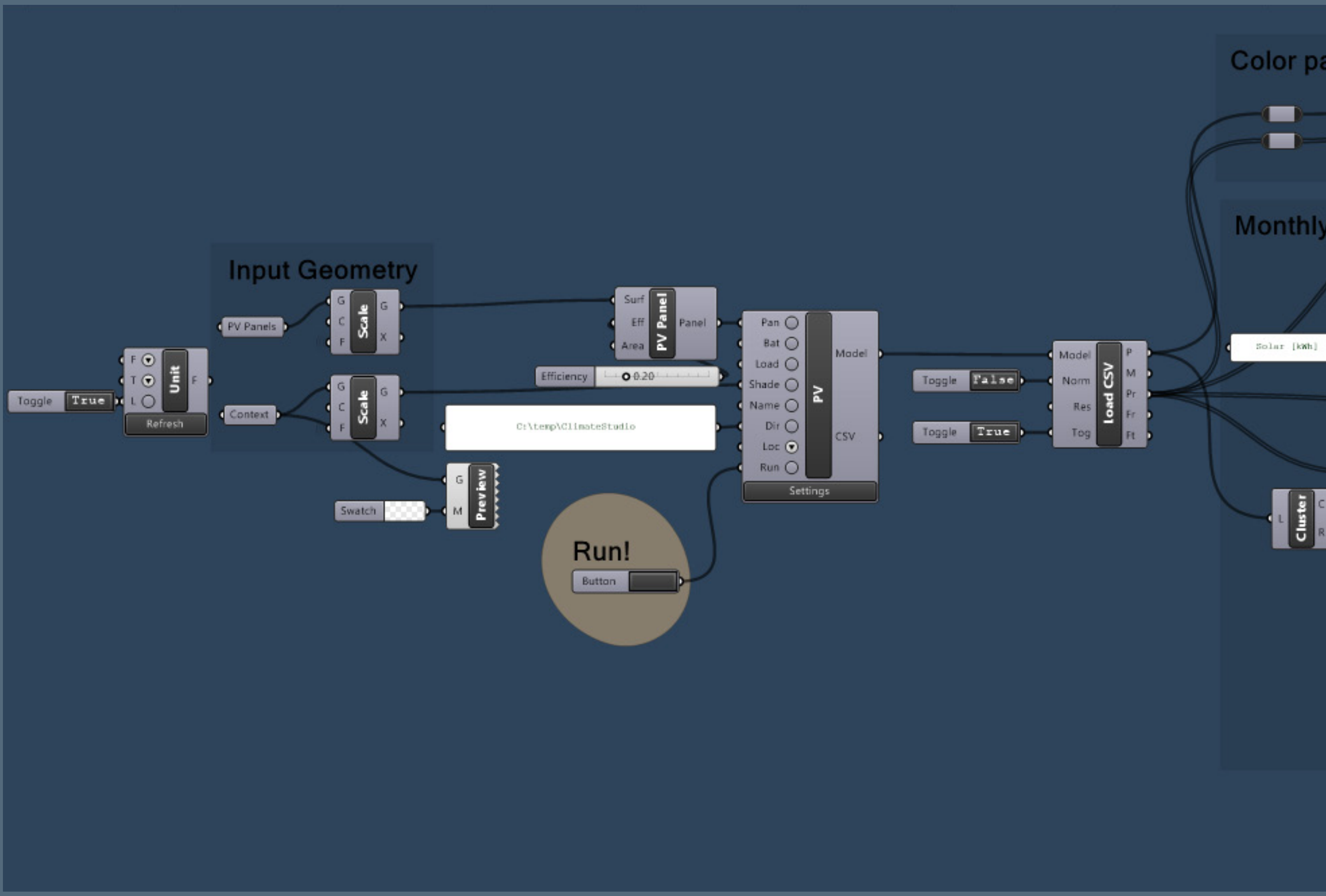
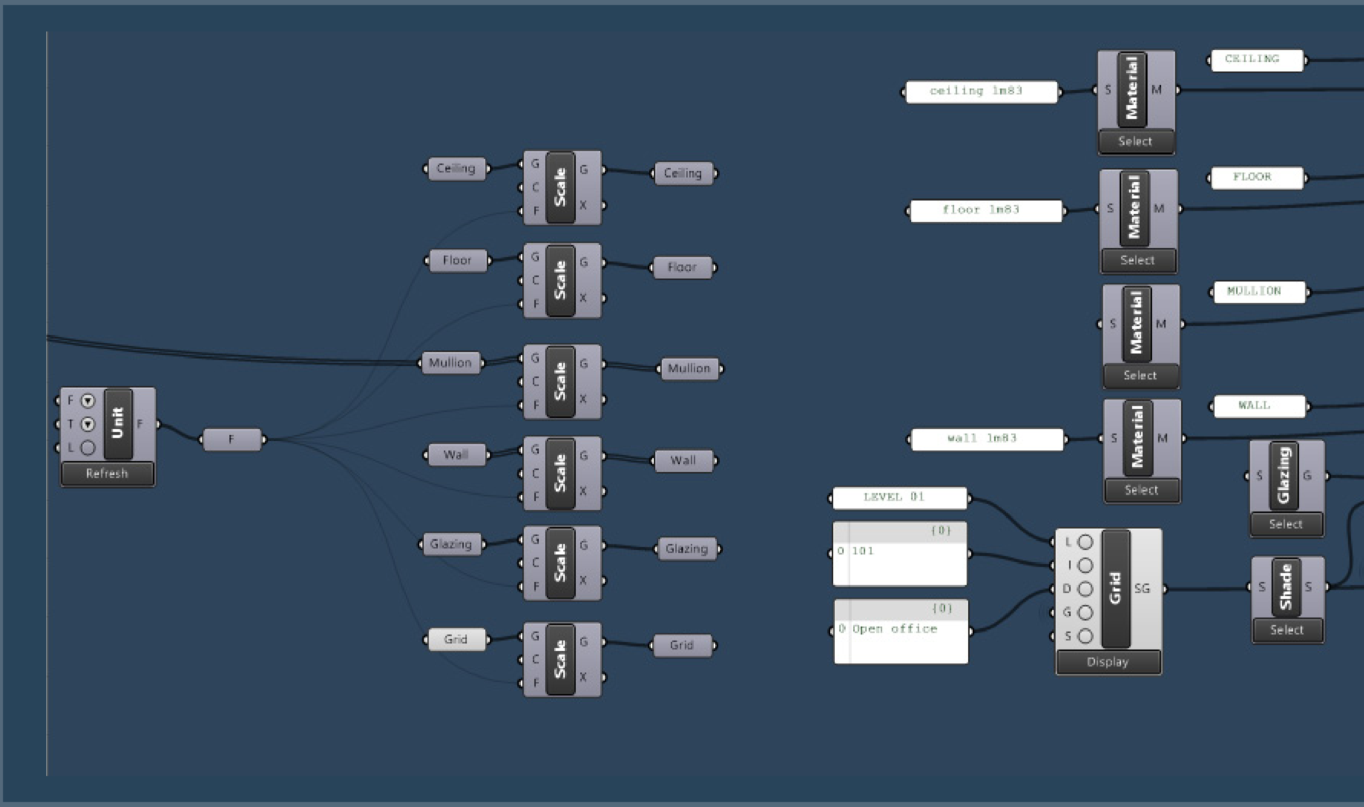
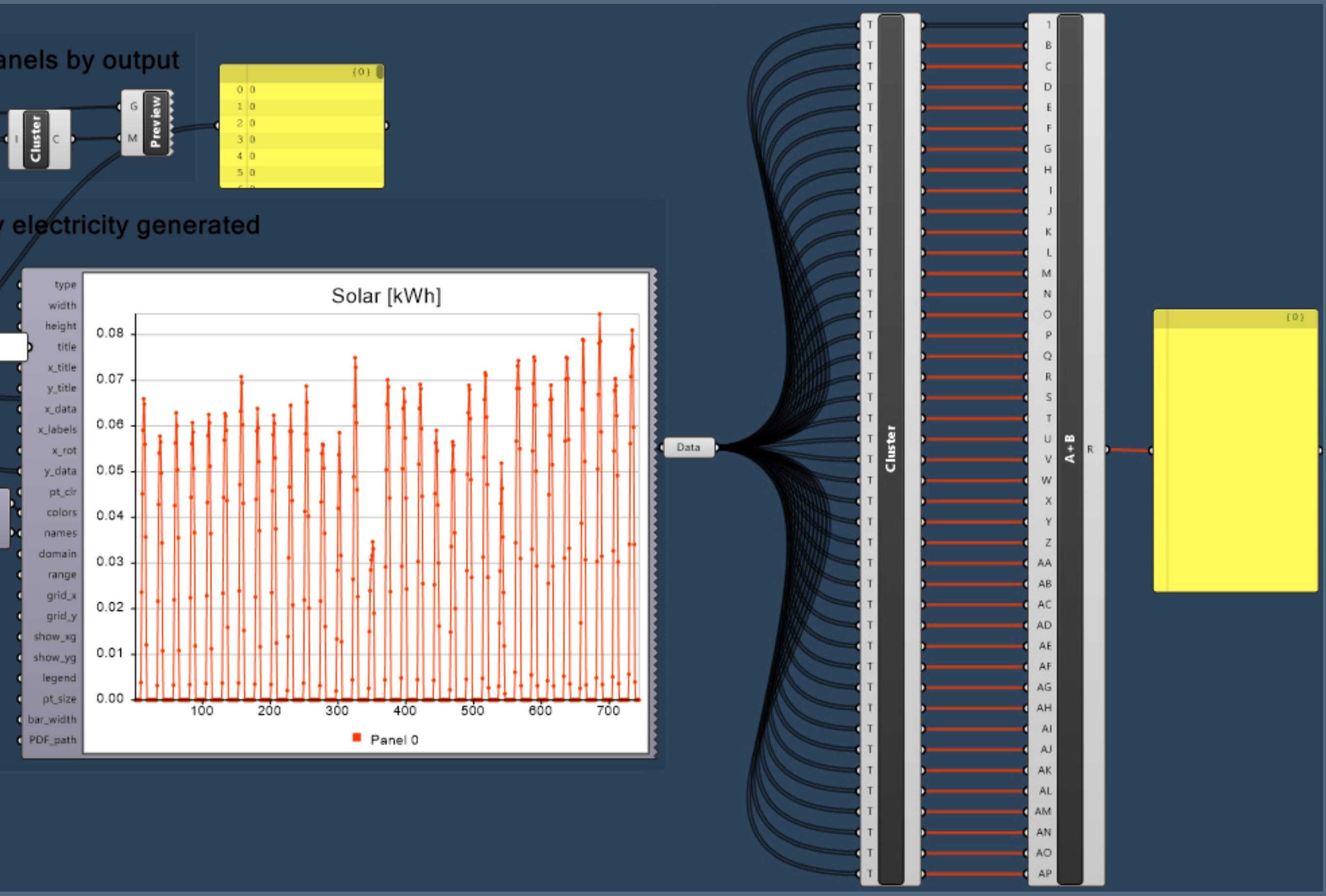
PV system_ Energy Production



PV system_ Daylight Analaysis





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0 0
1 0
2 0
3 0
4 0
5 0
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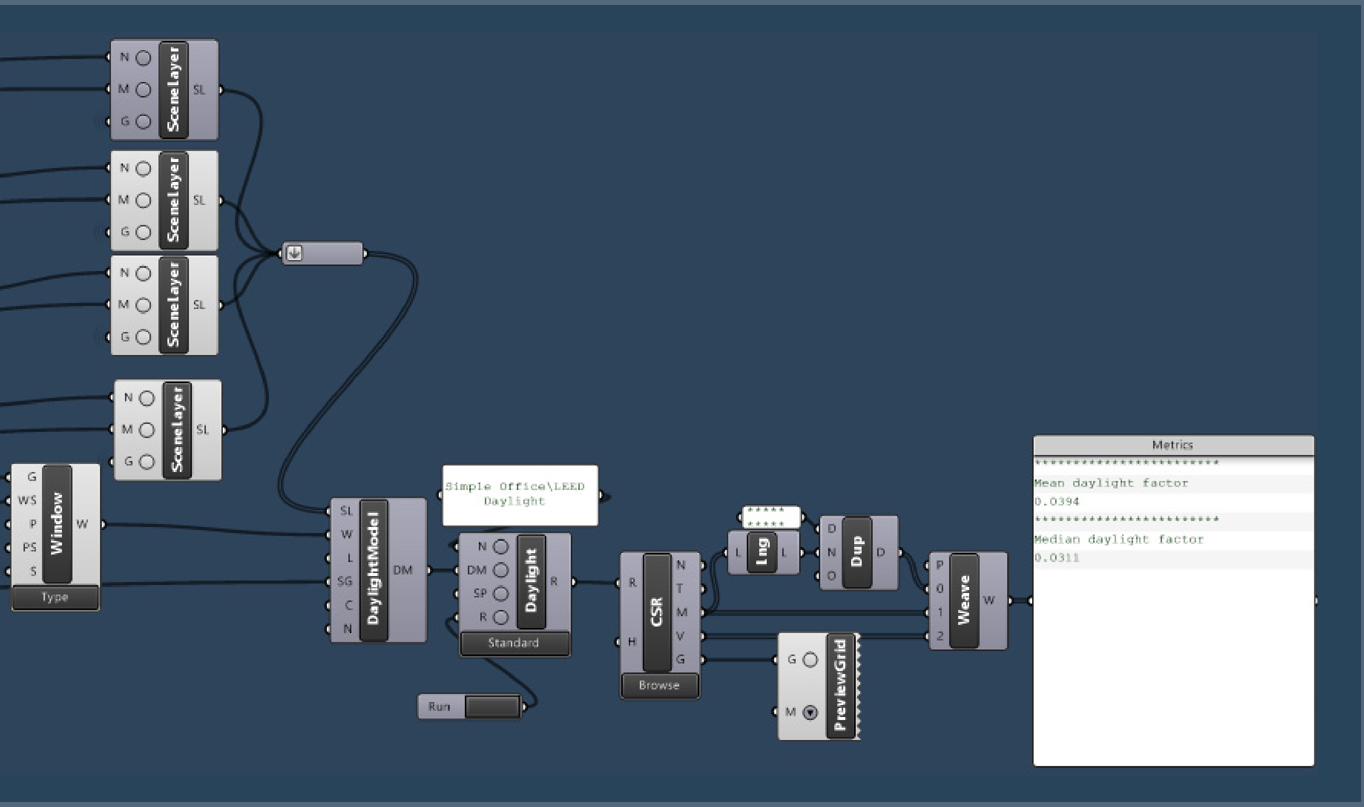
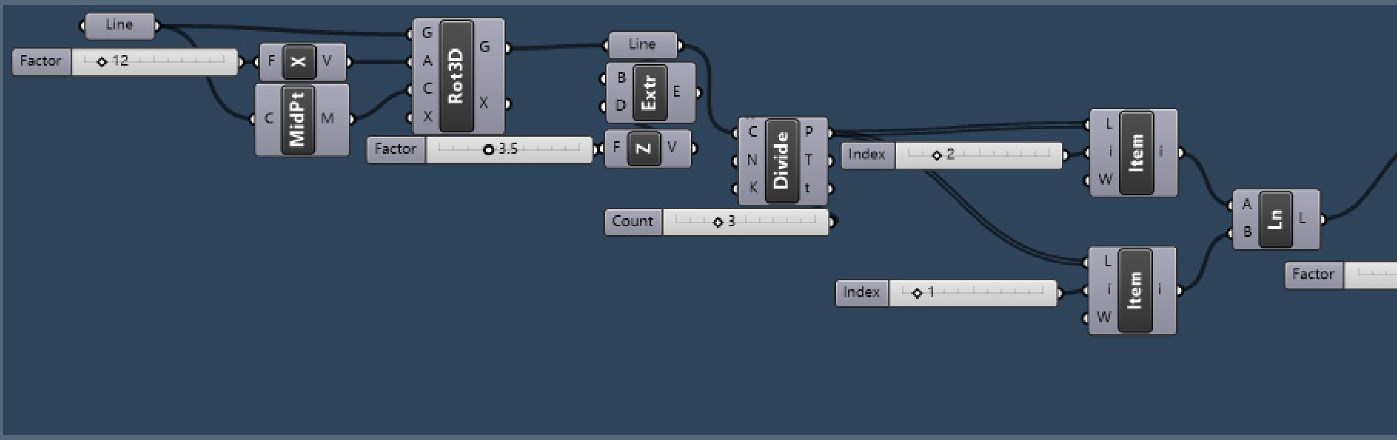


```
Simple Office\LEED
Daylight
```

```
Metrics
************************
Mean daylight factor
0.0394
************************
Median daylight factor
0.0311
```

Design n.1



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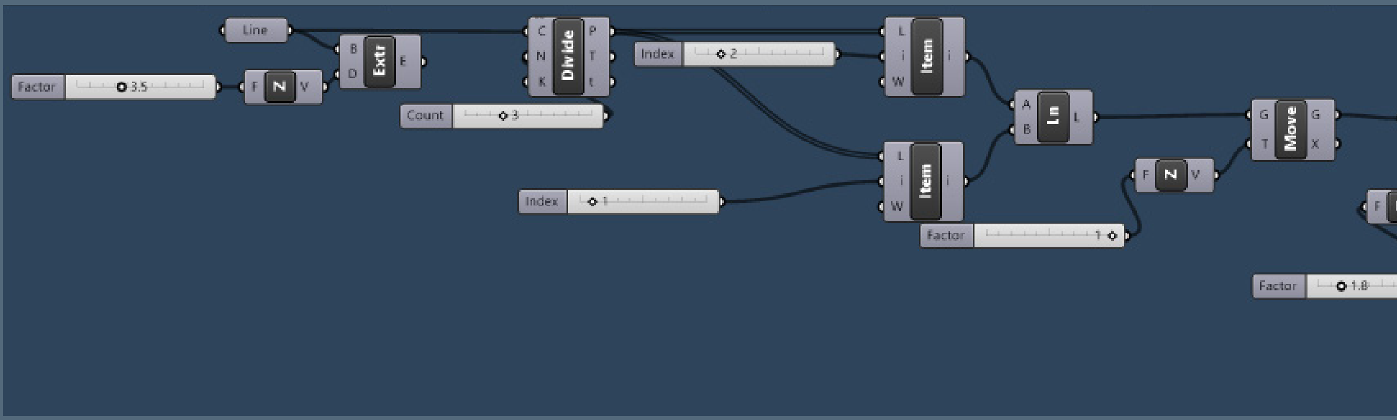
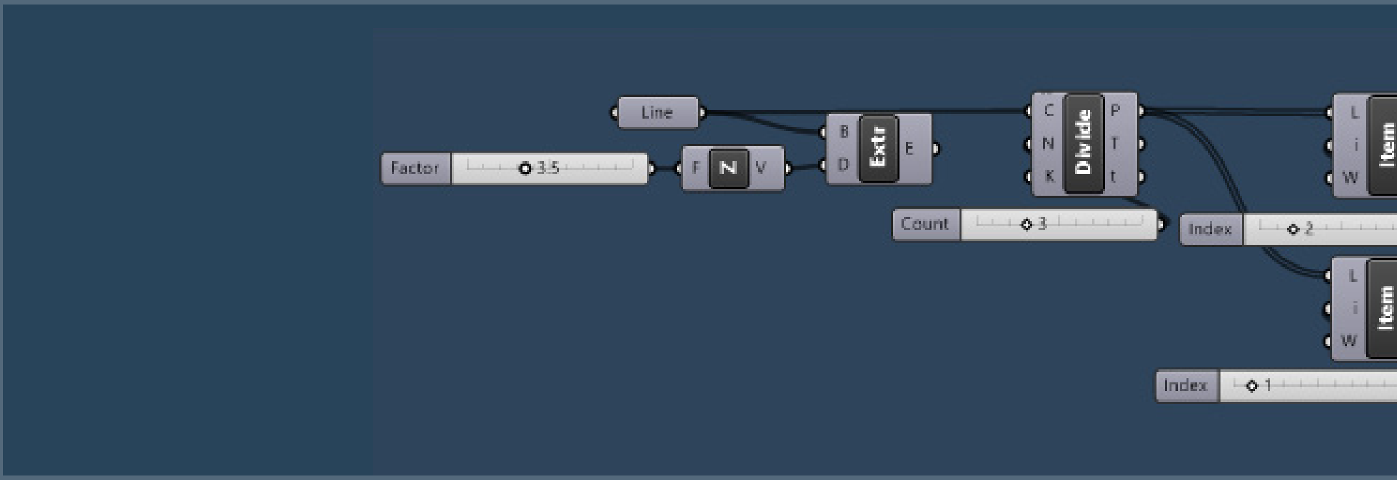
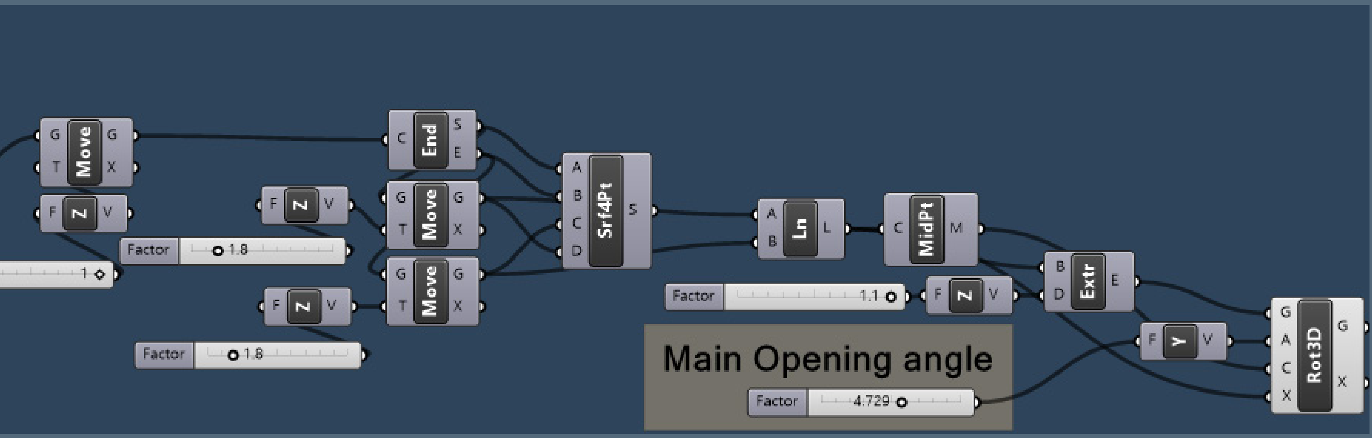


Design n.3





Factor 1.8

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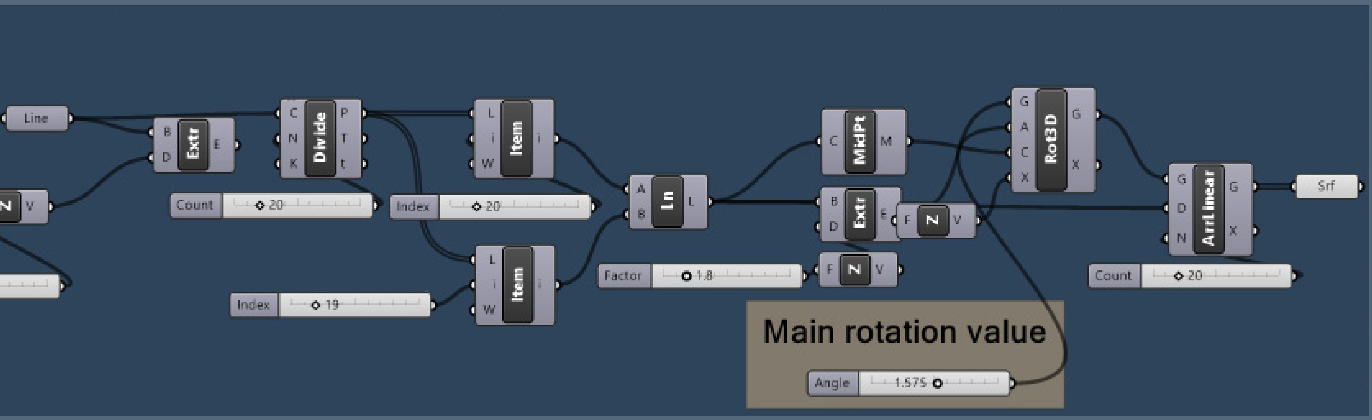
Factor 1.8

Factor 1.1

Factor 4.729



Count 20

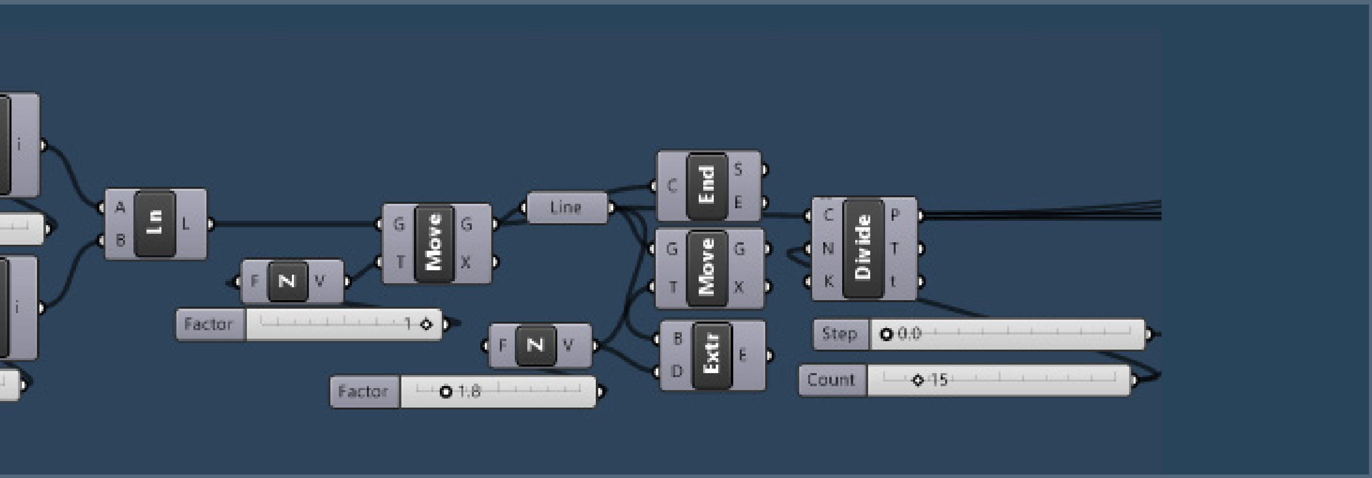
Index 20

Index 19

Factor 1.8

Count 20

Angle 1.575

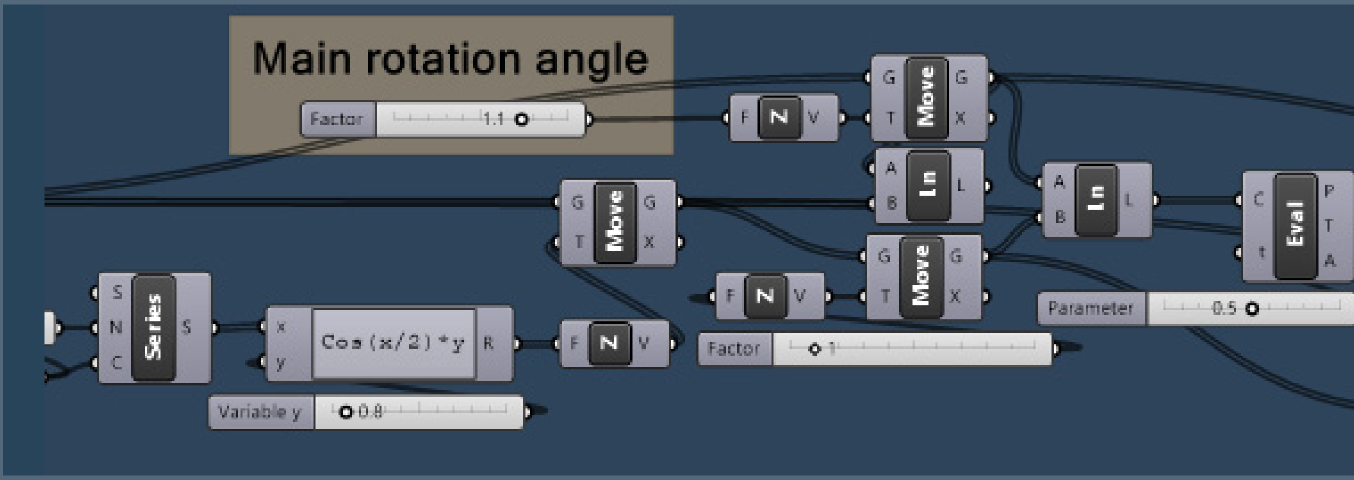


Factor 1

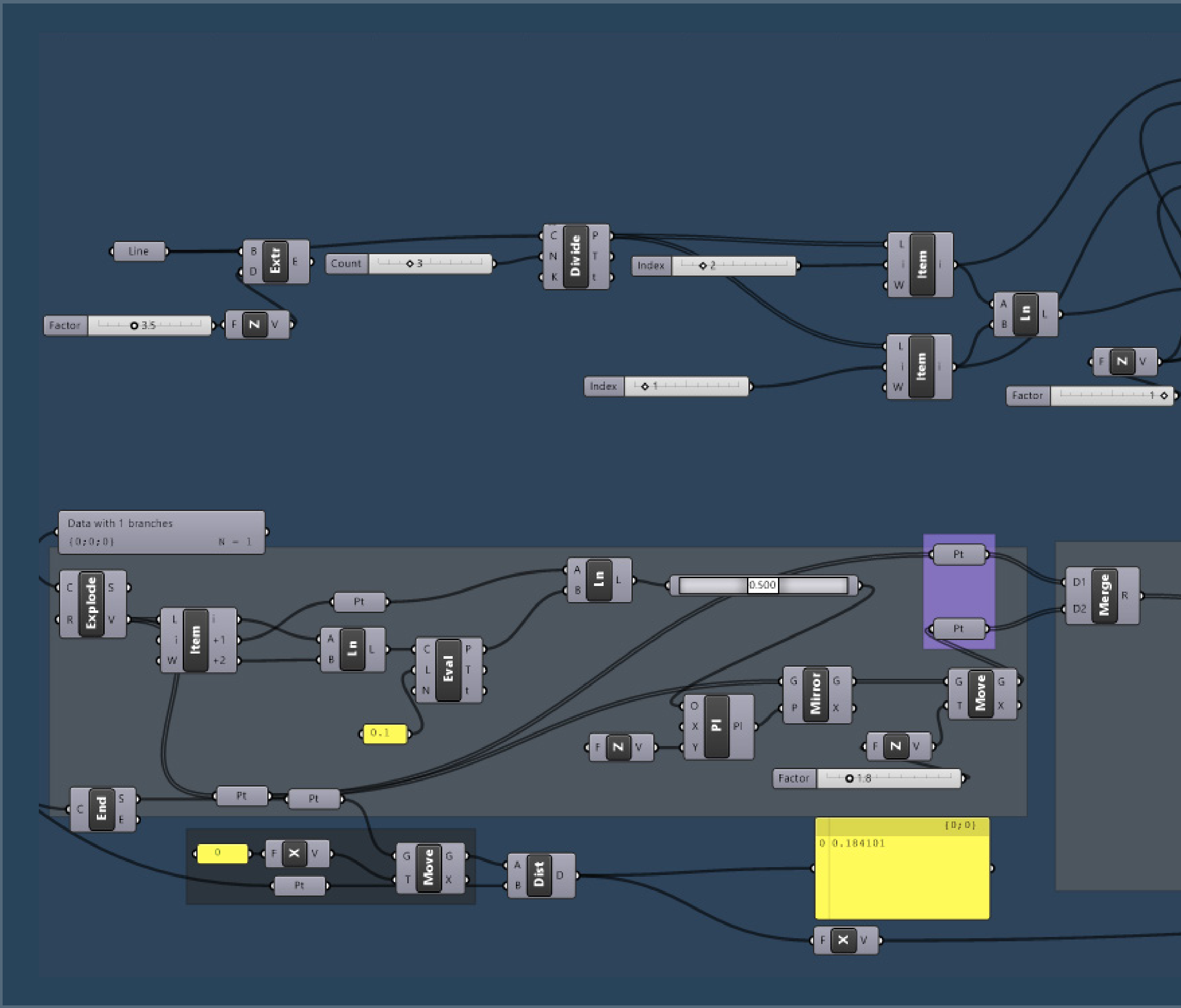
Factor 1.8

Step 0.0

Count 15


Main rotation angle
Factor
1.1
Move
Ln
Ln
Move
Move
Eval
Series
Cos(x/2)*y
Variable y
0.8
Parameter
0.5
Factor
1

Design n.4


Line
Extr
Factor
3.5
Count
3
Divide
Index
2
Item
Item
Index
1
Ln
Factor
1
Data with 1 branches
{0;0;0}
N = 1
Explode
Item
Pt
Ln
Ln
Eval
0.1
0.500
Pt
Pt
Merge
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Move
Factor
1.8
End
Pt
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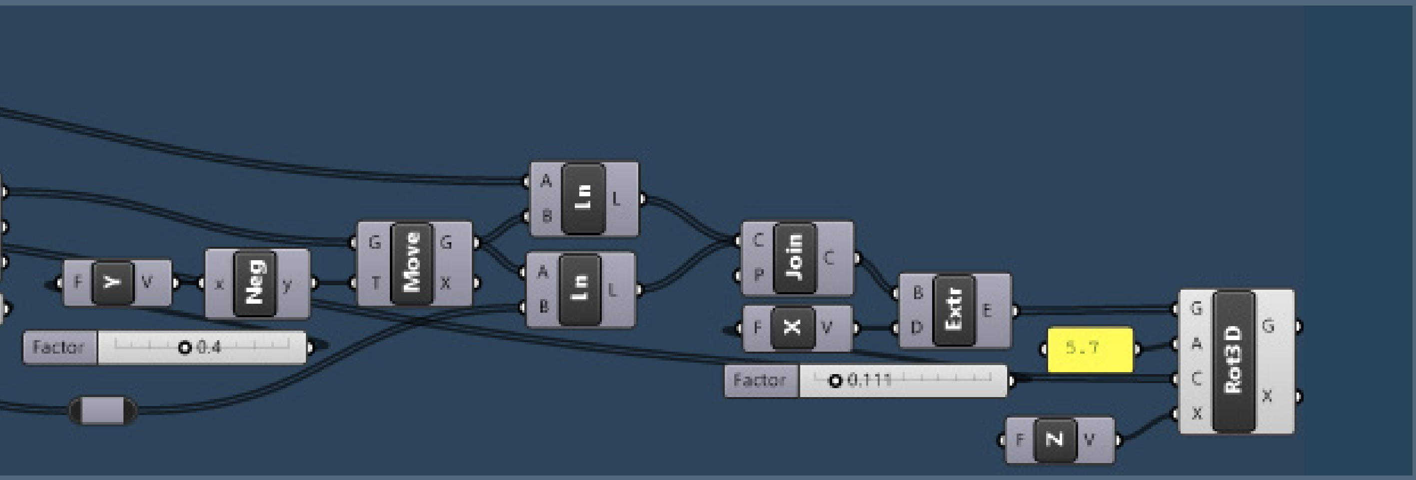
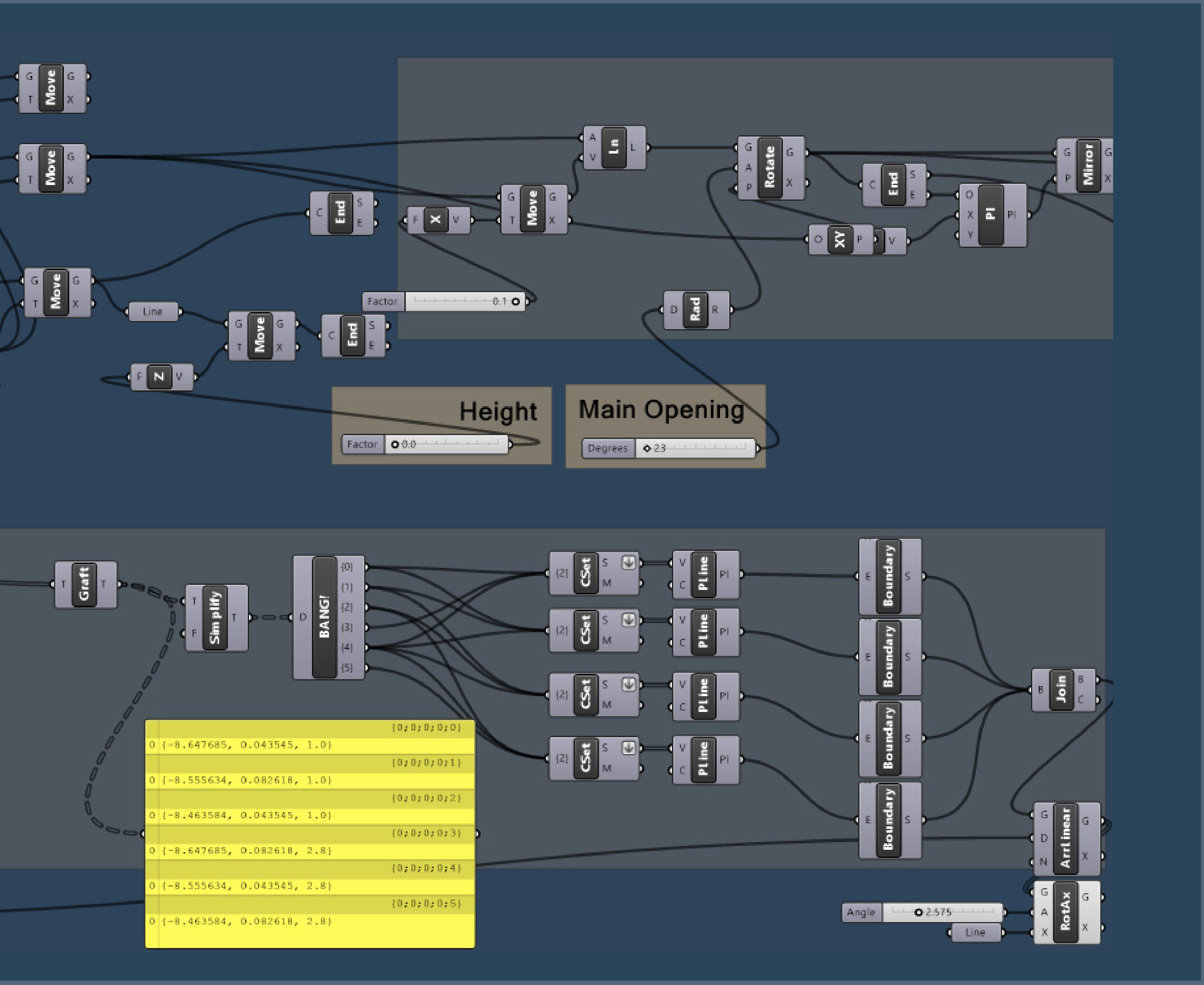


Factor 0.4

Factor 0.111

5.7



Factor 0.1

Height

Factor 0.0

Main Opening

Degrees 23

Angle 2.575

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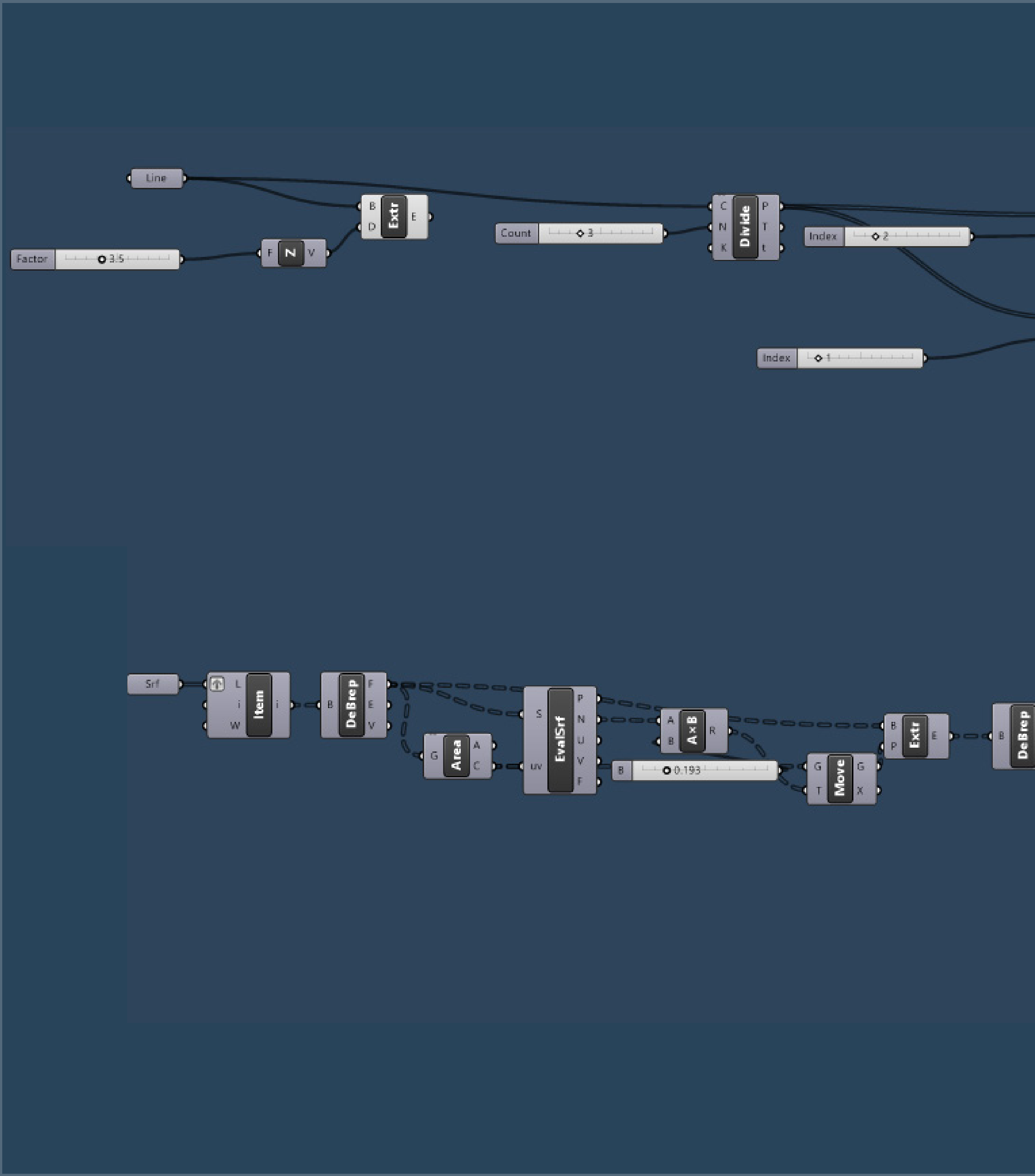
                         {0;0;0;0;2}
0 {-8.463584, 0.043545, 1.0}
                         {0;0;0;0;3}
0 {-8.647685, 0.082618, 2.8}
                         {0;0;0;0;4}
0 {-8.555634, 0.043545, 2.8}
                         {0;0;0;0;5}
0 {-8.463584, 0.082618, 2.8}
```

Design n.5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Index 2
Index 1
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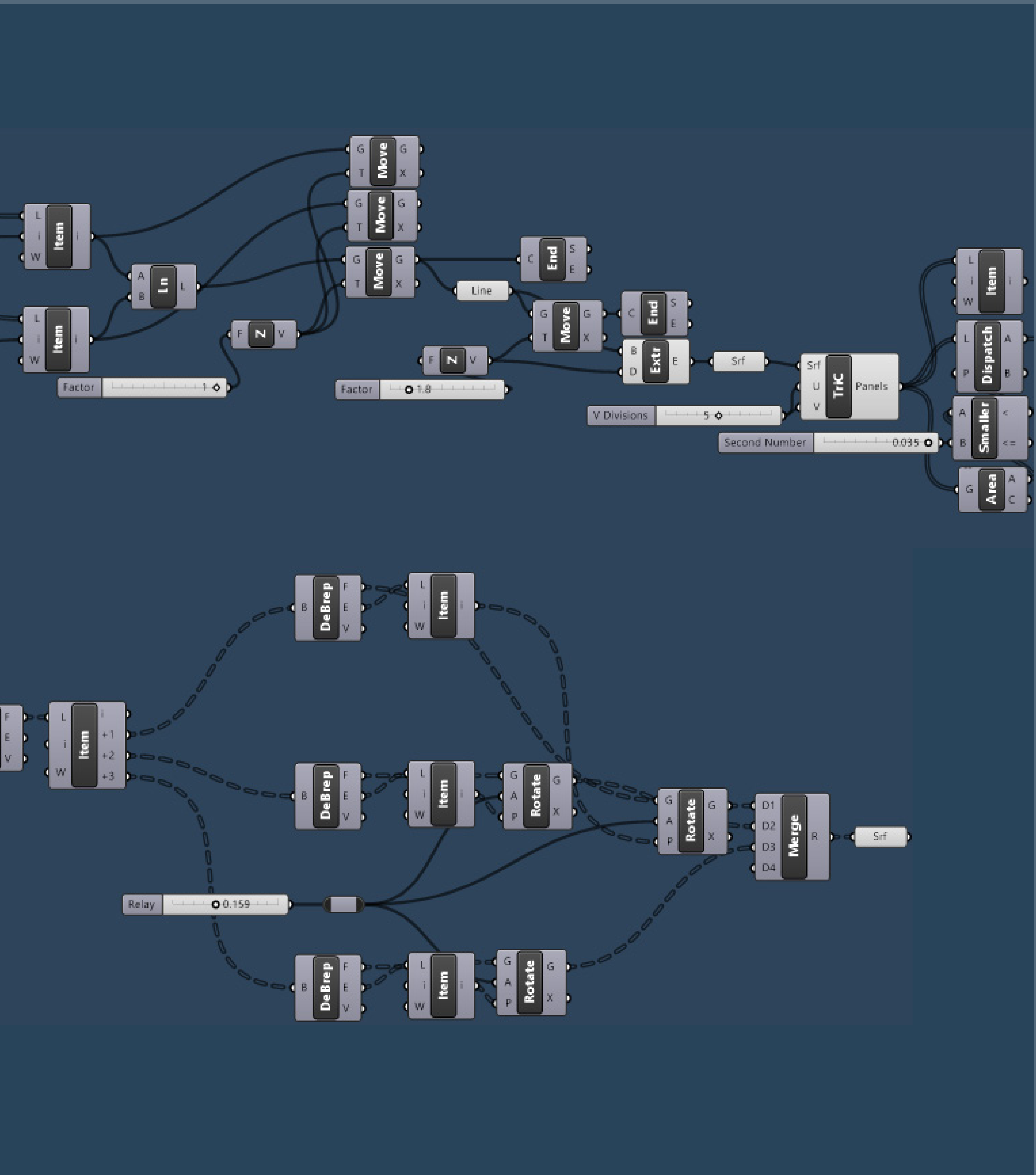
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5
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Smaller
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DeBrep
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DeBrep
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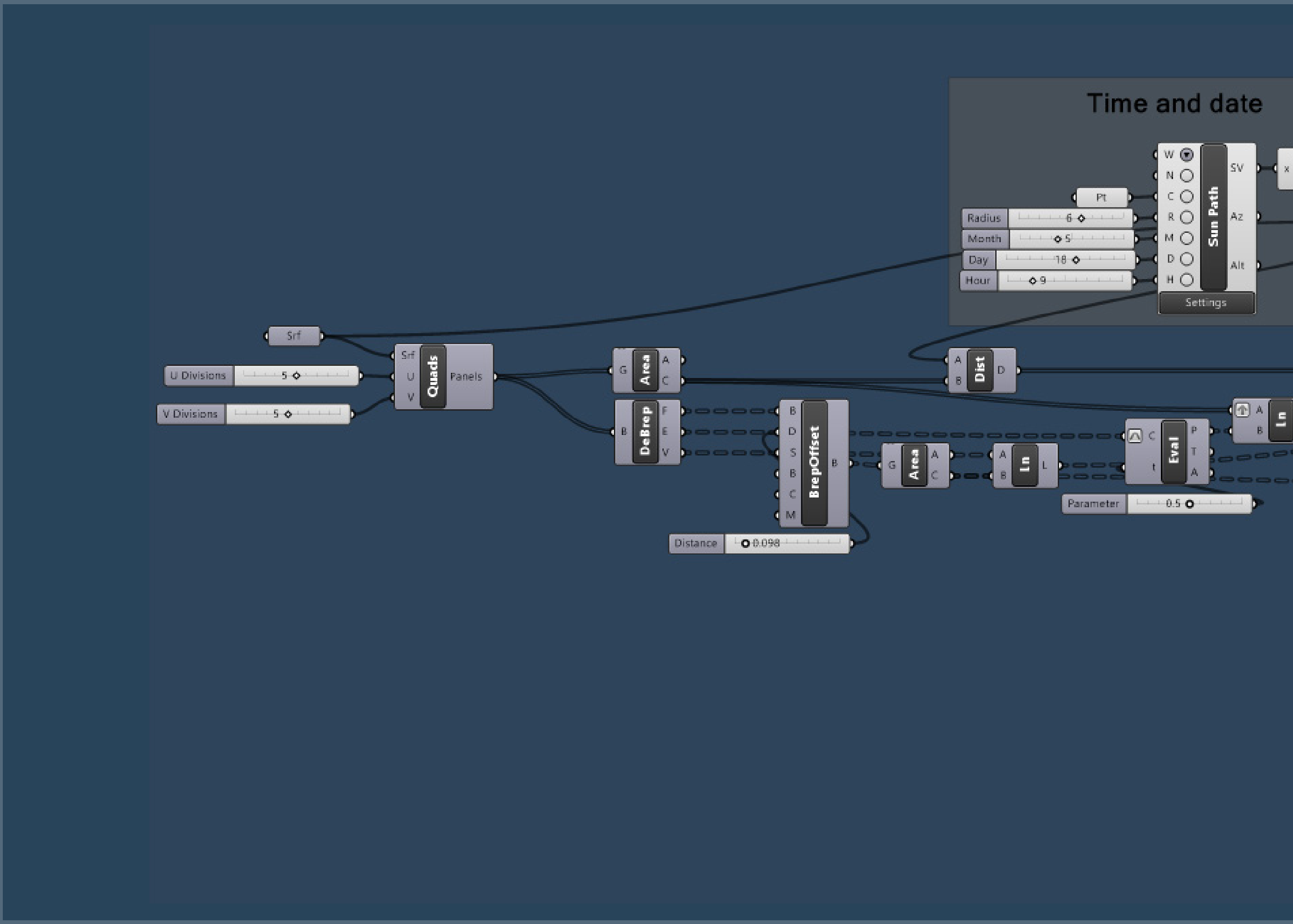
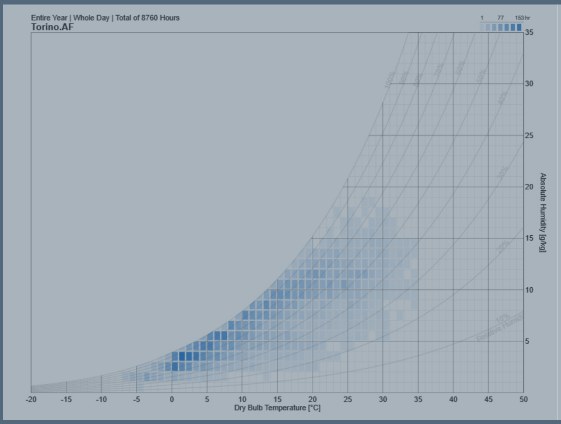
Rotate

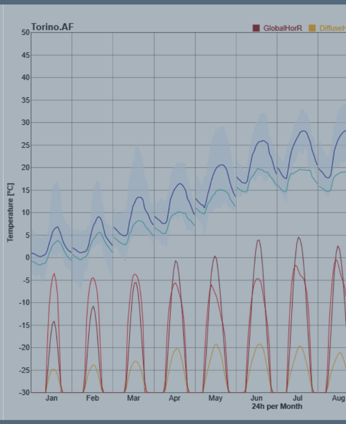
Design n.6

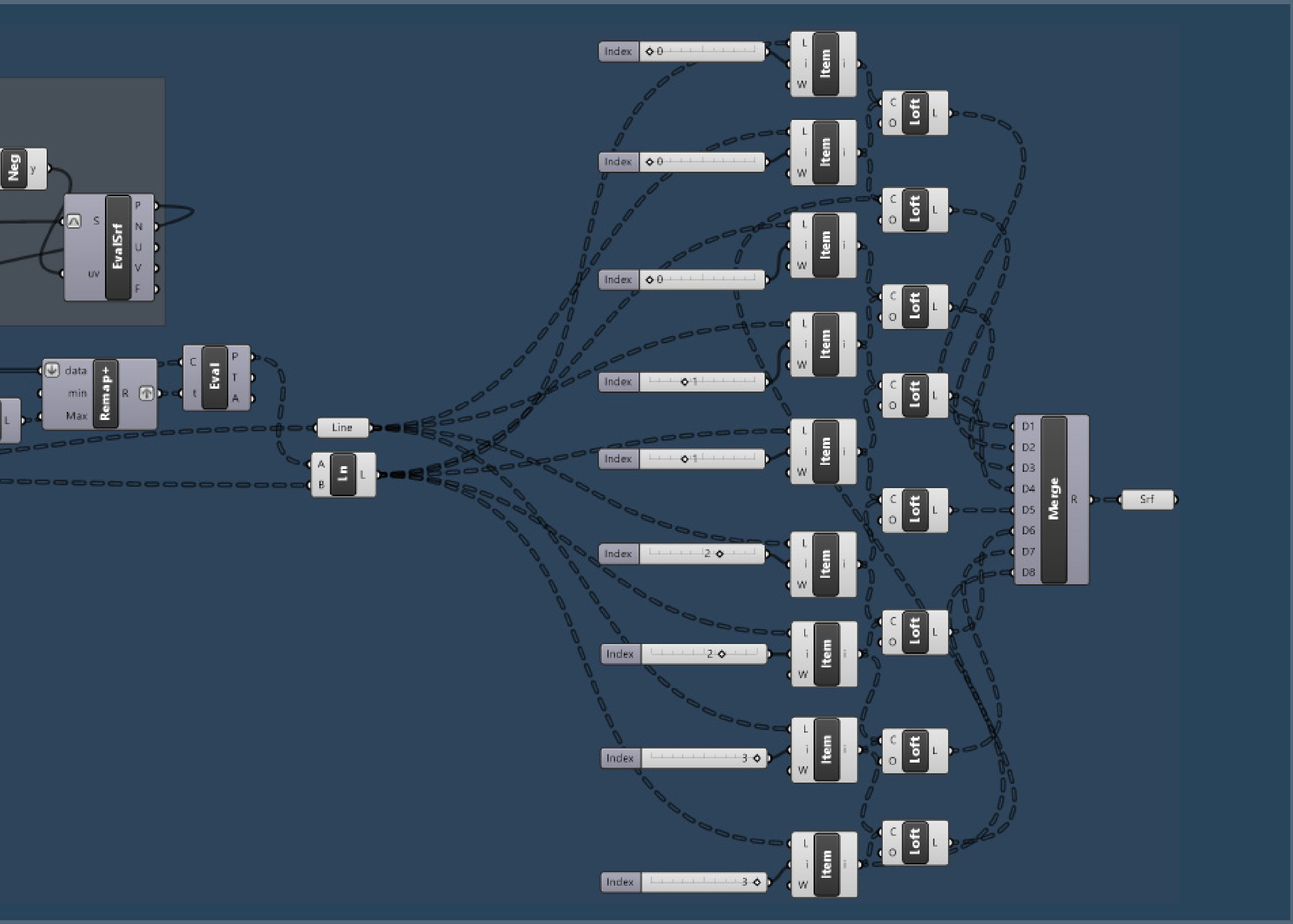


Weather and the Data (ClimateStudio)

ITA_PM_Torino.AF.160595_TMYx.2007-2021
Koeppen climate Zone: Temperate, No Dry Season, Warm Summer (Cfb)
ASHRAE climate zone: Mixed (4)
Average annual temperature: 13 °C
Annual total solar radiation: 1,343 kWh/m2
Heating Design Conditions
Coldest month: January
Coldest week: 1/13 - 1/19
Typical winter week: 1/ 6 - 1/12
Annual HDD for 18 °C is: 2,801
Design temperature 0.04%: -4.6 °C
Cooling Design Conditions
Hottest month: July
Hottest week: 8/10 - 8/16
Typical summer week: 7/ 6 - 7/12
Annual CDD for 10 °C is: 1,582
Design temperature 99.6%: 32 °C






Neg
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1
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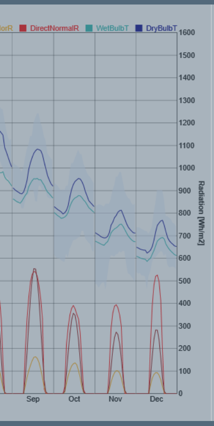
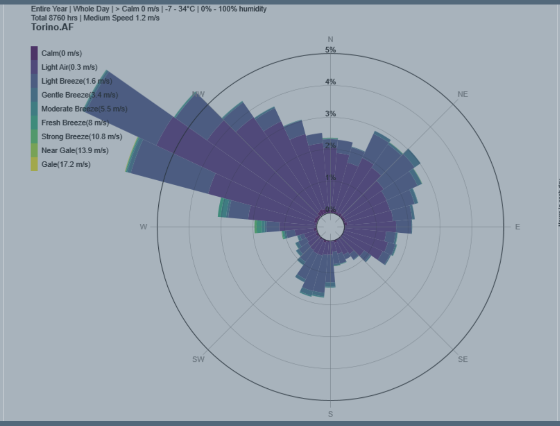
Merge
R
Srf


lorR
DirectNormalR
WetBulbT
DryBulbT
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Radiation [Wh/m2]
Sep
Oct
Nov
Dec


Entire Year | Whole Day | > Calm 0 m/s | -7 - 34°C | 0% - 100% humidity
Total 8760 hrs | Medium Speed 1.2 m/s
Torino.AF
Calm(0 m/s)
Light Air(0.3 m/s)
Light Breeze(1.6 m/s)
Gentle Breeze(3.4 m/s)
Moderate Breeze(5.5 m/s)
Fresh Breeze(8 m/s)
Strong Breeze(10.8 m/s)
Near Gale(13.9 m/s)
Gale(17.2 m/s)
N
NE
E
SE
S
SW
W
NW
5%
4%
3%
2%
1%
0%


UTCI | Entire Year | Whole Day | Total of 8760 Hours | > Calm 0 m/s | -7 - 34°C | 0% - 100% humidity
Torino.AF
Hours in each day
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Days in a Year
Extreme Cold Stress
0
0
Strong Cold Stress
24
1049
2245
No Thermal Stress
4458
846
Strong Heat Stress
138
0
Extreme Heat Stress
0 hrs

Dynamic and Adaptive Photovoltaic Shading Systems: Design and Architectural Integration for Energy Production and Indoor Comfort.

Roshanak Roshan Kharrat/
S301099

Politecnico di Torino
Turin, Italy
December 2024