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MASTER OF SCIENCE THESIS SUBJECT:

USER-SPECIFIC AUTOMATED KINETIC SHADING DESIGN IMPLEMENTING MULTI-OBJECTIVE OPTIMIZATION AND MACHINE LEARNING TOOLS

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Abstract - English

With the increasing demand for sustainable design and green buildings, performance is becoming an important driving force behind design decisions. Currently, however, possible solutions explored to better building performance, considering the variety of technological developments in other fields, are limited. Two of the main limitations for an early designer are performance evaluation methods and automation systems to facilitate buildings to become smart. This research proposes a new shading performance optimization and automation process that can help designers evaluate both daylighting and energy performance, generate optimized smart design options that can be optimized during their service life to provide user-specific solutions to occupants' needs.

The proposed method of performance optimization utilizes various tools and technologies including parametric design, building simulation modeling, Genetic Algorithms, and Machine Learning tools. In this method, prevalent shading design alternatives are explored through parametric design. Daylighting and energy modeling simulations are performed to evaluate shading device performance. Genetic Algorithms are used to identify design options with optimal energy and daylighting performance. And a user-specific automation algorithm is developed to automate the performance of dynamic shading devices. A case study is conducted to verify the effectiveness of the overall design process. Various results were analyzed and the potential influence of design decisions in different shading designs was discussed. Finally, possible future work related to this research is discussed.

Keywords: automation; control agent; Machine Learning; multi-objective optimization; optimization; parametric design; Roller Blinds; shading design; smart building; Venetian blinds

Abstract - Italiano

Con la crescente domanda di design sostenibile e di edifici verdi, le prestazioni energetiche stanno diventando un fattore decisivo e determinante di ogni progetto. Attualmente, tuttavia, le possibili soluzioni esplorate per migliorare le prestazioni dell'edificio, considerando la varietà degli sviluppi tecnologici in altri campi, sono limitate. Due dei principali limiti per un neo-progettista sono i metodi di valutazione delle prestazioni energetiche e i sistemi di automazione per agevolare le trasformazioni degli edifici in edifici intelligenti.

Questa ricerca propone un nuovo processo di ottimizzazione e automazione delle prestazioni di schermatura che può aiutare i progettisti a valutare sia l'illuminazione diurna che le prestazioni energetiche, generare opzioni di progettazione intelligente ottimizzate che possono essere ottimizzate durante la loro vita utile per fornire soluzioni specifiche alle esigenze degli occupanti.

Il metodo proposto per l'ottimizzazione delle prestazioni utilizza vari strumenti e tecnologie tra cui la progettazione parametrica, la modellazione di simulazione di edifici, gli algoritmi genetici e gli strumenti di apprendimento automatico. In questo metodo, le alternative di progettazione dell'ombreggiatura prevalenti vengono esplorate attraverso la progettazione parametrica. Per valutare le prestazioni del dispositivo di ombreggiatura vengono eseguite simulazioni di modellizzazione dell'energia e dell'illuminazione diurna. Gli algoritmi genetici vengono utilizzati per identificare le opzioni di progettazione con prestazioni energetiche e di luce diurna ottimali. E viene sviluppato un algoritmo di automazione specifico dell'utente per automatizzare le prestazioni dei dispositivi di ombreggiatura dinamica. Viene condotto un caso di studio per verificare l'efficacia del processo di progettazione complessivo. Sono stati analizzati vari risultati ed è stata discussa la potenziale influenza delle scelte progettuali in diversi progetti di ombreggiatura. Infine, viene discusso il possibile sviluppo della ricerca in futuro.

Keywords: automazione; agente di controllo; apprendimento automatico; ottimizzazione multi-obiettivo; ottimizzazione; progettazione parametrica; Tende a rullo; progettazione dell'ombreggiatura; edificio intelligente; veneziane

Abstract - Persian

با افزایش تقاضا برای طراحی پایدار و ساختمانهای سبز ، عملکرد در حال تبدیل شدن به یک نیروی محرکه مهم در تصمیم گیریهای طراحی است. در حال حاضر ، با این حال ، با توجه به تنوع پیشرفت های فن آوری در زمینه های دیگر ، راه حل های ممکن برای عملکرد بهتر ساختمان محدود است. دو مورد از محدودیت های اصلی برای یک طراح اولیه روش های ارزیابی عملکرد و سیستم های اتوماسیون برای تسهیل هوشمند سازی ساختمان ها است. این تحقیق فرایند بهینه سازی عملکرد و اتوماسیون سایه بانی جدید را ارائه می دهد که می تواند به طراحان کمک کند تا هم میزان نورگیری و هم عملکرد انرژی را ارزیابی کنند ، گزینه های طراحی هوشمند بهینه سازی شده را ایجاد کنند که می توانند در طول عمر خود بهینه شوند تا راه حل های مختص کاربر را برای نیازهای ساکنین ارائه دهند.

روش پیشنهادی بهینه سازی عملکرد از ابزارها و فن آوری های مختلفی از جمله طراحی پارامتریک ، مدل سازی شبیه سازی ساختمان ، الگوریتم های ژنتیک و ابزارهای ماشین لرنینگ استفاده می کند. در این روش ، گزینه های رایج طراحی سایه بان از طریق طراحی پارامتریک بررسی می شوند. شبیه سازی طراحی نورگیری و مدل سازی انرژی برای ارزیابی عملکرد سیستم سایه بان انجام می شود. از الگوریتم های ژنتیک برای شناسایی گزینه های طراحی با انرژی بهینه و عملکرد روشنایی استفاده می شود. و یک الگوریتم اتوماسیون کاربرمهور برای اتوماتیک کردن عملکرد دستگاه های سایه بان پویا ساخته شده است. یک مطالعه موردی برای بررسی میزان موثر بودن روند کلی طراحی انجام شده است. نتایج نهایی مورد تجزیه و تحلیل قرار گرفت و تأثیر بالقوه تصمیمات طراحی در طرح های مختلف طراحی سایه بان مورد بحث قرار گرفت. در نهایت، کارهای آینده احتمالی مربوط به این تحقیق مورد بحث قرار گرفته است .

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To the loving memory of my father.

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1. INTRODUCTION

1.1 Problem Statement

Energy Crisis and climate change have increased the concerns for sustainability around the world. In the last half-century, the amount of energy and electricity which are consumed in buildings sector has increased, it is predicted that it is also going to increase during the next few decades. In other words, the subject of building energy has an important effect on the increase of pollution of the environment and changing the world climate. By considering this fact that the amount of fuel fuels source is limited and going to decrease during the time. According to sustainable goals, as an important subject of these days, it is essential to keep this kind of energy sources. All over the world, governments try to guard the planet and the main goal is to keep for future generation, with smart using.

What is more obvious that all buildings need the energy to create comfort and a healthy environment for their occupants, for more clarification, buildings use this energy to produce comfort for residents. There is no doubt that, in addition to this, other parameters are also effective such as outdoor environment and weather conditions and solar angles. They are based on the building envelope, which provides the primary barrier between the outdoor and conditioned indoor environment. Making a balance between energy use and demand reduction and keeping the comfort of occupants is a big challenge and needs lots of notices. Trying to make the effective design of elevations and using a different type of shadings for transparent parts are some of the ways which are attractive these days. Shading systems can make a balance between occupants' comfort and building energy consumption. As a member of envelop system, shadings are known strategies to control the energy-using of buildings and controlling comfort (N. A. Al-Tamimi and S. F. S. Fadzil, 2011). Controlling daylight has many positive effects not only on building energy performance but also on occupant comfort and productivity. These solutions have several potential benefits such as reduction of greenhouse gas emissions (S. M. Al-Masrani, K. M. Al-Obaidi, N. A. Zalin, and M. I. Aida Isma, 2017) reduced building energy consumption and demand and also to provide monetary and other non-energy benefits.

Referring to the emerging information and communication technologies (ICT), the concept of smart is receiving a great attention worldwide. In particular, in the field of built environment, transversal studies highlight the fundamental role of smart houses and their significant impacts on the quality of user's life.

With the continuous advancement of computational technology, there are numerous building performance simulation tools available for designers and engineers to evaluate various aspects of building performance. Building performance simulation has been applied to different stages of building design and construction (Augenbroe, 2002). The early design stage is where most building design decisions are made, and where there is the greatest potential to achieve high-performance building designs (Miles, Sisk & Moore, 2001). Designing a systematic process for dynamic shading is essential and can

be achieved by investigating the design, mechanism, and control of this system. Therefore, to reach the best performance and strategy, it is necessary to highlight the parameters involved in the design of dynamic shading systems. Furthermore, the effect of shading geometry and position on comfort and energy demand based on climate conditions should be considered in designing. Hence, in addition to distinguishing the role of these factors in meeting the criteria for appropriate design, defining the dynamic shading is crucial as a system that has models, components, and mechanisms with different control strategies. In addition, aspects such as cost, maintenance, and technical installation should be considered.

Current methodologies for active control of dynamic shadings are based on specific rules to control environmental factors. They are entirely deterministic methods that always allocate an action to mitigate threshold values of a controlling environmental parameter (S. M. Al-Masrani and K. M. Al-Obaidi, 2019). Normally, guidelines are based on beam solar radiation, measuring the beam illuminance on the window, or illuminance levels on the work plane.

New control methodologies have shown improvement of rule-based and sensor-based methodologies to include more complex criteria (N. Delgarm, B. Sajadi, F. Kowsary, and S. Delgarm, 2016). In the last few decades, technological improvements for advanced envelope systems have changed the scenario related to glazing and material properties, actuators, shading devices, lighting systems, and their control, etc.... allowing to reduce solar gains, increase the visible light transmission, lower the maintenance costs, and adapt to changing climate stimuli, therefore a new path for the future design of high-performance envelopes is almost well delineated. However, the major weakness of current shading control systems is that each group has its own rule-based control. Many new systems that have been introduced recently do not yet have specific methods for design and control strategies. For instance, new forms inspired by nature (biomimetics) or origami expand the field of what kinematic solar shading could become in the future (M. Pesenti, G. Masera, F. Fiorito, and M. Sauchelli, 2015). Still, their performance has not been modeled systematically. The assumption driving the development of more complex dynamic shading systems is that the added complexity will widen the design field and provide better performances [17]. However, the origins of the kinematic systems and their real performance are rarely discussed. Current methods do not allow precise systematic design. In this context, innovative designs are often based on the intuition of experienced designers rather than on a data-driven design method.

1.2 Research purposes

This thesis focuses on two sections. Beginning with introducing a non-deterministic methodology for designing Shading Devices in office buildings based on the passive operation (predetermined schedule) by using NSGA II genetic algorithm optimization and integrated simulation of daylight and energy balance. Following with an automation algorithm which utilizes Machine Learning methods to predict user preference in terms of visual comfort thresholds. The methodology is based on the interpolation of pre-calculation of energy and daylight simulations and a combination of different control strategies for dynamic shading systems and applying optimization techniques with the

objective of global minimum energy cost and strict conditions of occupant comfort to find the proper design variables and control strategy.

The structure of the dissertation starts with the introduction chapter, in the introduction, the general concepts of parameters that are related to the discussion were defined. Chapter two studies a related discussion of the thesis in the frame of literature review. In chapter three is the general methodology followed in this thesis, the application of mentioned methods to a case study are discussed in chapter four. In chapter five the main results are discussed and undergone a thorough analysis. Also, discussions related to possible future works of the thesis are explained in said chapter.

2. LITERATURE REVIEW

2.1 Sustainable building

Humanity tries to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. Development should provide the modern needs of each society without imposing any harm on the environment or causing any sacrifice of the future generations' power for securing their needs. This kind of development is permanent and sustainable.

Sustainability is a complicated concept and is defined differently by different groups of people. Sustainability means consistency, coherence, and continuity. It is active, implying movement, and is a gesture for a possible future. Sustainability, despite its fundamental and universal mottos and promotion of environmental conservation, recommends a local attitude. It considers the slogan, "think universally but act locally," to provide realistic and feasible solutions while also providing protection of diversity (Khaleghi, 2019). Sustainability emphasizes relationships rather than pieces in isolation. The ecological movement has focused attention during the last century on the degradation of natural systems. This brings to light the connections between natural and human communities and between nature and culture. Sustainability has come to mean that we are one species on a web and that we are dependent on the natural world for our survival. There is a growing awareness and acceptance that population growth, resource consumption, and pollution are combining to weaken the ecology of the planet. There is evidence to suggest that we are altering the energy flows and material and nutrient cycles of the planet significantly enough to endanger and threaten a healthy future for humans and many other life forms. As the built environment is the main consumer of resources (materials and energy), a society in pursuit of sustainability must now, and in the future, concentrate on sustainable architecture.

Most simply, the idea of sustainability, or ecological design, is to ensure that our actions and decisions today do not inhibit the opportunities of future generations. This means making sure that our efforts work with our Earth's ecological systems rather than in opposition to them. Given that all human actions alter the systems we live in, the challenge of sustainability is a complex issue. It includes looking at how we attain the resources we use, using them in a way to get the most from them, and eliminating the idea of 'waste' from our vocabulary. There is no way to know with certainty how complex ecological systems will react to our influence, but there is an undeniable responsibility to act to the best of our knowledge.

2.2 Energy aspect of building

The energy model aim is to calculate the energy cost demand of buildings and energy cost saving. Whole-building energy modeling allows architects, engineers, and energy consultants to design a building's envelope, systems, and operation schemes to match its anticipated use profile and local conditions and to maximize energy efficiency or return on investment while subject to constraints such as the first cost. A 2013 study of 1,112 design projects submitted to the American Institute of Architects 2030 Commitment program shows that buildings designed using energy modeling have a design energy

consumption that is 44% lower than the 2003 stock. Buildings designed using prescriptive one-system-at-a-time rules outperform stock by only 29%There are technical challenges for building energy modeling that makes it more complicated this subject. (DOE (Department of Energy), 2015)According to the study aim, these challenges are included, Continued improvements to open-source modeling tools to make them faster, more accurate, and easier to use while keeping up with emerging building technologies, empirical validation, and calibration of energy modeling engines including new strategies for benchmarking model results against large numbers of well-monitored buildings, facilitated by low-cost sensors, controls, and communications capabilities. Requirement of measured information about temperature, equipment usage, occupancy, infiltration rates, and other critical variables. Modeling should account for different conditions and provide ranges of expected outcomes given reasonable distributions of inputs. (Pickard. K, 2013)

2.3 Comfort criteria and building

As mentioned before creating comfort environment is a priority. During the time human being have shown that always try to reach this, a place with lots of tranquility. It is important to know in each comfort discussion human health is a foremost point. Because by considering any reason, if built environment is leading to any sickness or even negative impact on the health of people it would be a matter of concern.

According to information of ASHRAE (ASHRAE, 2010), people spend about 80 to 90 percent of their time at the house, it is a considered number. Again, according to the same reference (ASHRAE, 2010) studies indicate that a vast range of subjects that are related to the occupant's comfort and their health have connected to building properties. All these witnesses are the reason for increasing the tendency of starting studies that are related to the human being comfort and building design. According to ASHRAE2004 new building regulations and legislation and green building guidelines have tried to highlight past ideas of sustainability and in this way, most of the time they ignored psychological, cultural, and sociological parameters which influence building different types of comfort. There are studies (EPA, 2000) which are studied the relationship between indoor air quality and the work performance of occupants, they focus their studies on an educational environment (school) and try to show the cause, consequences of poor indoor air quality of schools on child abilities to learn. They believe that poor air quality reduces a person's ability to perform especially in tasks requiring concentration, calculation, and memory activities. In the end, there are solutions for school systems to use tools to maintain air quality indoors.

In other studies, De Giuli and his colleagues studied to show if working or studying in a comfortable environment enhances not only well-being, but also satisfaction and therefore productivity and learning, they showed that problems which are related to indoor environmental quality such as insufficient air exchange by means of open windows, occasional insufficient lighting levels over the desks and, in general, nonuniform illuminance-distribution, probably due to improper solar shading use or even inappropriate shades. Pupils complained mostly about thermal conditions in warm seasons, poor indoor air quality, and noise (Figure 2.*1*). Classroom conditions depended strongly on teachers' preferences. All of these are connected to the senses of discomfort

in occupants, their focus was also on educational building (Italian primary schools) (De Giuli et al., 2012). There are other studies that were focused on the performance of the people in office buildings (Bluyssen et al., 1995), in their studies, their main aim was to develop assessment procedures and guidance on ventilation and source control, which help to optimize energy use in office buildings while assuring indoor air quality and tried to report presents the results, conclusions, and recommendations of the audit performed in 56 buildings in Europe. Furthermore, assessment procedures of indoor air quality and energy performance of office buildings are discussed and challenges for the future are given. Altogether researchers indicate that the relationship between the comfort of occupants and the built environment is complicated and lots of parameters such as thermal, visual, acoustic, and chemical would be able to touch comfort criteria.

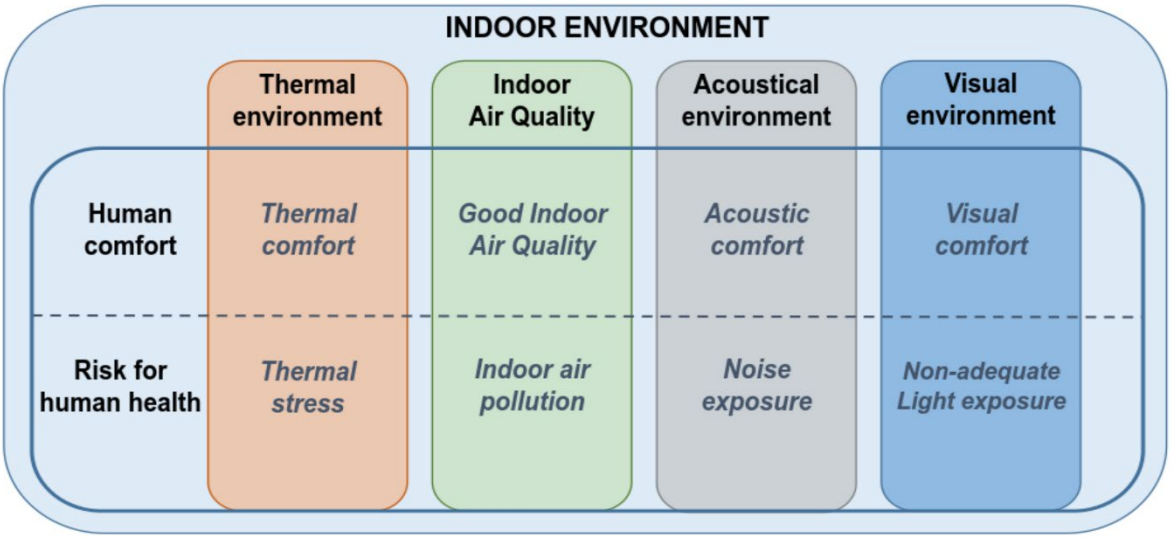


Figure 2.1 .Main aspects related to the comfort and to the risk for human health for the four IEQ environmental factors (Fantozzi, F; Rocca,M, 2020).

2.3.1 Thermal comfort

Thermal comfort concept is defined in ASHRAE standards; it is defined as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation".in that reference the thermal environment is also defined "the characteristics of the environment that affect a person's heat loss" (ASHRAE, 2017).

The thermal comfort of occupants depends on several factors, such as the air temperature, radiant temperature, humidity, air movement, metabolic rate, and clothing levels (Figure 2.2). In-office settings, the metabolic rate is constant, and clothing levels are also constant for each season. The other variables for example air temperature, humidity, radiant temperature, and air movement can vary based on daily weather, location of the occupant in space, and operation of HVAC systems. In air-conditioned buildings, air movement is constant, therefore it is not very important to monitor airspeeds, but for naturally ventilated buildings, airspeeds can vary depending on outdoor airspeed. Although monitoring of airspeeds is important, it is challenging

because there is a high variation in air movement around the office desk, chairs, and other furniture. However, as better methods to monitor airspeeds are developed in the future, it should be one of the parameters that are monitored. In buildings with radiant heating systems, monitoring radiant temperatures is important. However, for buildings without radiant heating systems, connecting to a model of sun movement and weather forecast might be sufficient. In addition, relative humidity has a small impact on thermal comfort in the range that is found in most indoor environments and might not be important to monitor in air-conditioned buildings where humidification or dehumidification is performed.

Thermal comfort is the outcome of a well-balanced combination of building systems adapted to both the location of the building as well as the type of activity performed within the building or the room of the building. Although thermal sensitivity varies from one person to another, according to age (the very young and very old being particularly sensitive), gender, dress, activity, cultural habits, etc., the basic principles behind thermal comfort are largely universal. According to all the previous discussion, thermal comfort can be explained with three groups of conscious interactions between personals and environmental factors in other words it is divided into three categories: 1- Physical interactions 2- Physical interactions 3- Socio-Psychological interactions (Diana Enescu,2019).

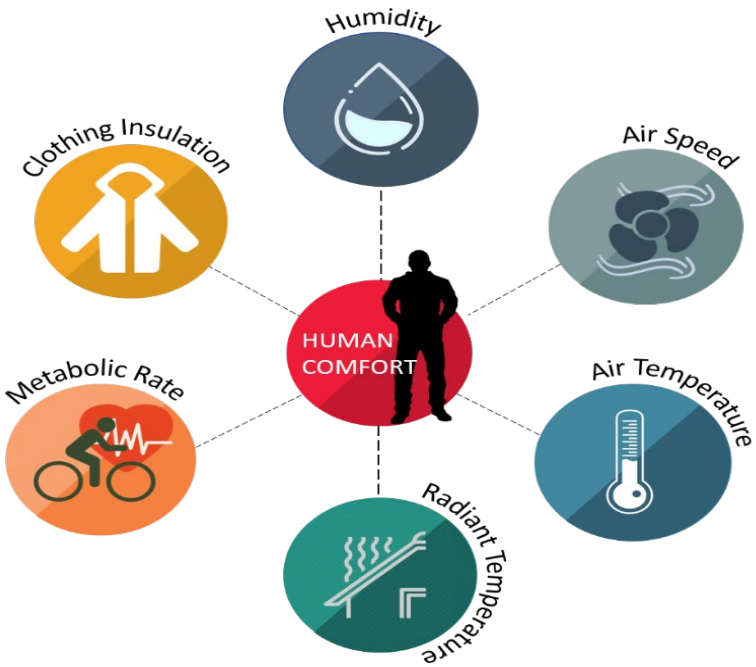


Figure 2.2. Factors affecting human thermal comfort (simulationhub, 2019).

2.3.1.1 Physiological interactions

It is about the way of our bodies work and interacts with the environment. In other words, our bodies strive to balance our heat exchanges with the environment continuously, by speeding up or slowing down our heartbeat to modify our blood flow and regulate heat distribution, by shivering when too cold to increase heat production,

by sweating more when too hot to reduce skin temperature thanks to evaporation. A comfortable indoor environment limits the efforts our bodies need to make to regulate body temperature, establishing a good energy balance.

2.3.1.2 Physical interactions

In this category, the main parameters of the environment around us which is affected human comfort are noticed, such as air temperature, air humidity, air movement, room surface temperature. In the physical environment, thermal energy is transferred through conduction, radiation, and convection. Conduction is energy transfer via a solid, such as the floor or wall. Convection is an energy transfer from a solid to an adjacent gas or air or water. And radiation is the energy emitted from a surface, such as a radiator.

2.3.1.3 Socio- Psychological interactions

It is related to human feeling at the existed time, for example, if we are tired, stressed, happy, and another kind of sense it has an important role in our understanding from the quality comfort. An individual's current emotional state, mood, level of fatigue, etc. will affect their experience of an environment. Expectations play an important role in how an individual experiences the physical world but more generally, perceptions are likely to base on one's own thermal history. Other environmental factors, noise, or glare, for example, may influence thermal perception, leading to an increased sensation of overheating.

2.3.2 Visual comfort

In studies usually, visual comfort is considered firstly in comparison to thermal comfort. Criteria of visual comfort have proven to be dominant in the adaptation of solar protection. The heat protection function is operated as such only when direct radiation strikes the user immediately. The requirement for visual contact to the outside, glare reduction, and daylighting are put before the necessary heat reducing function. It is proven, that users accept an amount of glare for a free view of the outside (Wienold J, 2004).

By considering the definition of global performance targets for lighting in buildings, it is obvious that review and classification of indices for assessing visual comfort is a key element. In addition to this, it would be effective if shared criteria are defined, because in this way it is easy to define and design high energy-efficient systems, these kinds of systems are able to provide a high quality of visual comfort for the built environment and simultaneously they manage the energy consumption, controlling and decreasing the total energy use. In European standards, there is the definition for visual comfort (EN 12665), "a subjective condition of visual well-being induced by the visual environment" (EN 12665, 2011). Visual comfort depends on different parameters, 1- the physiology of the human eye, 2- the physical quantities describing the amount of light and its distribution in space, 3- the spectral emission of the light source.

By considering the needs of occupants, the visual comfort has been studied by different factors to define those needs and their relation to the lighting of the environment, such as 1- the amount of light, 2- the uniformity of light, 3- the quality of light in rendering colors,4- the prediction of the risk of glare for occupants.

In the various studies, there is several terms are used for describing the type of assessment delivered by a visual comfort index, these terms depend on the time

discretization. So visual comfort indices can be assessed by adopting the terms short-term and long-term. Short-term are those indices that deliver an instantaneous assessment of a given light environment; long-term is, instead, those indices that summarize in a single value an assessment of a given light environment over an extended period. Several indices assess a given light environment by comparing the actual values of one or more physical quantities with given reference values (Carlucci. S,2015).

2.4 Daylight aspect of building

2.4.1 Importance of daylight and natural light

Light, or Visible Light, commonly refers to electromagnetic radiation that can be detected by the human eye. The entire electromagnetic spectrum is extremely broad, ranging from low energy radio waves with wavelengths that are measured in meters to high energy gamma rays with wavelengths that are less than 1 x 10-11 meters. Electromagnetic radiation, as the name suggests, describes fluctuations of electric and magnetic fields, transporting energy at the Speed of light (which is ~ 300,000 km/sec through a vacuum). Light can also be described in terms of a stream of photons, massless packets of energy, each traveling with wavelike properties at the speed of light. A photon is the smallest quantity (quantum) of energy that can be transported, and it was the realization that light traveled in discrete quanta that were the origins of Quantum Theory. (Stark, Glenn,2021)

visible light is not inherently different from the other parts of the electromagnetic spectrum, with the exception that the human eye can detect visible waves. This in fact corresponds to only a very narrow window of the electromagnetic spectrum, ranging from about 400nm for violet light through to 700nm for a red light. Radiation lower than 400nm is referred to as Ultra-Violet (UV) and radiation longer than 700nm is referred to as Infra-Red (IR), neither of which can be detected by the human eye (Figure 2.3). The transport of energy by light plays a critical role in life. About 1022 joules of solar radiant energy reach Earth each day. Perhaps half of that energy reaches Earth's surface, the rest being absorbed or scattered in the atmosphere. In turn, Earth continuously reradiates electromagnetic energy (predominantly in the infrared). Together, these energy-transport processes determine Earth's energy balance, setting its average temperature and driving its global weather patterns. The transformation of solar energy into chemical energy by photosynthesis in plants maintains life on Earth. (Exelis,2014)

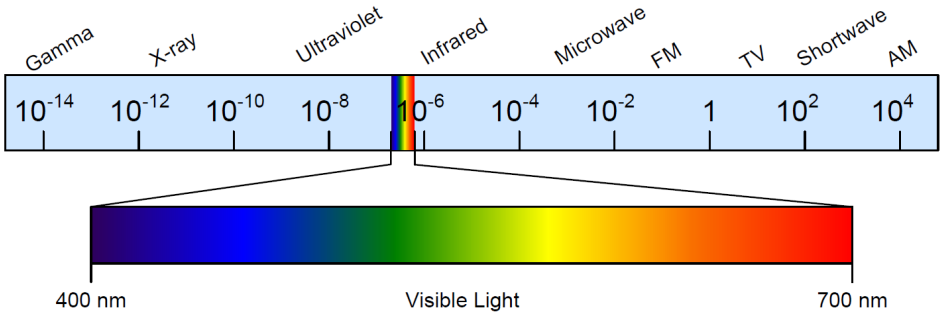


Figure 2.3. Electromagnetic radiation wavelength, (Stark, Glenn,2021)

Before 1940 natural light was the main source of lighting in buildings but after that in a duration of about 20 years, the light requirement of occupants to electric and artificial light had increased in buildings. (L. Edwards and P. Torcellini,2002). In recent years according to global worries about energy consumption and environmental concerns, daylight has been considered as a vital parameter of architectural design. The built environment industries try to use this parameter as much as it is possible by using different methods and strategies in building designing because it is obvious it is not possible to change the physics of daylight, it does not change from the origin, but the design of buildings and their use is possible to change. Daylighting is often integrated into a building as an architectural parameter and for energy savings. As we discussed in the comfort part, the benefits of daylight are not narrowed only in architecture and energy effects (energy consumption), the physiological and psychological aspects of natural light and its effect on occupant's comfort could not be neglected. Creating a comfortable space for users and its connection to the environment provides benefits as significant as energy savings to building owners and managers.

Daylight has the impact of making a person feels more comfortable, satisfied, and healthier and creates a productive environment. As known, sunlight is the major source of vitamin D which is responsible for the production and creation of teeth and bones. To stay healthy and get the necessary amount of Vitamin D needed by the body, a person should be exposed to the sun for at least 15 minutes per day. No artificial light can coordinate or correspond to the color variety of sunlight. The human eyes can effectively adjust and recognize things and objects better when sunlight is provided, and it enhanced with using windows since it gives people a sense of contact and interaction with the outside. Human brain cells get important information and energy from the illuminated surroundings which play a major role in regulating mood, how people react, and mental health. (L. Edwards and P. Torcellini,2002).

2.4.2 Benefits of Daylight

One essential benefit of daylight that it grants visual exchange channels to the outside; it provides views for the building's occupants. In many of the research of windowless spaces, many people occupying those areas mentioned they would prefer to have contact with the exterior world. Although the desire for a view looks important, it also relies on whether this view is providing enough daylight and whether a certain view is necessary. In other words, daylight is the relationship between architecture and how natural light is optimized in a space or place for greater health and wellbeing benefits. understanding how daylight flows into a specific space over the course of the day and at different times of the year can influence how light is incorporated into the building design to benefit the end-user. Effective use of daylight is not just about light, however. The sun can be a source of heat within a building and having the sun shining through the window is also aesthetically pleasing creating a positive feeling of visual comfort for building users.

How daylighting design relates to the wider building performance and daylighting relation to the performance of building is investigated on two levels. The first level is in terms of artificial lighting consumption. Secondly, daylighting also has an impact on energy performance of construction because essentially, light is radiation. This means when light reaches to the building it can contribute to thermal comfort in winter and in

turn, reduce a building's heating needs. By the same token however, too much light during the summer means a space may require extra cooling. A good daylighting strategy should consider how a building varies during the seasons to prevent it being too cold or overheating, but also how the flow of light works alongside windows and roof lights, as well as dynamic shading protection. Currently, daylight is used by architects and designers as a tool to create very complex and impressive building day light effect. However, more broadly, understanding of the natural course of the sun and its effects depending on the orientation of the building and its location could be better understood by the design community.

2.4.3 Effects of daylight on energy consumption and thermal comfort

Daylighting refers to the use of sunlight, skylight, and overcast sky illumination to provide functional interior lighting that is appropriate to specific programmatic areas and comfortable to the occupant. As mentioned before, when daylight is integrated as part of the design strategy in construction systems, it can provide substantial energy savings. The way that daylight contributes, minimizing the amount of artificial light using by maximum use of daylight possibility during the days, so reduces electricity consumption for lighting and lower HVAC costs (Gwaivangmin.B, 2016) however the solution of its thermal effect on hot days should be noticed. Energy balance is the difference between the profits of heat energy in the building and its losses. The energy efficiency of the house is a ratio of the amount of energy saved as compared to the amount of energy consumed or forecast.

Efficient use of energy means reducing the energy consumption of production, operation, and running of services. The building refers to the energy needed for heating, cooling, ventilation, and air-conditioning or electricity consumed by the device. Public buildings also define the energy needs for lighting purposes (DOE, 2015). Among passive design strategies, daylighting is one of the effective design solutions for improving building energy efficiency. According to the studies daylighting in a building can satisfy the human visual response, and it can make a more attractive and pleasing environment Daylighting is recognized as an important and useful strategy in the design of energy-efficient buildings. Daylight illuminance, particularly on vertical surfaces, plays a major role in determining and evaluating the daylighting performance of a building. (Li, D; Lam, J, 2001). Over the last three decades, there has been a growing concern about reducing energy consumption associated with artificial lightings. It is estimated that electrical lighting consumes 25–40% of the total electrical energy in a typical commercial building in the United States. Daylighting could be considered as a cost-effective alternative to artificial lighting which not only reduces the demands for electrical energy, but also provides occupants with a pleasant, attractive, and healthy indoor environment. By installing daylight responsive control systems in an office building, considerable energy savings were achieved (Shishegar, N.; Boubekri, M, 2017). To summarize, the use of a daylighting system in buildings can provide benefits regarding visual comfort as well as the potential for energy consumption reduction. If the admitted daylighting in the building is well-controlled, it can provide great potential for energy-saving by reducing energy consumption for artificial lighting, heating, etc., while uncontrolled daylighting can cause overheating and glare.

2.4.4 Effects of daylight on visual comfort

Generally, good visibility is defined by an adequate quantity of light for the expected visual task, uniform distribution of illuminance and luminance, sufficient directionality to model three-dimensional objects and surfaces (direction of incident light from the side or from above), the absence of glare, and sufficient spectral content to render colors accurately when required (Carlucci. S,2015). The required daylight level and degree of control over the visual environment are among the most important criteria. The aims of room daylighting are to adequately illuminate visual tasks, to create an attractive visual environment, and to save electrical energy. Both the building design scheme and the way of application of systems have important roles to reach these types of goals. The effects of daylighting systems on the view to the outside are deniable. According to past discussions, optimizing the view to the outdoor is a priority in a daylighting design, in the design process, the visual contact with the exterior must be maintained under all facade operating conditions. In this way should be remembered the visual function parameters are used to determine whether a given lighting condition permits sight or visibility, these parameters are directly related to the physiology of the eye (Ruck. N, 2001).

2.4.5 Effects of daylight on facade

To design sustainable, visually comfortable, and low energy buildings; it is necessary to consider optimization of visual, thermal, and acoustic comfort conditions in the building façade design phase. Daylighting is an important design parameter in the façade design and evaluation of daylight performance for the building façade alternatives in the early design phase should be provided. Efficient use of daylighting in buildings is only possible by means of daylight performance analysis in terms of visual comfort conditions starting from the building design stage and the integration of obtained results with the building façade design process. Thus, with the help of performed daylight performance analysis, it is possible to avoid problems that can be encountered in the future, and optimization of façade design alternatives can be done considering effective use of daylight.

Providing maintained illuminance levels inside a building using daylighting, the prevention of daylight- glare, obtaining sufficient exterior contact and view out with the outside environment are the main features expected from a façade design in terms of daylight performance. Today, diverse daylighting analysis methodologies and tools have been developed and are being used to ensure desired amount of natural light in buildings. Sun-shading systems is one of the significant solutions which are more considered by designers in facade design. Their variability is noticeable.

Sun-shading systems must provide thermal and visual comfort both reliably and economically. Efficient use of energy is vital. Electric lighting contributes to a significant part of the total energy use in the world. At the same time, they should prevent unwanted solar gains in summer and permit high solar gains in winter. Efficient use of daylighting offers a significant reduction in overall energy use. Shading devices are equipment that are used externally or internally or in between the building spaces to protect from direct sunlight. Objective is to create comfortable internal environment to reduce heat gain during summer, reduce the cooling loads and therefore minimize costs.

- Improving internal environment for greater comfort.

- Some shading devices improve the internal or external aesthetics of building.
- Therefore, it is essential to use shading devices

2.4.6 Daylight performance metrics

Although there are several studies that they have tried that review the visual comfort indices there are no studies about the four factors involved in visual comfort altogether. Additionally, there is no general agreement on methodology and metrics to evaluate the individual factors of visual comfort (Carlucci. S,2015). Carlucci and his colleagues have done a literature review and standards analysis. According to the study aim, looking for visual comfort metrics, including their advantages and limitations associated. Some of such measurements and methods are as follows: Illuminance, Daylight Factor, Continuous Daylight Autonomy, Spatial Daylight Autonomy, Useful Daylight Illuminance, Frequency of Visual Comfort, Intensity of Visual Discomfort. The following, by the needs of research, are defined the visual comfort indices which were used in most studies.

2.4.6.1 Illuminance

Illuminance measures the amount of light on a surface per unit area, and its unit is lux. Illuminance is the most used metric to evaluate the brightness of the indoor environment. Recommended levels of illuminance are defined by the Illuminating Engineering Society (IES) according to the space type, the type of visual tasks, the age of occupants, etc. Illuminance is typically expressed in lux. Illuminance levels can be measured with a lux meter or predicted using computer simulations with recognized and validated software for example VELUX daylight visualizer. Different illuminance thresholds are associated with the different building typologies and kinds of uses of spaces in a building. For daylighting, the total energy balance between lighting and thermal loads (i.e., from solar heat gains) is an added consideration. For paper-based tasks such as reading and writing, satisfactory task illuminance levels can exceed recommended electric lighting levels by factors of two or more if there is no glare and if the associated heat gains have a minimal mechanical system energy impact (especially in cooling-dominated climates). For computer-based or other self-illuminating tasks characterized by low luminance values (lower than 85 cd/m2), however, these guidelines may represent the maximum range of illumination, because exceeding these guidelines can often result in reduced visibility. In a typical office use, the European standard EN 12464-1 (EN 12464-1, 2011) and most authors suggest a reference value of 500 lx evaluated on the work-plane (Carlucci. S,2015), while others consider sufficient 425 lx (Asdrubali. F, 2003) or even 300 lx (David. M, 2011).

2.4.6.2 Luminance

Luminance is the measure of the amount of light reflected or emitted from a surface. It is typically expressed in cd/m^2.Luminance seen in a given point of a surface along a given direction is a physical quantity that measures the luminous intensity emitted in such direction per unit of the visible area around the given point Luminance levels can be measured with a luminance meter or through the use of high dynamic range (HDR) imaging techniques together with a digital camera and luminance mapping software (e.g. Photo lux), Luminance levels can be predicted through the use of computer simulations with recognized and validated software for example VELUX daylight visualizer.

Luminance is the measure of light used to evaluate visual comfort and glare in the interior.

The identification of the acceptable absolute luminance value of glare sources (as contrasted to the ratio of the luminance of the source relative to the background) is the most critical issue when attempting to define an upper limit value of the glare factor for a particular glare scene. Moreover, there is no general agreement on such upper limit values. For good visibility, some degree of uniformity across the task plane is desirable. Poor visibility and visual discomfort may result if the eye is forced to adapt too quickly to a wide range of light levels. Illuminance and luminance ratios such as maximum-to-average or average-to-minimum are used to quantify lighting uniformity and are typically measured across a horizontal work plane at a height of 0.8 m above the floor for paper or reading tasks. For office lighting, for example, the ANSI/IESNA RP-1 guidelines set maximum contrast ratios among all task, background, and remote surfaces within the occupant's field of view (Marty. C, 2003).

Maximum thresholds for the luminance of the source of 2000 nits at any point and between 500 and 2000 nits for peripheral view are proposed by Dubois and can be doubled if the glare source is natural light. Wienold and Christoffersen proposed 2 000, 4 000, and 6 000 nits as thresholds for 'acceptable', 'just uncomfortable', and 'intolerable glare' respectively. Similarly, Shin, Yun proposes 3 200, 5 600, and 10 000 nits respectively for the same three categories (Carlucci. S,2015).

2.4.6.3 Daylight factor

Daylight factor (DF) measures the ratio of the indoor illuminance to the outdoor illuminance under overcast sky conditions. DF is easy to measure and calculate, and its concept is intuitive. Thus, it is the most frequently used metric to evaluate the daylight condition of a building. However, DF is a static daylight metric, which means it does not change with the building location or orientation, and many daylighting design problems cannot be detected by DF (Reinhart, Mardaljevic, & Rogers, 2006).

The usual method for computing natural illuminance for a given location in a building is the daylight factor approach, which based on the traditional overcast sky without sunlight, as defined by the International Commission on Illumination (CIE). The DF approach can be analytically calculated using simple design aids and annual daylight data are not required. The point daylight factor (PDF) has shown the effectiveness of daylight-linked controls in saving energy on electric lighting (Li. D, 2017).

The average daylight factor (ADF), which is directly related to window area and less detailed input data than those provided by the PDF could be a useful daylighting criterion. The vertical daylight factor (VDF) representing light coming directly from the sky and daylight reflected from surrounding buildings and the ground onto a vertical surface has been appropriately used for compact urban areas with large exterior obstructions, such as Hong Kong. The degree to which external structures obscure the view of the sky (Li. D, 2017).

2.4.6.4 Climate-based daylight factor

The amount of daylight in a building's interior depends on the availability of natural light outside at that location, as well as the properties of the building spaces and its surroundings. The evaluation of daylight performance should, therefore, take account of

the availability of daylight on site in addition to the properties of the space (CIE, 1970). Using recorded climatic data (outdoor diffuse illuminance), we can determine what DF levels will be needed to reach the target illuminance level over a given period of the year. The example below shows how the target DF is determined from climate data to achieve daylight levels of 300 lux for 50% of the year.

2.4.6.5 Daylight autonomy

Daylight Autonomy (DLA) was firstly proposed by the Association Suisse des Electricians in 1989 and was refined by Reinhart and Walkenhorst, it is defined as the percentage of the occupied hours of the year when a minimum illuminance threshold is met by the sole daylight (Carlucci. S,2015).

Daylight autonomy (DLA) is the ratio of the number of hours in the year when the illuminance provided by daylighting is above the minimum illuminance requirement, to the total number of hours occupied in a year (Reinhart & Walkenhorst, 2001). DLA is a dynamic daylighting metric. Dynamic daylight metrics are based on time series of illuminances, which are based on annual solar radiation data for the building site (Reinhart, Mardaljevic, & Rogers, 2006). The primary advantage of dynamic daylight performance metrics over static metrics is that they 11 consider the quantity and features of daily variations of daylight together with irregular meteorological events (Reinhart, Mardaljevic, & Rogers, 2006). DLA is a long-term, local index referred to the amount of natural light available at a given point of the space during occupied hours. It conceives the visual performance through a single value expressed as a percentage.

2.4.6.6 Useful daylight illuminance (UDI)

Useful daylight illuminance (UDI) is the ratio of the number of hours in the year when illuminance provided by daylighting is within a useful range, to the total number of occupied hours in a year (Nabil & Mardaljevic, 2005). UDI aims to determine the daylighting level that is neither too dark nor too bright (Reinhart, Mardaljevic, & Rogers, 2006). Daylight illuminances in the range of 100 to 300 lux are considered effective either as the sole source of illumination or in conjunction with artificial lighting. Daylight illuminances in the range of 300 to around 3000 lux are often perceived as desirable. Recent examples in school daylighting design in the UK have led to recommendations to achieve UDI in the range of 100–3000 lux for 80% of occupancy hours (Carlucci. S,2015). However, in this study a range between 150 to 1000 lux is defined for the default useful daylight illuminance (**UDI_d**) and a smart variable threshold calculated by using linear regression algorithm is used for user-preferred useful daylight illuminance (**UDI_u**).

. Useful daylight illuminance (UDI) is a daylight availability metric that corresponds to the percentage of the occupied time when a target range of illuminances at a point in space is met by daylight.

2.4.7 Daylight simulation

In daylight, the term simulation is used to mean different things depending on the context, and in some cases, it refers to a broader concept of lighting design that utilizes simulation internally to calculate lighting performance metrics. Example outputs from these simulations can be luminance, illuminance, and color, which could be processed to calculate performance metrics such as daylight glare probability (DGP) or daylight autonomy (DA), which are used in the lighting design process. In another word, daylight

simulation computer-based calculation of the amount of daylight available inside or outside of a building under one or several sky conditions. Simulation outputs may be discrete numbers (illuminances and luminance) under selected sensor points within a scene or visualizations of a scene. Wong (2017) reviewed various methods to evaluate the daylighting performance of buildings, including scale models with simulators, mathematical models, full-scale models for field measurement, and computer simulation software. This review evaluated the strengths and weaknesses of each method and found that the computer simulation method is the most used in the building design stage because of its capability of involving design variants and its accurate results.

2.5 Glare

2.5.1 Concept of Glare

Glare is a complex phenomenon and several approaches characterized by different complexity in the calculation have been used for assessing it or for predicting potential discomfort events. glare is caused when intraocular light scatters occur within the eye, the contrast in the retinal image is reduced typically at low light levels, and vision is partly or totally impeded for example when the eye is confronted by headlights from oncoming automobiles. With windows and daylighting systems, which are large-area light sources, disability.

glare can at times be significant. The physiological mechanisms of discomfort glare are not well understood; an assessment of discomfort glare is based on size, luminance, and several glare sources, source-task-eye geometry (or glare source locations within the field of view), and background luminance. The Daylighting Glare Index (DGI) is used to indicate the subjective response to a large-area glare source and can be calculated for a person facing the window or the sidewall at various distances from the window wall (Hopkinson,1972).

The direct approach consists of measuring or calculating the luminance of a given light source seen by a given observation point. A more elaborated approach relates the glaring risk to the luminance contrast of objects present in the visual field of an observer. Other glare indices are based on equations that relate some key factors to subjective judgments of the degree of discomfort experienced in indoor environments. In essence, such indices consider the contrast between the luminance of the glare source, the source angular size seen from the observer, and the background luminance as seen from the position of the observer (Carlucci. S,2015).

2.5.2 Glare metrics

2.5.2.1 Daylight glare index

Discomfort Glare Index (DGI) derives from the CGI and aims at predicting glare from large sources, such as a window, described by its luminance. In other words, DGI is predicted glare from a large source, such as a window. DGI values are associated with several levels of discomfort glare. A value of DGI equal to 22 is considered a reasonable acceptability threshold. DGI is a short-term, local, according to several authors, has some noticeable limitations: 1- it refers only to uniform light sources: this excludes direct sunlight and does not consider that non-uniform sources can cause more glare when positioned perpendicularly to the line of view and less glare when located between 10° and 20° from the line of view 2- DGI is not reliable when the source fills almost the whole

field of view and when the background luminance equals the source luminance; 3- a few differences between the value predicted by DGI and the evaluation in real sky conditions were determined(Carlucci. S,2015).

2.5.2.2 Discomfort Glare Probability

(DGP) is a glare index for the measurement of glare caused by daylight. Ev [lux] is the vertical eye illuminance at eye level. DGP describes the fraction of disturbed occupants under the specific daylight situation. The equation is valid within the range of DGP between 0.2 and 0.8, and for vertical eye illuminance above 380 lx

2.5.2.3 Discomfort Glare Probability Simplified

Simplified DGP-based indices have been proposed aiming at shortening simulation times in respect to standard DGP, but they cannot be used in the case of direct sun transmission into a room. The Enhanced Simplified DGP (GPS) is proposed and validated against two full-year hourly datasets by Wienold (Wienold. J, 2009) to keep at the same time a certain degree of simplicity in respect to standard DGP in situations where direct sun transmission into a room cannot be neglected. Firstly, depends on the vertical eye illuminance, and secondly depending on the local quantities, it is computed by using a simplified image that just includes the main glare sources, not calculating the exact luminance distribution. A significant time reduction is obtained by neglecting the indirect ambient reflections, however, leading to reasonable results in most cases if compared to DGP.

DGPs were developed to overcome time-consuming, repetitive work. For the evaluation of the dynamic DGP values, a glare rating classification based on simulations and simplified discomfort glare probability is proposed. This method is suitable to compare different façade solutions as well as control strategies. DGPs is closely related to DGP. Moreover, according to the relationship of E_v and DGP, it can be determined that the criteria for glare index as E_v corresponds to the DGP. In this proposal, the E_v criterion for dynamic simulation with DIVA-for-Rhino is set to 3000 lux, and this value corresponds to a DGP of 0.4 (Carlucci. S,2015).

2.5.3 Simplified Point-Hour Glare Probability

GPPH is a simplified metric developed specifically for this project. It is defined as number of points in the grid of 4x5 imposed inside the space at work-plane height that exceeds 3000 lux at each hour of the year. Its simplified nature creates significant restrictions in terms of predict real glare discomfort; however, it could be a proper metric to compare two very similar cases of shading design over the course of the year since it is not direction dependent and could be measured rapidly and objectively.

2.6 Shading system

2.6.1 Shading systems classification

Suitable solar protection is an architectural decision above all. The formative individuality of a building can be produced by its application. Shading device can influence the building energy consumption through intercepting the incoming daylights. The main function of a shading system is to protect the transparent parts of the building against entering unwanted solar radiation. Various types of shading systems can be categorized into the moving system and using place and type of control (Figure 2.4). There is no single best way to organize and carry out shade classification, as the optimum

method depends upon several factors. The most crucial of these is whether the manufacturer needs to match shades from batch to batch. (Reinhart. C, 2020)

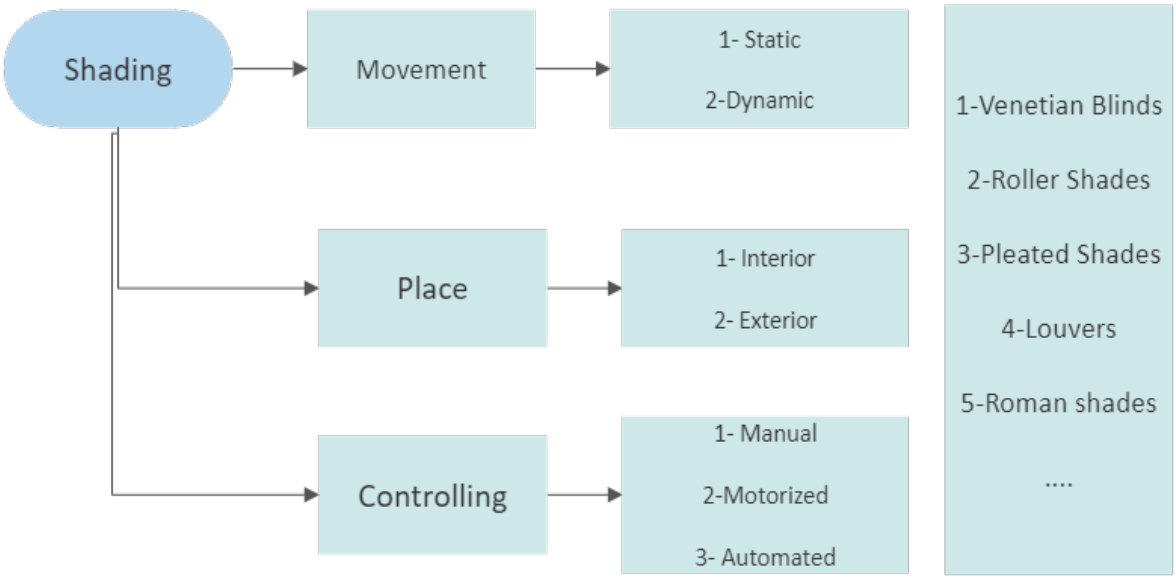


Figure 2.4.Classification of shadings in different Categories

2.6.2 Shading classification by movement

According to the possibility to move the building, shadings are divided into two important categories, 1- Static shading: The fixed shadings are not able to move and 2- Dynamic shading: this kind of shading is movable and adjusted manually or with another way of control. dynamic shading can be operated manually by the occupants directly or through motorized devices, or automatically through sensors and actuators. The efficiency of the manually operated type is very low since occupants do not change the position and angle of the blinds every time it is desirable for an increase in comfort and energy reduction. It is very difficult to predict the energy-saving performance of a manually operated dynamic system. Wymelenberg noted in his studies that motorized shading controlled by occupants offers a significant improvement in energy performance compared to manually controlled ones (Wymelenberg, K.V, 2012). Energy-saving predictions using manually controlled shading devices based on the theoretical control principle can lead to overestimating the energy saving.

2.6.2.1 Static shading

Static shading is established by projecting facade elements or elements prepositioned to the building face. These can be vertical or horizontal in their main orientation or be designed three-dimensional. The elements are fixed about the course of the sun and the resulting solar angles. By geometry and formal composition, the elements attain an angle selectivity. The elements can be shaped to intercept the summer sun and let the winter sun pass. Static shadings are widely employed all over the world for years for their simplicity, relatively cheap cost, easy

maintenance, and good performances. There are many types of static devices, such as overhangs, vertical fins, egg-crate structures, louvers, loggias, balconies, and roofs, and their application strongly depends on the direction faced by the glazing that needs to be shaded. Static solar protection is a more robust system energetically and technically. Nevertheless, it needs a precise interpretation, because of its consequences for the interior climate and thus energy consumption, as it is not alterable. Hence, the design of static solar protection must be such, that it contributes permanently to higher user comfort and to the lowering of the building 's energy consumption.

2.6.2.2 Dynamic shading

A dynamic shading system is composed of moveable elements that work within an algorithm. The definition of a dynamic shading system can be associated with intelligent facade applications, which have been proven to increase inhabitants' comfort due to their interaction with the external and internal environments. Therefore, the term dynamic' refers to continuous and developing change, along with frequent updates. because the light available changes dynamically; the design of static shading systems adhering to both high and low levels of light is difficult. Dynamic solar shading has the potential to dramatically reduce the energy consumption in buildings while at the same time improving the thermal and visual comfort of its occupants.

2.6.3 Control systems for shading

There are different types of controlling possibility for shading system, manually by users, Motorized one and automated controlling. Benefits and Weakness of different type of shading controlling to fulfill the requirements for optimizing energy efficiency and human comfort, an automated shading system should react in real-time to changes in the environment and be user-friendly in terms of accessibility and definition. Real-time is defined to be a reaction in a computer to a change in conditions "as it happens," or within less than one minute of the change. Furthermore, the program should be configurable for fine-tuning over the long term and provide flexibility, a critical element for occupant satisfaction. The system shall react in real-time to:

A. manages solar radiation

B. reduce excessive brightness

C. assess when established thresholds for heat load have been exceeded

D. assess changes in the sky condition (clear or cloudy)

E. maximize human comfort while supporting energy-efficient systems

F. interface with third-party BMS/BAS systems such as BACnet, KNX, and Lon works

G. interface with third-party lighting control systems (occupancy sensors, demand control, work schedule control, etc.)

H. provides a browser-based GUI for remote-user access

I. provides a user-friendly shade-position override

J. provide configurable settings for fine-tuning over time

2.6.3.1 Manual controls

Manual control is the simplest type of shader as it does not incorporate a motorized device. As occupants operate it manually, the initial investment is small, and the installation of the shader is simple. However, the direct operation of the shaders according to environmental variations is an inconvenient factor from the perspective of building occupants. Additionally, considering effective countermeasures is difficult as weather conditions can change dynamically. Occupants operate shaders only when glare makes conditions uncomfortable. Aside from this condition, they tend not to operate the shaders but rather to use artificial lighting, even when daylight comes into the building sufficiently without glare (Jennifer King, 2017). Manually deployed shading devices will decrease interior daylight levels. User switching behavior for manually controlled systems is known to be motivated by non-energy efficiency considerations.

2.6.3.2 Motorized control

Motorized shades are operated by motors, implying that remote or central operation is possible. Compared to manual shaders, operation and management are easy and convenient. However, the initial investment requirements have increased and effective countermeasures according to environmental changes are difficult because the operation is determined according to decisions by occupants. The motorized shader may become less economically efficient considering the high initial investment. Poor design, faulty installation, and lack of system commissioning will degrade the performance of automated lighting control systems, as well as contribute to user dissatisfaction (Jennifer King, 2017).

2.6.3.3 Automatic control

Manual or motorized shaders, though commonly used, have limitations to their level of potential improvement because proper countermeasures according to changes in indoor and outdoor conditions are difficult. To overcome these limitations, shaders need to be controlled automatically. Automated shaders are automatically controlled by sensors according to the outdoor weather condition to enhance environmental performance. They utilize a built-in control algorithm that maintains comfortable indoor conditions. They can provide optimum indoor conditions as dynamically changing weather conditions are checked continually. In addition, productivity is increased because occupants can concentrate on their work without operating the shaders (Hyun Kim. J, 2009).

2.6.4 Shading classification by placing

Shading devices can be divided into two broad categories, interior, and exterior. Exterior systems are most suitable for solar shading; interior systems allow for solar gains. Exterior shading devices are 30- 35% more effective than interior shading devices (Lee. J, 2015). solar protection mounted before the facade shows a higher effect concerning solar reduction than if mounted inside. It limits the entry of heat before it reaches the glass plane. As outside equipment is exposed to higher wind and weather strain, they must be carried out more stable than those mounted on the interior. A further disadvantage of interior mounted shading is the impediment of window service. The possibility of opening windows and with its passive ventilation should be maintained.

That is why, among other reasons, adjustable solar protection devices are also accommodated in the space between the glazing planes. The solar protection effect is slightly raised, as the heat radiation does not immediately reach the internal glass plane.

2.6.4.1 Exterior shading

External shading is an efficient method to reduce unwanted glare generated by direct sunlight to increase occupants' comfort. Its success depends on robust construction and correct use and should preferably be automated. It can be adapted for use in most European climates. Exterior devices are costly because they must be constructed to resist all weather conditions. Moveable exterior systems require a lot of maintenance and often collect dust. Exterior devices have a better performance than interior devices and their efficiency depends on the type and correct sizing (Luca. F, 2018). If properly designed they can save buildings' energy consumption, reducing the amount of direct solar radiation during the warm season and at the same time keeping it during the cold season when it is more beneficial. External shading is more effective than internal shading in reducing overheating as most of the heat in solar radiation is prevented from reaching a building surface. External shading can reduce solar heat input by 80% to 90% (Xie X, 2018)

2.6.4.2 Interior shading

Internal shading is almost always adjustable or retractable and is typically in the form of roller or Venetian shaders or curtains. It is easily adjusted and maintained, and sometimes can provide night-time blackout. It is also generally cheaper and is particularly effective at controlling diffuse and reflected light, the major causes of glare. Curtains and shaders can moderate brightness, and Venetians and louvers can redirect the light. Internal devices do not stop all the direct sunlight until it has passed through the glazing: that means that the solar energy enters as short-wave radiation which will be absorbed by walls, furniture, and floors; once the short-wave radiation has been absorbed, it will be long-wave infrared radiation, which means there is a heat build-up in the room. However, honeycomb shading and highly reflective internal shading may be also thermally efficient. A further disadvantage of interior mounted shading is the impediment of window service. The possibility of opening windows and with its passive ventilation should be maintained (Salwa M, 2019).

2.6.5 Different typology of shading

The transparent facade enjoys steady popularity in administrative architecture. The demand for thermal protection in summer usually conflicts with the potential use of daylight and possible winter solar gains. Now growing importance falls to the precise consideration of the building envelope to minimize energy for cooling, heating, and artificial lighting. Solar protection plays a decisive role in the interaction of these factors (Salwa M, 2019).

Many new typologies of shading systems have appeared recently, but it is difficult to compare those new systems to existing typologies due to the control algorithm being rule-based as opposed to performance-driven. Since solar shading is a design problem, there is no single right answer. What is the metric to determine if a system has reached its optimal kinematic design?

At present, there are no reliable standard methods for the evaluation of the effectiveness of sun-shading systems. This means that architects and building designers must make their own decision on the methodology. Frequently, this decision is wrong, as we know from buildings with overheating problems in summer. The most frequent problem in our experience is that people do not want to use the shading systems in the way they are planned to be used. One example: In many cases, building designers assume that people are willing to close the slats of Venetian shaders in summer, which is not true in most cases. The demands of the future users of the building must be considered in an early stage of the planning process! The effectiveness of a sun-shading system must be assessed with methods that are able to take the various demands into account. This means that the planning team of a building must agree on a control strategy that fits with the priorities of the future users. Gives an overview of the requirements for sun shading systems. The most important factors for the behavior of users are the thermal and daylighting requirements.

A study conducted on a simulated model of a typical high-rise office building located in Delft tested different types of shading for total energy saving determining that internal switchable and adjustable blind systems have the best performance. Studies using optimization strategies for the variation of external overhang and internal blinds in a side-lit office room facing south in Trieste show that the best solution for primary energy is the one with the smallest external shading with a reduction comparing the no shading base case of 24 and 26.5 percent for double glazing and triple glazing window, respectively (Luca, F, 2018). Roller shades appear to be the first form of a manufactured roller shade product utilizing a fabric screen cloth. Roller shades are usually installed at the top of a window and lowered, depending on the altitude or height of the Sun above the horizon, to block the penetration of the solar ray. Invariably, roller shades were used to screen the upper portion of the window, leaving the lower portion open to admit natural light—now called daylighting—and views to the outside.

2.6.5.1 Venetian Blinds

Contrary to their name, Venetian blinds are thought to be from Persia, not from Venice. They were brought west to Europe in the 18th Century, and they quickly became cemented as one of the most popular types of window treatment and they are still incredibly popular today. Venetian blinds are the most popular style of blinds. They feature horizontal slats that attach with string or strips of cloth known as tapes.

A Venetian blind has horizontal slats, located one above another. Venetian blinds are basic horizontal slats made of metal, vinyl, PVC, or plastic. Wood slats are sometimes used but, in the US, these are now usually referred to as wood blinds. Parallel slats of wood, metal or plastic aligned horizontally or vertically.

By using strips of cloth called fabric tapes, or by cords, by which all slats in unison can be rotated through nearly 180 degrees. The slats can be rotated such that they overlap with one side facing inward and then in the opposite direction such that they overlap with the other side facing inward. Between those extremes, various degrees of separation may be affected between the slats by varying the rotation. There are also lift cords passing through slots in each slat. When these cords are pulled, the bottom of the blind moves upward, causing the lowest slats to press the underside of the next highest

slat as the blind is raised. Slat width can be between 16 and 120 mm, with 25 mm being a common width.

2.6.5.2 Roller Shades

One of the most versatile types of window blinds is roller shades. Roller shades are usually made from synthetic or natural fabrics and can be rolled up or down to suit needs.

Custom-made roller blinds come in a blackout, room darkening, light-filtering, and sunscreen/solar fabric options. They are mounted on a metal headrail and operated with a side chain or spring mechanism. Cheaper and ready-made blinds often come with a PVC pole instead of a metal headrail.

Roller shades are available in different styles, made from natural or synthetic materials and they are exactly what they sound like, rolling up or down from the top to let the light in or block it out, most economical, while the more elegant solutions involve valances or other options to hide the moving parts and leave the window treatment looking very polished and nearly invisible. roller shades are available with additional features like thermal or blackout linings.

2.6.5.3 Pleated Shades

pleated shades are very similar to Venetian blinds, being made of a piece of material that can fold into pleats by pulling a string threaded through it on either side. This allows the shade to be raised or lowered in the same way that Venetian blinds are operated, by pulling a cord that pulls the fabric up. Pleated shades have a softer look than traditional horizontal blinds because they lack the sharp right angles of the slats, and they can provide more coverage of the window since there are no gaps in the material. Pleated shades offer versatility for light control, with the choice of transparent, light-filtering, or blackout for maximum control. It is possible to be Chosen from a wide variety of colors, patterns, and designs. Typically made from fabric or durable paper, pleated shades can help decrease energy use in the summer by choosing light colors that will reflect sunlight away from the window and result in energy cost savings.

2.6.5.4 Louvers

Louvers are made up of individual louvers or slats that clip onto a sliding track at the top and are joined together by weights and stabilizing chains at the foot of the blind. Each slat hangs vertically or horizontally, and the entire blind is operated by a chain (or wand) and a separate cord. They Work on the same principle as the Venetian blinds except that they close across rather than down. The slats are wider than Venetian blinds but less opaque. louvers are for east- and west-facing sun control.

2.6.5.5 Roman shades

Roman shades (also known as Roman blinds) are very traditional window covering made from fabric or materials like jute or seagrass. Roman shades are available both lined and unlined to suit different needs. The linings often offer additional features, like blackout and thermal linings.

They can be bright, cheerful, and as colorful as favorite paintings, or they can be ethereal, light, and effortlessly blend into surroundings. Roman Shades are simply made from a flat piece of material that folds up accordion-style and is pulled up by a cord that

evenly raises the blind. Like other different types of window treatments, roman shades when lowered provide light control, privacy and can even help with temperature control if lined with insulating fabric. However, unlike other treatments, when raised they provide the look of a decorative fabric valance to adorn windows.

2.6.6 Venetian shaders and rollers (multi-Objective) systems

Most building professionals have indicated the convenience of using interior shading controls regardless of the advantages of exterior shadings. If shading devices are installed on the exterior of the building, they can block solar radiation effectively before it passes through the fenestration glazing. On the other hand, when interior shading devices are applied, far-IR radiation reradiated from the interior surfaces cannot go through the glass before it is absorbed, which increases cooling energy consumption during the overheating period. A combination of external shading and internal glare protection can reduce the overall energy demand by more than 25% compared to solar control glazing and/or only internal mounted shadings. High reflective internal mounted shadings cannot reach the performance of external shadings. They can improve the cooling demand compared to a standard internal mounted blind system, but only if high-quality surfaces are used (Carletti C, 2014).

The comfort and energy demand of a building are influenced significantly by the transparent part of a façade. To prevent the building from overheating and to provide a visually comfortable indoor environment at the same time(Figure 2.5), movable shading devices (like Venetian blinds or internal roller blinds) are used frequently. The control algorithms of the blinds (e.g., manual or cutoff) influence the incoming flux of the solar radiation and therefore the illuminance distribution, the visual and thermal comfort, and finally yet importantly the energy demand of a building (Carletti C, 2014).

Additionally, the number of shading systems available today on the market is very huge and it is not always easy to choose the best solution for a building. Many parameters influence the choice of the system and of the control strategy itself. The building's energy performance using different shading designs has been studied already in different research for example like Venetian blinds (Simmler, 2008) and internal shadings (Florides, 2000). But most existing studies investigated either only the thermal comfort and its influence on the energy demand (Tzempelikos, 2010; Hien, 2005; Kuhn, 2006; Kuhn, 2001; Afnor, 2003) or the visual comfort and its influence on the energy demand (Li, 2008). Only a few studies investigate the visual and thermal comfort of static and dynamic shading devices in office buildings: Nielsen (Nielsen, 2011) performed simulations for three types of façades (without solar shading, with fixed solar shading, and with dynamic solar shading). David (David, 2011) investigated different types of solar shadings in non-residential buildings and Tzempelikos investigated external roller shades. (Tzempelikos, 2007) Shading systems often claim to own special features, but this evaluation shows, that the influence on the total energy demand is only small, when the system is mounted inside. Outside mounted systems offer in all investigated cases the best solar protection. The visual comfort (glare and view) is mainly influenced by the control strategy of the blinds. Glare-based control strategies have only a minor impact on the lighting energy and daylight autonomy (Carletti C, 2014).

Shading devices are essential elements in a building. Well-designed shading devices can significantly reduce energy spent on thermal comfort and glare issues and promote daylight utilization instead of electric lighting. Roller shades and Venetian blinds are movable shading devices commonly used to minimize undesirable natural light transmitted through a glazing system. Experimental (Kunwar et al., 2019) and simulation-based (Chan and Tzempelikos, 2013; Shen and Tzempelikos, 2012; Tzempelikos and Athienitis, 2007; Tzempelikos and Shen, 2013) studies on roller shades and Venetian blinds have shown that energy consumption for lighting or cooling could be reduced along with occupants only experiencing imperceptible glare when proper control strategies are assigned. However, the benefit of natural illumination for areas distant from external walls is lesser when only roller shades or only Venetian blinds are used (Chan and Tzempelikos, 2015).

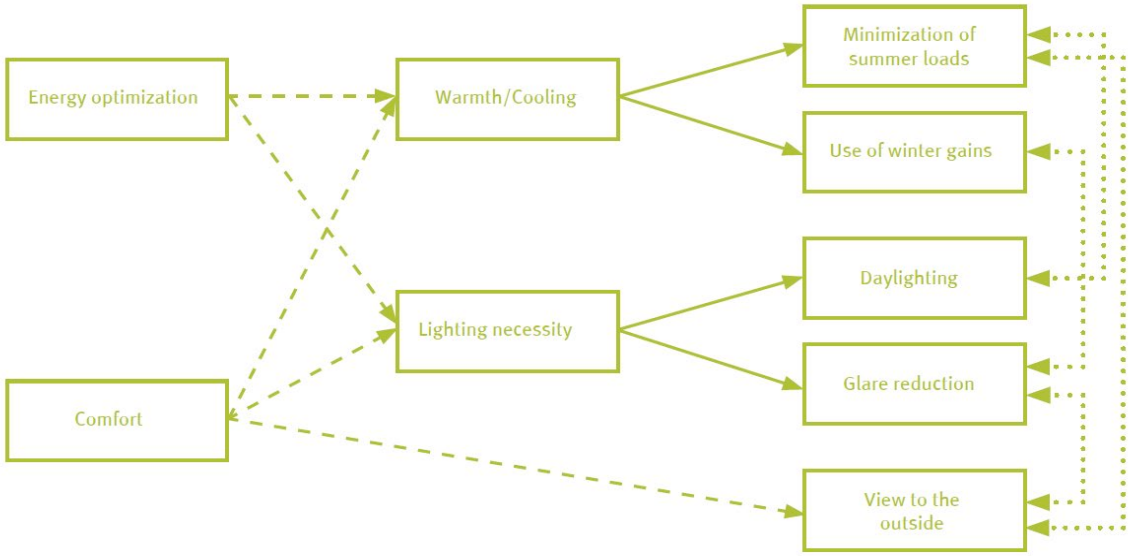


Figure 2.5.Catalogue of criteria in accordance with the demands of the IEA for the assessment of solar protection devices (Hans, 2006).

2.6.7 Importance controlling shading systems

When properly controlled or designed, Venetian blinds can act as a light-redirecting system as well. Chan and Tzempelikos (2013) have shown that proper rotation of the tilt angle and consideration of the slats' material characteristics could redistribute daylight deeper into space. The Venetian blind control strategies proposed by Eltaweel and Su (2017) can block undesirable incident sunlight while maximizing daylight penetration into office rooms. Subsequently, different types of shading devices have been combined, such as light-redirecting systems and common movable shades, into an integrated facade system with multiple sections to take advantage of the individual system components' strengths. A multi-sectional facade design offers more opportunities for saving energy and enhancing human comfort, as studies of Chan and Tzempelikos (2015) showed. both indicated that combinations of automated Venetian blinds and movable controlled roller shades significantly improve visible and thermal comfort. Olbina and Hu (2012) studied the daylighting and thermal performance of automated split-

controlled blinds. Fernandes et al. (2013) explored the lighting energy savings potential of split-pane electrochromic windows with blinds, collaboratively controlled for daylight provision and visual comfort. This integration of various devices extends beyond the installation of different systems in different sections to the combination of several systems in one section. It is essential to evaluate different control strategies when evaluating a multi-sectional facade combination. Tzempelikos et al. (2007) presented an idea of controlling Venetian blind automatically and roller shade manually. Meresi (2016) analyzed an external light shelf and semi-transparent blinds' optimal angles when combined but did not further explore automated control strategies' potential. Chan and Tzempelikos (2015) controlled the blind or the light shelf's angle on the top section according to solar incident angles and the roller shade by an illuminance setpoint on the work plane. Two systems were controlled independently. For a facade splitting blinds into three sections, Olbina and Hu's (2012)'s algorithm first asked the occupants to determine the sections' opening sequence (top section or middle). It then rotated the selected section's slats until the reference point's illuminance is higher than the target. When one section reached its maximum opening angle, the controller then started to rotate slats in the next section. Fernandes et al. (2013) developed an algorithm for controlling facades, which combined two independently controlled electrochromic panes with a Venetian blind. The algorithm started by iteratively deploying the blinds to block the direct sun. Then it reduced electrochromic panes' transmittance till the facade operation meet specified visual comfort conditions. In another case study (Do, Cong, 2020) the results demonstrate that the combinations of roller shades, blinds, and proper control algorithms greatly increase daylight near a rear wall compared to cases with only controlled roller shades, and do not cause glare.

2.7 Optimization

This study uses an optimization algorithm to determine the behavior of a shading system. The algorithm searches the best position of the shades at a given time step considering an objective and constraints. Thermal comfort is considered by the setpoints of the thermal analysis performed in Grasshopper software (LB and HB plugins). The temperature setpoints guarantee the thermal comfort of the occupants. No matter what the shading typology is, no matter if it is the baseline case, the thermal comfort is maintained by the setpoints and a room temperature in that range is expected at any given moment. The shading systems will have an impact on the amount of energy necessary to maintain this setpoint temperature. Therefore, thermal comfort is implicitly guaranteed in this methodology. To reach the final energy balance, the electric energy generation is calculated at each shading position. In contrast, visual comfort is a direct constraint of the optimization algorithm. The daylight level is calculated directly from the positions of the shades. for any solar radiation or shading situation, with enough energy provided for the system, air temperatures that respect the set-points can be achieved. However, not all these situations lead to satisfying visual comfort. Therefore, visual comfort is the controlling constraint in optimization. The controlling strategy can be flexible in terms of the constraints and objective definitions of building requirements it can switch to the objective of improving energy balance while considering thermal and visual comforts as constraints in the presence of occupants or only consider the building

as an energy system and improve the energy balance of the building by minimizing energy consumption if the user is not present in the space.

Multi-objective optimization is used for achieving optimal decisions due to the trade-offs between objectives that may be in conflict. The multi-objective genetic algorithm is defined to determine

the optimal configuration for dynamic shading operation [28]. GA is a global search technique that can escape from local optimal. This algorithm is extremely parallel, random, and adaptive, which is based on "natural selection and survival of the fittest" [29]. Genetic algorithms are initiated by selecting a population of randomly generated solutions for the problem. They move from the generation of one solution to another by developing new solutions using objective evaluation, selection, crossover, and mutation operators. The GA has been applied in several office building energy system research, such as applying optimal control systems for dynamic insulation materials applied to office buildings and it has been proven that GA is very efficient in comparison with the baseline it has shown meaningful developments in the optimization results [8]. Variables: positioning, tilt angle, and typology of shading Constraints: glare (max 3000 Lux), design requirement, comfort criteria Objective functions: minimizing heating, cooling, and electric lighting cost and maximizing electricity cost saving due to BIPV electricity generation

2.7.1 Multi-Objective Optimization

In building design problems, designers often need to deal with multiple conflicting objectives, such as maximum thermal comfort versus minimum energy consumption, or maximum equipment capacity versus minimum cost. There are two common methods to solve this problem. The first method is the weighted sum model, where different weight is applied to various objectives, and the weighted objectives are summed up to a single cost function. Then the problem is transformed into a single objective problem. The weighted sum approach is easy to apply, but the result heavily depends on the weight allocated to each objective, which requires professional knowledge and experience. The second method is Pareto optimization, which is to find the trade-off front or Pareto front between each objective. The pareto front is defined based on the concept of dominance (Evins, 2013)

2.7.2 Genetic Algorithms

Genetic algorithm is the most popular optimization algorithm in building performance studies. Genetic algorithm was first proposed by Holland (1975) in the 1970s as a heuristic search method. It is based on the natural selection process in biological evolution (Galletly, 1998). It recurrently modifies a population of solutions using principles that can be observed in nature, such as selection, crossover, and mutation. Genetic algorithm randomly selects solutions of good performance from the current population and uses them as parents to produce the next generation, and the population "evolves" toward an optimal solution (MathWorks, 2016). It is suitable for building performance optimization for the following few reasons: it can handle both continuous and discrete variables; it allows parallel simulations on multi-processor computers; it is suited to solve multi-objective problems; it is robust in handing discontinuity, multi-modal, and constrained problems; it is robust to high simulation failure rates (Nguyen, Reiter, & Rigo, 2014).

3. METHODOLOGY

3.1 Overview

The overall research strategy and process are shown in (Figure 3.1) There are four main steps. The first step is defining the inputs parameters, the inputs of the project are based on different categories, included climate base, building parameters, and data such as orientation and materials, and project consideration. The second step is to select the best shading system as a suitable solution for the design part according to different strategies, analyzing input parameters based on the durable integration model to select the main strategy for the thesis, based on energy and daylight simulation and glare. This step is comparing different results of optimization in terms of energy and daylight. After this the next part of this step is to identify design parameters and build a parametric design model. The third step is the optimization processes, the best solution which is selected by previous part tools is analyzed. In the fourth step the control system is studied and how the control system work. All these stages are monitored on one case study and results are presented in this thesis.

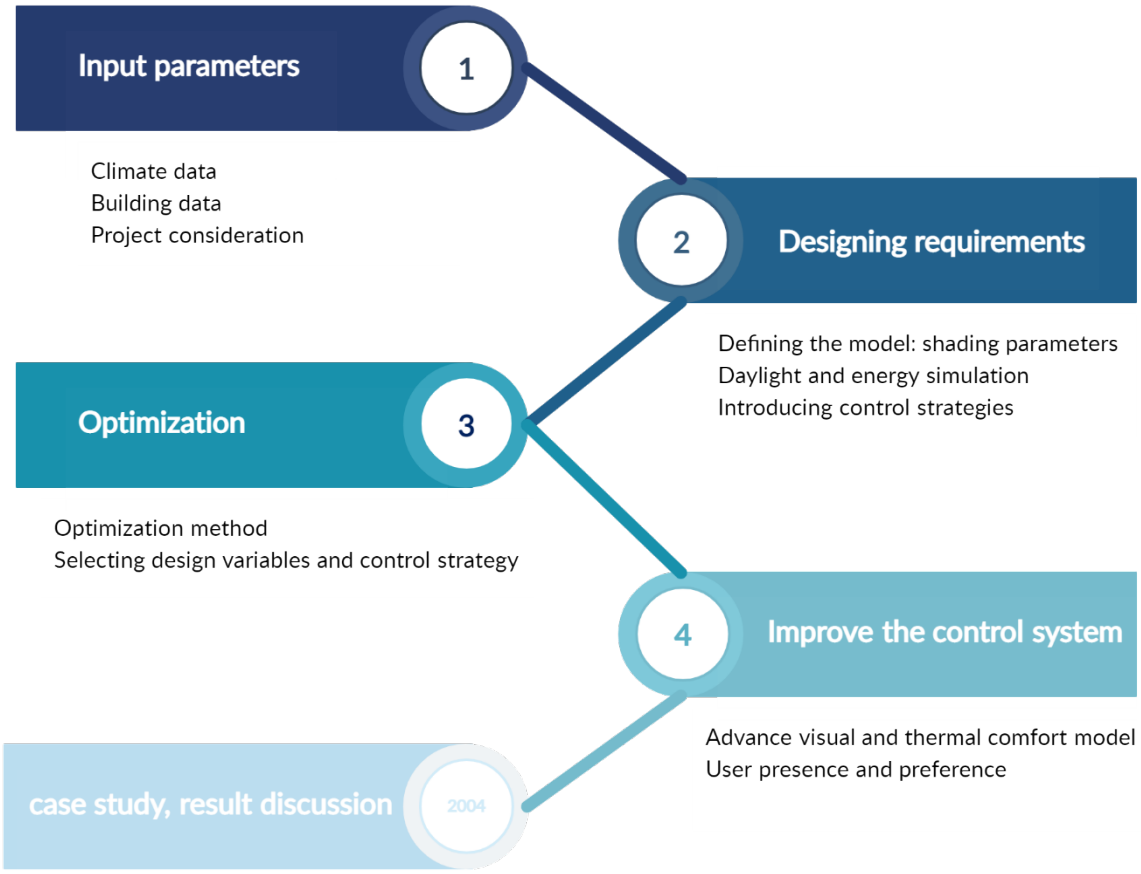


Figure 3.1overall research strategy and process of thesis

3.2 Input Data

Several categories of data is mentioned in this section, including climate data, building data, data related to daylighting, and data related to building energy.

3.2.1 Climate data

A proper dynamic shading design necessitates an accurate understanding of the sun movements in a specific site considering several parameters, as illustrated. The first parameter is the sun position in the sky during different seasons in terms of altitude and azimuth angles as shown in the (Figure 3.2) The second parameter is the peak temperature and insolation. The third parameter is the solar flux of direct and diffuse light in a year, including intensity, peak values, and fluctuation rates. The fourth parameter is sky models identified by cloud cover and the frequency of cloud formation, which affects the availability of direct sunlight. Hence, understanding these parameters could control light and heat loads in buildings, which leads shading devices to achieve high performance. In this part, different climate parameters are studied and analyzed, by considering the aim of the thesis, energy simulation, and daylight simulation, and glare studied needed different data are studied according to the place of the project to reach climate data, sun position, direct and diffuse solar radiation, sky model and weather data.

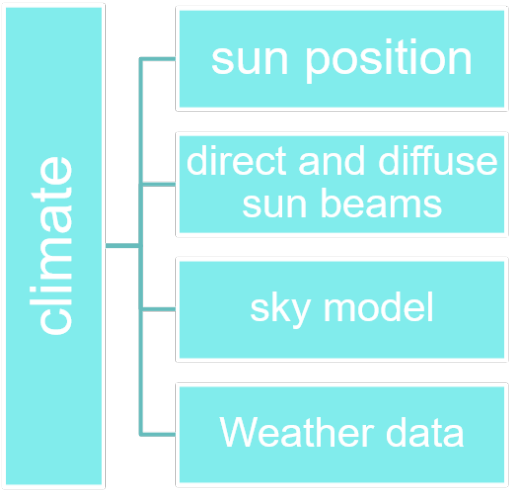


Figure 3.2 Dynamic shading design climate necessitates.

3.2.2 Building modeling

The morphology of the building itself generates some constraints which should be considered in the early design phase of the facade elements The architectural requirements provide some limitations for the typology of the shading system, schedule of the operation, the geometry of the building, building typology, various aspects of building envelope like a window, architectural aspects, the requirement of the user, typology of consuming, and cost limitation.

3.2.2.1 Defining shading system

According to the selection of the thesis by considering the literature review, the main solution of the project is the integration of common shading devices, roller shades, and Venetian blinds. 5 strategies are considered, this step is based on energy and daylight simulation in grasshopper and by using honeybee and ladybug plugin (Figure 3.3). To achieve energy savings from daylighting, it is necessary to install a lighting control system in the building. Lighting controls can adjust the level of electricity to complement the

illumination provided by daylight or turn off the light when daylight illuminance is adequate. A daylighting simulation is required first to calculate the illuminance at the lighting sensor positions for every hour in a year. Then a year-long lighting schedule will be generated. The schedule will be input into the energy model to incorporate the electrical lighting, heating, or cooling energy requirement differences due to daylighting. Ladybug and Honeybee have the functions of exporting and importing lighting schedules, which makes each daylighting and energy simulation sequence automated. According to the comparison of the output of this stage, the best strategy is selected. (Figure 3.3) shows the workflow of this process in grasshopper.

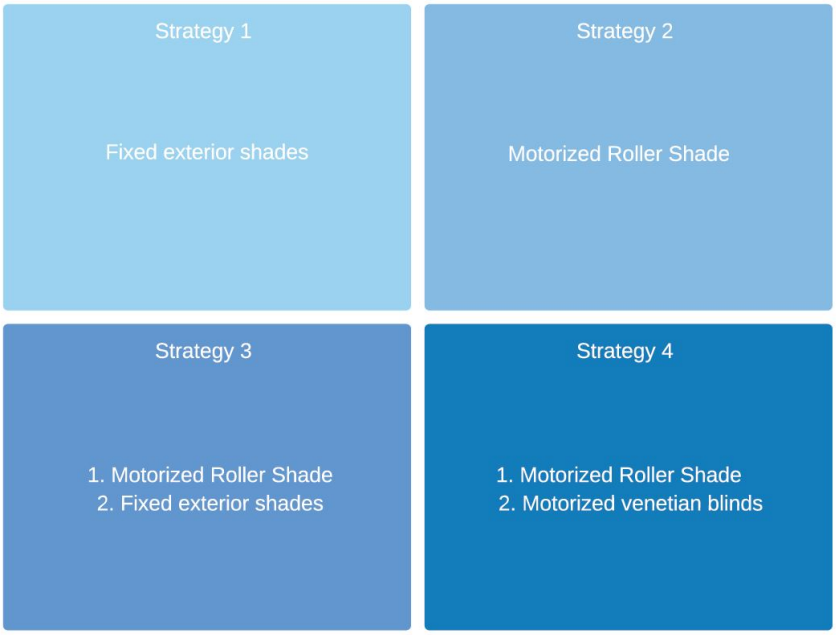


Figure 3.3.Recommended strategies of thesis

3.2.2.2 Designing shading system

After selecting the suitable strategy, as there are numerous independent and dependent variables (Figure 3.4) so some of the variables are a considered fix and others are analyzed to reach a suitable solution for the design of selected shadings. Also, the system of shadings movement is analyzed in this part.

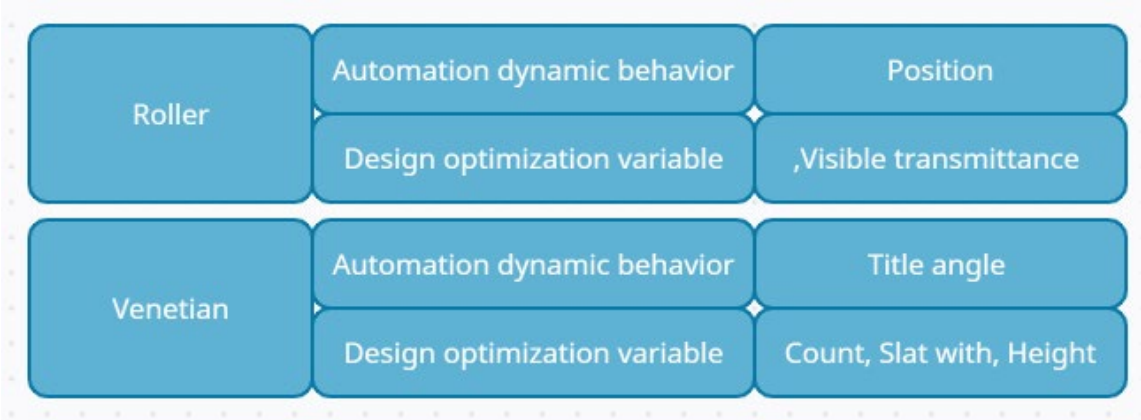


Figure 3.4. Independent and dependent variables of shadings system

General case and initial considerations

To define venetian blind and rollers different variable, initial Latin alphabet is considered (Table 3.1).

Table 3.1. General case and initial considerations for Venetian and roller

vertical window dimension	**A1**	**rotation (tilt) angle**	
horizontal window dimension	A2	slat thickness	
projected shaded area		transmittance	
projected open area		reflectance	
window area		height of the projection of the shaded area (one slat)	
vertical distance between rotated slats	d	Roller shade Position index	P
dimensional ratio	D	Roller shade Visible transmittance	
view factor	F		
fraction of projected shaded area			
fraction of projected open area			
slat width	L		

Venetian Blind

Consider the vertical window (Figure 3.5), the window has dimensions A1. A2 and it is equipped with a (horizontal) venetian blind consisting of N slats of width L (Figure 3.6). Given the fact that the slats may overlap when closed, the minimum slat width can be calculated from dividing the height of the window by the number of successive slats:

$$L = \frac{B1}{N} \qquad (1)$$

$$A_b = B1 \,.\, A2 = A2.\, L.N \quad (2)$$

$$A_W = A1.A2 = N.L.A2 + (A1 - B1)A2 \quad (3)$$

When the slats are set at horizontal position, they cover the minimum (vertically projected) window area. When they rotate to an angle, the projected shaded area increases. If S is the height of the vertical projection of the shaded area (by one slat) on the window plane, the total projected window area shaded by the entire blind would be equal to

$$A_b(\beta) = N \,.\, S(\beta).\, A2 = A2 \,.B1 \, \frac{S(\beta)}{L} \quad (4)$$

The fraction of the projected shaded area is:

$$F_b(\beta) = \frac{A_b(\beta)}{B1.A2} = \frac{S(\beta)}{L} \quad (5)$$

The fraction of the projected shaded area to total area:

$$F_{bt}(\beta) = \frac{A_b(\beta)}{B1.A2} + (A1 - B1)A2 = \frac{S(\beta)}{L} + (A1 - B1)A2 \quad (6)$$

The gaps between the tilted slats allow the penetration of incoming radiation as well as some outdoor view. The equivalent projected open area is equal to

$$A_{gv}(\beta) = B1.A2\,(1 - F_b) + (A1 - B1)A2 = B1.A2\left(1 - \frac{S(\beta)}{L}\right) + (A1 - B1)A2 \quad (7)$$

A venetian blind cross-section with two successive equally spaced flat slats tilted to a random angle is shown in (Figure 3.6) The rotation angle is measured counterclockwise starting from the horizontal position. The range of rotation angle is therefore 0–90 (horizontal-fully closed) to block sunlight.

since they would allow direct radiation inside). Each slat has a width (L) and a thickness (d) and can rotate about a horizontal axis located at the center of the blind and perpendicular to the paper surface. The distance between the centers of two successive slats at horizontal position is equal to L, for them to close tightly without gaps (occupants often want to have privacy). The projection of each half of the slat width on the vertical plane is equal to (L sin b)/2 and the vertical distance (gap) between the two successive blinds is

$$d = L(1 - sin\,\beta) - \delta\, cos\,\beta \quad (8)$$

If considering 0 then

$$d = L(1 - sin\,\beta) \quad (9)$$

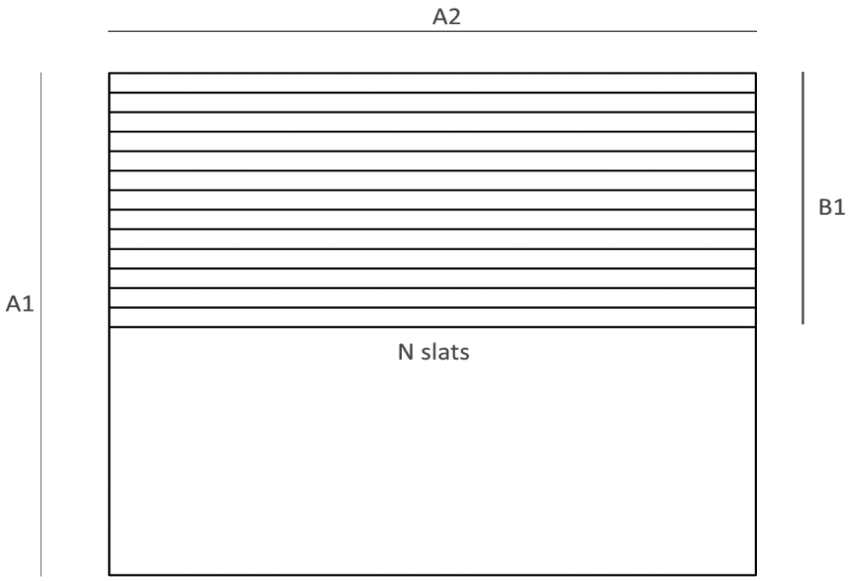


Figure 3.5. vertical window is equipped with a (horizontal) venetian blind.

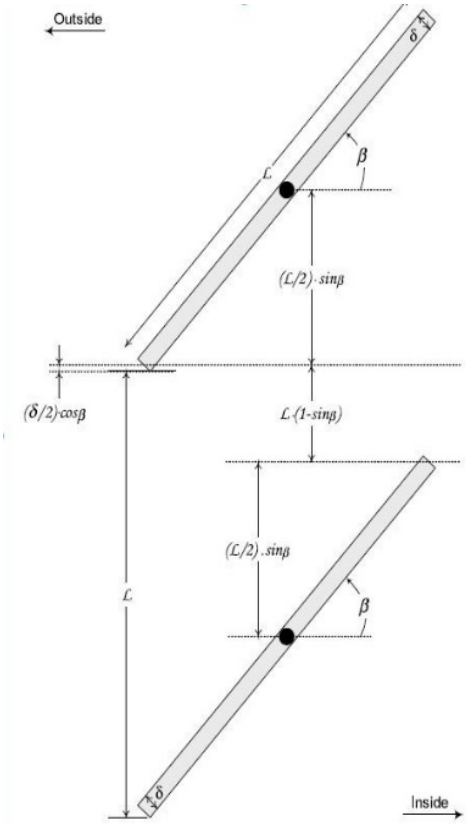


Figure 3.6. Venetian blind cross-section

Roller shades

The most important function of interior roller shades is to block direct sunlight so that the occupants are not disturbed by glare. Therefore, four different shading control strategies are developed and modeled to maximize daylight utilization, minimize energy consumption, and reduce the risk of visual discomfort according to different shading properties.

Visible transmittance

The term “openness factor” refers to the “open” or “see-through” percentage of the shading fabric. Openness allows a visual connection to the outside, as well as direct light transmission. Different solar shading fabrics have different degrees of weave density and therefore different openness factors.

describes the percentage of visible light transmitted through the fabric and is related to the color and openness factor of the fabric. Typically, light colored fabrics have higher visible transmittance than darker fabrics of the same openness.

Roller shades position (Figure 3.7), selecting an intermediate shade position (index P) that allows the maximum amount of daylight (reducing lighting energy use) and heating cooling load, while maintaining visual comfort and thermal comfort.

$$A_{gt}(\beta, p) = A2(B1\left(1 - \frac{S(\beta)}{L}\right)) + (A1 - B1) - P \quad (10)$$

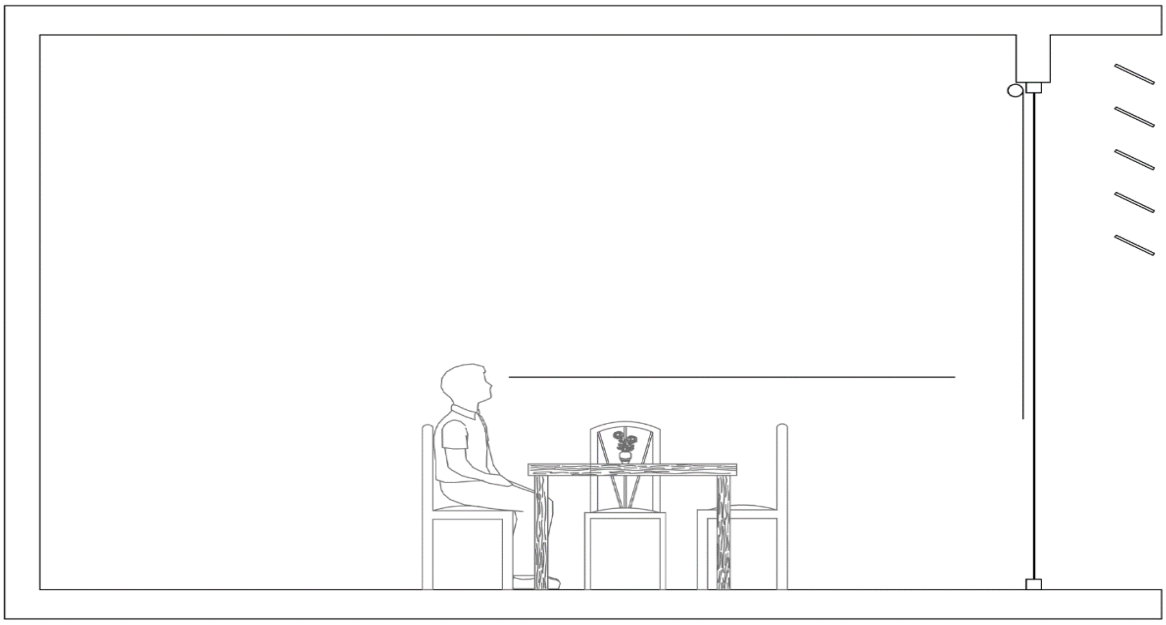


Figure 3.7. Roller and venetian blind cross-section

3.2.3 Daylight Modeling

The process begins in Grasshopper with design variables and building geometry. Ladybug and Honeybee provide the functions of daylight modeling (Figure 3.9). In the daylighting modeling process, the building geometry is connected to the building component properties (External wall, Internal wall, Window etc.) setting such as transparency, reflectance, u-value, etc. Then the building component is connected to daylighting simulation component (the input is weather file and other simulation settings). After the simulation, Ladybug imports the simulation result file back to grasshopper reads the daylight performance metrics and generates an annual lighting schedule. The final aim of the optimization process is to find the maximum UDI, which is the percentage of hours in a year. The design variables, daylighting metrics of each simulation are exported to an Excel file for final presentation in graphical form.

3.2.4 Energy Modeling

The energy model aim is to calculate the energy cost demand of buildings and energy cost saving. The climate data is used as input and the building baseline is defined in simulation software (Grasshopper - Ladybug and honeybee plugins) (Figure 3.8). The thermal comfort of the space is characterized by indoor air temperature and the heating and cooling setpoints specified by the adaptive comfort method. In the energy modeling process, building geometry is connected to a Honeybee thermal zone component. Honeybee automates the process of intersecting the masses and finding adjacent surfaces. Honeybee assigns construction sets, schedules, and internal loads for each space based on the building type and climate zone. The lighting schedule generated by daylighting simulation is also added to the energy model. For each time step, the thermal simulation calculates the indoor air temperature regarding the solar heat gain received through the windows, and the heat exchange with internal surfaces and with the external environment and internal loads (defined schedules).

The overall procedure is the same as daylighting optimization. The difference is only in the optimization objective, which is the minimum energy required for the building. Therefore, the fitness input for optimization is the total energy load for heating, cooling, and electrical. The variables energy metrics (Cooling, Heating, Electrical Load) are exported to an Excel file for the final drawing.

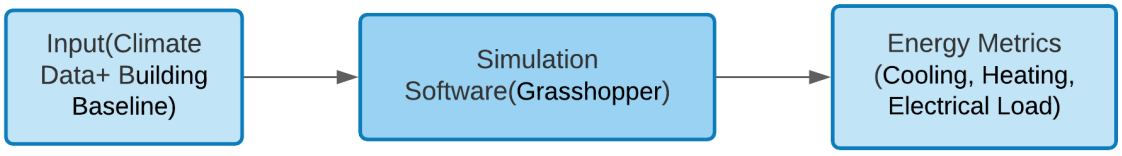


Figure 3.8. Energy optimization process graph

3.2.5 Glare analyzing

Glare is another parameter which is analyzed in this thesis as a key one. The index of glare numerical method is explained in continue. The main aim of optimization phase is to reduction Glare risk in 1- annual percentage of direct sunlight on floor 2- annual percentage of direct sunlight on work-plane and front wall. All the analysis is done in

Grasshopper and then the percentage of glare are calculated in Excel, also the number of points that are in glare risk are counted by excel.

Daylight glare index

(DGI) predicts glare from a large source, such as a window. The BRE and Cornell University conducted this study Ls [cd/m2] is the luminance of a glare source, Lb [cd/m2] is the background luminance, ùs [sr] is the solid angle subtended by the source, and s [sr] = ùs /P is the solid angle subtended of the source, modified for the effect of the position of its elements in different parts of the field of view.

$$DGI = 10\,log_{10}\,0.48\ \sum_{i=1}^{n} \frac{Ls^{1.6}\Omega s^{0.8}}{Lb + 0.07\ \omega s^{0.05}\ Ls} \quad (11)$$

Discomfort Glare Probability

(DGP) is a glare index for the measurement of glare caused by daylight. Ev [lux] is the vertical eye illuminance at eye level. DGP describes the fraction of disturbed occupants under the specific daylight situation. This index is developed by Wienold et al. [26]. The higher the DGP, the higher the glare.

$$DGP = 5.87 \times 10^{-5} Ev + 9.18 \times 10^{-2}\ log\ (1 + \sum_i \frac{Ls,i^2\ \omega s,i}{Es^{1.87}\ Pi^2}) + 0.16 \quad (12)$$

Discomfort Glare Probability Simplified

DGPs were developed to overcome time consuming, repetitive work. For the evaluation of the dynamic DGP values, a glare rating classification based on simulations and simplified discomfort glare probability is proposed. This method is suitable to compare different façade solutions as well as control strategies. DGPs is closely related to DGP. Moreover, according to the relationship of Ev and DGP, it can determine that the criteria for glare index as Ev corresponds to the DGP. In this proposal, the Ev criterion for dynamic simulation with DIVA-for-Rhino is set to 3000 lux, and this value corresponds to a DGP of 0.4.

$$DGPs = 6.22 \times 10^{-5} \times Ev + 0.184 \quad (13)$$

3.2.6 Multi-Objective Optimization

This study uses an optimization algorithm to determine the behavior of a shading system (Figure 3.9). The algorithm searches the best position of the shades at a given time step considering an objective and constraints.

Thermal comfort is considered by the setpoints of the thermal analysis performed in Ladybug and Honeybee. The temperature setpoints guarantee the thermal comfort of the occupants. No matter what the shading typology is, no matter if it is the baseline case, the thermal comfort is maintained by the setpoints and a room temperature in that range is expected at any given moment. The shading systems will have an impact on the amount of energy necessary to maintain this setpoint temperature. However, not all these situations lead to satisfying visual comfort. Therefore, visual comfort is the controlling constraint in optimization.

The controlling strategy can be flexible in terms of the constraints and objective definitions of building requirements it can switch to the objective of improving energy balance while considering thermal and visual comforts as constraints in the presence of occupants or only consider the building as an energy system and improve the energy

balance of the building by minimizing energy consumption if the user is not present in the space.

In this thesis, multi-objective optimization is used for achieving optimal decisions. The multi-objective genetic algorithm is defined to determine the optimal configuration for dynamic shading operation. GA is a global search technique that can escape from local optimal. This algorithm is extremely parallel, random, and adaptive, which is based on "natural selection and survival of the fittest". Genetic algorithms are initiated by selecting a population of randomly generated solutions for the problem. They move from the generation of one solution to another by developing new solutions using objective evaluation, selection, crossover, and mutation operators. The GA has been applied in several office building energy system research, such as applying optimal control systems for dynamic insulation materials applied to office buildings and it has been proven that GA is very efficient in comparison with the baseline it has shown meaningful developments in the optimization results.

Multi-objective optimization is also like the previous two processes. The only difference is that it uses a different optimization engine, that can evaluate multiple objectives at the same time. Wallacei, a multi-objective optimization plug-in for Grasshopper, is used to perform the optimization. The two objectives are maximum average UID, and minimum total cooling, heating, and lighting load. The target is to find a design with a balanced performance between daylighting and energy. Wallacei by default finds the minimum value of each objective, so the objective to be maximized (average UDI). Pareto frontiers with trade-offs between each performance metric are found after the optimization process.

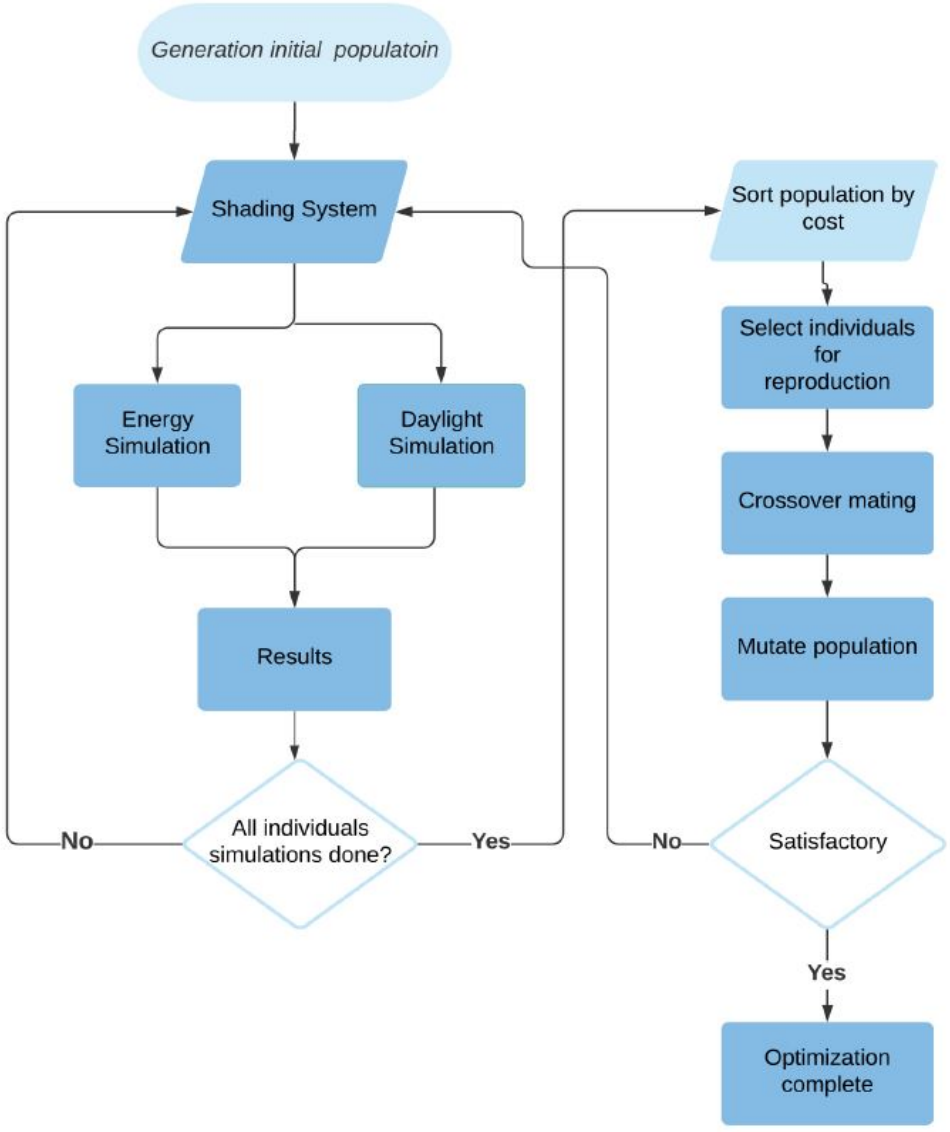


Figure 3.9. Multi-Objective Optimization Diagram

3.2.7 Real-time user preferred illuminance Control System

Initially this methodology was developed to be implemented in real-time conditions; however, prolonging of the restrictions due to the pandemic in the year 2020 and 2021, forced the authors to settle for a simulated testing. Nevertheless, the real-time methodology in the following paragraphs is modified in the next chapter to suit the simulation environment.

in this section of the study an algorithm is developed utilizing several real-time sensors to provide the optimal visual comfort condition unique to each user (Figure 3.10), provided they are alone in a small office or a home-office. Beginning with a check of outdoor and indoor temperature the system decides in which seasonal condition should the control center perform. This condition is checked by a simple dry bulb temperature sensor outside (T_{out}) of the room in proper setting and an operative temperature sensor (T_{in}) inside the room to not only check the seasonal which is defined as winter if T_{out} is lower than 15°C and summer if higher than 25°C. T_{in} is used to determine the degree from comfort which plays a role in decision making of control center when the user is absent.

Second step is to check whether the user is present in the room. This is done by a couple motion sensors. One of which installed immediately inside the entrance, and the other outside. Together they can determine if the user is present in the room or not. If user is not present the control system performs as explained in section 4.6.10.

If the user is inside the room, next is to check the presence of direct sunlight on the work-plane, if yes, the angle method explained in section 4.6.5 is applied. If no, the control system proceeds to WPI control. If WPI sensor signals too much light, it signals to venetians closing down until WPI lies inside the threshold. On the other hand, if WPI sensor signals too little light venetians open until satisfaction is reached. This satisfaction threshold starts with generic values related to the tasks the user performs in the space such as 300 – 1000 lux for normal office work, but as the user is given power to overrule the automation system at any point through their cellphone, these data are used to generate a machine learning process predicting user preference after the minimum number of data is collected.

Glare is controlled simultaneously and similarly but through roller blinds. Rollers are always open unless glare exists. In which case roller closes down until glare sensor signals a DGP lower than 0.30.

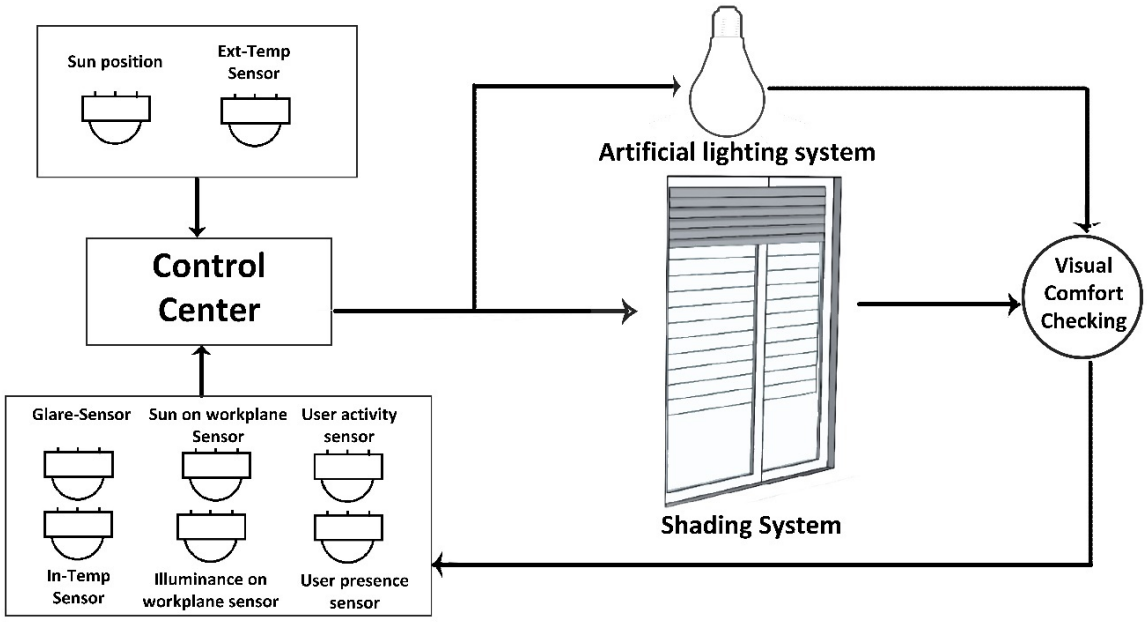


Figure 3.10. utilizing several real-time sensors to provide the optimal visual comfort condition unique to each user.

4. CASE STUDY

4.1 Case description

4.1.1 Location

The case study analyzed in this section is located in Lecco. This decision was made mainly due to the data collection restrictions. Data used in this study was collected in the home-office of the one of the authors of this text.

4.1.2 Building

The case study is a home-office on the 3rd floor of a multifunctional building in Lecco (Figure 4.1) in the north of Italy, the building has 4 floors in a residential, commercial context (Figure 4.2). The main entrance to the building is from inside of the courtyard which is surrounded by other multistorey buildings (Figure 4.3).



Figure 4.1.Position of Building in Lecco Map



Figure 4.2.Case study Building



Figure 4.3.Modeling of studied building

4.1.3 Climate Conditions

Climate is one of the most important factors that determine buildings' energy consumption because of the direct relationship between outdoor temperature and building cooling and heating load. Daylighting performance is greatly influenced by the latitude of the building location. According to the Köppen (Figure 4.4) climate classification), Lecco is in climate E. climates type E are controlled by the polar and arctic air masses of high latitudes (60° N and S and higher). These climates are characterized by low temperatures and precipitation and by a surprisingly great diversity of subtypes. Lecco has the oceanic climate prevailing. There is rainfall during all months of the year. The average annual temperature for Lecco is 20° degrees. It is dry for 206 days a year with an average humidity of 69%. By considering the aim of this dissertation, climate, and needed information in each step of the dissertation are extracted from the EnergyPlus weather file of Lecco climate by using the Ladybug component of Grasshopper Rhino. (Figure 4.5, Figure 4.6, Figure 4.7).

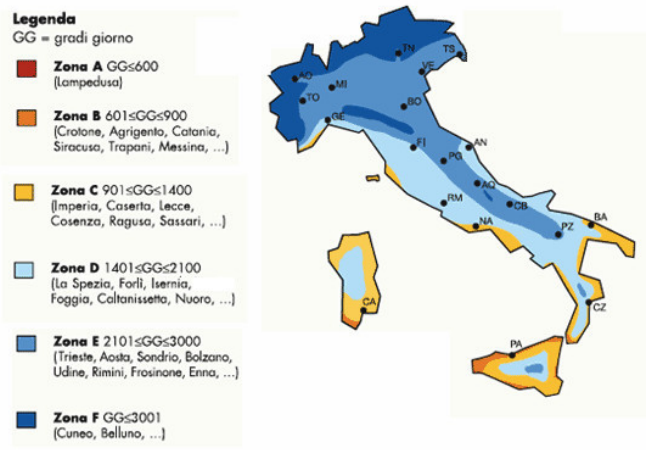


Figure 4.4. Köppen climate classification

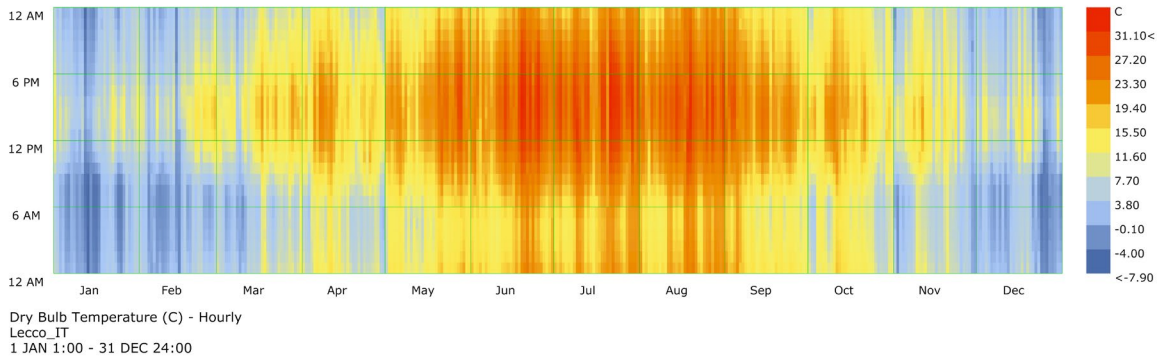


Figure 4.5.Lecco, Italy Temperature Profile

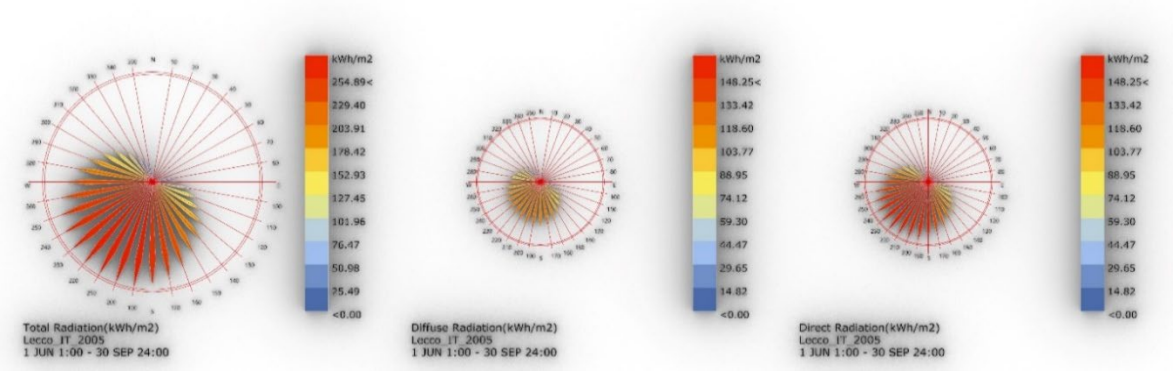


Figure 4.6.Summer sunlight direction on the case study unit

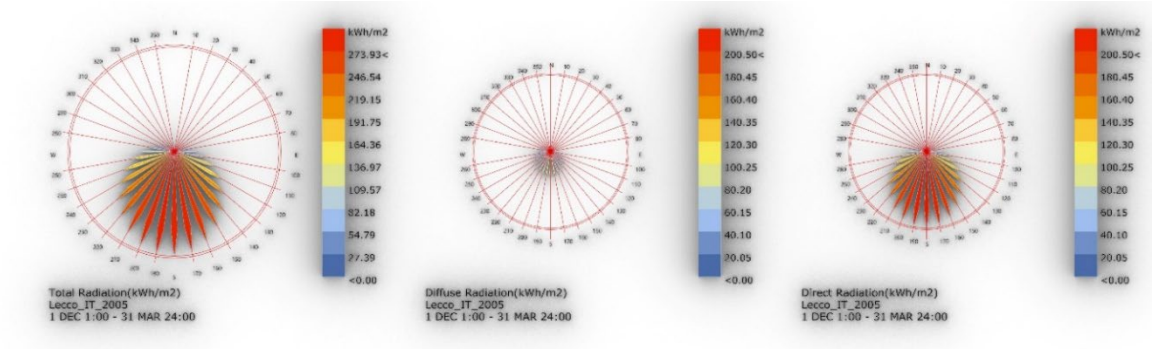


Figure 4.7.Winter sunlight direction on the case study unit

Assuming any internal space with an internal dry bulb temperature of 5 degrees higher than the outdoor temperature, the baseline adaptive comfort of Lecco can be drawn as follows. (Figure 4.8)

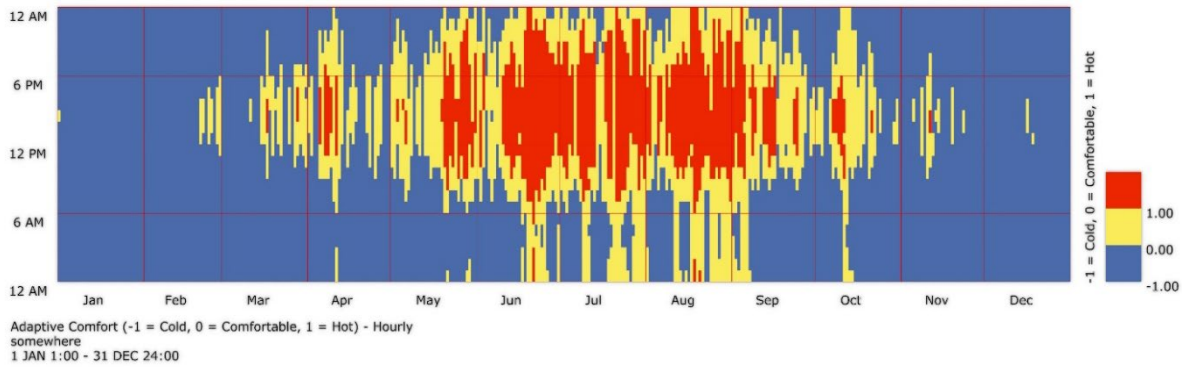


Figure 4.8. annual hours out of comfort in terms of EN15251 adaptive comfort

Lecco's cumulative sky dome at 21st day of February and August. (Figure 4.9)

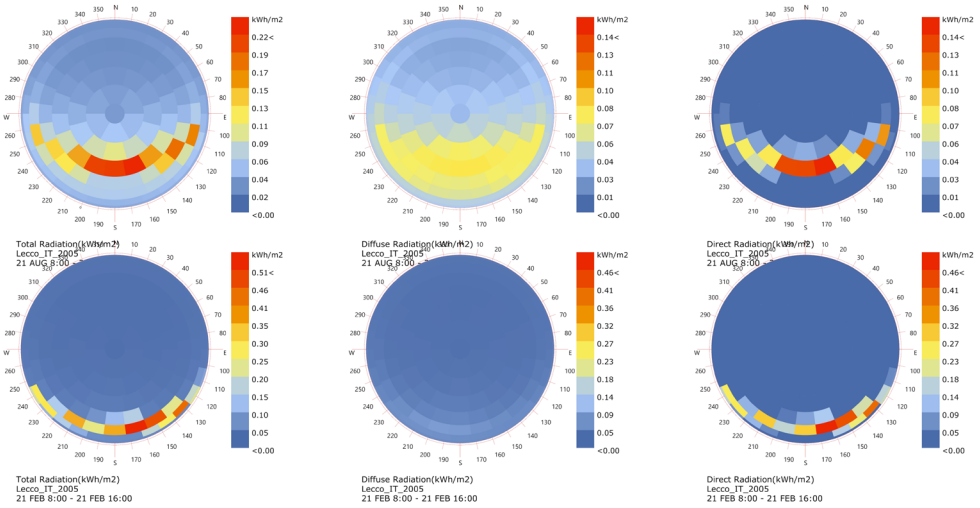


Figure 4.9. Left to right: Total Radiation, Diffused radiation, Direct radiation (Top: June, Bottom: February)

4.1.4 Unit Properties

The details and fixed parameters of the space under study in this office unit of this case study is discussed as follows. The height of the room (from ground to the ceiling) is 3 meters. The space area is approximately 18 Square meters, and it is confined by 3 interior walls and one exterior wall. The exterior wall is in southwest orientation and has two windows, the total area of the windows is about 7 square meters. The height of the windows are 2.7 meters (Table 4.1). The details of layers material are calculated by using EN ISO 13785 and listed in Table 4.2, Table 4.3, Table 4.4. The U-Value of material in ceiling, floor, interior, exterior walls, and windows are presented in Table 4.5.

The studied office is about 60 square meters, included 3 locations, 2 rooms, one service, and a small space for circulation. One of these rooms is chosen as the main space for studying, the orientation of this room is in south-west (Figure 4.10).

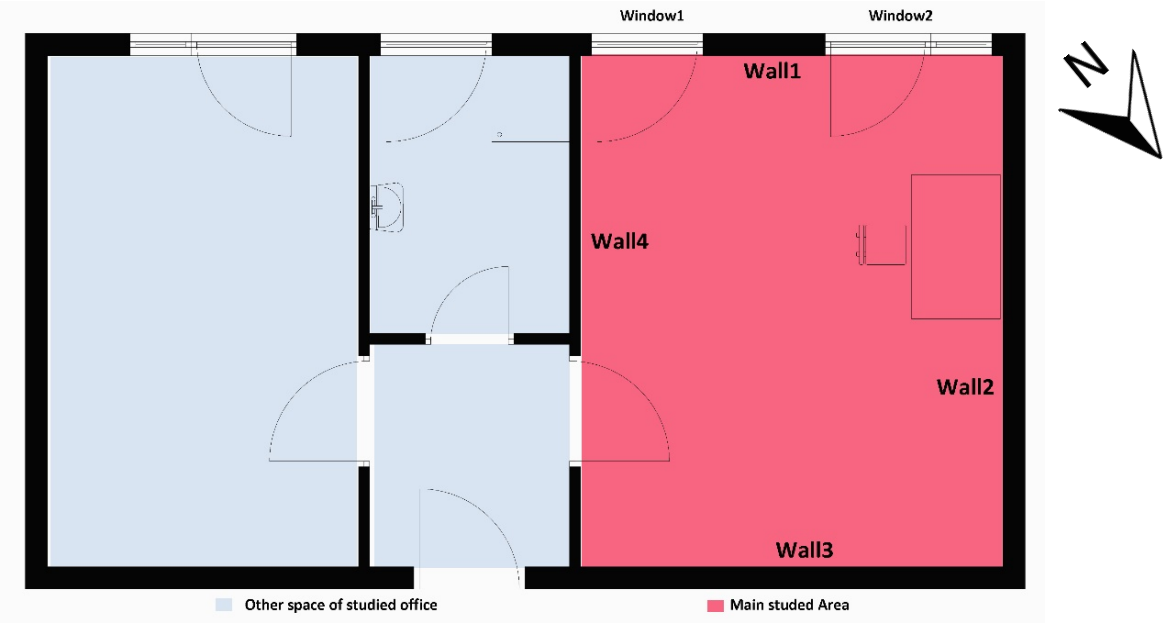


Figure 4.10.Studied office Drawing Plan.

Building shape, layer properties of building elements, and window properties are explored for use in optimal daylighting and energy performance. To simplify the problem, the placement of the doors and the interior partition are not considered in the optimization process. Since the building belongs to about the 90th decade, the details of the most predominant technologies of the time in northern Italy were considered in Calculating properties of parameters. The Tabula project (Figure 4.11) as a very solid reference about existing buildings in Europe and Italy was used as a reference. The walls are assumed with two layers of hollow brick + insulation and in the case of windows, insulated double glass is the existing situation.

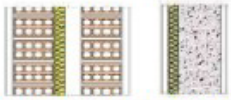
Building-type	ROOFS/CEILINGS[1]	FLOORS	WALLS	WINDOWS	DOORS
APARTMENT BLOCK  1976-1990	 Ceiling with reinforced brick-concrete slab, low insulation	 Floor with reinforced brick-concrete slab, low insulation	 Hollow wall brick masonry (40 cm), low insulation. Concrete masonry (also prefabricated, 18 cm), low insulation	 Double glass, air filled, metal frame without thermal break	-
APARTMENT BLOCK  1991-2005	 Ceiling with reinforced brick-concrete slab, medium insulation	 Floor with reinforced brick-concrete slab, medium insulation	 Concrete masonry (also prefabricated, 30 cm), medium insulation. Hollow brick masonry (40 cm), medium insulation	 Double glass, air filled, metal frame with thermal break	-

Figure 4.11.. Building Properties of 90th decade according to Tabula project (National Building Typologies, 2012)

Table 4.1. Main parameters of studied room

Parameter	Type	Area	Length	Height
Wall1	Opaque	4.70	3.80	3.00
	Window1	2.70		
	Window 2	4		
Wall2	Opaque	13.80	4.60	
Wall3	Opaque	11.40	3.80	
Wall3	Opaque	13.80	4.60	

Table 4.2. Properties of interior wall of studied room

N	Layers	Thickness [ma]	λ [W/mK]	ρ [kg/m3]	C [J/kgK]
1	Polyester resin	0.005	0.190	1400	1200
2	Plaster	0.02	0.7	1400	1000
3	Hollow brick	0.15	0.45	1000	1000
2	Plaster	0.02	0.7	1400	1000
1	Polyester resin	0.005	0.190	1400	1200
RESULTS					
fd [-]		ϕ [h]	hI[kJ/m2K]		U [W/m2K]
0.584		6.06	58.56		1.63

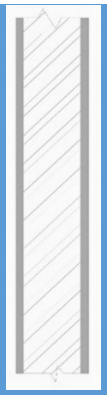


Table 4.3. Properties of ceiling and floor of studied room

N	Layers	Thickness [ma]	λ [W/mK]	ρ [kg/m3]	C [J/kg K]
1	Polyester resin	0.0050	0.190	1400	1200
2	Plaster	0.0200	0.700	1400	1000
3	concrete	0.1500	2.300	2300.0	1000
4	Wooden floor	0.0150	0.170	700	1600
RESULTS					
fd [-]		ϕ [h]	hI[kJ/m2K]		U [W/m2K]
0.439		5.61	59.05		2.64

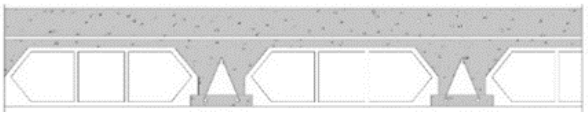


Table 4.4. Properties of exterior wall of studied room

N	Layers	Thickness [ma]	λ [W/mK]	ρ [kg/m3]	C [J/kgK]
1	Polyester resin	0.005	0.190	1400	1200
2	Plaster	0,02	0.7	1400	1000
3	Hollow brick	0,15	0.45	1000	1000
4	Rockwool	0.0540	0.04	160.0	1030
5	Air cavity	0.0460	0.024	1.3	1012
3	Hollow brick	0.1000	0.45	1000.0	1000
6	Cement lime plaster	0.0300	0.700	1600.0	1100
RESULTS					
fd [-]		ϕ [h]	hI [kJ/m2K]		U [W/m2K]
0.158		1.66	53.80		0.25

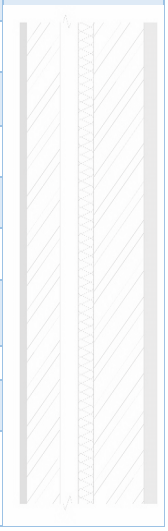


Table 4.5. U value of different elements

	Element	U-Value
1	Exterior Wall	0.25
2	Interior Floor	2.64
3	Interior Ceiling	2.64
4	Interior Wall	1.63
5	Window	3.5

4.1.5 Building Façade system

Units of this complex has independent shading systems working on each window. However, the most prevalent shading device is the Italian favorite, rolling shutters called serranda. relying on the independency of the units to introduce another system that could work better with automation however, aesthatically it will not be too far from the existing context(Figure 4.12).



Figure 4.12.picture of the building complex of case study

4.2 Survey

A survey was done by the authors over the course of four months collecting data regarding illuminance levels over their own desk whilst working inside their own home-offices during the obligatory isolation period imposed by Italian government due to the global pandemic of the year 2020.

4.2.1 Instruments

Simple light meter app on the cellphones is used at a fixed 30cm distance perpendicular to the measured point surface from each point of measurement to keep the same level of accuracy.

Second instrument is the survey sheet to collect all the desired data. The sheet can be seen in the **Appendix I**.

4.2.2 Method

The survey was done by the authors through capturing their own preferred illuminance levels and the existing condition by writing down the illuminance level of 5 points on the work-plane and a point on the wall in front of them (Figure 4.13) 5 points on the work-plane and a point on the wall in front of them, if any, and perpendicular to their field of vision. Other variables collected consist of the activity they were doing and the position of their sit toward the window. The Table 4.6below describes the variables of data collected during this survey.

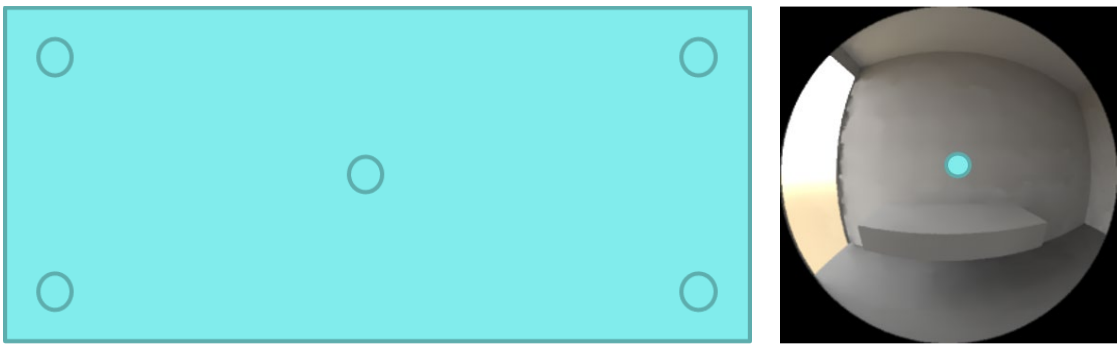


Figure 4.13.5 points on the work-plane and a point on the wall in front of them

Table 4.6.Description of survey sheet inputs

Time of Capture		Hour of Day
Higher Threshold Blinders Percentage		Percentage of the area of shading that covers the window in the higher threshold of user
Lower Threshold Blinders Percentage		Percentage of the area of shading that covers the window in the lower threshold of user
Fully open	Middle Point	User Measures the light of each characterized point by lux meter when the shading is fully closed, and nothing covers the glass. The unit of each point value is LUX
	Point1	
	Point2	
	Point3	
	Point4	
	Front	
Highest Acceptable	Middle Point	User Measures the light of each characterized point by lux meter when the shading is closed until the higher threshold of the user. The unit of each point value is LUX.
	Point1	
	Point2	
	Point3	
	Point4	
	Front	
Lowest Acceptable	Middle Point	User Measures light of each characterized point by lux meter when the shading is closed until the lower threshold of the user. The unit of each point value is LUX.
	Point1	
	Point2	
	Point3	
	Point4	
	Front	
Position Toward Window	Behind	According to the position of workplace and window user can choose different positions according to the window.
	Front	
	Left	
	Right	
State of Comfort (At fully open)	Great	It is the state of user about the comfort of exist situation when the shading is fully closed.
	Satisfied	
	Low	
Activity		For Survey, the user activities are emphasized on special activities includes: Reading Writing Horizontal screen work (Cell Phone, Tablet) Vertical screen work (Computer, laptop Cellphone, Tablet)

4.3 Simulation Baselines

4.3.1 Simulation period

To reduce the number of simulations since in some parts simulations need to be done several times for each hour of the year, from 9am to 5pm of twelve days, one day per month, in the year has been chosen for the simulation purpose of this study. 9 hours in the 21st day of each month provides 108 hours in total in the year which includes several variations of the sky including cloudy sky in warmer days and sunny sky in colder days. Daily hours are chosen to initiate from 9 and end in 5 because not only it complies with the most prevalent office hours that exist, but it also restricts our energy and lighting load to the hours including daylight.

4.3.2 Energy simulation baselines

Default small office schedules and load rates used for all energy simulation from this point forward in the study are indicated in (Table 4.7) and default schedules in (Table 4.8, Table 4.9, Table 4.10) below. Note these are the baseline values and used in all simulation unless indicated otherwise in a specific section of the study.

Table 4.7 default loads.

Equipment Load Per Area (W/m^2)	**7.6424**
Infiltration Rate Per Area -Façade (m^3 / s-m^2)	0.0002
lighting Density Per Area (W/m^2)	11.8404
Number Of People Per Area (ppl/ m^2)	0.0565
Ventilation Per Area (m^3 / s-m^2)	0.0003
Ventilation Per Person (m^3 / s-person)	0.0024

Equipment Load Per Area: The desired equipment load per square meter of floor. Values here are in W/m2 (Watts per square meter).

Infiltration Rate Per Area -Façade: The desired rate of outside air infiltration into the zone per square meter of exterior facade. Values here are in m3/s-m2 at 4Pa (Cubic meters per second per square meter of exterior facade). ASHRAE recommends the following general infiltration rates based on the area of the facade exposed to the outdoors:

lighting Density Per Area: The desired lighting load per square meter of floor. Values here should be in W/m2 (Watts per square meter).

Number Of People Per Area: The desired number of per square meter of floor at peak occupancy. Values here are in ppl/m2 (People per square meter).

Ventilation Per Area: The desired minimum rate of outdoor air ventilation through the mechanical system into the zone in m3/s per m2 of floor. Values here are in m3/s-m2 (Cubic meters per second per square meter of floor).

Ventilation Per Person: The desired minimum rate of outdoor air ventilation through the mechanical system into the zone per person in the zone. Values here are in m3/s-person (Cubic meters per second per person in the zone). In effect, an input here will mimic demand-controlled ventilation, where the ventilation through the mechanical system will change depending upon the occupancy.

Weekday

Table 4.8 default weekday schedules

Hour	Occupancy schedule	Occupancy Activity Schedule	Heating-Set point Schedule	Cooling Set point Schedule	Lighting Schedule	Equipment Schedule	Infiltration Schedule
24	0	120	15.6	26.7	0.05	0.4	1
1	0	120	15.6	26.7	0.05	0.4	1
2	0	120	15.6	26.7	0.05	0.4	1
3	0	120	15.6	26.7	0.05	0.4	1
4	0	120	15.6	26.7	0.05	0.4	1
5	0	120	15.6	26.7	0.1	0.4	1
6	0.1	120	21	24	0.1	0.4	0.25
7	0.2	120	21	24	0.3	0.4	0.25
8	0.95	120	21	24	0.9	0.9	0.25
9	0.95	120	21	24	0.9	0.9	0.25
10	0.95	120	21	24	0.9	0.9	0.25
11	0.95	120	21	24	0.9	0.9	0.25
12	0.5	120	21	24	0.9	0.8	0.25
13	0.95	120	21	24	0.9	0.9	0.25
14	0.95	120	21	24	0.9	0.9	0.25
15	0.95	120	21	24	0.9	0.9	0.25
16	0.95	120	21	24	0.9	0.9	0.25
17	0.7	120	21	24	0.7	0.8	0.25
18	0.4	120	21	24	0.5	0.6	0.25
19	0.4	120	21	24	0.5	0.6	0.25
20	0.1	120	21	24	0.3	0.5	0.25
21	0.1	120	21	24	0.3	0.5	0.25
22	0.05	120	15.6	26.7	0.1	0.4	1
23	0.05	120	15.6	26.7	0.05	0.4	1

Saturday

Table 4.9 default Saturday schedules

Hour	Occupancy schedule	Occupancy Activity Schedule	Heating Set point Schedule	Cooling-Set point Schedule	Lighting Schedule	Equipment-Schedule	Infiltration Schedule
24	0	120	15.6	26.7	0.05	0.3	1
1	0	120	15.6	26.7	0.05	0.3	1
2	0	120	15.6	26.7	0.05	0.3	1
3	0	120	15.6	26.7	0.05	0.3	1
4	0	120	15.6	26.7	0.05	0.3	1
5	0	120	15.6	26.7	0.05	0.3	1
6	0.1	120	21	24	0.1	0.4	0.25
7	0.1	120	21	24	0.1	0.4	0.25
8	0.5	120	21	24	0.5	0.5	0.25
9	0.5	120	21	24	0.5	0.5	0.25
10	0.5	120	21	24	0.5	0.5	0.25
11	0.5	120	21	24	0.5	0.5	0.25
12	0.5	120	21	24	0.5	0.5	0.25
13	0.5	120	21	24	0.5	0.5	0.25
14	0.1	120	21	24	0.15	0.35	0.25
15	0.1	120	21	24	0.15	0.35	0.25
16	0.1	120	21	24	0.15	0.35	0.25
17	0	120	21	24	0.05	0.3	0.25
18	0	120	15.6	26.7	0.05	0.3	1
19	0	120	15.6	26.7	0.05	0.3	1
20	0	120	15.6	26.7	0.05	0.3	1
21	0	120	15.6	26.7	0.05	0.3	1
22	0	120	15.6	26.7	0.05	0.3	1
23	0	120	15.6	26.7	0.05	0.3	1

Sunday

Table 4.10 default Sunday schedules

Hour	Occupancy schedule	Occupancy Activity Schedule	Heating Set point Schedule	Cooling Set point Schedule	Lighting Schedule	Equipment Schedule	Infiltration Schedule
24	0	120	15.6	26.7	0.05	0.3	1
1	0	120	15.6	26.7	0.05	0.3	1
2	0	120	15.6	26.7	0.05	0.3	1
3	0	120	15.6	26.7	0.05	0.3	1
4	0	120	15.6	26.7	0.05	0.3	1
5	0	120	15.6	26.7	0.05	0.3	1
6	0	120	15.6	26.7	0.05	0.3	1
7	0	120	15.6	26.7	0.05	0.3	1
8	0	120	15.6	26.7	0.05	0.3	1
9	0	120	15.6	26.7	0.05	0.3	1
10	0	120	15.6	26.7	0.05	0.3	1
11	0	120	15.6	26.7	0.05	0.3	1
12	0	120	15.6	26.7	0.05	0.3	1
13	0	120	15.6	26.7	0.05	0.3	1
14	0	120	15.6	26.7	0.05	0.3	1
15	0	120	15.6	26.7	0.05	0.3	1
16	0	120	15.6	26.7	0.05	0.3	1
17	0	120	15.6	26.7	0.05	0.3	1
18	0	120	15.6	26.7	0.05	0.3	1
19	0	120	15.6	26.7	0.05	0.3	1
20	0	120	15.6	26.7	0.05	0.3	1
21	0	120	15.6	26.7	0.05	0.3	1
22	0	120	15.6	26.7	0.05	0.3	1
23	0	120	15.6	26.7	0.05	0.3	1

4.3.3 Impact of sky models

Climate-based daylight modelling is the prediction of luminous quantities (i.e., illuminance and/or luminance) using realistic sun and sky conditions that are derived from data in standardized climate files. A climate-based analysis is intended to capture all the unique sun and sky conditions over a period rather than be simply a "snapshot" of specific conditions at a particular instant. Because of the seasonal variation of daylight, the evaluation period is normally taken to be an entire year, in this dissertation due to the time-consuming energy simulations done in OpenStudio however, one day per month was chosen instead.

Different sky models are adopted according to the needs of each particular project. Climate-based sky model, diffusive sky model, sunny with sun, and sunny without sun (Appendix II) are some of the most utilized sky models in research projects related to daylighting.

In this project a climate-based sky model (Figure 4.14) is chosen due to its variation of sky models for each hour. whereas all other models have to some degree a uniformness, climate-based sky model includes unpredictability especially in the case of direct sunlight which helps the project indicate its smartness in detecting the actual situation of the context. This choice has another justification and that is due to the limitations of the tools to simulate the building solar gains under skies different from climate-based sky variations.

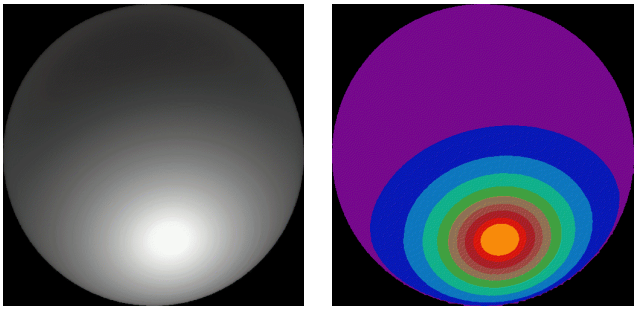


Figure 4.14 Climate based sky model

4.4 Shading Design – shading strategy

Referring to the methodology, this study is comprised of two parts. First part is focused in defining the shading strategy most effective for each case and then defining its optimal geometrical properties. Second part mainly focuses on the automation system.

For this specific unit combinations consisting of venetian blinds and roller blinds systems are considered due to their prevalence and effectiveness.

4.4.1 Shading strategy

In this part of the study, several shading strategies (Figure 4.15) is explored and compared to see which strategy would be more beneficial to select for this unit. These strategies are all variant adoptions of external venetian shadings and internal roller blinds over the windows.

Venetians are chosen due to the fact that not only are they very common and easily controllable, but they also come in very durable materials. Therefore, they are suitable to be used externally. On the other hand, the roller blinds are very effective when it comes to control glare but a durable fabric to be used externally and provide the excellence in effectiveness could be rare and expensive. Thus, roller blinds are chosen to be internal devices which could potentially be of help in cold winters by trapping the solar heat inside while blocking direct sun.

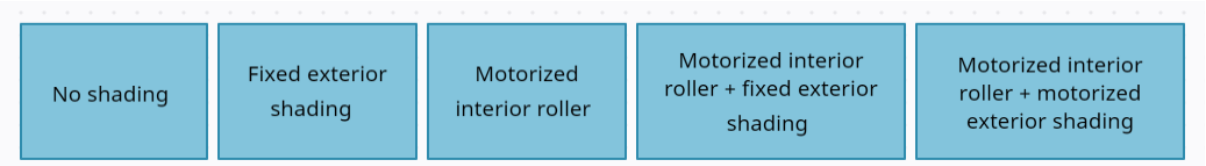


Figure 4.15 Five strategy type

4.4.2 Determining slat angles

In the following sections of study, there are strategies that utilize fixed exterior venetian blinds. To find the best possible position of these fixed shadings annual simulations has been done on the daylight autonomy on the work-plane. Average work-plane daylight autonomy is compared and slats in -35° (Figure 4.16) are chosen for this usage Figure 4.17.

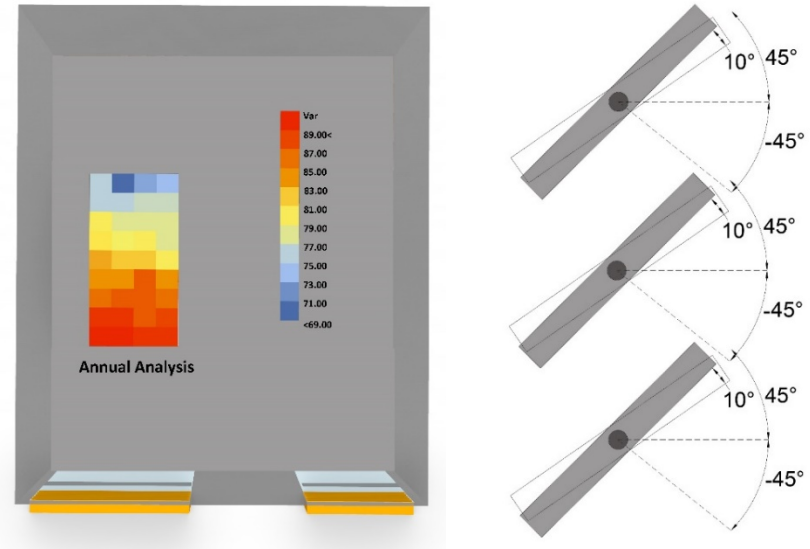


Figure 4.16 DLA on work-plane with slats at -35°

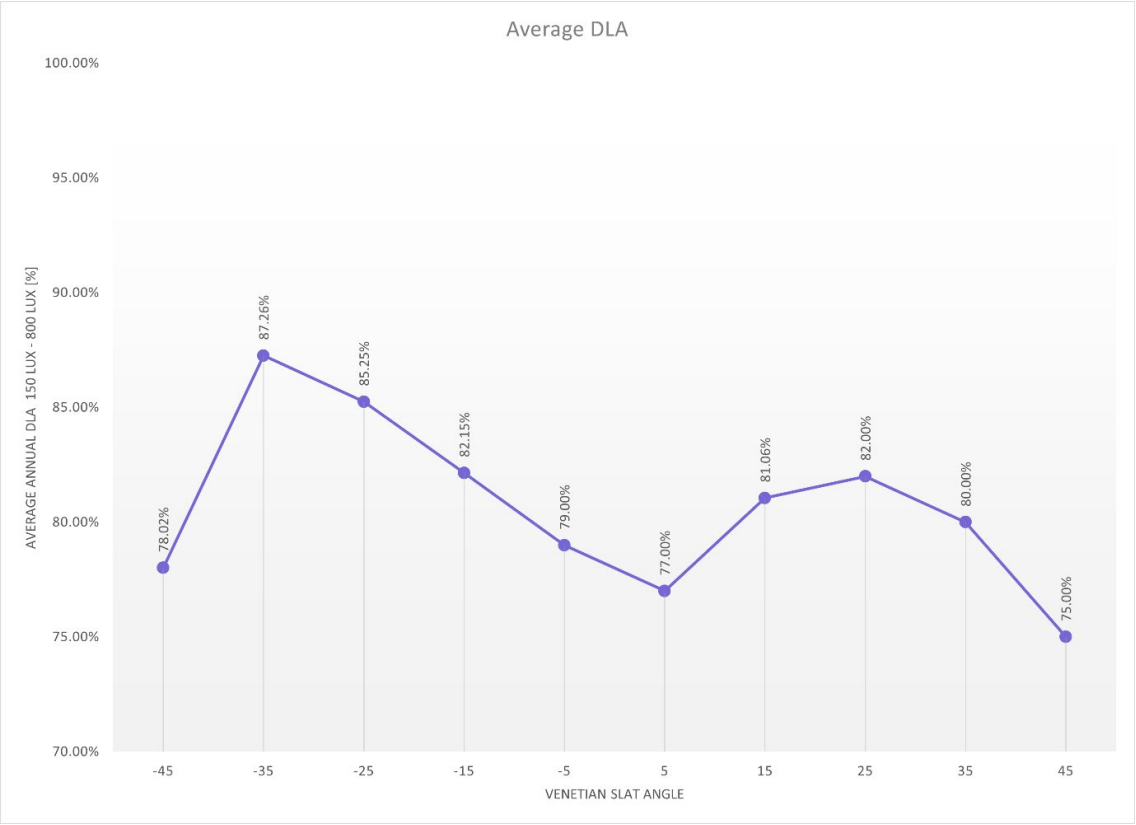


Figure 4.17. Average DLA of Venetian different slat angle

4.4.3 Automation strategies

4.4.3.1 Motorized interior roller blinds

Considering 0.65 kWh/m² as the maximum threshold and 0.15 as the minimum, the automation work by remapping these values for roller height values between 0 to 250 cm(Figure 4.18).

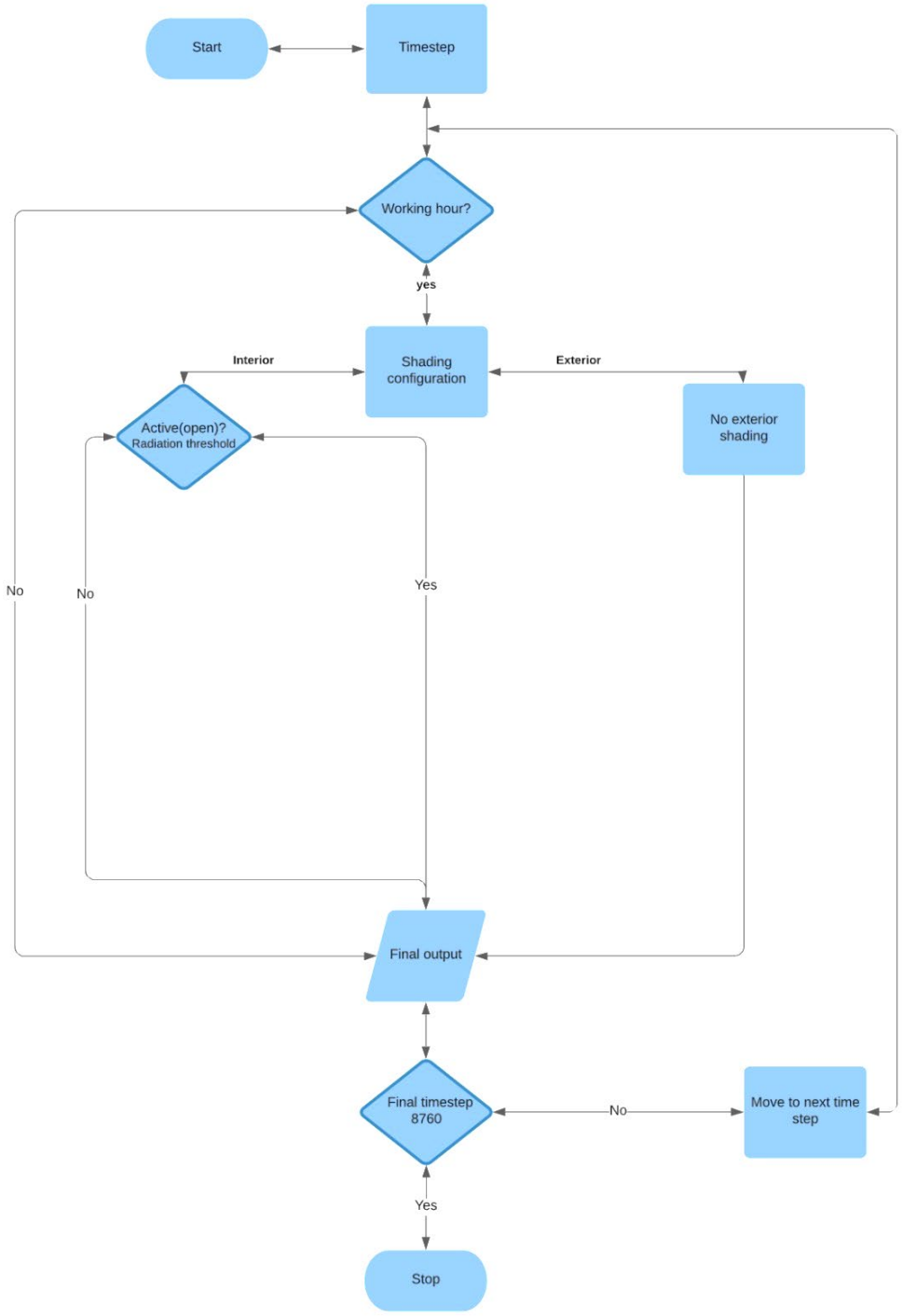


Figure 4.18 Graphical diagram of third strategy02

4.4.3.2 Motorized exterior venetian blinds and interior roller blinds

Keeping the same strategy for interior roller blinds system, in cases where exterior venetians are also motorized the following automation system is in practice. The exterior shading automation systems designed to keep the slats perpendicular to the direct sun vector hitting each slat in the summer period and conversely parallel in the winter position. This system is a simplex attempt to reach a maximized solar gain in the winter period and a minimized solar gain in the summer period (Figure 4.19).

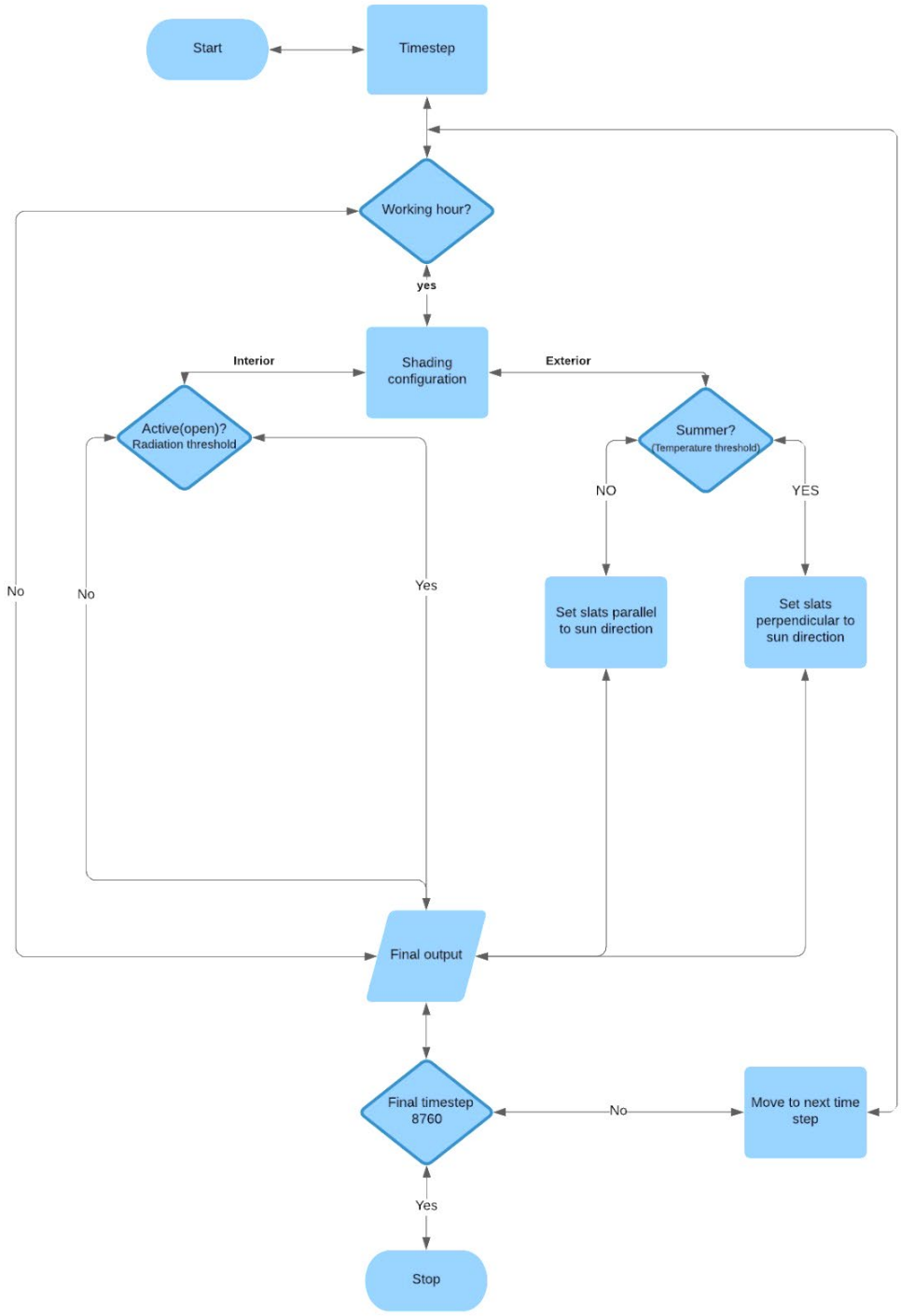


Figure 4.19 Graphical representation of preliminary automation of venetian blinds

4.4.4 Strategy 00 - No shading (ST00)

First strategy is no shading at all (Figure 4.20) This strategy is studied mainly to discover the need of additional shading devices. Since in some cases the location and orientation of the building and its context eliminates any need for additional shading devices. The different types of energy load of room for strategy00 are presented in Figure *4.21*. In Figure *4.22* there is a comparison between the solar which is gained by 2 windows of the studied room when the first strategy is activated and diffused direct radiation of Lecco for one year.

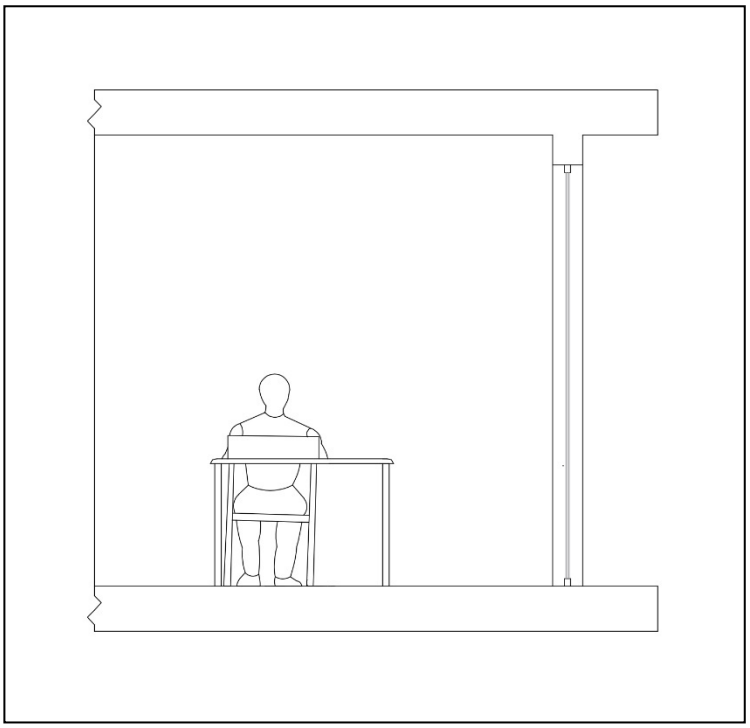


Figure 4.20. There are no shadings on windows.

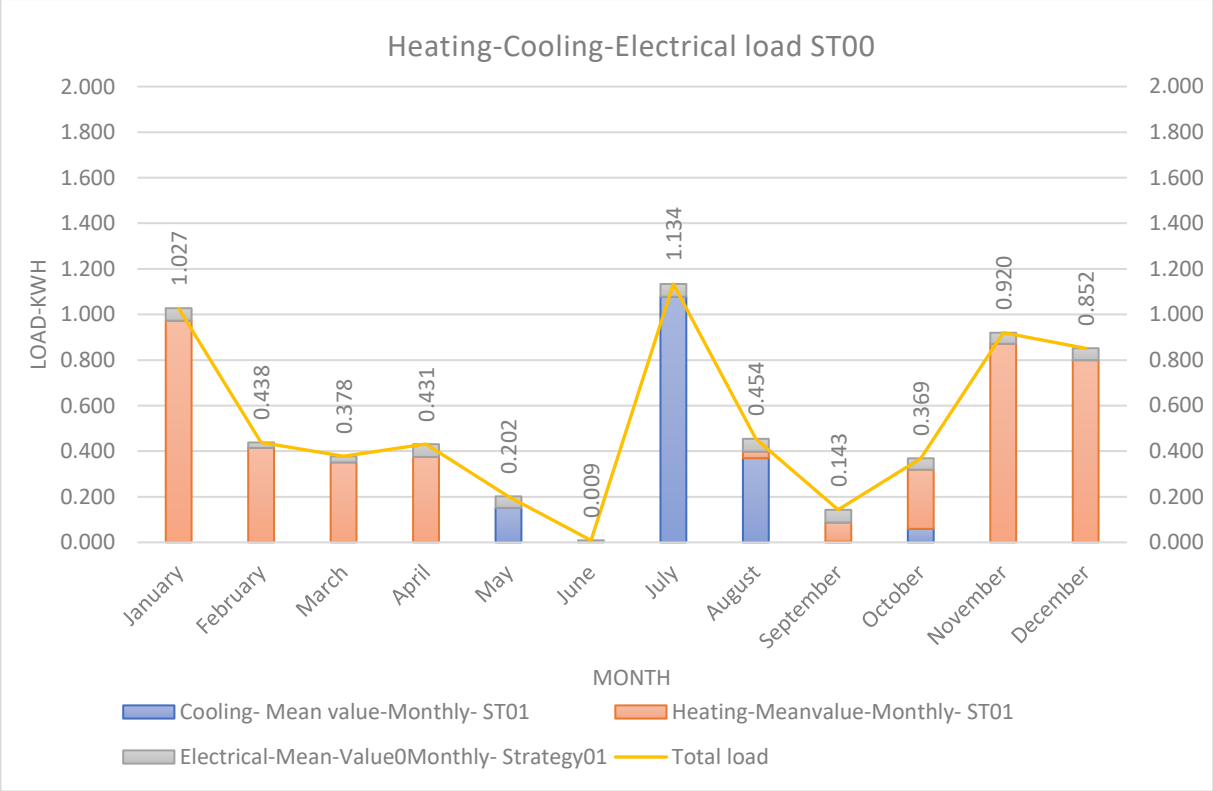


Figure 4.21. Heating-Cooling-Electrical load ST00

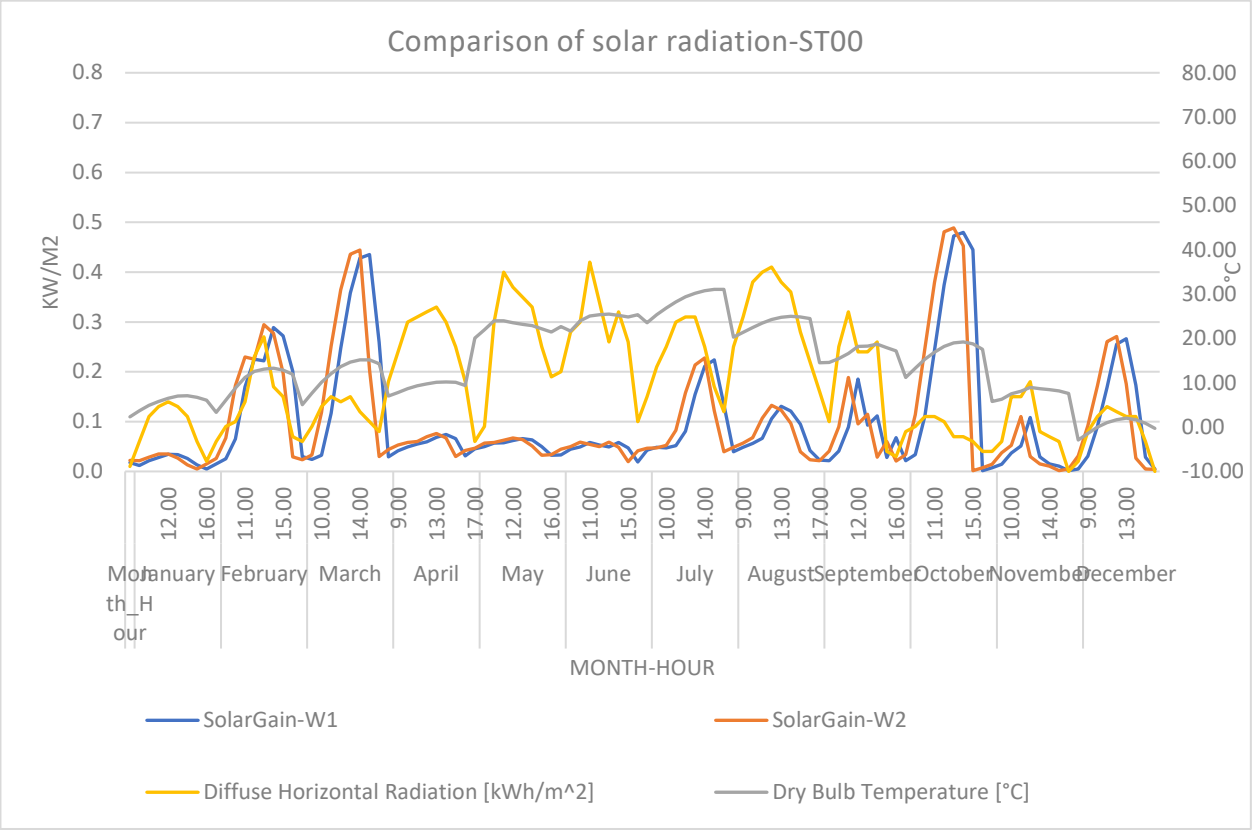


Figure 4.22. Comparison of solar radiation-ST00

4.4.5 Strategy 01 - Fixed exterior shading (ST01)

Second Strategy is fixed exterior shading employing venetian blinds (Figure *4.23*) with total height of 70cm from the top of the windows down. This height is covered by a total number of 6 slats with the width of 12cm. As indicated earlier in this chapter the optimal angle for the fixed external venetians is with the angle of -35 degrees, 0 being perpendicular to the window surface. The different types of energy load of room for strategy01 are presented in Figure *4.24* In Figure *4.25* there is a comparison between the solar which is gained by 2 windows of the studied room when the first strategy is activated and diffused direct radiation of Lecco for one year.

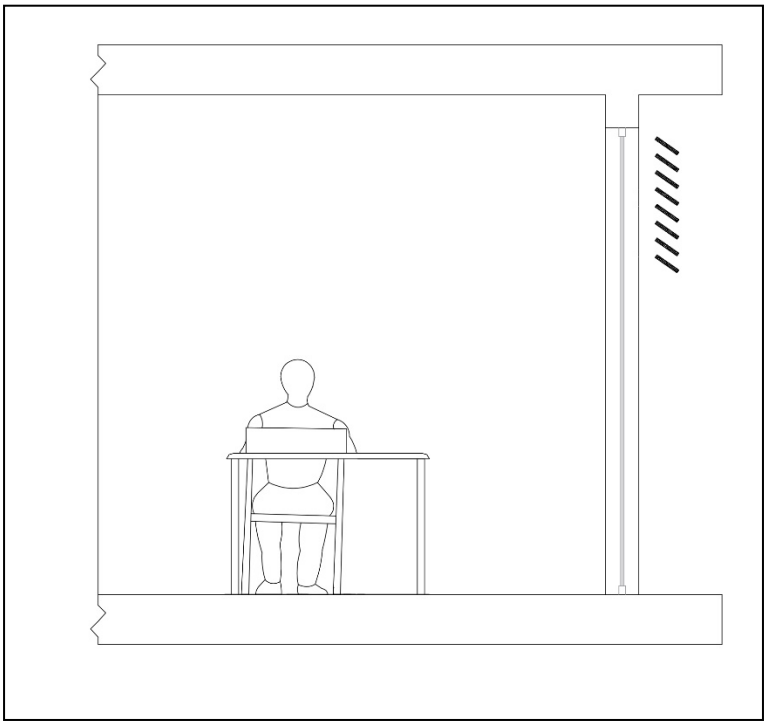


Figure 4.23. Heating-Cooling-Electrical load ST001

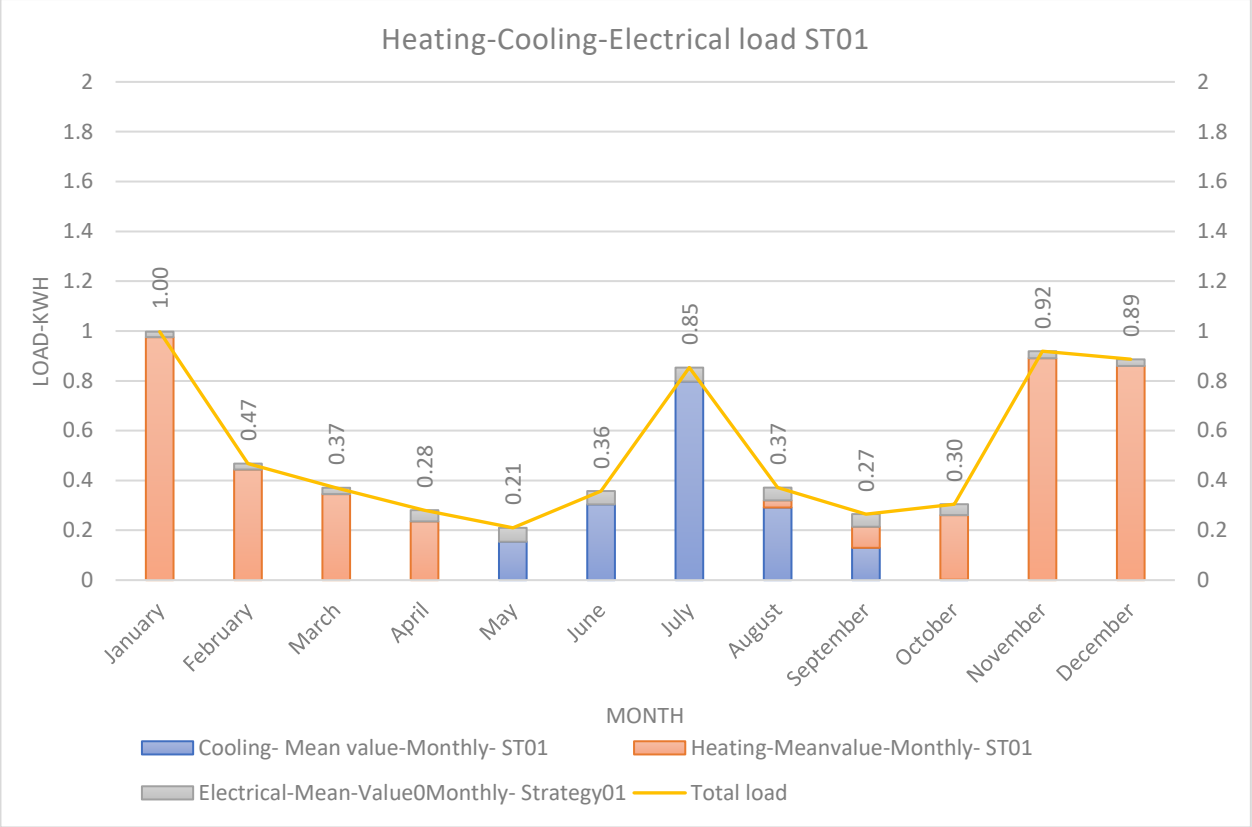


Figure 4.24. Heating-Cooling-Electrical load ST001

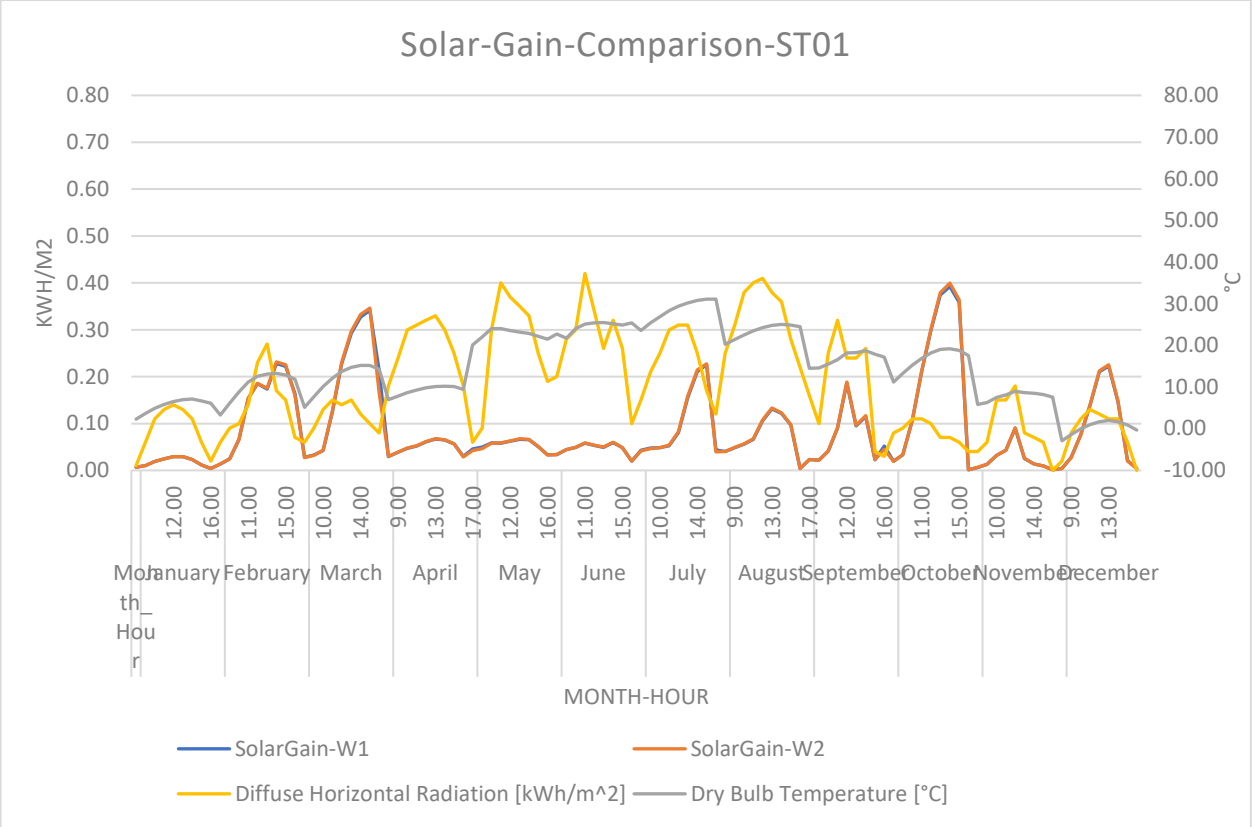


Figure 4.25. Comparison of solar radiation-ST001

4.4.6 Strategy 02 - Motorized interior roller (ST02)

Third strategy consist of a motorized interior roller blinds shading device (Figure *4.26*) that is automated considering the amount of direct solar radiation rose in the direction perpendicular to the façade.

The roller diffuse transmission is 30% and roughness, specular reflection, and specular transmission 0% and its color (105,105,105) gray. The different types of energy load of room for strategy02 are presented in Figure *4.27*. In Figure *4.28* there is a comparison between the solar which is gained by 2 windows of the studied room when the first strategy is activated and diffused direct radiation of Lecco for one year.

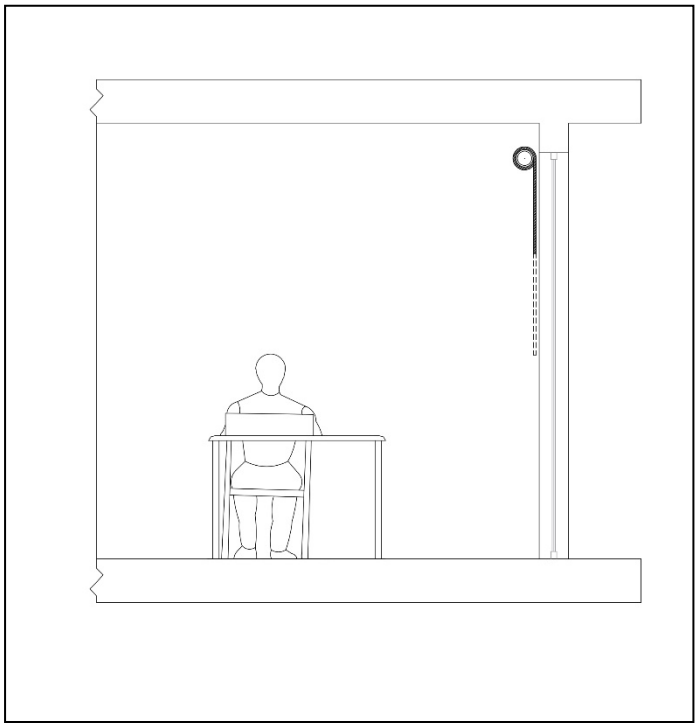


Figure 4.26. Third strategy consist of a motorized interior roller blinds shading device.

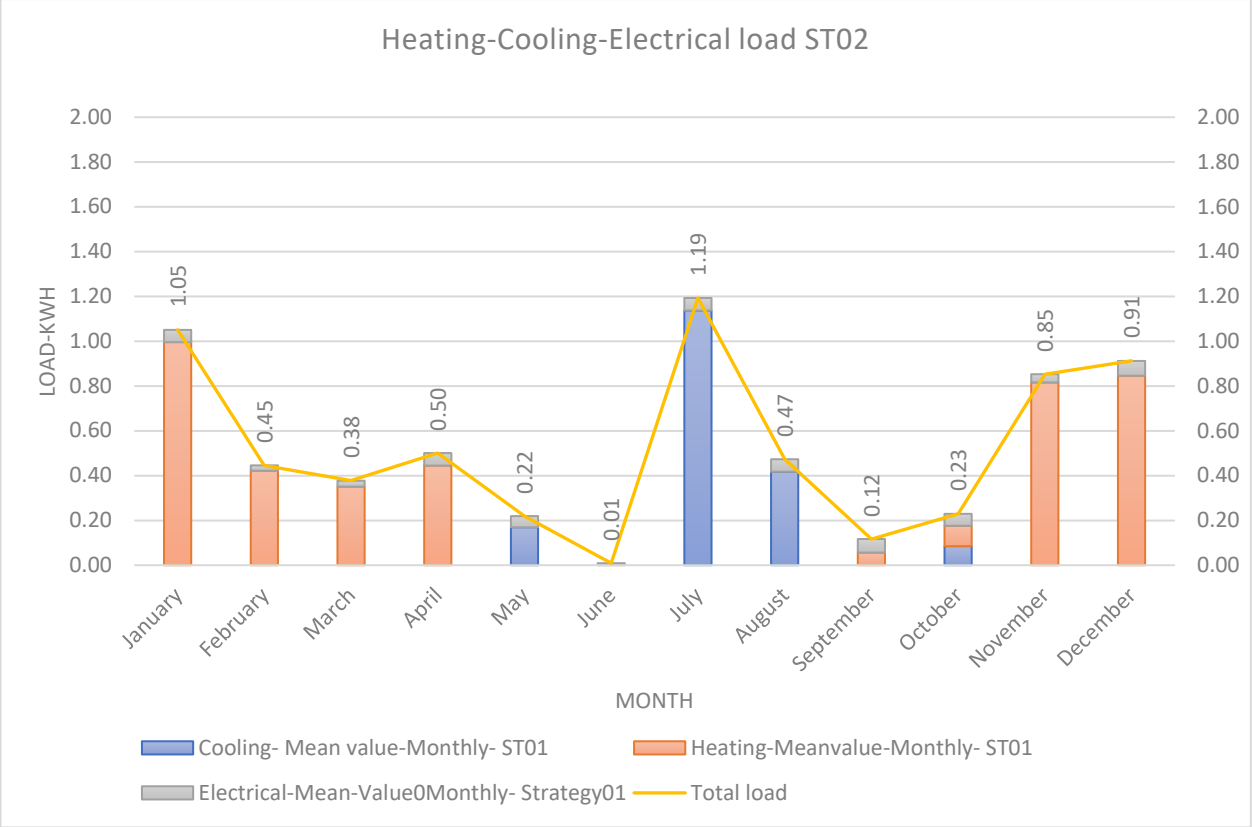


Figure 4.27. Heating-Cooling-Electrical load ST02

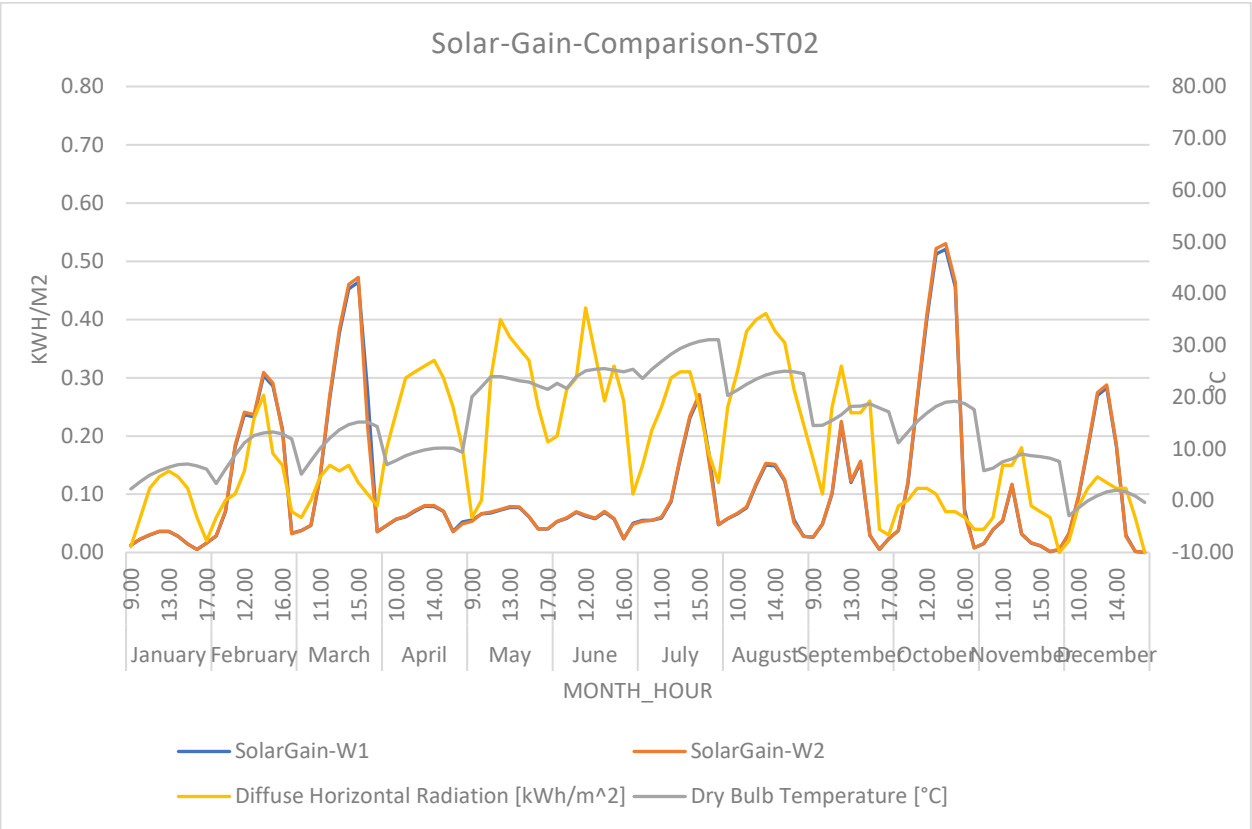


Figure 4.28. Comparison of solar radiation-ST02

4.4.7 Strategy 03 – Motorized interior roller and fixed exterior shading (ST03)

Fourth Strategy (Figure *4.29*) is fixed exterior shading employing venetian blinds same as second strategy together with roller motorized interior roller blinds same as the third strategy with the difference in that the roller blinds top bar installed under venetian shades meaning the window is divided in two parts top part shaded by exterior venetians and middle to bottom by roller blinds.

The different types of energy load of room for strategy 03 are presented in Figure *4.30*. In Figure *4.31* there is a comparison between the solar which is gained by 2 windows of the studied room when the first strategy is activated and diffused direct radiation of Lecco for one year.

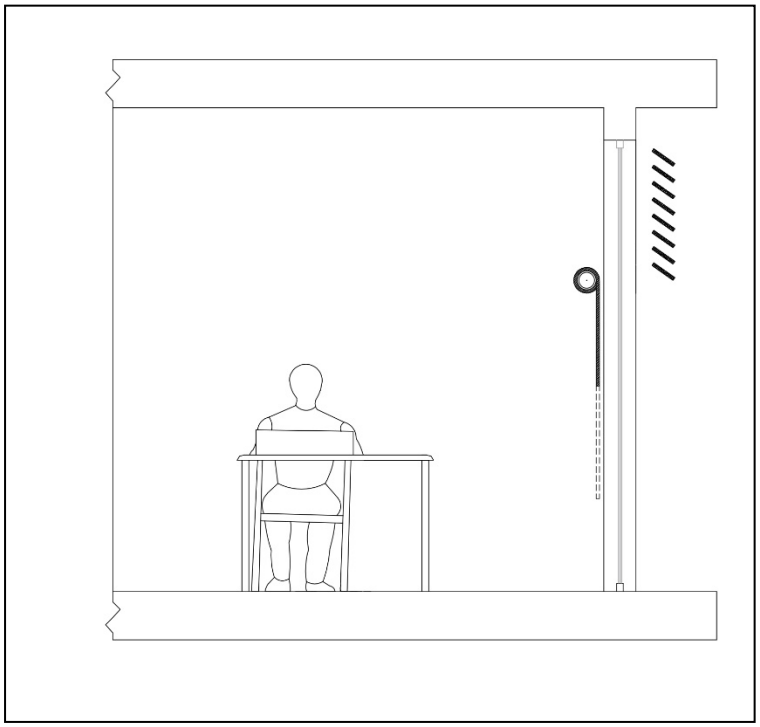


Figure 4.29. Fixed exterior shading employing venetian blinds with roller motorized interior roller blinds.

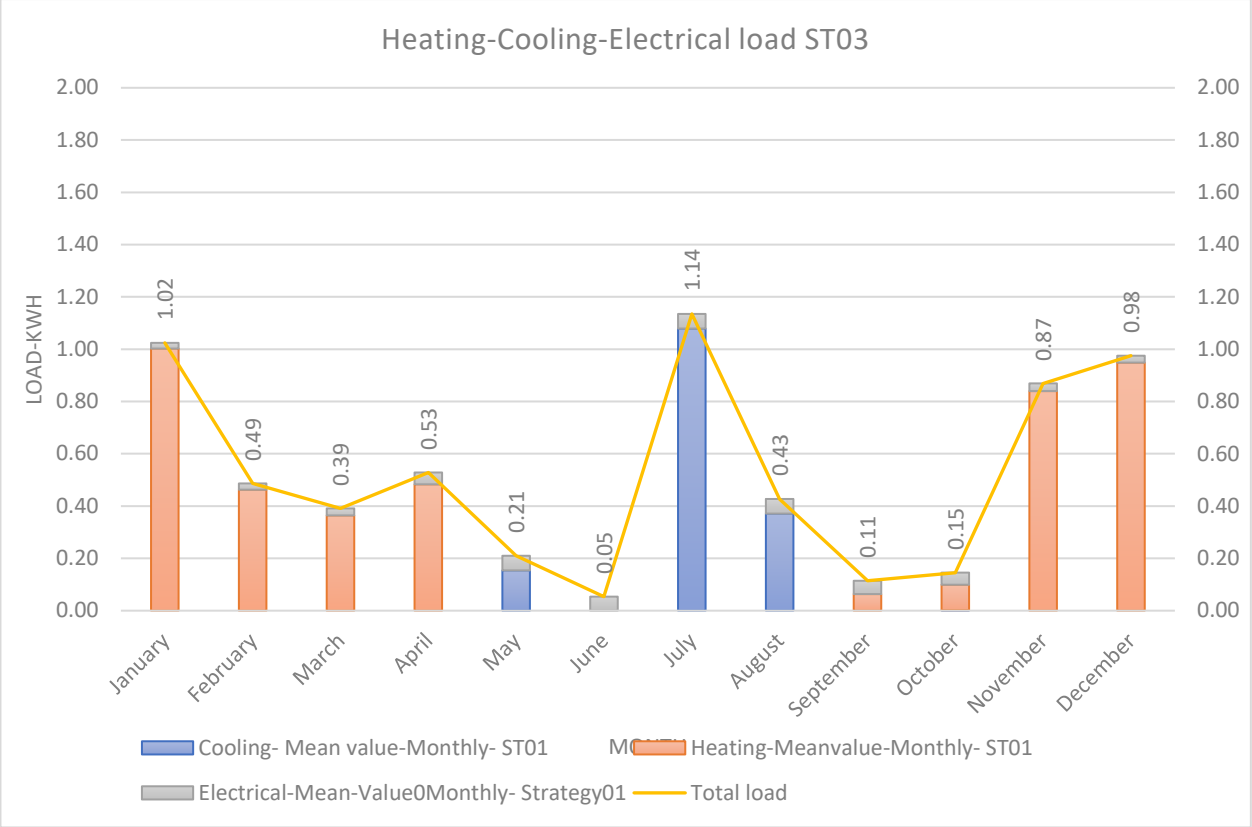


Figure 4.30. Heating-Cooling-Electrical load ST03

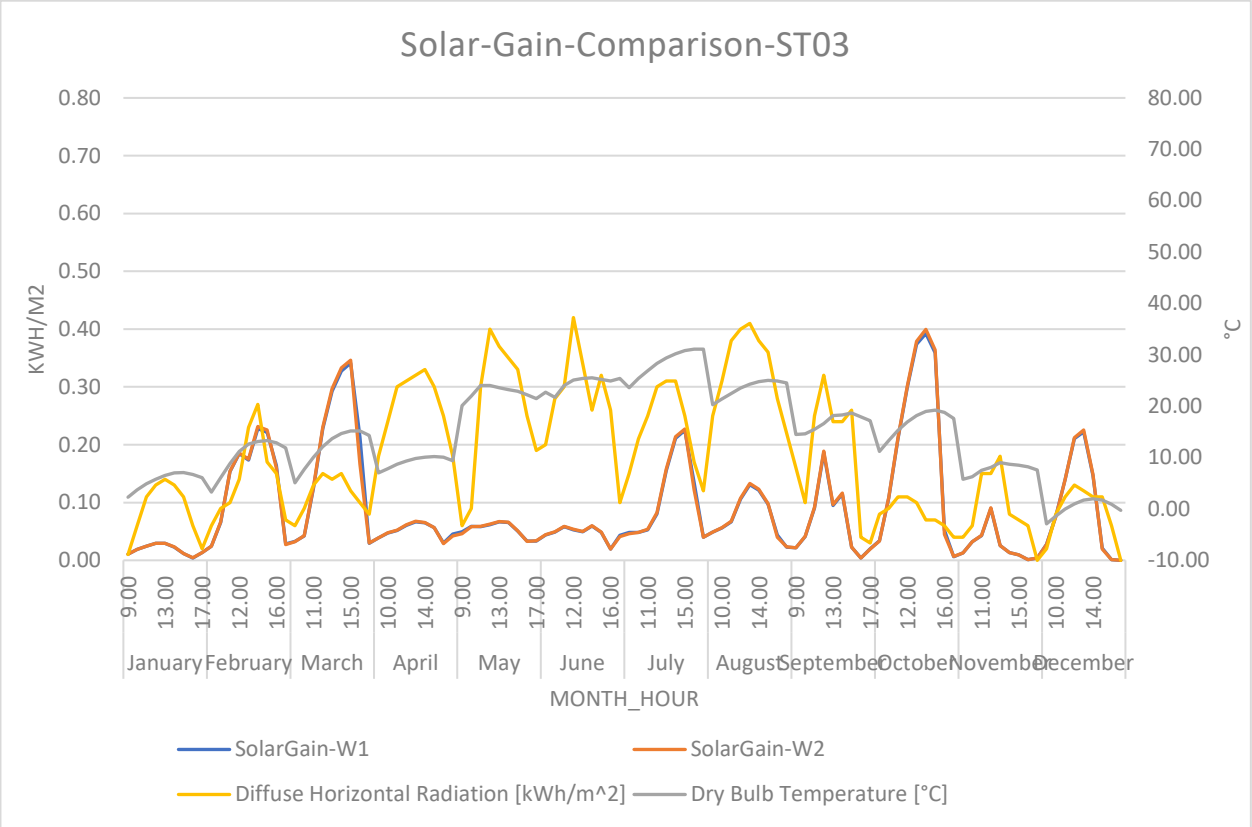


Figure 4.31. Comparison of solar radiation-ST03

4.4.8 Strategy 04 - Motorized interior roller and motorized exterior shading (ST04)

Fifth strategy employs the same devices as the fourth strategy and the only difference is that the exterior shading is also motorized (Figure *4.32*).

The different types of energy load of room for strategy04 are presented in Figure *4.33*. In Figure *4.34*there is a comparison between the solar which is gained by 2 windows of the studied room when the first strategy is activated and diffused direct radiation of Lecco for one year.

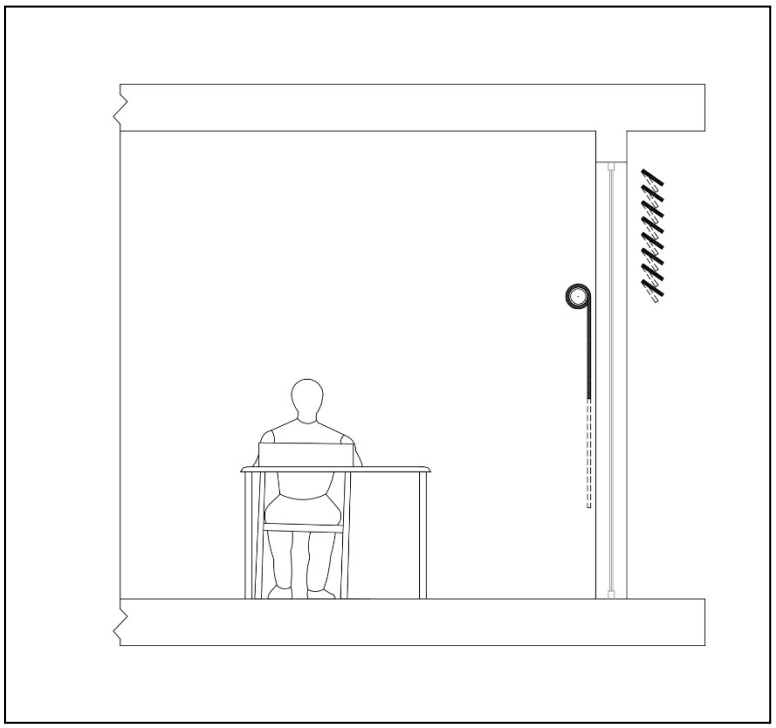


Figure 4.32. Motorized exterior shading employing venetian blinds with roller motorized interior roller blinds.

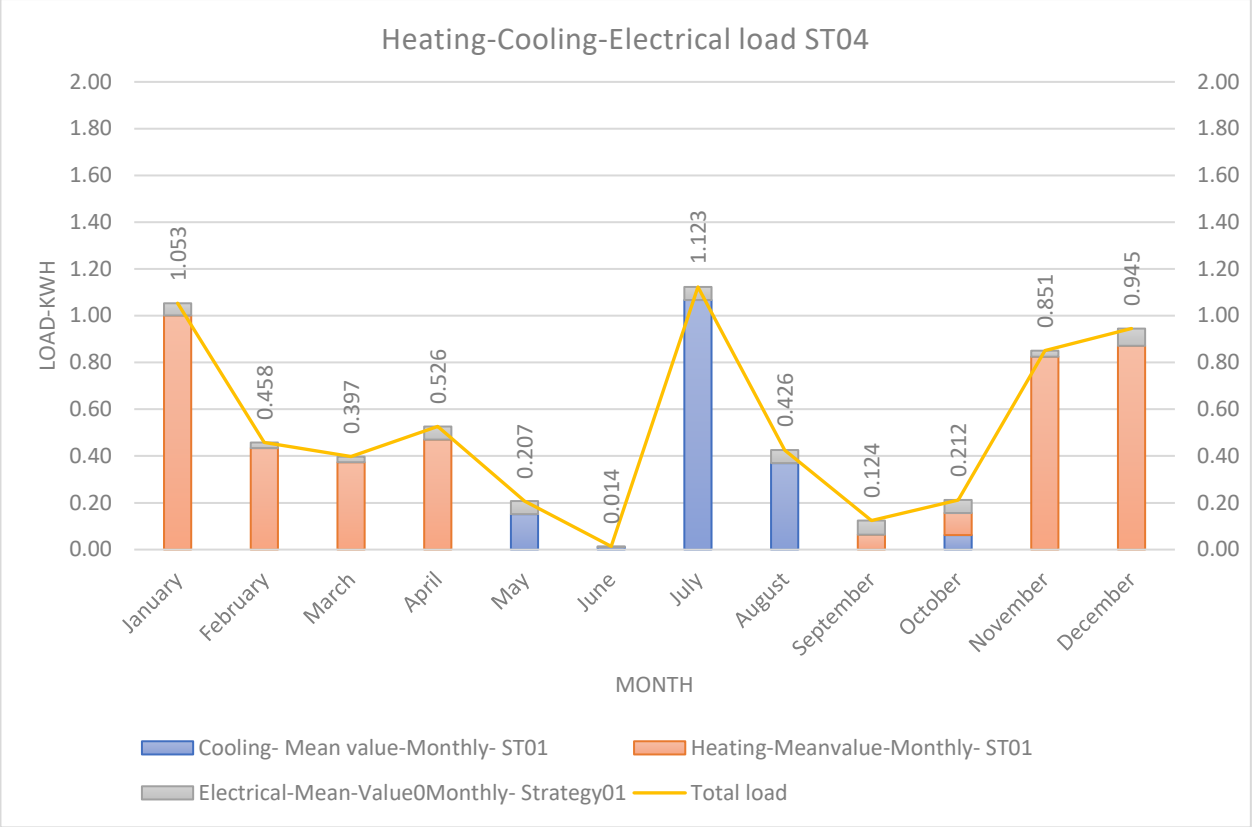


Figure 4.33. Heating-Cooling-Electrical load ST04

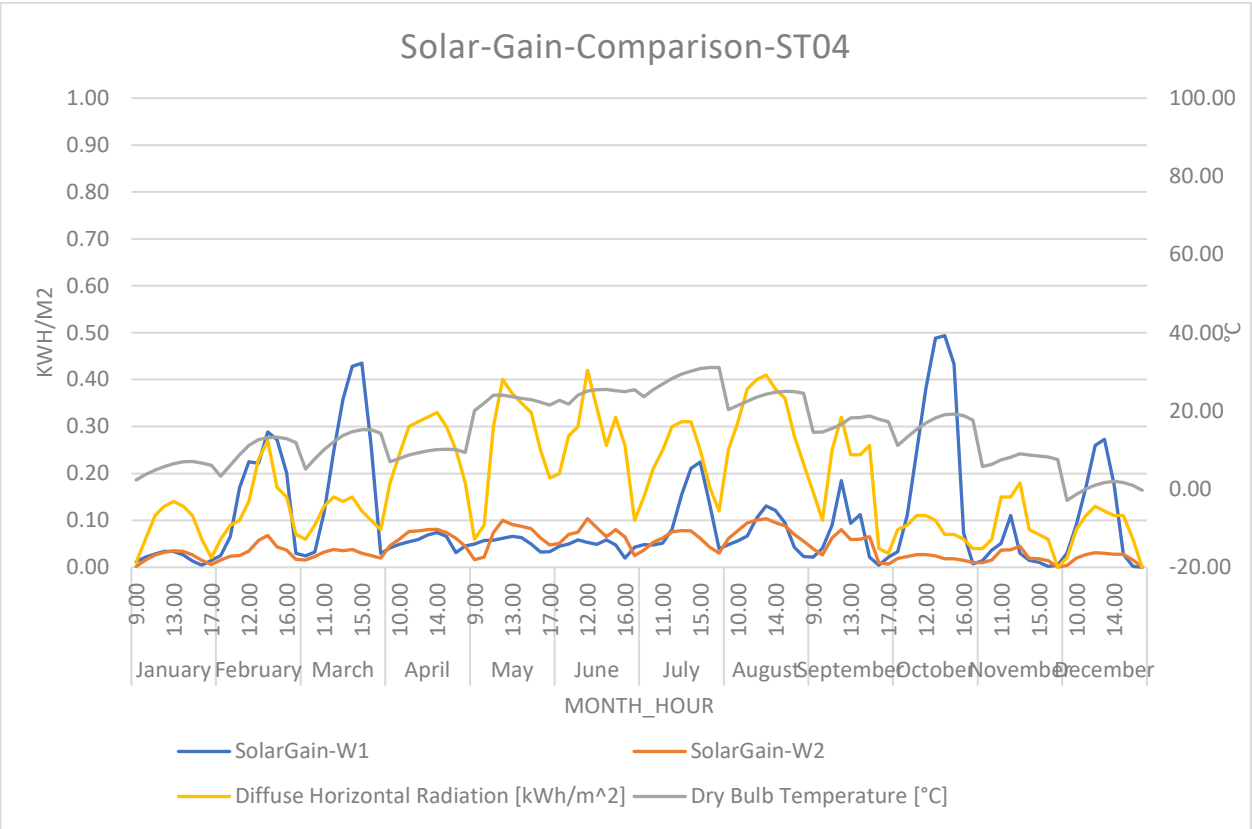


Figure 4.34. Comparison of solar radiation-ST04

4.4.9 Comparing performances

Simulating the different strategies for one day a month for the whole working duration of the office, the results considering energy and illuminance is compared as an instrument to indicate the optimal strategy to choose at this stage.

4.4.9.1 Cooling load in different Strategies

In this part, the mentioned strategies are compared in terms of cooling load (Figure *4.35*), heating load (Figure *4.36*), and electrical lighting load (Figure *4.37*). Since the office is designed with a dim switch to dim the artificial lighting inside in case occupant point in the office has reached the desired illuminance which for this study since the main aim is to design for the office workers in the covid situation with computers, 150 lux is chosen as the threshold.

The comparison of the loads (Figure *4.38*) indicates several aspects of each strategy but what is important here is that which strategy imposes the overall least total load.

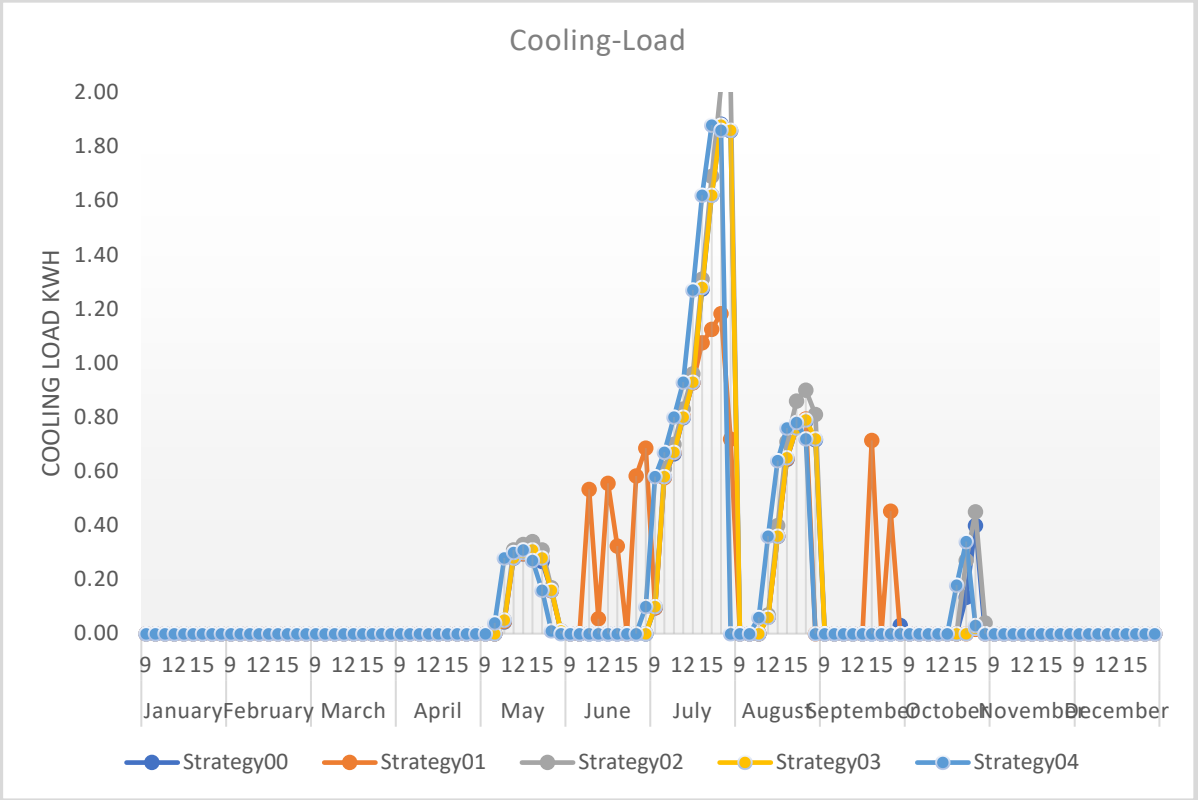


Figure 4.35. Comparison of cooling load in 5 strategies

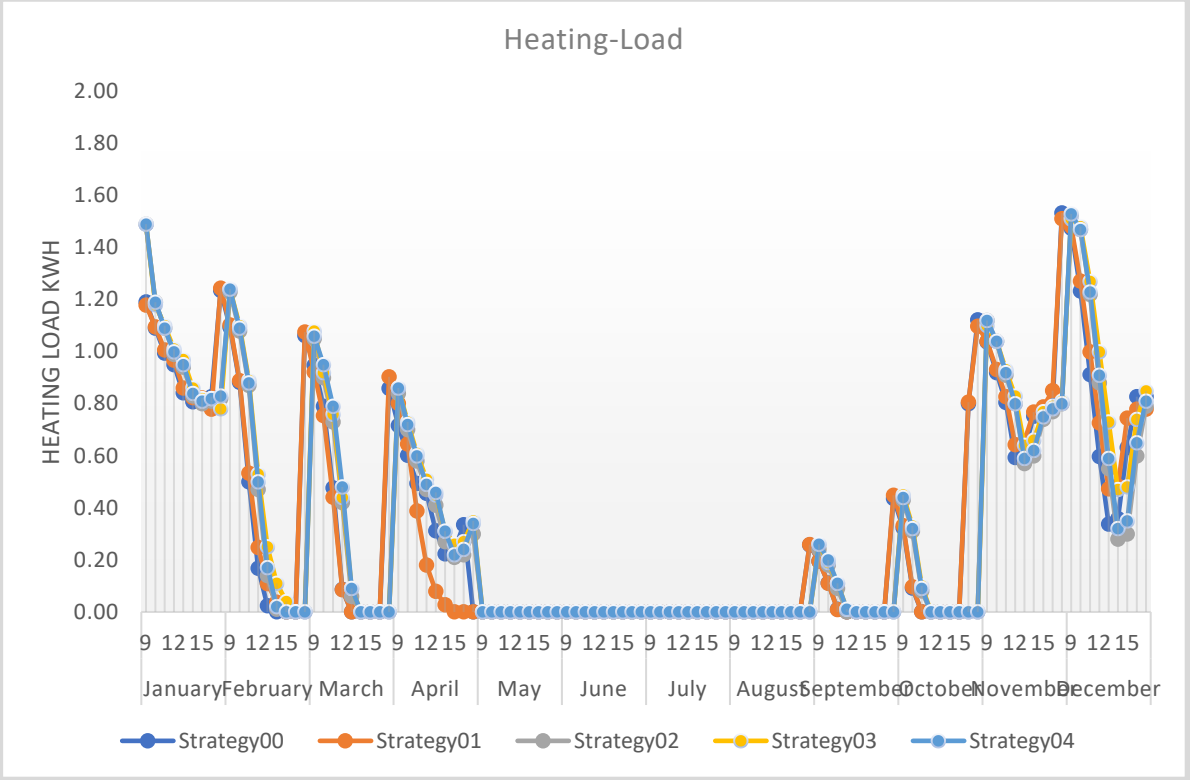


Figure 4.36. Comparison of heating load in 5 strategies

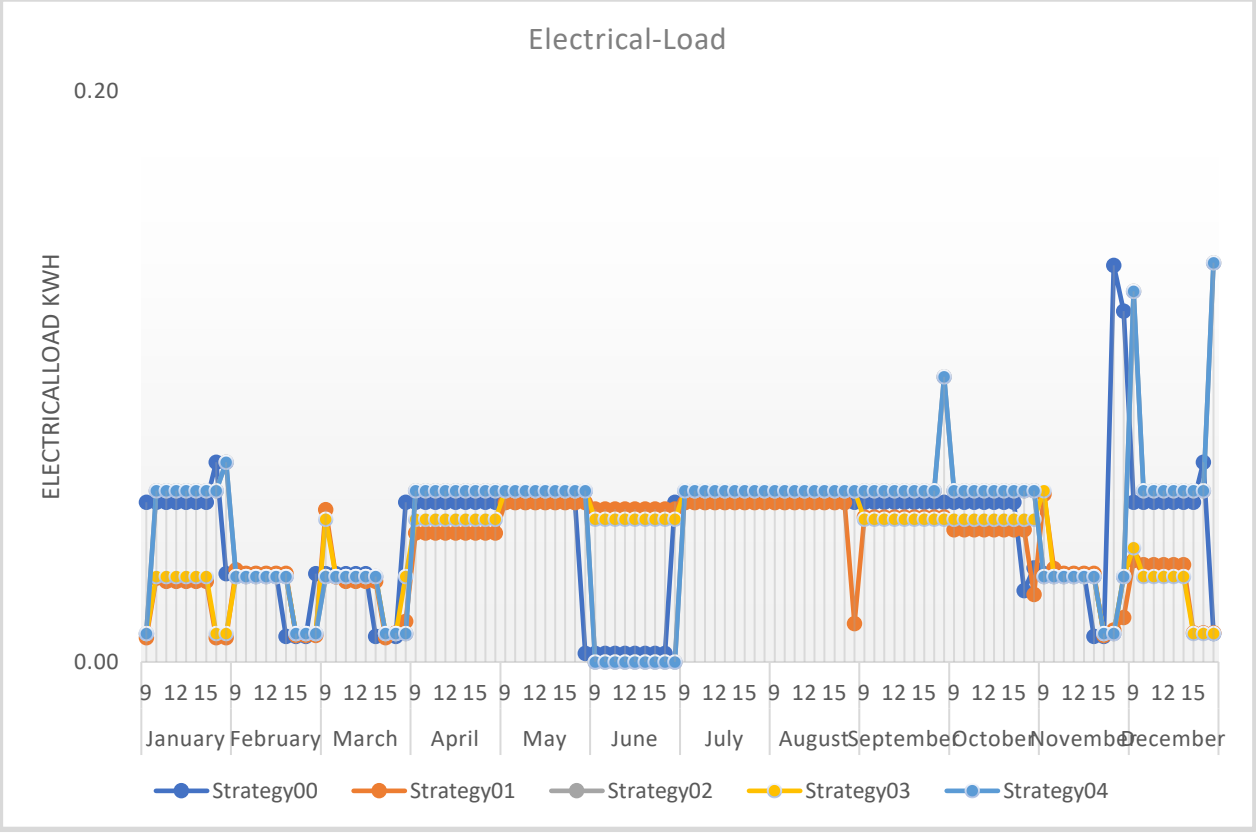


Figure 4.37. Comparison of electrical lighting load in 5 strategies

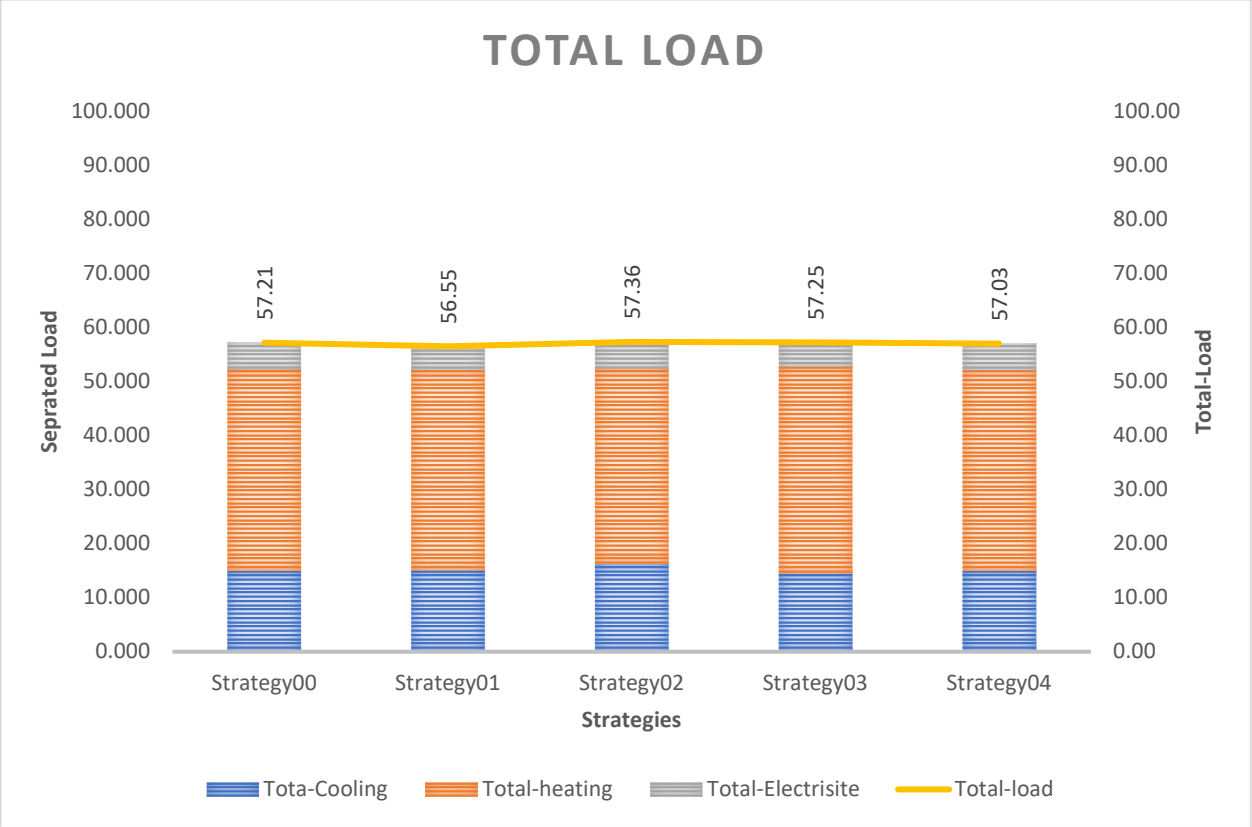


Figure 4.38. Comparison of total load in 5 strategies

4.4.9.2 Illuminance in different Strategies

In this part overall performance of the strategies is compared in terms of Useful Daylight Illuminance (UDI_d) and Glare Probability. A threshold between 150 to 1000 average lux inside the room is defined as useful illuminance threshold for each hour simulated, and any average illuminance value for each hour over 3000lux is defined as probable glare.

Following bar charts (Figure *4.39*) indicates not only the monthly performance of each strategy but also an overall annual value to be compared. Evidently, a maximum value of annual UDI_d and a minimum amount of annual glare probability (Figure *4.40*) is the goal to reach for each strategy at this stage.

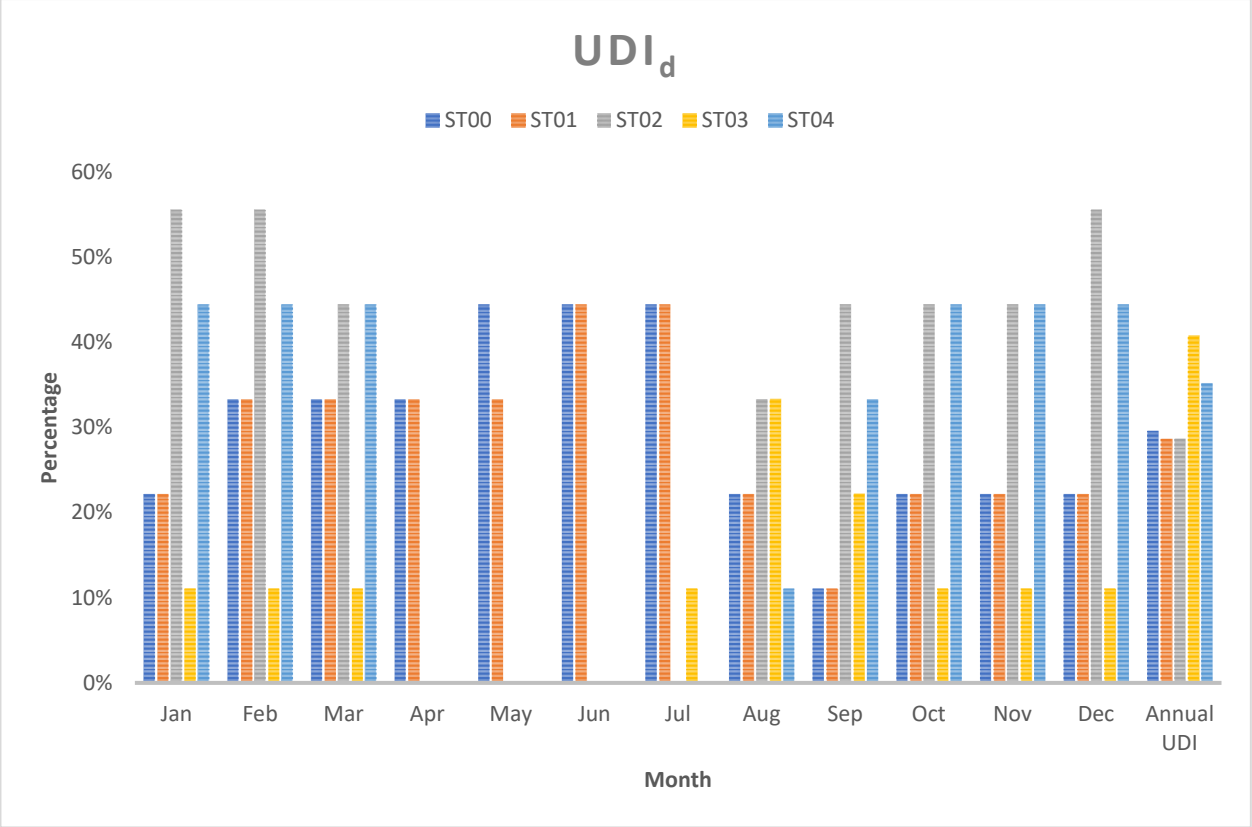


Figure 4.39. Monthly Daylight Illuminance performance in 5 strategies

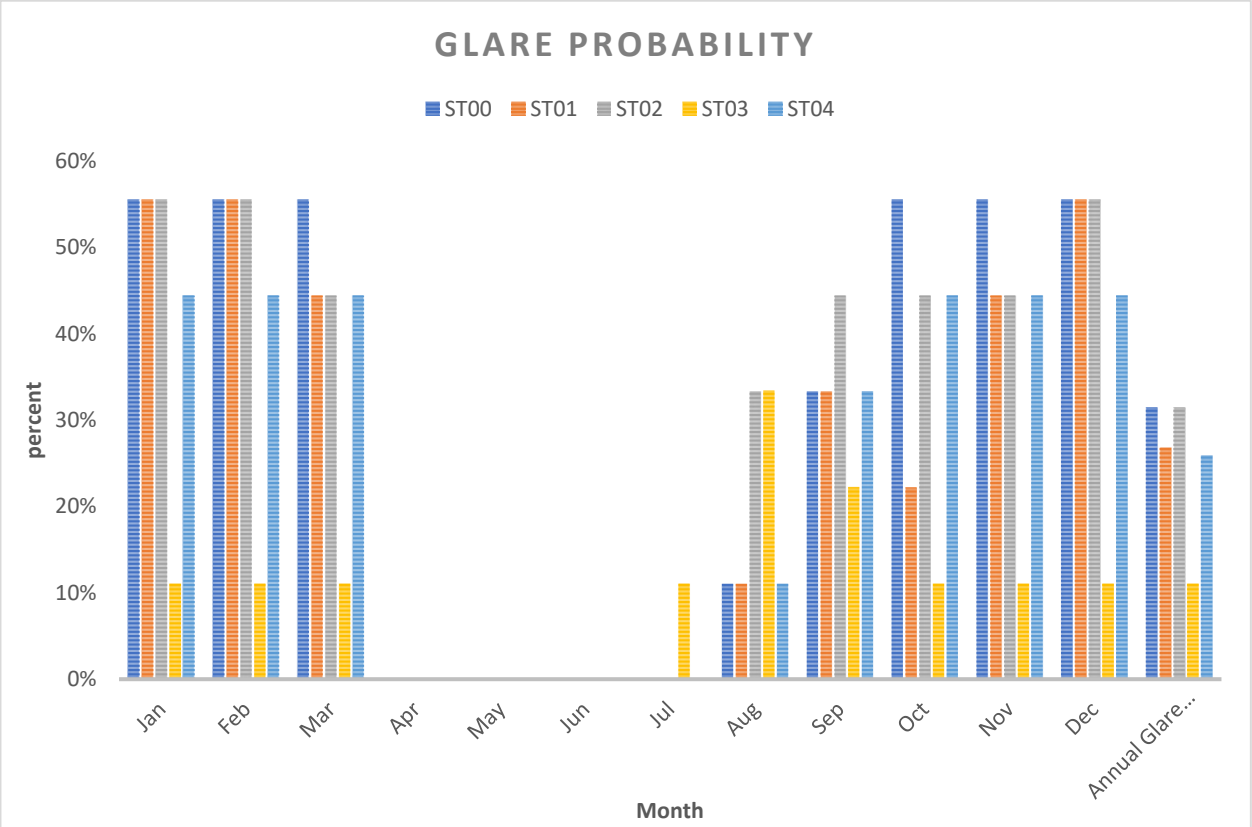


Figure 4.40. Annual glare probability in 5 strategies

4.4.10 Selected Strategy for case study

Although values are not so indicative and a significant difference cannot be detected in the outcomes, a mixture of external shadings and internal roller blinds can work better than each alone or without any shadings. Thus, from here forward the configuration of both internal and external shadings is chosen. Next, there will an optimization of the geometry of the shadings.

4.5 Shading design – Multiobjective evolutionary optimization

In multi-objective optimization, there are several potential methods for selecting the best design based on defined objectives. As previously described MOO is a process of mass iteration that is refined through an algorithm to deliver the most optimal result. This process began with using Galapagos, a vanilla Grasshopper component that was only single objective, and was also not capable of running daylight and energy objectives. Therefore, Wallacei, a MOO evolutionary solver plugin that uses NSGA II algorithm as the basis of its calculation was used as replacement, delivering better controlled and faster optimization with better visualization capability. Parameters represent the "genes" which correspond to combinations of sliders controlling the shading geometry properties. Loads and daylighting results of the said combinations are the "objectives", which in this algorithm are the values to compare. A pool of genes (population) is generated and adjusted in an effort to achieve optimal simultaneous fitness value of the objectives (Figure 4.41). Multi objective optimization is used for achieving optimal decisions due to the trade-offs between objectives that may be in conflict. The multi-objective genetic algorithm is defined to determine the optimal configuration for dynamic shading operation.

The variables of dynamic shading design that contribute to the most variance of Daylight and energy performance in the exterior shading include Venetian height, Count, and width, and in the case of interior roller, the visible transmittance. (Table *4.11* and Table *4.12*) All the variables are considered significant in the model based on the five objectives defined in the optimization including Cooling, Electrical, Glare, Heating, Illuminance in the first step (Table *4.13*) and in the second step Primary energy, Glare and Illuminance defined to find the best design solution (Table 4.14 and Table4.15).

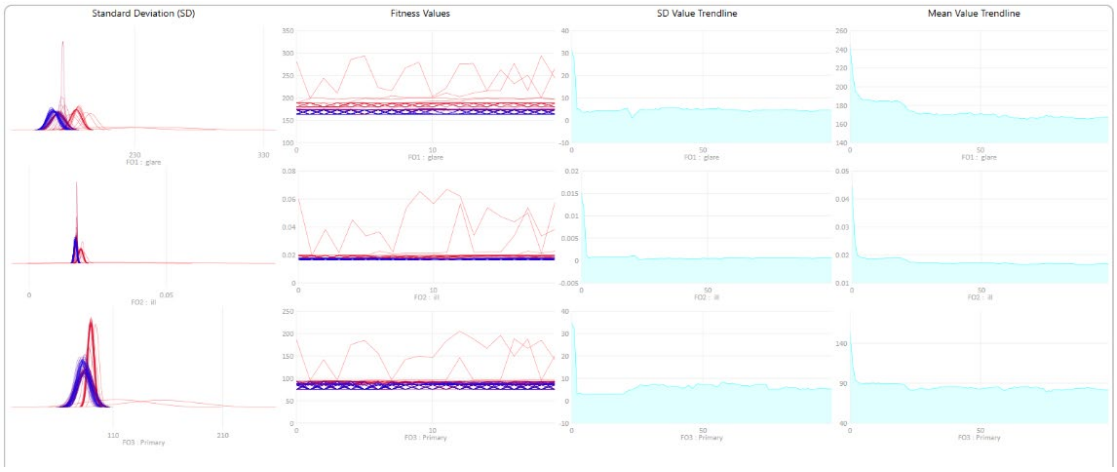


Figure 4.41.optimal simultaneous fitness value of the objectives

4.5.1 Genes

Genes are mentioned before are made up of combination of four variables (Figure 4.42). Genes are mentioned before are made up of combination of four variables. Roller blinds' visible transmittance, venetian singular slat width, the number of venetian slats and the overall height of the section of the window that is covered by venetian blinds.

Visible transmittance of the roller blinds is tested in a range from 30% to 75% with 15% intervals. Such variable is particularly important because even though roller blinds come into effect when there is a need to control glare, at the same time they cannot hinder too much of the useful daylight illuminance and on the other hand too much visible transmittance might render the roller ineffective in terms of glare control.

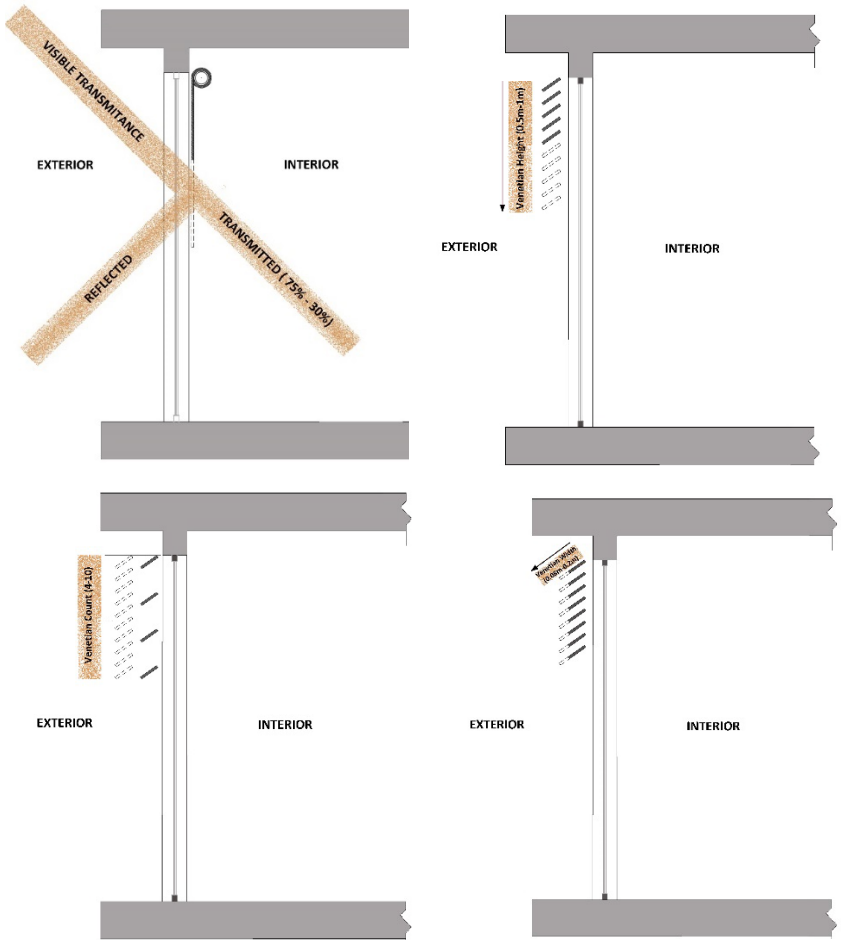


Figure 4.42.Genes are mentioned before are made up of combination of four variables

Table 4.11. The variables of dynamic shading design

	Variable	Genome Code
1	Roller VT	0
2	Width	1
3	Venetian height	2
4	Count	3

Table 4.12. Quantity of different variables of dynamic shading design

Genome Code	Count	Venetian height	Width	Roller VT
0	4	0.5	0.08	0.3
1	6	0.7	0.12	0.45
2	8	0.9	0.16	0.6
3	10	1	0.2	0.75

4.5.2 Objectives

In the initial phase of the optimization the 5 allocated objectives are cooling load, heating load and electrical lighting load and useful daylight illuminance and number of probable glare hours of the space under study. First three correspond to the side of choosing the optimal energy performance of the shading system and glare and useful illuminance on the side of effective daylighting. The main goal of this phase was to indicate the average fitness ranking of the objectives in comparison and finding if there exists a problematic objective standing out. In the second phase of the optimization 3 objectives of primary energy, UDI_d, and probable glare hours are used. Using these objectives, the final optimized geometrical properties of the shading system is chosen.

Table 4.13. Five objectives defined in the optimization.

	Objective	Allocated number in algorithm
1	Cooling	0
2	Electrical	1
3	Glare	2
4	Heating	3
5	UDI_d	4

Table 4.14. Three objectives defined for the best design solution and their corresponding.

	Objective	Allocated number in algorithm
1	Glare	0
2	UDI_d	1
3	Primary-Energy	2

Table4.15.. Different Primary energy index

	Load type	Primary energy index
1	Cooling	**2.5**
2	Heating	**1.1**
3	Electrical	**2.5**

4.5.3 Outcome

A deeper discussion regarding the outcome of these two steps of optimization is done in the next chapter here only for the sake of the study outcome is indicated the final outcome of this section. Pareto from solution is chosen as the method of choosing the best possible solution of the MOO. (Figure 4.43) shows Pareto fronts method on the 3D plot. The Pareto fronts remaps the fitness values outputted by the simulation and assigns a distinct axis for each objective. Fitness objectives Glare, Illuminance and Primary energy are display on the X, Y and Z axes, respectively. The Selected solution in this method is highlighted by red dot. The Genome decode of the selected solution presented on the Figure 4.16.

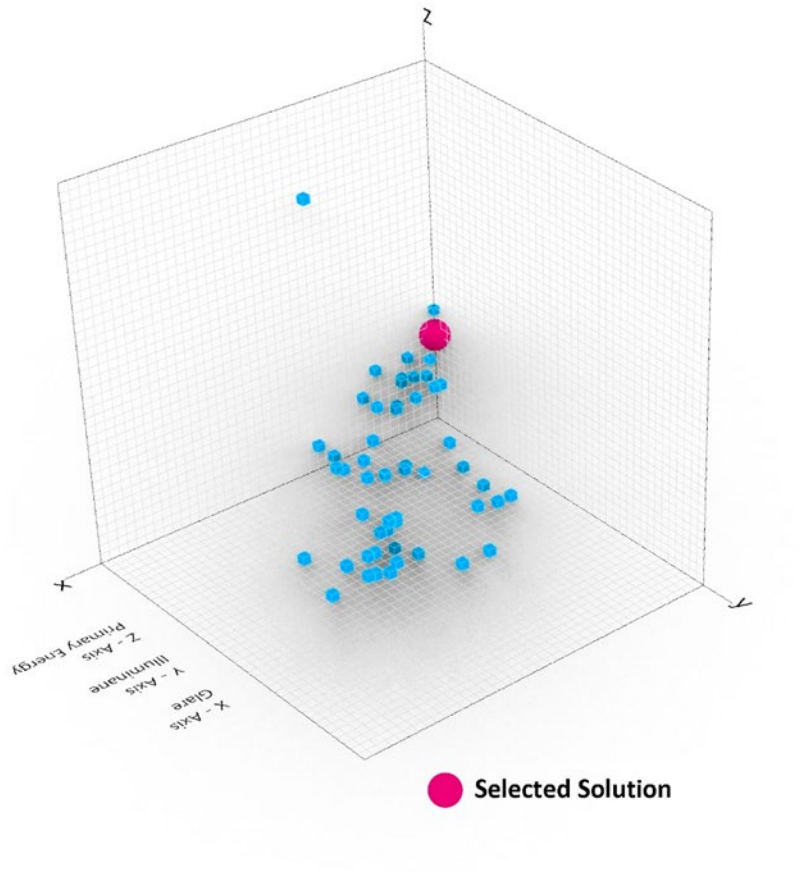


Figure 4.43 Pareto front Graph of the Genome decode of the selected solution.

Table 4.16. The Genome decodes of the selected solution

Generation: 9 // Individual: 15	1	2	2	2
Genome Decode				
Roller VT	0.45			
Width	0.16			
Venetian height	0.9			
Count	8			

4.6 Automation system simulation

4.6.1 Automation system workflow

The automation algorithm follows the same logic of the methodology but since the theory is developed for real-time automation, some modifications were needed for simulation friendly workflow. In the following sections the specific differences with the real-time algorithm are indicated.

4.6.2 View factor

In simulation algorithm view factor is considered by maximizing possible view to outside. Thus, the default position of the venetian blinds is divided into two categories. Summer meaning outdoor temperature is higher than 25°C and winter meaning the outdoor temperature is lower than 15°C. Referring to the initial automation system, in summer condition the venetians are fully closed as default position and opened minimally to grant the workspace with proper lighting. Yet, in other conditions, either winter or comfort condition, the venetians are positioned to provide the best possible view to sky and outside. Considering the natural human field of vision, all possible positions of the venetians are studied to find the percentage of the 180° view to sky and 60° cone of view to outside in 360° around the perimeter of user sitting area circle. The maximum possible view was found in the state where venetians had a +10° rotation. Every other situation here forward is compared to this maximum and is sought to keep over 70% unless direct sunlight exists on work-plane. Any override of the user is evidently given priority(Figure 4.44).

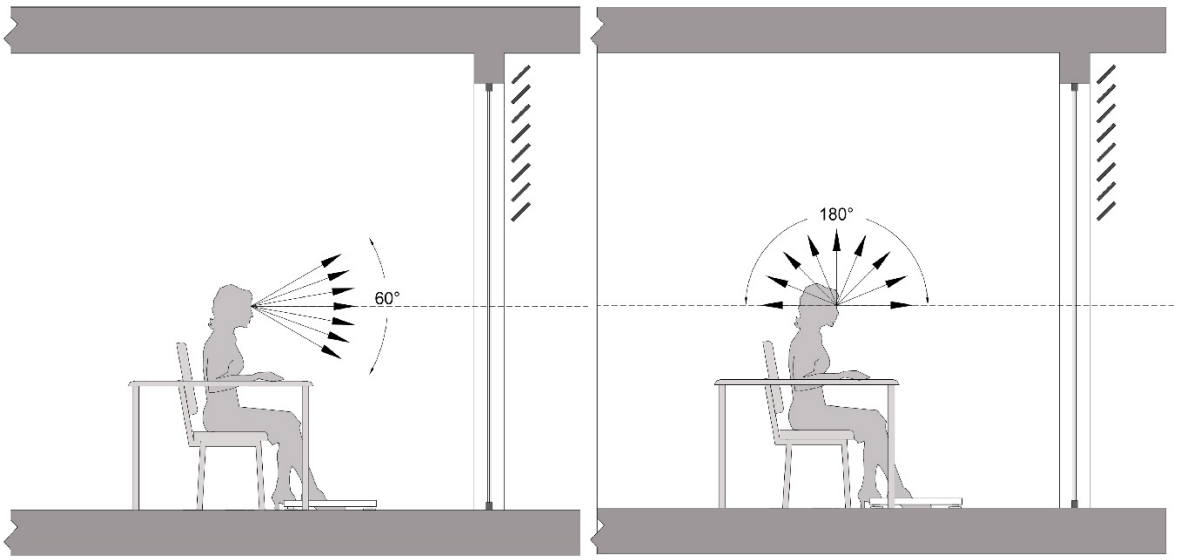


Figure 4.44.The natural human field of vision

4.6.3 Work-Plane

While in real-time algorithm the placement of the work-plane and user default view port is pinpointed by camera sensors and deep learning algorithm, in this study the placement is modeled directly inside the space from the surveyed case study.

4.6.4 User presence sensor

As explained previously, user-presence is found by the use of sensors in real-time algorithm. This could not be done through simulation thus a stochastic schedule is developed using the survey explained in section 4.2.

The occupancy model was a model derived from room-based occupancy measurements in multi-person home offices. Along with the illuminance, occupancy data was also monitored and logged every hour for four offices over 75 weekdays and 30 weekend days. Using a multivariate linear regression algorithm, a 24-hour occupancy probability was reached. This probability percentage (Figure 4.45)was used to build a stochastic model that predicts individual occupancy state on an hour-by-hour basis.

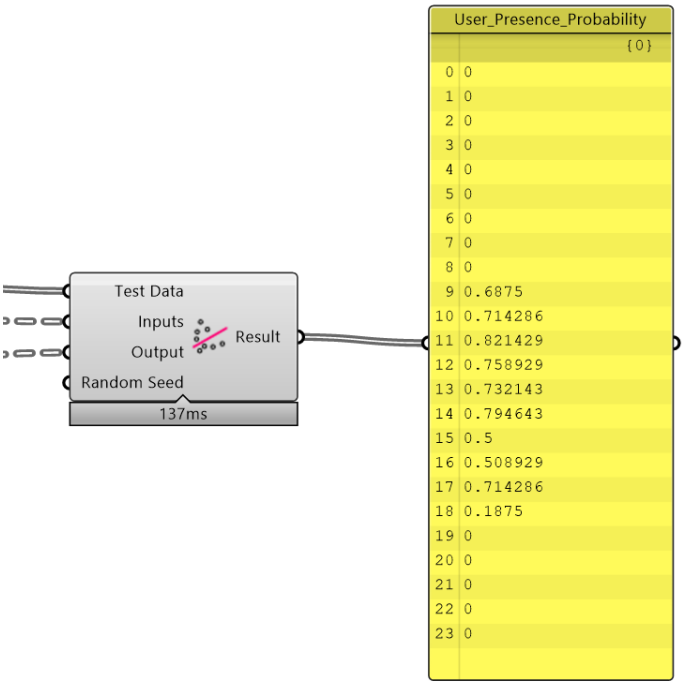


Figure 4.45. User probability percentage

This model was chosen as the preferred dynamic occupancy model because it represented longer occupancy periods compared to the other models. However, this model had significant nighttime occupancy which tended to reduce the difference of lighting energy performance between the independent and integrated controls cases. This is because during the nighttime, lighting savings are only driven by occupancy-based switching and thus during nighttime hours all the controls cases perform the same regarding lighting energy savings. However, analysis can be separated for daytime hours versus nighttime hours, the end solution chosen was to have occupancy governed by the dynamic statistical model until 5 pm, and then to limit nighttime occupancy to 30 min.

4.6.5 Sun on work-plane

Initially a sensor checks whether any part of the work-plane is subjected to direct sunlight, while venetian slats are at their default state and roller blinds are fully open. If yes, then following section of automation is activated. The vector starting from the closest point subjected to direct sunlight (a_0) to sun's position is taken. Two possible incidents might occur. (A) the vector passes through a point (b_v) in the venetian covered section of the windows. (B) the vector passes through a point (b_r) in the roller blinds covered section of the windows.

In the case (A), all the venetian slats from the horizontal line passing through (bv) upward are fully closed, meaning turned to -90° position.

In the case (B), not only do the venetian slats are ordered to be closed, but the roller blinds also roll down to point b and that is done through remapping the ratio between the angles between the vector from a_0 to sun and the vector from a_0 to horizon (α_r) over the vector from a_0 to conjunction of the surfaces of window covered by roller and venetians and the vector from a_0 to horizon (α_0) to the maximum length of the roller(Figure 4.46).

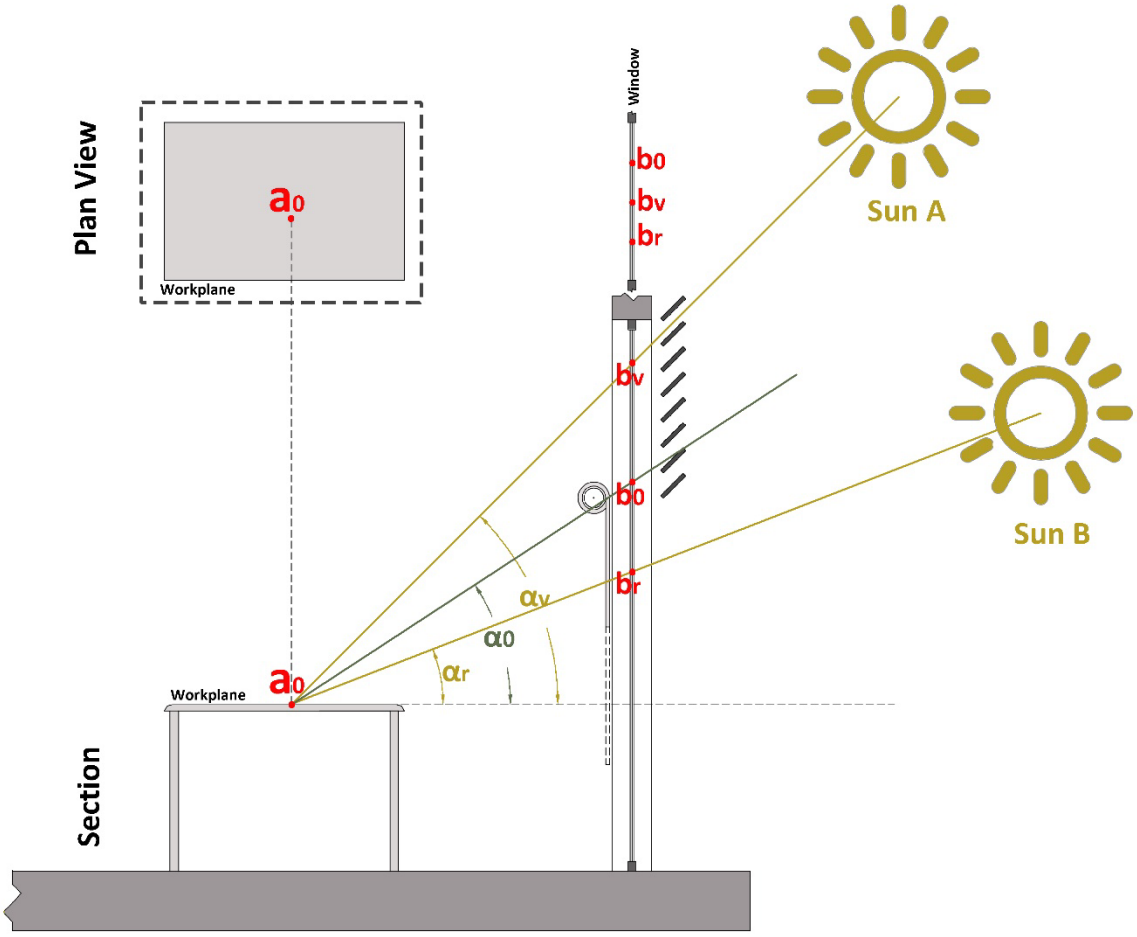


Figure 4.46.Sun on work-plane

4.6.6 User preference through machine learning

Contrary to real-time algorithm that a generic default setting is used to the define the useful daylight illuminance threshold until enough data is collected by user override tool, in simulation algorithm the data collected from the survey is used to start with occupant's preference using a linear regression algorithm. Thus, from this section onward, UDI_u is utilized.

4.6.6.1 Data preprocessing

The raw data collected in the survey consists of illuminance level of 5 points on the work-plane surface and one in front of the user. The first five can be used to produce a gradient of light on the table. Such gradient can be used for simulating a camera-sensor controlled daylighting algorithm which is what is introduced in the real-time algorithm methodology. However, for the purposes required for this case study an average value of the illuminance value on the table, referred as WPI here onward, is sufficient.

4.6.6.2 Machine learning process

At each instance, the data collected represent WPI at three stage of winter default, comfort higher threshold, and comfort lower threshold. two linear regression processes are utilized to train a model capable of predicting user preference.

Using the default threshold WPIs as the training inputs, two sets of linear regression work simultaneously to produce user preferred UDI thresholds at each simulated instance considering the WPI at default condition of shadings (Figure 4.47, Figure 4.48).



Figure 4.47 initial linear regression performed using the minimum data collected

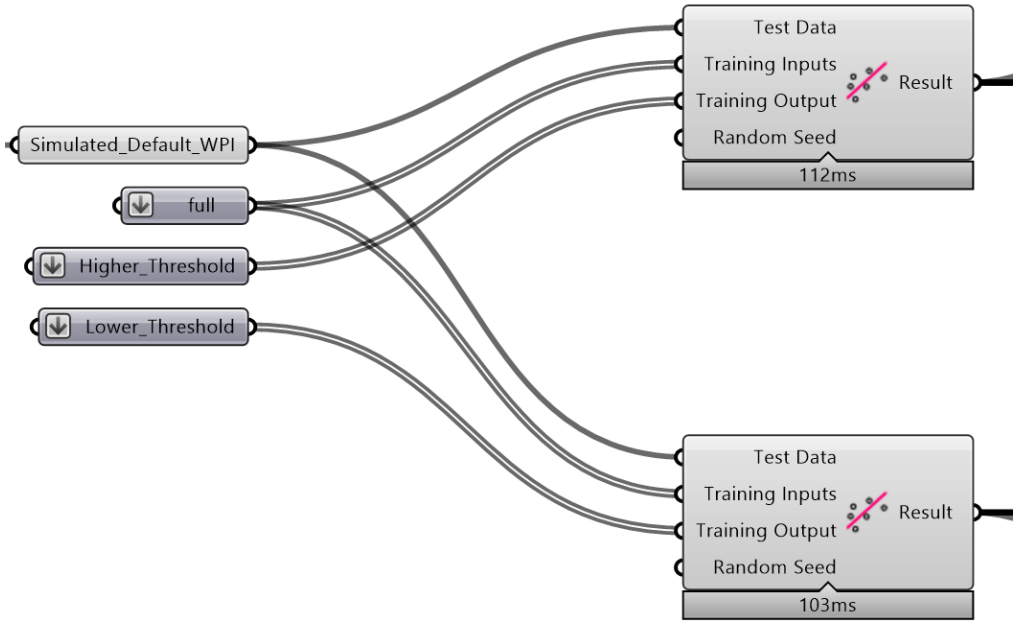


Figure 4.48 Using LunchBox Linear Regression component in Rhino Grasshopper to train the control algorithm for user preference.

The user override tool explained further on this document, also produces the opportunity that the data set produced through survey be updated all the time, by adding the recorded data at the instance when user decides to override the automation decision to further restrict or expand the comfort threshold to the data set(Figure 4.49).

4.6.7 Average illuminance on work-plane sensor

The WPI sensor in real life is modeled easily in grasshopper using honeybee components. But, due to the restriction of loop creation in simulation environment, for the algorithm to be able to decide the best possible solution at each instance it simulates the WPI for all the possible venetian positions. In summer condition it starts from fully closed venetian, -90°, and with opens up with 10° rotations until WPI is inside the user-preferred threshold. In winter condition, this process is reversed starting from +10° position of the venetians and closing down toward -90°. This method is taken in favor of reducing solar heat gain in summer condition and maximizing it in winter(Figure 4.50).

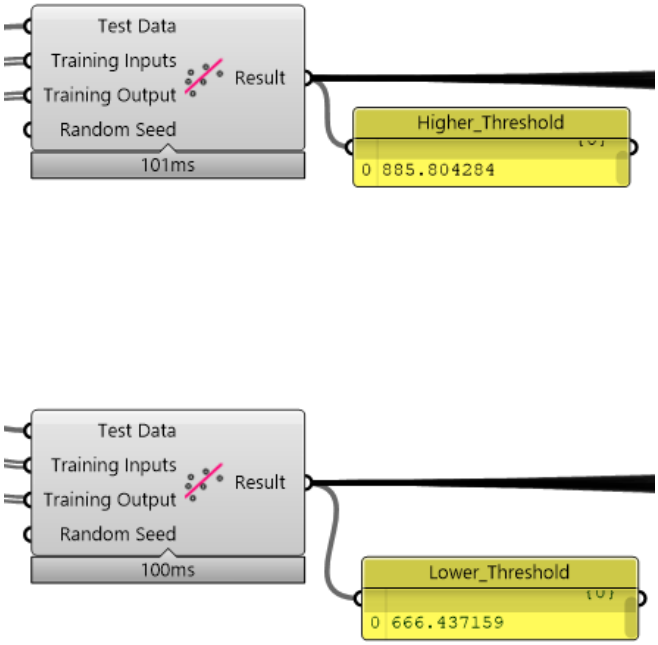


Figure 4.49 Linear Regression defining the user preferred thresholds.

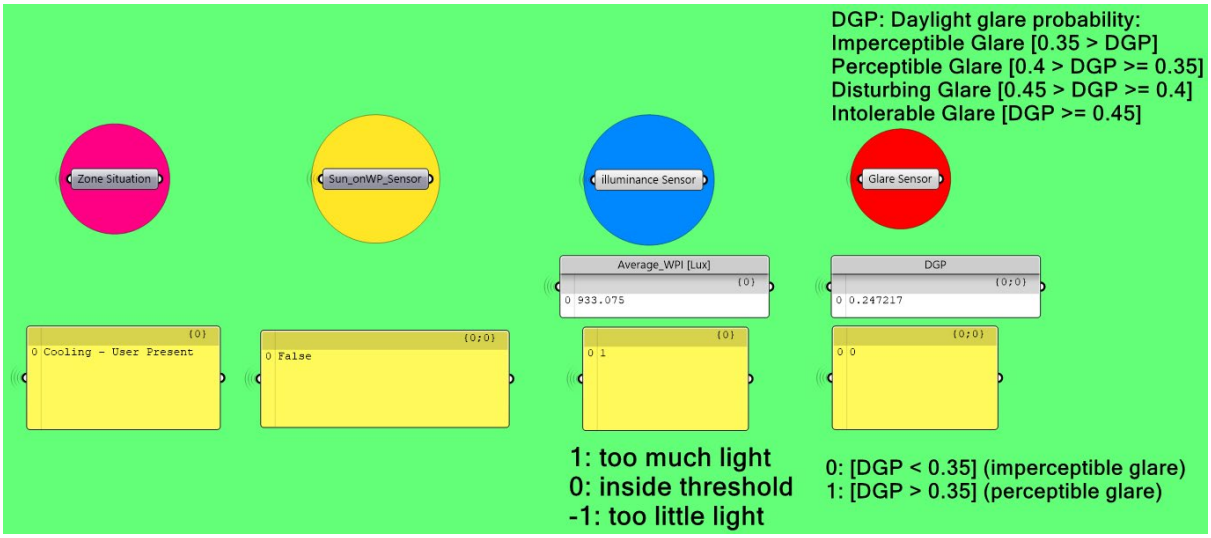


Figure 4.50 Control Center of simulation environment

4.6.8 DGP sensor (directional)

Since the average illuminance on work-plane is already checked in the last step, the only probable cause of glare can be a significant difference on eye-level illuminance inside the room and outside and the only solution to control this significant difference in contrast is through shutting roller blinds. Similar to the WPI control the DGP control in simulation studio cannot go through a loop so it is check for the whole length of the roller blinds with 30cm intervals, the least length of roller that delivers imperceptible glare meaning a DGP lower than 0.30 is chosen (Figure 4.51, Figure 4.52).

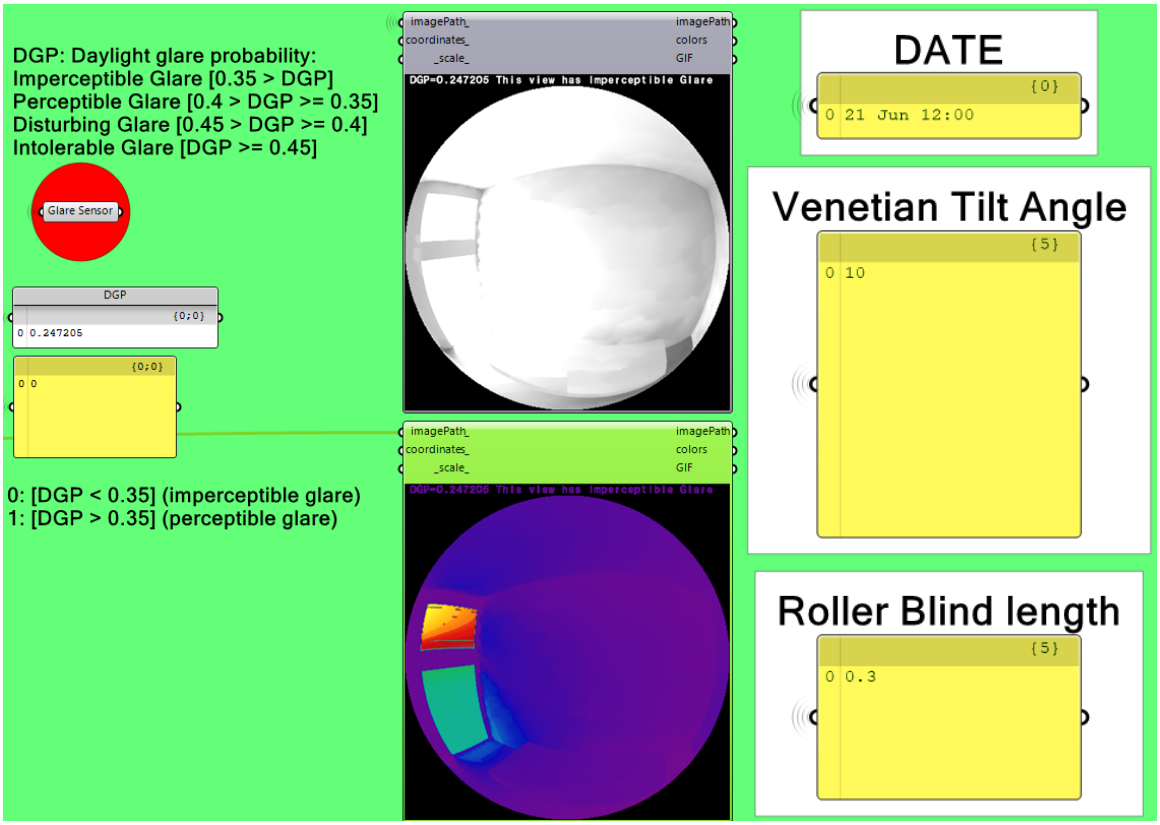


Figure 4.51 Glare control center

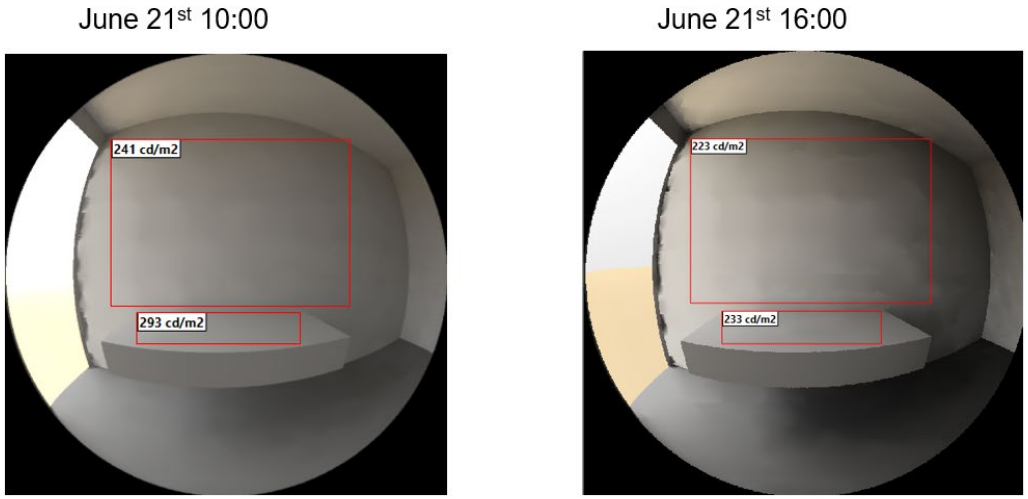


Figure 4.52 contrast control using EvalGlare prior to design of the automation algorithm.

4.6.9 User override

In this automation algorithm, the user is given the possibility to override the shading control at any instant they feel it is necessary. This feature is developed to give the user control due to several reasons, effect of feelings on the desired lighting, the never-ending battle between glare and view to outside, the possibility of activities that require specific lighting and so on.

The feature is introduced into the simulation environment through a OSC and MIDI connection from cellphone to gHawl component in Rhino Grasshopper. The OSC environment comprises of a toggle switching between manual and automated shading system, a fader control, controlling the roller blinds, a radial fader controlling the venetians' angle(Figure 4.53).

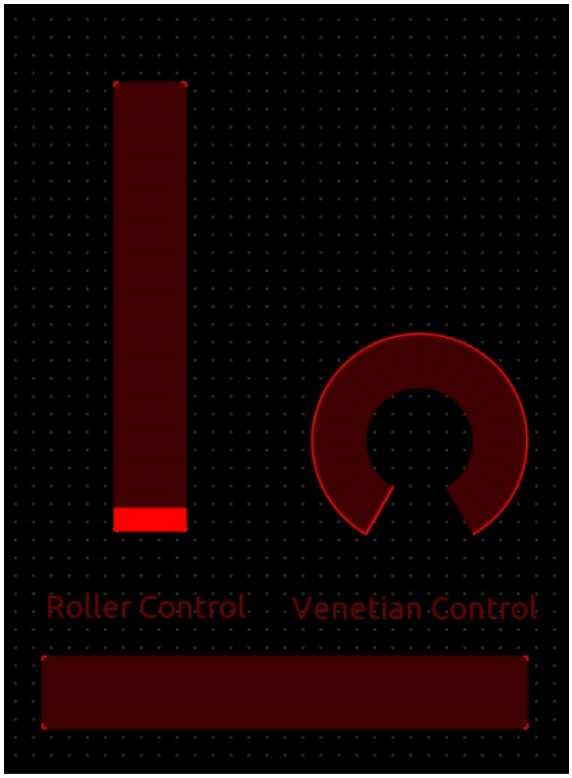


Figure 4.53 OSC environment inside the Cellphone

4.6.10 User absent control

In case the user is not present the system switches to full energy saving mode. Initially only using external temperature sensor it decides which condition room should be in. in summer condition, meaning outdoor dry bulb temperature over 25 both roller and venetians will be fully closed to avoid any solar gains, contrastingly, in winter fully open to receive as much possible solar gains. This being the default setting, system constantly uses the indoor operative temperature sensor to calculate the temperature difference with adaptive comfort limits. In case there is more than 5° from comfort in summer situation rollers open up and in winter venetians close down. In case the there is more than 10° from comfort in summer condition both venetian and roller open and in winter condition both close(Figure 4.54).

4.6.11 Simulation Decision tree

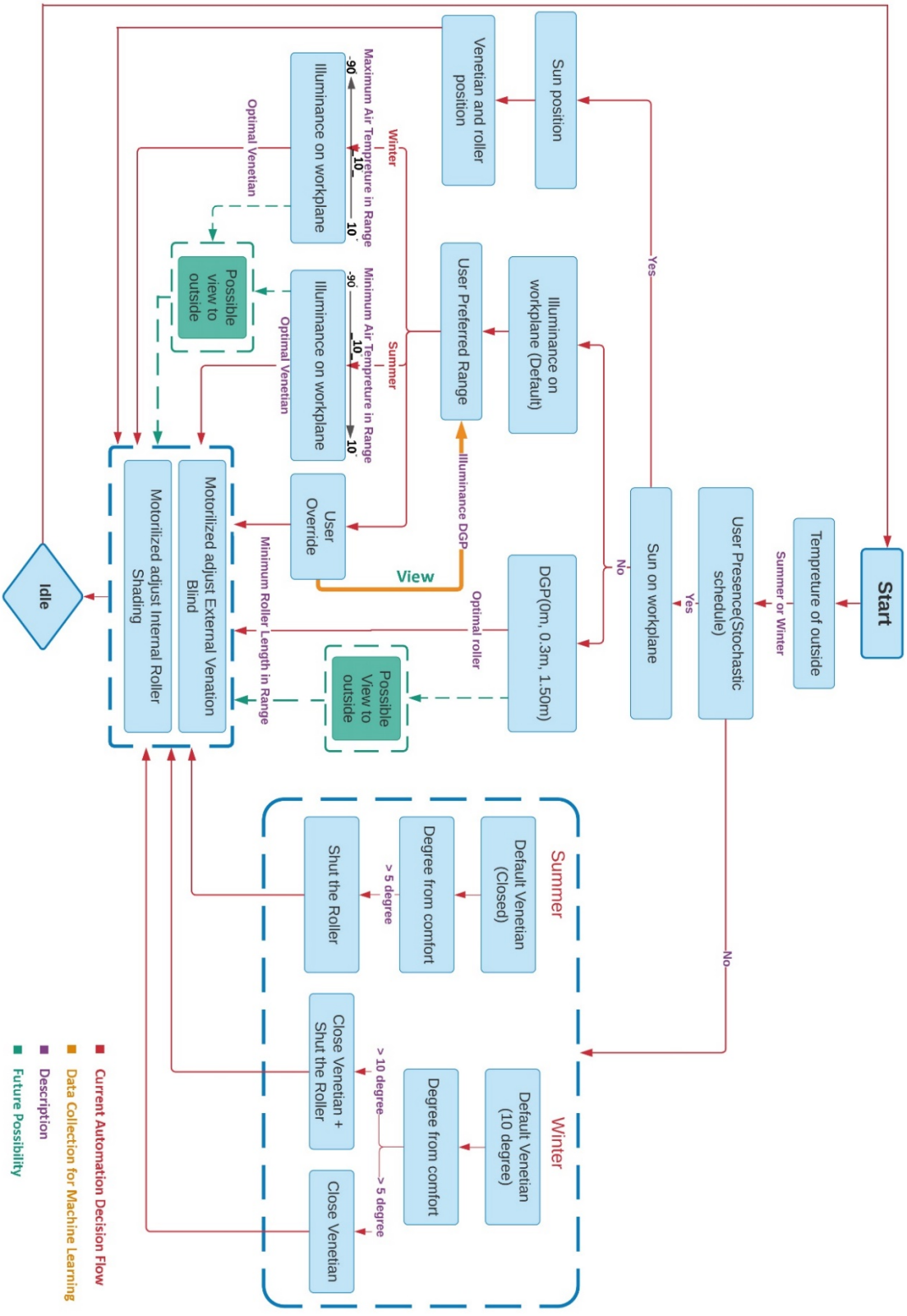


Figure 4.54 simulation automation decision tree

5. RESULTS AND DISCUSSION

5.1 Multi objective optimization (Shading Optimization)

In this section after restating the variables and objectives, we make deeper dive into the selection method of the best solution out of the NSGA II evolutionary multi-objective optimization using the pareto front selection method(Table *5.1*, Table *5.2*, Table *5.3*, Table *5.4*, Table 55.).

Table 5.1. The variables of dynamic shading design

	Variable	Genome Code
1	Roller VT	0
2	Width	1
3	Venetian height	2
4	Count	3

Table 5.2. Quantity of different variables of dynamic shading design

Genome Code	Variable	Count	Venetian height	Width	Roller VT
0		4	0.5	0.08	0.3
1		6	0.7	0.12	0.45
2		8	0.9	0.16	0.6
3		10	1	0.2	0.75

Table 5.3. Five objectives defined in the optimization.

	Genome Code	Variable
1	Cooling	1
2	Electrical	2
3	Glare	3
4	Heating	4
5	Illuminance	5

Table 5.4. Three objectives defined in the best design solution.

	Genome Code	Variable
1	Glare	1
2	Illuminance	2
3	Primary-Energy	3

Table 55. Different Primary energy index

	Load type	Primary energy index
1	Cooling	**2.5**
2	Heating	**1.1**
3	Electrical	**2.5**

5.1.1 Results and discussion

the generation size (how many individuals per generation) is 20 and generation count (how many generations in the simulation) is 100 for this simulation. In the first step of the optimization analysis five objective defined. The effect of the different population scenarios on each objective represented on parallel coordinator plot (Figure *5.1*).

Table 5.6 Algorithm Parameters

Crossover Probability	**0.9**
Mutation Probability	1/n
Crossover Distribution Index	20
Mutation Distribution Index	20
Random seed	1

Crossover Probability (0.0 to 1.0) - the percentage of solutions in the generation that will reproduce for the next generation.

Mutation Probability (0.0 to 1.0) - The percentage of mutations taking place in the generation (Deb et. al. recommends the mutation probability to be 1/n, where 'n' is the number of variables (sliders) in the design problem. As such, the default value is 1/n).

Crossover and Mutation Distribution Index (0 to 100) - A large distribution index value gives a higher probability for creating offspring near parent solutions and a small distribution index value allows distant solutions to be selected as children solutions.

The parallel coordinate plot analysis provides the solutions in the population (Table 5.6).

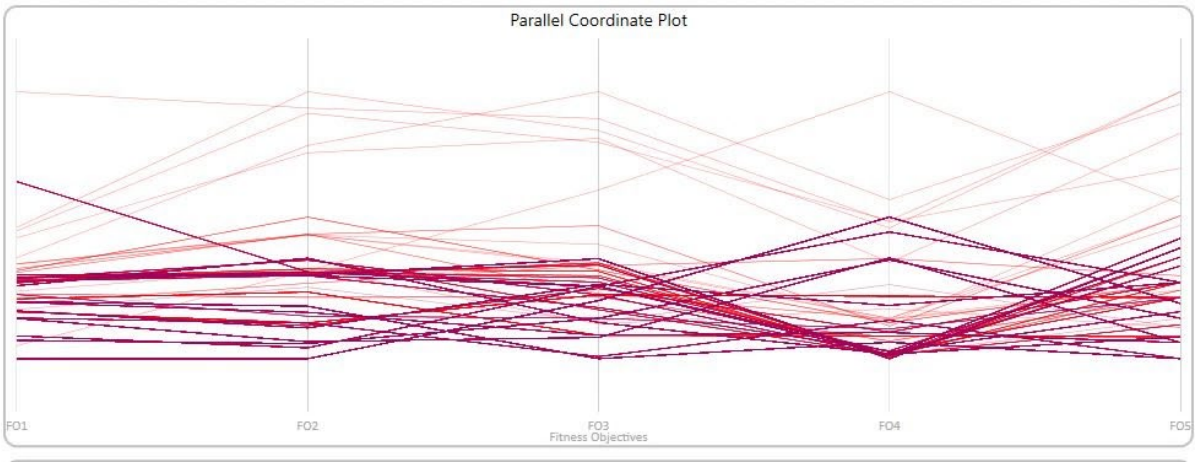


Figure 5.1. F01. Cooling, F02. Electrical, F03. Glare, F04. Heating, F05. Illuminance

The Standard Deviation Trendline Chart presents the standard deviation value, for each of the objectives of cooling load (Figure *5.2*), electricity load (Figure *5.3*), glare (Figure *5.4*), heating load (Figure *5.5*), illuminance (Figure *5.6*) respectively, for each generation across the entire simulation from start to end.

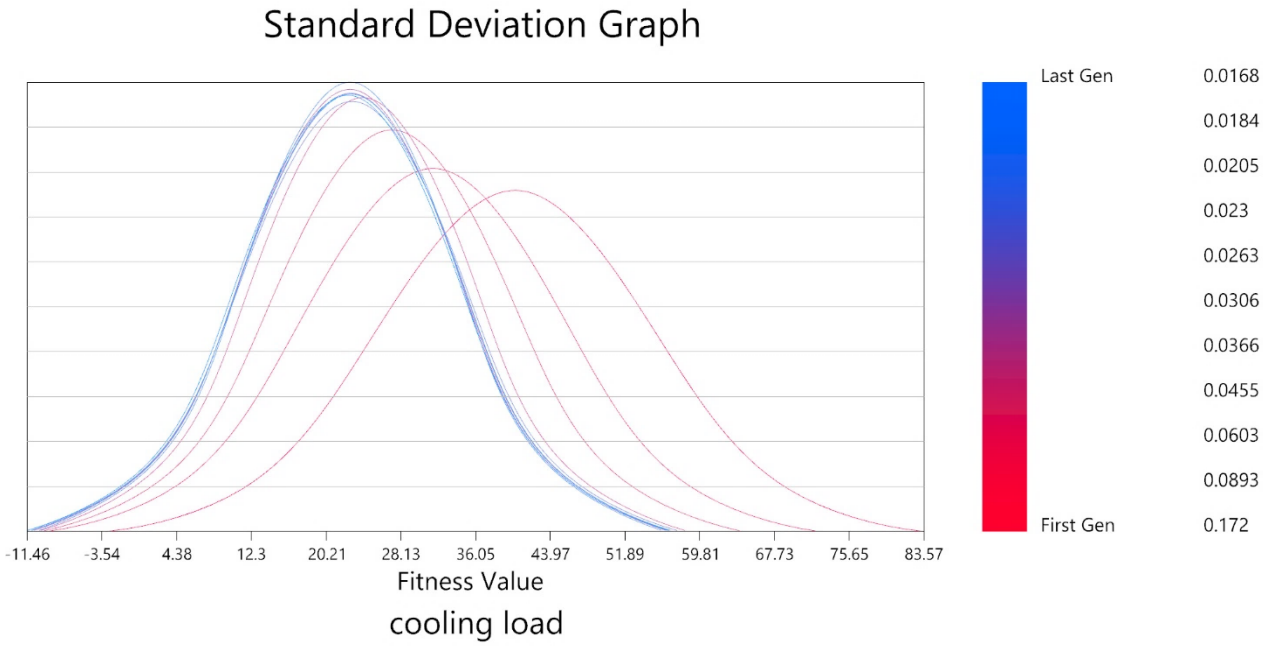


Figure 5.2. Standard Deviation Trendline of cooling load

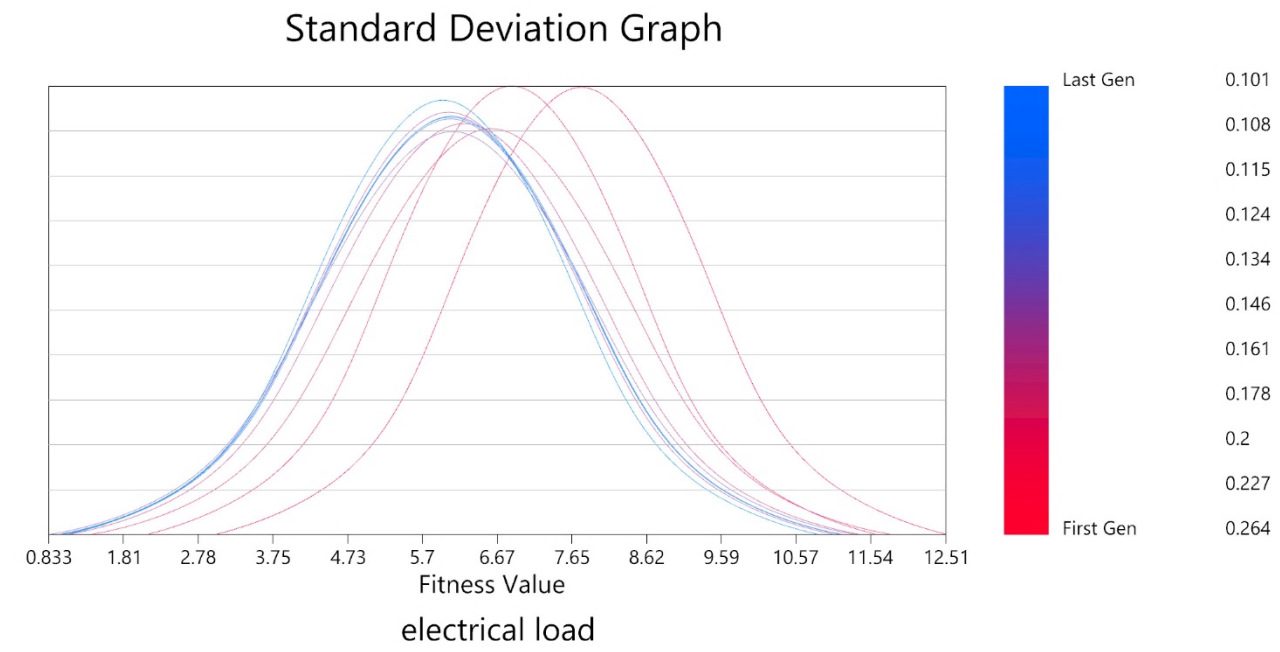


Figure 5.3. Standard Deviation Trendline of electrical load

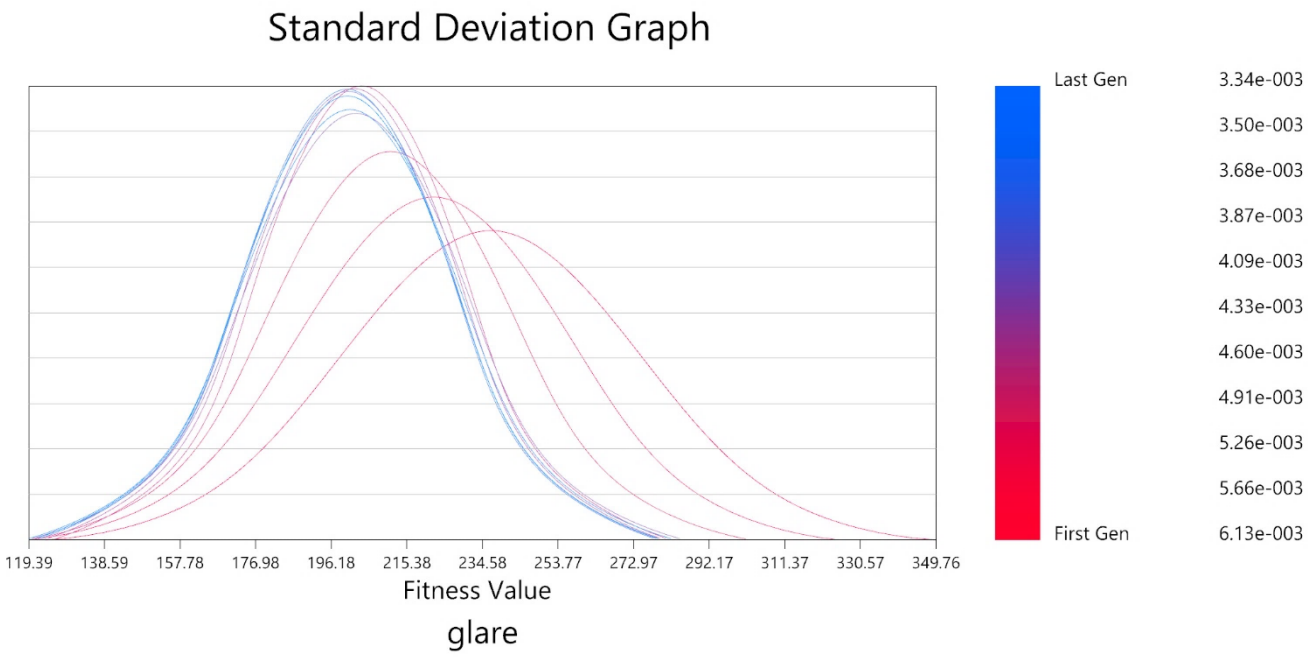


Figure 5.4. Standard Deviation Trendline of glare

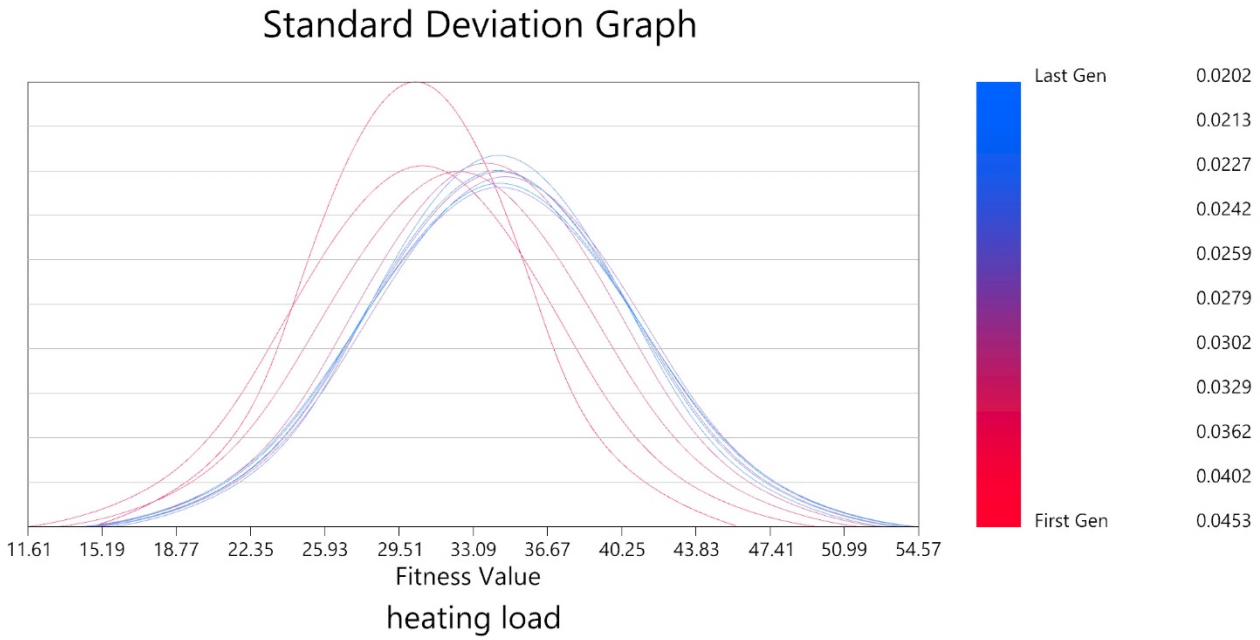


Figure 5.5. Standard Deviation Trendline of heating load

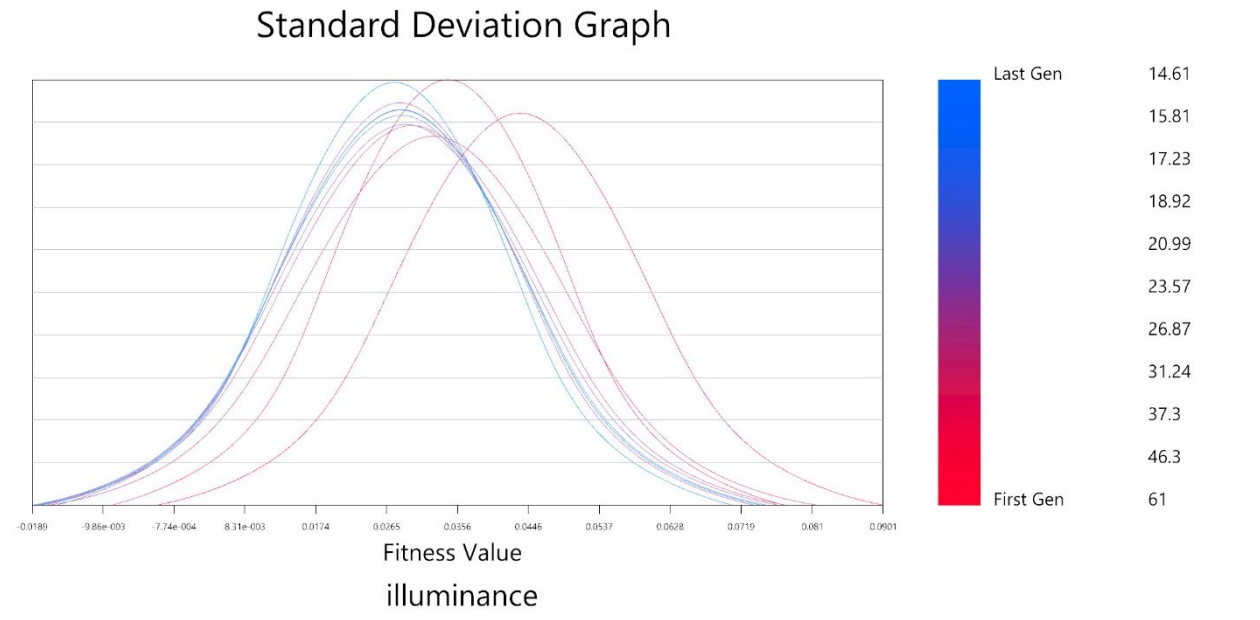
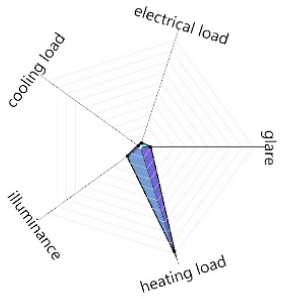
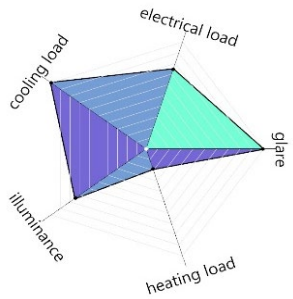
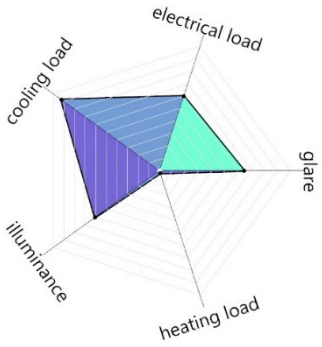
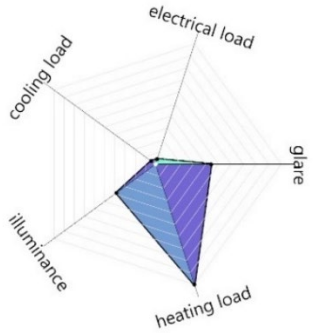
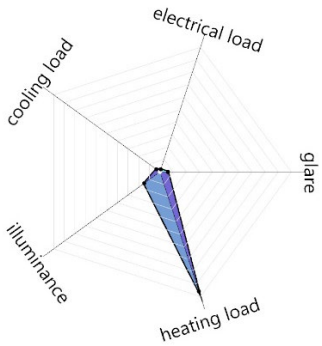
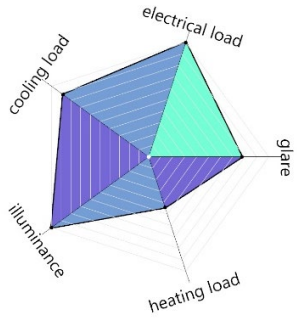
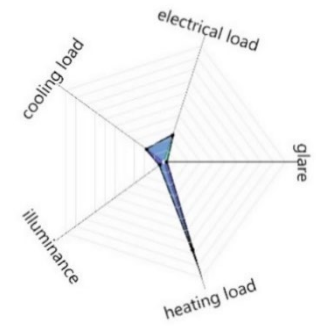
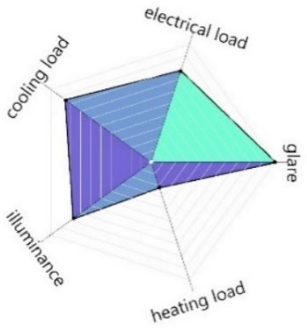
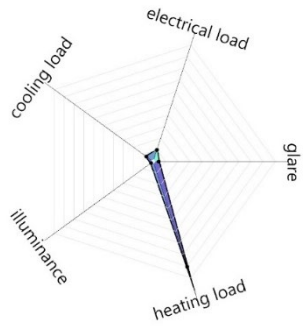
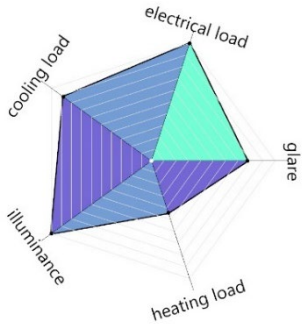


Figure 5.6. Standard Deviation Trendline of illuminance

Table *5.7* shows the best and worst solution for each objective. Results highlights the trade of between the daylight and energy performance objectives in each scenario.

Table 5.7. Best and worst solution for five objectives in first step of the optimization

Best Scenario		Worst Scenario	
Cooling load			
	Cooling load Rank 0 Generation 3 // Ind.26 Cooling load Rank: 0 / 2000 Fitness Value: 5.826408 Electrical load Rank: 35 / 2000 Fitness Value: 3.787602 Glare Rank: 145 / 2000 Fitness Value: 173 Heating load Rank:1949/ 2000 Fitness Value: 46.610477 Illuminance Rank: 238 / 2000 Fitness Value: 56.999544		Cooling load Rank 1999 Generation 0 // Ind.96 Cooling load Rank: 1999 / 2000 Fitness Value: 59.587361 Electrical load Rank: 1478 / 2000 Fitness Value: 7.353117 Glare Rank: 1983 / 2000 Fitness Value: 294 Heating load Rank:341/ 2000 Fitness Value: 23.530173 Illuminance Rank: 1478/ 2000 Fitness Value: 28.811801
Heating Load			
	Heating load Rank 0 Generation 2 // Ind.74 Cooling load Rank: 1843/ 2000 Fitness Value: 44.502853 Electrical load Rank: 1181 / 2000 Fitness Value: 7.022684 Glare Rank: 1274 / 2000 Fitness Value: 204 Heating load Rank:0/ 2000 Fitness Value: 22.098295 Illuminance Rank: 1195 / 2000 Fitness Value: 33.001122		Heating load Rank 1999 Generation 0 // Ind.165 Cooling load Rank: 46 / 2000 Fitness Value: 9.488771 Electrical load Rank: 46 / 2000 Fitness Value: 4.306778 Glare Rank: 861 / 2000 Fitness Value: 197 Heating load Rank:1999 / 2000 Fitness Value: 46.610513 Illuminance Rank: 745/ 2000 Fitness Value: 49
Electrical load			
	Electrical load Rank 1999 Generation 8// Ind.4 Cooling load Rank: 28 / 2000 Fitness Value: 5.826408 Electrical load Rank: 0 / 2000 Fitness Value: 3.787602 Glare Rank: 83 / 2000 Fitness Value: 173 Heating load Rank:1915 / 2000 Fitness Value: 46.610477 Illuminance Rank: 262/ 2000 Fitness Value: 56.999544		Electrical load Rank 1999 Generation 0 // Ind.32 Cooling load Rank: 1757 / 2000 Fitness Value: 43.08422 Electrical load Rank: 1999 / 2000 Fitness Value: 9.88471 Glare Rank: 1543 / 2000 Fitness Value: 229 Heating load Rank:862 / 2000 Fitness Value: 34.500409 Illuminance Rank: 1999/ 2000 Fitness Value: 14.60643

Best Scenario		Worst Scenario	
Glare			
	Glare Rank 0 Generation 8 // Ind.110 ..... Cooling load Rank: 317 / 2000 Fitness Value: 14.108832 Electrical load Rank: 429 / 2000 Fitness Value: 4.844034 Glare Rank: 0 / 2000 Fitness Value: 163 Heating load Rank:1512/ 2000 Fitness Value: 37.308562 Illuminance Rank: 44 / 2000 Fitness Value: 61.001647		Glare Rank 1999 Generation 0 // Ind.44 ..... Cooling load Rank: 1693 / 2000 Fitness Value: 40.882802 Electrical load Rank: 1535 / 2000 Fitness Value: 7.706037 Glare Rank: 1999 / 2000 Fitness Value: 299 Heating load Rank:396 / 2000 Fitness Value: 25.059495 Illuminance Rank: 1533/ 2000 Fitness Value: 25.371695
Illuminance			
	Illuminance Rank 0 Generation 4 // Ind.30 ..... Cooling load Rank: 99 / 2000 Fitness Value: 11.891878 Electrical load Rank: 163 / 2000 Fitness Value: 4.626318 Glare Rank: 53 / 2000 Fitness Value: 164 Heating load Rank:1804/ 2000 Fitness Value: 39.756933 Illuminance Rank: 0/ 2000 Fitness Value: 61.001647		Illuminance Rank 1999 Generation 0 // Ind.32 ..... Cooling load Rank: 1757 / 2000 Fitness Value: 43.08422 Electrical load Rank: 1999 / 2000 Fitness Value: 9.88471 Glare Rank: 1543 / 2000 Fitness Value: 229 Heating load Rank:862 / 2000 Fitness Value: 34.500409 Illuminance Rank: 1999/ 2000 Fitness Value: 14.60643

5.1.2 Selection Method

In the second step of optimization primary energy considered as the objective instead of the final energy (cooling, heating, and electricity load). Primary energy consumption measures total domestic energy demand, while final energy consumption refers to what end users consume. Therefore, in this paper The Primary Energy Factor (PEF) connects primary and final energy. It indicates how much primary energy is used to generate a unit of electricity or a unit of useable thermal energy.

To find the best scenario two method introduced. initially, Average Fitness Rank method used by analyzing the parallel coordinate plot (PCP).

5.1.2.1 Average of fitness rank method

Average Fitness Rank: This method orders the solutions according to their mean fitness by calculating the mean fitness rank of each solution's fitness objectives. The result of Figure Figure *5.7* highlights the results of generation 5 individual 20 as the best scenario. The Selected solution in this method is highlighted by red dot. The Genome decode of the selected solution presented on the Table *5.8*.

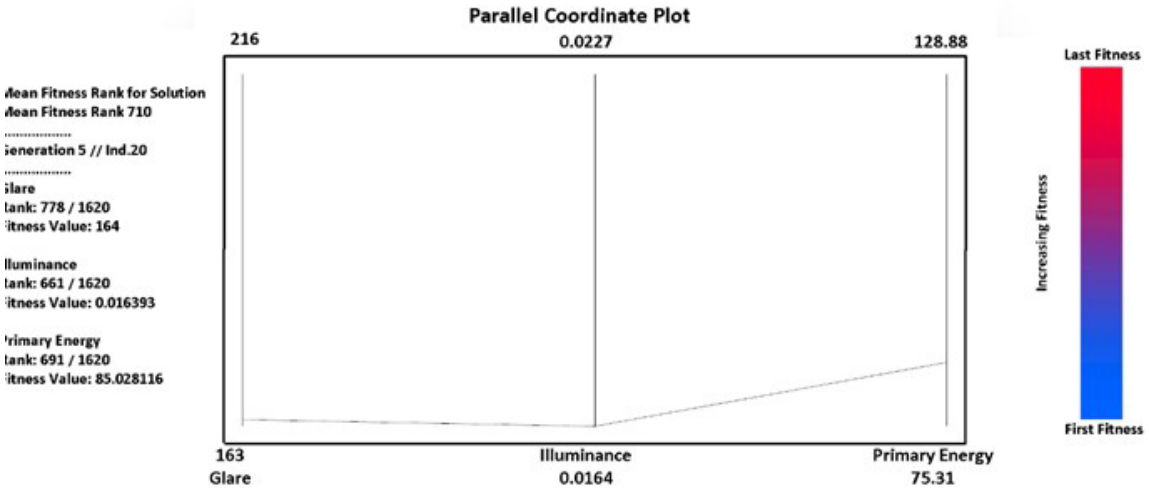


Figure 5.7. Genomes decode of the selected solution

Table 5.8.Genomes decode of the selected solution

Generation: 5 // Individual:20	Genome Decode	1	2	3	2
Roller VT	0.45				
Width	0.16				
Venetian height	1				
Count	8				

5.1.2.2 Pareto Front Solution

Figure *5.8*. Pareto front Graph of the Genome decode of the selected solution. shows Pareto fronts method on the 3D plot. The Pareto fronts remaps the fitness values outputted by the simulation and assigns a distinct axis for each objective. Fitness objectives Glare, Illuminance and Primary energy are display on the X, Y and Z axes, respectively. The Selected solution in this method is highlighted by red dot. The Genome decode of the selected solution presented on the Table *5.9*

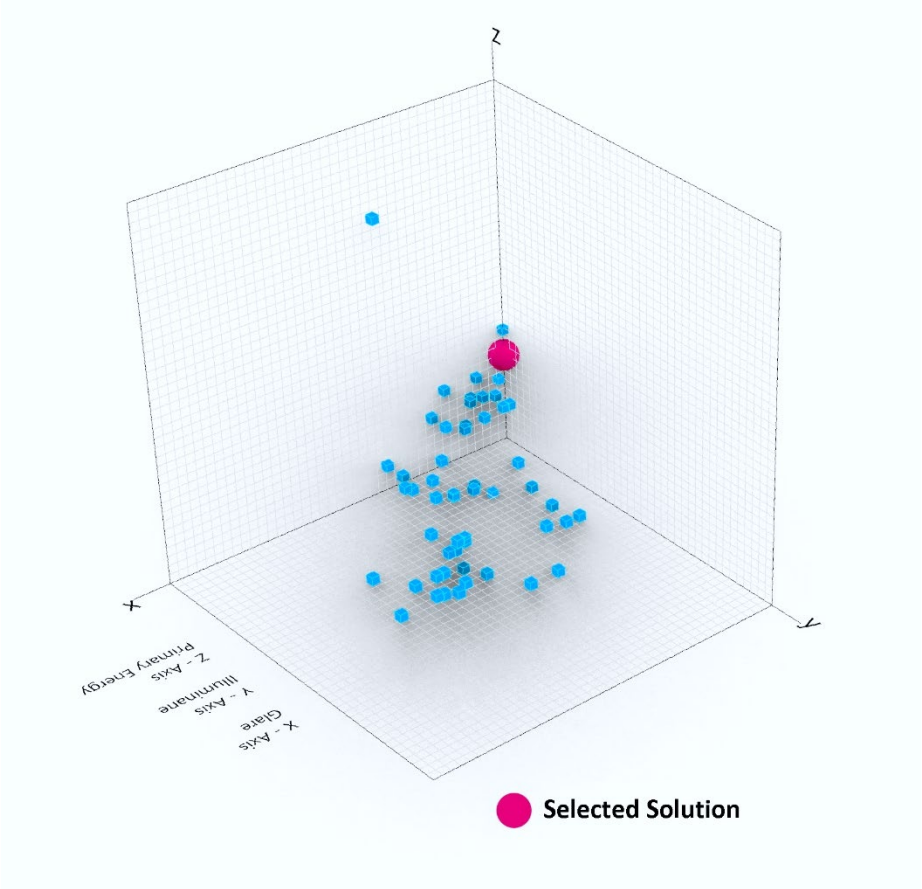


Figure 5.8. Pareto front Graph of the Genome decode of the selected solution.

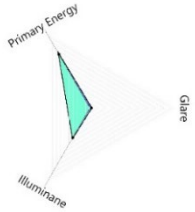
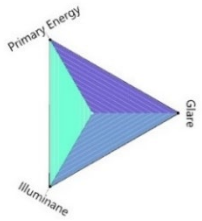
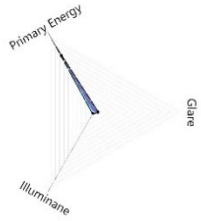
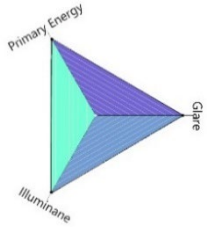
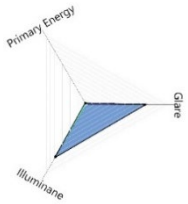
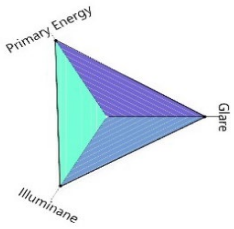
Table 5.9. The Genome decodes of the selected solution.

Generation: 9 // Individual: 15

	1	2	2	2
	Genome Decode			
Roller VT	0.45			
Width	0.16			
Venetian height	0.9			
Count	8			

Table *5.10* shows the best and worst solution for each objective. Results highlights the trade of between the glare, illuminance, and primary energy objectives in each scenario.

Table 5.10.the best and worst solution for three objectives in second step of the optimization

Best Scenario		Worst Scenario	
Glare			
VT 0.6 Width 0.16 Height 0.98 Count 	Glare Rank 0 Generation 5 // Ind.63 ..... Glare Rank: 0 / 1620 Fitness Value: 163 Illuminance Rank: 652 / 1620 Fitness Value: 61.001 Primary Energy Rank: 1203 / 1620 Fitness Value: 88.42	VT 0.6 Width 0.08 Height 0.5 Count 4 	Glare Rank 1619 Generation 0 // Ind.54 ..... Glare Rank: 1619 / 1620 Fitness Value: 216 Illuminance Rank: 652 / 1620 Fitness Value: 45.00 Primary Energy Rank: 1609 / 1620 Fitness Value: 96.44
Illuminance			
VT 0.6 Width 0.16 Height 0.9 Count 8 	Illuminance Rank 0 Generation 11 // Ind.55 ..... Glare Rank: 47 / 1620 Fitness Value: 163 Illuminance Rank: 0 / 1620 Fitness Value: 61.001647 Primary Energy Rank: 1227 / 1620 Fitness Value: 88.421583	VT 0.3 Width 0.08 Height 0.9 Count 4 	Illuminance Rank 1619 Generation 0 // Ind.65 ..... Glare Rank: 1590 / 1620 Fitness Value: 201 Illuminance Rank: 1619 / 1620 Fitness Value: 44.000528 Primary Energy Rank: 1602 / 1620 Fitness Value: 96.128776
Primary Energy			
VT 0.6 Width 0.16 Height 0.7 Count 6 	Primary Energy Rank 0 Generation 7 // Ind.72 ..... Glare Rank: 1175 / 1620 Fitness Value: 173 Illuminance Rank:1229 / 1620 Fitness Value: 56.999544 Primary Energy Rank: 0 / 1620 Fitness Value: 75.30655	VT 0.6 Width 0.16 Height 0.7 Count 6 	Primary Energy Rank 1619 Generation 1 // Ind.68 ..... Glare Rank: 1553 / 1620 Fitness Value: 197 Illuminance Rank:1469 / 1620 Fitness Value: 52.999788 Primary Energy Rank: 1619 / 1620 Fitness Value: 128.868603

5.2 Automation results

In this section, the outcomes related to automated control system is discussed in depth. In the first section the energy impact is evaluated, and values related to the energy consumption of the final design solution is compared to non-automated and existing conditions. In the second section, performance related to visual comfort and illumination is evaluated. Putting these two together, enables the authors to discuss the worthiness of the overall solution developed. As stated previously in chapter 3 and 4, due to the time-consuming nature of the simulations required for this study, we are unable to produce annual and summary results; however, we can analyze results related to two days, 21st of August and 21st of February, and visualize the effectiveness of the system in a comparison basis.

5.2.1 Impact on illumination quality

The improvement of WPI quality, meaning within the user-preferred threshold, is evident in the following charts. Even the quality improvement in terms of fixed standard thresholds can be seen, although it can also be seen that a design based on fixed thresholds is very restricting and could in some cases be disadvantageous. The author is of the opinion that using fixed thresholds for daylight design is comparable to applying fixed thresholds for thermal comfort design prior to realizing the veracity and potential of adaptive comfort models.

5.2.1.1 Impact on illuminance on work-plane

In the (Figure 5.9) it is exhibited the overall change in WPI. Not only a proper control over the quality of daylight emitted on the work-plane is evident in these charts but they also indicate the role of artificial lighting compensating wherever the sunlight is not enough or is of poor quality i.e., glare is imminent.

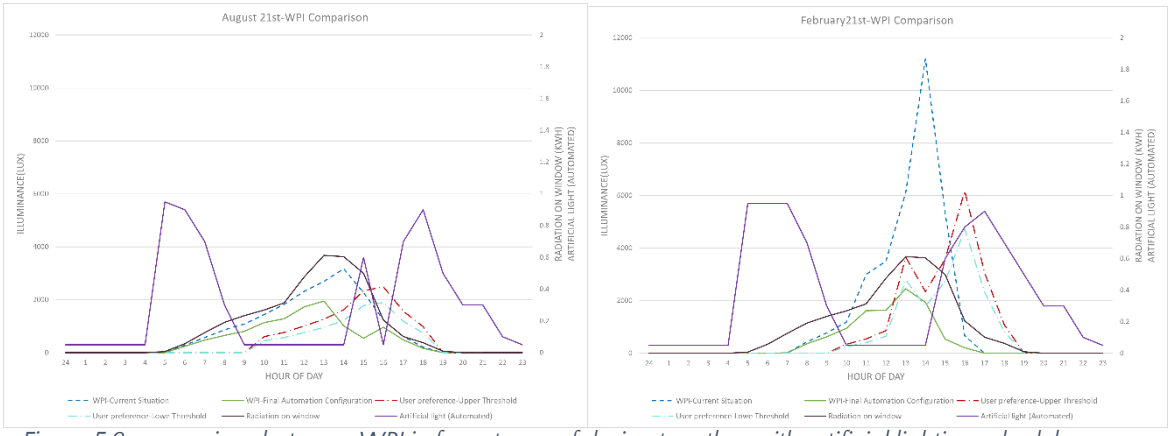


Figure 5.9 comparison between WPI in four stages of design together with artificial lighting schedule

In (Figure 5.10) it is exhibited the stages of WPI in comparison with a static threshold for acceptable illuminance on work-plane which is common to use. It is evident that static thresholds not only do not provide optimal daylight illuminance for the user, but also could be very restrictive for the building designer. Thus, the use of artificially intelligent systems that could provide adaptive visual comfort indices and thresholds could also be of help to building designer, among other benefits related to building energy and lighting performance.

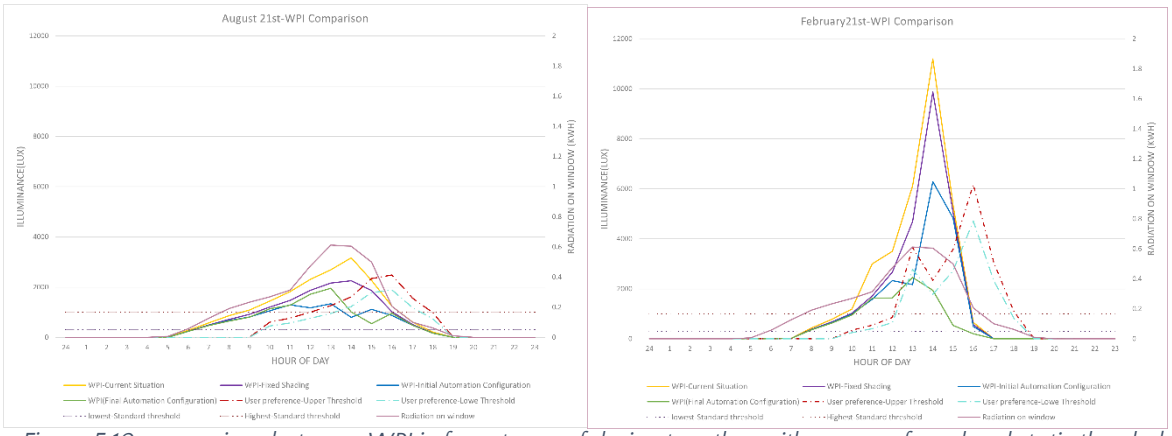


Figure 5.10 comparison between WPI in four stages of design together with user-preferred and static thresholds

It is worth mentioning that the thresholds in this automation algorithm were not used to keep illuminance on work-plane strictly inside the threshold but a guide to control the illuminance. Since the priority was to keep minimum 70% possible view to outside and also glare should be controlled, it can be seen that the WPI in final automation has a significant improvement but not strictly inside the threshold.

5.2.1.2 Impact on glare control

It is evident in (Figure 5.11) the significant improvement of the quality of lighting inside the unit in terms of control with strictly no amount of glare over imperceptible accepted in this study.

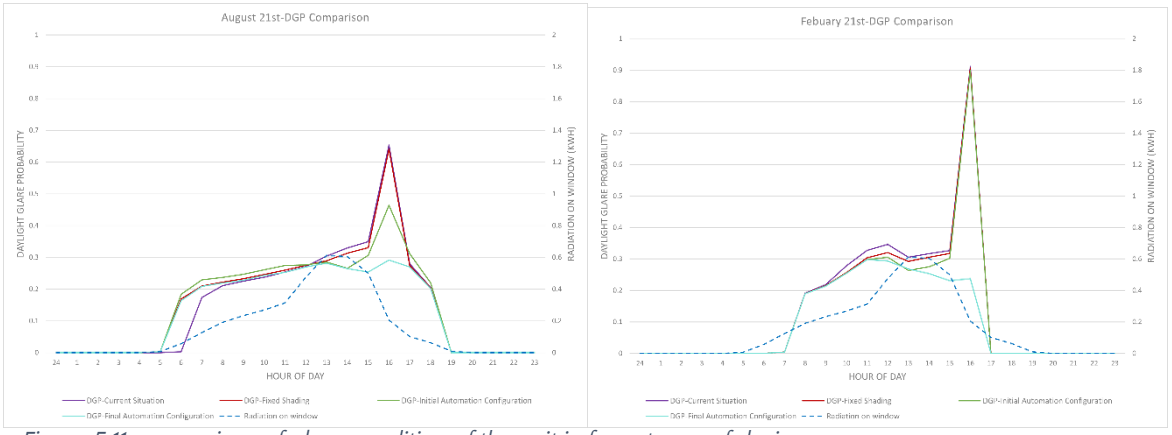


Figure 5.11 comparison of glare condition of the unit in four stages of design

Since the glare was kept strictly under imperceptible threshold which in some case might cause a blockage to the view to outside, but since the user can always override the positioning of roller blinds, not only would they be able to choose their own preference at any time even if it is to have some glare but be able to have a better view to outside, but this data could also be collected for further training of the machine.

5.2.2 Energy impact

Plainly, different shading systems affect the overall energy consumption of the buildings through prevention or exposure of the space subjected to solar gains. An effective shading system can significantly reduce this load imposed on the building. On the other hand, a motorized dynamic shading system introduces an additional energy consuming unit to the building. In this section, the positive and negative effects and finally the overall impact on the unit energy consumption is discussed.

5.2.2.1 Effect of automation

Four stages of the study are presented in the following charts comparing their total thermal load change over the course of two days in the summer season and winter season. Indicating the hourly sky condition using radiation emitted on the surface of the right window without any shading, we see the current condition of the unit and the influences of fixed shading proposed in the first stage, the initial automation after shading geometry was optimized and the final automation proposed.

Thermal condition of the unit analyzed separately utilizing the dry bulb temperature of outdoor, indoor operative temperature, temperature of the external surface of the glass, total thermal load of the space and the fixed radiation on window explained previously (Figure 5.12, Figure 5.13, Figure 5.14, Figure 5.15).

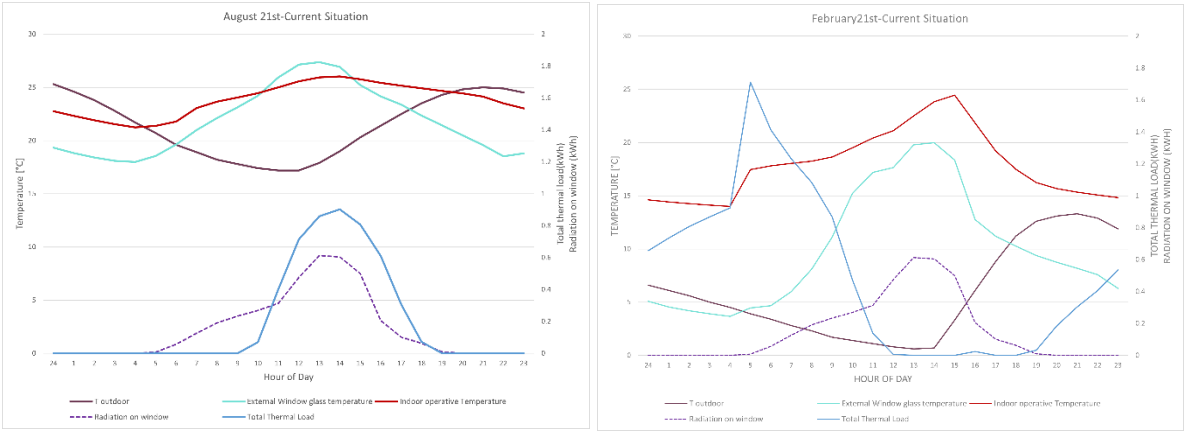


Figure 5.12 simulated thermal condition of the unit - current condition of the unit.

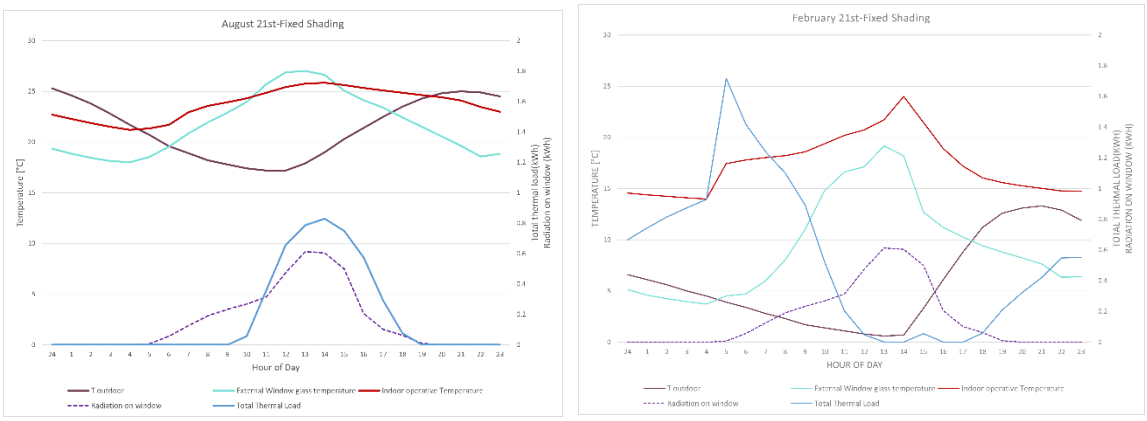


Figure 5.13 simulated thermal condition of the unit – Static Shading.

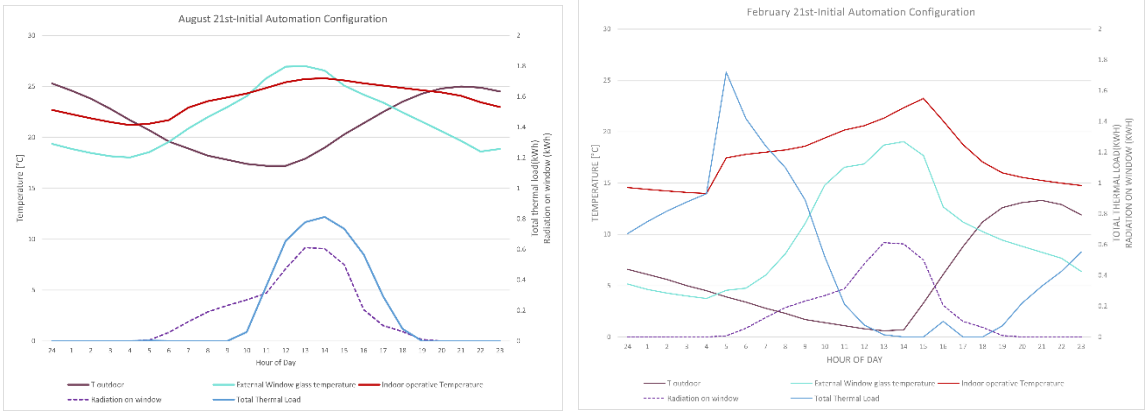


Figure 5.14 simulated thermal condition of the unit – Initial automation system after geometrical optimization.

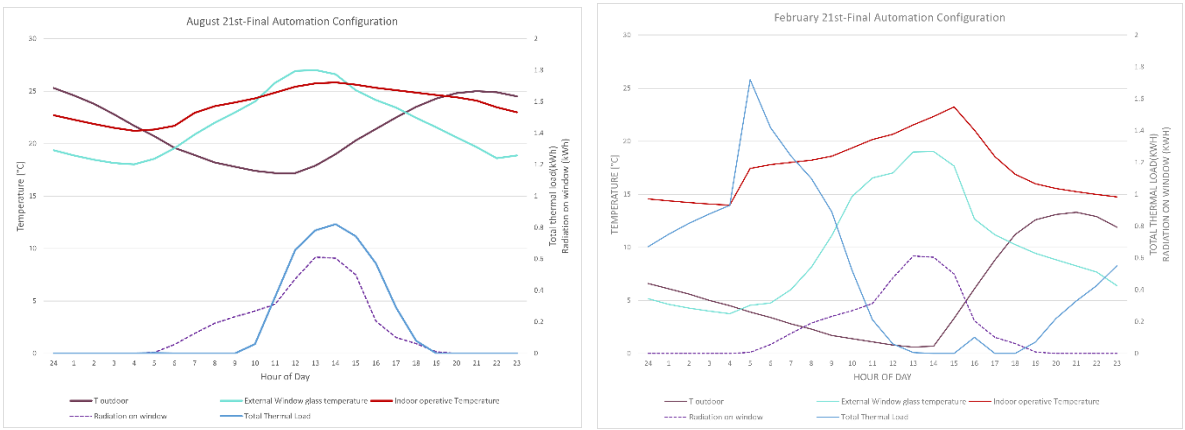


Figure 5.15 simulated thermal condition of the unit – Final automation configuration.

We can see the slight improvements in terms of indoor operative temperature and total thermal load in the following charts (Figure 5.16, Figure 5.17).

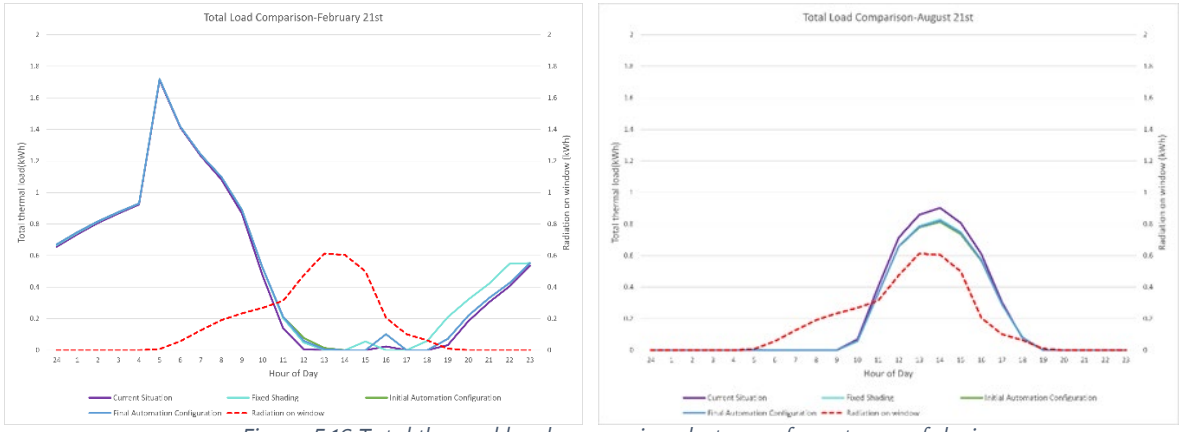


Figure 5.16 Total thermal load comparison between four stages of design.

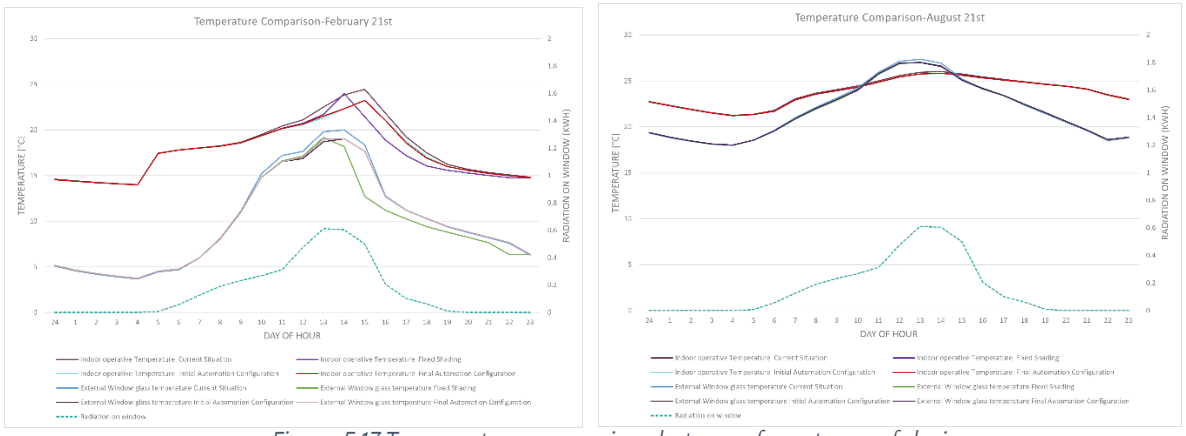


Figure 5.17 Temperature comparison between four stages of design.

Since the user presence was modelled through a stochastic schedule, an energy saving or temperature comparison could not be effective in explaining the effectiveness of the overall design. However, we can indicate the potential of energy saving in regarding artificial lighting by analyzing the automated dimming switch system in this project which utilizes the user presence schedule and WPI. (Figure 5.18) exhibits the difference between a conventional office artificial lighting schedule and the ones used in this project. The amount of artificial lighting load saved through this automation is evident.

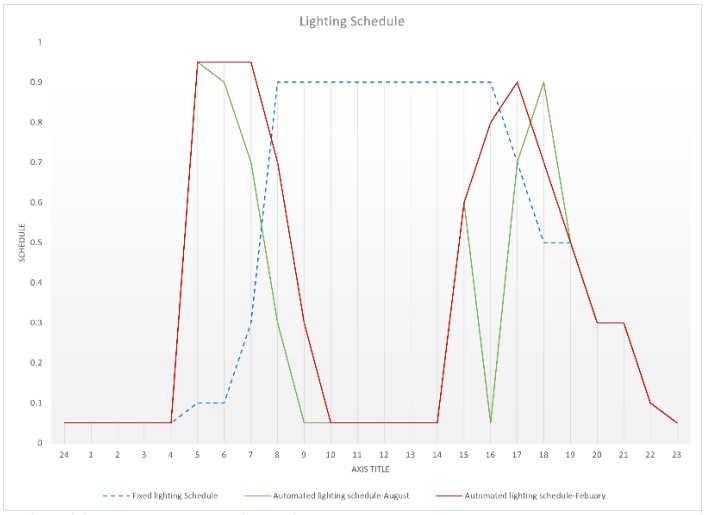


Figure 5.18 dimmed artificial lighting schedules of Aug and Feb 21st compared to static office lighting schedule.

5.2.2.2 Motor energy

To calculate energy consumption by positioning the venetian blinds device, an electric engine power equal to 160 W ((Astea,N; Compostellaa,J; Mazzona,M, 2012)) was considered. This electric power was multiplied by the time needed to operate the device. Electric consumption due to rotation of slat elements was considered, during the time in which automated venetian blinds was activated, assuming four rotations in an hour.

Similarly, to calculate energy consumption by positioning the roller blinds device, an electric engine power equal to 70 W (Astea,N; Compostellaa,J; Mazzona,M, 2012) was considered and the electric power was multiplied by the time needed to operate the device. Electric power due tubular motor rotating was considered, during the time in which automated roller blinds was utilized, assuming 1 full opening and closing every other hour (Table 5.11).

In both cases an equivalent engine power of 0.5 W was considered for the period where the system is in idle condition.

Table 5.11 Shading motor annual energy consumption

	Venetian Blinds	Roller Blinds
Shading devices' electricity consumption (kWh/year)	0.293	0.016
Primary energy conversion factor (-) -	2.17	2.17
Primary energy consumption (kWh/year)	0.636	0.034

Evidently, the overall additional energy consumption of the shading system is less than 1 kWh/year even taking into account the energy consumption of all the sensors it is still safe to say that its impact could be neglected.

5.3 Overall impact

It can be seen from the results of the previous sections that although this shading device might not save the building a significant amount of energy in terms of thermal load, but it has strong potential to save energy in terms of electrical lighting loads while it can immensely improve the quality of the daylight exploitation without imposing additional loads.

5.4 Discussion and future work

As mentioned in the results section of this chapter, the limited number of samples and the linear model of prediction restricts the precision of the machine learning process of this design. Thus, conducting more research on another model that could increase the precision of prediction of user needs is prudent (Figure 5.19).

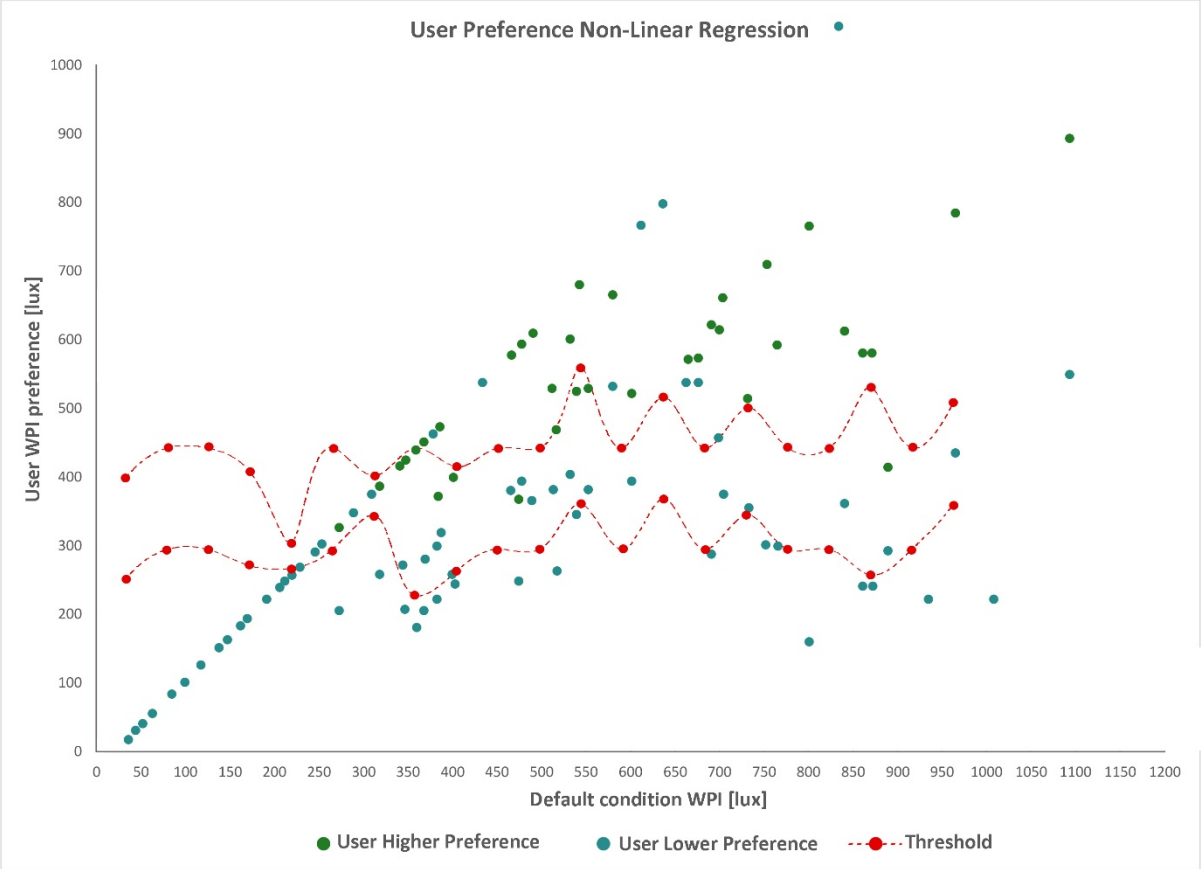


Figure 5.19. User Preference Non-Linear regression

User presence in this project was done through stochastic schedule developed through data collected by conduction of surveys. However, in the general methodology developed for real-time machine another method is suggested which is to use a couple of motion sensors. This method is already researched by other scholars and its precision is still not quite satisfactory. An expedient solution to this issue is development of an algorithm using deep learning techniques. This is advantageous because not only does it help indicate user presence precisely, but this could also be developed to indicate user's activity and task related illuminance preference. The survey sheet used for this study predicted this and data from the survey could be used for such developments.

6. CONCLUSION

This study addresses the importance of user-specific illumination and daylighting in personal workspaces and an automated shading solution for a small office unit utilizing a configuration comprising of external venetian blinds and internal roller blinds which works using specific user preference in terms of illuminance on work-plane threshold is delivered.

This solution was elaborated by initially developing a generic methodology that could be employed in real-time operations. It then, was verified by the means of surveys and simulations.

Verification phase of the methodology was done on a case study located in Lecco, Italy which is a personal home-office of one the authors of this thesis. The project was done in 5 major steps:

- First step was doing a survey collecting data regarding the user preference in comparison to existing condition and several other parameters.
- Second step was studying and selecting cost-effective and locally prevalent shading devices compliant with the project's key goal, illuminance control. External venetian blinds and internal roller blinds was chosen in this case.
- Third step was determination of shading implementation strategy. 5 strategies were studied and compared in terms of cooling, heating, electrical lighting load and UDI and glare probability imposed inside the room. Among the strategies mentioned in (Table 6.1) strategy 5 was selected, not because of a significant deviation in their performance but because it provided the project with more flexibility in terms of control.

Table 6.1 shading implementation strategies studied.

Strategy no.	1	2	3	4	5
Description	No shading	Fixed exterior shading	Motorized interior roller	Motorized interior roller + fixed exterior shading	Motorized interior roller + motorized exterior shading

- Fourth step was to optimize the geometrical attributes of the shading system in terms of both energy and daylighting performance. To do so, an evolutionary multi-objective optimization method was utilized. In this step, venetian slat width, number of slats and total height of the window covered by venetian blinds and also in the case of the roller blinds the fabric visible transmittance were optimized using heating, cooling, electrical loads and UDI and probable glare point-hours as initial objectives which finally was reduced to primary energy UDI and probable glare point-hours. (Table 6.2)
- Lastly, in step five the final automation algorithm was developed. The control system works with an intertwined script that cannot be arranged into chronological steps; hence, the author only mentions the factors taken into account. System's primary concern when the user is present is to keep the possible view factor maximum other than the cases when perceptible glare exists in users field of view. Second concern of the machine is to keep the illuminance on the work-plane inside the user's preferred

range considering the existing condition initially by daylight and if not possible, either due to deficiency of adequate light or the occurrence of observable glare, by artificial lighting. The user's preferred threshold is predicted by entering existing illuminance condition into the machine learning model trained by performing linear regression on the data collected through the aforementioned survey to predict the most probable preference of the user in regard to this specific condition. However, at any point the user is given the ability to override the control system and manually change the position of the shading devices through their cellphone which not only provides user with the required control but also helps the system optimize itself by collecting this data and adding it to the machine learning training set. In cases of existing of direct sunlight on the work-plane a vector from closest point of this occurrence to the window to the sun is drawn and the point at which this vector passes through the façade helps the control system to order the proper control. If it goes through the plane that is covered by venetians venetian blinds will be closed, and if lower, roller blinds will be closed until the point where lower line of the roller blind fabric reaches the point of intersection. In cases that the mentioned situations do not occur the venetian blinds will control the amount of daylight on the work-plane. Lastly, in case the user is not present in the room, the system switches to energy-saving mode, meaning it will let the solar gains enter in full amount in heating conditions and stops it as much as possible in cooling conditions; however, the temperature inside and outside is observed by the system and in case the degree from comfort exceeds the thresholds defined the system will order to modify shading position to help the room keep the conditions inside close to comfort at all times.

Table 6.2 Optimization genes and objectives

Genes	Genome code	Objectives I	Reference no.	Objectives II	Reference no.
Roller VT	0	Cooling	0	Glare	0
Width	1	Electrical	1	UDI_d	1
Venetian height	2	Glare	2	Primary-Energy	2
Count	3	Heating	3		
		UDI_d	4		

Since the simulations performed were solely in comparative basis and the duration of the simulations did not include condition of a whole solar year, no definite result was used to deduce conclusions in this thesis; however, from several comparison it could be inferred that a multi-objective optimization process could potentially indicate optimal geometrical features of the shading system that has significant performance improvement in comparison with most of the rest of possible configurations. Moreover, a proper user-specific automation algorithm is able to potentially improve the quality of illuminance on user's workstation according to their specific preference which graphs indicate this feature not only does not put more pressure on daylight designer, it even helps them by considering the user's ability to adapt to the contextual lighting condition. Automation system is also able to reduce the electrical lighting load by considering user presence and active considering the illuminance level on their work-plane which would reduce the need for artificial lighting significantly. Considering the typically practiced fixed

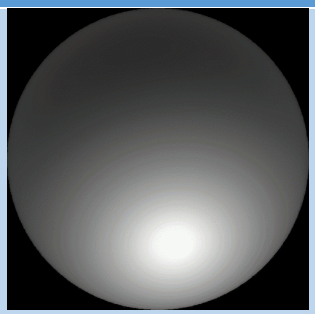
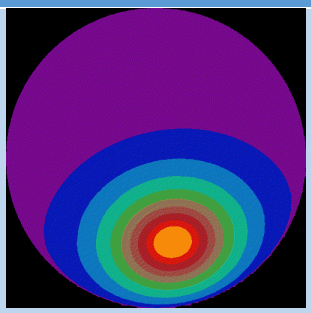
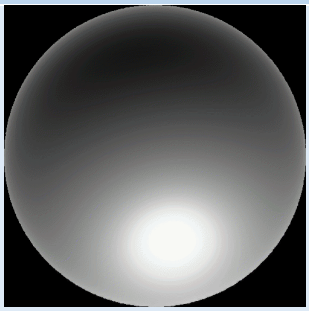
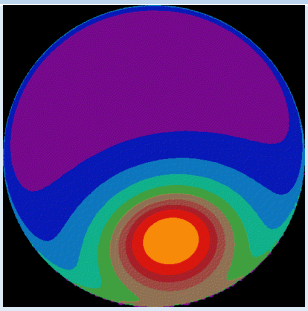
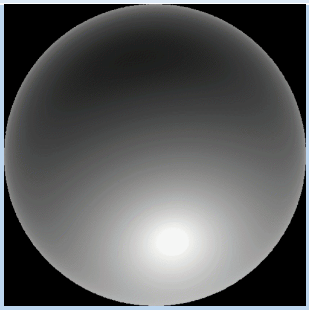
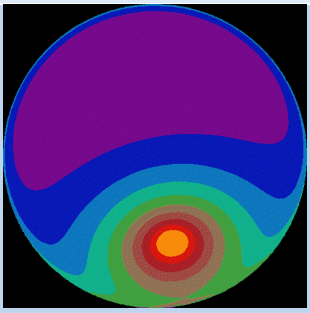
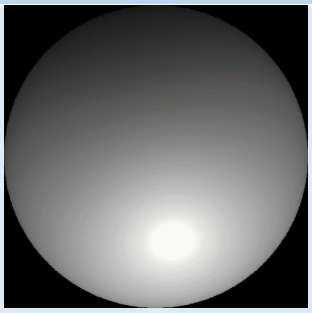
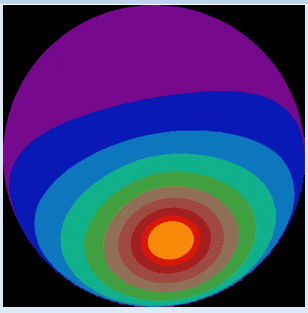
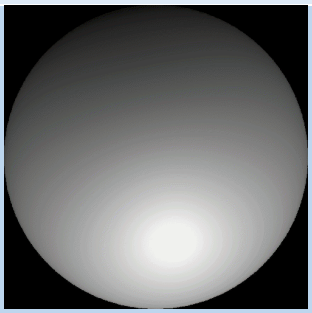
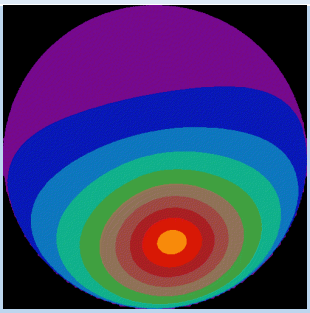
lighting schedule of offices this can be a significant improvement in terms of electrical lighting load. Moreover, this system can potentially reduce the heating and cooling loads imposed inside singular office spaces by executing an energy-saving mode when user is absent inside the space.

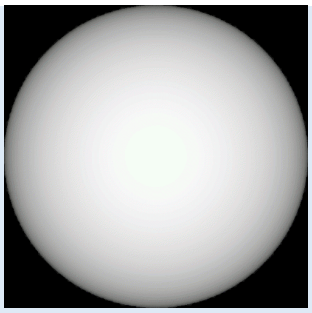
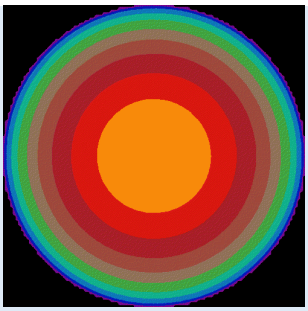
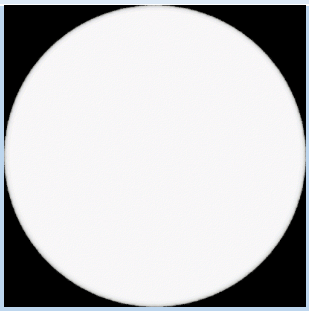
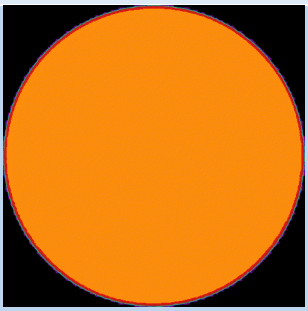
This system can be further studied and improved in several aspects. Additional data collection from more cases and development of a more precise machine learning model provides the possibility of further studying and verifying the accuracy of this automation system. Moreover, by developing a deep learning model it is possible to reduce the number of sensors required. A complete deep learning model can potentially utilize one camera sensor to indicate the work-plane illuminance, glare, user presence to mention a few. Finally, a complete simulation, however time consuming, can further verify the effectiveness of this system.

APPENDIX I

		Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Hour 7	..
Time of capture									
Higher threshold blinders %									
Lower threshold blinders									
Full	Middle Point								
	Point1								
	Point2								
	Point3								
	Point4								
	Front								
Higher Threshold	Middle Point								
	Point1								
	Point2								
	Point3								
	Point4								
	Front								
Lower Threshold	Middle Point								
	Point1								
	Point2								
	Point3								
	Point4								
	Front								
Position toward window	Behind								
	Front								
	Left								
	Right								
State of Comfort (At fully open)	Great								
	Satisfied								
	Low								
Activity									

APPENDIX II

Type	Sky model	Sky False color
Climate-based sky		
Sunny with sun		
Sunny without sun		
Intermediate with sun		
Intermediate w/o sun		

Cloudy sky		
Uniform sky		

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