



# Development of an adaptive solar shading system based on analysis of study cases

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# CONTENTS

ABSTRACT	1
01  INTRODUCTION	3
01 1 NEED FOR SUNLIGHT	4
01 2 DAYLIGHTING IN ARCHITECTURE	5
01 3 NEED FOR SOLAR CONTROL	5
01 4 NEED FOR ADAPTATION	5
01 5 PROBLEM STATEMENT	6
01 6 OBJECTIVE	6
01 7 RESEARCH QUESTIONS	6
01 8 SCOPE OF STUDY	6
01 9 APPROACH AND METHODOLOGY	7
01 10 PLANNING AND ORGANIZATION	8
02  DAYLIGHT	9
02 1 TERMINOLOGY	10
02 2 LIGHT AND VISION	11
02 2 1 THE SURFACE ACTIONS OF LIGHT	11
02 2 2 VISUAL PERFORMANCE OF THE EYE	11
02 2 3 VISUAL ADAPTATION	12
02 2 4 VISUAL FIELDS	12
02 3 DAYLIGHT	13
02 4 INDOOR DAYLIGHT	13
02 5 VISUAL COMFORT	14
02 6 GLARE	16
03  DAYLIGHT IN OFFICE BUILDINGS	19
04  SHADING SYSTEMS	23
04 1 INTERNAL SOLAR SHADING SYSTEMS	24
04 2 EXTERNAL	24
04 2 1 FIXED	25
04 2 2 ADJUSTABLE	25
04 2 2 1 ACTIVE	26
04 2 2 2 PASSIVE	26
04 3 LIGHT-DIRECTING SYSTEMS	26
04 4 CUSTOM SOLUTIONS	26
04 5 GENERAL RULES ON CHOOSING SHADING DEVICES BASED ON ORIENTATION	27
04 6 MAINTENANCE	27
05  ADAPTATION	29
05 1 DESIGN	30
05 2 MOTION	30
05 3 SUN SENSOR	30
05 4 LEVELS OF ADAPTATION MECHANISMS	31
05 4 1 SMART MATERIALS	31
05 5 ADAPTATION AND USER	32
06  SYSTEM REQUIREMENTS	33
07  BUCKY LAB PROJECTS	37
08  STUDY CASES	51
09  SIMULATIONS	65
09 1 METHODOLOGY	66
09 2 SELECTION CRITERIA	67

09 3 SIMULATION RESULTS	68
09 3 1 REFERENCE ROOM   South facing	68
09 3 2 REFERENCE ROOM   West facing	69
09 3 3 TESSELLATE   West facing	70
09 3 2 AL BAHAR TOWERS   South facing	72
09 3 3 CHEROKEE LOFTS   West facing	74
09 3 4 KIEFER TECHNIC SHOWROOM  South facing	76
09 3 5 THYSSENKRUPP QUARTIER Q1   West facing	78
09 4 COMPARISONS	80
09 4 1 IN TERMS OF ORIENTATION	80
09 4 2 IN TERMS OF ADAPTATION MECHANISM	82
09 4 3 KIEFER TECHNIC SHOWROOM_WEST - CHEROKEE_WEST	87
10  DESIGN	89
10 1 DESIGN RESEARCH	90
10 2 GOALS	92
10 3 THE CONCEPT	92
10 3 1 SMART GLASSES	92
10 3 2 POLYMER DISPERSED LIQUID CRYSTAL	93
10 4 DEFINING GEOMETRY	94
10 4 1 OPTIMIZATION	98
10 5 SHADING SYSTEM CONFIGURATION	99
10 6 GLASS CONNECTIONS	99
10 7 FACADE STRUCTURE ANALYSIS	100
10 7 1 PROPOSED CONNECTIONS	101
10 8 TECHNICAL DRAWINGS	103
10 9 FACADE ASSEMBLING	106
10 10 VISUALIZATIONS	108
11  LIGHTING PERFORMANCE	115
11 1 DAYLIGHT ANALYSIS - COMPUTER BASED SIMULATIONS	116
11 1 1 PROPOSED SHADING SYSTEM   South - oriented	116
11 1 2 PROPOSED SHADING SYSTEM   West - oriented	121
11 2 DAYLIGHT ANALYSIS - COMPUTER BASED SIMULATIONS   THE NETHERLANDS	126
11 2 1 PROPOSED SHADING SYSTEM   South - oriented	126
11 2 2 PROPOSED SHADING SYSTEM   West - oriented	128
11 3 PHYSICAL MODEL	130
12  FEASIBILITY	137
12 1 MANUFACTURING	138
12 2 COST	139
12 3 ENERGY USE	139
12 4 MAINTENANCE	142
13  CONCLUSIONS & FURTHER RESEARCH	143
13 1 CONCLUSIONS	144
13 2 FURTHER RESEARCH	145
14  REFLECTION	147
BIBLIOGRAPHY	150
APPENDIX A	153
APPENDIX B	217
APPENDIX C	227
APPENDIX D	229

## ABSTRACT

Over the last years, solar shading systems have become integral parts of the building envelope. New designs, technologies and materials are constantly introduced and tested in shading industry. Nowadays, adaptation in solar shading systems is the almost exclusive goal of every design. Adaptive solar shading systems are preferable as they adapt to external climate conditions and indoor needs, succeeding high performance and efficiency at the same time.

The term "adaptation" is eventually related to movement. The plurality of adaptive solar shading systems perform by making use of integrated movement mechanisms. Ten Bucky-lab projects and ten study cases are analyzed in terms of visual comfort and analytical daylight simulations are conducted for the latter. The computer-based simulations focus on the annual daylight performance of each system in Athens. This procedure contributes in understanding in depth the way that adaptive shading systems perform, by evaluating their efficiency performance. This research highlighted the most efficient systems, under basic shading principles. However, their movement mechanisms are relatively expensive and require frequent maintenance or even replacement.

The proposed solar shading system introduces a new generation of adaptive shading systems which are static and their adaptation mechanism is related to the material of the system and its properties. Smart glass technology and PDLC (Polymer Dispersed Liquid Crystal) devices allow the fluctuation of the transparency coefficient of the glass. They are mainly used as vertical glazing on the building envelope in order to provide shade to the interior. Nevertheless, being vertical, they do not only block daylight but also view to the exterior space. The proposed solar shading system makes use of this innovative technology in a more efficient way. An external three-dimensional grid, with vertical and horizontal components perpendicular to the facade of the building is placed in front of the curtain wall system, shading the interior and allowing view to outside simultaneously.

Computer-based simulations are performed in detail for west and south orientations. A reference room on the 10th floor of an office building located in Athens is concerned. In addition, the proposed system is evaluated for the same reference room but located in Amsterdam via basic daylight simulations.

The concept of this shading system is to provide the opportunity to control the transparency in great variety. Each component of the system can be controlled individually. Thus, either all or particularly selected horizontal and/or vertical shading components may be transparent or translucent. If shading is not needed, it may be totally invisible. As a result, the proposed shading system performs efficiently at any orientation and under any daylight conditions.

Regarding efficiency performance, the proposed shading system provides acceptable indoor daylight conditions throughout the year in both examined orientations. The system requirements set for this research (daylit area, daylight autonomy, useful daylight index and glare percentage) are fulfilled. Focusing on its contribution in the energy consumption of the reference room, 35% energy saving is accomplished in south orientation and 16% in west orientation. These outcomes concern only the location of Athens.

01

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INTRODUCTION

The building envelope separates the outdoor from the indoor environment. It can be characterized as the interface between exterior and interior space controlling the interaction. A façade can either prohibit or allow external climate conditions to affect indoor climate. Nowadays, indoor space is a fully independent environment, potentially controlled thanks to high performance electrical and mechanical equipment. Lighting, temperature and air quality can be controlled independently, without any influence from the outside climate conditions. However, "sustainability" implies an environmentally friendly way of living and introduces the need for reduction of energy consumption. From this point of view, outdoor environment is not an excluded element, separated from the interior, but an aspect that should influence the interior space and be used in favor of indoor comfort and energy saving. Hence, the building envelope should not be a barrier but a selective climate filter.

Energy consumption related to dominant uses is approximately half of the total one, with space heating counting for 22.5%, cooling for 14.8% and lighting for 14.4% (Adriaenseens, et al, 2014). At the same time other surveys show that 21% of CO<sub>2</sub> emissions come from residential buildings and 19% come from commercial buildings (Reinhart, 2013). To overcome all these negative and harmful for the environment facts, measures for controlling the correlation between the interior and the exterior seem to be essential.

Mikkel Kragh and Annalisa Simonella from Arup Façade Engineering at ICBEST 2007 have got to the following conclusion:

*"There is no direct correlation between U-value and overall energy performance in a building with high internal heat gains, as an office building. In other words, the main driver is exposure to solar radiation."*

Thus, solar control is one of the major aspects affecting indoor climate.

## 01 | 1 NEED FOR SUNLIGHT

Light has a double essence. Except for enabling sight, it influences dramatically human body. From biological point of view, light modulates the circadian rhythm which is responsible for regulating many body functions such as the metabolism, the blood circulation and the hormone production (CELMA, 2011). Thus internal clock is completely synchronized by sun's path during the day (Fig 01). This correlation is known since 1960, and until nowadays the biological and the psychological effects of light are indisputable. Human brain is totally synchronised with the 24-hour period of the day and so all body functions are in correlation with daylight. Body temperature, fatigue, mood, productivity and human performance in general are influenced by sunlight (Dr Sergio Altomonte, n.d.).

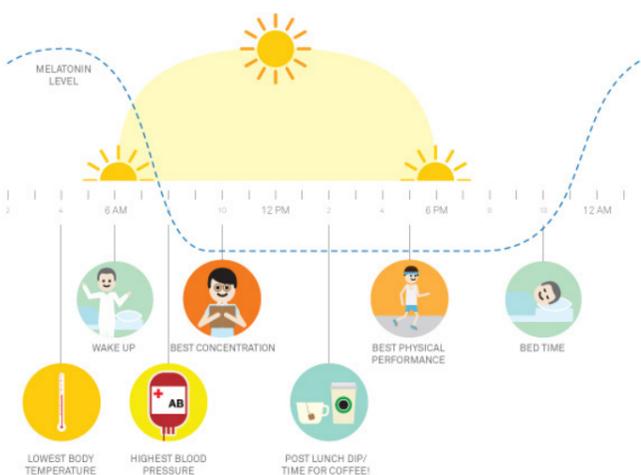


Fig 01 | Circadian rhythm.  
Source | <https://fuzzyscience.wikispaces.com/Circadian+Rhythm>

In addition, sun movement helps humans be aware of the time of the day, the seasons, as well as geographical and spatial location (Guzowski, M., 2000). A term that worths being mentioned at this point is "biophilia". According to dr. Erich Fromm, "biophilia" describes the willing of humans to be in touch with nature, meaning both flora and daylight. This is why solar control is so important. In particular, in the field of architecture, the purpose of the solar control is not only to block but also to import sunlight where needed.

## 01 | 2 DAYLIGHTING IN ARCHITECTURE

Daylighting is the controlled use of natural light in and around buildings and it implies a process by which direct sunlight and diffuse daylight are reflected, scattered, admitted and /or blocked to achieve a desired lighting effect (Reinhart, 2013). Daylight entering an indoor space can affect it either in a positive or a negative way. The benefits, when entering an interior space, are basically the connection with the outdoor environment and the view, as well as the fluctuating illumination of space. Light is a dynamic source of nature, as it will be analyzed later. Thanks to light, individual's visual comfort is improved and, last but not least, its contribution in reduction of energy consumption for lighting and heating in a building is unquestionable. On the other hand, there are drawbacks as well, like overheating and glare.

At this point the introduction of the term "Mediterranean double skin façade" is essential.

*"Mediterranean double skin is a continuous glass façade with a set of sunshades on the outsides for solar protection".* Renzo Piano

At places such as Mediterranean Sea, meaning warm and sunny ones, solar control is totally required. Though, incoming daylight except for being controlled should also be able to be adjusted according to indoor needs.

## 01 | 3 NEED FOR SOLAR CONTROL

"Solar shading" is a term describing all the methods used for controlling the penetration of sunlight in the interior. These methods range from shade trees over special sun shading systems placed on building facades.

## 01 | 4 NEED FOR ADAPTATION

Focusing on solar control, the aim is to use it in favor of user's visual and thermal comfort. Demand of daylight is related to time and date. Incoming light can be used for heating when it is needed (e.g. during winter time) and should be obstructed other times (e.g. during summer time) in order to reduce heat gain. Along these lines, adaptability of solar control systems throughout the day and the year is required.

Solar design is usually static and fixed at the opening position on the building envelope, performing at maximum only under conditions. Nonetheless, new generation materials, designs and technologies enable the adaptation of sun shading systems responding to lighting condition and date - time data.

Buildings are living things and need to react to external stimuli. Passive or active solar designs can be incorporated to offer ideal indoor climate conditions. Passive are the systems that react because of their nature, without the need of an external source. For example materials that change their shape in accordance to temperature and sun presence. On the other hand, active designs depend on mechanical sources. The purpose of a building is to provide stable indoor environment under all circumstances.

The aim of this project is to make a research about solar control and in particular investigate on the various proposed designs of adaptive sun shading systems. Research papers and analysis on study cases will define the characteristics of the optimum design according to climate conditions. Based on this data, the final product will be a design of adaptive sun shading system that controls daylight obtaining optimum visual comfort of the user.

## 01 | 5 PROBLEM STATEMENT

Solar light and heat caused by incoming daylight are highly effective parameters of indoor climate and they affect both the energy needs and the comfort of the user. Daylight can be both beneficial or harmful. Thus, controlling it seems essential. In order to obtain a “nearly zero-energy” buildings and achieve the optimum indoor comfort, an appropriate solar control system must be used. Its design and its performance should be defined based on the building location and its climate, the orientation of the building and its indoor needs.

## 01 | 6 OBJECTIVE

### Main objective

Design a sun shading system that can adapt its elements in order to provide visual comfort to individuals during the course the day, throughout the year.

### Sub objectives

Create a design answering to the needs of an office building.  
Optimize the specifications of the proposed design with computer simulations.  
Conduct real model measurements to assess its efficiency.

## 01 | 7 RESEARCH QUESTIONS

### Main question

Which adaptation mechanism contributes more to the lighting performance of a sun shading system in office buildings?

### Sub questions

What are the criteria influencing the design of a sun shading system?  
In which way the climate and the orientation are affecting the design of a sun shading system?  
Which is the optimum position of the design in respect with the glass panes?  
Which material performs the best as far as it concerns the proposed design?  
How is the proposed design performing in terms of maintenance?

## 01 | 8 SCOPE OF STUDY

<b>Location</b>	Athens vs Amsterdam
<b>Climate</b>	Mediterranean vs Temperate Maritime
<b>Dates for analysis</b>	21 <sup>th</sup> of June & 21 <sup>th</sup> of December (& 21 <sup>th</sup> of March)
<b>Time spectrum</b>	08:00-18:00
<b>Boundary conditions</b>	Horizontal daylight management
<b>Building</b>	Office building
<b>Interior</b>	Close plan

## 01 | 9 APPROACH AND METHODOLOGY

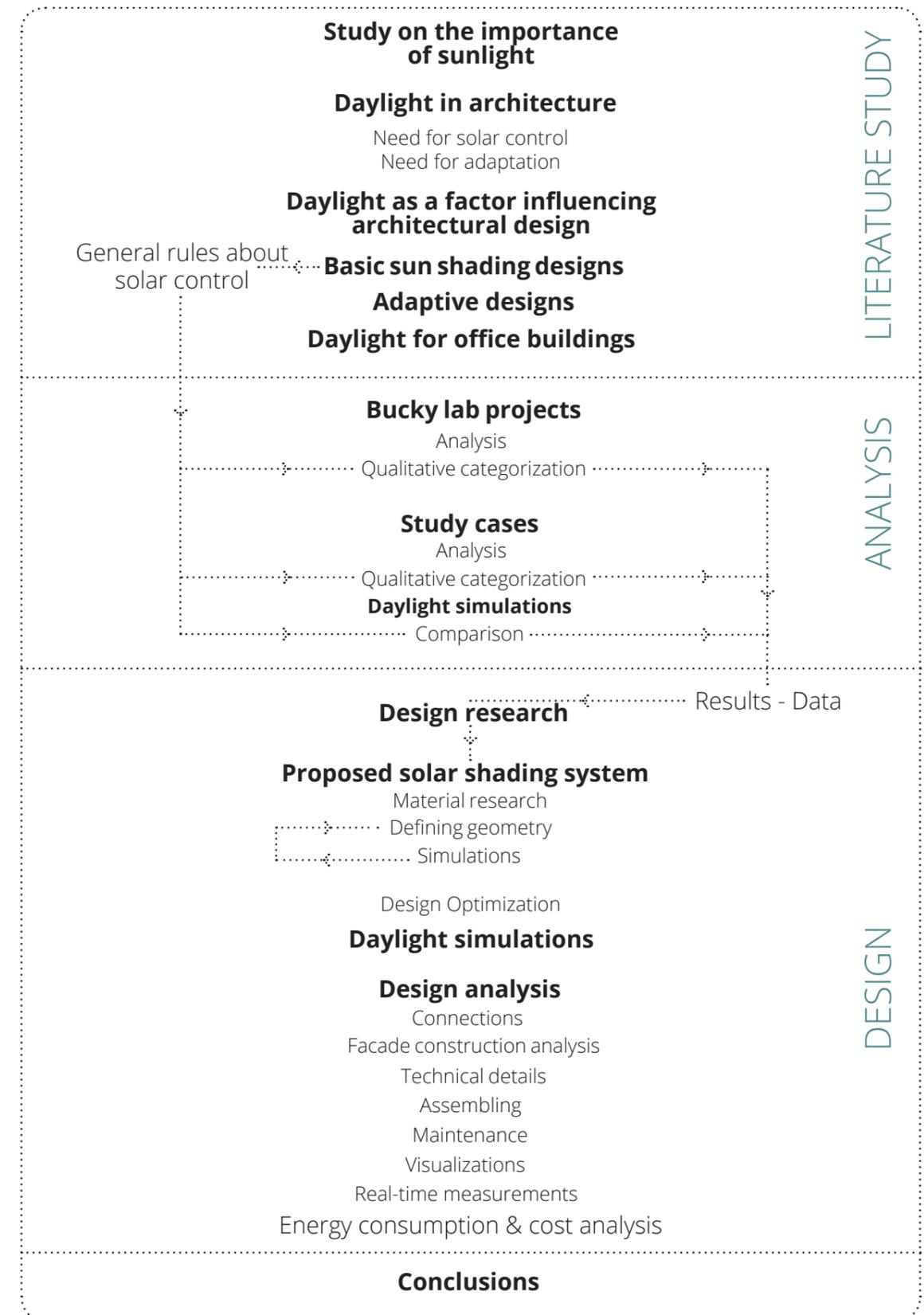


Table 01 | Project time planning.

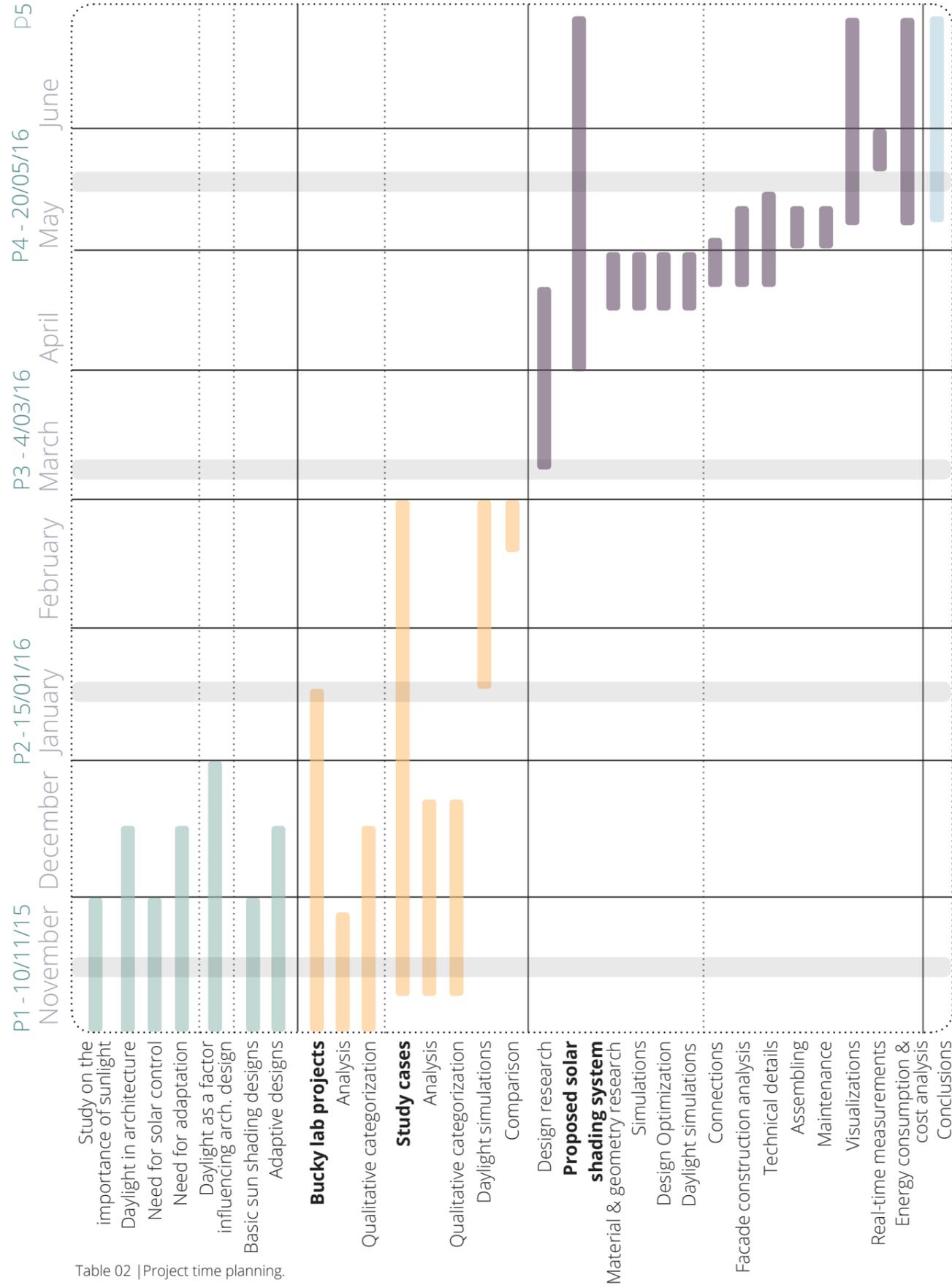


Table 02 | Project time planning.

# 02

## DAYLIGHT

## 02 | 1 TERMINOLOGY

**Brightness** | Brightness is the subjective impression of light illuminating one surface as compared with another surface. (Michel, L., 1996)

**Brightness Contrast** | This property is the basic mechanism for seeing. Contrast threshold expresses the ability of a person to distinguish the objects from the background and thus it is equal to the difference between the luminance of the task and the luminance of the immediate background divided by the luminance of the background (Pritchard, D.C., 1995)

**Daylight** | Part of global solar radiation capable of causing visual sensation. (IEC, 1987) (ILV 845-09-84)

**Daylight factor or daylight coefficient (D)** | ratio of illuminance at a point on a given plane due to light received directly and indirectly from a sky of assumed or known illuminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky (IEC, 1987) (ILV 845-09-97). In common words, daylight factor describes the ability of a building to let natural light in.

**Daylight zone** | the size of this area is specified as follows:

Depth = height of the lintel above door - height of reference plan \* 2.5

Width = 1/4 \* depth

**Illuminance (E)** | The luminous flux density at a point on a surface, i.e. the luminous flux incident per unit area. (Pritchard, D.C., 1995) Expressed in lux = lm/m<sup>2</sup>

**Light** | The range of electromagnetic solar radiation that can be perceived with the human eye.

**Luminance (L)** | The brightness of light being reflected and emitted or transmitted from a surface per unit area in a given direction. Expressed in cd/m<sup>2</sup>. (Lechner, 1991).  $L = \rho \times E$ , where  $\rho$  = reflectance and  $E$  = Illuminance (Helms, R. N., & Belcher, M. C., 1991).

**Luminance ratio** | Is the ratio between the luminances of two surfaces (Michel, L., 1995). Typically, a maximum ratio of 40 to 1 should not be obtained (Helms, R. N., & Belcher, M. C., 1991).

**Luminous flux ( $\Phi$ )** | The light emitted by a source, or received by a surface. The quantity is derived from radiant flux (power in watts) by evaluating the radiation in accordance with the relative luminous efficiency of the "standard" eye. [lumen] (Pritchard, 1995)

**Lux (lx)** | The SI unit for illuminance, equal to one lumen per square meter, 1lx = 1lm/m<sup>2</sup>.

(Pritchard, D.C., 1995)

**Solar radiation** | The direct radiation from the sun plus the diffuse - indirect- radiation reflected from the sky and the surroundings [ kWh/m<sup>2</sup> ] (Herzog et al, 2004).

## 02 | 2 LIGHT AND VISION

The electromagnetic spectrum consists of various bands which are defined by their wavelength range. Visible light is a small part of it, ranging from 380nm (violet) to 780nm (red) of the electromagnetic spectrum (Fig 02). The different values of the light spectrum represents the different colours that the human eye identifies (Pritchard, 1995).

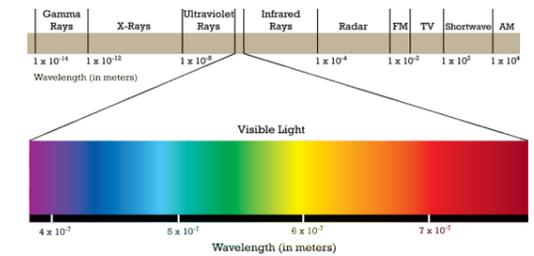


Fig 02 | Electromagnetic spectrum. Source | <http://www.pion.cz/en/article/electromagnetic-spectrum>

### 02 | 2 | 1 THE SURFACE ACTIONS OF LIGHT

Light travels in rays passing through atmosphere and air layers. When light reaches a physical material, the possible actions are the following (Fig 03) (Michel, L., 1995):

**Absorption** | Light is absorbed by the material and transformed into another kind of energy, most probably heat.

**Reflection** | Light is reflected back in space in three possible ways. It can be reflected with the same angle as the angle of incidence (specular reflection), it may be moderately disturbed (spread reflection) when it reaches matte surfaces or it may hit rough surfaces and be reflected in any angle (diffuse reflectance).

**Transmission** | Light is transmitted from one material to another and it is refracted, meaning that its direction is changed. The new angle depends on the initial angle of incidence and the refractive index, of the material to which light is transmitted.

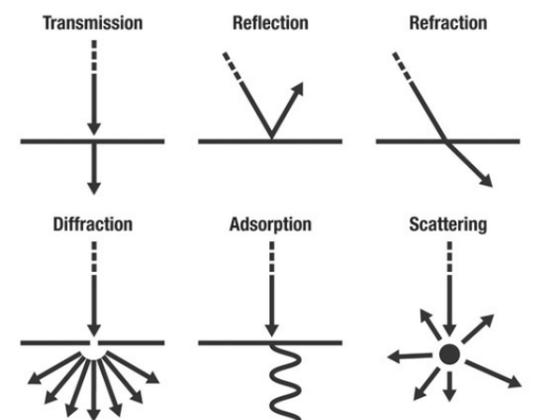


Fig 03 | A light ray when reaches a physical material. Source | <http://weekklysciencequiz.blogspot.nl/2011/09/when-light-meets-matter.html>

### 02 | 2 | 2 VISUAL PERFORMANCE OF THE EYE

The eye is a really delicate and complex sensory organ that enables living creatures to see and understand the surrounding environment. The visual image is captured from the eye and through the optical nerves it is "transferred" to brain. In brief, the light reflected from an object is captured by the lens of the eye and transferred to the brain through the optical nerve (Fig 04).

The ability of the eye to see and the quality of the visualization depends on two categories of factors. The first category is related to human body including:

- Optical performance of the eye
- Colour perception
- General condition of the eye.

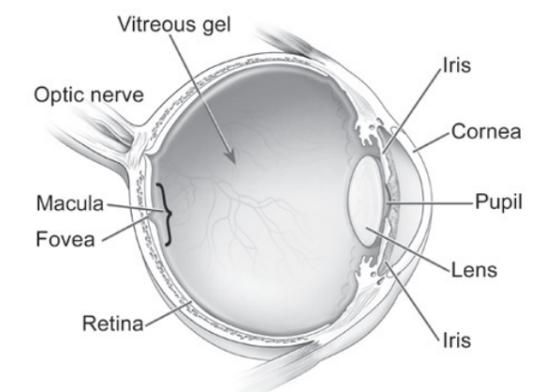


Fig 04 | Diagram of the eye. Source | <https://nei.nih.gov/health/eyediagram>

While the other category is related to environment, including:

- Relative brightness of the task and its surroundings
- Glare from the task or surrounds
- Contrast of light and shade and contrast of colour
- Movement in the task

## 02|2|3 VISUAL ADAPTATION

The eye always reacts to lighting conditions and adapts to them in order to perform better. The first mechanism reacting is the pupil's diameter which is adapted by the iris in an effort to control the amount of light entering the eye. Secondly, the retina ganglion cells adapt their response levels to the average illumination of the retina. The last one is the main adaptation mechanism and it defines two thresholds: a lower boundary regarding the lowest possible luminance values in order to experience sight, and an upper boundary for the values above which glare sensation will occur (Fig 05).

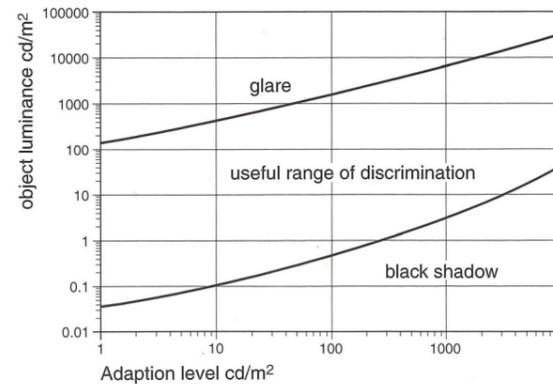


Fig 05 | Luminance values thresholds. (Baker, N. V., & Steemers, K., 2002).

## 02|2|4 VISUAL FIELDS

The individual's visual field is another very important aspect of indoor lighting. It is bounded by a cone with an apex of approximately 140°, divided in three parts. The first one is called "area of central vision" and it describes the center of the area where the human eye is focusing. This field is characterized as a fovea and it is bounded by a cone with 1° apex. The second circular zone is called "ergorama" and it contains a broader area of the visual field limited in cone of 30°. In this zone, the vision is progressively blurred with the center being the focus point. It should be mentioned that this is the area where the task field is also located. Finally, the third zone involves the outer part of the visual field. It is called "panorama" and its boundaries are being set by the parts of the face such as the forehead, the nose and the cheeks, approximately at 60° (Fig 06).

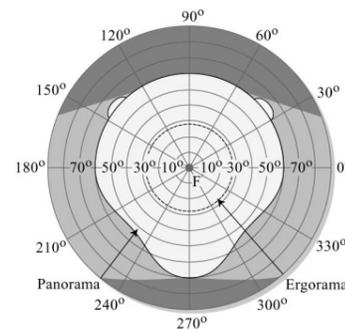


Fig 06 | Visual field. Source | <https://www.flickr.com/photos/mitopencourseware/4818063279>

Except for the focus area, the orientation of the task is equally important. A reference task can be either horizontal or vertical. In the first case, the ergorama and the panorama contain part of the work-plane and the floor. In the case of vertical tasks, the vision field is directed to the walls, the windows and part of the ceiling. The division between these two orientations is essential because they demand different lighting management. Vertical tasks though, are greatly influenced by direct light, so direct glare is a phenomenon that should be controlled. Both of the cases require adequate light levels which are defined by standard illuminance requirements and specific luminance ratios in order to avoid visual discomfort. (Baker, N. V., & Steemers, K., 2002).

## 02|3 DAYLIGHT

Daylight direction continuously changes during the day and throughout the year. As depicted in Fig 07, during summer, sun path is closer to the vertical plane, whereas during winter, the sun path is closer to the horizontal planes (Fig 07). This fact can be justified due to the inclination of the axis of the earth by 23.5° relative to the plane of its orbit around the sun. The two extremes regarding the sun path are on the 21<sup>st</sup> of June, when the sun is straight overhead at the tropic of Cancer and the 21<sup>st</sup> of December, when its position is straight overhead at tropic of Capricorn. For that reason, solar angles change every day for a specific location. The amount of daylight entering an indoor space depends on the solar angle at that time (Fig 08). Based on the position of the sun, the daylight penetrating from a window can be either direct or not.

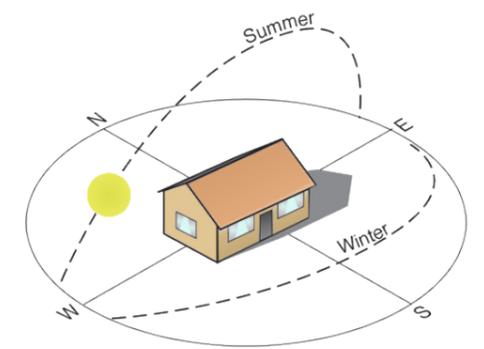


Fig 07 | The solar paths during winter and summer. Source | <https://www.nachi.org/building-orientation-optimum-energy.htm>

Except for its direction, its intensity varies as well depending on the time of the day and the weather conditions. It can take values from a few thousands lux during a dark, cloudy day to 100,000 lux during a sunny and clear-sky day.

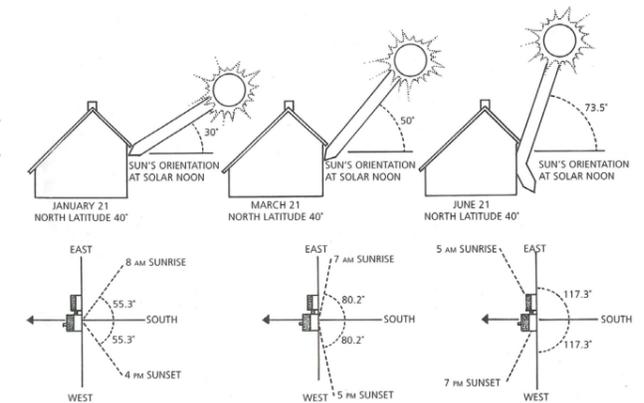


Fig 08 | Solar angles and breadth of sun exposure. (Kachadorian, J., 1997)

In addition, its colour temperature (CCT)<sup>1</sup> changes. Morning light could be characterized as cold and blue, whereas afternoon light is more warm and yellow (Altomonte, S., n.d.). These are some of the reasons that natural light cannot be replaced by artificial light. Artificial systems can be controlled regarding their output levels, but it is not possible to adjust their CCT and angle of incidence.

Concluding, sunlight management is essential. The need for daylight and view to outside environment in combination with energy saving thanks to heat loads of incoming daylight, necessitate introduction of shading devices on each building envelope. Thus the goals of a daylight management plan is to satisfy user's need while serving sustainability.

## 02|4 INDOOR DAYLIGHT

Daylight entering an indoor space can have various characteristics depending on bioregional forces. These are the track of the sun, the conditions of the sky (clear or overcast), the climate and the nature of the site (Guzowski, M., 2000). Incoming light is influenced dramatically by the surrounding environment. High-rise buildings, trees or other external factors may block the sun from reaching the building envelope. As a consequence, the illuminance level in the interior is dramatically lower than the exterior illuminance, reaching only the 2-5% of it and a maximum value of 500 lux (Eicker, U., 2003).

<sup>1</sup> CCT is defined as the correlated colour temperature of a light source and it is expressed in Kelvin. The value of the CCT is related to the density of the source meaning that higher light levels, present higher value of CCT. However, CCT value is used in order to define whether the source gives away "warm" or "cold" light. Reddish-yellow colour has a low CCT value, in contrast with blueish light that has high CCT value.

Nonetheless, once sunlight has entered the indoor area it can be characterized as horizontal or vertical based on the opening from which it enters. This project focuses on horizontal lighting that enters from the façade of a building. In this case, daylighting penetrating depends on the geometry of the room. The ceiling height in combination with the lintel height of the window. The higher the lintel of the window is, the more light in penetrating the room, striking the ceiling and then being reflected into the interior. Another characteristic of geometry influencing the illuminance of a room is the depth of it. Assuming a certain quantity of light penetrating from an opening at a specific time in rooms with different geometry, light intensity will vary as light tends to be distributed all over the available area.

In general, the aim of lighting regarding sight is to reveal the task and appropriately reveal the background (Pritchard, D. C., 1995). Three factors defining indoor lighting are its quantity, its quality and its distribution (uniformity). The term quantity describes the amount of light being perceived. In daylight analysis, the quantity of light is expressed with the measured illuminance and it is used in order to evaluate whether the amount of light is adequate enabling high visual performance. The quality of the incident light is more difficult to be investigated. It is related to comfort (visual and thermal) and it can be described through the feelings of the occupants. More specifically, it can be described with "like" or "dislike" and "need" or "don't need" adjustments. A factor regarding quality could also be the distinction direct and diffuse sunlight. Direct sunlight is entering indoor space straight away, while diffuse sunlight has first been reflected on surfaces. Last but not least, distribution describes how light is being spread over a task area (Carlucci et al., 2015). Even lighting creates harmonious and calm background that contributes to good visual comfort. Thus, these factors define whether the indoor lighting management is acceptable or not and this evaluation can be done either by comparing these values with specific requirements or by analyzing the visual comfort of the users.

## 02 | 5 VISUAL COMFORT

In order to define how an individual feels in an indoor space, some terms regarding comfort have been introduced. For each field of the indoor climate, there is a respective term. Thus, there are the terms visual comfort, thermal comfort, acoustic comfort and last but not least air quality. These four fields define completely the conditions in an indoor space, with only the first two being influenced by windows.

Focusing on lighting for built environments, the terms visual and luminous comfort are used. Luminous comfort is interpreted as the clear reception of visual messages from the visual environment (Steeners, K., et al, 1993). Therefore, luminous and visual comfort are similar terms referring to the same state. The term visual comfort will be used for the rest of the report.

The basic meaning of visual comfort is the description of a state during which the occupant feels pleasant does not feel any need for change respecting lighting. In addition occupant's visual perception should be the optimum one. Based on this definition, visual comfort seems to be subjective, and is affected by the personality, the culture and the traditions of someone's bioregion (Guzowski, M., 2000). However, it is written that visual comfort is influenced by the physiology of the human eye and basically by the physical quantities describing the amount of light and its distribution in space (Carlucci et al., 2015).

Hence, visual comfort can be evaluated using objective values related to lighting. An occupant sees sufficiently when he is able to distinguish the foreground from the background and all the objects being in this space. The basic factor influencing his visual perception is the illuminance level regarding which, there are specific requirements, refer to Table 03, varying based on the usage of the space and the actions taking place in it.

Standard maintained illuminance (lx)	Characteristics of the activity/ interior	Representative activities/ interiors
50	Interiors used rarely with visual tasks confined to movement and casual seeing without perception of detail.	Cable tunnels, indoor storage tanks, walkways.
100	Interior used occasionally with visual tasks confined to movement and casual seeing calling for only limited perception of detail.	Corridors, changing rooms, bulk stores, auditoria.
150	Interiors used occasionally with visual tasks requiring some perception of detail or involving some risk to people, plant or product.	Loading bays, medical stores switch-rooms, plant rooms
200	Continuously occupied interiors, visual tasks not requiring perception or detail.	Foyers and entrances monitoring automatic processes, casting concrete, turbine halls, dining rooms.
300	Continuously occupied interiors, visual tasks moderately easy, i.e. large details >10 min arc or high contrast.	Libraries, sports and assembly halls, teaching spaces, lecture theaters, packing.
500	Visual tasks moderately difficult, i.e. details to be seen are of moderate size (5-10 min arc) and may be of low contrast. Also colour judgment may be required.	General offices, engine assembly, painting and spraying, kitchens, laboratories, retail shops.
750	Visual tasks difficult, i.e. details to be seen are small (3-5 min arc) and of low contrast, also good colour judgment may be required.	Drawing offices, ceramic decoration, meat inspection, chain stores.
1000	Visual tasks very difficult, i.e. details to be seen are very small (2-3 min arc) and can be of low contrast. Also accurate colour judgment may be required.	General inspection, electronic assembly, gauge and tool rooms, retouching paint-work, cabinet making, supermarkets.
1500	Visual tasks extremely difficult, i.e. details to be seen extremely small (1-2 min arc) and of low contrast. Visual aids and local lighting may be of advantage.	Fine work and inspection, hand tailoring, precision assembly.
2000	Visual tasks exceptionally difficult, i.e. details to be seen exceptionally small (<1 min arc) with very low contrasts. Visual aids and local lighting will be of advantage.	Assembly of minute mechanisms, finished fabric inspection.

Table 03 | Illuminance requirements (BS EN 12464-1:2002 Light and lighting - Lighting of work places - Part 1: Indoor work places. In accordance with Chartered Institution of Building Services Engineers. CIBSE 1994 Interior Lighting Code as well).

**Luminance** is another physical quantity related to visual comfort. Luminance can be defined as the brightness that a person perceives with his eyes.

**Luminance ratio** is a relative index to luminance and a fundamental aspect as well, as far as it concerns visual comfort. Luminance ratio or in other words contrast, describes the difference between the luminance values on the various visual fields (refer to "Visual fields"). The elements forming an environment become visible when receiving light and mainly because of the difference in brightness of each one of them. However extreme differences may cause discomfort. The eye can adapt to most prevalent brightness in the field of view, when the brightness is fairly uniform. So, standards requirements are necessary for this index as well.

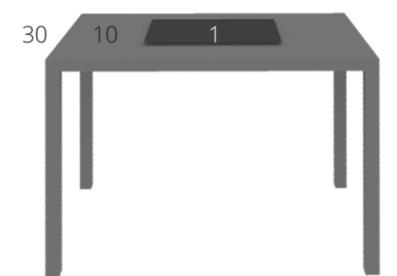


Fig 09 | Luminance ratio for visual comfort under natural lighting conditions. (Beck, W., et al, 2010)

Individual's tolerance in high contrast varies depending on the source of luminance, meaning that if the light is natural then its tolerance is higher. A categorization is possible depending on the visual fields included. More analytically, the required value of the luminance difference between the central visual

field and the ergorama should be lower than the value defining the luminance difference between the ergorama and the panorama. Referring to daylight, luminance ratio at the area of the task field should not be higher than 1/5 (or even 1/3). In the visual field of 30° should not be higher than 1/10, followed by the luminance ratio in the visual field of 60°, which should not exceed the value of 1/30 (Fig 06) (Beck, W., et al, 2010).

## 02 | 6 GLARE

The aim of a successful daylighting management is to provide indoor space with adequate light for efficient visual performance and a pleasant environment. Glare is the main aspect related to visual comfort. As a term, glare describes the difficulty in seeing in the presence of strong and dazzling light. It can be caused by either too bright task or background or by great contrast. There are two kinds of glare. Discomfort glare describes a situation that is visually uncomfortable, while disability glare describes difficulty in seeing (Altomonte, S., n.d.). Either direct light source or light by reflection (veiling glare) can cause glare (Pritchard, D.C., 1995). In general, glare is caused by high exterior illuminance and direct sunlight reflected by surfaces and objects in the indoor space. Another common fact including glare incidence is related to computer monitors on which the high illuminance of the surroundings may be reflected disabling seeing. Except for difficulty in sight and discomfort, glare can also cause physiological disorders such as pain, fatigue or increased tension.

High luminance ratios are the main reason causing glare. The time period of the presence of the light source, the intensity of the light source. Other factors influencing the intensity of glare are the location, the surroundings and the direction of view (Helms, R. N., & Belcher, M. C., 1991). Glare can be characterized as half-subjective phenomenon and so it is difficult to be quantified, but special indices have been developed to enable measuring it.

Efforts have been made in order to describe the sensation of discomfort glare. Though, most of them derive from experiments with artificial glare sources, necessitating the research on new glare equations under daylight conditions. The most representative equation is the following:

$$G = \frac{L_s^e * \omega_s^f}{L_b^g * f(\psi)}$$

CIE 055-1983

Where  $L_s$  is the luminance of the glare source,  $\omega_s$  is the solid angle subtended by the source,  $\psi$  is the angular displacement of the source from the observer's line of sight and  $L_b$  the general field of luminance controlling the adaptation levels of the observer's eye. (Wienold, J. & Christoffersen, J. 2006).

Modifications on these equations were made in order to incorporate daylight effects as well. The Cornell equation or daylight glare index was introduced

### DAYLIGHT GLARE INDEX (DGI)

In order to estimate the amount of glare, the indice of glare index has been introduced. It refers to glare caused by windows in office buildings. It is defined as the difference between the luminance of an object in relation to the luminance of interior surfaces surrounding the window (Hopkinson, 1972). The definition is as follows:

$$DGI = 10 \log 0.48 \sum_{i=1}^n \frac{L_s^{1.6} \Omega_s^{0.8}}{L_b + 0.07 \omega_s^{0.5} L_s}$$

Where  $L_s$  [cd/m<sup>2</sup>] is the luminance of a glare source,  $L_b$  [cd/m<sup>2</sup>] is the background luminance,  $\omega_s$  [sr] is the solid angle subtended by the source, and  $\Omega_s = \omega_s/P$  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 (Gyeong Yun, et al, 2014).

Glare criterion corresponding to mean relation	DGI
Just imperceptible	16
Noticeable	18
Just noticeable	20
<b>Acceptable</b>	<b>22</b>
Just comfortable	24
Uncomfortable	26
Just intolerable	28
Intolerable	30

Table 04 | Daylight glare index.

However, the correlation between glare from windows and predicted glare is not as strong as in the case of artificial light.

### DAYLIGHT GLARE PROBABILITY (DGP)

Jan Wienold and Jens Christoffersen introduced a new approach for daylighting which is the Daylight glare probability (DGP). This index uses the "percent of people disturbed". Based on human reactions regarding the lighting of an indoor space, caused by disability and discomfort glare. By taking into account the vertical illuminance at the position of the individual's eye the final DGP equation was defined as follows:

$$DGP = 5.87 * 10^{-5} E_v + 9.18 * 10^{-2} \log (1 + \sum_i \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} p_i^2}) + 0.16$$

(Wienold, J., & Christoffersen, J. ,2006)

03

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DAYLIGHT  
IN OFFICE BUILDINGS

Office rooms are spaces where people need to be focused and productive. For this reason a pleasant and comfortable environment is required. The experience in a room is influenced by many aspects, one of which is lighting. Visual comfort and user acceptance of these luminous indoor environments are two basic issues when it comes to indoor lighting management. Daylight is really beneficial for human body and psychology and, as it is well-known, people prefer natural light over artificial light. Hence, the objective of lighting management in office buildings is to obtain adequate lighting provided mainly by daylight and at the same time to control it in such a way that the user feels satisfied. Glare, windows luminances and luminance ratios are the main factors defining lighting experience in office buildings.

As far as it concerns the structure of modern office buildings, the plurality of them has a fully glazed envelope, or large glazed areas filling the whole façade area. As a result incident solar light influences dramatically indoor space in terms of visual comfort.

Openings and especially windows are the building elements providing daylight to indoor spaces, though they do offer view as well. View to outside is a very important factor when talking about office buildings. People spend many hours in these spaces and they need to have a moment of refreshment and relaxation by looking outside and also change their focus point and relax their eyes. Moreover, a view to outside allows people to know about the weather conditions and have a feeling about the time of the day. Light penetration into the interior has a double function. At first, it increases the general brightness of the room. Luminance levels of the room are usually higher -especially when the sky is clear- decreasing the need for artificial light. Task illumination is also possible, depending on weather conditions. Last but not least, the variations of daylight brightness and colour offers better visualization and 3-d perception of the space.

As it is already mentioned (Table 03), 300-500 lux are adequate to provide good illuminance to a workspace, and 500 lux in more strict regulations such as standard NS-EN 12464-1, 2011. However, the glare and the distribution of the incoming light are as important factors in order to obtain visual comfort of the users.

Most of the regulations refer to horizontal workplanes, but the last few years more and more computer systems are installed in the workspace. So the reference plane should not be just horizontal any more, but vertical as well. The vision range of the users has also changed prescribing new rules about glare control. However, the index of illuminance is not depended on the direction of the reference plane so the required values are the same for both horizontal and vertical task plans.

Focusing on glare, the general characteristic have been already stated (refer to "Pritchard, D. C. (1995). Lighting (5th ed.). London: Longman Scientific & Technical."). The main parameters relevant to glare are the brightness of a source, the intensity of light in the direction of the occupant and the background brightness. When heads-up tasks<sup>1</sup> take place, direct glare is the main problem. The direct glare zone is defined from 45° to 90°, where 0° are at the vertical axis. In order to define direct glare, vertical illuminance should be evaluated.

Focusing now on luminance ratio which evaluates the distribution of light, most of the standards request a value higher than 0.8 to claim uniformity and pleasant lighting conditions. However this value refers to artificial light. When it comes to natural light, an individual shows tolerance, accepting lower values, which means greater differences, having as a maximum 0.1 or even 0.3 depending on the visual field they refer to.

1 | The term "heads-up tasks" describes actions when the individual is standing upright and is looking around the environment at the height of eye level.

As far as it concerns daylight factor, its value should be at least 5%, in order to assume a pleasant interior space. However, daylight factor may not be the ideal indice for evaluating a solar shading as it implies many simplifications. By definition, it refers to overcast -cloudy- skies, so its value is not influenced by the position of the sun, the amount of cloud in the sky and its distribution and the time of the day and the year. These factors are of major importance and they should be taken into account. Daylight factor is a simplified design index which evaluates whether the minimum illuminance requirements are fulfilled under the worst case scenario or not. So in the case of more sunny days, the requirements will be by far fulfilled. In order to evaluate the quality of solar protection and daylight new indices have to be introduced (David et al., 2011).

In 2006, Reihart CF. et al. introduced the index "daylight autonomy" ( $C_m$ ) which quantifies the percentage of time when the minimum illuminance requirements are fulfilled on the workplane. In other words, it is the amount of time during which specific light levels are available through the use of just daylight. This index is influenced by the illuminance requirements and it gives out results comparable to the schedule of occupancy (David et al., 2011).

Another index related with the time that the required illuminance levels are accomplished is the "useful daylight index" (UDI). UDI defines the time when daylight level is neither too low nor too high, meaning its value is between the two extremes, 300 and 2000 lux. Then daylight autonomy is translated as the sum of the useful daylight index and the sun patch index (David et al., 2011).

In addition an index regarding glare was introduced. "Sun patch index on work plane" (SP) deals with glare caused by large source of daylight such as windows and specifically the one based upon the presence of beam of solar illuminance on the working area and its reflection. The glare experienced when looking at the window and the view outside is appreciated as well with this index. SP is defined as the ratio of the surface of the working area where the level of illuminance is higher than 8000 lux. The smaller this value is, the more efficient the shading device can be characterized (David et al., 2011).



Fig 10 | Indoor view of office room with automatic solar shading devices and sensors.  
Source | <http://www.bine.info/en/topics/buildings-city/operation-optimisation/news/zufriedenheit-mit-bueroklima-auf-dem-teststand/>

04

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SHADING SYSTEMS

For long time now, solar control is a very important aspect as far as it concerns buildings. Sun light researching the skin of the building influences both energy consumption and individual's comfort. The objective is high performance daylighting, which entails adaptive solar control, responsive to sunlight, and optimum visual comfort, focusing particularly on glare protection. There is a huge variety of shading devices, each one of which act in a different way. Following the main categories of these devices will be analyzed

The main characteristic of a shading system is the position where is it placed regarding the opening. The possible positions are inside, in-between or outside, so the two categories that eventuate are the internal and the external shading systems (Fig 11).

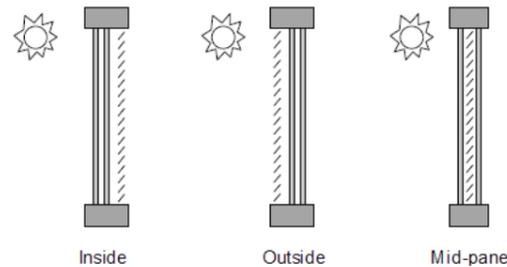


Fig 11 | Possible positions of a sun shading system.  
Source | [http://www.designbuilder.co.uk/helpv1/Content/Window\\_shading\\_internal\\_1.htm](http://www.designbuilder.co.uk/helpv1/Content/Window_shading_internal_1.htm)

#### 04|1 INTERNAL SOLAR SHADING SYSTEMS

Internal shading system can be placed indoors -in front of the window- or even in-between the glass panes. Based in studies, they reduce heat gains only by 15% because thermal energy has already entered the room (Sustainable Energy Info, n.d.) but they are quite efficient with protecting from glare. For this reason internal shading systems are more suitable for working spaces as they facilitate working on computers and they create a more pleasant indoor environment. This position of placement in beneficial as the system is not exposed to weather conditions and by being protected the need for maintenance is eliminated. Moreover, an internal shading device can be adjusted easily offering privacy, glare protection and insulation when needed. However, this position may cause issues as well. In case of need for replacement of either the glass pane or the system the whole unit need to be replaced, making the process more complicated and expensive. The most representative examples of internal shading devices are roller shades, drapes, Venetian, Holland and Austrian blinds and sun screens made of foils or textile.

#### SUN SCREENS

Sun screens use fabric for blocking or filtering the sun. The shade cloth can vary on its characteristics, giving a variety of results. The first aspect that can be changed is the openness or in other words the translucence. It can take values from 0 to 18 percent. The transparency is comes from the density of the fabric and it defines visible light transmittance. Last but not least the backing of the fabric influences significantly solar performance. For instance, white backing is reflecting sunlight managing rejection of solar heat (Carmody, J., 2004).

#### 04|2 EXTERNAL

External shading devices are placed in front of the building envelope and thus they are exposed to weather conditions. This should be taken into account during designing as it may affect their performance. Moreover, their maintenance should be consider, as well as their replacement if need appears. Based on studies, external shading devices are more effective, reducing by 70-85% heat gains (Sustainable Energy Info, missing). They can be sub-divided to fixed and adjustable ones.

#### 04|2|1 FIXED

The fixed sun shading devices consist a part of the building and they lack flexibility. Though their big benefit concerns maintenance, as they are quite durable and usually simple enough. They perform better at north-facing openings and the most usual systems of them are overhangs, louvres (fixed or pivot-mounted). Fig 12 presents the main categories of fixed shading systems.

	3-D View	Section/Plan	Ideal orientation	View restriction
Horizontal single blade			South	★★★★
Outrigger system			South	★★★★
Horizontal multiple blades			South	★★★☆☆
Vertical fin			East/West	★★★☆☆
Slanted Vertical fin			East/West	★★★☆☆
Eggrate			East/West	★★★☆☆

Fig 12 | General types of exterior fixed shading device.  
Source | [http://www.bembook.ibpsa.us/index.php?title=Solar\\_Shading](http://www.bembook.ibpsa.us/index.php?title=Solar_Shading)

#### 04|2|2 ADJUSTABLE

On the contrary, adjustable shading systems (movable) can adapt throughout the day or the year, responding to dynamic nature of weather or user's comfort level. The movement of the system can be very simple or very complex. The standard and more simple systems are roller blinds, horizontal sliding shades and venetian blinds, using as a material textile or wood. However, the field of adjustable sun shading systems is very wide. Various interesting ideas do already exist and also keep on being introduced.

## 04|2|2|1 ACTIVE

This field of adjustable shading systems contains designs that adjust to certain conditions using mechanisms. These mechanisms can be activated by sensors or manually. So active systems do not respond directly to stimuli. The most common active designs rely on cable networks which motion the whole structure. Thus, individual do are able to control these systems and adjust them in favor of their comfort.

## 04|2|2|2 PASSIVE

Passive sun shading systems react to external stimuli thanks to special materials that incorporate. These materials are called smart materials and are able to respond to specific climate conditions because of their substance. More analytically, the human intervention is not need as the systems is activated by nature and adapts on its own. Although this characteristic seems appealing and zero energy consuming, it is not always desirable. Due to this characteristic individuals cannot control the system, giving them no freedom to optimize their comfort.

## 04|3 LIGHT-DIRECTING SYSTEMS

This type of systems intend to insert light in a room and specifically to areas located away from the façade and the windows by redirecting it. Therefore, these systems, that improve the illumination-in-depth, are necessary. They are placed at the upper part of the window and in some cases they are combined with glare control designs. There are two basic categories, the ones that reflect the light and are basically horizontal systems and the ones that redirect light in a different angle into the interior space and are basically vertically inserted into the shading system. In general, these systems can be used for lighting very deep rooms and for offering sufficient light level through diffuse light.

### LIGHT SHELVES

Light shelves are daylight systems placed at the upper part of the window and have double function. Firstly, they shadow the opening acting like overhangs and secondly they illuminate the inner part of the room. By reflecting the light on the ceiling of the room, thanks to the reflective material at the top of the system, they improve illuminance distribution in it.

### MIRROR - LAMELLAS

These systems are usually divided in two parts, the upper one that is guiding the light to the interior and the lower one that remains closed and controls glare. There are variations of these designs concerning either different position placement or costum designs (Eicker, U. , 2003).

### PRISM SYSTEMS

Systems containing prism-profile panels can be used for both blocking and redirecting sunlight. Depending on their rotation angle they enable light diffusion and therefore glare control or completely blocking of sunlight by redirecting it (Eicker, U. , 2003).

## 04|4 CUSTOM SOLUTIONS

Costume designs cover a very wide range of geometries, materials and movement. Designers constantly introduce new products, some of which are more experimental and others are established

as standard systems. A drawback of costume-made designs is that sometimes their maintenance is difficult due to their form.

## 04|5 GENERAL RULES ON CHOOSING SHADING DEVICES BASED ON ORIENTATION

(Sustainable Energy Info, n.d.)

### SOUTH AND NORTH OPENING

- Horizontal devices are mostly used because of the sun's path as the light reaches the façade mainly vertically.
- Preferably adjustable sun shading system in order to allow incoming light during winter period and block it during summer period
- Angled systems should be avoided as they block earlier morning and later afternoon daylight.

### EAST AND WEST OPENING

- Angled shading devices can control low morning and afternoon daylight.
- Egg crate and brise soleil are considered to be efficient on these façades as they are able to block low sun as well
- Adjustable systems are preferable as these parts of the building receive sunlight only a few hours during the day.

## 04|6 MAINTENANCE

An adaptive solar shading systems consist of parts, which are forced to movement several, or even many times during the day. This movement is possible thanks to mechanisms, small or big and sensors which need to be maintained inevitably. They may be broken or fail and as a consequence the system may not function properly.

- In order to ensure the best possible performance, the solar shading system has to be integrated in the initial design. The necessary provisions can contribute in longer lasting shading system.
- Another way to build more efficient shading devices is to think in a practical way. The system has to be as simple as possible, sacrificing sometimes the aesthetic parameter.
- Once the system is already designed and produced, it has to be installed properly. The manufacturer's instructions should be taken into account in order to achieve a proper installation and a safe mechanical system.
- Even after installation, a regular check-up is appropriate. An annual maintenance and cleaning will preserve the shading system for longer time and will contribute to the maximum possible efficiency.
- Last but not least, the whole structure of the shading system must be accessible, as well as its sensors.

05

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ADAPTATION

Light intensity varies throughout the day. Trying to obtain the best possible visual performance, the eye adapts to the perceived amount of light. Pupil's diameter is adjusted by the iris in order to control the amount of light entering the eye. Hence, vision is achievable under various lighting conditions. In the same way, the buildings should adapt to external lighting conditions, enabling pleasant indoor environment during most the time that it is being occupied.

The term "adaptability" defines objects that are able to change one or more of their characteristics, with the most common being their shape, when conditions change. Focusing on the field of architecture and solar control, a sun shading system is described as adaptive when it is able to change its structure after a stimuli acts on it.

Adaptation introduces two aspects. The first one is the design of the system and the movement that it performs, while the other one is the way that this motion occurs.

### 05|1 DESIGN

As far as it concerns the design, the potentials are unlimited. There are already numerous interesting designs which combine different materials and geometries with every possible type of movement and there are still too many to be introduced. The only limit is imagination. When using the term "design", we refer to the shape and the geometry of the system, meaning its structure and the parts forming it. Usually, these factors are influenced by the location and the orientation serving performance's efficiency.

### 05|2 MOTION

Regarding the actuator of the change, this can be nature or the individual. Nature-responsive systems are these that react to climate conditions, while manual solar shading systems are activated by the individual. As far as it concerns the nature-responsive systems, which are also called automatic systems, they do not require any attention and they adjust to provide indoor comfort and energy saving even in the absence of individuals. There is another possible categorization, including passive and active systems. Passive systems are called the ones that react to external weather conditions making use of the properties of the material which they are made of. Smart materials present kinetic properties in the presence of specific weather conditions. So the systems made of these materials in combination with the proper design are able to adapt to fluctuations of external conditions. On the contrary, active nature-responsive systems are the ones that need a sensor in order to be activated. The sensor identifies the external conditions and it activates the system depending on how it has been programmed. Last but not least, manual systems are activated by the user. Each individual has the freedom and the opportunity to totally control the shading system according to his needs. The activation can be done either with electric cable network or with hands-on mechanisms.

### 05|3 SUN SENSOR

The most important sensor for adaptive sun shading systems is the sun sensor. This device identifies the incident sunlight, measured in lux, and it reacts according to the set limits. So when illuminance is higher than the threshold value, the sensor activates the system. The position of the sensor should be selected carefully. The sensor has to be exposed to the most intense solar radiation in order to prevent from unpleasant indoor conditions. Another issue regarding a sun sensor is its maintenance. It has to be placed at a position where access is possible.

Concluding, as it is already mentioned, the sensor (Fig 13) activates the shading system depending on

a threshold value. Though, illuminance level may fluctuate too much causing the continuous movement of the shading system and as a consequence the irritation of the individual and extreme energy consumption. For this reason the introduction of hysteresis is important as it will prevent the immediate adjustment of the system. Frequently, the hysteresis is set up at 8 to 10 minutes.



Fig 13 | Sun sensor.  
Source | <http://www.elsner-elektronik.de>

## 05|4 LEVELS OF ADAPTATION MECHANISMS

As far as it concerns the adaptation mechanisms, they can be divided into two sub-categories, the macro-level and the micro-level mechanisms. An adaptive system may incorporate either just one or even both of them at the same time. The macro-level adaptation mechanisms are the ones that can be seen and recognized with naked eye. The motion occurring has a result on the geometry of the system, causing folding, sliding, rotating, rolling etc. The actuators of these mechanisms are mainly sensors driven by external energy input. An important issue regarding macro-level mechanisms is their maintenance. Movement mechanisms with big parts need regular inspection and service. On the contrary, micro-level adaptation mechanisms refer to material changes and they are usually invisible. The materials properties change causing a greater change of the whole system.

The most commonly used mechanisms, in adaptive buildings, are the macro-level ones, which cause large changes and are driven by computerized systems. However, macro-level mechanisms are also possible to be driven by micro-level mechanisms rather than pure external stimuli and sensors.

### 05|4|1 SMART MATERIALS

Smart materials constitute a group of materials that presents kinetic properties. They are considered to be a sub-category of the micro-level mechanisms. They can be also used in order to actuate macro-level mechanisms. They can play the role of sensors-actuators and/or components of the shading systems. More analytically, they can activate the motion of the structure either in a passive or active way and at the same time consist components of the whole system.

**Thermobimetals** are smart materials, already introduced in shading devices. They are artificial and consist of two welded metals, steel and copper. Because of the different expansion coefficients of the two metals, the compound curves at temperature increase. They can be used as actuators, replacing the movement mechanisms or as surfaces (Fig 14) producing shadow-surfaces that curl under circumstances changing the geometry, the shadow produces and the air flow. They are considered to be passive, nature-responsive components, but they can be activated in a manual way as well.



Fig 14 | Metal that breathes by Doris Kim Sung.  
Source | <http://www.archiproducts.com/it/notizie/45139/bloom-l-installazione-curata-da-doisu-studio-architecture.html>

**Shape memory materials (SMM)** (Fig 15) are another group of smart materials widely used in architecture, aerospace engineering, medicine etc. Alloys such as copper-aluminum-nickel alloy and nickel-titanium alloy are more commonly used, being able to change their shape when stimulated. Certain

SMA are able to regain their initial shape as well. SMA can be activated by both nature and electricity. In the second case, their movement is totally controlled by individuals.

Electroactive polymers are smart materials that worth to be mentioned as well. Electric current stimulates the polymer thanks to electrodes covering its surfaces. In this way, reduction of thickness and expansion in 2 dimensions is obtained. So electricity enables the alteration concerning both their size and shape (Fig 16). One of their advantages is that they do not consume too much energy as they maintain their alteration after simulation. In addition, when simulated, they can sustain large number of loads which is a positive characteristic especially if they are applied in external shading systems. (Maragkoudaki, 2013)



Fig 15 | Flexinol Wire by Ana Escobar and Eryka Bueno.  
Source | <http://thetranstudio.com/2015/05/04/sma-scales/>

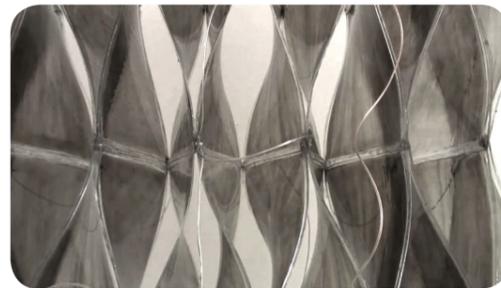


Fig 16 | Shape Shift.  
Source | <http://caad-eap.blogspot.nl/> (Zahner, 2015)

## 05 | 5 ADAPTATION AND USER

Nowadays, automatic control of shading systems is quite popular with advanced technologies incorporated. Different kinds of sensors enable the control regarding various aspects. For example temperature and illuminance levels, two widely-used criteria, impose whether solar shading is needed or not and if yes, in what extent.

The question is whether a fully automated shading system is the optimum solution for solar control or not. An automatic control can regulate in the optimum way indoor daylight conditions. However, the user himself needs to feel free to adjust indoor environment conditions according to his needs. Even if the conditions are ideal, the lack of potential to intervene causes negative feelings. Concluding, an automatic system performing in favor of good visual comfort and energy reduction is useful but the occupant should have to opportunity to over-ride it.

# 06

## SYSTEM REQUIREMENTS

To begin with, there is no perfect daylight control system. The first reason lies on the fact that visual comfort is partially subjective. Each individual has specific needs and preferences regarding sunlight, so there cannot be one daylight control system satisfying them all. The second reason is the variety of indoor light requirements depending on the usage of the space and the different needs related to the location and the position of the building.

However, there are requirements able to define the performance of a sun shading system. As Ignacio Fernández Solla underlines, 'Effective sunscreen' is a screen that reduces solar gains when there is direct solar radiation but lets daylight in when there isn't. Evoking these words, visual comfort introduces two main fields of requirements, efficient illuminance levels, acceptable luminance values -quantitative criterion- and acceptable luminance ratio values in combination with glare protection -qualitative criterion-. In simple words, there should be a lot of light penetrating indoor space without causing any discomfort. By making use of the indices introduced in the previous chapters, we can evaluate the daylight control systems. Focusing on office buildings, the design of the daylight control system should fulfill the following requirements:

Daylit area |  $DA_{500\text{lux}}[50\%] > 80\%$  of floor area

Daylight autonomy |  $DA > 80\%$  for active occupant behavior

Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000\text{lux}}[50\%] > 60\%$  for the active occupant behavior

Daylight glare probability |  $DGP < 0.35$

Glare | 0.3% of occupied hours

Luminance value | Boundaries according to external lighting conditions (refer to "Fig 05 | Luminance values thresholds.")

Luminance ratios at workplane |  $>1/5 = 0.5$  in the task field,  $>1/10 = 0.1$  in the visual field of  $30^\circ$  (central visual field) &  $>1/30 = 0.03$  in the visual field of  $60^\circ$  (ergorama)

Direct daylight should be avoided especially for the task field. Diffuse daylight is preferable, as the space is lightened uniformly, with no extremes, creating a pleasant atmosphere.

Moreover, some characteristics integrated in a shading device can influence greatly its performance. Adaptation is a major aspect as it enables the optimum performance of the system throughout the day and the year. The systems needs to adapt to external conditions at least during working hours, when individuals make use of the indoor space. Automated control systems can contribute in energy saving by adjusting the daylight control systems. By obtaining the optimum state of the system in relation to the elements, energy consumption can be reduced. Visual and thermal comfort will be achieved as much as possible without the use of the installed electrical and mechanical devices. Though, individuals should be able to control the system themselves in order to feel pleasant and comfortable in the space. So control by users is required as well.

In addition to the system requirements concerning its performance, there should also be requirements concerning its geometry. First of all, it should allow view to the exterior space. There is no index available to measure the provided view to outside, for that reason the evaluation has to be qualitative. A simple design, able to "disappear" from window view, is preferable in the most of the cases.

Another issue that should be taken into account is the appearance of a solar shading system. The aesthetics are a totally subjective but important criterion, which is influenced by the personality and the background of each individual. A solar shading system is a component on the envelope of a building and it affects totally the impression of it, as well as the aesthetics of both the external and internal environment.

Last but not least, the window should be accessible and easy to open for natural ventilation of the space, cleaning and maintenance.

07

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BUCKY LAB PROJECTS

BUCKY LAB PROJECTS MAP PREVIEW



01  
The Crystal  
Facade

02  
Hazy Facade

03  
Origami  
sun shading

04  
lightBOX

05  
The Stretching  
Sunscreen

**material**

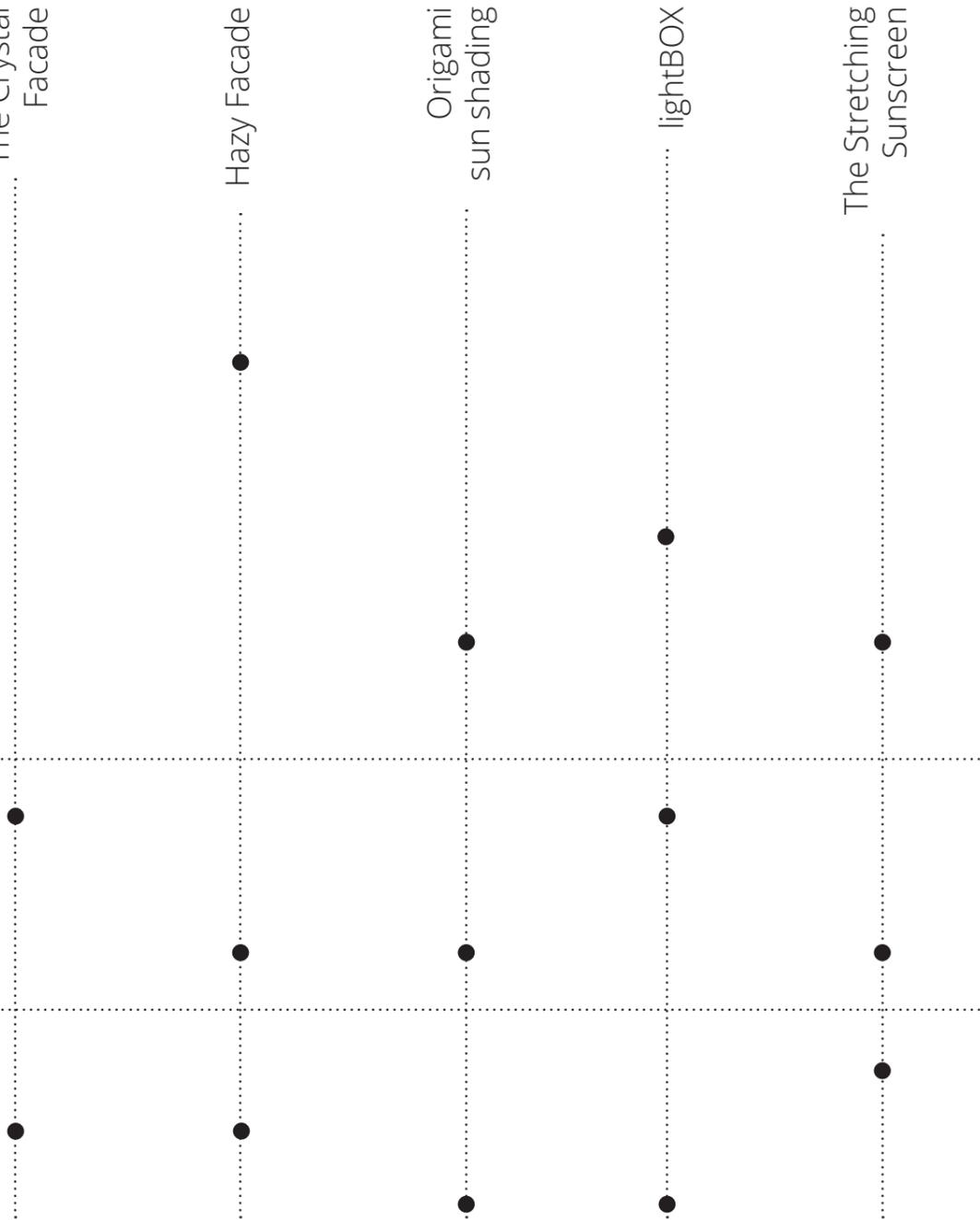
bimetal coil  
sanded  
glass tubes  
metal  
paper  
/textile  
textile  
glass

**position**

outside  
inside  
in between

**movement**

sliding  
rotating  
folding



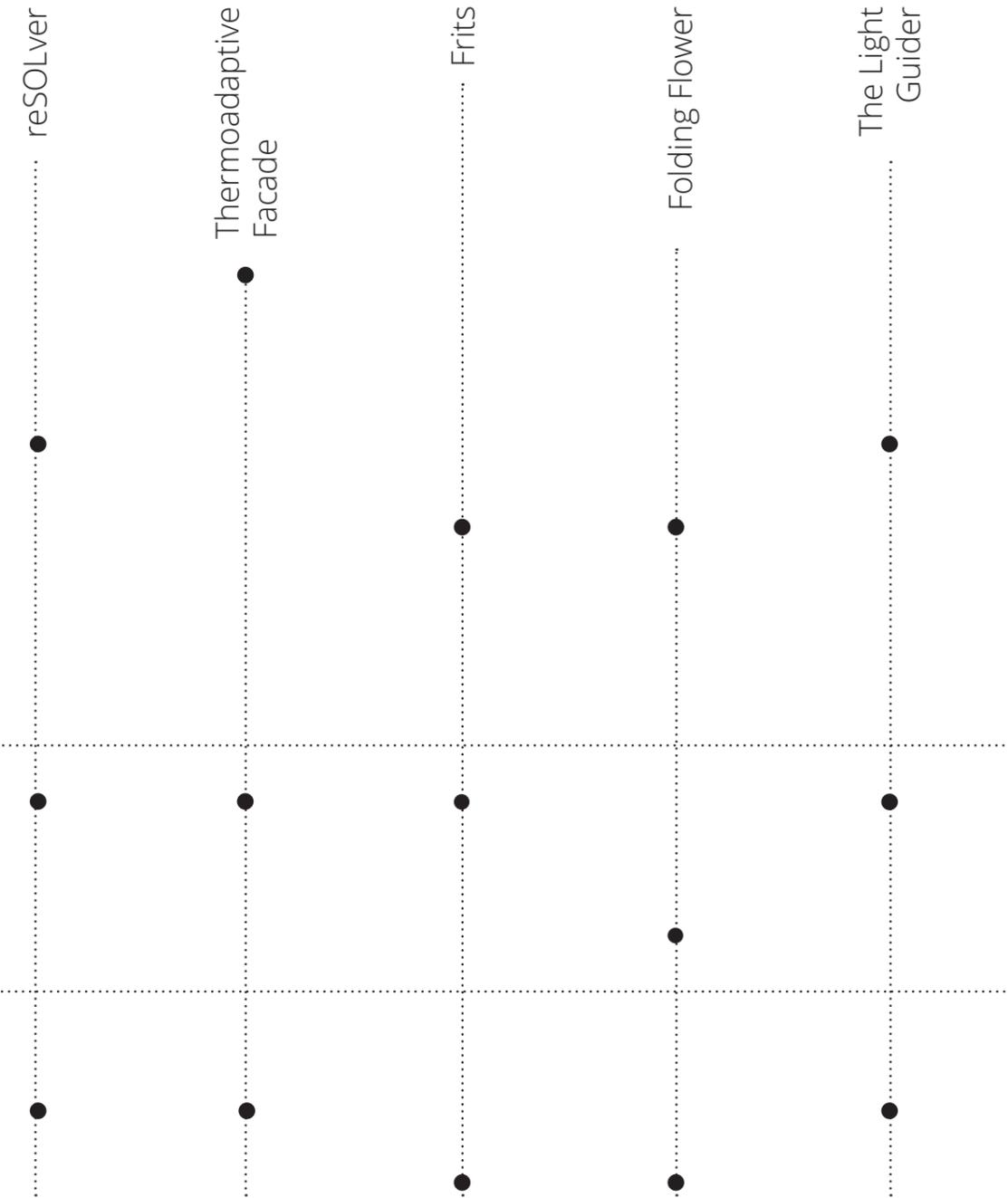
06  
reSOLver

07  
Thermoadaptive  
Facade

08  
Frits

09  
Folding Flower

10  
The Light  
Guider



# 01 | The crystal façade | Balour

Dynamic shading system  
 Material | unknown  
 Position | outside  
 Type of movement | Rotation  
 Vertically & horizontally

Solar shading | +++  
 Glare control | ++  
 Redirecting light | -  
 View to outside | +

Moves manually  
 Adjusts to sun path  
 Controls daylight



Complexity

**THE CRYSTAL FAÇADE** **BUCKY LAB**

An elegant, dynamic shading system that gives the user control over the lighting levels inside.

The Crystal Façade, or Balour in Arabic, is an open, shading, second skin to the façade. Balour is a structure that both shades at least 75% while also keeping 50% of the view to the outside at any time. The vertically rotating elements follow the sun's path during a sunny day to provide 75-100% shade. The horizontally tilting elements can be flipped upward so as to become a 75% open structure, letting daylight in when the sun needs not to be blocked i.e. on a cloudy day.

**ANGLE OF THE SUN** **SHADING PRINCIPLE** **RULE** **EXCEPTION**

**GEARS & WORM WHEELS**

**ARCHITECTURAL IMPRESSION**

Students: B. E. F. Boschman, K. Strootman, A. F. Struksma  
 Supervisor: Dr.-Ing. Marcel Blouw  
 Course: Bucky Lab msc 1 Spring Semester 13/14



Challenge the future

# 02 | Hazy Façade

Dynamic shading system  
 Material | sanded glass tubes  
 Position | in-between  
 Type of movement | Rotation  
 Vertically

Solar shading | ++  
 Glare control | +  
 Redirecting light | -  
 View to outside | +

Hands on mechanism  
 Controls daylight and outside view



Complexity

**Hazy Façade** **BUCKY LAB**

Sun shading by sanded glass tubes

The concept is based on the principle of turning square glass tubes. The tubes are sanded on one side and left polished on the other sides. When you are looking straight through the tube you have a clear view. When you turn the tubes a quarter by pulling the lever, the glass tube façade moves from a transparent view into a translucent view.

The tubes are placed gradually in a cavity of two glass plates. The tubes, divided in two groups, rotate clockwise and counter clockwise. With 1 mm interspace they will not hit each other. The tubes have a socket with a rotation pin on both ends of the tubes.

These rotation pins are pinned to gears which are attached to the mechanism. The gears move along gear strips which are connected with one big main gear. This gear can be controlled by a pull bar, which makes it a hands-on-mechanism.

**Vertical detail**

**Exploded view**

Students: Kas de Valk, Jordy Wilders  
 Supervisor: Dr. Ing. Marcel Blouw  
 Course: Bucky Lab MSc 1



Challenge the future

## 03 | Origami Sun Shading

Dynamic shading system

Material | textile

Position | in-between

Type of movement | Folding  
Vertically

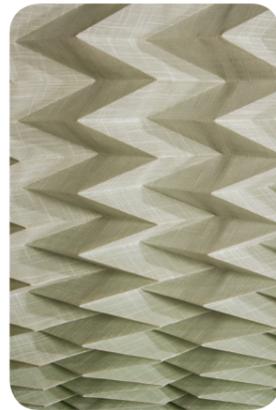
Solar shading | +++

Glare control | ++

Redirecting light | -

View to outside | +

Moves manually  
3-dimensional



Complexity

**Origami Sun Shading**

Introducing three-dimensionality & dynamics

There are already a huge variety of blinds and sun-shading systems on the market and each year companies try to come up with new concepts. Our goal is to make a prototype of a new product that imposes the basis for a new innovative product for a comfortable indoor environment with an eye for design.

The idea behind the Origami Sun Shading is to create a breath-taking structure behind glass that solely uses geometry to shade the sun. The origami that is used is simple yet extraordinary. The relatively modest V-pleats create unusual three-dimensional surfaces with great expressive faces. They form changing patterns of light and shade creating a dynamic surface that can bring an interior to a whole another level.

**Students:** Chiara Scanagatta, Dinçer Erçel, Ebru Kaymaz

**Supervisor:** Dr.-Ing. Marcel Billow

**Course:** Bucky Lab Msc 1

## 04 | lightBOX

Dynamic shading system

Material | unknown

Position | outside

Type of movement | Rotating-folding

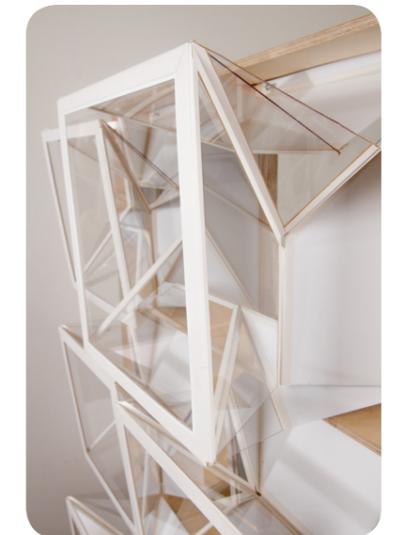
Solar shading | ++

Glare control | ++

Redirecting light | -

View to outside | +

Moves manually  
Controls daylight and out-side view



Complexity

**lightBOX**

Sun shading & light diffusing system

The Lightbox functions as a sunshade and a light diffuser when you open and/or close the system. The folding and unfolding of the box is based on an origami fold. The folding direction of the planes makes it possible to redirect light and thereby more evenly spread it into a room. The Lightboxes give people the opportunity to control the amount of (direct) sunlight in a building, control the amount of diffusion of the light and the view due to the Lightbox app.

1. Arduino: the heart of the system is an Arduino which is connected to a computer with a Grasshopper script.
2. Open Sound Control: the app gives users control over the Lightboxes.
3. Actuation system: the servo-engines and Lightboxes are provided with 3D printed gears. In this way the unfolding of the boxes is made possible.

## 05 | The Stretching Sunscreen

Dynamic shading system

Material | textile

Position | in-between

Type of movement | Folding-stretching  
Vertically

Solar shading | +++

Glare control | +++

Redirecting light | -

View to outside | +

Moves manually

Adjusts transparency



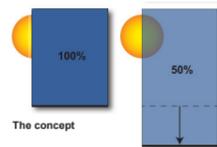
Complexity

### The Stretching Sunscreen

Make your facade as transparent as you like

#### The product

The Stretching Sunscreen is an innovative sunscreen able to adjust the amount of light that passes through. Normally a sunscreen is not very flexible, but this one is at its most. The performance and transparency can be dialed in just by adding more or less tension.



#### Applicability

The system is simple and light-weight, making it very applicable. It can be used with any type of facade, from regular windows to high-tech double facades. Next to a sunscreen it could also be a privacy screen, for example in offices or in hospitals.

#### Imagination

The concept was derived from a balloon. A balloon is completely opaque when not blown up. By inflating it with air the material gets stretched, becomes thinner and increases in transparency gradually.

#### The prototype fabric

Finding the right material was the most critical task for this project. The chosen material is normally used in clothing. It is a woven elastic, composed of elastic threads in one direction and regular non-stretchable yarns as filling in the other direction. Stretching the elastic increases the distance between the fillings, thereby increasing transparency.

#### Further development

If this project were to be developed further to be brought onto the market, the stretching material has to be better customized. If so, the system could get a wider transparency-range. Also fire safety, UV-resistance and water resistance for outdoor applications are not yet taken into account.



Students  
Supervisors  
Course

Jos Noordzij // Arash Khoshnevis  
Marcel Bilow // Peter van Swieten  
Bucky Lab, msc1 AE / BT



Delft University of Technology

## 06 | reSOLver

Dynamic shading system

Material | unknown

Position | outside

Type of movement | Rotation  
Vertically

Solar shading | +++

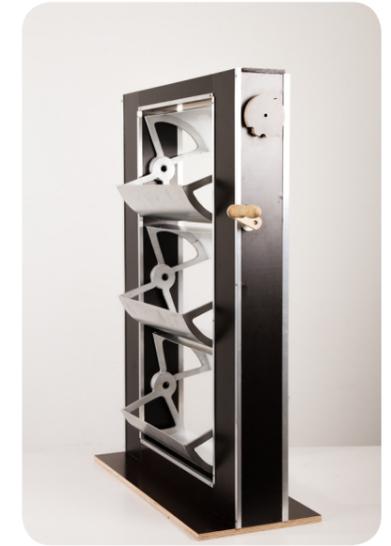
Glare control | +++

Redirecting light | ++

View to outside | ++

Moves manually

Focuses on overheating, lack of daylight at the back of the room and glare problems



Complexity

### reSOLver

A complete daylight management solution

The reSOLver concept focuses on three issues regarding the sun and daylight: overheating, lack of daylight further away from the facade and glare problems. Most existing solutions, like window blinds, cover only part of these problems and often block out all daylight and the view.

The goal of the reSOLver is to address all these problems, while maintaining visibility through the facade. By using circular blinds with a high-reflective convex side and a diffuse-reflective concave side, the reSOLver is able to:

- Selectively block out the sun, keeping the heat out while maintaining visibility
- Redirect sunlight to the ceiling and further into the room
- Prevent glare problems, without keeping the daylight out

By doing so the reSOLver reduces the need for airconditioning and artificial lighting and improves the quality of the indoor space.

Entire configuration is turned to desired angle  
Only inner blind is turned to change the configuration

Students: Kirolos Abdalla, Jeroen ter Haar, Robert van Houten  
Supervisor: Dr.-Ing. Marcel Bilow  
Course: Bucky Lab Msc 1

TU Delft  
Delft University of Technology

Challenge the future

# 07 | Thermoadaptive façade

Dynamic shading system

Material | bimetall coil

Position | outside

Type of movement | Rotation  
Horizontally

Solar shading | +++

Glare control | ++

Redirecting light | -

View to outside | +

Nature responsive



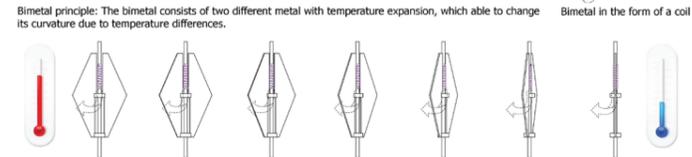
## THERMO ADAPTIVE FACADE



Turning panels by a bimetall coil

A dynamic but simple system that responds to the environmental changes and provides shading without using energy and with no human control. The function of the Thermo Adaptive Façade T\_A\_F is simple. It provides shading by the automatic rotation of panels which respond to the environmental temperature differences. The force for this rotation is being given by a bimetall coil that is attached to them. The coil expands when the temperature increases and therefore rotates the panels. The panels are able to rotate in an angle of 90 degrees within a temperature range of 8-28 °C.

Bimetal principle: The bimetal consists of two different metal with temperature expansion, which able to change its curvature due to temperature differences.



28 °C The bimetal coil expands when the temperature rises and therefore rotates the panel

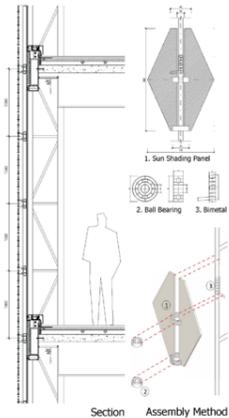
8 °C



View from the inside when the panels are closed



View from the inside when panels are open



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Melissa Krisanti Tanuharja (4326989)  
Supervisor: Dr.-Ing. Marcel Billow (4326989)  
Course: Bucky Lab Msc 1



Challenge the future



Complexity

# 08 | Frits

Dynamic shading system

Material | unknown

Position | outside

Type of movement | Folding  
Vertically-horizontally

Solar shading | +++

Glare control | ++

Redirecting light | -

View to outside | ++

Moves manually

Controls the size of the opening and thus incoming daylight



## Frits

Dynamic folding modular solar shading



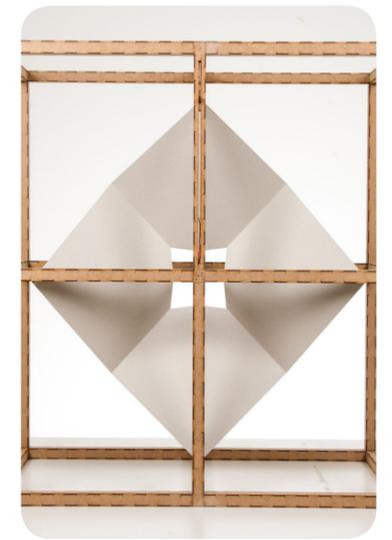
Frits is a folding solar shading system. Being a dynamic system Frits' shape can be adjusted depending on the position of the sun. The folding mechanics are driven inside the frame with integrated sliders and pulleys. Connecting all pulleys with each other will make the system fold simultaneously. The modularity of the system makes it possible to be placed on different types of buildings.



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Supervisor: Dr.-Ing. Marcel Billow (4326989)  
Course: Bucky Lab msc 1



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Complexity

## 09 | Folding flower

Dynamic shading system  
 Material | textile  
 Position | in-between  
 Type of movement | Folding

Solar shading | +++  
 Glare control | ++  
 Redirecting light | -  
 View to outside | ++

Moves manually  
 Controls the opening and thus the incoming daylight



Complexity

**FOLDING FLOWERS**  
 Origami inspired sun shading

**BUCKY LAB**

Exploded view of the facade

Detail 1:5

Our sun shading system is inspired by origami. The possibility of making faceted 3D structures out of a flat piece of paper, just by folding it. We translated this to foldable 'flowers' made out of a polyester fabric. These flowers are able to roll themselves up without the use of a secondary mechanism. (See them in motion by scanning the QR-code below with your smartphone!).

The foldable flowers are made with a process called pleating. With this process, two molds were used to generate a specific pattern on the polyester fabric that lays in-between these two layers. Our molds were made out of a special paper and folded in a circular wrapping pattern. This package of three different layers will be heated and patted under pressure to make the folds permanent.

The flowers are operated manually from the interior. By pulling on one cord from the inside you can roll out a cluster of several flowers, as is shown in our mock-up, depending on the amount of shading the user wants to create. It is possible to pull them all the way out or in any other position. When you want less shading you just give slack to the cord and the flowers roll back up by themselves.

Because the flowers are the centrepiece of the design, the frame is kept as slender as possible. For this the whole is placed in between a double skin facade, to protect it against the forces of nature like wind and rain. The frame is made out of aluminium profiles using snap fit connections. This way they can be opened for repairs and maintenance.

Scan the QR-code to see the flowers in motion!

Section of the facade

Interior view

Exterior view

artex | komazo

Students: Wouter Vlietstra & Carlyn Simoon  
 Supervisor: Dr.-Ing. Marcel Bliw  
 Course: Bucky Lab msc 1

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## 10 | The Light Guider

Dynamic shading system  
 Material | unknown  
 Position | outside  
 Type of movement | Rotation  
 Vertically-Horizontally

Solar shading | ++  
 Glare control | ++  
 Redirecting light | +++  
 View to outside | +

Moves manually  
 Controls direct and indirect sunlight providing shadow and diffuse light at the same time



Complexity

**The Light Guider**  
 Aiming for comfort, sight and atmosphere

**BUCKY LAB**

This sunshading system is made to direct and guide light and sight. Not only can it block or let light through by rotating away or towards the direction of light, but it can also direct the vision of people looking through it. This makes the system flexible towards a wide range of possibilities. It allows to block direct sunlight while still having indirect light and being able to look outside in a certain direction. Beside these possibilities, the triangles and the effects they have on the shadow provide an interesting atmosphere.

The system works by using rotatable triangular and vertical lamellas. These two types of lamellas and rotations allow the system to be pointed toward each desired direction. To provide optimal lighting situations, it can also be connected to a system that automatically tracks the sun and act on it. Also, it can be integrated in a climatic system when placed in a dual façade.

These interesting features make this system a good solution to the problems each façade has to deal with and makes it a 'beyond borders' solution.

Details of lamella

Section 1:20

Students: Lars Hammer, Nick de Lange, Yi-Chien Liao  
 Supervisor: Dr.-Ing. Marcel Bliw  
 Course: Bucky Lab msc 1

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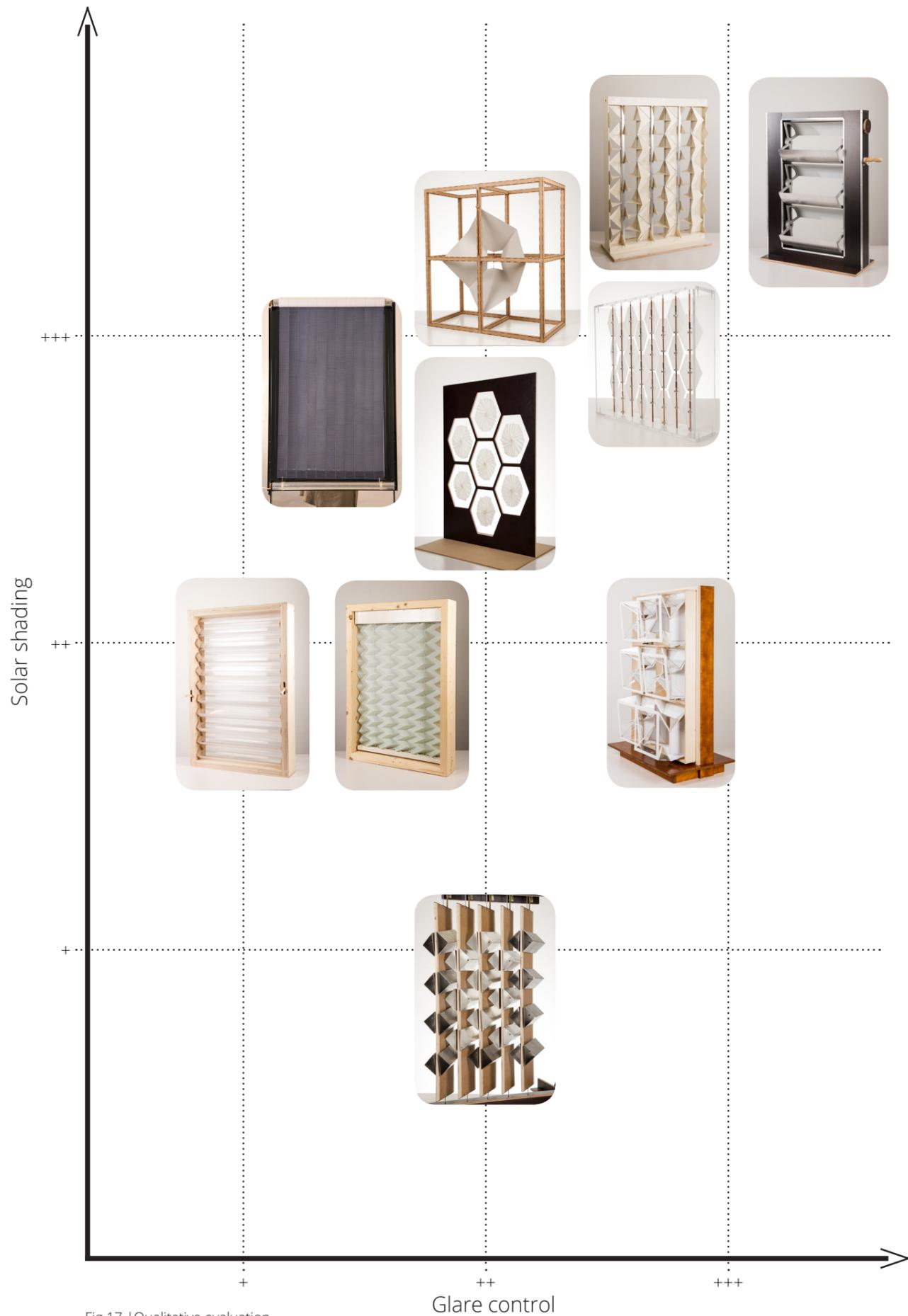
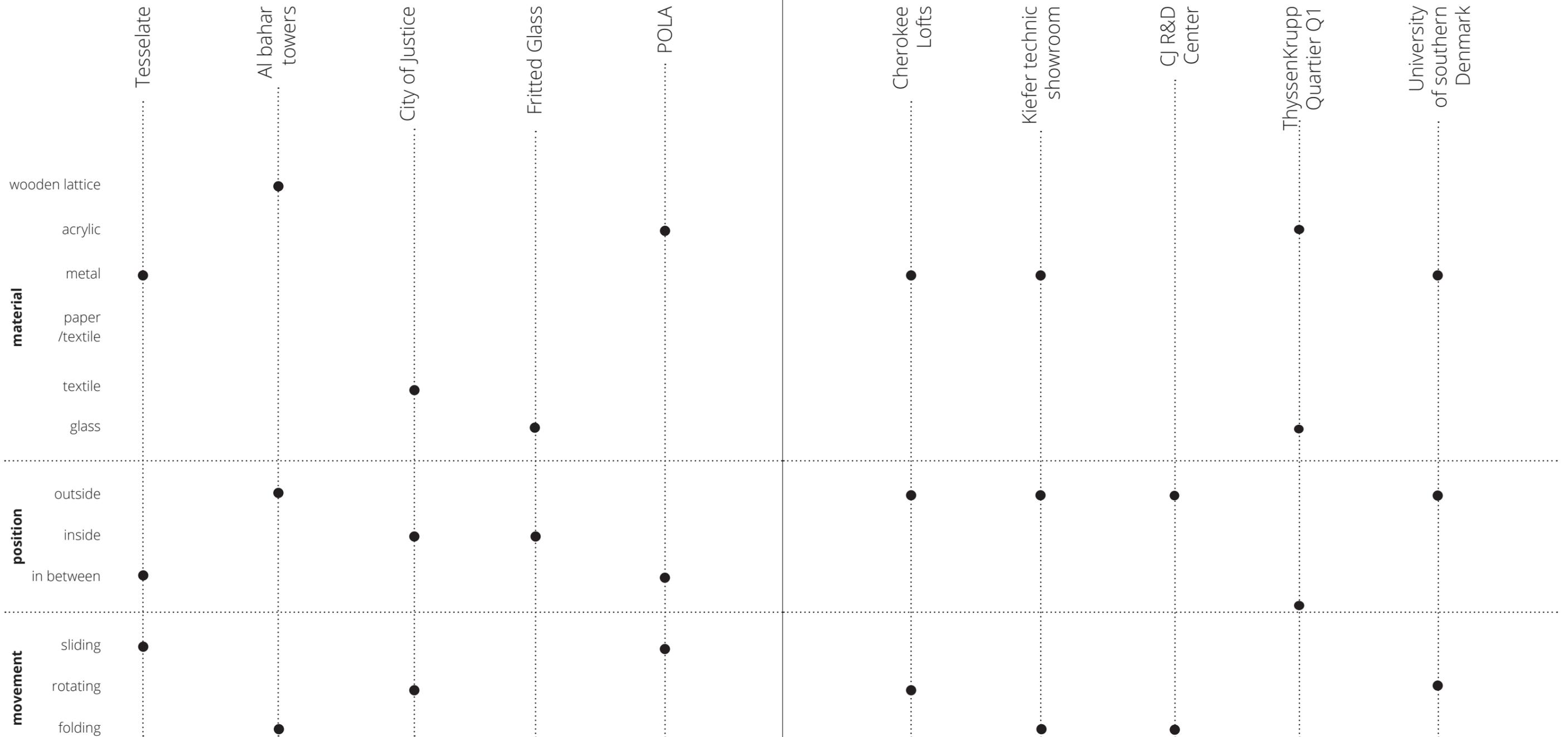
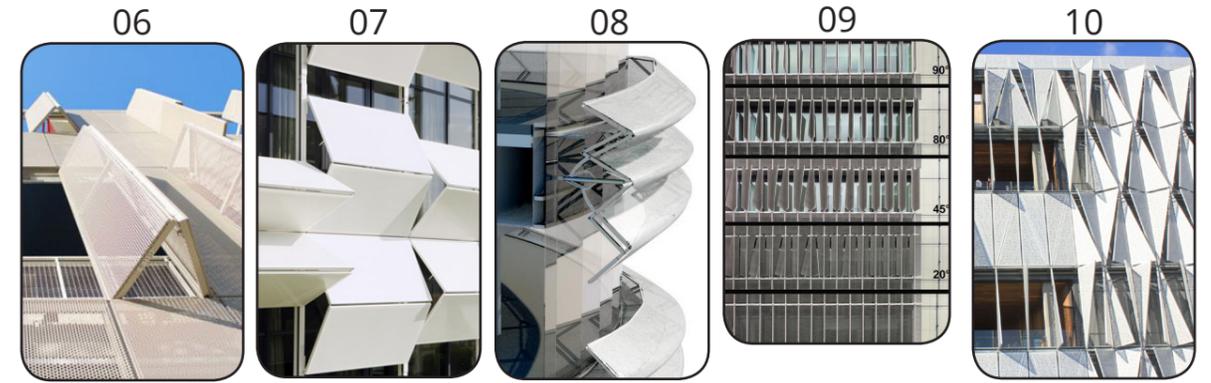
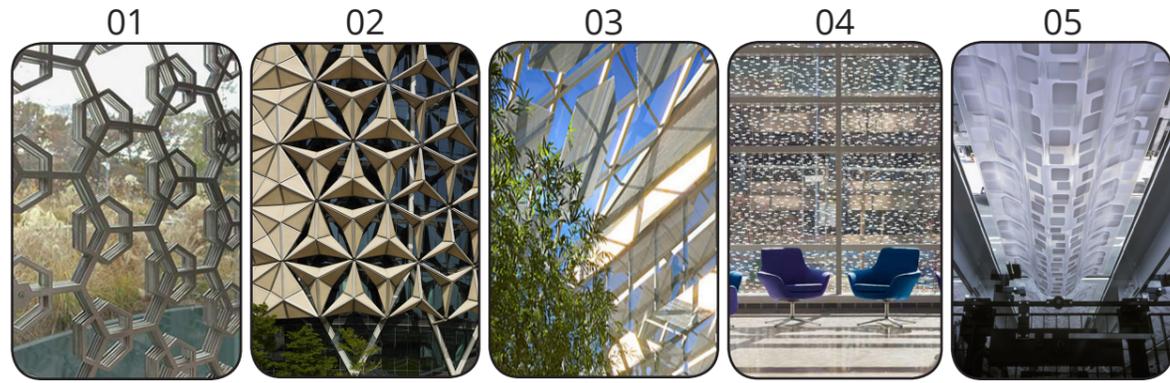


Fig 17 |Qualitative evaluation.

# 08

## STUDY CASES

STUDY CASES MAP PREVIEW



## 01 | Tessellate

Center for Geometry and Physics at Stony Brook  
Design | Zahner & ABI



Fig 18 | (Zahner, 2015)

Orientation | S  
Solar shading | +  
Glare control | ++  
View to outside | +++

This design is an animated stainless steel Tessellate™ Kinetic Surface. It consists of 4 perforated panels which move with the force of only one single motor, which controls the speed and the acceleration as well. The panels are placed in layers and they shift and revolve around one another in order to create different patterns. The stimuli for this movement is the temperature which is measured by a sensor and activates or not the movement. In addition light levels and time of day can be used as stimuli as well. When the perforated patterns are aligned, daylight is allowed to enter the space and the view outside is possible. On the contrary, when they have been moved the façade becomes opaque. The different combinations can be used to regulate airflow and privacy as well. Another application of this technique is combined with fritted glass (refer to "08 | Frits")

The system is a modular system with its own frame and glaze panes at both sides and the perforated pattern can be costumed, with any kind of design.

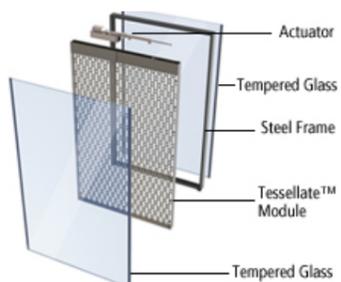


Fig 21 | (Zahner, 2015)

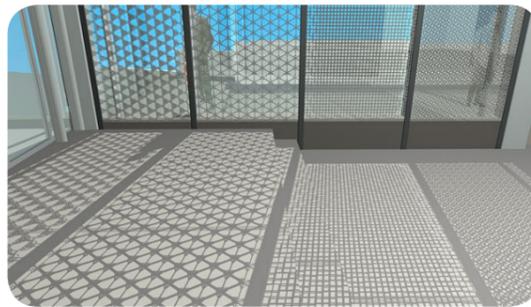


Fig 19 | (Zahner, 2015)

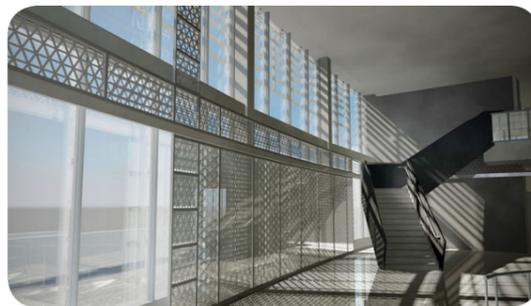


Fig 20 | (Zahner, 2015)

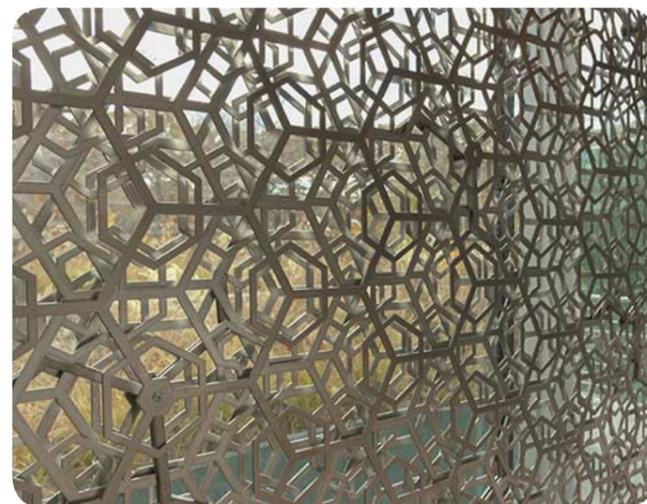


Fig 22 | (Zahner, 2015)

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Adaptivebuildings.com. (2015). Adaptivebuildings.com. Retrieved 2 December, 2015, from <http://www.adaptivebuildings.com/simons-center.html>.  
Zahner, A. (2015). Zahner. Retrieved 2 December, 2015, from <http://www.azahner.com/portfolio/stony-brook>.

## 02 | Al bahar towers

AEDAS Architects



Fig 23 | (Ahr-globalcom, 2015)

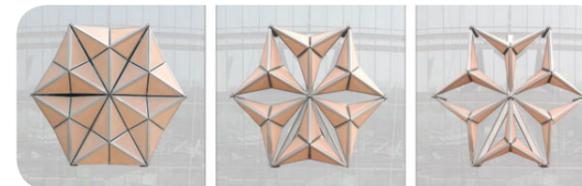


Fig 24 | (Archdaily.com, 2012)

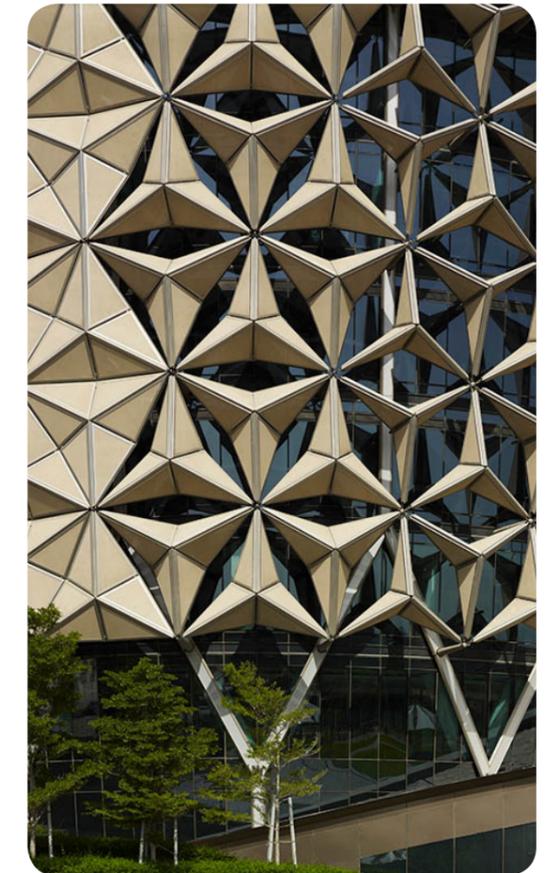


Fig 25 | (Ahr-globalcom, 2015)

Orientation | S, E, W  
Solar shading | +++  
Glare control | +++  
View to outside | +

The world's largest computerized dynamic façade consists of flowers able to fold and unfold, forming a curtain wall, 2 meters offset from the envelope of the building. The system covers the 2/3 of the façade, spreading in front of the east, the west and the south side.

The flowers are made of wooden lattice shading screen covered with fiberglass and PTFE and they are partially transparent filtering the incoming light. They adapt their shape responding to sun's path in order to control solar gain and glare. As measured, 50% reduction of solar gain is actually obtained. Each one has an independent frame for reasons of simplicity and maintenance.

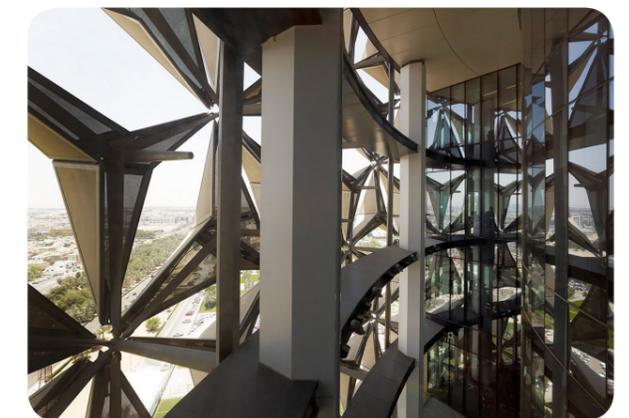


Fig 26 | (Ahr-globalcom, 2015)

References |  
Ahr-globalcom. (2015). Ahr-globalcom. Retrieved 2 December, 2015, from <http://www.ahr-global.com/Al-Bahr-Towers>.  
Archdaily.com. (2012). ArchDaily. Retrieved 2 December, 2015, from <http://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas>.

## 03 | City of Justice

Foster + Partners



Fig 27 | (Adaptivebuildingscom, 2015)

Orientation | S, E, W  
Solar shading | ++  
Glare control | +  
View to outside | +

The Strata shading system minimizes unwanted solar gain but still allows daylight to enter the atrium. It consists of hexagons following the structural profile of the canopy and being able to extend or retract. When extended, they cover the openings filtering the incoming light, while, when retracted, they almost "disappear" leaving the openings completely uncovered. These shading schemes are controlled through an algorithm combining real-time measurements of the sun light with historic solar gain data.



Fig 28 | (Adaptivebuildingscom, 2015)



Fig 29 | (Adaptivebuildingscom, 2015)

References |  
Adaptivebuildingscom. (2015). Adaptivebuildingscom. Retrieved 2 December, 2015, from <http://www.adaptivebuildings.com/city-of-justice.html>.  
Archicentralcom. (2015). Archicentralcom. Retrieved 2 December, 2015, from <http://www.archicentral.com/city-of-justice-madrid-spain-foster-partners-5180/>.

## 04 | Fritted glass

Spencer Finch, Brooklyn, NY



Fig 30 | (Jo ann day, 2015)

Fritted glass is a simple technique for sun shading. Patterns and grids can be imprinted on the glass pane transforming it to partially opaque. The name is out of the "frits" which are pigmented glass particles and is the base of the paint applied for these silk-screened designs.

Orientation | -  
Solar shading | +  
Glare control | +  
View to outside | +++

They can be used either as single layer, meaning the shading is fixed, or as multiple layers, enabling the adaptation of the system. In this case, the different layers revolve around one another achieving various densities based on whether the frits are aligned or not. The same technique is combined with perforated metallic or plastic panels (refer to "Tessellate"). In this case, the system is single layered and painted by hand on both sides to the glass pane.



Fig 31 | (Jo ann day, 2015)



Fig 32 | (Jo ann day, 2015)



Fig 33 | (Jo ann day, 2015)

References |  
Jo ann day. (2015). Hopkinsmedicineorg. Retrieved 2 December, 2015, from [http://www.hopkinsmedicine.org/the\\_johns\\_hopkins\\_hospital/about/enhanced\\_facilities/art\\_architecture/magical\\_frit.html](http://www.hopkinsmedicine.org/the_johns_hopkins_hospital/about/enhanced_facilities/art_architecture/magical_frit.html).

## 05 | POLA Ginza Building Façade

ABI & Hoberman Associates



Fig 34 | (Openbuildingscom, 2015)

Orientation | S, E  
 Solar shading | +++  
 Glare control | ++  
 View to outside | +

The curvature and the pattern of the scaled rectangles in combination with the special lighting takes the appearance of a breathing life. The façade is characterized as dynamic, beautiful and iconic at the same time.



Fig 35 | (Openbuildingscom, 2015)

The 14-store showroom building of Pola in Tokyo needed an outstanding shading system for its envelope. In collaboration with design architect Yasuda Atelier and executive architect Nikken Sekkei, they designed curved shutters made of acrylic. They are placed in-between the double glazed façade and are flexible enough to be able to fold at the side and when needed to extend preserving its initial curvature. Hinges and horizontal shaft with rollers are placed at the top of the panels in order to slide them.



Fig 36 | (Hobermancom, 2015)

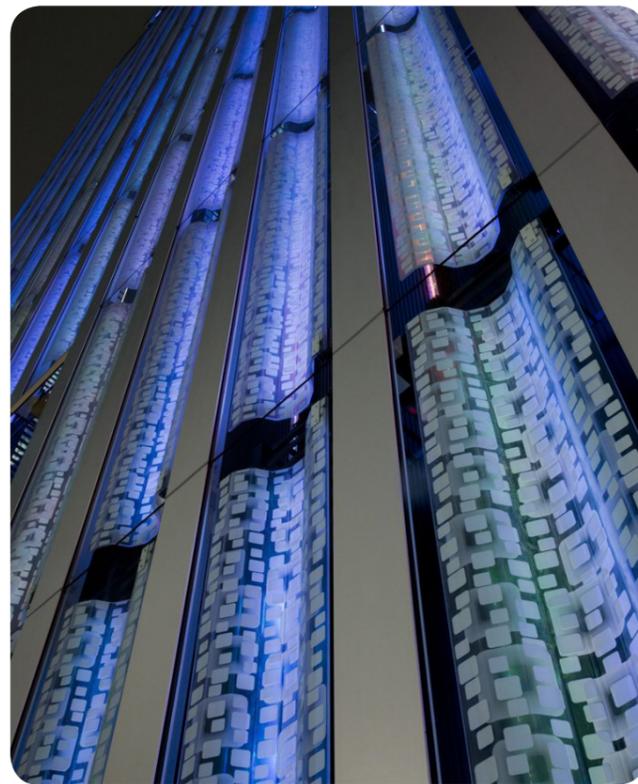


Fig 37 | (Openbuildingscom, 2015)

References |  
 Hobermancom. (2015). Hobermancom. Retrieved 2 December, 2015, from [http://www.hoberman.com/portfolio/pola.php?projectname=POLA Ginza Building Façade](http://www.hoberman.com/portfolio/pola.php?projectname=POLA%20Ginza%20Building%20Fa%C3%A7ade).  
 Ming3dcom. (2015). Ming3dcom. Retrieved 2 December, 2015, from <http://ming3d.com/DAAP/ARCH713fall11/?author=8>.  
 Openbuildingscom. (2015). OpenBuildings. Retrieved 2 December, 2015, from <http://openbuildings.com/buildings/pola-ginza-building-profile-5357>.

## 06 | Cherokee Lofts

Pugh & Scarpa Keep Cool



Fig 38 | (Treehuggercom, 2015)

The shutters that can be totally controlled from individuals offer sunlight protection, street noise reduction and natural ventilation at the same time. Moreover they contribute to building's safety creating an indoor totally protected pedestrian walk with outside view when wanted.

A double skin facade covered with perforated anodized steel shutters transforms this building into a sustainable building, performing even better than regular energy efficient buildings in California so far. It is the first LEED (Leadership in Energy and Environmental Design) Gold Certified Building in Hollywood.

Orientation | E  
 Solar shading | ++  
 Glare control | ++  
 View to outside | ++



Fig 39 | (Worldarchitecturenewscom, 2015)



Fig 40 | (Treehuggercom, 2015)

References |  
 Worldarchitecturenewscom. (2015). Worldarchitecturenewscom. Retrieved 2 December, 2015, from <http://backstage.worldarchitecturenews.com/wanawards/project/lofts-at-cherokee-studios?source=sector>.  
 Treehuggercom. (2015). TreeHugger. Retrieved 2 December, 2015, from <http://www.treehugger.com/sustainable-product-design/cherokee-lofts-by-pugh-scarpa-keep-cool-the-old-way.html>.

## 07 | Kiefer technic showroom

Ernst Gleichenberg & Partner | Austria



Fig 41 | (Architoniccom, 2015)

The components are placed at edge of the slabs and when they are unfolded they cover half of the upper floor height and half of the below one. Thus it is possible that the entire facade is covered or fully unprotected.

Perforated aluminum shutters performing with electric power fold vertically offering solar control. The “M” shape vertical section enables the folding and unfolding based on user’s willing, while the system can be programmed to operate responding to external condition as well.

Orientation | S  
 Solar shading | +++  
 Glare control | ++  
 View to outside | +



Fig 42 | (Design-milkcom, 2010)



Fig 43 | (Architoniccom, 2015)

References |  
 Architoniccom. (2015). Architonic. Retrieved 2 December, 2015, from <http://www.architonic.com/aisht/dynamic-facade-kiefer-technic-showroom-ernst-giselbrecht-partner/5100449>.  
 Design-milkcom. (2010). Design Milk. Retrieved 2 December, 2015, from <http://design-milk.com/kiefer-technic-showroom-in-austria-by-ernst-giselbrecht-partner/>.

## 08 | CJ R&D Center | Kinetic Façade

Yan Krymsky

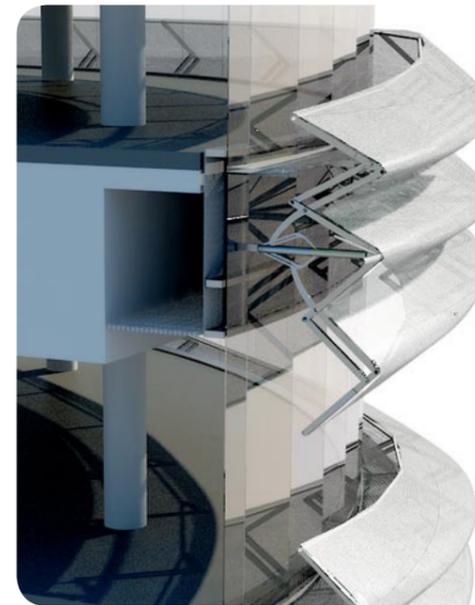


Fig 44 | (Wordpresscom, 2015)

This kinetic facade consists of parts placed on the envelope of the building at slab height. The principle of this shading device is similar to the one of Kiefer technic showroom (refer “Kiefer technic showroom”). The motion is activated by a pistol-like mechanism which pulls or pushes the middle part of each component. Thanks to accordion hinges the component expands or folds being able to cover half of the floor height underneath and half of the above one at the same time. Thus, it can fully cover the facade or leave it unprotected. The system is designed to respond to both solar radiation and individual’s input.

Theoretical project

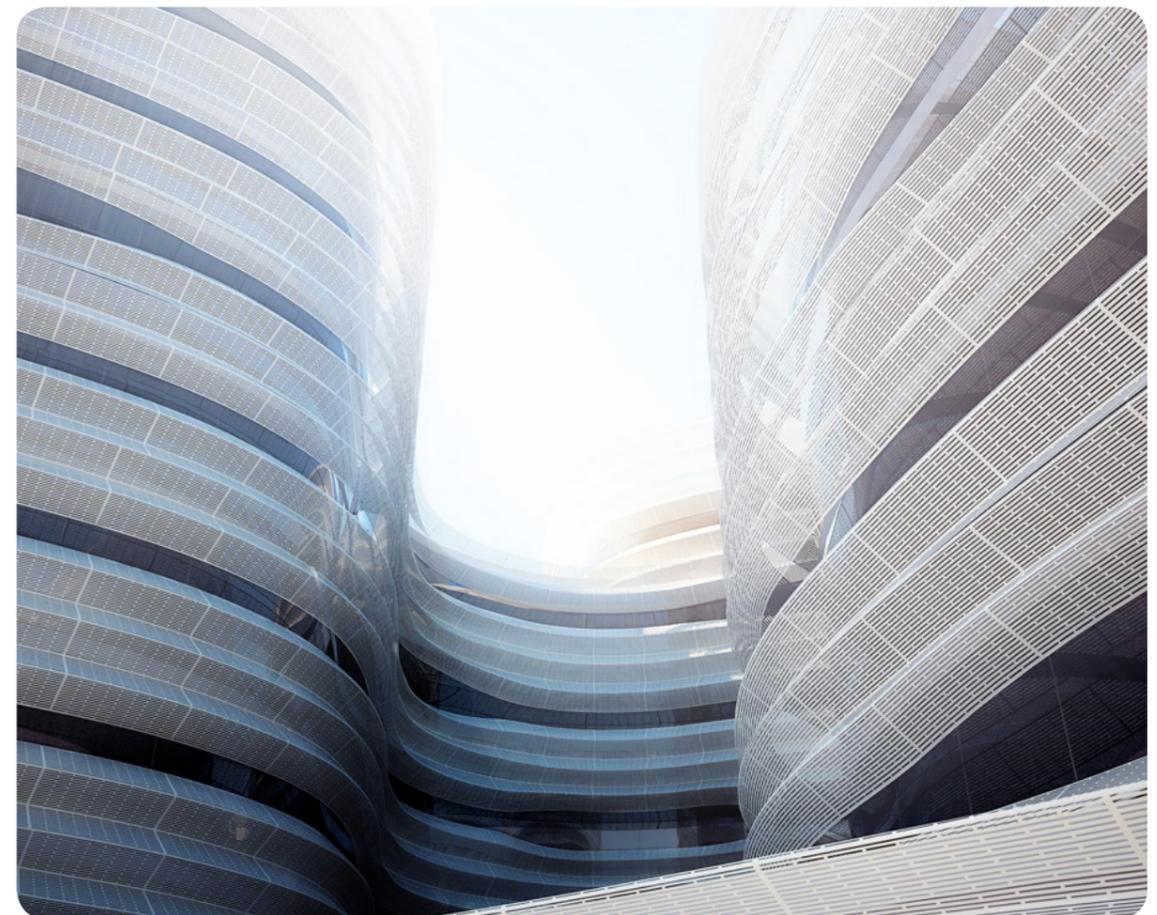


Fig 45 | (Wordpresscom, 2015)

References |  
 Wordpresscom. (2015). Wordpresscom. Retrieved 2 December, 2015, from <https://yazdanistudioresearch.wordpress.com/tag/adaptive-building-facades/>.

## 09 | ThyssenKrupp Quartier Q1

Chaix & Morel et associés and SWD Architects | Germany



Fig 46 | (Façades Confidential., n.d.)

Fraunhofer Institute for Solar Energy Systems introduced 400,000 slats rotate in order to offer optimum indoor conditions through out the day. The material used is chromium- nickel-molybdenum stainless steel, called Nirosa and combined with steel sheeting with zinc and magnesium coating are a new proposal for more economic aluminum profiles. Having a rotation spectrum from 0°-90°, they can be adjusted fully to fulfill every requirement regarding solar shading. At the same time they control the view at the outside. Even though they seem to be vertical sun shadings, they are horizontal slats, mat on one side and glossy on the other redirecting sunlight indoors at areas away from the facade. 1,600 motors enable the rotation of each group of slats with a vertical axis. The signals for activation are give from a weather station at the top of the building.

Orientation | S, E, W  
Solar shading | +++  
Glare control | ++  
View to outside | ++

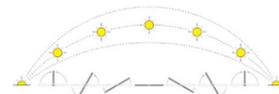


Fig 47 | (Gallery-Q1, ThyssenKrupp Quarter Essen, n.d.)

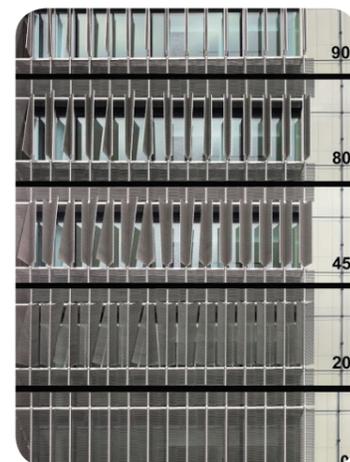


Fig 49 | (Façades Confidential., n.d.)



Fig 48 | (Façades Confidential., n.d.)

References |  
Façades Confidential. (n.d.). Retrieved December 20, 2015, from <http://facadesconfidential.blogspot.nl/2010/12/thyssenkrupp-quarter-facades-giants.html>.  
Gallery - Q1, ThyssenKrupp Quarter Essen / JSWD Architekten Chaix & Morel et Associés - 18. (n.d.). Retrieved December 20, 2015, from [http://www.archdaily.com/326747/q1-thyssenkrupp-quarter-essen-jswd-architekten-chaix-morel-et-associés/510bd652b3fc4be6060000be\\_q1-thyssenkrupp-quarter-essen-jswd-architekten-chaix-morel-et-associ-s\\_tk\\_q1\\_pic-to\\_sunshade-png/](http://www.archdaily.com/326747/q1-thyssenkrupp-quarter-essen-jswd-architekten-chaix-morel-et-associés/510bd652b3fc4be6060000be_q1-thyssenkrupp-quarter-essen-jswd-architekten-chaix-morel-et-associ-s_tk_q1_pic-to_sunshade-png/).

## 10 | University Of Southern Denmark

Henning Larsen Architects

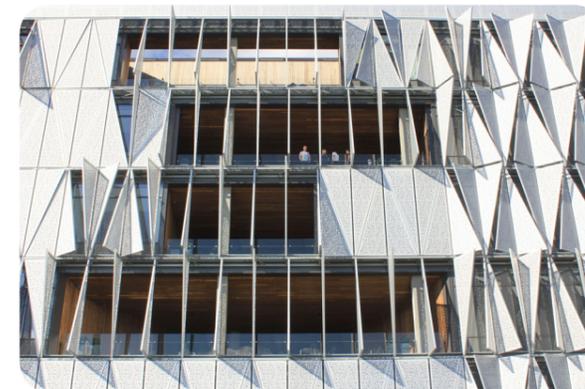


Fig 50 | (Kinetic Architecture, n.d.)

Under the same design principle as ThyssenKrupp Quartier Q1, uses 2,000 sensor-controlled perforated aluminum shutters for daylight control. The frame is made of galvanized steel and its length is 60 cm. Some of the formed triangles are fixed at 30° or 60°, while others are able to rotate from 0° to 90°.

Orientation | N, S, E, W  
Solar shading | +++  
Glare control | ++  
View to outside | +



Fig 51 | (Kinetic Architecture, n.d.)



Fig 52 | (It's all about the perforations, n.d.)



Fig 53 | (Kinetic Architecture, n.d.)

References |  
It's all about the perforations. (n.d.). Retrieved December 20, 2015, from <https://www.ribaj.com/products/campus-kolding-university-of-southern-denmark>.  
Kinetic Architecture. (n.d.). Retrieved December 20, 2015, from <http://www.modlar.com/inspiration/kinetic-architecture/#kolding-campus-university-of-southern-denmark/6>.



## 09 | 1 METHODOLOGY

In order to analyze in detail a solar control system and evaluate the efficiency of its performance and the visual comfort that it offers, daylight simulations should be conducted. For this purpose, DIVA-for-Rhino, developed by Solemma LLC, is used in order to measure daylight availability and conduct glare analysis. This software uses validated simulation engines like Radiance, Daysim and Energy Plus and enables simulations for lighting and thermal comfort. (<http://diva4rhino.com/>)

This project focuses on high-rise office buildings with fully-glazed envelopes. The interior is a close plan space, so the objective of the simulations is a room-level study. A reference room is placed on the 10<sup>th</sup> floor in order to simulate the lighting conditions at approximately 30m above earth level and at the same time avoid possible shadows caused from obstacles nearby (e.g. others buildings and trees). The selected for further analysis solar shading systems, are placed on the façade of this reference room in order to obtain the simulation results.

Description of the office room geometry:  
Length | 5.4m., Width | 3.6m., Height | 2.7m.

To begin with, the location of the reference room is defined in Athens, Greece and the respective Energy Plus Weather file (EPW), developed by the U.S. Department of Energy, has been imported. The next step is to define the task area, which is a horizontal surface at 0.90m supposing the floor height is at 0m. The simulation nodes are placed on a grid of 0.5m. \* 0.5m. Continuing with the modeling of the shading systems, each system is produced, having three different states, in Rhino and Grasshopper. The first state represents the system at the initial form when it provides the least possible shading. The second state is the middle phase, when the system has already transformed providing partial shading and finally, during the third state, the system is fully extended covering the maximum of the opening. In DIVA, the shading input is defined as dynamic, mechanical system with possible states these three forementioned stages. It is also defined as manually controlled which means that the occupants activate the shading system when they experience visual discomfort ( $DGP > 0.4$ ) or direct light is present on their workplane. As far as it concerns the materials and the reflection index of the building elements, the default material properties of DIVA are being used. This means that the ceiling is assigned with 70% reflectance, the floor with 20% and the inner walls 50%. The outside ground is assigned with a reflectance of 10%, the furniture in the room have a reflectance of 50%. Last but not least, the glass on the facade is defined as a double glazing with 80% transparency coefficient.

In order to evaluate and compare the various shading system to each other, the same material has been selected for all of them. In this way, the results will be influenced only by the various geometries. The "Generic TranslucentPanel\_20" material has been selected which means that the shading elements are considered to be translucent with light transmittance value at 20%.

The first type of simulations conducted is the annual glare analysis. South and west orientations are tested for each shading and each one of them is modeled as a dynamic shading system, with the possible states mentioned earlier, the open, the half and the closed one. These simulations are made with a view towards the window. Using these results, a daysim report is then obtained, giving analytical data regarding the light performance of the device and the indoor lighting conditions. The required illuminance is set at 500 lux. The results obtained during this analysis are the "Daylit area", "Daylight factor", "Glare percentage", "Daylight autonomy", "Useful daylight autonomy" and a proposal regarding the time-schedule of the dynamic system. Some of the indices are not used regularly, so a quick description is necessary. The index "Daylit area ( $DA_{300lux}[50\%]$ )" refers to the percentage of the floor area where the illuminance levels are above 500lux for at least 50% of the occupied hours. Furthermore, the

"Glare percentage" describes the percentage of the occupied hours during which DGP takes unacceptable values, according to the annual glare analysis. By comparing the results of all the systems in east, south and west orientation, a first evaluation about the most efficient orientation for the performance of each system can be done.

After selecting the orientation where each shading system performs more efficiently at, based on the results mentioned above, the third part of simulations includes indoor visualizations for more specific information as far as it concerns the indoor environment and the lighting management, as well as visual comfort in the office room. Specific dates are selected which are 21<sup>st</sup> of June, 21<sup>st</sup> of December, the longest day and night respectively, and 21<sup>st</sup> of March as a neutral date. Two cameras have been placed in the room, the first one is a perspective camera capturing the whole room and having as a target the window in order to illustrate the individual's lighting experience in that space. The second one is a fish-eye 180° camera which represents the view of an individual while working, focusing on the computer screen. A time-series analysis from 8:00 until 18:00, occupancy schedule, rendering the conditions every 4-5 hours, gives a first impression about the shading system and its performance. Pictures with both natural and false colors are being produced, enabling the calculation of brightness and luminance ratio at any position. Both of these simulations take place under clear sky with sun. This sky condition is the worst case scenario allowing the evaluation of the shading device under extreme conditions.

It is worth mentioning the procedure followed in order to obtain luminance ratio values. In order to calculate the requested values, the visual field of 30° and 60° (Fig 55), meaning the ergorama and the panorama have to be projected on the visualizations. Afterwards, the lowest and the highest values are detected and recorded. Luminance ratio is the proportion of the lowest over the highest value.

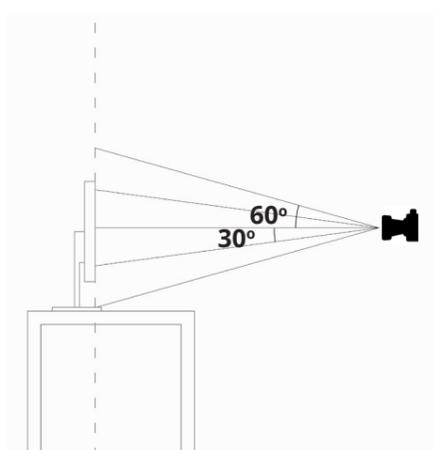


Fig 55 | Visual fields projected on computer view.

Regarding the computer view, the exact position of the camera and its target are known, so the direct distance between these two elements is known as well. With the use of trigonometry, we can calculate the radius of these two concentric circles. Having as center the point of the target and calculated values, we can define the ergorama and the panorama.

As far as it concerns the window view, the circles defining these two visual fields are too big, exceeding the surface of the facade. As a simplification, the whole opening is considered to be the ergorama.

## 09 | 2 SELECTION CRITERIA

Ten Bucky lab projects and ten study cases have already been analyzed briefly and evaluated qualitatively. After focusing on these shading systems, the five most representative solar shading systems of the study cases are selected for further analysis.

[Tessellate](#) | [Al bahar towers](#) | [Cherokee lofts](#) | [Kiefer technic showroom](#) | [ThyssenKrupp Quartier Q1](#)

### 09|3 SIMULATION RESULTS

As it is already mentioned, the annual glare analysis results (DGPs) are used as input for the “Daylight Autonomy” simulation, in order to obtain the “Daysim report”. At first, simulations are conducted for the reference room without shading system in order to record the existing situation and the needs regarding solar control for south and west orientation. Hence, every tested shading system is compared with the lighting performance of the reference room at the respective orientation. The examined shading systems are defined as adaptive solar shading systems with the three possible states. After comparing the results regarding the two different orientations for each one of the shading systems, the most efficient orientation can be outlined. All the analytical reports can be found in “APPENDIX A”. The following table summarizes the results.

	DA <sub>500lux</sub> [50%]	DA	UDI <sub>&lt;100-2000lux</sub> [50%]	Glare
Reference south	100%	89%	56%	8.1%
Reference west	94%	84%	68%	6.1%
Tessellate south	100%	86%	63%	1%
Tessellate west	84%	79%	73%	0.6%
Al bahar south	67%	65%	79%	0%
Al bahar west	53%	56%	91%	0.2%
Cherokee south	100%	87%	62%	0%
Cherokee west	89%	81%	71%	0.1%
Kiefer south	98%	84%	68%	0%
Kiefer west	79%	75%	79%	0.1%
Q1 south	99%	86%	64%	0%
Q1 west	85%	78%	75%	0.3%

Table 05 | Daysim report results.

The following cases are selected for further analysis:

- Tessellate west
- Al bahar towers south
- Cherokee lofts west<sup>1</sup>
- Kiefer south
- ThyssenKrupp Quartier Q1 west<sup>1</sup>

#### 09|3|1 REFERENCE ROOM | South facing

The lighting performance results of the reference room, compared with the set requirements illustrate the problems regarding lighting conditions and the imply the improvements needed.

- Daylit area | DA<sub>500lux</sub>[50%] > 80% of floor area = 100% ✓
- Daylight autonomy | DA > 80% for active occupant behavior = 89% ✓
- Useful daylight illuminance | percentage of space with a UDI<sub><100-2000LUX</sub>[50%] > 60% for the active occupant behavior = 56% ✗
- Glare | < 0.3% of occupied hours = 8.1% ✗

1 | These two shading systems appear to perform better when they are south oriented. However, their geometry is suitable for west orientation. Hence the west oriented cases are selected for further analysis.

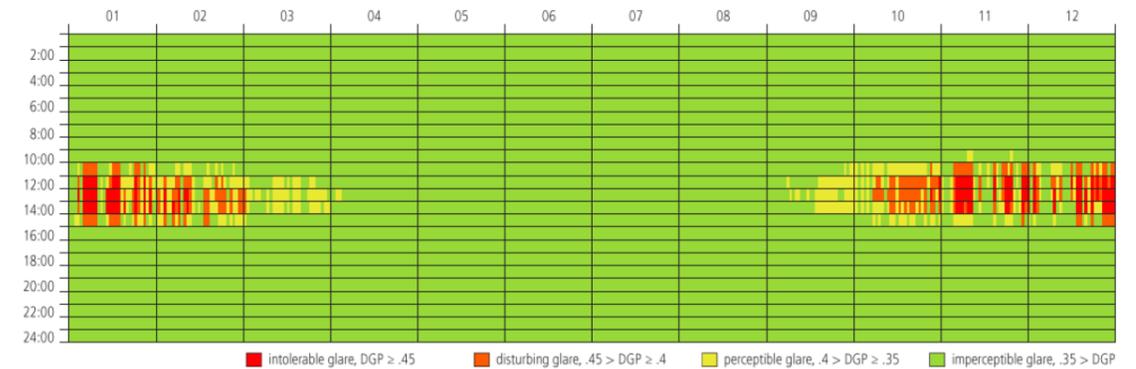


Fig 56 | South orientation - without shading annual glare analysis.

Fig 54 illustrates the experienced glare throughout the year. As it is mentioned at the explanation text below the graph, the green color represents the imperceptible glare which is totally acceptable and yellow color represents the perceptible glare, which is acceptable as well, while the orange and red color illustrate the disturbing or even intolerable glare which needs to be treated.

Based on these results, the problematic periods for the south orientation are observed during winter. More specifically, from October until February, during noon, the experienced glare is disturbing or even intolerable and needs to be treated. These facts can be justified by the fact that during winter months the sun position is lower, so it is possible to enter indoor space unblocked especially around 12 o'clock when it is perpendicular to the south-oriented facade. During March and September the glare is perceptible but still acceptable.

#### 09|3|2 REFERENCE ROOM | West facing

By following the same procedure for west orientation, it is possible to analyze the light experience in the room throughout the year.

- Daylit area | DA<sub>500lux</sub>[50%] > 80% of floor area = 94% ✓
- Daylight autonomy | DA > 80% for active occupant behavior = 84% ✓
- Useful daylight illuminance | percentage of space with a UDI<sub><100-2000LUX</sub>[50%] > 60% for the active occupant behavior = 68% ✓
- Glare | < 0.3% of occupied hours = 6.1% ✗



Fig 57 | West orientation - without shading annual glare analysis.

The results presented in Fig 55 show that the west-oriented facade needs improvements from February until September. The problems occur mainly from 15:00 until 19:00, during sunset, when the sun is located low and it enters indoor space.

09|3|3 TESSELLATE | West facing

The Daysim report results show if the Tessellate-west completes the requirements set.

- Daylit area |  $DA_{500LUX} [50\%] > 80\%$  of floor area = 84% ✓
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 79% ✓
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX} [50\%] > 60\%$  for the active occupant behavior = 63% ✓
- Glare |  $< 0.3\%$  of occupied hours = 0.6% ✗

So, this system does not perform as required. The way it performs, shifting and revolving the perforated steel panels is interesting, though not adequate for providing pleasant visual comfort.



Fig 58 | Tessellate - 1st state annual glare analysis.



Fig 59 | Tessellate - 2nd state annual glare analysis.



Fig 60 | Tessellate - 3rd state annual glare analysis.

Fig 56, Fig 57 and Fig 58 present the experienced annual glare when each of the states (open, half closed, closed) is applied. None of these three states offers pleasant lighting experience, as none of them protects totally from glare. This particular shading system contributes in creating an interesting and playful atmosphere and it partially filters daylight penetrating from the openings, but not adequately.

The problems occur mainly from February until October, from 15:00-19:00 hours. Hence, this shading system is less efficient when the sun is at high positions. While the system is moving, adapting the second and third state's geometry its efficiency gets better during summer months, especially from May until August.

In an effort to analyze further this system, the focus is set at the third state which is the most efficient of all as it is the densest one. Visual comfort problems occur on the 21<sup>st</sup> of March, specifically at 18:00. So using the indoor visualizations, it is possible to understand the situation in detail.

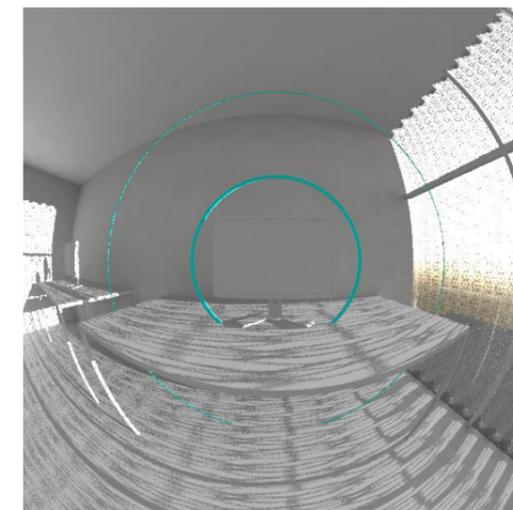


Fig 61 | Tessellate - 3/21-18:00 - 3<sup>rd</sup> state - Computer view.

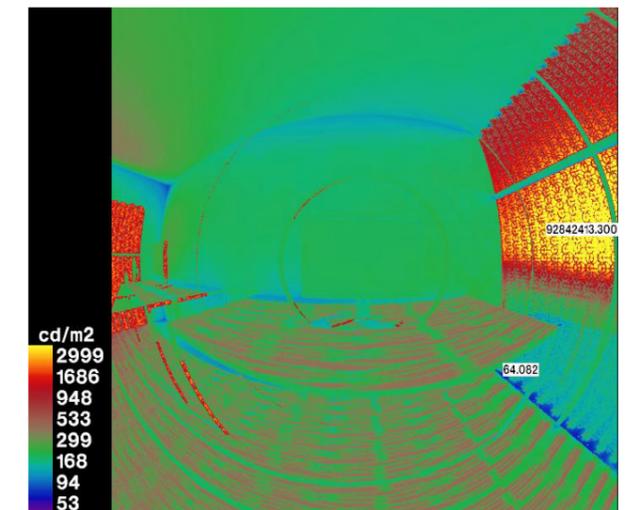


Fig 62 | Tessellate - 3/21-18:00 - 3<sup>rd</sup> state - Computer view.

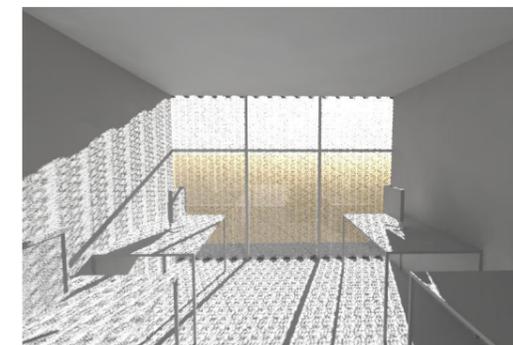


Fig 63 | Tessellate - 3/21 - 18:00 - 3<sup>rd</sup> state - Interior view.

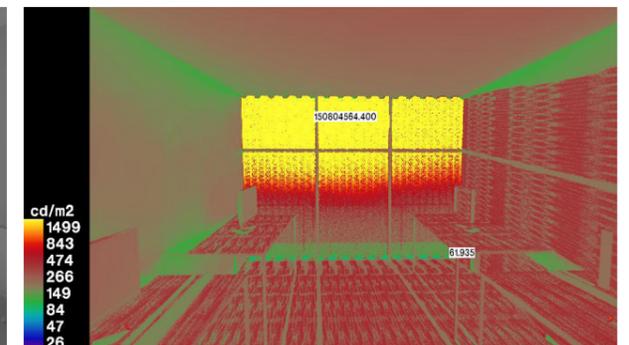


Fig 64 | Tessellate - 3/21 - 18:00 - 3<sup>rd</sup> state - Interior view.

Based on the computer-view pictures Fig 59-62, daylight is not completely blocked and direct daylight reaches the task field. Even though the luminance ratio is within acceptable values, direct daylight is still not acceptable as it may be disturbing for the user.

09 | 3 | 2 AL BAHAR TOWERS | South facing

- Daylit area |  $DA_{500LUX} [50\%] > 80\%$  of floor area = 67% ✘
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 65% ✘
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX} [50\%] > 60\%$  for the active occupant behavior = 79% ✔
- Glare |  $< 0.3\%$  of occupied hours = 0% ✔

These results justify that the system does not perform as required. It provides visual comfort at the expense of adequate daylight.

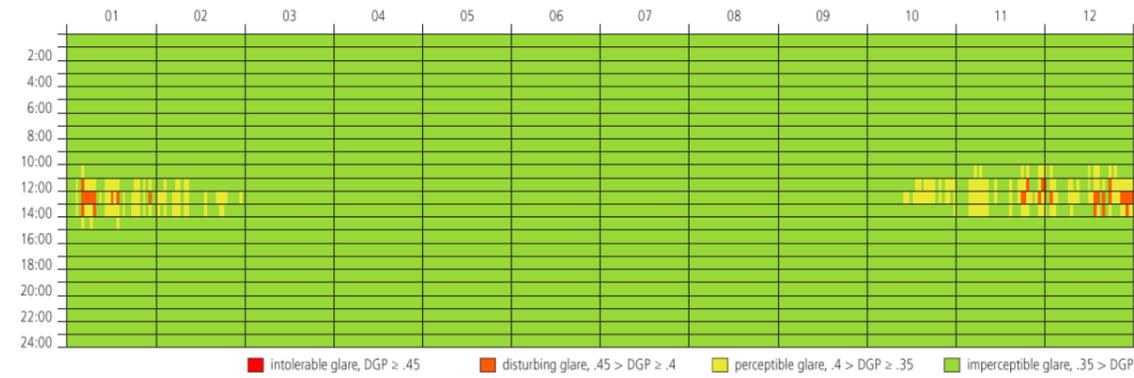


Fig 65 | Al bahar towers - 1st state annual glare analysis.

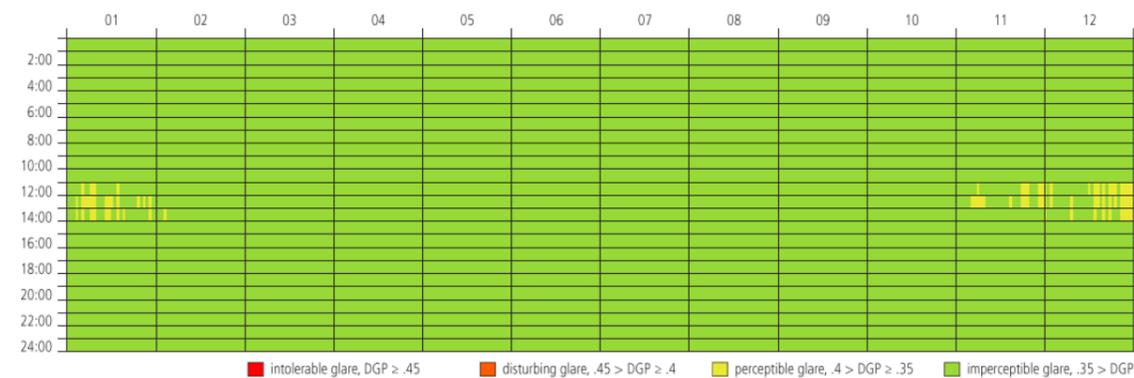


Fig 66 | Al bahar towers - 2nd state annual glare analysis.

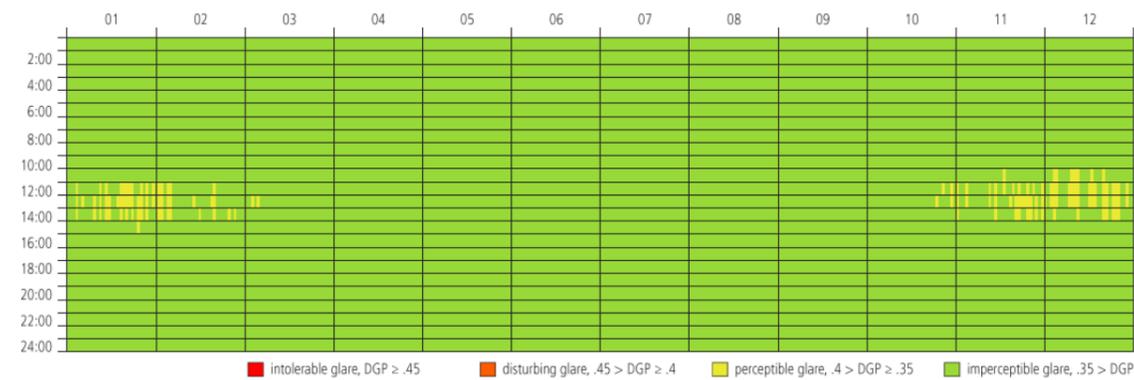


Fig 67 | Al bahar towers - 3rd state annual glare analysis.

Based on Fig 63-65, the first state is incapable to provide visual comfort during the whole year. The second and the third state offer acceptable indoor environment regarding daylight.

The problems occur mainly during winter months, from 11:00 until 14:00, illustrating an efficiency problem when the sun is at low positions. In an effort to analyze further this system, indoor visualizations using the computer and the interior view of the room, during the first state at 12:00 on the 21<sup>st</sup> of December are presented.

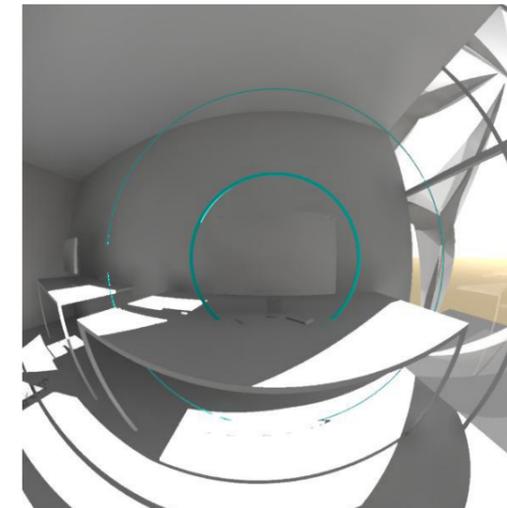


Fig 68 | Al bahar - 12/21 - 12:00 - 1<sup>st</sup> state - Computer view.

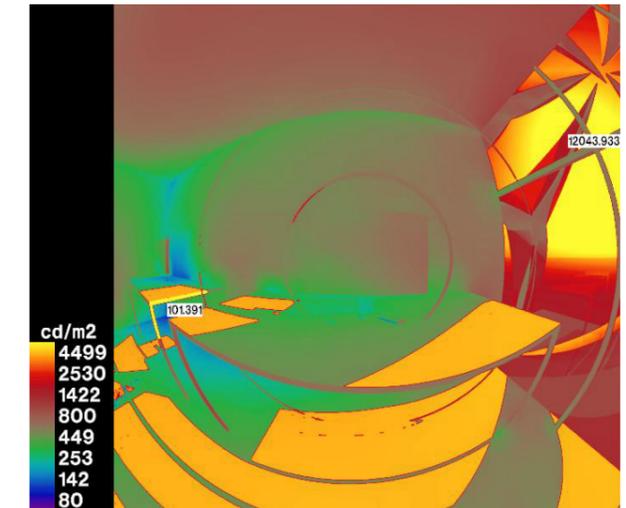


Fig 69 | Al bahar - 12/21 - 12:00 - 1<sup>st</sup> state - Computer view.

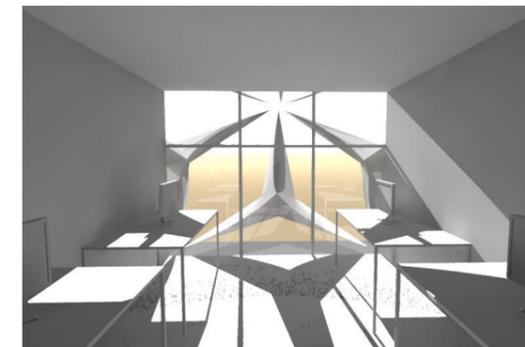


Fig 70 | Al bahar - 12/21 - 12:00 - 1<sup>st</sup> state - Interior view.

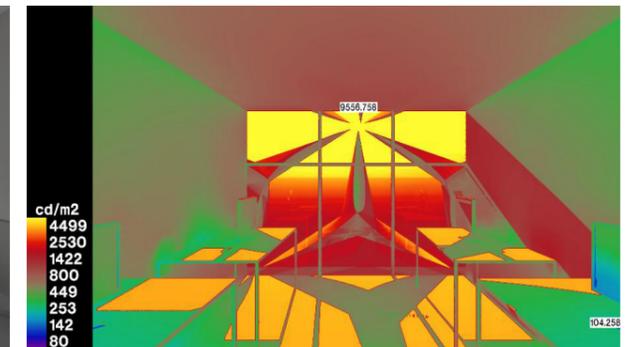


Fig 71 | Al bahar - 12/21 - 12:00 - 1<sup>st</sup> state - Interior view.

Based on Fig 66 and Fig 67 which illustrate the computer view, the luminance ratio is within acceptable values. The values should be higher than 0.1 in order to be acceptable and the picture shows that there not such extreme luminance values. However, direct daylight reaches the task field, which is not acceptable according to the system requirements.

As far as it concerns the pictures with the window view, the intense daylight blocked by the shading system creates "hard" shadows which cause high contrast and as a result visual discomfort.

09|3|3 CHEROKEE LOFTS | West facing

- Daylit area |  $DA_{500LUX}[50\%] > 80\%$  of floor area = 89% ✓
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 81% ✓
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX}[50\%] > 60\%$  for the active occupant behavior = 71% ✓
- Glare |  $< 0.3\%$  of occupied hours = 0.1% ✓

All the requirements set for visual comfort are fulfilled, so this shading system performs efficiently.



Fig 72 | Cherokee Lofts - 1st state annual glare analysis.

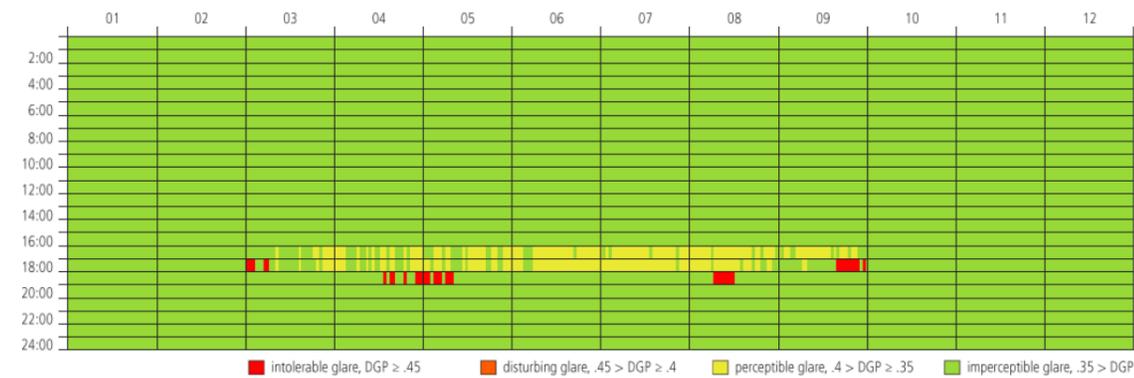


Fig 73 | Cherokee Lofts - 2nd state annual glare analysis.

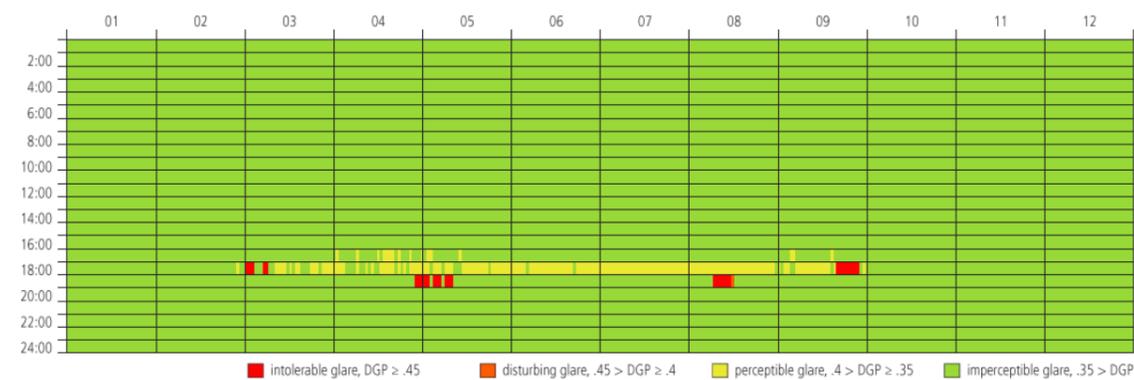


Fig 74 | Cherokee Lofts - 3rd state annual glare analysis.

According to Fig 70-72, the first state seems to cause glare during a long period, whereas the second and the third state perform better in terms of visual comfort.

However, in an effort to analyze the performance of the system in detail, it is important to focus on the problematic periods. The problems occur mainly from March until September, at 15:00-19:00. So, it is concluded that this shading system is less efficient when the sun is at high positions, during evening hours. The second and the third states seem to be by far more efficient than the first one. Considering that the second and the third state protect equally from glare, the second state is the most efficient enough as it allows view to outside as well.

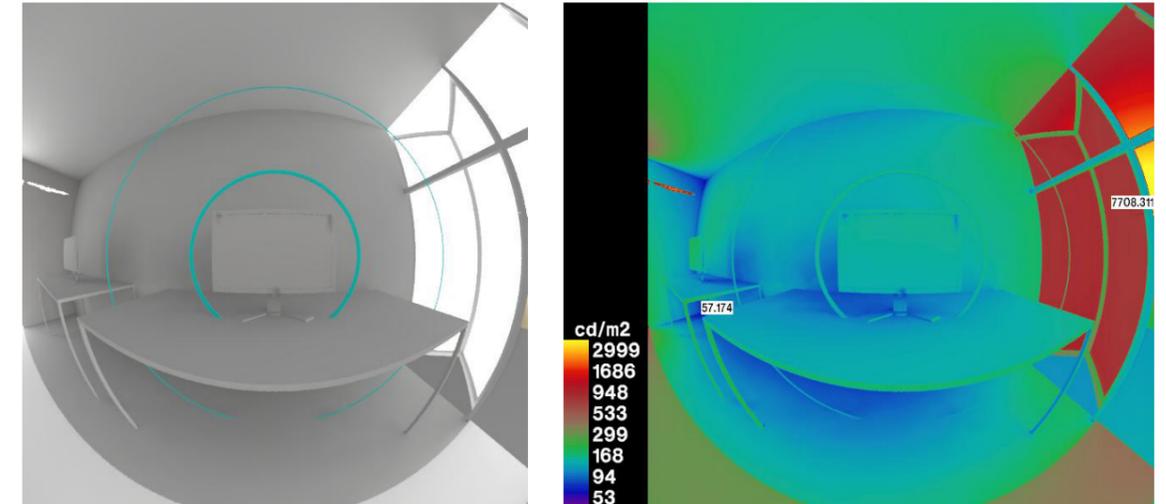


Fig 75 | Cherokee - 9/21 - 18:00 - 2nd state - Computer view. Fig 76 | Cherokee - 9/21 - 18:00 - 2nd state - Computer view.

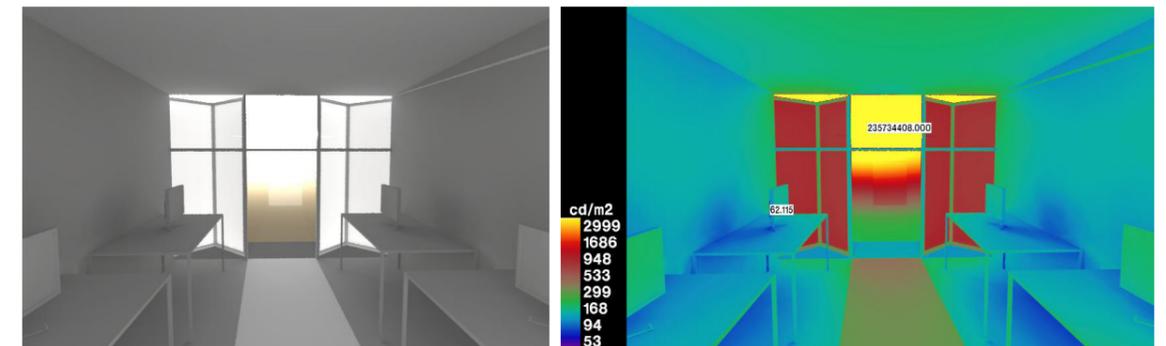


Fig 77 | Cherokee - 9/21 - 18:00 - 2nd state - Interior view. Fig 78 | Cherokee - 9/21 - 18:00 - 2nd state - Interior view.

Based on Fig 73 and Fig 74, the luminance values in both ergorama and panorama are almost the same, so the luminance ratio value is acceptable.

Regarding the interior-view pictures, Fig 75 and Fig 76, the sky is very bright and the luminance value at this area are too high. As a result, the luminance ratio has a high value which is not acceptable.

09 | 3 | 4 KIEFER TECHNIC SHOWROOM | South facing

- Daylit area |  $DA_{500LUX}[50\%] > 80\%$  of floor area = 98% ✓
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 84% ✓
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX}[50\%] > 60\%$  for the active occupant behavior = 68% ✓
- Glare |  $< 0.3\%$  of occupied hours = 0% ✓

The system does perform as required fulfilling all the conditions for visual comfort.

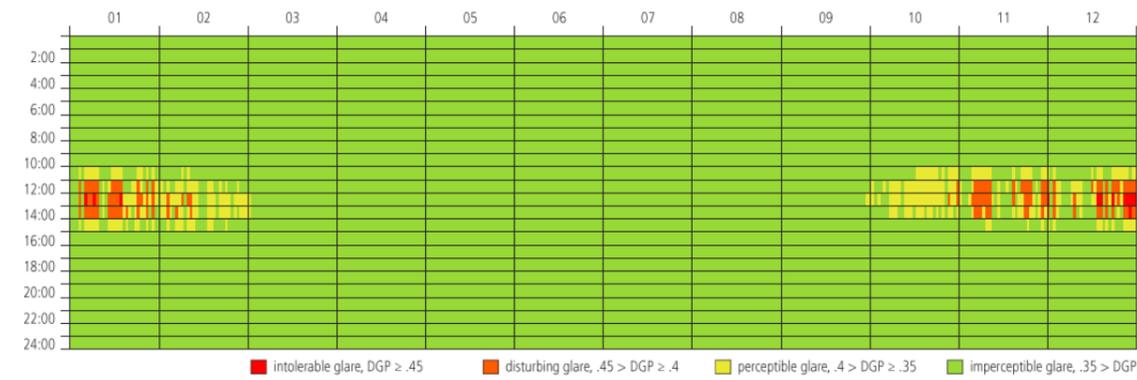


Fig 79 | Kiefer Technic Showroom - 1st state annual glare analysis.

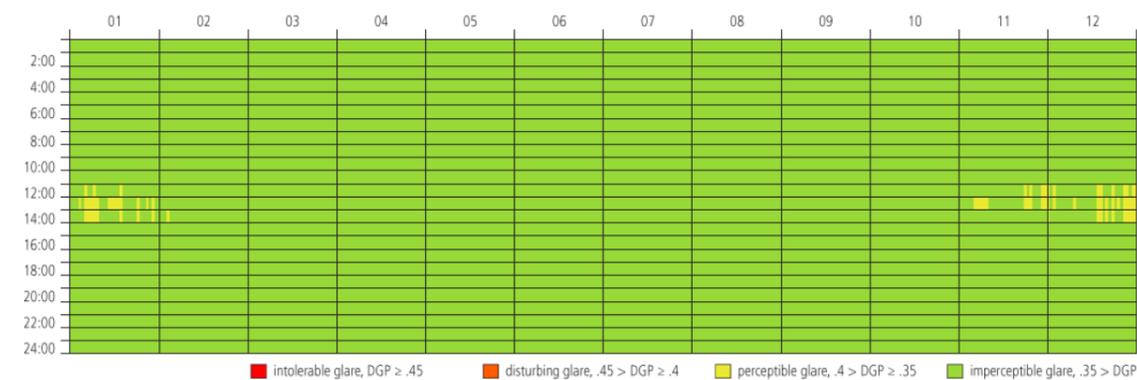


Fig 80 | Kiefer Technic Showroom - 2nd state annual glare analysis.

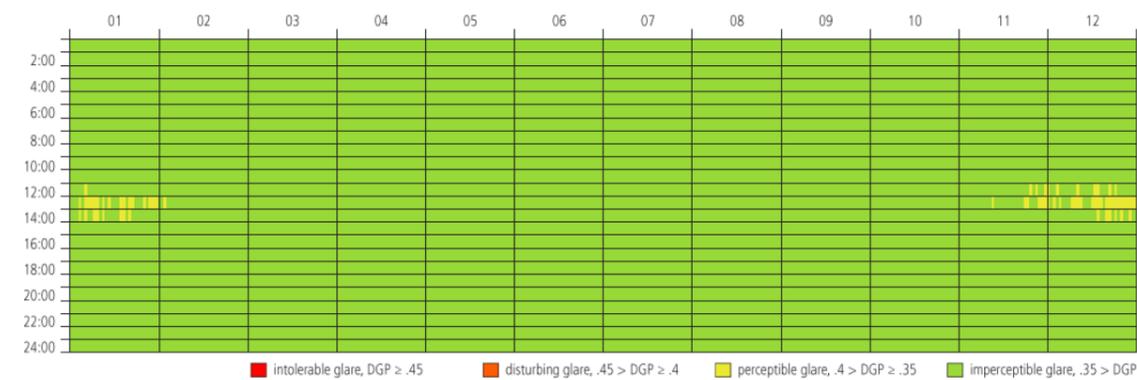


Fig 81 | Kiefer Technic Showroom - 3rd state annual glare analysis.

According to Fig 77-79, disturbing glare occurs only when the first state of the shading system is active. The two others provide acceptable conditions as far as it concerns visual comfort. So, the further analysis focuses on the first state. Glare is noticed during winter period, from 11:00 to 14:00, so the case which needs to be analyzed is the one at 12:00 on the 21<sup>st</sup> of December.

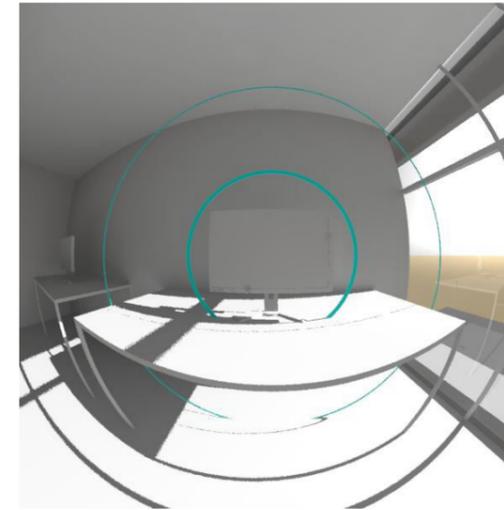


Fig 82 | Kiefer - 12/21 - 12:00 - 1<sup>st</sup> state - Computer view.

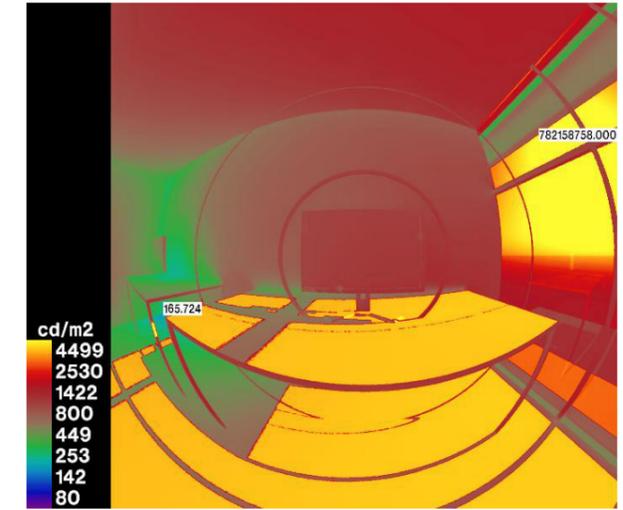


Fig 83 | Kiefer - 12/21 - 12:00 - 1<sup>st</sup> state - Computer view.



Fig 84 | Kiefer - 12/21 - 12:00 - 1<sup>st</sup> state - Interior view.

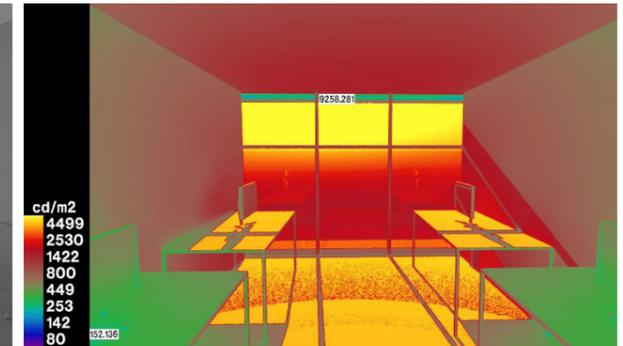


Fig 85 | Kiefer - 12/21 - 12:00 - 1<sup>st</sup> state - Interior view.

Based on Fig 80-83, even though luminance ratio is within acceptable limits, direct daylight enters unblocked the indoor space. In this case, glare and visual discomfort is caused by the intense daylight penetrating from the window opening.

09|3|5 THYSSENKRUPP QUARTIER Q1 | West facing

- Daylit area |  $DA_{500LUX}[50\%] > 80\%$  of floor area = 85% ✓
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 78% ✓
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX}[50\%] > 60\%$  for the active occupant behavior = 75% ✓
- Glare |  $< 0.3\%$  of occupied hours = 0.3% ✓

This system fulfills the requirements as well providing a pleasant indoor environment.



Fig 86 | Thyssenkrupp Quartier Q1 - 1st state annual glare analysis.



Fig 87 | Thyssenkrupp Quartier Q1 - 2nd state annual glare analysis.

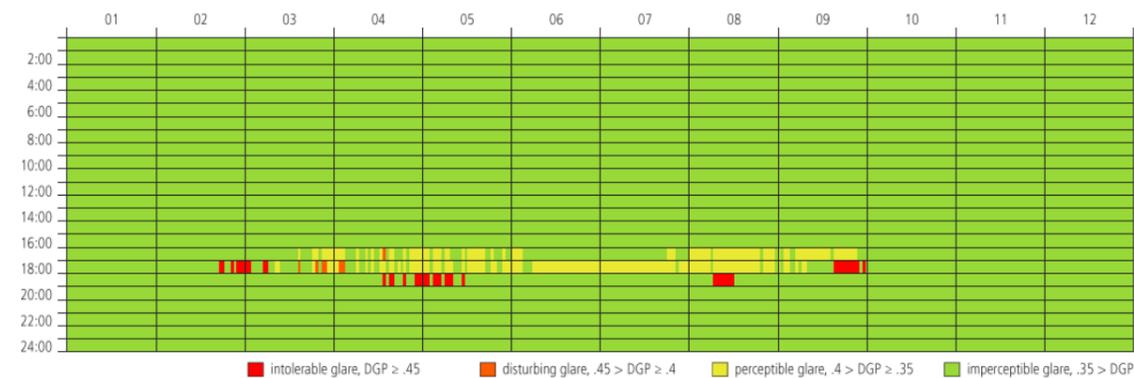


Fig 88 | Thyssenkrupp Quartier Q1 - 3rd state annual glare analysis.

According to Fig 84-86, none of the states protects totally from discomfort glare. The first state is the least efficient, presenting problems from February to September during evening hours. The performance of the second state is relatively optimized, being more efficient during summer months, while the third state of the shading system is the most efficient of all.

In an effort to understand better the way this shading system performs, indoor visualizations during the first state, on the 21<sup>st</sup> of June at 18:00 is justifying the experienced glare.

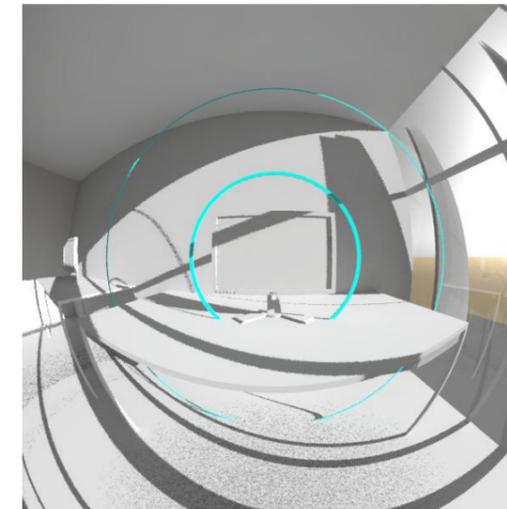


Fig 89 | Thyssenkrupp - 6/21 - 18:00 - 1<sup>st</sup> state - Computer view.

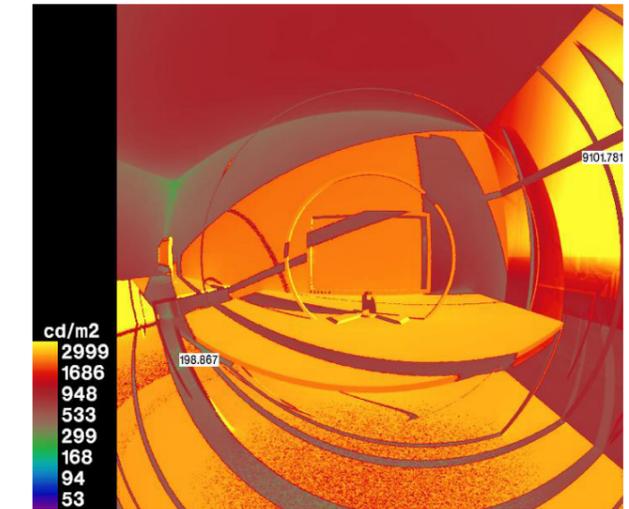


Fig 90 | Thyssenkrupp - 6/21 - 18:00 - 1<sup>st</sup> state - Computer view.

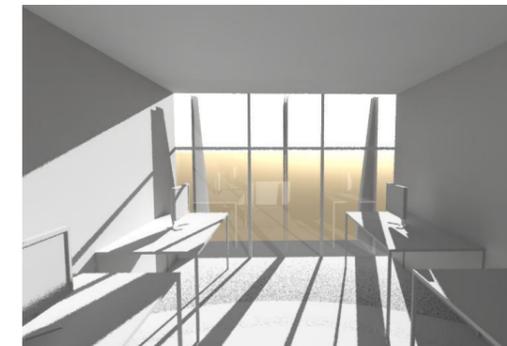


Fig 91 | Thyssenkrupp - 6/21 - 18:00 - 1<sup>st</sup> state - Interior view.

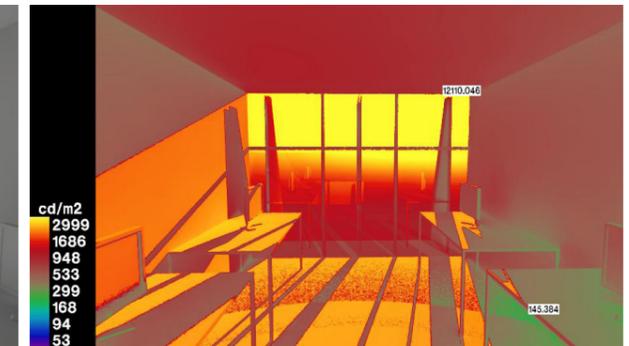


Fig 92 | Thyssenkrupp - 6/21 - 18:00 - 1<sup>st</sup> state - Interior view.

Based on Fig 87 and Fig 88, luminance ratio is within the acceptable limits as no extremes in luminance values are observed, though, direct daylight reaches the task fields which is unpleasant and unacceptable.

## 09 | 4 COMPARISONS

### 09 | 4 | 1 IN TERMS OF ORIENTATION

South

Requirements	Al bahar towers	Kiefer technic showroom
DA <sub>500lux</sub> [50%] >80	67%	98%
DA >80	65%	64%
UDI <sub>&lt;100-2000lux</sub> [50%] > 60%	79%	88%
Glare < 0.3%	0%	0%

Table 06 | Comparison of Daysim report results for south orientation.

The annual glare graphs of the two shading systems (refer to Fig 65 - 67 and Fig 79 - 81) justify that these two shading systems perform similar to each other. This is also validated by the values of the indices obtained which are almost the same, except for the Daylit Area. The Al bahar towers shading system provides less light to the interior of the room which is not adequate according to the requirements.

Furthermore, the annual glare graphs illustrate that the Al bahar towers' shading system performs more efficiently at the first state. However, the differences are too small and by taking into account that the first case obstructs a large part of the view to outside, they are considered as negligible. Concluding the most efficient shading system is the one at Kiefer technic showroom.

West

Requirements	Tessellate	Cherokee lofts	ThyssenKrupp Quartier Q1
DA <sub>500lux</sub> [50%] >80	84%	89%	85%
DA >80	69%	81%	78%
UDI <sub>&lt;100-2000lux</sub> [50%] > 60%	73%	71%	75%
Glare < 0.3%	0.6%	0.1%	0.3%

Table 07 | Comparison of Daysim report results for west orientation.

According to Table 07, the most efficient system is the one at the Cherokee lofts. It provides the largest amount of light while at the same time it protects from glare. As it is already mentioned, the glare percentage refers to the dynamic shading system, therefore to the optimum combination of the three states. Though, each one of the states of the Cherokee lofts shading device is more efficient than the respective states of the other two devices. The graphs illustrating the annual glare (refer to Fig 54 - 56, Fig 72 - 74 & Fig 86 - 88) justify the most efficient performance of the Cherokee lofts' system.

More analytically, the Tessellate system is already exempted from the comparison as its performance is not acceptable. On the other hand, the Cherokee lofts' system and the ThyssenKrupp Quartier Q1 are quite similar to each other, concerning both geometry and performance. In an attempt to specify their performance in detail, the comparison between their most extreme differences is necessary. The performance of the first and the second states are almost the same. However, their efficiencies during the second state appear some differences. The first case presents acceptable glare values, in contrast with the second case that presents disturbing lighting conditions. So focusing on the 2nd state, on the 21<sup>st</sup> of March at 18:00, an analysis of the indoor visualizations is helpful.

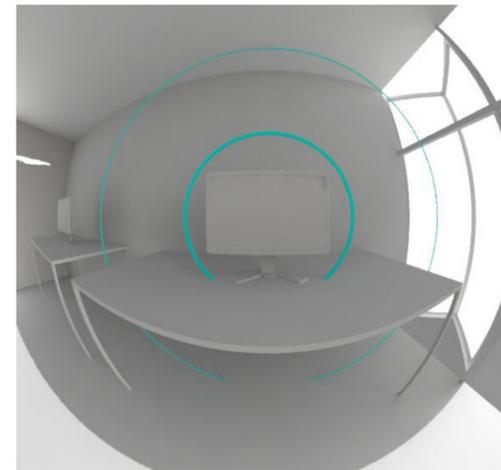


Fig 93 | Cherokee - 3/21 - 18:00 - 2<sup>nd</sup> state - Comp. view.

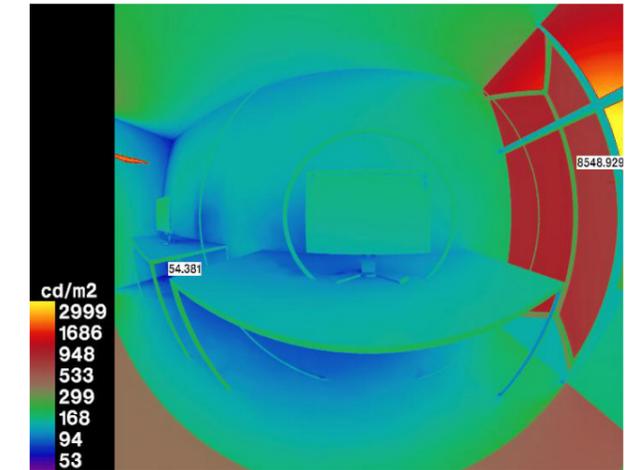


Fig 94 | Cherokee - 3/21 - 18:00 - 2<sup>nd</sup> state - Computer View.

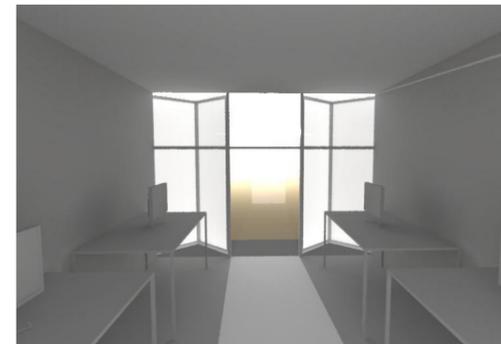


Fig 95 | Cherokee - 3/21 - 18:00 - 2<sup>nd</sup> state - Interior view.

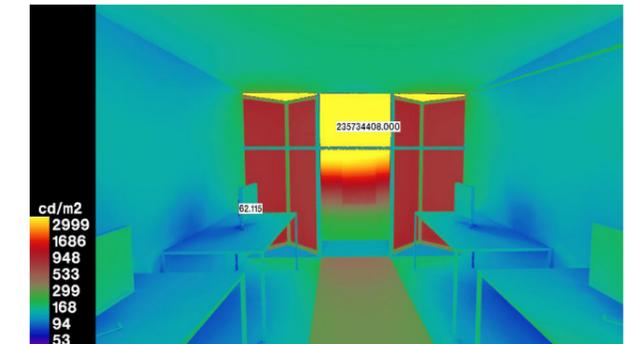


Fig 96 | Cherokee - 3/21 - 18:00 - 2<sup>nd</sup> state - Interior View.

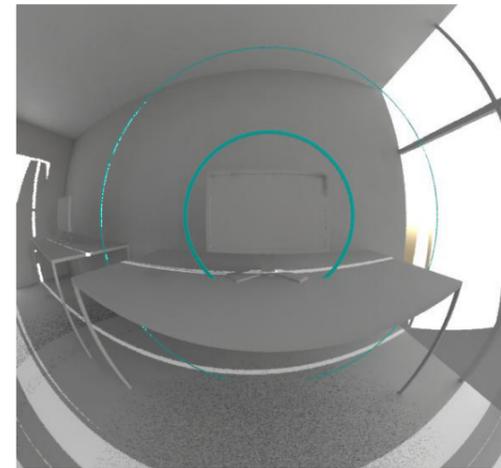


Fig 97 | Thyssenkrupp - 3/21 - 18:00 - 2<sup>nd</sup> state - Comp. view.

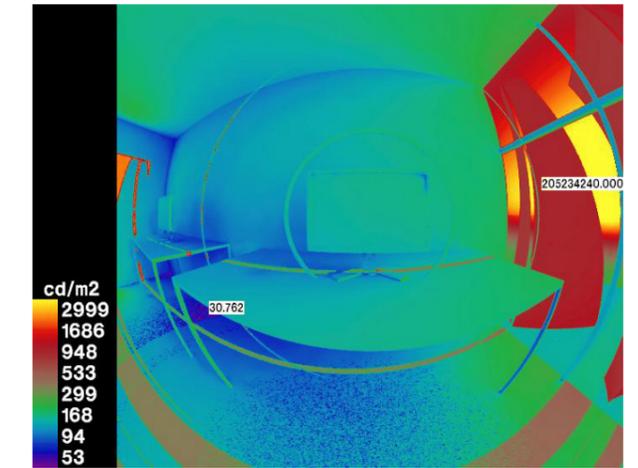


Fig 98 | Thyssenkrupp - 3/21 - 18:00 - 2<sup>nd</sup> state - Comp. view.

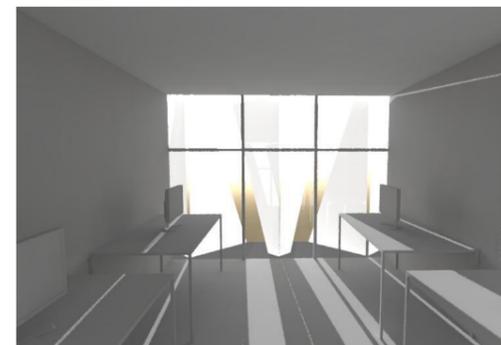


Fig 99 | Thyssenkrupp - 3/21 - 18:00 - 2<sup>nd</sup> state - Inter. view.

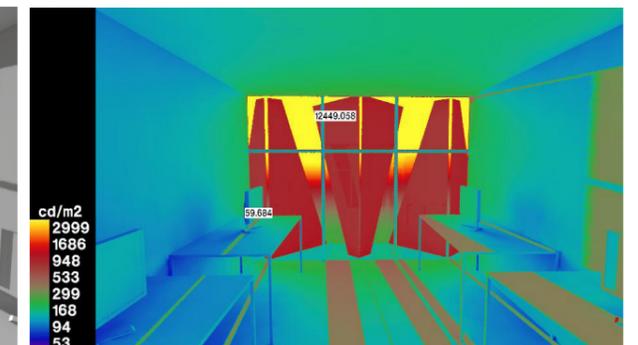


Fig 100 | Thyssenkrupp - 3/21 - 18:00 - 2<sup>nd</sup> state - Interior view.

It is hard to detect the differences concerning the lighting conditions for these two cases in order to define the cause visual discomfort at the second case. Though, it is obvious that the ThyssenKrupp Quartier Q1 causes too hard shadows and a disturbing pattern. The luminance ratio values are within acceptable values, but still this fluctuation of luminance values may be disturbing. The uniformity obtained is not the desired one. At the same time, this shading system provides less view to outside as it is fixing in the middle of the window. Even when solar control is not required, the shading system is obvious blocking a general view to outside.

## 09 | 4 | 2 IN TERMS OF ADAPTATION MECHANISM

There are various adaptation mechanisms that can be incorporated in adaptive shading systems. The ones presented so far are the most representative ones. Their efficiency is influenced by many aspects as the location, the orientation, the period of the year. It is interesting to compare the performance of the same shading principle in different orientations. The Kiefer technic showroom and the Cherokee lofts use the same shading principle which is the folding of the geometry at the edges of the opening. In the first case which is south oriented, the geometry has a horizontal axis and it folds at the lintel and the sill of the window. On the contrary, the second case is west oriented and the geometry folds at the sides of the window having a vertical axis. Except for the fact that these two cases have the same shading principle, they are the most efficient ones for the south and the west orientation respectively.

Requirements	Kiefer technic showroom	Cherokee lofts
$DA_{500\text{lux}} [50\%] > 80$	98%	89%
$DA > 80$	64%	81%
$UDI_{<100-2000\text{lux}} [50\%] > 60\%$	88%	71%
Glare < 0.3%	0%	0.1%

Table 08 | Comparison of Daysim report results of shading systems with the same shading principle.

In terms of glare, both of the systems perform efficiently. Though, the amount of light that they provide fluctuates a lot. The first case, completes the requirements regarding the Daylit area and the UDI. However, the DA value is not acceptable. This means that the illuminance values are not adequate throughout the whole year. On the other hand, the second case fulfills all the requirements.

The annual glare graphs (refer to Fig 79 - 81 and Fig 72 - 74) describe in detail the performance of each one. In the first case, glare occurs only when the first state is activated and specifically from November until January at noon. This means that there is an efficiency problem when the sun is at low positions, fact that is expected because of the geometry of the shadings system. In the second case, the first state is the least efficient causing glare from March until September during afternoon hours. Hence, the drawback of the system is that it cannot block daylight when the sun is at high positions. The visualizations of the computer and the window view during both 21<sup>st</sup> of June and 21<sup>st</sup> of December will illustrate the drawbacks of each system.

21<sup>st</sup> June

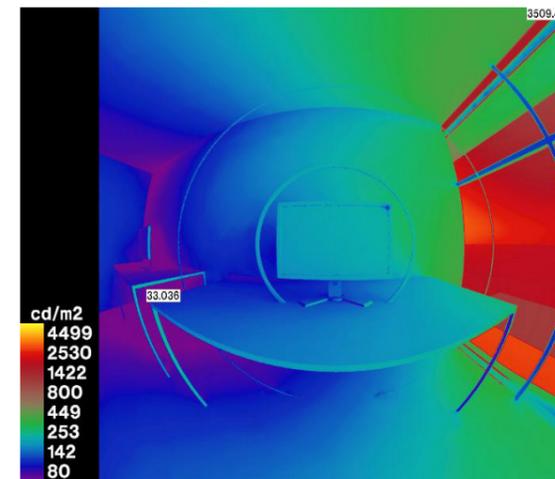


Fig 101 | Kiefer - 6/21 - 8:00 - 1<sup>st</sup> state - Computer view.

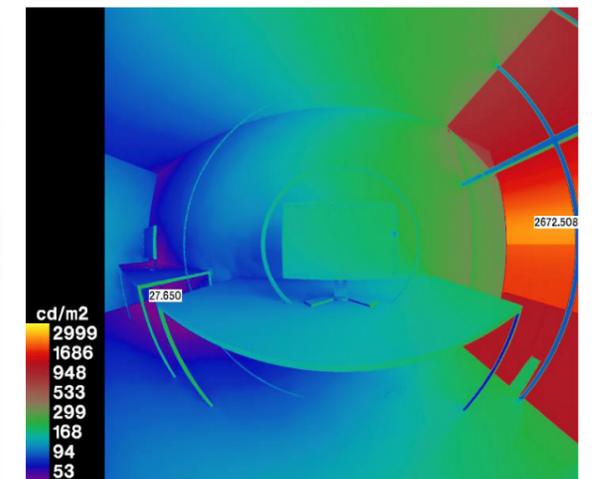


Fig 102 | Cherokee - 6/21 - 8:00 - 1<sup>st</sup> state - Computer view.

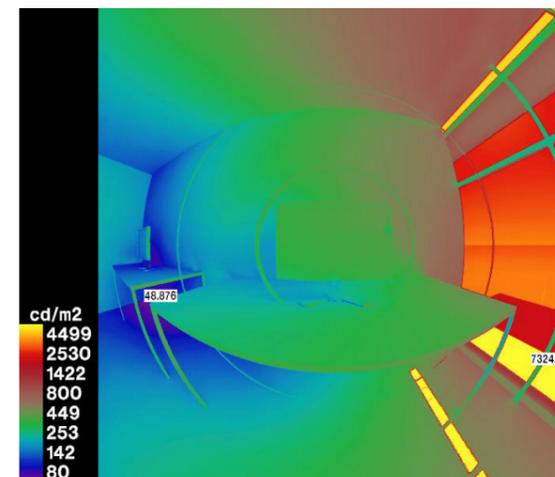


Fig 103 | Kiefer - 6/21 - 12:00 - 1<sup>st</sup> state - Computer view.

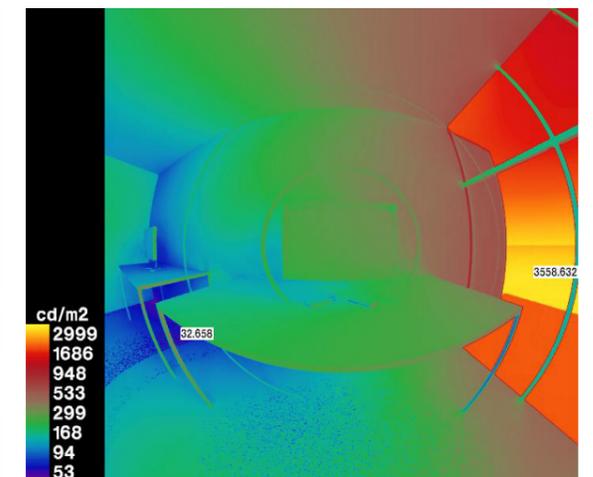


Fig 104 | Cherokee - 6/21 - 12:00 - 1<sup>st</sup> state - Computer view.

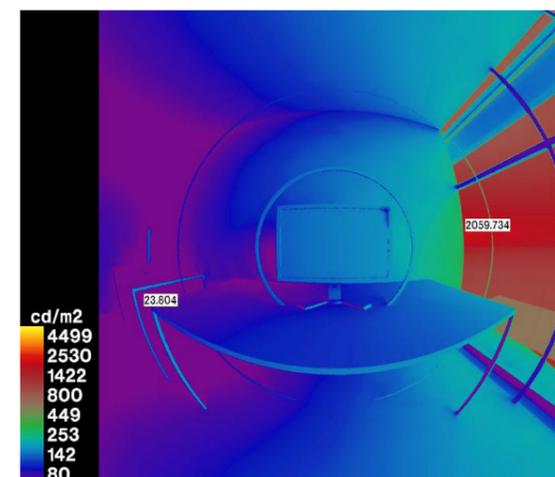


Fig 105 | Kiefer - 6/21 - 18:00 - 1<sup>st</sup> state - Computer view.

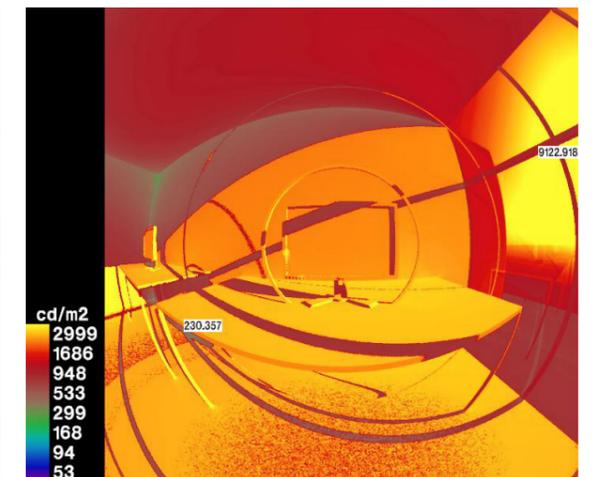


Fig 106 | Cherokee - 6/21 - 18:00 - 1<sup>st</sup> state - Computer view.

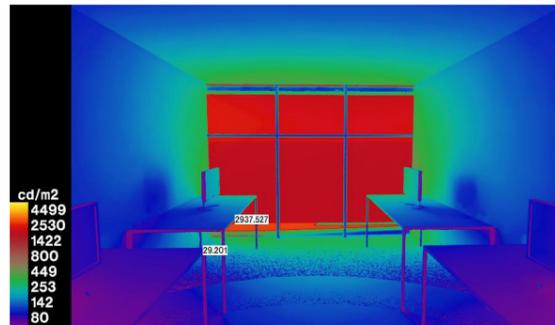


Fig 107 | Kiefer - 6/21 - 8:00 - 1<sup>st</sup> state - Interior view.

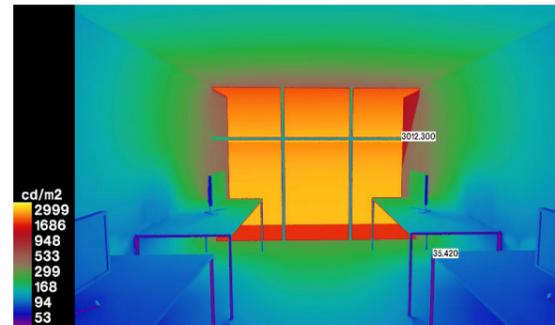


Fig 108 | Cherokee - 6/21 - 8:00 - 1<sup>st</sup> state - Interior view.

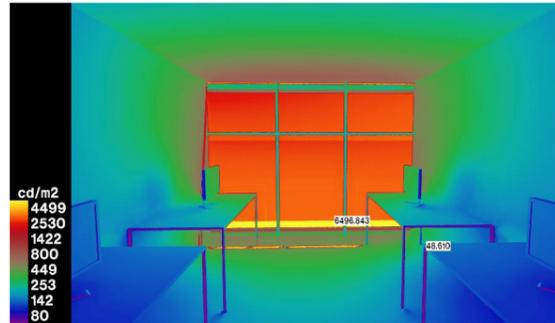


Fig 109 | Kiefer - 6/21 - 12:00 - 1<sup>st</sup> state - Interior view.

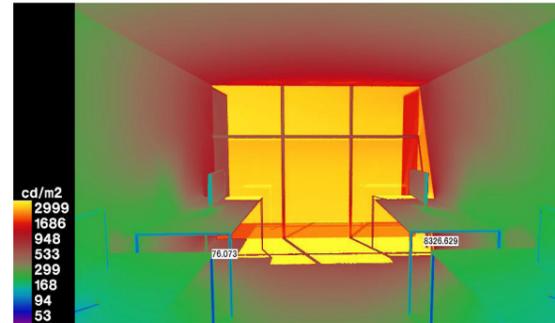


Fig 110 | Cherokee - 6/21 - 12:00 - 1<sup>st</sup> state - Interior view.



Fig 111 | Kiefer - 6/21 - 18:00 - 1<sup>st</sup> state - Interior view.

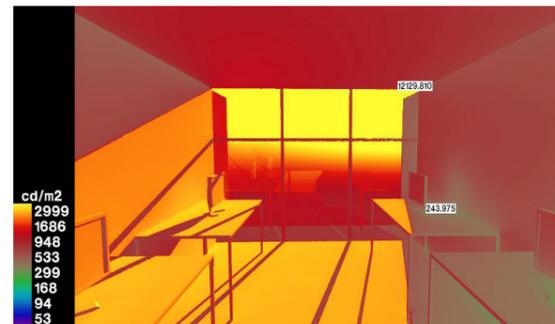


Fig 112 | Cherokee - 6/21 - 18:00 - 1<sup>st</sup> state - Interior view.

According to the annual glare graphs, the performance of the Cherokee lofts' system is not efficient during summer months. This fact can be noticed at the pictures illustrated above. As it is already mentioned, direct daylight may cause discomfort and glare. This is the situation during afternoon hours when a large amount of daylight enters indoor space.

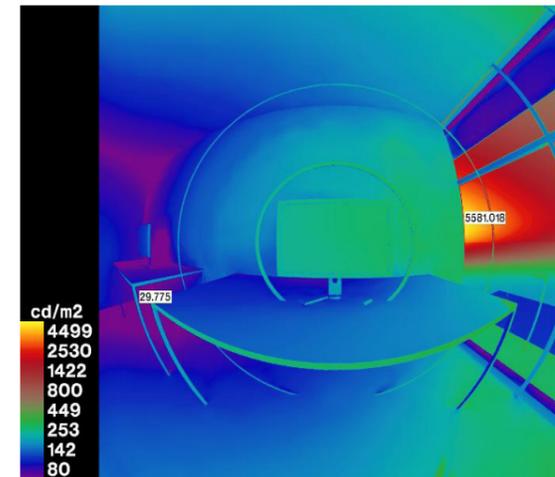


Fig 113 | Kiefer - 12/21 - 8:00 - 1<sup>st</sup> state - Computer view.

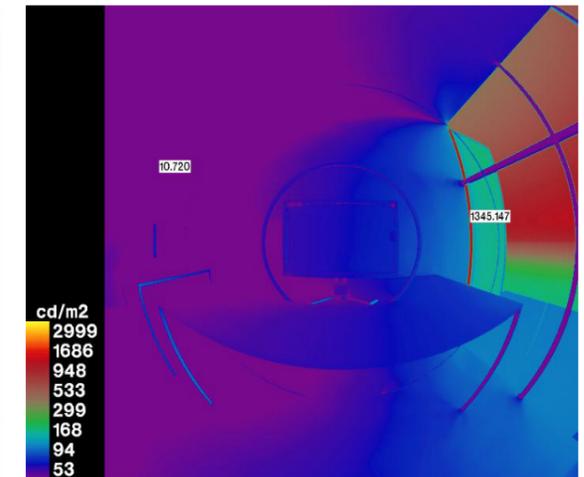


Fig 114 | Cherokee - 12/21 - 8:00 - 1<sup>st</sup> state - Computer view.

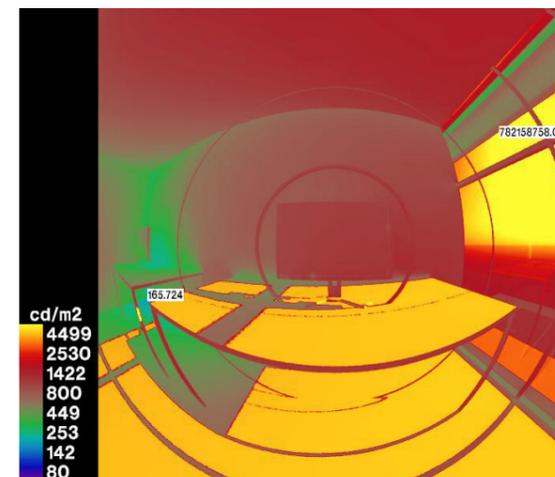


Fig 115 | Kiefer - 12/21 - 12:00 - 1<sup>st</sup> state - Computer view.

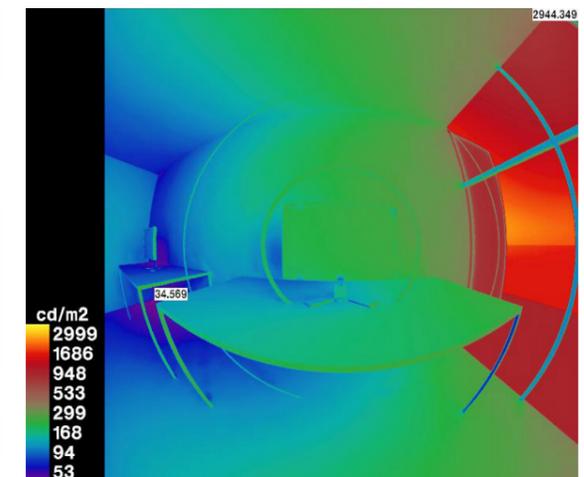


Fig 116 | Cherokee - 12/21 - 12:00 - 1<sup>st</sup> state - Computer view.

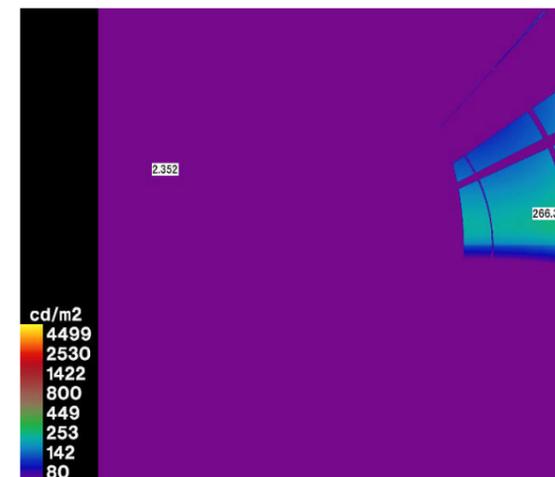


Fig 117 | Kiefer - 12/21 - 18:00 - 1<sup>st</sup> state - Computer view.

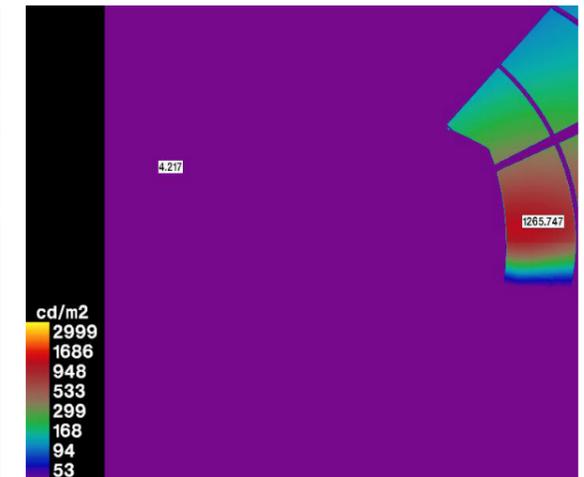


Fig 118 | Cherokee - 12/21 - 18:00 - 1<sup>st</sup> state - Computer view.

### 09 | 4 | 3 KIEFER TECHNIC SHOWROOM\_WEST - CHEROKEE\_WEST

In the previous chapters, Kiefer technic showroom appears to be the most efficient, based on the requirements set for this graduation project. According to the general rules, this system is more efficient when it is south orientated because of its geometry which has a horizontal axis. It is interesting though, to investigate how this shading system performs when it is west oriented. Based on the annual glare analysis results, its efficiency is equivalent to the ones designed for west orientation. This is actually justified by the fact that its geometry has a horizontal axis, but expands vertically. Hence, at the second and third state it complies with the rules set for west oriented shading devices.

The annual glare graphs illustrate the problematic periods of this shading system.

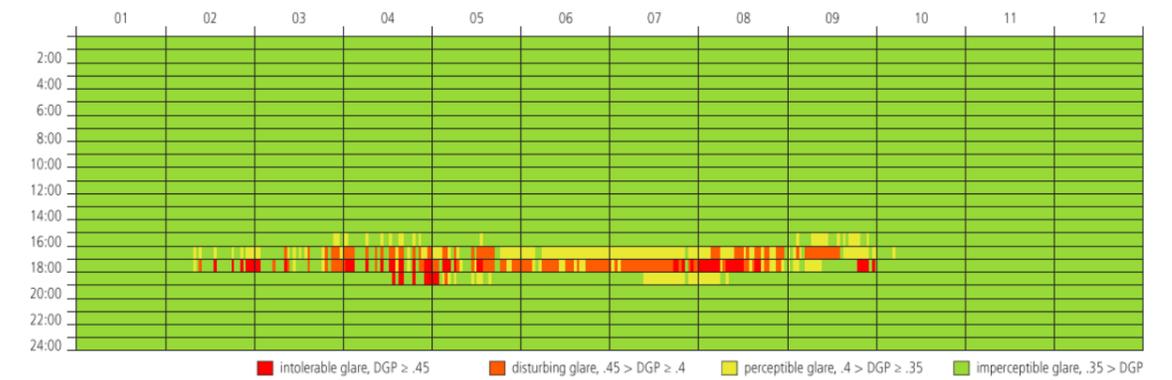


Fig 125 | Kiefer technic showroom\_west\_1st state annual glare analysis.

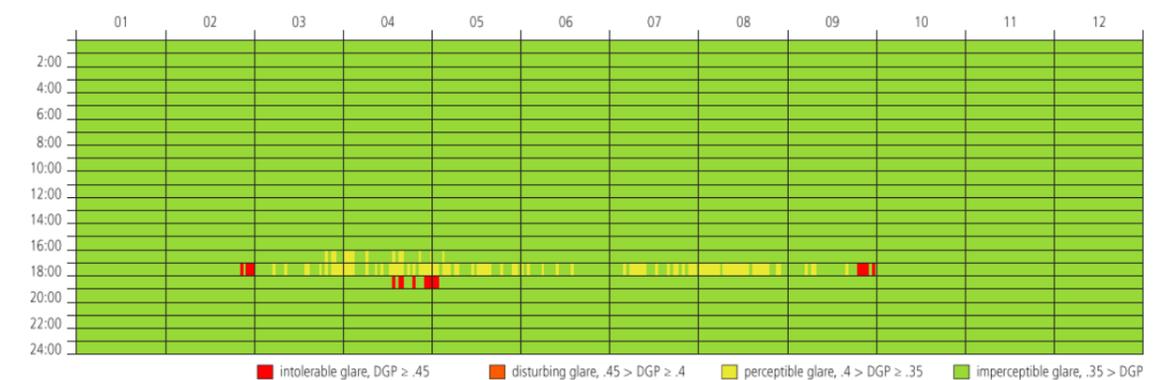


Fig 126 | Kiefer technic showroom\_west\_1st state annual glare analysis.

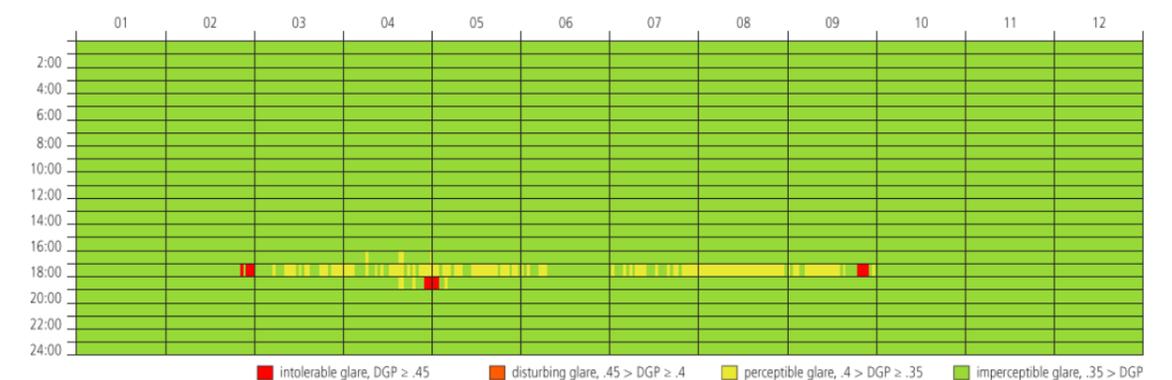


Fig 127 | Kiefer technic showroom\_west\_1st state annual glare analysis.

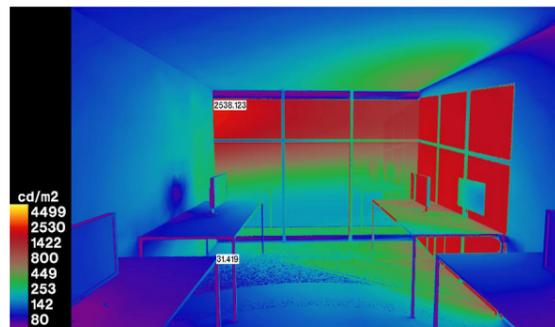


Fig 119 | Kiefer - 12/21 - 8:00 - 1<sup>st</sup> state - Interior view.

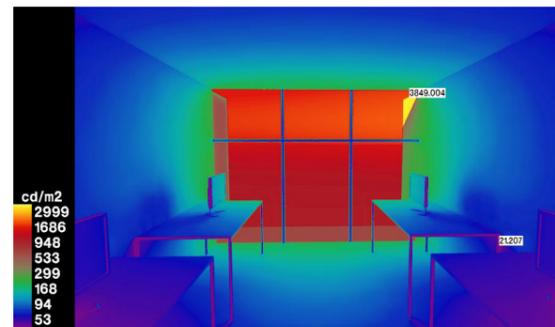


Fig 120 | Cherokee - 12/21 - 8:00 - 1<sup>st</sup> state - Interior view.

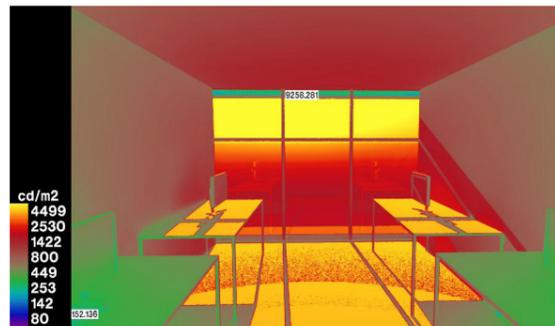


Fig 121 | Kiefer - 12/21 - 12:00 - 1<sup>st</sup> state - Interior view.

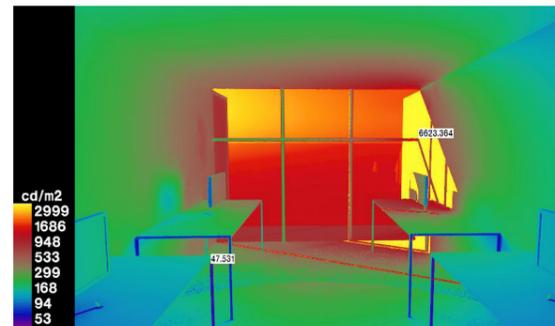


Fig 122 | Cherokee - 12/21 - 12:00 - 1<sup>st</sup> state - Interior view.

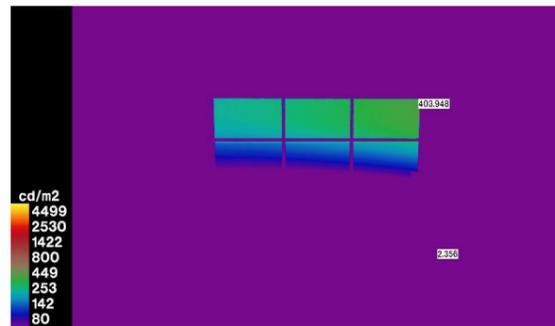


Fig 123 | Kiefer - 12/21 - 18:00 - 1<sup>st</sup> state - Interior view.

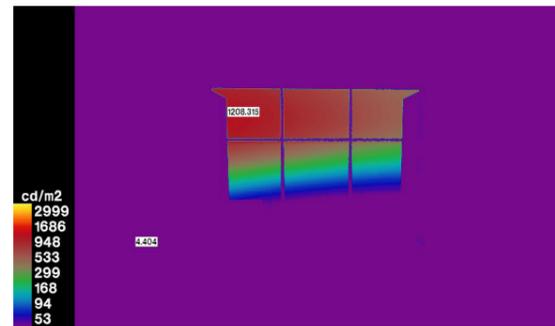


Fig 124 | Cherokee - 12/21 - 18:00 - 1<sup>st</sup> state - Interior view.

Accordingly to the annual glare graphs, the Kiefer technic showroom does not perform as required during winter time. This is indeed confirmed by the indoor visualizations. It is obvious that from the beginning of the day until noon the daylight penetrating from the opening is direct and not filtered at all. These conditions are capable of causing visual discomfort. On the other hand the Cherokee lofts' system appears to perform ideally, creating a pleasant indoor environment.

To sum up, both of these shading system present performance problems concerning either glare protection or daylight autonomy. Nonetheless, glare protection is one of the most important requirements, so the **Kiefer technic showroom** is the one performing in the most efficient way.

The daysim report gives analytical information about the performance of the system. It is interesting to compare it with the most efficient shading system of the ones selected for west orientation.

Requirements	Kiefer technic showroom west	Cherokee lofts west
DA <sub>500lux</sub> [50%] >80	79%	89%
DA >80	75%	81%
UDI <sub>&lt;100-2000lux</sub> [50%] > 60%	79%	71%
Glare < 0.3%	0.1%	0.1%

Table 09 | Comparison of Daysim report results of shading systems with the same shading principle and orientation.

Most of the values are acceptable, except for the daylight autonomy value which is slightly lower than the required one. So, this system performs efficiently at both south and west orientation. The comparison between the two systems shows that both of them are quite efficient. The only drawback of the first system is that it provides less daylight to the interior, without it being a really important characteristic of the system. The values of the first two indices, which are the daylit area and the daylight autonomy, show that its performance is almost acceptable. More specifically, the daylit area value as required, meaning that a sufficient percentage of space has adequate lighting for more than half of the working day. On the other hand, the daylight autonomy value, which expresses that mean value and is slightly lower than required, shows that there are low values during the day.

In order to understand better the way this system performs, indoor visualizations (Fig 128-131) during the problematic periods are useful. Based on the annual glare graphs, the glare problems occur from February until September. The visualizations illustrate the situation on the 25<sup>th</sup> of June at 18:00.

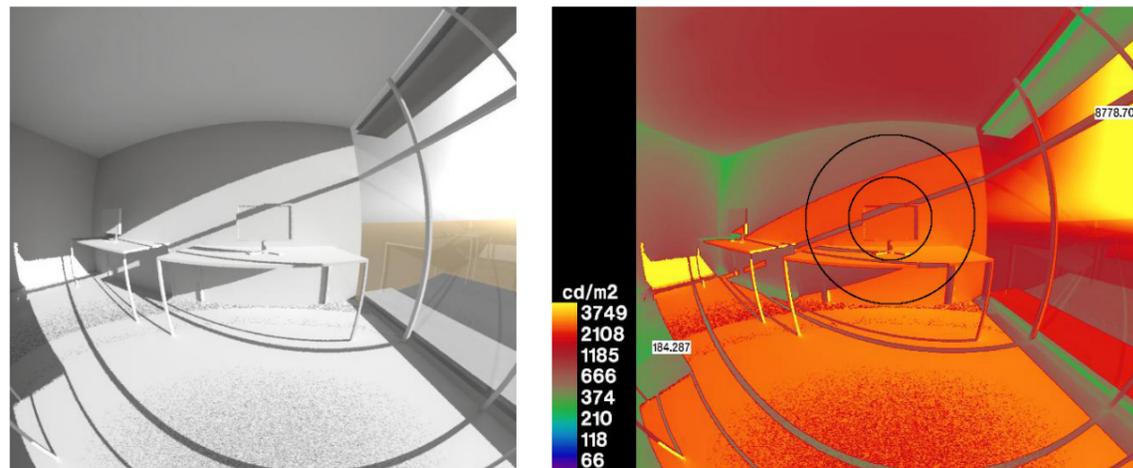


Fig 128 | Kiefer - west - 6/25 - 18:00 - 1<sup>st</sup> state - Comp. View. Fig 129 | Kiefer - west - 6/25 - 18:00 - 1<sup>st</sup> state - Comp. View.

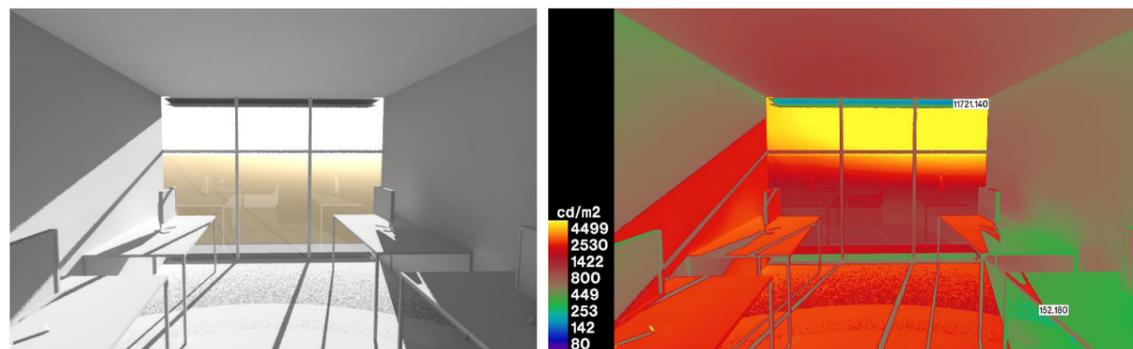


Fig 130 | Kiefer - west - 6/25 - 18:00 - 1<sup>st</sup> state - Inter. View. Fig 131 | Kiefer - west - 6/25 - 18:00 - 1<sup>st</sup> state - Inter. View.

10 | 1 DESIGN RESEARCH

Design research is a very important and demanding procedure, during which all the gained knowledge has to be recalled. The exploitation of the knowledge and the personal experience is the key for designing an efficient and innovative solar shading system. At first the theory of daylight and afterwards the appropriate evaluation of existing systems, technologies and materials can lead to a promising solar shading design.

It is a time-consuming procedure which requires trials of various designs and their evaluation. The analysis of the performance of each proposed design is extremely important for the advance of this procedure. Constant optimizations and abundance of new design ideas are the intermediate steps before the conclusion to the most efficient shading system. A design should be evaluated in terms of both visual comfort and performance. The main objective of this graduation thesis is visual comfort. Nevertheless, the way a system performs is equally important. Simplicity in construction, performance and maintenance should always be the goals.

In this case, during the design research various shading systems were proposed and evaluated. Experimentations with movement mechanisms and materials led to the final design. The selection criteria were the performance efficiency, the simplicity and the innovation. The design research process is briefly presented at the following table via some examples of the proposed designs:

Concept	Fabric layers	Calatrava garage door	Twisting ropes	Origami foldable fins	3-dimensional interweaving		
Preliminary ideas							
Concept	Stretchable fabric as movement mechanism	3 point expansion for both vertical and horizontal shading	Scissors	Pistons	Brackets - Curtain system	Stretchable fabric creating 3-dimensional shading system	Non-elastic fabric rolling like a conveyor belt
1 <sup>st</sup> state							
2 <sup>nd</sup> state							

Table 14 | Proposed design concepts.

Various designs and systems were proposed, analyzed and finally rejected. More analytically, experimentations with stretchable or nonelastic fabrics and movement mechanisms as well are proven to be deficient.

Fabrics are proposed as building envelope materials lately because they are lightweight. Under this idea, fabrics could be used for a lightweight solar shading system as well. Proposed designs used the textile either as covering or instead of movement mechanisms. Both of these ideas were rejected. Stretchable fabrics are not appropriate for exterior use as they are not UV-resistant, while nonelastic fabrics were more promising but still not good enough as they demanded too complicated supporting systems. Continuing with the movement mechanisms, various designs have already been proposed and tested. In general, innovative designs are sought out. The question though is whether they are efficient enough or not and whether the cost for the construction, the installation and the maintenance is paid back by the energy saving. During design research all of the proposed mechanisms were characterized as too complicated or not worthy and finally rejected.

As a result, a new approach to the idea of adaptation was introduced. The new ambition was to design a very simple and adaptive solar shading system.

## 10|2 GOALS

It is a fact that there is not perfect sun shading system. Each building has different characteristics demanding different types of shading devices in order to fulfill them. However, the real problem comes when the building is multifaceted and different orientations have to be shaded.

The goal of this graduation thesis is to design a solar shading system which will adapt not only to the needs of the users throughout the day and the year but also the orientation of the façade. According to the basic rules for shading devices, the south oriented façades need horizontal shading elements while the east/west oriented façades need vertical ones.

The challenge is to design a solar shading system which changes its direction and can be both horizontal and vertical. The change in direction is a relatively new concept and thus unexplored. There are a few examples of shading systems based on this principle, but usually they perform in a very complicated way. This complexity causes extra construction and maintenance costs for the shading system. To conclude, change in direction and simplicity are the goals of the new design.

## 10|3 THE CONCEPT

The need for both horizontal and vertical elements necessitates the presence of a grid. So, the basic idea of the proposed shading system is a 3-dimensional grid placed in front of the building's envelope. Depth is also essential for the shading as it influences the efficiency of the shading system. The grid though blocks the view to outside and may also block daylight even when it is desired. So, the need for fluctuation in opacity is now introduced. The research for materials which are able to change their opacity coefficient highlighted the technology of smart glasses. There are already applications of the smart glass technology, but they are basically replacing the common vertical glazing of doors and windows. The innovation in this design is the fact that the smart glass components are vertical and horizontal, always perpendicular to the façade, so that they do not cover the total opening and they allow view to outside.

In conclusion, the main idea of this design is the change of the shading system's transparency. When shading is not required, the whole shading system can be transparent and almost invisible. On the other hand, when the sun is too intense and direct light penetrates the room, particular horizontal and/or vertical blades are able to become translucent according to the needs. Separate control systems can be installed to provide the opportunity of a dynamic façade. Each horizontal and the vertical blade can be switched on and off independently in order provide proper lighting conditions to the interior.

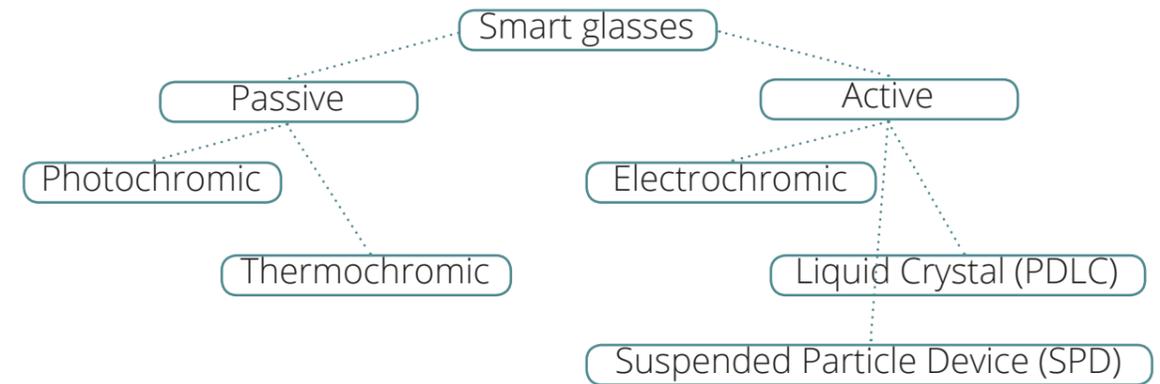
### 10|3|1 SMART GLASSES

Smart glass technology aims on controlling the amount of light and heat passing through. The main characteristic of these glasses is the fluctuation concerning their transparency or colour.

Passive smart glasses respond to UV radiation and heat (non-electrical stimuli), so cannot be controlled. In contrast, Active smart glasses respond to electrical stimulus and can be controlled manually or automatically. ("Smart Glass Windows," 13:02:10 UTC)

The control of the shading system is essential, thus active smart glass is necessary for this application. Electrochromic glass change its colour when electric current is applied on it, its disadvantage though is the switching speed which is very low. On the other hand, Suspended Particle Device switch states in only 2 seconds, but the disadvantage in this case is the blue colour at its darkest state. As a result the PDLC technology is the most appropriate for the proposed shading system.

## 10|3|2 POLYMER DISPERSED LIQUID CRYSTAL



The principle of this technology is the control the transparency coefficient of the glass only by applying electrical power. The glass panel can switch from the translucent state to the transparent one when current flows. The PDLC technology makes use of micro droplets of crystals which are encapsulated in a polymer matrix (film). In a static state, the liquid molecules are randomly oriented in the mixture refracting the light "hitting" on it. However, when electricity is applied, the molecules line up the direction of the electrical field, so the liquid crystals arrange in order and the light is now able to pass through and transmit. The switch between the transparent and the opaque (milky white or gray) state occurs in less than a second, directly when current is applied. It is also worth mentioning that the film does not degrade over the years.



Fig 132 | PDLC application. Source | <http://phaidonatlas.com/building/school-visual-arts/77015>.

This film is flexible but slightly stiff and fragile, so it requires protection. It can be adhesive, and so attached on transparent surfaces or laminated constituting the interlayer of a panel. This panel is composed of the switchable PDLC film of 1.2mm thickness, ITO-PET films which act as conductors, two high adhesion plastic interlayers (EVA/PVB) of 0.4mm thickness and two monolithic sheets, as the external layers. Glass or plastic sheets can be used at the sides, though glass is more suitable for façade applications as it is very clear and scratch-proof. The glass sheets may vary in thickness and characteristics. Different types of glass can be used in order to fulfill the needs of each application. Annealed, heat strengthened or fully tempered glass can be used depending on the required characteristics. Nonetheless, the lamination process makes the glass shatter proof and able to resist penetration. If one of the panes is broken, the laminated glass stays on place and can still carry the loads. Even so, the matter of safety is too important, especially for applications at the exterior. In this case, heat strengthened or fully tempered glass is preferable for even more secure product.

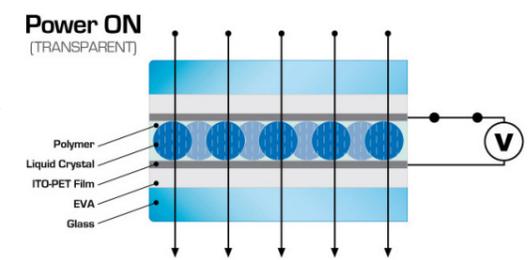


Fig 133 | PDLC-Transparent state.

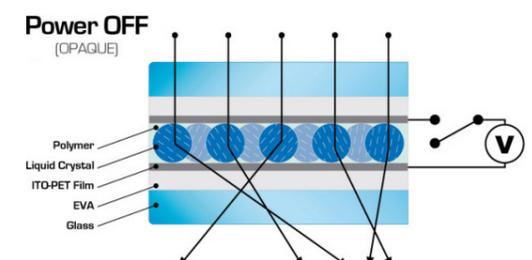


Fig 134 | PDLC-Translucent state.

Due to the fact that the space is used as an office room and daylight is required, a glass with high transmittance coefficient is needed. For this reason, the smart glass with the white colored translucent state has been selected, which has the following characteristics:

#### Technical specifications (white)

Transmittance (translucent state)	67%
Transmittance (transparent state)	75%
UV block	>98%
Solar reduction	40%
Operating temperature	-25°C - 85°C
Operating voltage	110 Volt AC
Energy use	0.4 Watt/m <sup>2</sup>
Specific weight	2.5 kg/m <sup>2</sup> (1mm)
Switching time	<0.1 s

("Switchable Privacy Glass Product Specifications," n.d. & "GLASS ON WEB-SmartGlass International," n.d.)  
Product specifications in APPENDIX D.

#### 10|4 DEFINING GEOMETRY

The dimensions of the blades and the distance between them are variables which can be defined according to the needs of each space. Based on the scope of this study, the room has an opening of 3.6m. \* 2.7m. and is located on the 10<sup>th</sup> floor of an office building in Athens (Fig 135 and Fig 136). The optimum combination of the width and the distance is examined in terms of visual comfort. DIVA for Rhino is used for simulating the indoor daylight conditions and conclude to the most efficient one. Two new materials are created and imported in the software representing the two states of the PDLC glass. The first one is based on the characteristics of PDLC glass when it is "off" and translucent. The second one represents the transparent state of the glass, when it is "on". Both of them have a high reflectance coefficient and are defined as glossy in order to depict the shading systems components which are made out of laminated glass.

Various combinations are simulated in order to conclude to the most efficient one. Annual glare analysis is time consuming and there is need for quick simulations of each system, indoor visualizations are selected as the most appropriate. Both the computer and the interior view are used for evaluating the systems. The annual glare analysis of the reference room has already highlighted the most critical periods for south and west orientation, thus the visualizations take place on the 21<sup>st</sup> of June for west orientation and 21<sup>st</sup> of December for south orientation. The first simulations examine the least possible elements in order to obtain a lightweight system which will provide unblocked view to the exterior. Though, the results are not acceptable, according to the system requirements set in the previous chapters. Hence, other grid combinations are examined in terms of the requested light conditions.

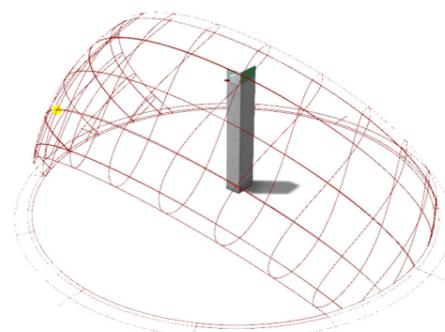


Fig 135 | South oriented facade.

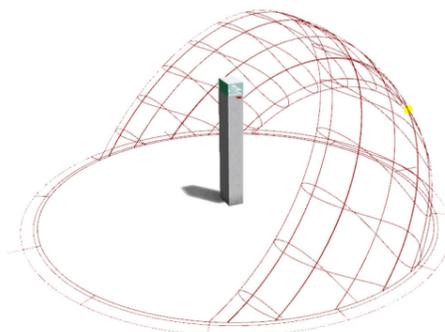


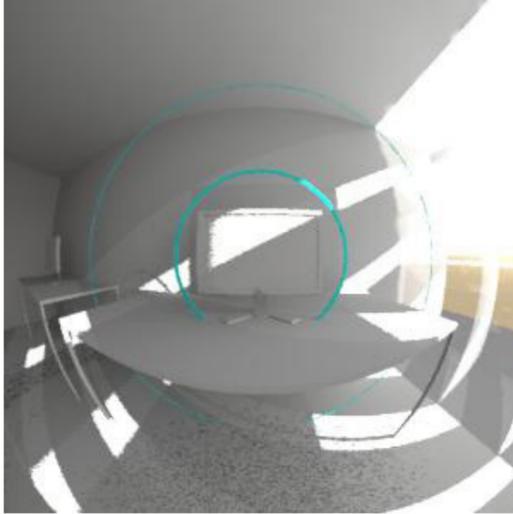
Fig 136 | West oriented facade.

As it is already mentioned the depth and the distance between horizontal and the vertical blades are the two variables which can be changed in order to obtain the most efficient shading system. After evaluating these two possibilities and their influence on the shading system, it is concluded that the first variable to be tested is the depth of the system. It is preferable to scale up the depth of the system, than add extra elements which will make system more dense. The deeper the system is, the more shadow it provides. However, there are constraints for the depth as well in order for this system to be stable enough and properly connected to the building.

The following figures illustrate the visualizations of the tested combination and justify why they have been rejected:

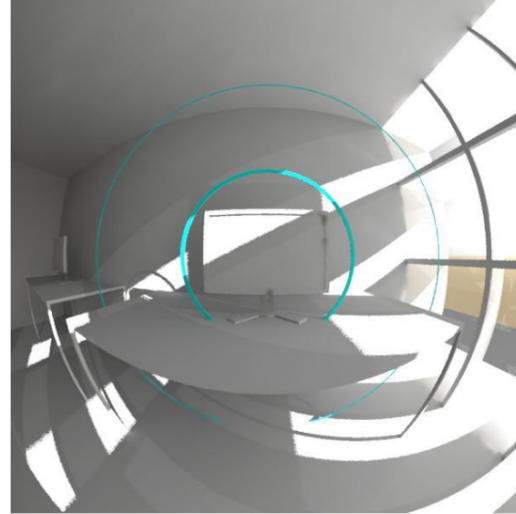
TESTED COMBINATIONS' OVERVIEW

1.20 every 0.80 | 3 pieces

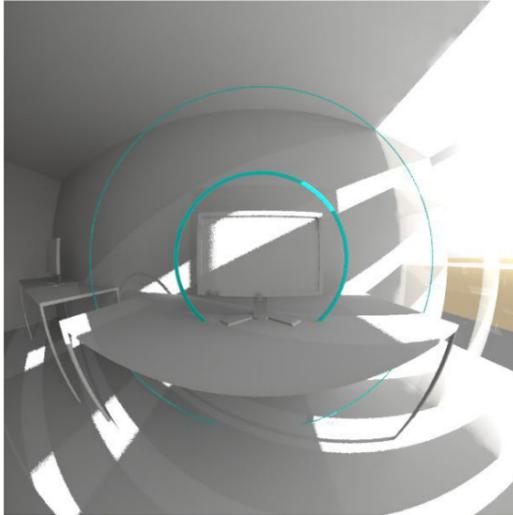


21/12 14:00 South orientation

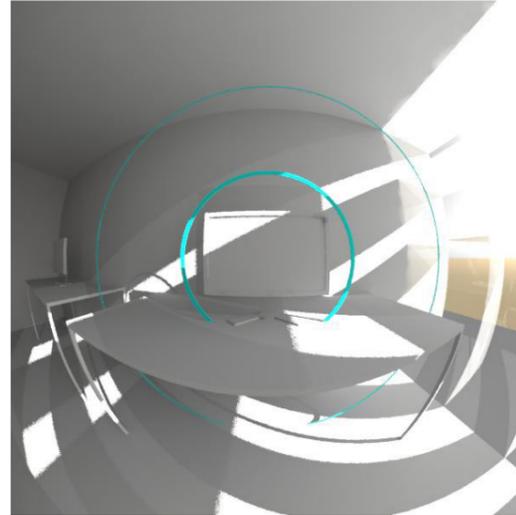
1.00 every 0.80 | 3 pieces



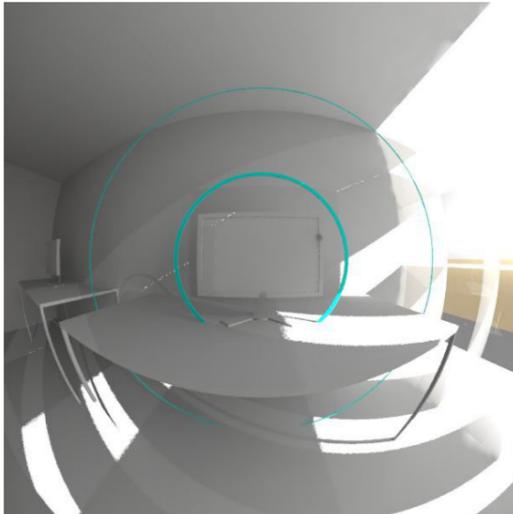
1.20 every 0.70 | 3 pieces



1.00 every 0.70 | 3 pieces

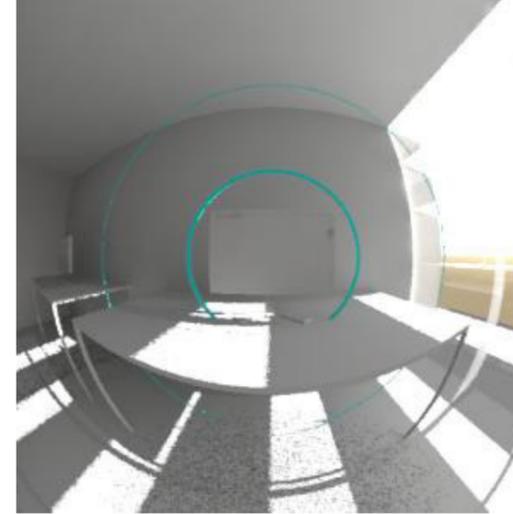


1.20 every 0.60 | 3 pieces

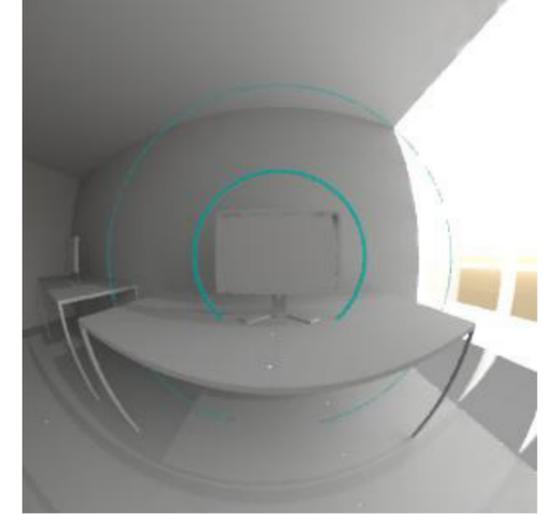


21/12 12:00 South orientation

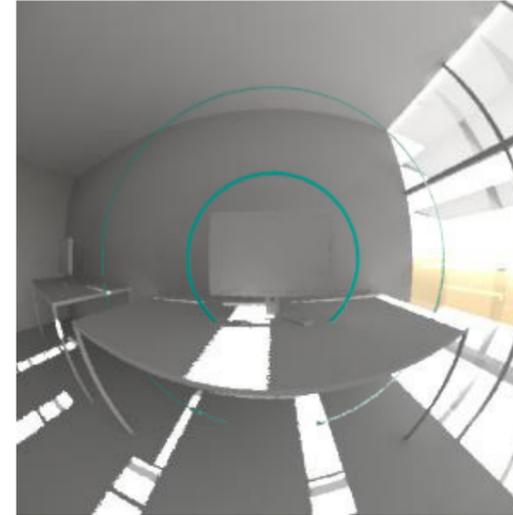
0.60 every 0.54 | 5 pieces



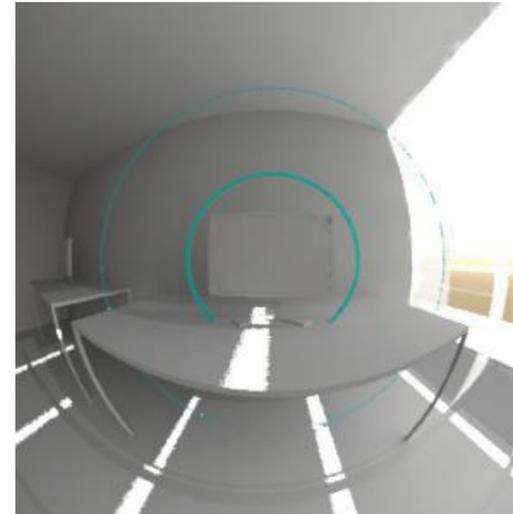
1.00 every 0.54 | 5 pieces



0.80 every 0.54 | 5 pieces



0.90 every 0.54 | 3 pieces



The two circles are used in order to define the ergorama and the panorama visual fields. There are luminance ratio value minimum requirements for each of these regions, which should not be exceeded. Though, before proceeding with the calculation of these values, the ergorama, the area where the task field is located and the eye of the user is concentrated should be protected from direct daylight. So even a simple visualization in true colors can illustrate the lighting conditions. The photos presented show that none of the tested combinations is accepted as they do not block efficiently direct daylight.

In the same way, other combinations were tested and proven inadequate for solar shading. Some of them allow direct daylight penetrate and reach the task field, while others are too dense and even though they protect from disturbing daylight, they create an unpleasant atmosphere. The ideal solar shading system is not the one that totally blocks daylight, but the one which controls it in the most efficient way.

Based on the simulations realized, the optimum design geometry, for the opening of 3.6m \* 2.7m., is 0.9m. deep , with 4 vertical blades placed every 1.2m and 4 horizontal blades located at the upper part of the opening, placed every 0.4m, refer to Fig 137.

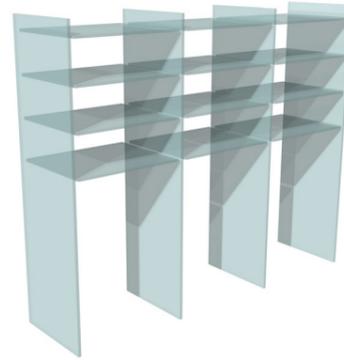


Fig 137 | Solar shading system geometry.

### 10|4|1 OPTIMIZATION

As far as it concerns the structural analysis, the main loads applied on the shading system are the self-weight and the load of the wind. The horizontal wind load is a very important factor which influences the structural performance of the shading system. The system performs as a frame because of the existence of components at both directions. The vertical components act as columns while the horizontal ones offer stiffness to the system. As it is already mentioned the horizontal elements are located only at the upper part of the system, which means that the lower part is the most crucial one. The vertical glass panels are exposed to wind forces which may cause abrupt failure. For this reason, an optimization of the shape of the vertical elements is introduced, the detraction of the exposed corner which will eliminate the problem (Fig 138). Regarding visual performance, this part does not contribute to the efficiency, so this change is possible. In conclusion, the new geometry characteristics makes the frame more stable and reduces its weight by 100kg at the same time. The exact dimensions of the solar blades are presented in Fig 139 and Fig 140.

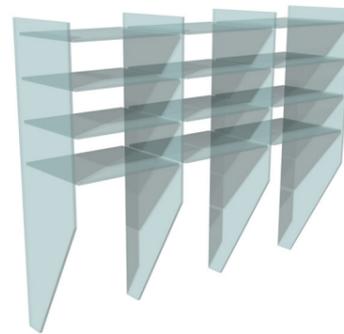


Fig 138 | Optimized solar shading system geometry.

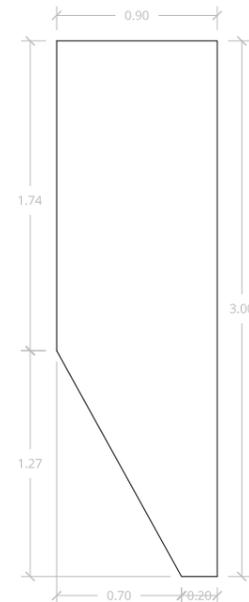


Fig 139 | 4 pieces of vertical blades.



Fig 140 | 4 pieces of horizontal blades.

The total weight of the shading system per room can be calculated given that the weight of float glass is 2.5kg/m<sup>2</sup> per 1mm thickness. The glass sheets of each component are 18mm thick in total and their surface is 19.82m<sup>2</sup>. Concluding, the total weight of the shading system is approximately 892 kg per room.

### 10|5 SHADING SYSTEM CONFIGURATION

The proposed material is the PDLC smart glass, thus all the components of the shading system are laminated glass panels. Taking into account that they are designed for external use, they should fulfill the terms of safety. Lamination process guarantees proper bonding between glass sheets and that in case of breakage the pieces stay on place. However, heat-treated glass sheets are proposed for extra safety.

The glass panel consists of three layers of float glass which are laminated together incorporating the PDLC smart film and the conductor films. The intermediate glass layer is a heat-strengthened glass sheet which is able to carry the loads even when it is broken. Slower cooling process during manufacturing procedure offers additional strength against wind pressure and/or thermal stresses. The thickness of this sheet is 10mm and it constitutes the main component of the glass panel. The PDLC smart film with the additional layers are placed at the side and finally two sacrificial glass layers are placed as external layers. These layers are 4mm thick, tempered glass sheets which provide safety breakage pattern (Fig 141) and ensure that no pieces of glass sheets may be severed from the glass panel. PVB adhesive layers of 0.76mm thickness are used for bonding the all the components together.

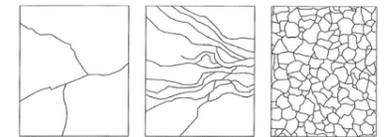


Fig 141 | Break patterns for annealed, heat strengthened and fully tempered (left-right).

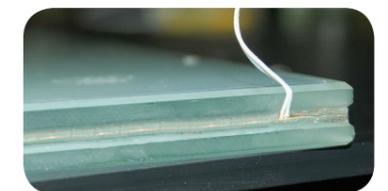


Fig 142 | PDLC smart glass, cable detail, Gaomingglass.

PDLC technology is activated when electric current is applied on it, making use of the conductor layers. Cables are connected to the conductor layers and supply with electricity the system as illustrated in Fig 142. As it is expected, the PDLC film and the conductor layers have to be protected from liquids and especially water because of the possibility of short circuit. Thus, all the profiles should be covered and waterproof. Aluminum cap rails are used for this reason which are installed with the use of strong double tape (Fig 143).



Fig 143 | Cap Rail - Stainless Steel - Glass Edge Protection, S3i GROUP.

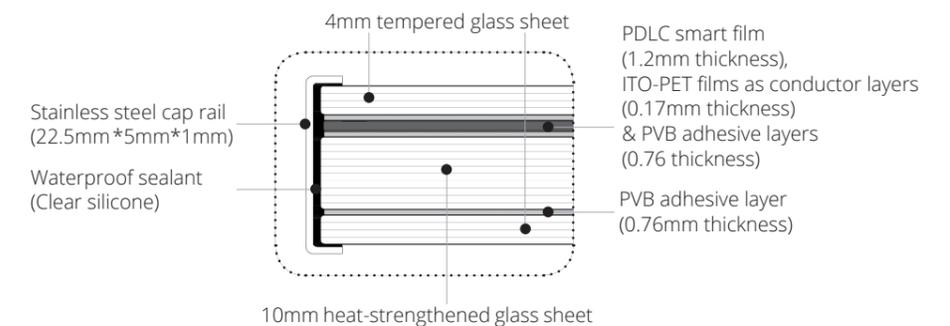


Fig 144 | Laminated glass panel | Scale 1:1.

### 10|6 GLASS CONNECTIONS

Until nowadays, various connections have been developed between two sheets of glass or glass and other materials. These connections can be divided into two categories, the mechanical connections and the adhesive ones.

Mechanical connections are the ones that use extra components such as metal components. Bolt connections and friction grip connections are techniques which require drilling of the glass sheets. This procedure is usually avoided as it damages greatly the glass and its surface, affecting its strength. Stresses are also concentrated near the hole, making the glass even more fragile and necessitating tempering. On the other hand, there are mechanical connections which leave the glass sheet intact. Framed and clamped glazings are distinctive examples where such mechanical connections are used.



Fig 145 | Glass laminated connection. Source | <http://www.eocengineers.com/project/apple-5th-avenue-mark-2-100>

The adhesive connections can be mechanical or not, which means that they may incorporate connections components or just use certain adhesives. These connections leave the glass intact as well and the problems mentioned above are avoided. The loads are distributed over an area and thus there are no extreme stresses. The strength, the stiffness and the durability of the connection has to be examined though. Various materials are used as adhesive such as the silicone, the polyurethane, the acrylate and the epoxy. Adhesive connections are widely used in laminated glass as well. The connection components can be placed at the position of the interlayer and be incorporated during the lamination process (Fig 145).

## 10|7 FAÇADE STRUCTURE ANALYSIS

A fully glazed, high-rise office building has been selected as the case study for the visual analysis and the installation of the proposed solar shading system. The building is supposed to have a typical structural core made out of concrete and a curtain wall system installed at the building envelope. The curtain wall systems are used as façade elements which cover the outer part of the building without carrying any loads. They are non-structural and they are made out of lightweight materials. In this case, the USC 65 unitized curtain wall system (Fig 146), developed by Schüco, is selected. Product specifications in APPENDIX D.



Fig 146 | USC 65, Schüco.

In general, the shading systems are attached to the façade and specifically the curtain wall. However, the proposed one is relatively heavy, because it is made out of glass, and for this reason it preferable to be connected to the core of the building. By connecting it to the floor slabs, it is more stable and it can withstand the forces applied on it. Unitized curtain wall system facilitates the connection to the building because the panels have separate frames and thus there is access to the floor slab through them.

As it is already mentioned, the solar shading system is a 3-dimensional grid. Before proceeding with the structure analysis of the system, the maximum possible dimensions of the glass panels have to be taken into account. The smart glass PDLC can be manufactured having a maximum size of 1.5 \* 3m. For this reason, only the vertical elements of the system can be comprehensive pieces. The horizontal elements are divided in 3 pieces and attached to the sides of the vertical ones.

The whole system acts as a frame, where the vertical elements take the place of the columns and they are connected to the floor slabs carrying the loads, while the horizontal elements maintain the distance between them and offer stiffness. So, there are two types of connections, the ones between the vertical components and the floor slabs (refer to Fig 147) and the ones between the glass components of the system (refer to Fig 148).

## 10|7|1 PROPOSED CONNECTIONS

All the elements of the shading system are laminated glass panels, so laminated connection components can be used as well. It is already mentioned that this type of connections are preferable as they are strong, durable and discreet at the same time.

To sum up, the proposed design consists of vertical and horizontal elements. The vertical ones perform as columns and the horizontal ones are attached on them. The shading system is connected to the building via the vertical elements. Two laminated connections are located at the top and the bottom part of each vertical element and during installation are fixed on a custom steel T profile. This profile is placed and anchored to the edge of the concrete floor slab and it courses between the two aluminum profiles of the curtain wall. The bottom part is customized forming a bracket which facilitates the connection of both glass panels. Each panel is suspended from the top connection. A joint is used at the bottom connection, enabling sliding, in order to accommodate possible material expansion and facilitate the installation process by damping the tolerances (Fig 147).

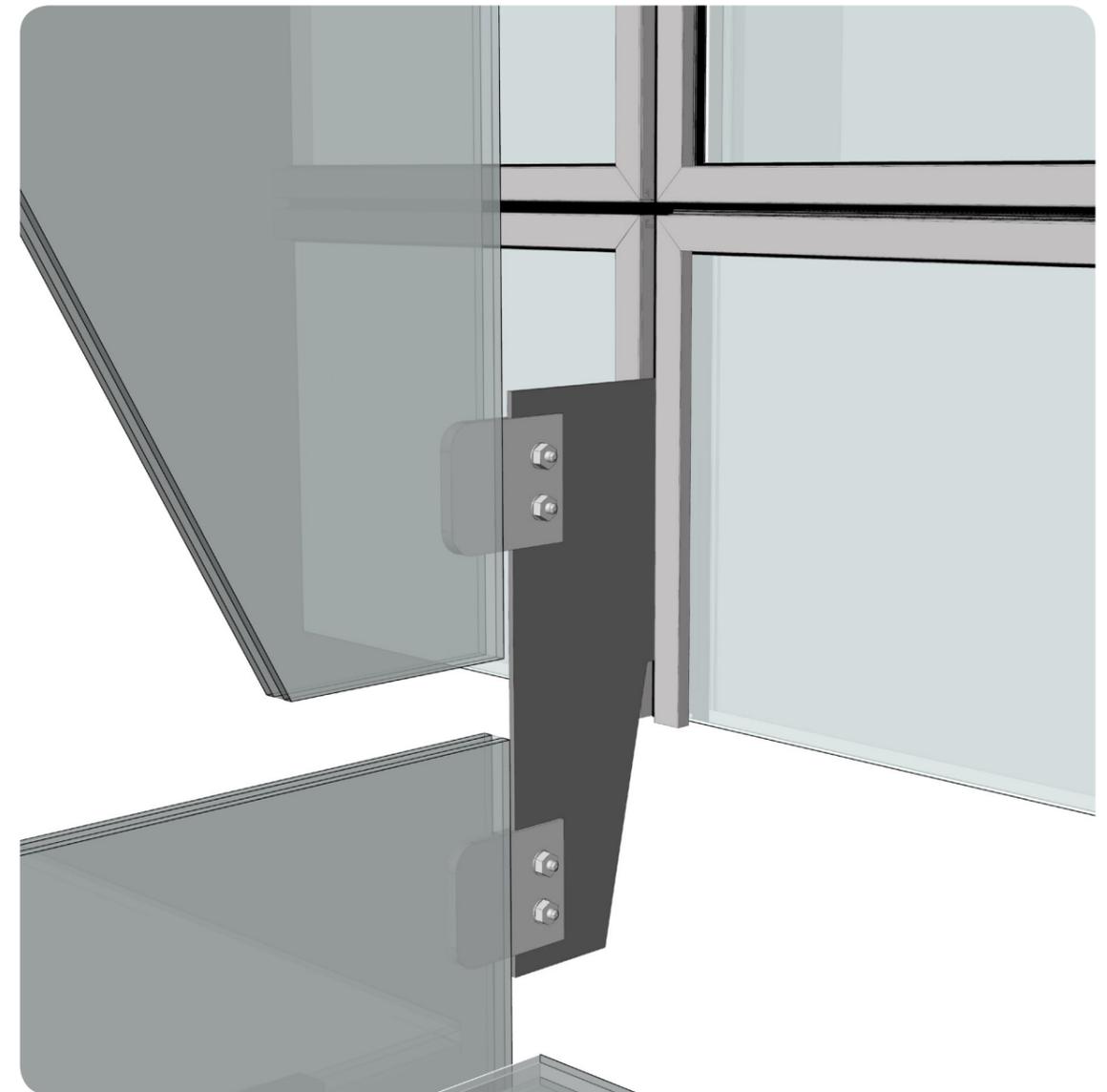


Fig 147 | Connection between shading system and slab.

As far as it concerns the horizontal elements, two embedded connections are laminated at each edge. These components are attached and fixed to metal connectors which are glued on the vertical panels (Fig 148). A strong and durable polymer adhesive is used for fixing the metal connectors at the side of each glass. ("GLASS ON WEB - Articles - Novel Laminated Connections," n.d.)

An extra component is installed at the sides of the connection of the vertical components in order to cover the cables of the glass panels until they reach the interior space. Except for the glass panel, the cables have to be protected from weather conditions, e.g. rain as well. Aluminum U profiles, which encapsulate the cables, are placed along the vertical panels. A removable cap is used for closing the open section, while enabling maintenance. At the point of the connection to the floor slab, the U profile becomes a plate which covers the two side of the steel component like a cap (Fig 150). Except for protecting the cables, it also covers the connection components for aesthetic reasons.

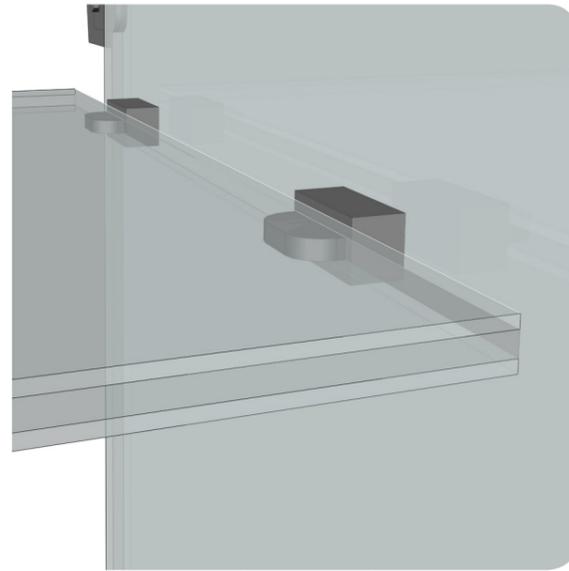


Fig 148 | Connection between two glass panels.

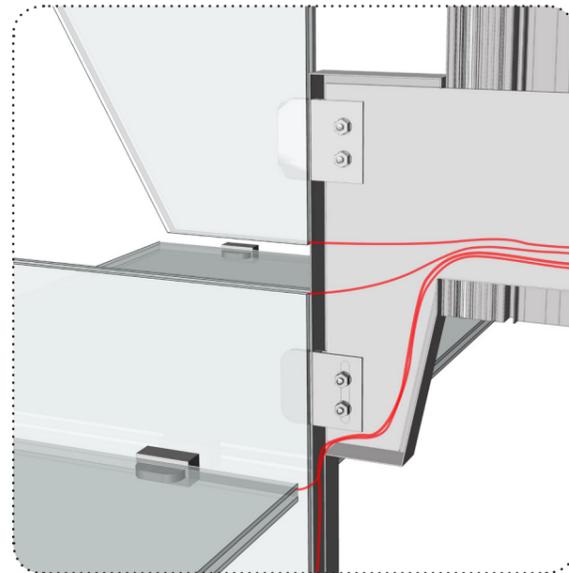


Fig 150 | Aluminum cap and cables detail.

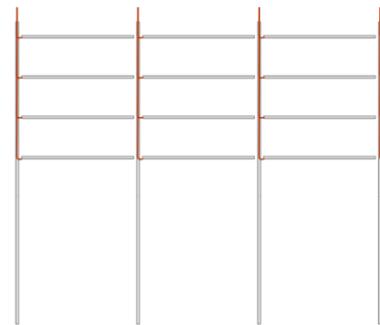


Fig 149 | Cables positions.

10|8 TECHNICAL DRAWINGS

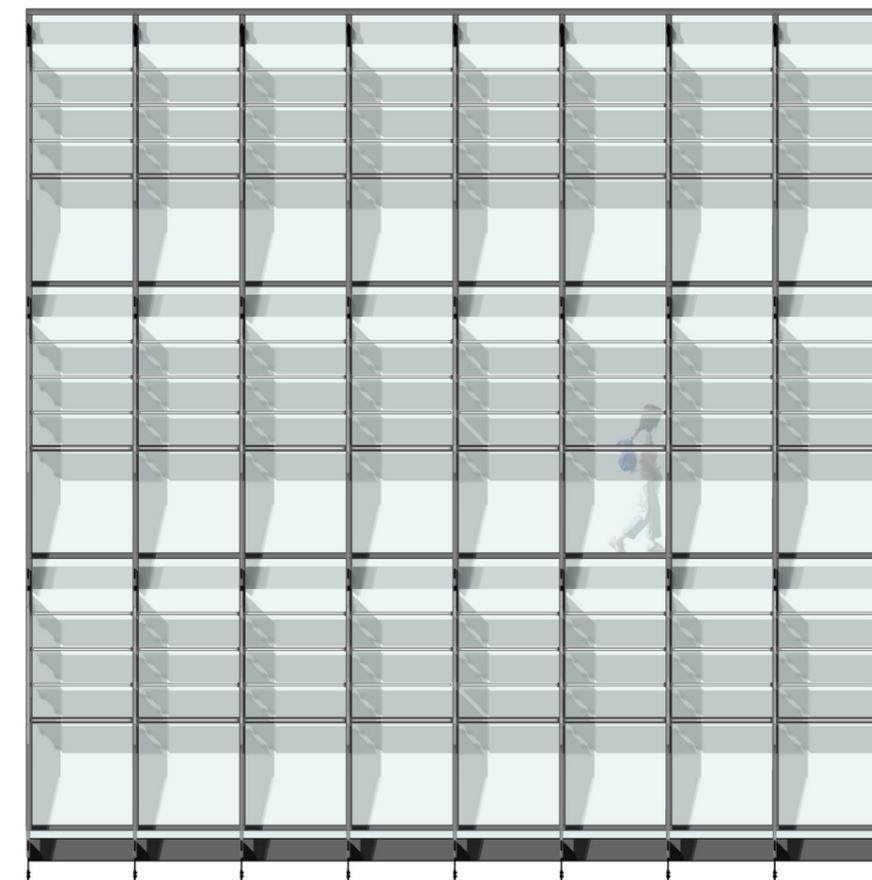


Fig 151 | Front view.

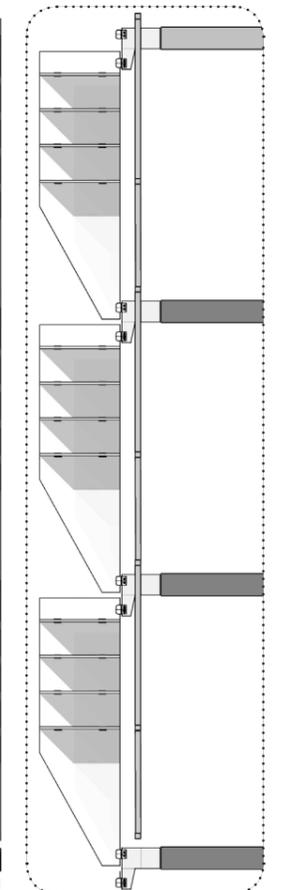


Fig 152 | Vertical section.

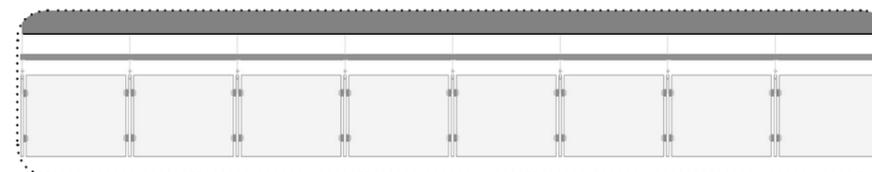
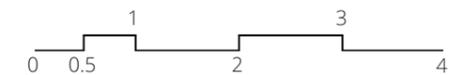
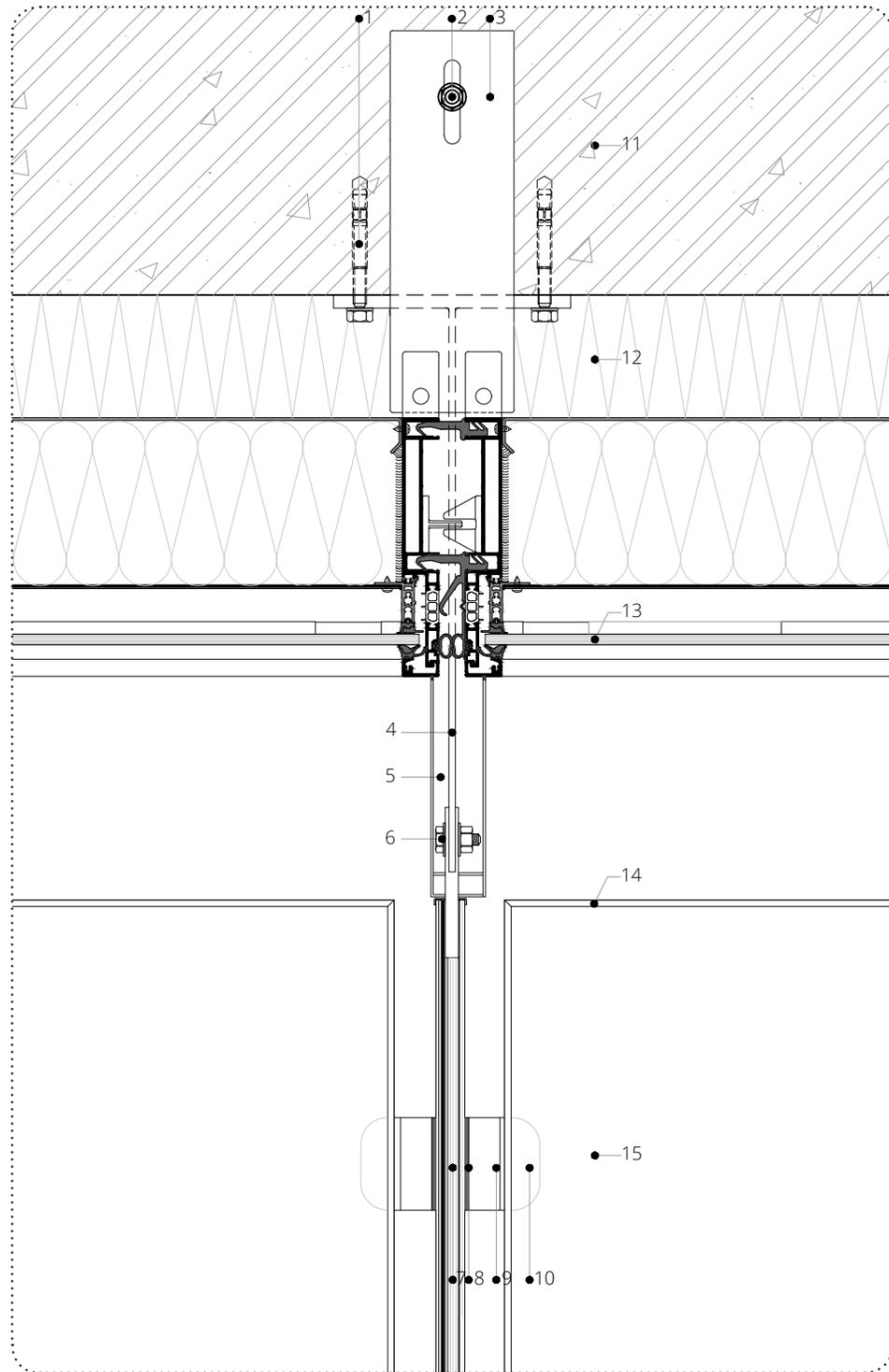


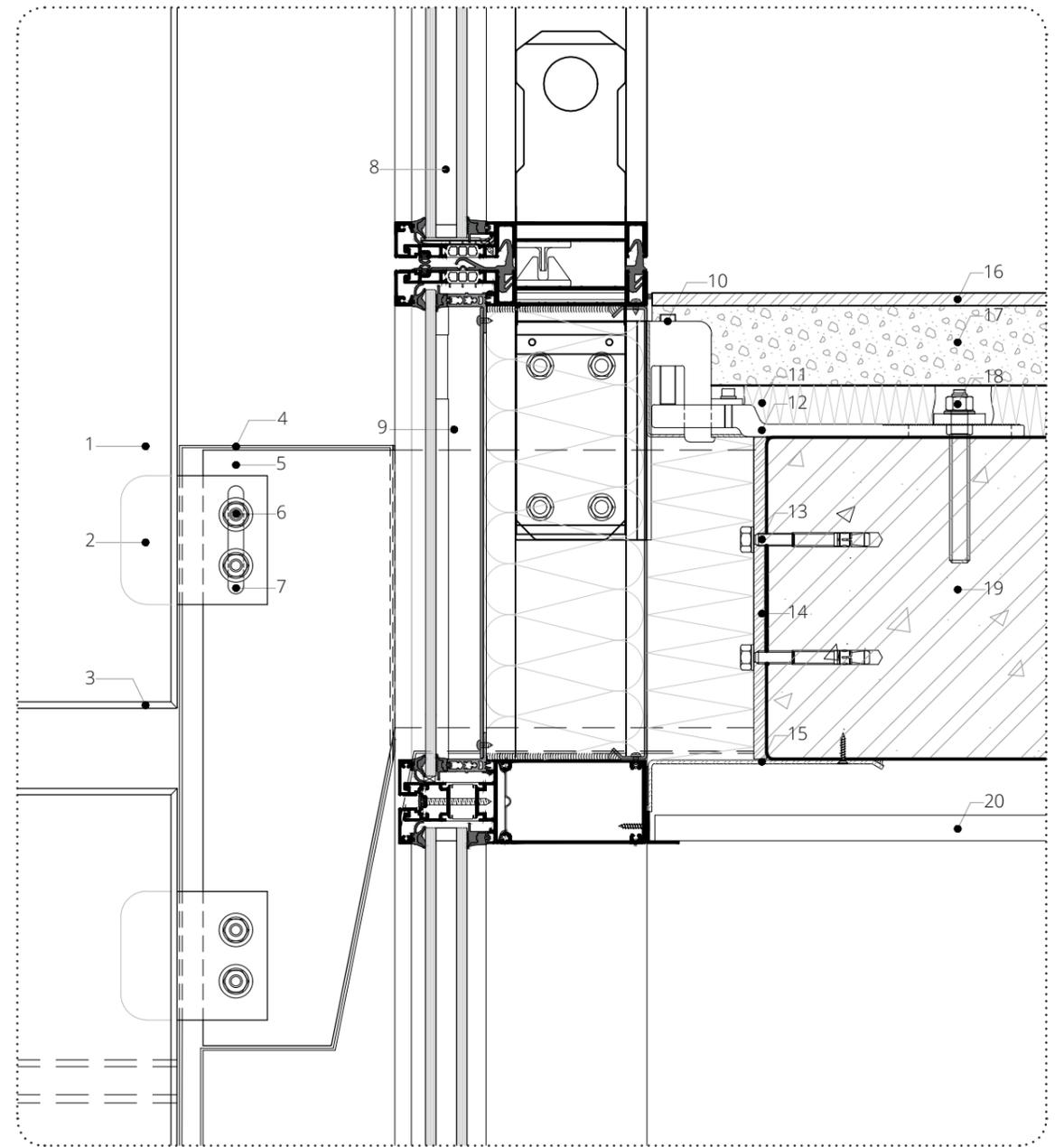
Fig 153 | Horizontal section.



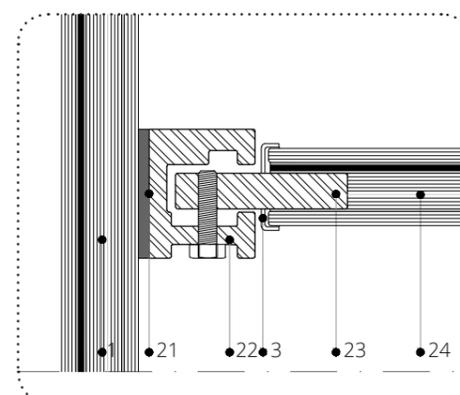


- |  |   |
|--|---|
| 1   Anchor screw M10                       | 9   Metal connector of vertical element                   |
| 2   Anchor screw M12                       | 10   Metal connector laminated in PDLC                    |
| 3   Steel plate, curtain wall connection   | 11   Precast concrete slab 2500mm                         |
| 4   Steel T profile (250mm x 180mm x 10mm) | 12   Stonewool insulation panel 90mm                      |
| 5   Aluminum cap                           | 13   Spandrel with single glazing and cover plate         |
| 6   Bolt M10                               | 14   Stainless steel protective rail (22.5mm * 5mm * 1mm) |
| 7   PDLC glass panel 280mm                 | 15   PDLC glass panel 240mm                               |
| 8   PVB laminated polymer                  |   |

Fig 154 | Connection detail | Horizontal section | Scale 1:5.



Connection detail | Vertical section | Scale 1:5.



- |  |                                  |
|--|----------------------------------|
| 1   PDLC glass panel 280mm                         | 16   Floor tile 10mm             |
| 2   Metal connector laminated in PDLC              | 17   Grobeton 60mm               |
| 3   Stainless steel rail (22.5mm * 5mm * 1mm)      | 18   Anchor screw M12            |
| 4   Aluminum cap                                   | 19   Precast concrete slab 250mm |
| 5   Steel T profile (250mm x 180mm x 10mm)         | 20   Ceiling plasterboard 20mm   |
| 6   Bolt M10                                       | 21   PVB laminated polymer       |
| 7   Slot for vertical adjustment                   | 22   Metal connector             |
| 8   Double glazing curtain wall panel              | 23   Laminated metal connector   |
| 9   Spandrel with single glazing and cover plate   | 24   PDLC glass panel 240mm      |
| 10   Metal component for vertical adjustment       |                                  |
| 11   Dow insulation 40mm                           |                                  |
| 12   Steel component for curtain wall installation |                                  |
| 13   Anchor screw M10                              |                                  |
| 14   Precast concrete slab 2500mm                  |                                  |
| 15   Steel L profile 3mm                           |                                  |

Fig 155 | Connection detail between the two glass panels | Vertical section | Scale 1:2.

## 10|9 Façade ASSEMBLING

The installation process includes the assembling of the solar shading itself and its installation on the building's envelope which take place simultaneously.

After the completion of the structural core of the building, the metal profile is anchored to the floor slab (refer to Fig 156) and then insulation is placed in order to prevent thermal bridges (Fig 157). Afterwards, the curtain wall panels are placed and fixed to the floor slab and the adjacent panels (refer to Fig 158, Fig 159). At this point, the construction of the building is completed, and the metal plates overhanging the façade are ready for supporting the sun shading system.

Regarding the shading system, one frame covers the opening of one room consisting of 4 vertical and 4 horizontal elements. Before being installed, it is assembled but not entirely fixed to allow tolerances. The vertical elements are connected to the metal profiles and then the final adjustment takes place (refer to Fig 160).

Cranes are used for lifting each frame and placing it at the right position on the building's envelope. At first the top part is fixed to the metal plate and afterwards the bottom part is pulled close to the façade until it is connected to the metal plate of the lower floor.

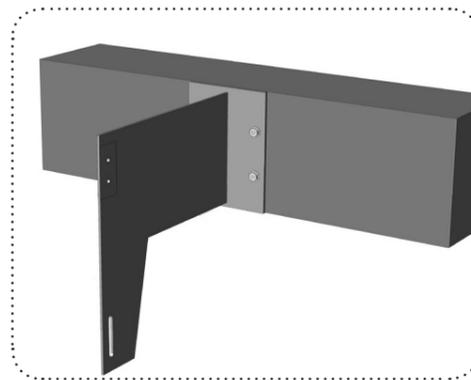


Fig 156 | Steel plate | 1<sup>st</sup> step.

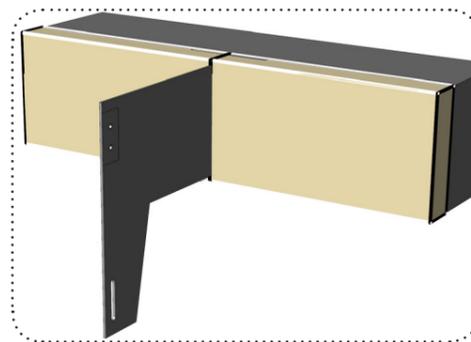


Fig 157 | Insulation panels | 2<sup>nd</sup> step.

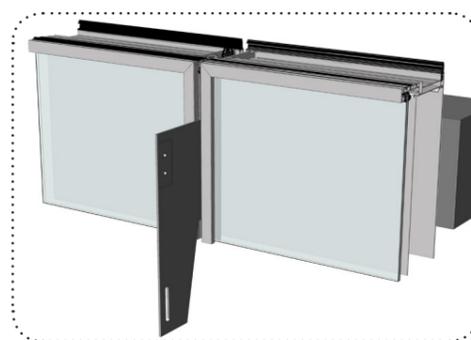


Fig 158 | Curtain wall-bottom row | 3<sup>rd</sup> step.



Fig 159 | Curtain wall-top row | 4<sup>th</sup> step.

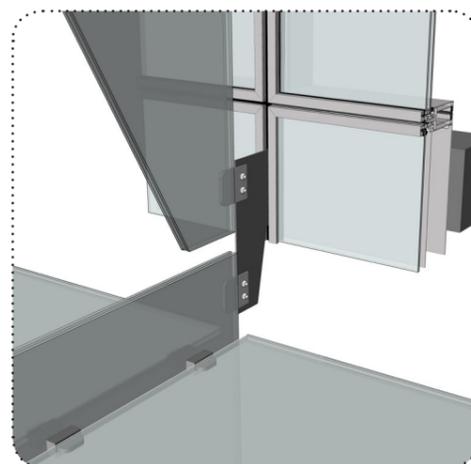


Fig 160 | Shading system | 5<sup>th</sup> step.

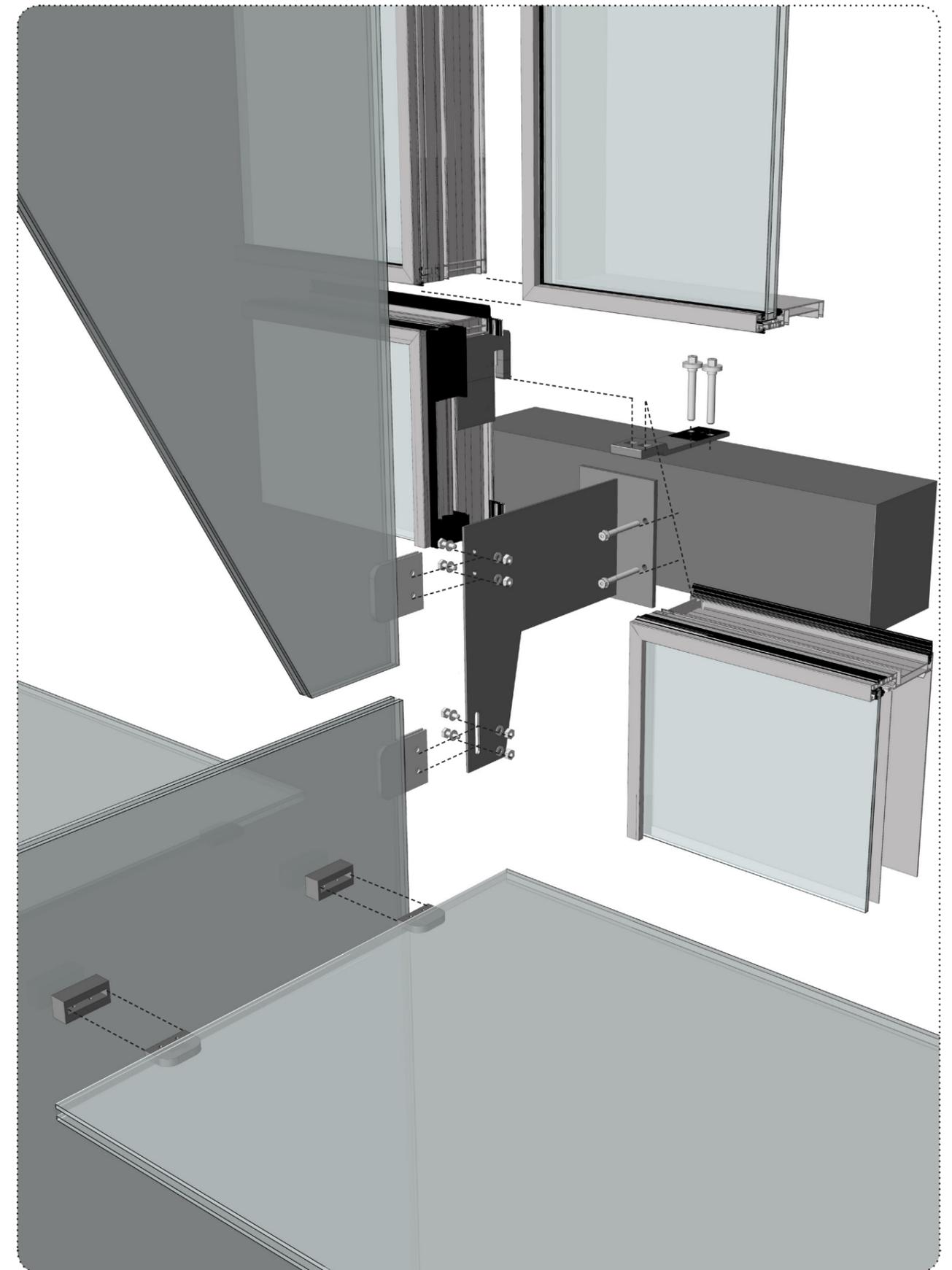


Fig 161 | Assembling diagram.

## 10|10 VISUALIZATIONS

The proposed solar shading system is designed for high-rise office buildings. However, it can be applied to any other type of building. Fig 162 and 163 illustrate two possible states of the shading system when it is west oriented. Both of them depict daylight conditions in Athens. Fig 162 is representative of morning hours (11 am) in September. The system is transparent as the sun does not reach directly the

west-oriented façade. On the contrary, Fig 163 display a condition during early-evening hours (4 pm) of the same day. In this case, the proposed solar system is translucent.

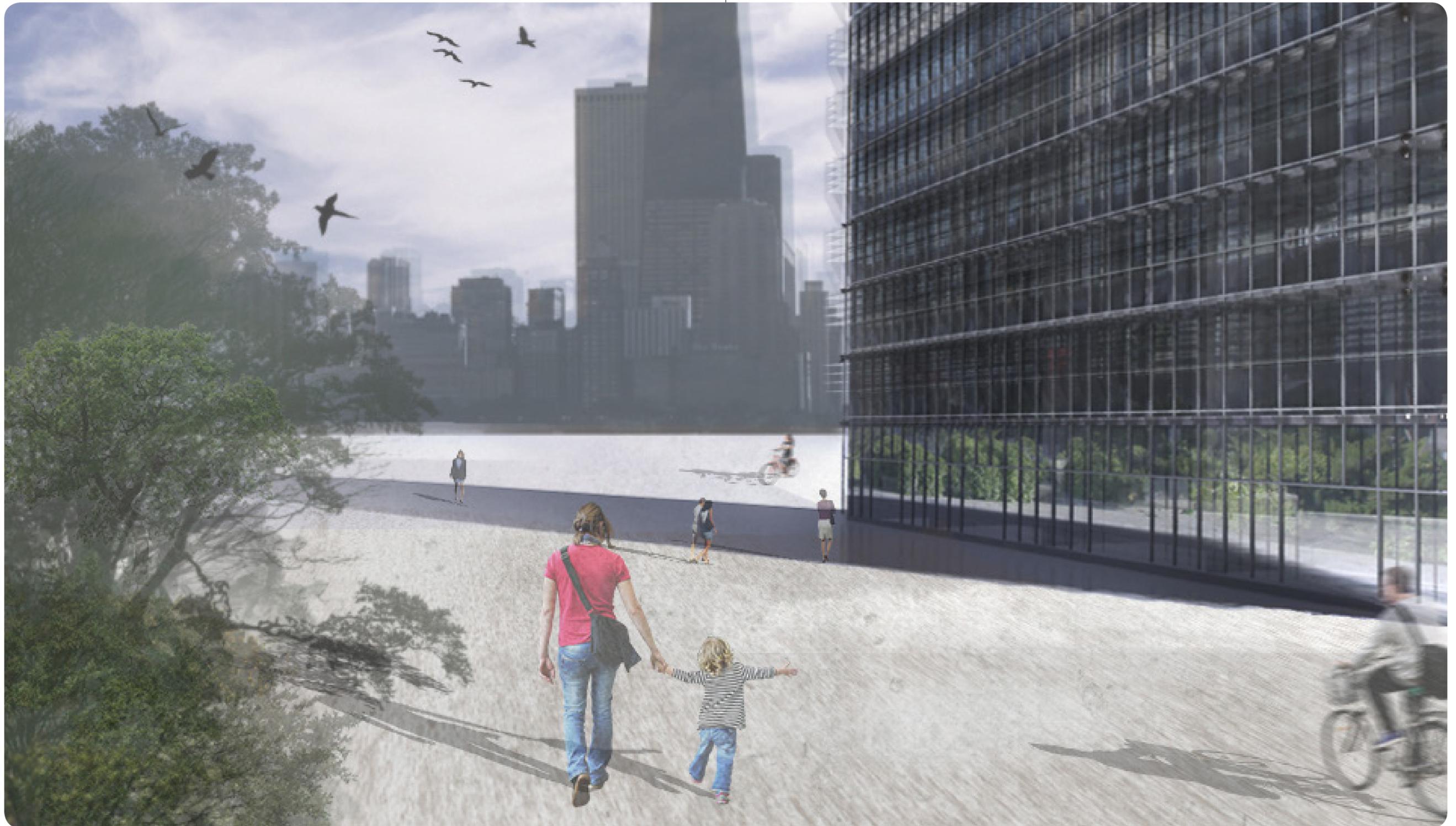


Fig 162 | Morning visualization - Transparent shading system.

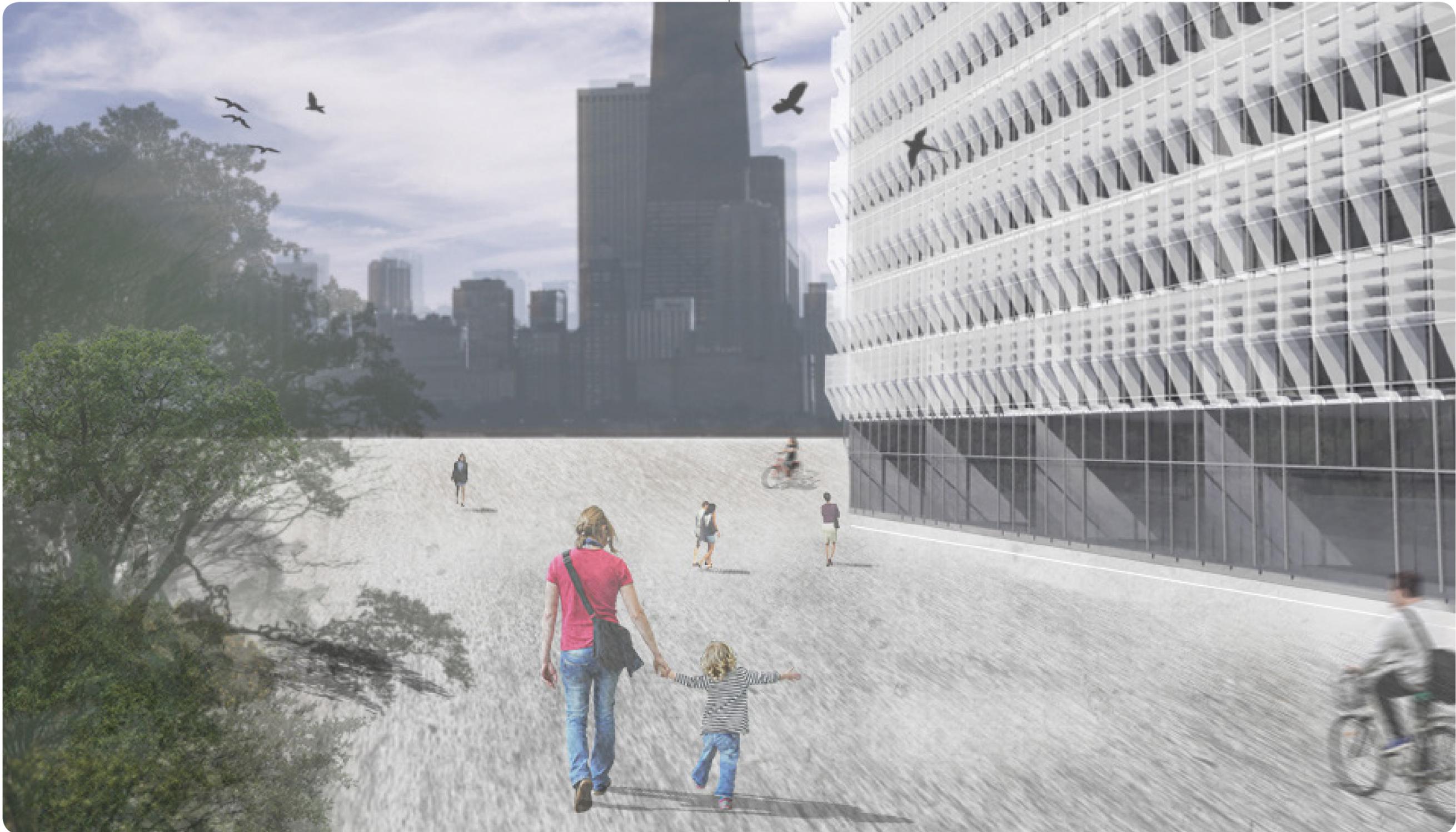
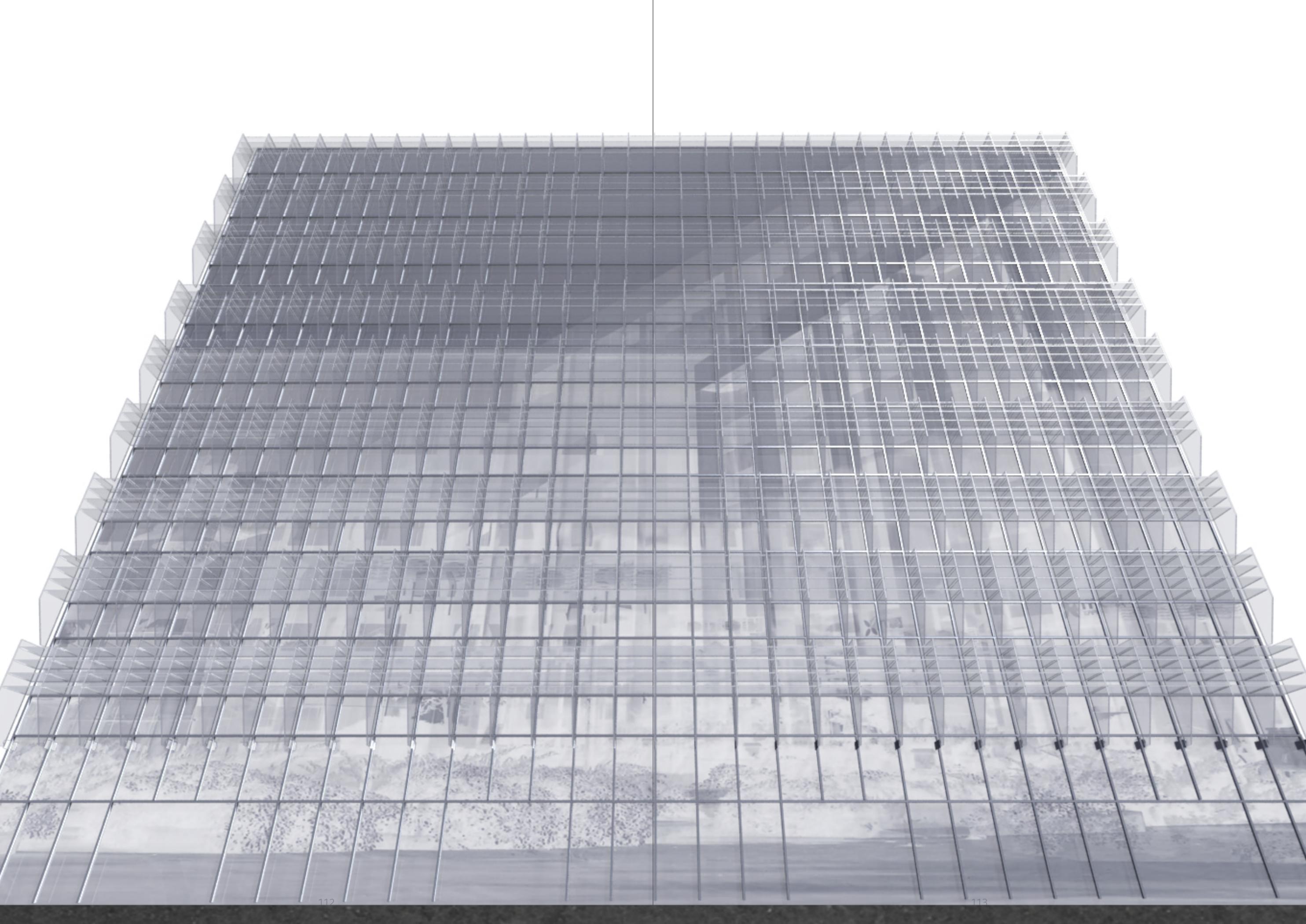


Fig 163 | Evening visualization - Translucent shading system.



11

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LIGHTING PERFORMANCE

## 11 | 1 DAYLIGHT ANALYSIS - COMPUTER-BASED SIMULATIONS

Once the geometry is defined, the system's daylight performance has to be tested. Annual glare analysis and daylight autonomy analysis are used to evaluate the efficiency of the system. During the first attempt, the shading system is roughly described and the horizontal and vertical elements cannot be controlled independently. The whole system is one shading group with two possible states, the totally transparent and totally translucent one. Thus, the obtained results give information about the efficiency of worst case scenario. Under these circumstances, the annual glare analysis and the Daysim Report is obtained. Afterwards, the shading system is simulated as the combination of two independent shading groups, the horizontal and the vertical one. A new Daysim Report is obtained which gives more analytical results about the system's performance. It should be mentioned that, in this case, the daylight autonomy simulation does not use the DGP schedules, but the incident irradiance value. The shading groups are closed once direct sunlight above 50w/m<sup>2</sup> is incident on the specified work place.

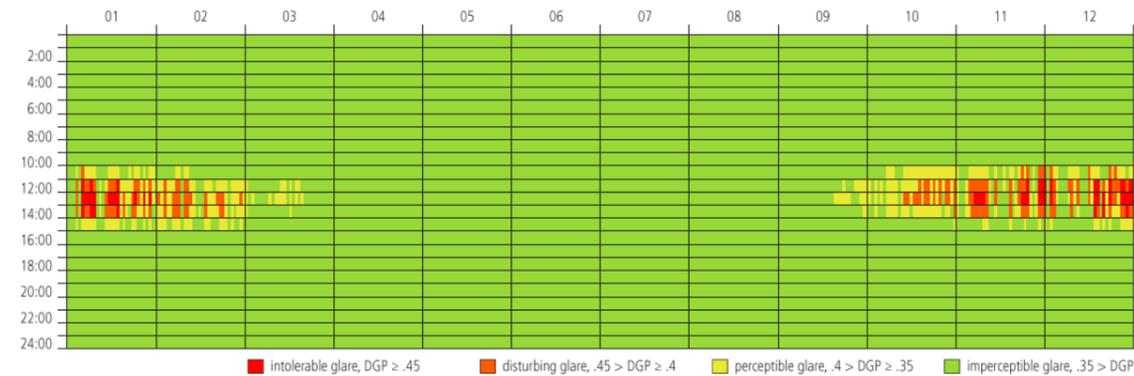


Fig 164 | Proposed shading system \_south\_transparent state annual glare analysis.

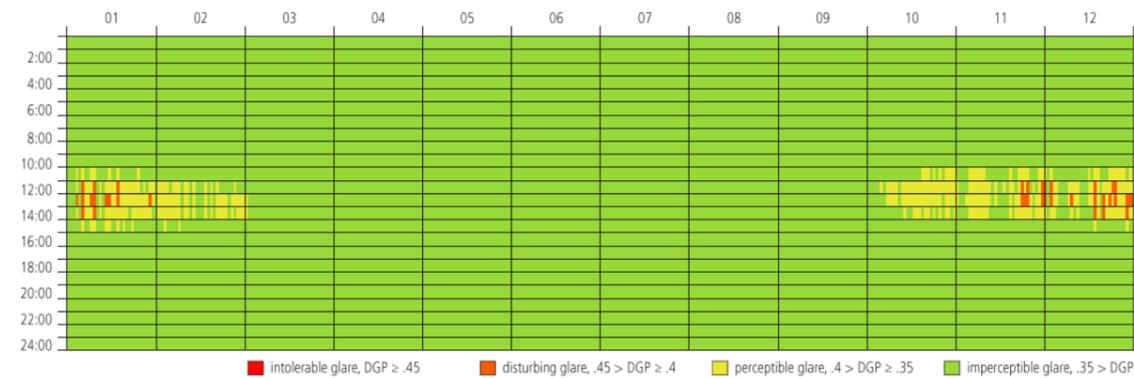


Fig 165 | Proposed shading system \_south\_translucent state annual glare analysis.

Fig 164 and Fig 165 show the annual glare analysis of the two states of the shading system. The transparent state does not protect sufficiently from glare and there are a lot of critical periods when experienced glare is disturbing, or even intolerable. On the contrary, the translucent state provides with more pleasant indoor lighting conditions. Glare occurs for 1% of the occupied hours, which is not acceptable according to the system requirements. However, it is perceptible but not disturbing except for a few moments, so it is concluded that the shading system performs efficiently.

The new, analytical daylight autonomy simulation is realized during with two shading groups, the horizontal (shading group 1) and the vertical one (shading group 2).

Daylit area |  $DA_{500lux}[50\%] > 80\%$  of floor area = 100% ✓

Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 87% ✓

Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX}[50\%] > 60\%$  for the active occupant behavior = 47% ✗

Glare |  $< 0.3\%$  of occupied hours = 0% ✓



### Warnings

ShadingGroup 1 has no reference sensors.  
ShadingGroup 2 has no reference sensors.

### Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\final\_south\final\_south\_intgain.csv

### Daysim Simulation Report

Daylit Area ( $DA_{500lux}[50\%]$ )	100% of floor area
Mean Daylight Factor	5.7%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	26% of occupied hours
Shading Group 2 open	35% of occupied hours

**Daylight Factor (DF) Analysis:** 73% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 6.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 87% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 100% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a  $DA_{MAX} > 5\%$  is 48% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a  $UDI_{<100-2000lux}$  larger than 50% is 47% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

### Simulation Assumptions

#### Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

#### User Description:

The total annual hours of occupancy at the work place are 3650.



#### Lighting Control:

There is no electric lighting system specified for the scene.

#### Shading Control:

• ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**

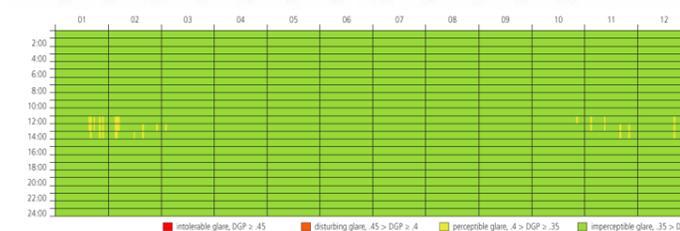
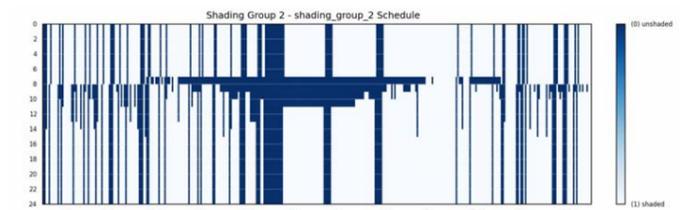
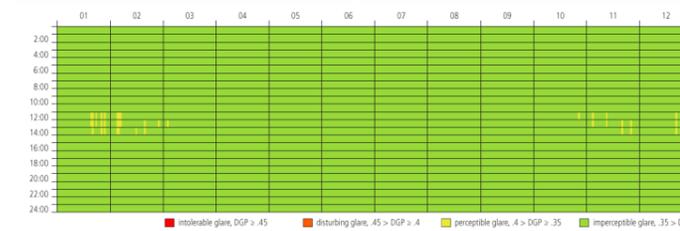
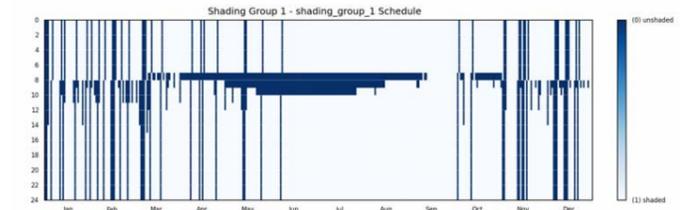


Fig 166 | Daysim report | South orientation | two shading groups.

According to the requirements set, all the values are acceptable, except for the value of the useful daylight illuminance. This index value must be higher than 60% and the obtained one is 47%. However, the fact that all the other indices have acceptable values justify that the shading system performs efficiently enough.

In order to justify the efficiency of the shading system, indoor visualizations are necessary. The 21<sup>st</sup> of December is the tested day specifically at 10:00, 12:00 and 14:00, when the critical conditions appear. The following visualizations are rendered with the most efficient combinations of translucent horizontal and vertical blades.

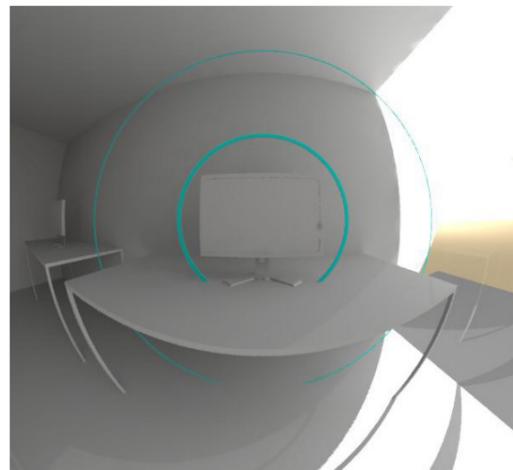


Fig 167 | 21/12, 10:00 | Computer view - True colors  
Horizontal and vertical blades-translucent state.

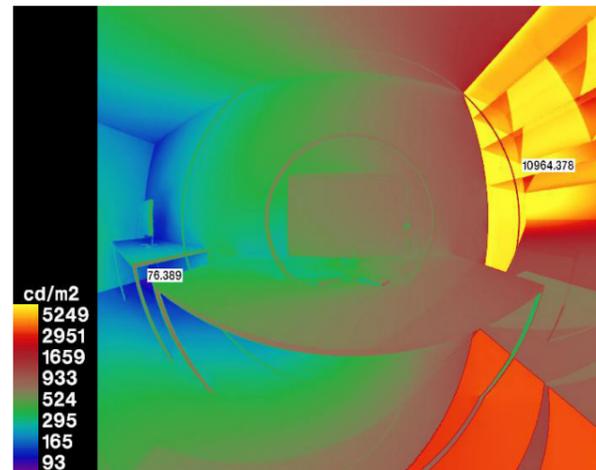


Fig 168 | 21/12, 10:00 | Computer view - False colors  
Horizontal and vertical blades-translucent state.

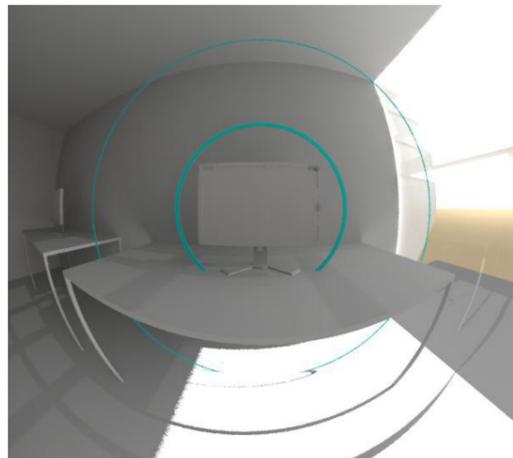


Fig 169 | 21/12, 12:00 | Computer view - True colors  
Horizontal blades-translucent state.

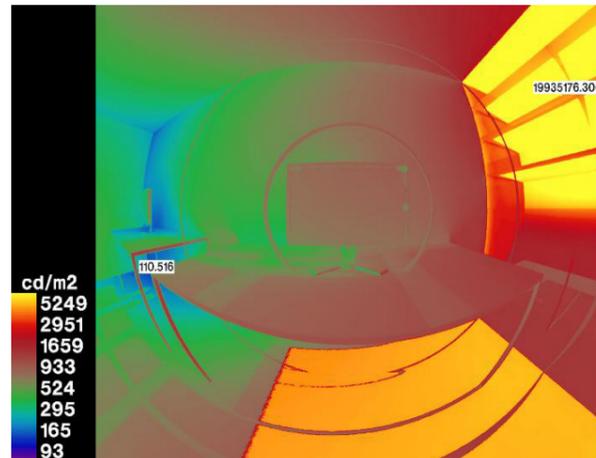


Fig 170 | 21/12, 12:00 | Computer view - False colors  
Horizontal blades-translucent state.

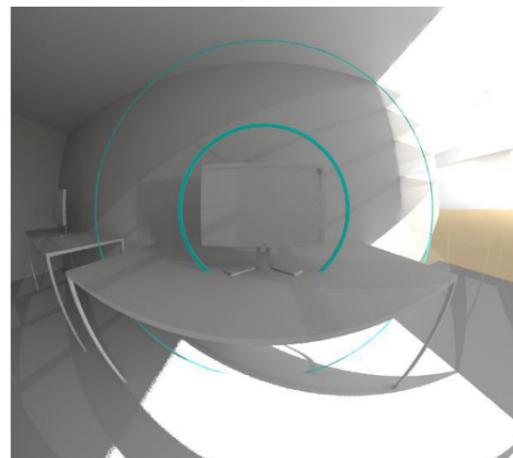


Fig 171 | 21/12, 14:00 | Computer view - True colors  
Horizontal blades-translucent state.

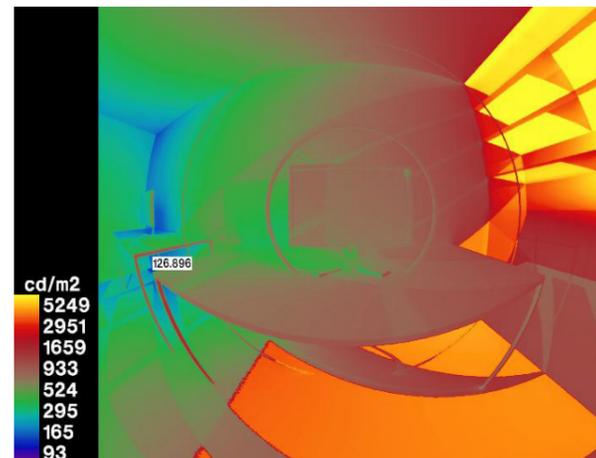


Fig 172 | 21/12, 14:00 | Computer view - False colors  
Horizontal blades-translucent state.

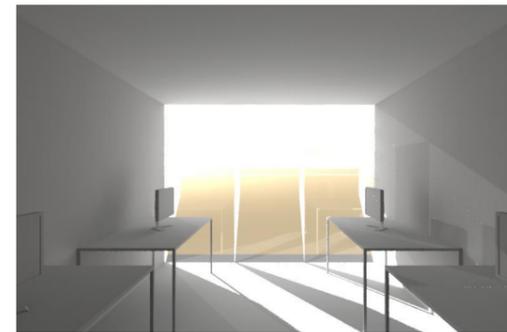


Fig 173 | 21/12, 10:00 | Interior view - True colors  
Horizontal and vertical blades-translucent state.

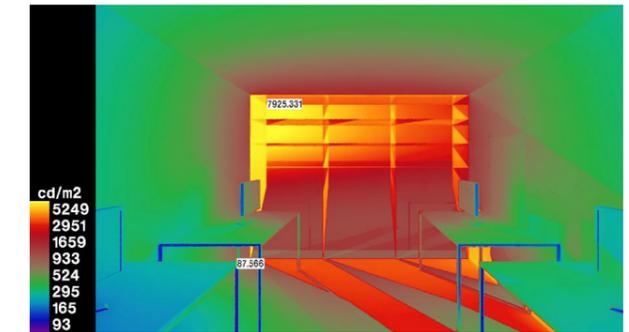


Fig 174 | 21/12, 10:00 | Interior view - False colors  
Horizontal and vertical blades-translucent state.

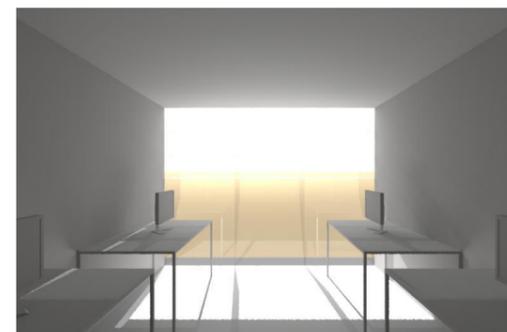


Fig 175 | 21/12, 12:00 | Interior view - True colors  
Horizontal blades-translucent state.

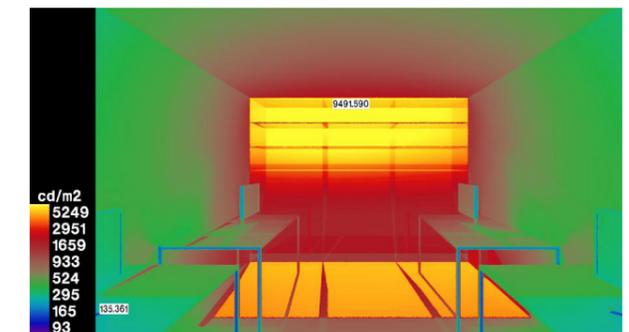


Fig 176 | 21/12, 12:00 | Interior view - False colors  
Horizontal blades-translucent state.

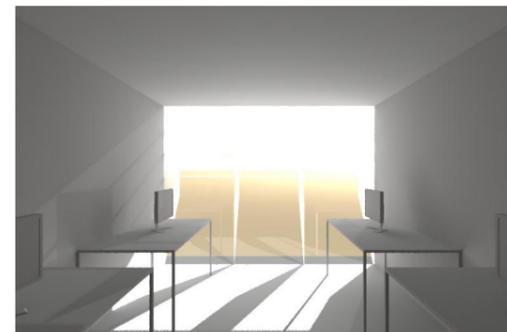


Fig 177 | 21/12, 14:00 | Interior view - True colors  
Horizontal and vertical blades-translucent state.

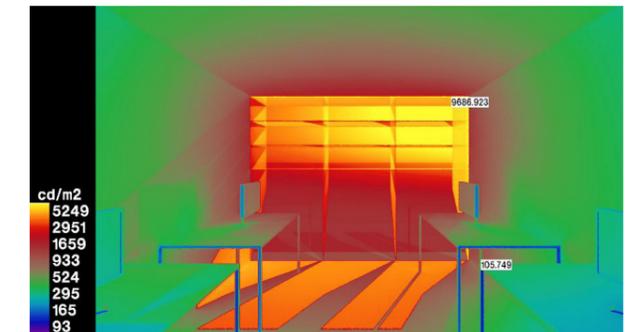
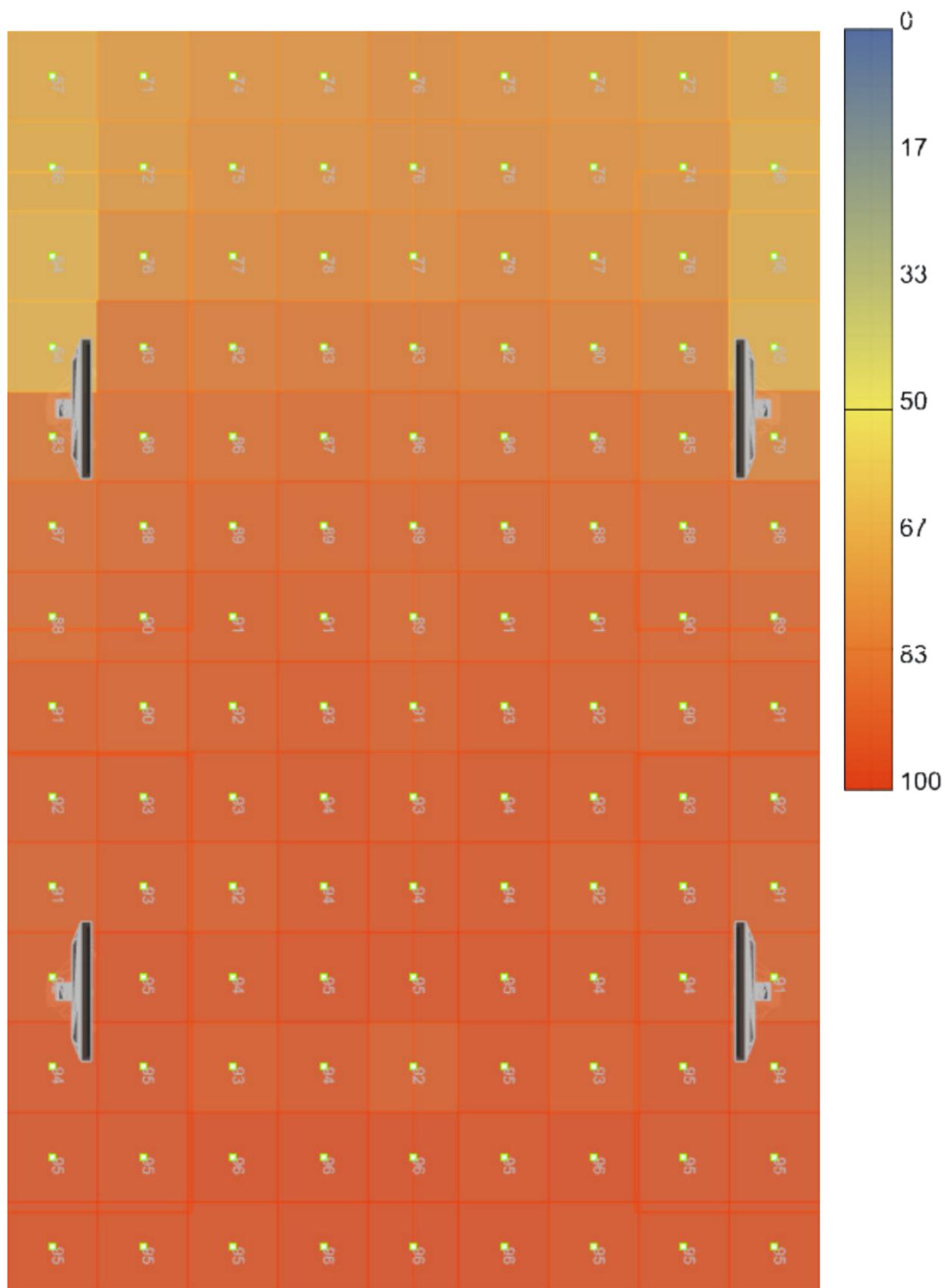


Fig 178 | 21/12, 14:00 | Interior view - False colors  
Horizontal and vertical blades-translucent state.

In these photos, the task field is always protected from direct daylight and the luminance values do not have extreme values. Hence, the efficiency of the proposed shading system is totally acceptable. These indoor daylight conditions ensure visual comfort.

DAYLIGHT AUTONOMY RESULTS (%)



Window

11 | 1 | 2 PROPOSED SHADING SYSTEM | West-oriented



Fig 179 | Proposed shading system \_south\_transparent state annual glare analysis.



Fig 180 | Proposed shading system \_south\_translucent state annual glare analysis.

In accordance with the procedure followed for south-oriented, annual glare analysis is first realized for the worst case scenario, when only two states of the shading system are possible, all transparent and all translucent. The translucent state is the most efficient one, as it is expected, and glare is experienced only during 0.3% of the occupied hours, which is acceptable.

The daylight autonomy simulation of the detailed shading system with the two shading groups gives the following results:

- Daylit area |  $DA_{500LUX}[50\%] > 80\%$  of floor area = 87% ✓
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 79% ✓
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX}[50\%] > 60\%$  for the active occupant behavior = 74% ✓
- Glare |  $< 0.3\%$  of occupied hours = 0% ✓

All the obtained values are acceptable according to the requirements set, which means that the shading system performs efficiently in west orientation as well.

The following indoor visualizations illustrate three daylight conditions during the most critical period which is the 21<sup>st</sup> of June from 14:00 to 18:00. Different combinations of translucent blades are used for obtaining the optimum visual conditions.

**Warnings**  
 ShadingGroup 1 has no reference sensors.  
 ShadingGroup 2 has no reference sensors.

**Simulation Tips**  
 Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIWA\temp\final\_west\final\_west\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	87% of floor area
Mean Daylight Factor	5.6%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	66% of occupied hours
Shading Group 2 open	76% of occupied hours

**Daylight Factor (DF) Analysis:** 74% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 79% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 87% for active occupant behavior.

**Continuous Daylight Autonomy (cDA) Analysis:** The mean continuous daylight autonomy is 91% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 37% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub>100-2000lux</sub> larger than 50% is 74% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.



**Lighting Control:**

There is no electric lighting system specified for the scene.

**Shading Control:**

• Shading Group 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**

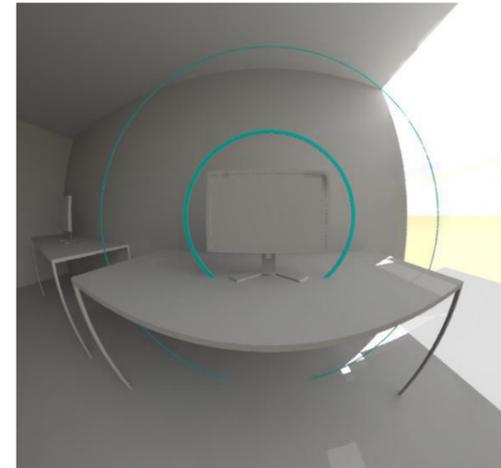
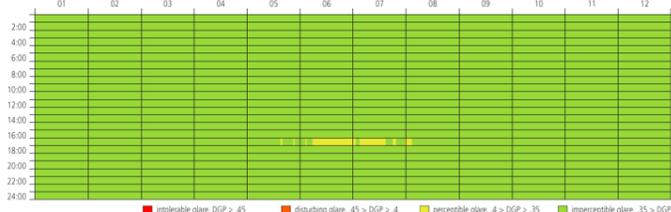
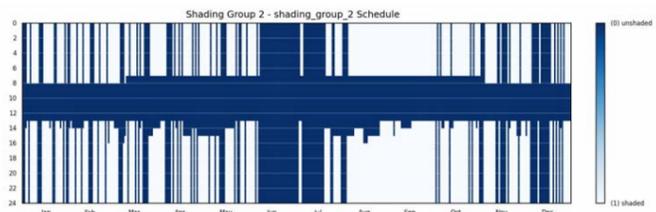
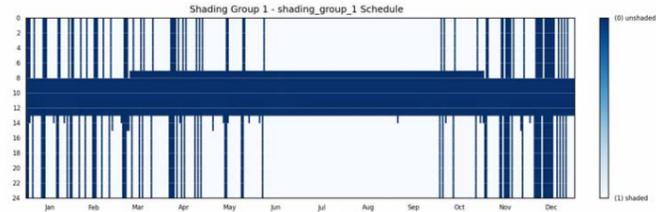


Fig 181 |21/6, 14:00 | Computer view - True colors  
Horizontal blades-translucent state.

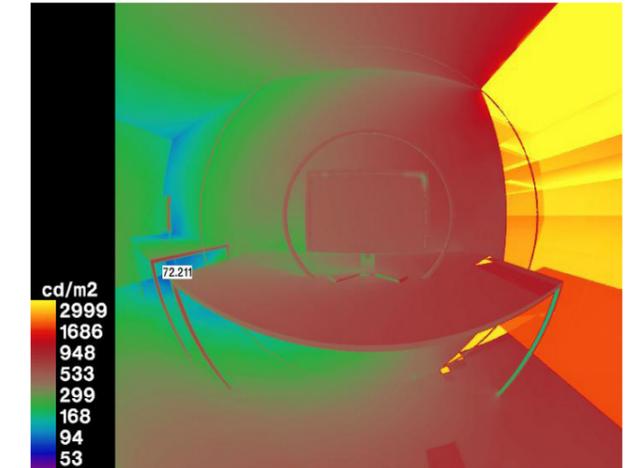


Fig 182 |21/6, 14:00 | Computer view - False colors  
Horizontal blades-translucent state.

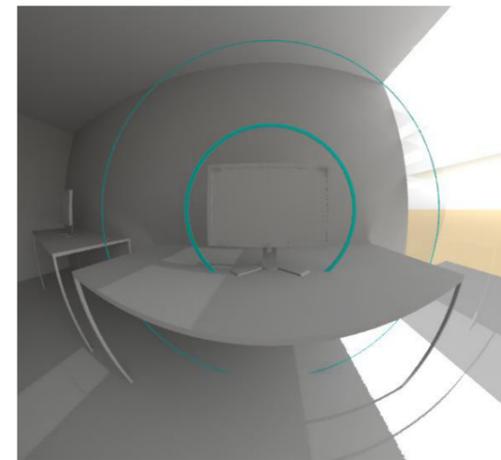


Fig 183 |21/6, 16:00 | Computer view - True colors  
Horizontal blades-translucent state.

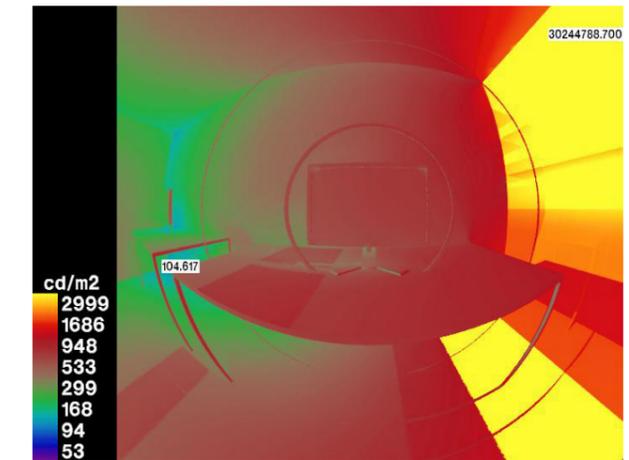


Fig 184 |21/6, 16:00 | Computer view - False colors  
Horizontal blades-translucent state.

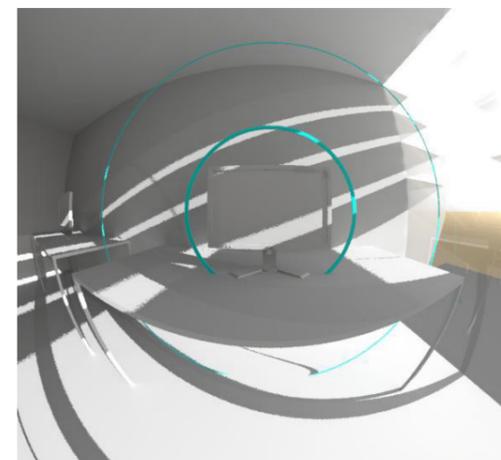


Fig 185 |21/6, 18:00 | Computer view - True colors  
Horizontal and vertical blades-translucent state.

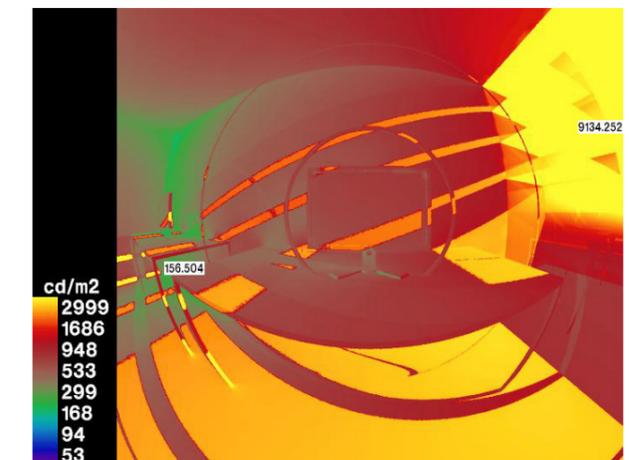


Fig 186 |21/6, 18:00 | Computer view - False colors  
Horizontal and vertical blades-translucent state.

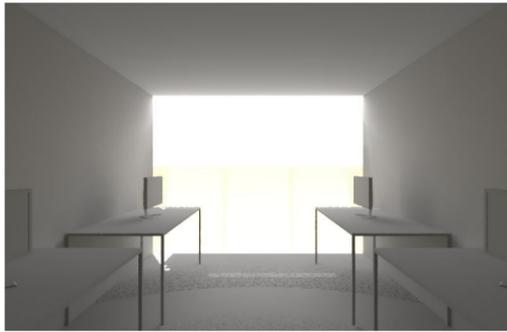


Fig 187 | 21/6, 10:00 | Interior view - True colors  
Horizontal and vertical blades-translucent state.

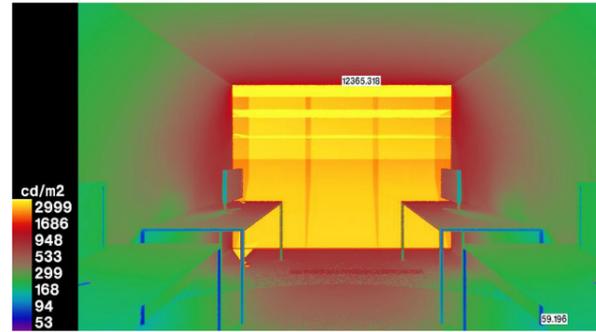


Fig 188 | 21/6, 10:00 | Interior view - False colors  
Horizontal and vertical blades-translucent state.

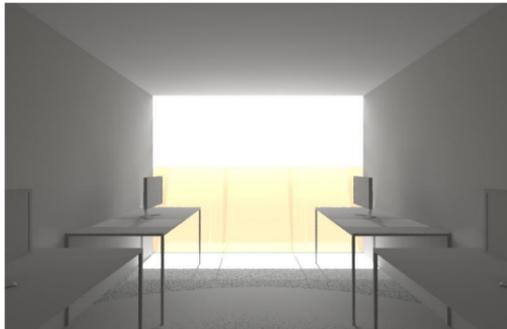


Fig 189 | 21/6, 12:00 | Interior view - True colors  
Horizontal blades-translucent state.

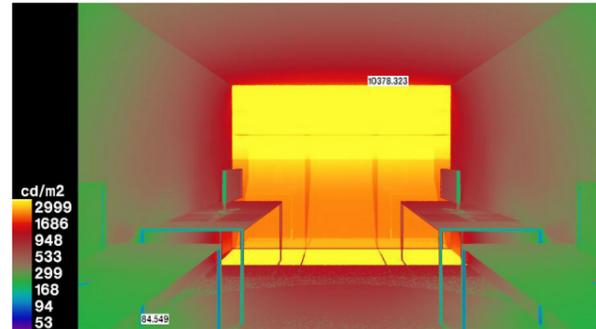


Fig 190 | 21/6, 12:00 | Interior view - False colors  
Horizontal blades-translucent state.



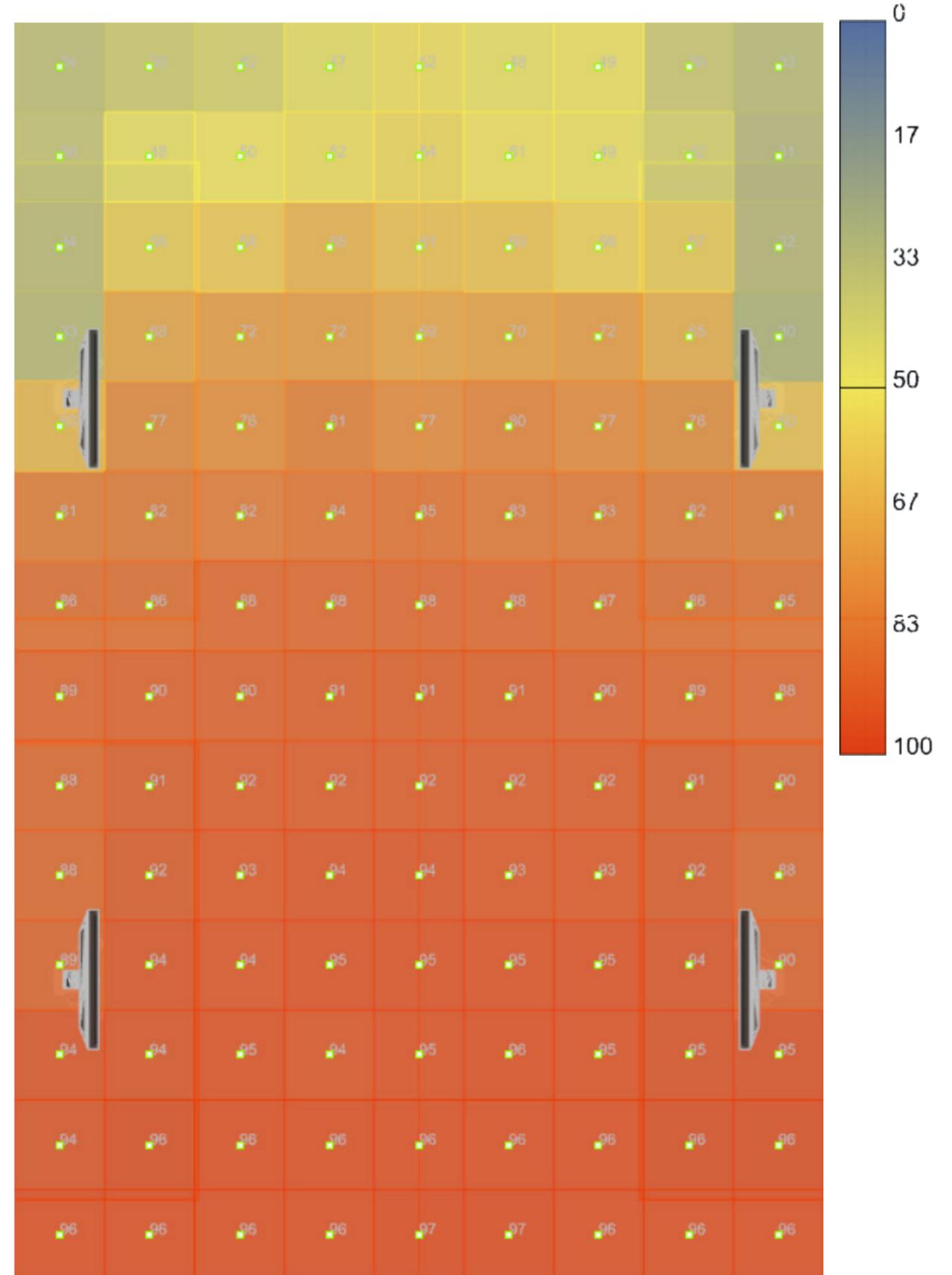
Fig 191 | 21/6, 14:00 | Interior view - True colors  
Horizontal blades-translucent state.



Fig 192 | 21/6, 14:00 | Interior view - False colors  
Horizontal blades-translucent state.

The visualizations illustrated above justify that the shading system performs as required throughout the day, except for the evening hours when the sun is low. At that time the horizontal blades are not capable to block daylight from penetrating. The solution is a deeper or denser 3-dimensional grid, but this would influence greatly the view to outside. The daylight analysis of the system for both south and west orientation illustrates that it is efficient enough through out the year.

DAYLIGHT AUTONOMY RESULTS (%)



Window

## 11 | 2 DAYLIGHT ANALYSIS - COMPUTER-BASED SIMULATIONS | THE NETHERLANDS

After analyzing the efficiency performance in the selected location which is Athens, it would be interesting to analyze how the proposed system performs in the Netherlands as well. In this case, the location is the city of Amsterdam and the tested orientations are south and west. The procedure for the daylighting analyses is the same as the one followed for the location of Athens. At first, the annual glare analysis is obtained for the worst case scenario, when the two possible states are the “all-transparent” and “all-translucent” ones. Afterwards, the daylight autonomy simulation takes place and the shading system is defined analytically. Results are now obtained for the various states of the shading system.

### 11 | 2 | 1 PROPOSED SHADING SYSTEM | South-oriented

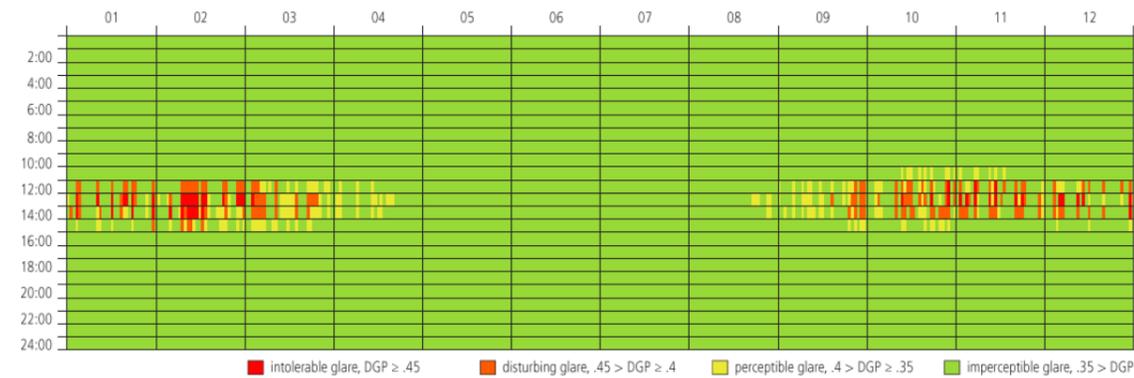


Fig 193 | Proposed shading system\_netherlands\_south\_transparent state annual glare analysis.

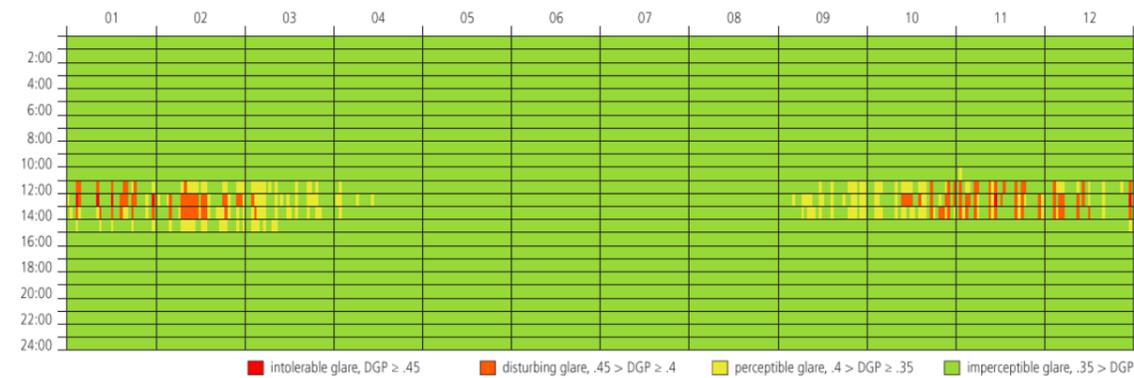


Fig 194 | Proposed shading system\_netherlands\_south\_translucent state annual glare analysis.

Fig 193 and Fig 194 give a first impression of the indoor lighting conditions when the shading system is “on” and “off” respectively. Glare is experienced when the shading system is transparent, though it is reduced when it is translucent.

The daylight autonomy gives more analytical results about the detailed shading system with the two shading groups, the horizontal and the vertical one. Following, the daylight indices are compared with the requirements.

Daylit area |  $DA_{500lux}[50\%] > 80\%$  of floor area = 81% ✓

Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 67% ✗

Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000LUX}[50\%] > 60\%$  for the active occupant behavior = 63% ✓

Glare |  $< 0.3\%$  of occupied hours = 0% ✓

The proposed shading system is efficient for south orientation in the Netherlands as well, though daylight autonomy's value is not acceptable. The rest of the indices appear to have good values, which is enough for justifying the performance efficiency.



**Warnings**  
ShadingGroup 1 has no reference sensors.  
ShadingGroup 2 has no reference sensors.

**Simulation Tips**  
Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\final\_south\final\_south\_intgain.csv

**Daysim Simulation Report**

Daylit Area ( $DA_{500lux}[50\%]$ )	81% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	48% of occupied hours
Shading Group 2 open	52% of occupied hours

**Daylight Factor (DF) Analysis:** 70% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 67% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 81% for active occupant behavior.

**Continuous Daylight Autonomy (CA) Analysis:** The mean continuous daylight autonomy is 80% for active occupant behavior. The percentage of sensors with a  $DA_{MAX} > 5\%$  is 42% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a  $UDI_{<100-2000lux}$  larger than 50% is 63% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

- Lighting Group 1 (manual\_control): 212.7 kWh

#### Simulation Assumptions

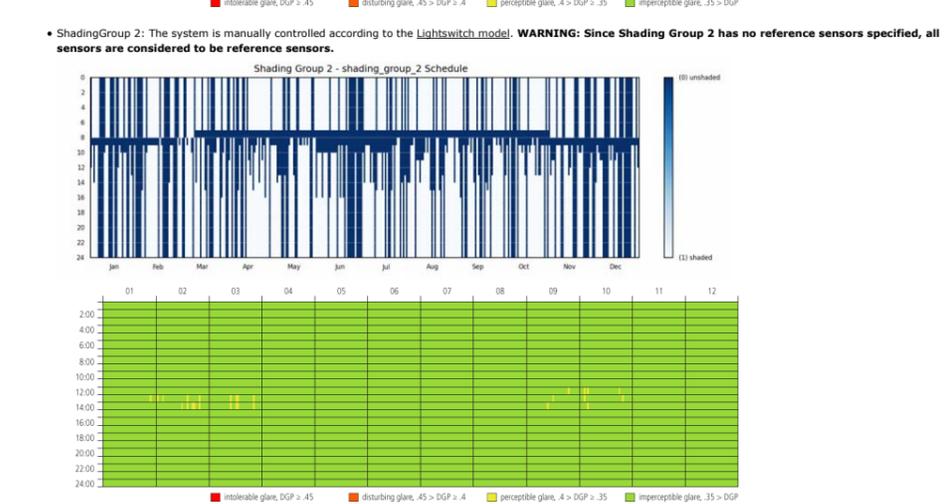
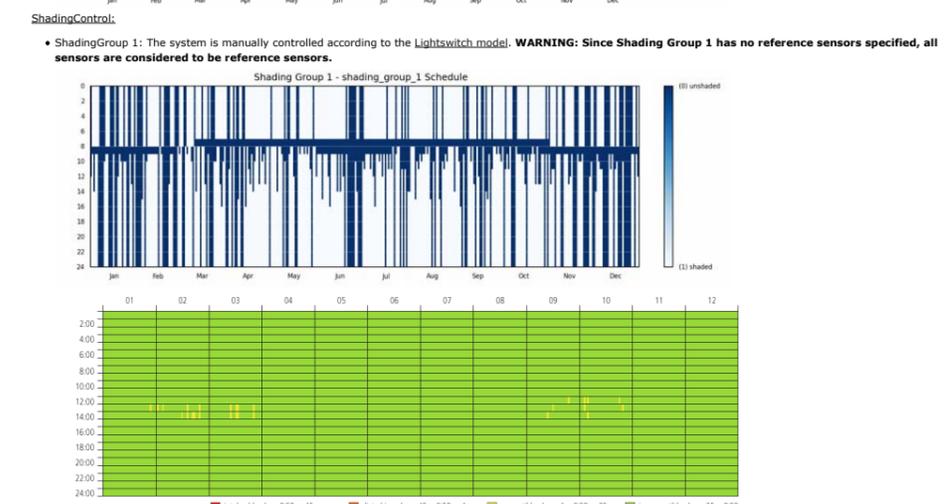
**Site Description:**  
The investigated building is located in AMSTERDAM\_NLD (52.30 N/ 4.77 W).

**User Description:**  
The total annual hours of occupancy at the work place are 3650.

**Occupied Hours: 3650 Schedule**

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



# 11 | 2 | 1 PROPOSED SHADING SYSTEM | West-oriented



Fig 195 | Proposed shading system\_netherlands\_west\_transparent state annual glare analysis.



Fig 196 | Proposed shading system\_netherlands\_west\_transparent state annual glare analysis.

Fig 192 and Fig 193 present the critical periods regarding visual comfort. Problems occur mainly from April to September. The transparent state cannot block the undesired daylight and glare is experienced, but the translucent state is more efficient and provides better lighting conditions.

The daylight autonomy gives more analytical results about the detailed shading system with the two shading groups, the horizontal and the vertical one. Following, the daylight indices are compared with the requirements.

- Daylit area |  $DA_{500lux}[50\%] > 80\%$  of floor area = 67% ✘
- Daylight autonomy |  $DA > 80\%$  for active occupant behavior = 67% ✘
- Useful daylight illuminance | percentage of space with a  $UDI_{<100-2000lux}[50\%] > 60\%$  for the active occupant behavior = 80% ✔
- Glare |  $< 0.3\%$  of occupied hours = 1% ✘

In contrast with the south-oriented shading system, the west-oriented is not that efficient because three of the tested indices do not have acceptable values. However, based on the annual glare graphs of the Daysim report, the experienced glare is almost negligible. Disturbing glare is experienced only a few days for one hour at the end of the day. Hence, it is concluded that the proposed shading system is relatively efficient when it is west-oriented in the Netherlands as well.



**Warnings**  
 ShadingGroup 1 has no reference sensors.  
 ShadingGroup 2 has no reference sensors.

**Simulation Tips**  
 Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\final\_west\final\_west\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	67% of floor area
Mean Daylight Factor	5.7%
Occupancy	3650 hours per year
Glare	1.0% of occupied hours
Shading Group 1 open	76% of occupied hours
Shading Group 2 open	82% of occupied hours

**Daylight Factor (DF) Analysis:** 75% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 60% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 67% for active occupant behavior.

**Continuous Daylight Autonomy (CA) Analysis:** The mean continuous daylight autonomy is 78% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 32% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 80% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:  
 • Lighting Group 1 (manual\_control): 215.5 kWh

**Simulation Assumptions**

**Site Description:**  
 The investigated building is located in AMSTERDAM\_NLD (52.30 N/ 4.77 W).

**User Description:**  
 The total annual hours of occupancy at the work place are 3650.

**ShadingControl:**  
 • ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



• ShadingGroup 2: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 2 has no reference sensors specified, all sensors are considered to be reference sensors.**



### 11 | 3 PHYSICAL MODEL

A physical model is used for measuring the system's performance in real time. The scaled mock-up - scale 1:5 - of Building Physics sector of TU Delft is used as a reference room with dimensions 1.08 \* 0.72 \* 0.54. Its geometry is in accordance with the reference room used for the computer-based simulations - scale 1:1.

The measurements took place in the faculty of Architecture (Fig 197), on the first floor, in the morning of the 26<sup>th</sup> of May. During this period the sky was mainly overcast, so there was not an opportunity to reproduce the exact same conditions under which the computer simulations were realized. In an effort to take maximum advantage of the sun, the mock-up was placed in front of the south-east facade of the building, on top of boxes, at 1.2 m. height. The aim was to have uninterrupted view to outside.

The mock up has two operable parts, one at the side (computer view) and one at the back (interior view) which are used for providing the camera with a view to the interior of the reference room. The camera used for these measurements is a calibrated digital camera, CANON EOS 350D, with lens SIGMA DC 18-50mm ex macro. A tripod was used for placing the camera at eye level with regard to the mock-up.

The mock-up has a removable front part, so that any type of facade can be installed and measured in terms of lighting performance. In this case the front part is removed in order to represent lighting conditions caused by a fully-glazed facade and the shading system is placed in front of the opening. Thin Plexiglas sheets are used as the shading elements, simulating the transparent state. Tracing paper is added on top and the sides of the Plexiglas sheets for simulating the translucent state. In order to ensure the reflectivity of the blades on both sides, an extra layer of acetate sheets is placed on top of the tracing paper.

Once the set-up is ready, the camera takes three pictures at a time. The first one is high exposed to light, the second one is low exposed and the last one is a normal picture with normal brightness and contrast levels. Afterwards, the pictures are imported to Technoteam software, combined in one picture and converted in a new false-colored picture.

The mock-up has two different positions, one perpendicular to the facade and one inclined by 15° to east, during which the mock-up is aligned to the sun (Fig 198). Pictures having an interior view are taken at both positions, while pictures with a window view are taken only when the mock-up is tilted, so there are three groups of measurements. Each of these 3 cases is tested under 4 different conditions which are the possible states of the shading system. The measured states are the "all transparent", "vertical translucent", "horizontal translucent" and "all translucent".

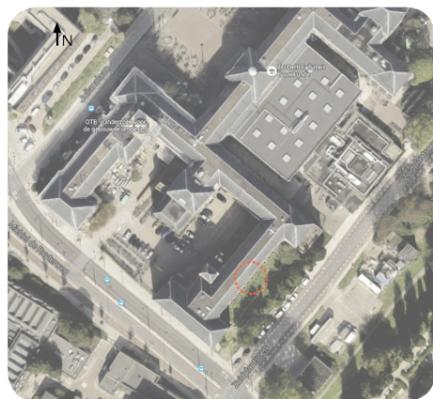


Fig 197 | Location, Delft.

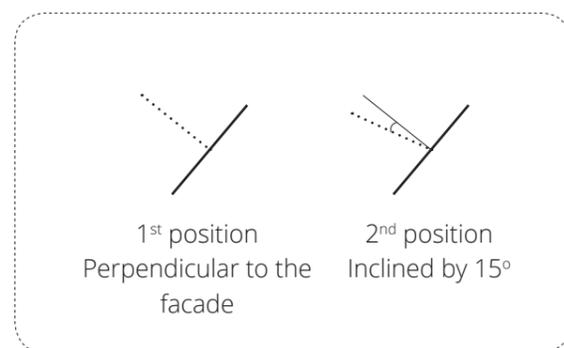


Fig 198 | Two positions of the mock-up.

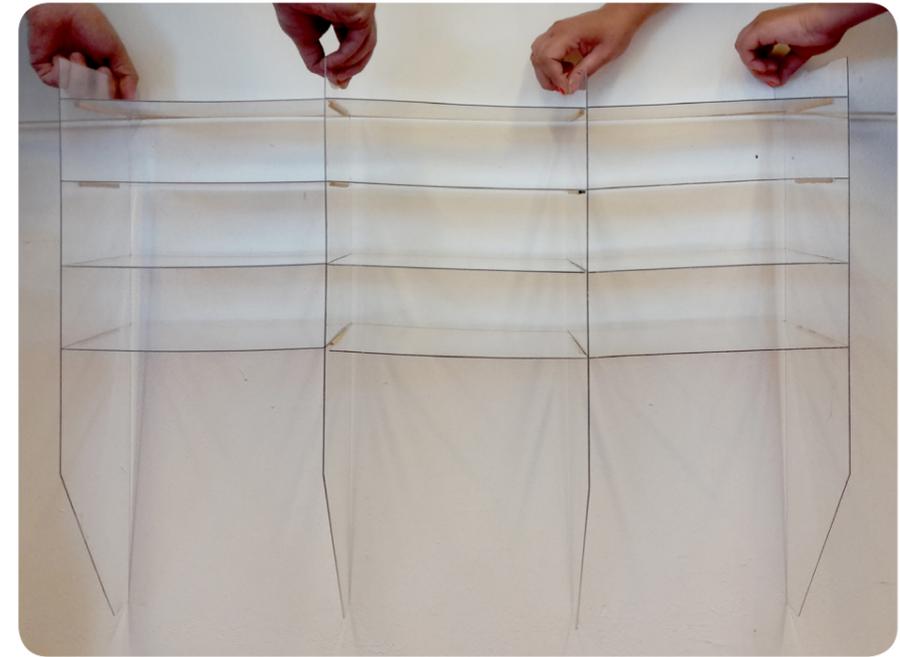


Fig 199 | Shading system prototype. (Transparent state)



Fig 200 | The mock-up with the proposed shading system placed in front of it. (Translucent state)

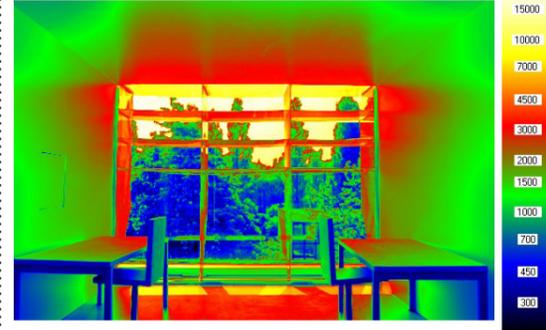
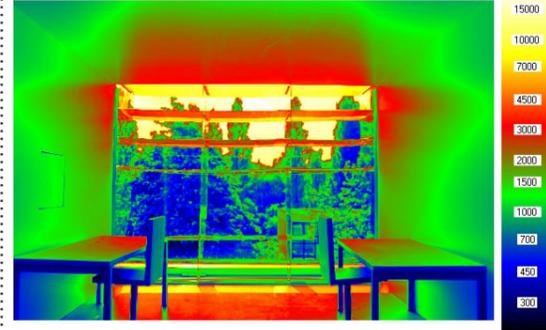
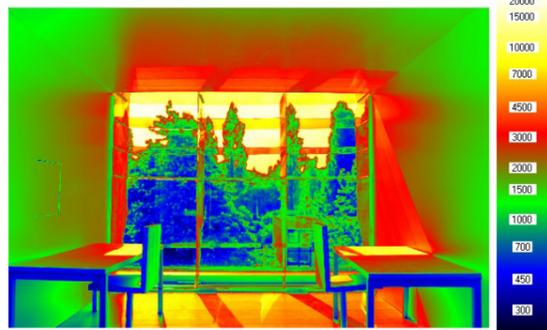
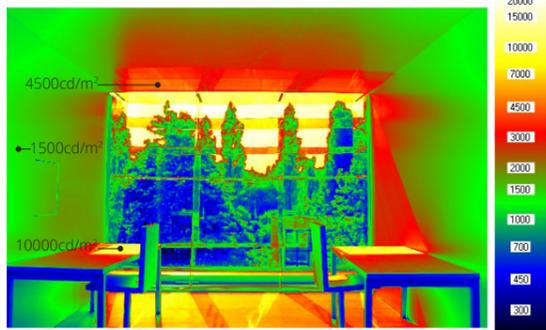
All transparent

Vertical translucent

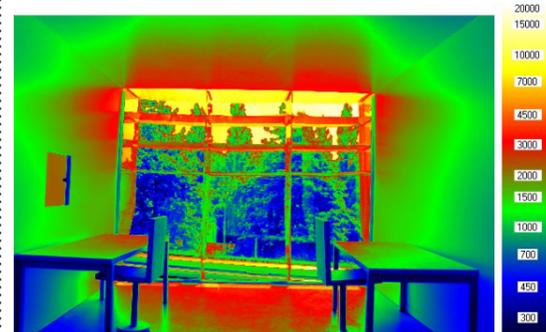
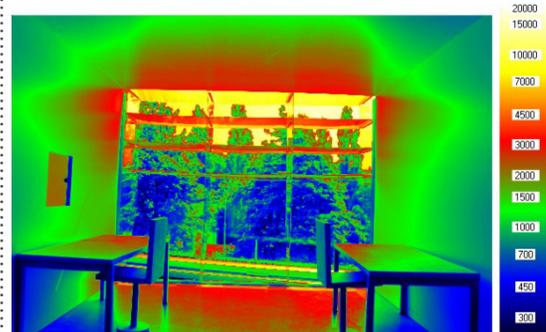
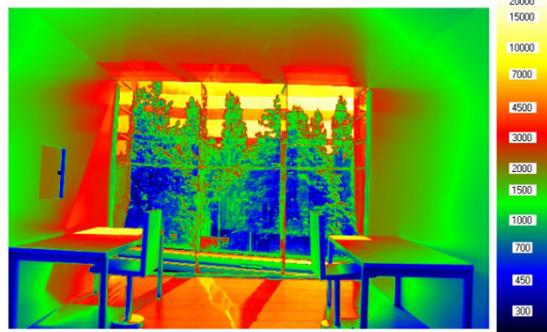
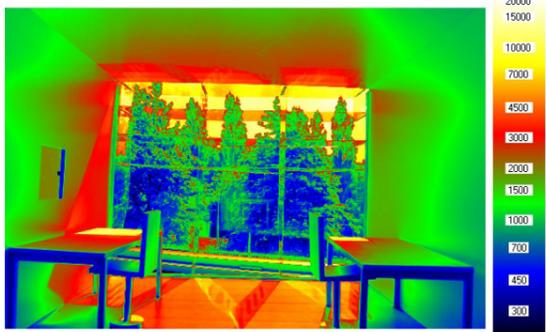
Horizontal translucent

All translucent

Perpendicular to facade



15° inclined to east | Interior view



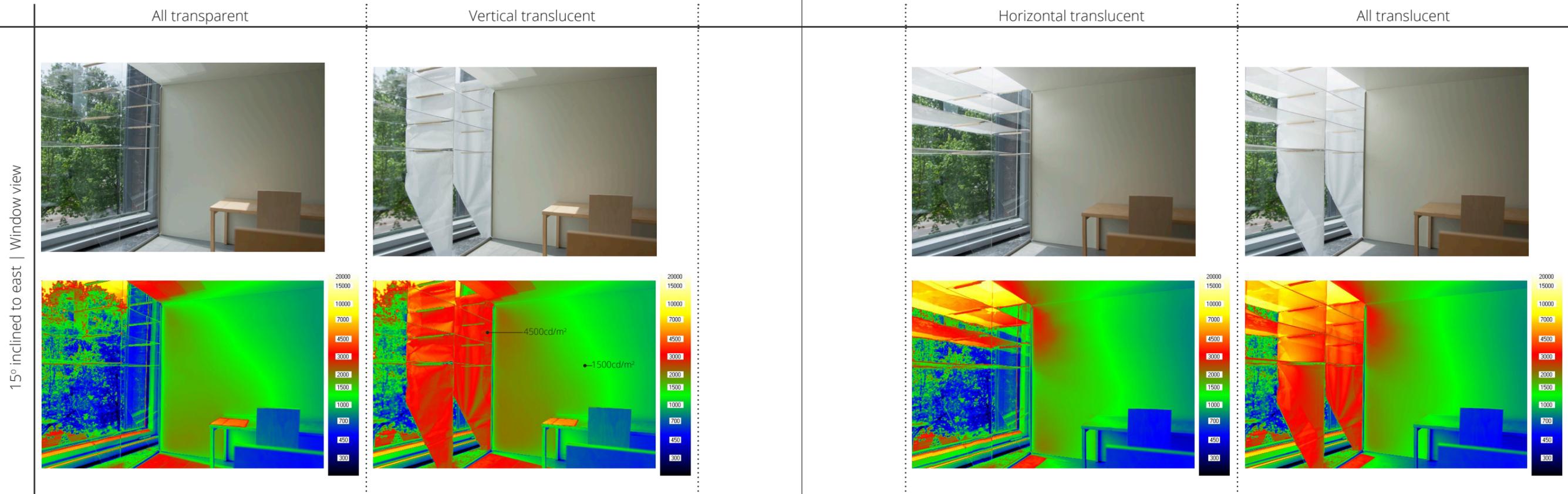


Table 15 | Real-time measurement pictures

Table 12 illustrates the three groups of measurements by true-colored and false-colored pictures. The true-colored pictures give an overview of the lighting conditions inside the reference room and the existence of direct daylight at the region of the task field (desk), while the false-colored ones give information about the luminance values.

Regarding the first two groups, when the camera has a view to the interior, the shading system is barely visible, so it does not affect the luminance values of the pictures. Focusing on the interior space, in the 1<sup>st</sup> and 2<sup>nd</sup> case, direct daylight reaches the task field and causes visual discomfort to the user. According to the system requirements, direct daylight is not acceptable on the task field as it can be disturbing. The focus area is the desk where the user is usually located. It is easily noticeable that only the horizontal blades, in the 3<sup>rd</sup> and 4<sup>th</sup> case, are able to block direct daylight on this area adequately. Moreover, the luminance does not present any extreme values and consequently the luminance ratio values are acceptable. As the lighting conditions are almost the same in these two cases, the 3<sup>rd</sup> one is concluded to be the most efficient because the absence of the translucent vertical blades allows daylight to enter the room and offers more view to outside.

Continuing with the 3<sup>rd</sup> group of measurements and the computer view, the true-colored pictures agree with the previous ones on that the two first cases do not block direct daylight, whereas the last two protect the task field and offer acceptable indoor lighting conditions. The false-colored pictures show that the translucent state of the vertical blades influence the luminance values greatly. The milky color of the blades give luminance values around 4500 cd/m<sup>2</sup>, while the wall at the side give luminance values around 1500 cd/m<sup>2</sup>. Based on these values, the luminance ratio is 0.3 which is acceptable for all visual fields.

One of the question risen during the development of the shading system was the possible disturbance of the user due to the reflectance of the blades. The outer layer of the blades is supposed to be glass which is glossy and reflective. During computer simulations, no reflections were observed, but it should be double-checked with the real-time measurements. The pictures of the two first states, the “all transparent” and the “only vertical translucent” cases show signs of reflection on the ceiling. In order to estimate whether it is disturbing or not, the luminance ratio values has to be calculated and compared with the minimum limit referring to panorama field. The luminance value at these regions are 4500 cd/m<sup>2</sup>, so compared with the average luminance value of the walls which is 1500 cd/m<sup>2</sup>, the luminance ratio value is 0.3 which is acceptable when compared with the minimum acceptable value which is 0.03 cd/m<sup>2</sup>.

It should also be mentioned that the materials of the ceiling, the walls and the floor affect highly the indoor lighting conditions. The color and the surface of these elements define the reflection of daylight indoors. So the possibility for reflection has to be checked for each future application.

# 12

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## FEASIBILITY

The proposed design aims at introducing a new generation of shading systems which are adaptive in terms of orientation and even invisible under request. The innovative technology of PDLC smart glass makes this concept possible and its feasibility is analyzed regarding the manufacturing process, the cost and the energy consumption during performance.

## 12|1 MANUFACTURING

Once the shading system is designed and adjusted to the requirements of each case study, the manufacturing begins. The first step is the manufacturing of the float glass sheets and their cutting in the required shape. Fig 201 illustrates the main processes during float glass production.

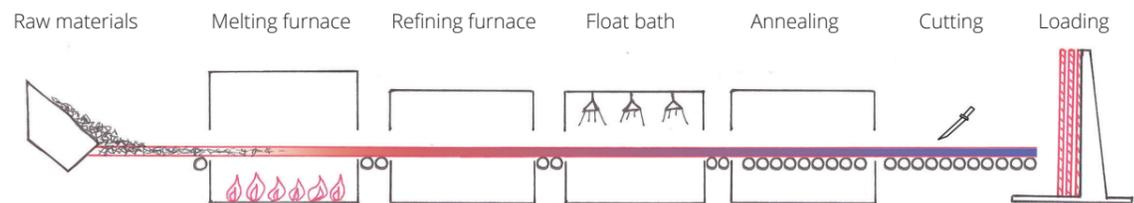


Fig 201 | Installation process.

The PDLC smart film is manufactured in a way similar to glass lamination. The two PET conductive films are used as barriers for the liquid crystal which incorporates the droplets and they are bonded all together under heating and pressure. Once the PDLC film is constructed, the adhesive EVA layers and the three glass sheets are added and laminated together. At this point the metal connectors are also placed and laminated with the whole glass panel. For this procedure special equipment is required which bond the layers firmly under heating and vacuum or pressure.



Fig 202 | Lamination process.

The shading components are ready for installation. Cranes are needed for the installation of both the curtain wall and the shading system. The facade of the building is completed following the steps of the assembling, refer to "10|9 FACADE ASSEMBLING". Afterwards, the shading system is placed and fixed piece by piece from right to left (Fig 203). At first, the vertical components are placed and fixed and afterwards the horizontal components are placed between them, completing the structure of the frame.

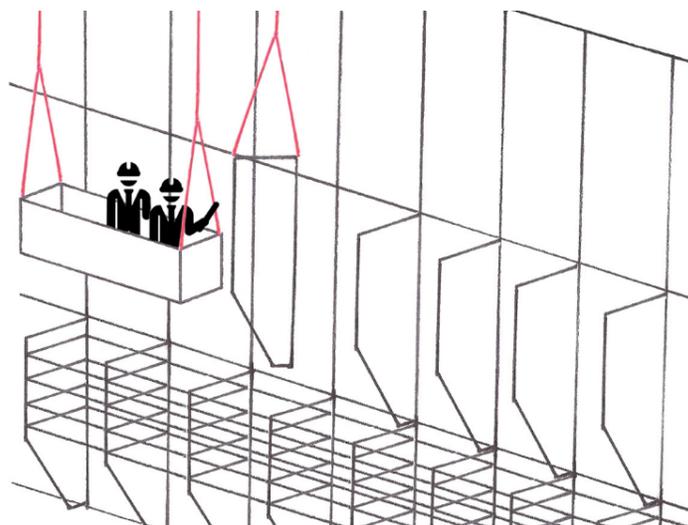


Fig 203 | Installation process.

## 12|2 COST

The estimation of the cost of the shading system is based on prices given by suppliers on web. It is worth mentioning that the prices are only currently valid. Innovative technologies such as PDLC smart glass become cheaper and as a result more affordable through out the years. Moreover, the price of certain components is given within a range because quality is a factor as well.

The cost calculation takes into account the main components of the proposed shading system which are the blades, the protective aluminum cap rail at their perimeter, the structural steel T-profile connection component and the cables. The final price of the proposed shading system is estimated within the range of 533 - 772 €/m<sup>2</sup>. The analytical calculations of the cost can be found in Appendix C.

The selection criteria of a product is the budget of the client and for this reason 3 cheaper alternatives are proposed as well. The first alternative uses AR acrylic sheets instead of glass sheets and so the system is lighter and cheaper. They are abrasion resistant (AR) in order to avoid scratches and weathering. In the second alternative, only the horizontal blades are dynamic, while the vertical ones are consistently translucent. The daylight simulations highlighted that the vertical blades contribute less to the system's efficiency, so if financial cuts are necessary, they can be static. The last alternative proposes a static solar shading system with consistently translucent components. All these alternatives are less durable or of a lower quality as they are not fully dynamic. Considering that the difference in price is relatively low, the proposed shading system is supposed to be the most efficient one.

## 12|3 ENERGY USE

This graduation thesis focuses on visual comfort, a value which expresses the users' experience in the room. The goal of the proposed shading system is to create pleasant indoor lighting conditions offering comfort to each individual. However, such aspects characterize the system only qualitatively. In order to evaluate the performance of the shading system, its contribution to the energy consumption of the building has to be calculated as well.

Two thermal analyses take place for each orientation, south and west. In the first case, the annual energy consumption of the reference room, when no shading system is applied, is calculated, while in the second case, the annual energy consumption of the reference room, when the proposed shading system is applied, is calculated. These thermal analyses give information about the energy consumption of the interior lighting, the interior equipment, the heating and the cooling of the space. Regarding artificial lighting, two Slotlights, "IP40 LED light line in light colour 3000 K" of Zumtobel, are placed aligned with the desks in the room. The lighting control is defined as "Manual On/Off Switch" which means that the software mimics the user's behavior turn off the lights when the levels reach 250 lux, based on the statistical analysis of the 2002 Lightswitch study. The annual results obtained from the thermal analysis are presented in Table 03 and the daysim reports are illustrated in appendix B. At this point, it should be mentioned that due to an error of the DIVA software, two different units are used for the same results, kWh in the graph and Joules in the Excel files. After careful consideration, it is concluded that the Joules is the appropriate unit and so all the results were transformed in kWh.

The procedure followed is always the same. However, in the second case, the energy consumption of the shading system is calculated and added as well. PDLC smart glass technology enables the switching from translucent to transparent by the supply of current. Its original state is translucent and once the current is on, it becomes transparent. The Daysim Report gives information about the performance of the shading system and it specifies the amount of time during which the system should be transparent (active). The energy use of PDLC is 0.4 W/m<sup>2</sup> ("Switchable Privacy Glass Product Specifications," n.d), so it is possible to estimate the energy use for south and west orientation independently.

Before proceeding with the consumption calculation, the basic characteristics of the shading system have to be mentioned:

Surface of horizontal elements: 12.96m<sup>2</sup> per room | 5.2 W/room = 5.2 (J/s) / room

Surface of vertical elements: 6.76m<sup>2</sup> per room | 2.75 W/room = 2.75 (J/s) / room

### SOUTH-ORIENTED FACADE

Energy consumptions	No shading system [kWh]	Proposed shading system [kWh]
InteriorLights: Electricity	33.46	42.47
InteriorEquipment: Electricity	839.14	839.14
Heating: EnergyTransfer	73.58	211.34
Cooling: EnergyTransfer	1274.90	338.10
<b>Energy consumed</b>	<b>2221.08</b>	<b>1431.04</b>

Table 10 | Annual energy consumption for south-oriented room.

The energy consumption of the system per room, per year, is:

Horizontal elements (5.2 J/s / room)

- 26% of working hrs active (949 hrs = 3,416,400s)
- 17.7 M Joules/room/year

Vertical elements (2.75 J/s / room)

- 35% of working hrs active (1277.5 hrs = 4,599,000s)
- 12.65 M Joules/room/year

**System's annual energy consumption = 30.35 MJoules / room | 8.43 KWh / room**

Energy consumptions	No shading system [kWh]	Proposed shading system [kWh]
Energy consumed	2221.08	1431.04
System's energy consumption	-	8.43
<b>Total energy consumption</b>	<b>2221.08</b>	<b>1439.74</b>

Table 11 | Total annual energy consumption for south-oriented room.

Concluding, the annual energy consumption of the reference room with no shading system applied is 2,221.08 kWh, while the annual energy consumption in the reference room with shading system applied is 1,439.47 kWh in total. Hence, the energy saving when using the proposed shading system is 35,19 %.

### WEST-ORIENTED FACADE

Energy consumptions	No shading system [kWh]	Proposed shading system [kWh]
InteriorLights: Electricity	43.50	50.97
InteriorEquipment: Electricity	839.14	839.14
Heating: EnergyTransfer	86.29	129.26
Cooling: EnergyTransfer	1114.13	722.75
<b>Energy consumed</b>	<b>2083.05</b>	<b>1742.11</b>

Table 12 | Annual energy consumption for west-oriented room.

The energy consumption of the system per room, per year, is:

Horizontal elements (1.6 J/s / room)

- 66% of working hrs active (2409 hrs = 8,672,400s)
- 13.9 M Joules/room/year

Vertical elements (3.6 J/s / room)

- 76% of working hrs active (2774 hrs = 9,986,400s)
- 35.95 M Joules/room/year

**System's annual energy consumption = 49.85 MJoules / room | 13.85 KWh / room**

Energy consumptions	No shading system [kWh]	Proposed shading system [kWh]
Energy consumed	2083.05	1742.11
System's energy consumption	-	13.85
<b>Total energy consumption</b>	<b>2083.05</b>	<b>1755.96</b>

Table 13 | Total annual energy consumption for west-oriented room.

Concluding, the annual energy consumption of the reference room with no shading system applied is 2,083.05 kWh, while the annual energy consumption in the reference room with shading system applied is 1,755.96 kWh in total. Hence, the energy saving when using the proposed shading system is 15.7 % (Fig 204).

### SOUTH-ORIENTED FACADE

### WEST-ORIENTED FACADE

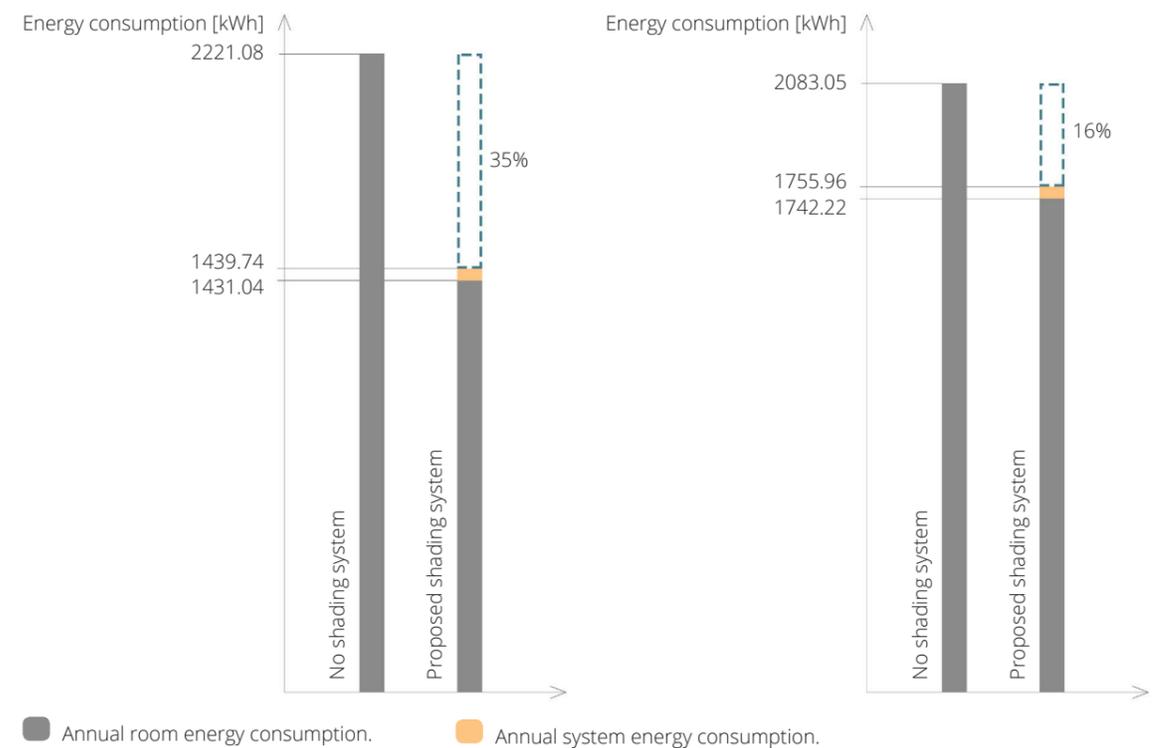


Fig 204 | Total annual energy consumption between no shaded reference room and shaded room .

## 12|4 MAINTENANCE

The plurality of the adaptive systems are based on motion. They manage to adapt to specific conditions via the movement of their components. For this reason, maintenance is needed frequently in order to assure durability and high performance. However, the proposed design, even though it is an adaptive solar shading system, it is fixed on the building envelope and no movement is incorporated. This fact influences to the maximum the maintenance procedure. As there are no mechanisms and moving parts, the only aspect influencing the system's efficiency is dirt. The glass panels have to be cleaned regularly through out the year in order to maintain their transparency. Dry or wet (with water or a window-cleaning liquid that does not contain alcohol, ammonia or acetones) cloth can be used for cleaning the glass panels.

In order to avoid building maintenance units (BMU) being suspended for cleaning the system, the curtain wall of the facade has operable components. These components give access to both vertical and

# 13

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## CONCLUSIONS & FURTHER RESEARCH

horizontal elements of the system. The horizontal glass panels are the ones that require cleaning more frequently because of their direction. An important detail of the horizontal glass panels is that they are slightly inclined in order to avoid rain water being gathered on top of them. An inclination of even  $1.5^\circ$  is enough for drainage.

## 13|1 CONCLUSIONS

The field of adaptive solar shading systems is very broad. The performance principles, the adopted materials, the geometry and the type of movement are some of the varying aspects, offering a wide range of designs. The purpose of this graduation thesis is to analyze and evaluate existing shading designs, and based on the results, propose a new innovative adaptive shading system.

The first part of this thesis deals with existing solar shading systems. Daylight simulations were conducted in order to evaluate their efficiency. The relationship between direction of the shading components and orientation of the facade is studied as well.

A building has more than one sides that may need solar shading. Ideally, in this case different shading systems should be used in order to obtain maximum efficiency. However, such a scenario is usually avoided due to financial and aesthetic reasons. The research on existing solar shading systems showed the lack of designs able to adapt to various orientations. Even though certain shading systems perform efficiently on south-oriented and west-oriented facades, they are not adequately developed. Concluding, there is need for a new adaptive solar shading system which should redirect its components according to the needs.

The second part of this thesis attempts to propose an innovative solar shading system, by using results obtained in the first part, which will perform efficiently in both south and west orientations. Various geometries, movement mechanisms and material types were studied. The outcome was the rejection of any movement mechanism. Every proposed design was either common and similar to an existing one, or innovative and too complicated, which means expensive as well. After reconsideration, it was concluded that the market is in need of a simple but adaptive shading system.

The proposed system is adaptive while being fixed, with no movement mechanisms. This is an unambiguous advantage due to the simpler design and the easiness in construction. In addition, extra costs related to movable parts such as performance costs and maintenance costs are omitted.

### SHADING PERFORMANCE

The main goal of the proposed design is to provide indoor visual comfort, including both adequate light and glare protection. When no shading is required, it becomes invisible. On the contrary, when daylight is intense and penetrates the room directly, it becomes translucent. Its shading efficiency is measured via daylight simulations and proven to be acceptable. Certain requirements (daylit area, daylight autonomy, useful daylight index and glare) are set in order to facilitate the evaluation of the daylight performance of the system and all of them are fulfilled for both orientations, throughout the year, referring to Athens. Extra daylight simulations are also conducted for the city of Amsterdam and guarantee the efficiency of the proposed shading system at this location as well.

### ENERGY CONSUMPTION

Except for the contribution of the shading system in visual comfort, its influence on the energy consumption of the reference room is examined as well via thermal analyses. The energy consumption of

the system is very low,  $0.4 \text{ W/m}^2$ , equal to the energy consumption of an alarm clock with LCD screen. Regarding the energy consumption of the room, the proposed shading system reduces cooling loads during summer months remarkably. Specifically, in south orientation, energy saving equals 35%, while in west orientation it equals 16%. Concluding, this solar shading system does not only offer ideal indoor daylighting conditions, but also promotes a green way of living.

### ASSEMBLING AND INSTALLATION

Effort was put in designing a delicate system with the least possible connections and frames. PDLC smart glass was used to construct the main body of the system, which is a laminated panel. The aluminum protective cap rails and the laminated connection components of the system are the only visible parts. In addition, system's depth equals 0.9m in order to provide adequate shading. The main loads acting on the shading system are its own weight and the wind load. The critical points of the system are the laminated connections and the glass components themselves. The dimensions of the used components are roughly estimated, based on selected material properties, to ensure stability. All laminated connections are designed to be robust enough to withstand and transfer the loads. The thickness of the glass panels and the steel plates is assessed against these loads as well.

## 13|2 FURTHER RESEARCH

The time frame of the graduation studio which is short and strictly defined, limits the potential for optimizations and broad analysis of the current project. For this reason, further research is recommended concerning various aspects of the proposed shading system.

### GEOMETRY

The main focus of this project is visual comfort. In order to set the requirements and test the proposed shading systems, assumptions had to be made. First of all, the shading system is applied on office buildings, meaning that the lighting conditions are measured only during working hours, 8:00 to 18:00. Secondly, the location is specified in order to use the specific sun path during the course of the day and the year. Last but not least, a reference room has been used for the simulations which has specific dimensions and is located on the 10<sup>th</sup> floor. All the assumptions are necessary for the procedure of the analysis, though they eliminate the universality of the system. The geometry has been defined based on these constraints which means that the shading system may not be that efficient under other circumstances.

### BUILDING SHAPE

The proposed solar shading system is designed for both east/west and south oriented facades. The goal is to be universally applied regardless building characteristics, such as the orientation, the building structure and its shape. However, the fact that the system is 3-dimensional grid gives the opportunity to apply it even on cylindrical buildings. The vertical elements can be placed at the extension of the circle's radii and the horizontal ones, having a trapezoid shape, could be placed between them in the same way as in the proposed system.

### MATERIALS

The material used for this product is the PDLC smart glass. It is selected as it can be both transparent and translucent providing shading when needed. This technology can be found either as a laminated glass or as a film, applicable on surfaces. The proposed shading system is placed outdoors, in front of the building envelope so it should be durable and resistant against any weather conditions. When

the polymer matrix is placed in between glass sheets, it is totally protected. However, glass is a relatively heavy material and it adds extra weight to the shading system, demanding strong connections. Another material, with similar properties could be proposed in order to reduce the weight. Plastic or composites may be appropriate for this use, even though plastics are scratched easily and this would reduce their clearness and transparency. Coatings may be used as well to protect the components from friction and surface weather. A first approach on different materials has already been done in order to reduce the cost of the system, though more analytical research is required.

#### STRUCTURAL PERFORMANCE

The laminated glass panels consist of three sheets of glass, one heat-strengthened of 10mm. thickness and two sacrificial layers of 4mm. thick tempered glass sheets. The main forces applied on them are the self-weight and the wind loads, which may not be neglected on high-rise buildings. In order to ensure that the frame is stiff enough, the thickness and the processing of the glass sheets have to be calculated analytically. Laminated connections are used for the assembling and the installation of the shading system. They have already been used in existing projects and proven to have satisfying structural performance. However, the materials and the connections configuration may vary according to the needs of the structural performance, so structural calculations could be done for this issue as well.

# 14

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## REFLECTION

## Personal Reflection

The present document constitutes a reflection of the process and the methodology followed during my graduation thesis. The following aspects are discussed:

### 1| The relationship between research and design

This research focuses on adaptive solar shading systems and explores adaptation mechanisms for east/west and south orientation, in terms of visual comfort. Various designs and adaptation mechanisms have been developed throughout the years, offering a wide range of alternatives. By analyzing and evaluating them, a data base was created which was used as a guide during the design process.

The methodology followed during the research part of the graduation thesis includes literature review on shading systems and the basic characteristics of daylight. To proceed with the analysis of study cases and the daylight simulations, essential was to get familiar with the terminology of daylight and the basic principles on how to control it. Ten academic and ten real projects were analyzed for inspiration and better understanding of the various shading principles. An initial evaluation and qualitative classification of their efficiency was performed as a first approach. Afterwards, computer-based simulations were conducted to obtain quantitative results in terms of efficiency.

The proposed design constitutes an adaptive solar shading system for both east/west and south oriented façades. Even though it is adaptive, it is designed to be fixed in place, without any movable parts. Its adaptation lies in the concept of transparency, as PDLC smart glass is used.

To conclude, research and design were totally interdependent during this graduation thesis.

### 2| The relationship between the theme of the graduation lab and the subject/case study chosen by the student within this framework (location/object)

The sustainable design graduation studio is a part of the Building Technology master program. There are three possible orientations, the Façade, the Structural and the Climate design. All of them explore new innovative technologies. The present study is related to adaptive shading systems, focusing on indoor visual comfort. Thus, the main objectives are the Climate and the Façade design.

Adaptive shading systems are considered to be innovative components of the building envelope as they react to external stimuli, by transforming the building into a living structure. They adapt in order to perform as efficiently as possible, by providing optimum indoor climate conditions and energy saving. Both visual and thermal comfort can be calibrated through solar control, therefore energy consumption can be reduced.

The present project aims to introduce a fixed adaptive shading system, free of movement mechanisms, by making use of the existing technology of the PDLC smart glass. Its performance efficiency, its structure and the way of its installation are objects of this study. Hence, this graduation project explores the application and the performance of innovative technologies with a sustainable approach.

### 3| The relationship between the project and the wider social context

Sustainability is becoming a crucial concept in everyday life. The connection between nature and the built environment is more than ever necessary, for the sake of a "green" way of living. Daylight is one of the most important aspects of nature which influences the built environment. Both thermal and visual comfort of indoor spaces are totally related to the incoming natural light.

This project focuses on the most efficient way of controlling daylight in terms of visual comfort. A successful daylight management results in reduction of artificial light needed and therefore reduction of electricity consumption. In addition, the impact of daylight in indoor thermal conditions is equally important. Heating and cooling loads can be by far limited during winter and summer time respectively only by controlling natural light which penetrates indoor space.

An adaptive shading system can trigger the interest of individuals in controlling and taking maximum advantage of nature. Adoption of such systems increases the environmental awareness and introduces sustainability as a way of life.

In addition, the proposed design highlights the importance of simplicity. Various designs have been developed during the last years, most of which are extraordinary and eye-catching. It is widely believed that anything extreme, big and complicated is smart and efficient as well. Reality, though, shows that such systems are usually too expensive to be structured and maintained. Hence, even though they have been designed in order to reduce energy consumption and improve indoor climate conditions, total expenses are not reduced. The proposed shading system is efficient in the most simple and delicate way. The transparency of the system is achieved by the smart glass technology, making it almost invisible when needed. Thus, this system is considered to be adaptive, as it changes its characteristics, even though it does not incorporate any movement mechanism. Because of that, both construction and maintenance costs are reduced.

Society has to think and act in a simple way. Robert Browning introduced the phrase "less is more" in one of his poems in 1855, which was then adopted by the architect Ludwig Mies van der Rohe in 1947. This phrase should find application in every aspect of life.

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- Smart Glass Windows. (13:02:10 UTC). Retrieved from [http://www.slideshare.net/glassapps/smart-glass-windows?next\\_slideshow=1](http://www.slideshare.net/glassapps/smart-glass-windows?next_slideshow=1)

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APPENDIX

**Warnings**

No warnings.

**Simulation Tips**

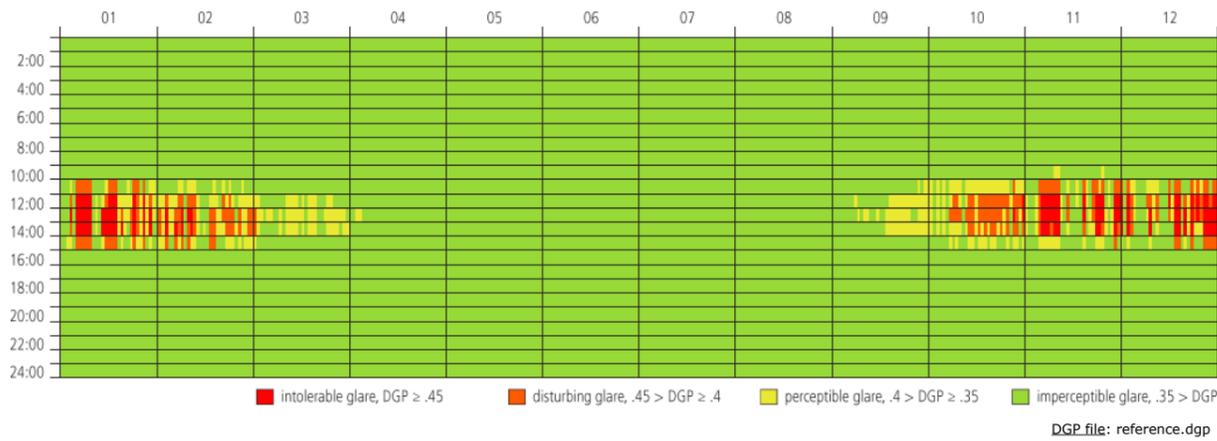
You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**  
Hourly values are shown for each view and shading state.

**Base Shading State**

View Name interior



Daysim header File: C:\DIVA\temp\reference\reference.he

**Warnings**

No warnings.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\reference\reference\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	100% of floor area
Mean Daylight Factor	7.3%
Occupancy	3650 hours per year
Glare	8.1% of occupied hours

**Daylight Factor (DF) Analysis:** 82% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone should qualify for the LEED-NC 2.1 daylighting credit 8.1 (see [www.usgbc.org/LEED/](http://www.usgbc.org/LEED/)).

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 89% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 100% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 95% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 64% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 56% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.

**Lighting Control:**

There is no electric lighting system specified for the scene.

**ShadingControl:**

There is no dynamic shading system in the scene.

Daysim header File: C:\DIVA\temp\reference\reference.he

**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

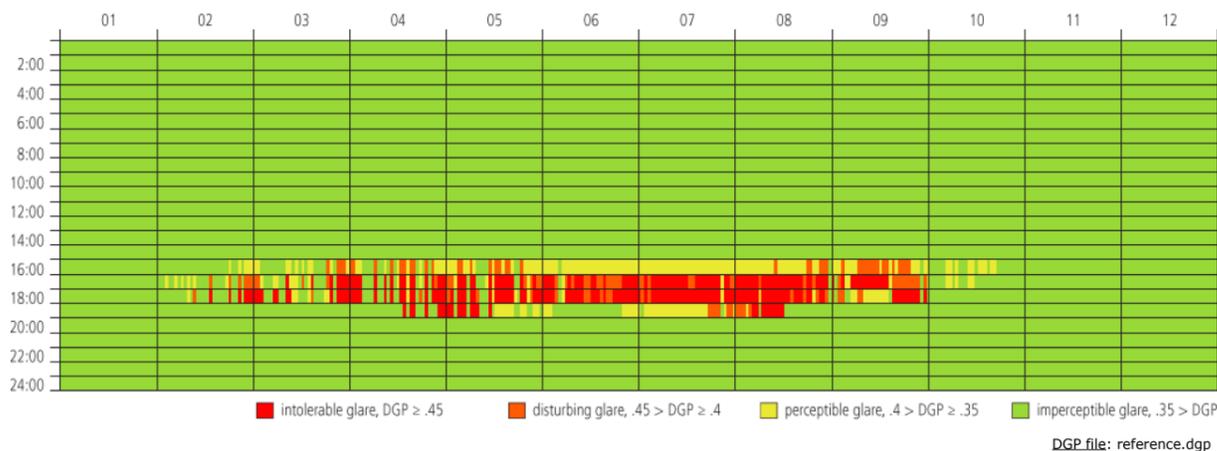
**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**

Hourly values are shown for each view and shading state.

**Base Shading State**

View Name interior



DGP file: reference.dgp

Daysim header File: C:\DIVA\temp\reference\reference.hea

**Warnings**

No warnings.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\reference\reference\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	94% of floor area
Mean Daylight Factor	7.4%
Occupancy	3650 hours per year
Glare	6.1% of occupied hours

**Daylight Factor (DF) Analysis:** 83% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone should qualify for the LEED-NC 2.1 daylighting credit 8.1 (see [www.usgbc.org/LEED/](http://www.usgbc.org/LEED/)).

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 84% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 94% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 55% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 68% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.

**Lighting Control:**

There is no electric lighting system specified for the scene.

**ShadingControl:**

There is no dynamic shading system in the scene.

Daysim header File: C:\DIVA\temp\reference\reference.hea

Warnings

No warnings.

Simulation Tips

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

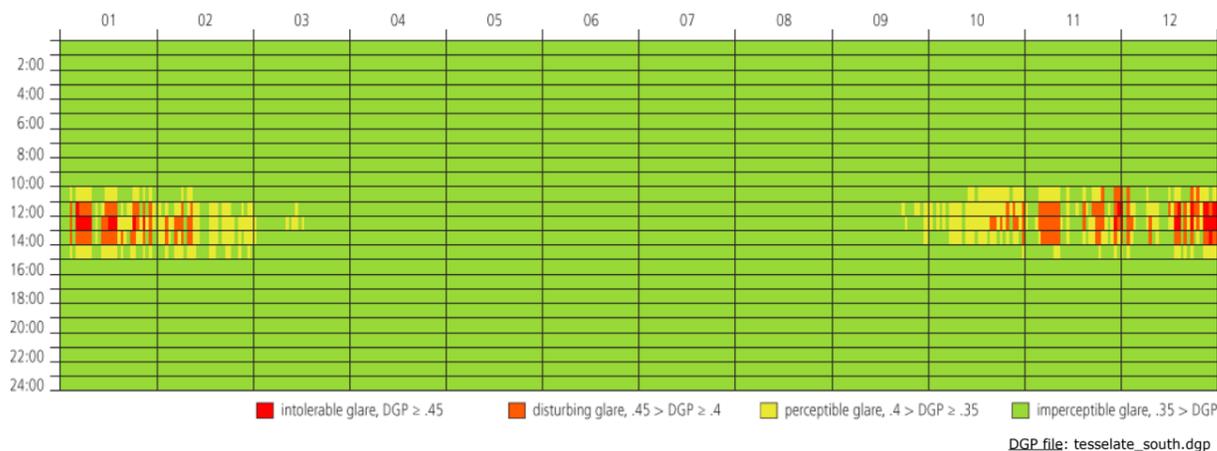
Annual Glare Simulation (eDGPs) Report

Visual Comfort Without Occupant Adaptation

Hourly values are shown for each view and shading state.

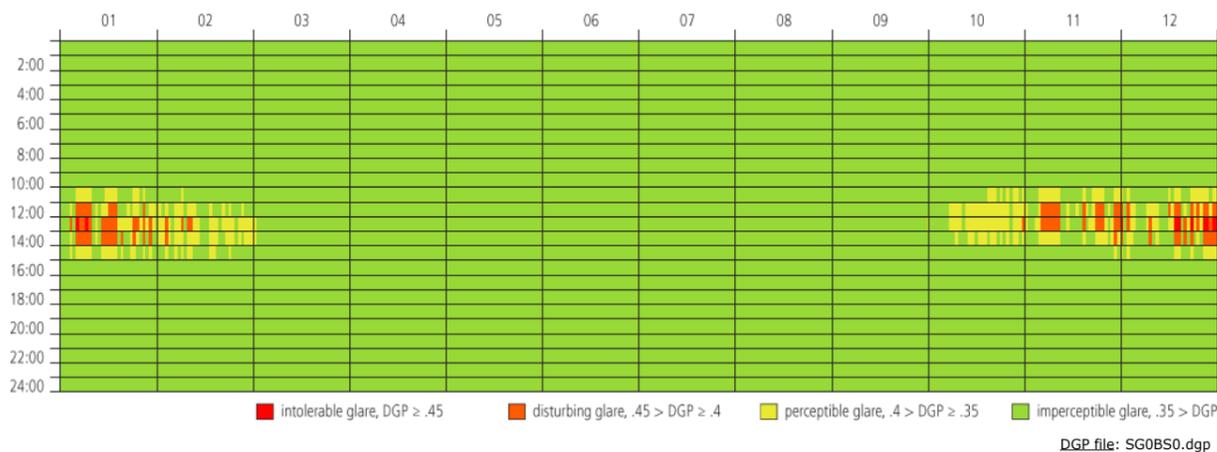
Base Shading State

View Name interior



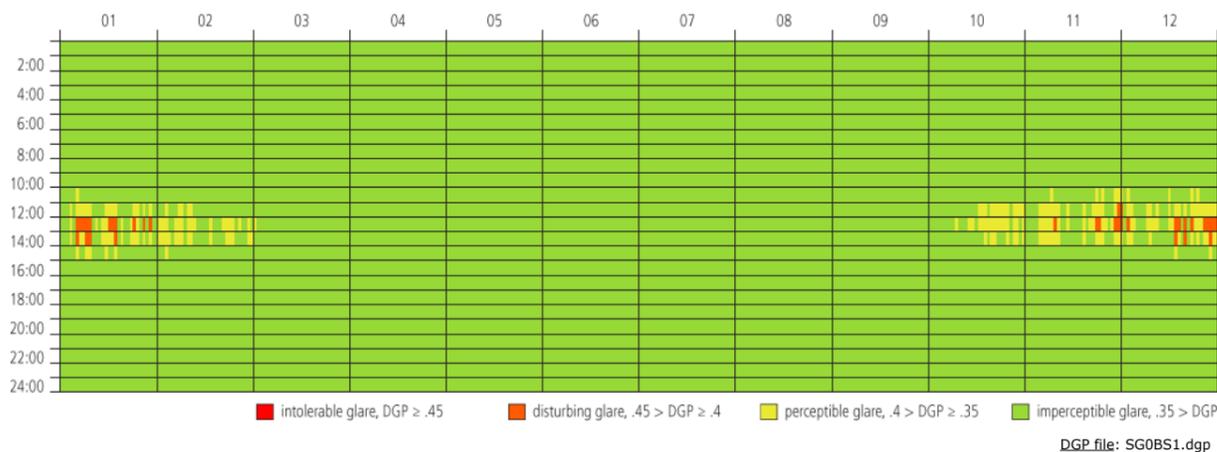
Shading Group 1; Status 1

View Name interior



Shading Group 1; Status 2

View Name interior



Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below

C:\DIVA  
 \temp\tessellate\_south  
 \tessellate\_south\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	100% of floor area
Mean Daylight Factor	6.3%
Occupancy	3650 hours per year
Glare	1.0% of occupied hours
Shading Group 1 open	89% of occupied hours

**Daylight Factor (DF) Analysis:** 74% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 86% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 100% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 53% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 63% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

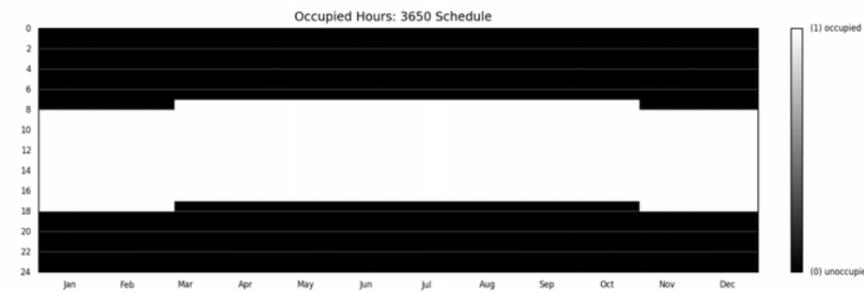
Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.



Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



Warnings

No warnings.

Simulation Tips

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

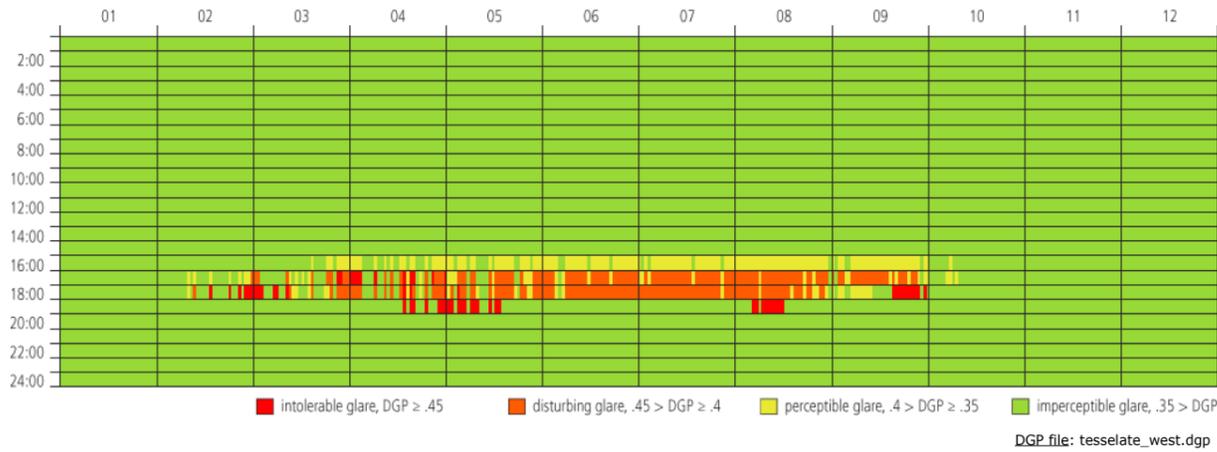
Annual Glare Simulation (eDGPs) Report

Visual Comfort Without Occupant Adaptation

Hourly values are shown for each view and shading state.

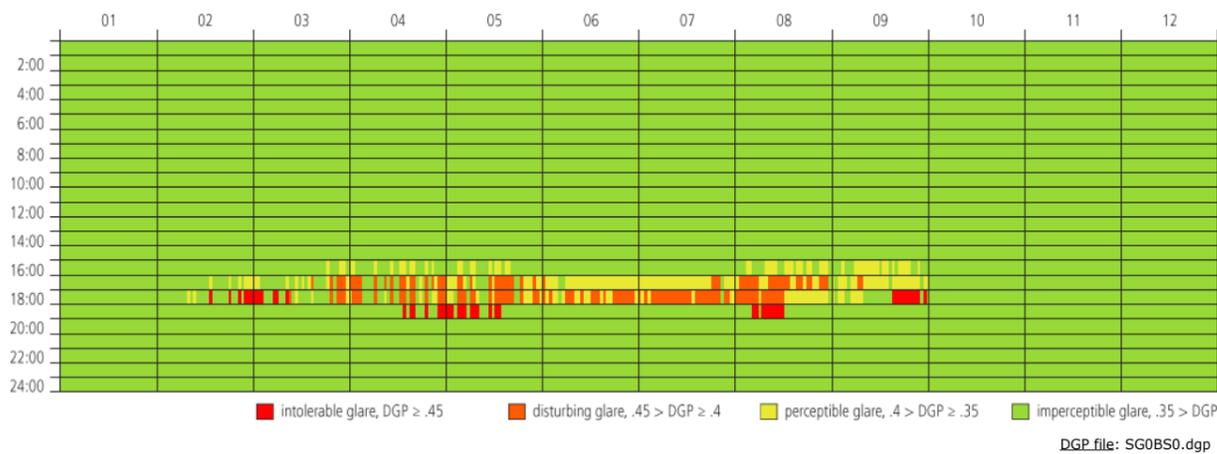
Base Shading State

View Name interior



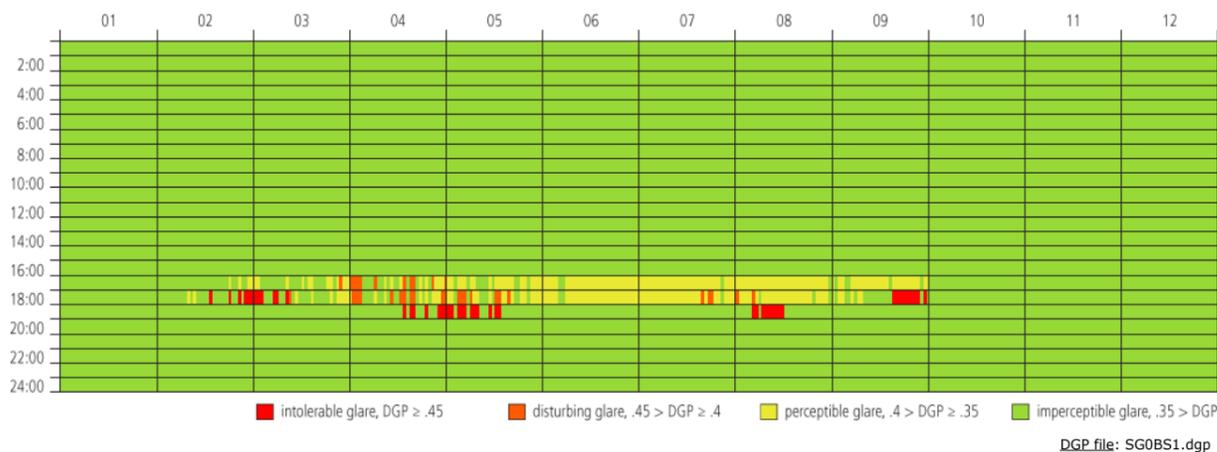
Shading Group 1; Status 1

View Name interior



Shading Group 1; Status 2

View Name interior



Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA  
\temp\tessellate\_west  
\tessellate\_west\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	84% of floor area
Mean Daylight Factor	6.4%
Occupancy	3650 hours per year
Glare	0.6% of occupied hours
Shading Group 1 open	96% of occupied hours

Daylight Factor (DF) Analysis: 72% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 79% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 84% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 92% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 48% for active occupant behavior.

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 73% for active occupant behavior.

Electric Lighting Use: The predicted annual electric lighting energy use is:

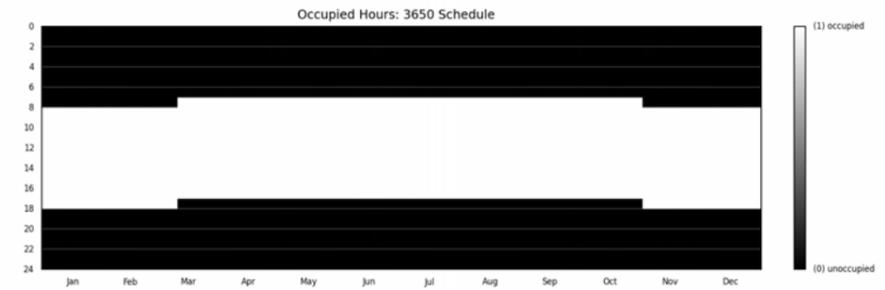
Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.

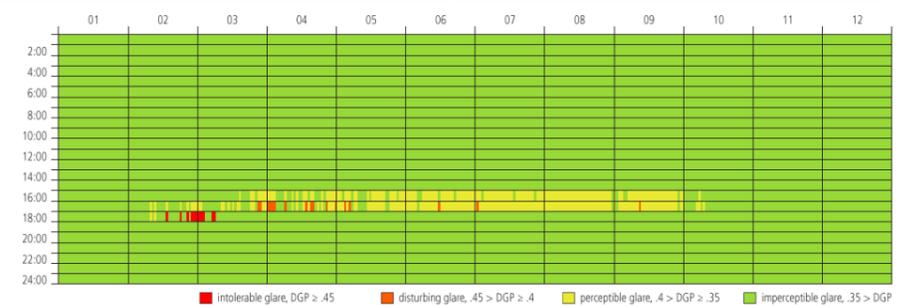
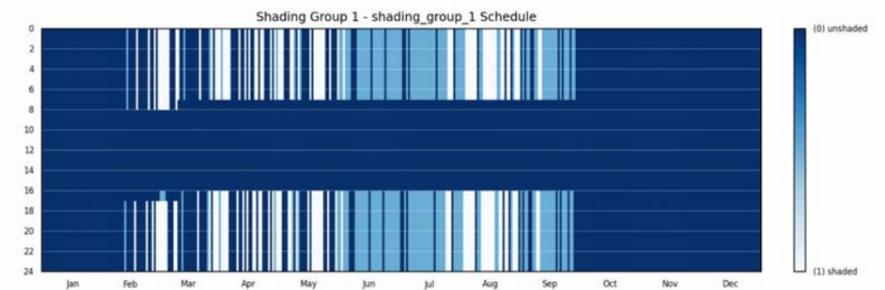


Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



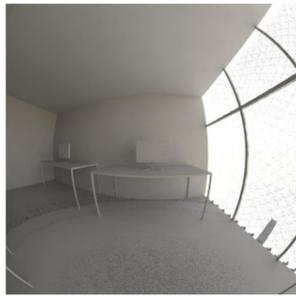


Fig 001 | Tessellate\_computer view\_6/21\_1st state\_8:00.

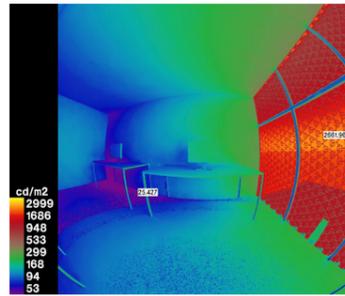


Fig 002 | Tessellate\_computer view\_6/21\_1st state\_8:00.

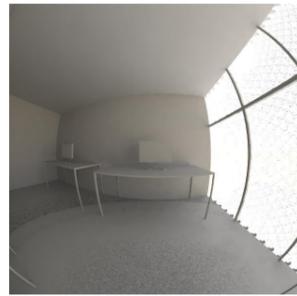


Fig 003 | Tessellate\_computer view\_6/21\_1st state\_12:00.

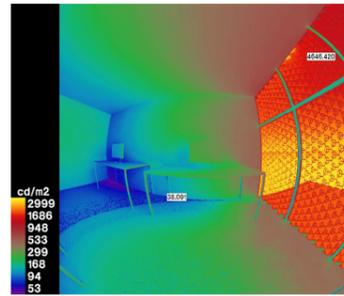


Fig 004 | Tessellate\_computer view\_6/21\_1st state\_12:00.

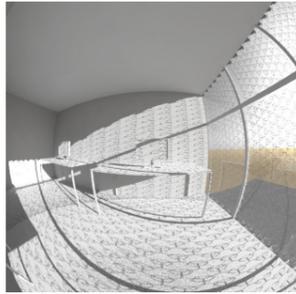


Fig 005 | Tessellate\_computer view\_6/21\_1st state\_18:00.

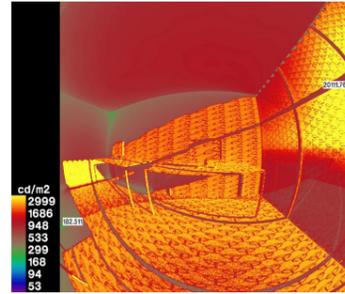


Fig 006 | Tessellate\_computer view\_6/21\_1st state\_18:00.

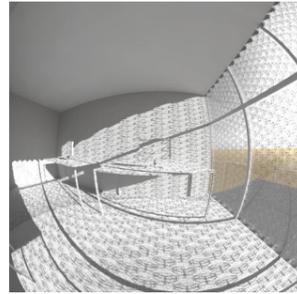


Fig 007 | Tessellate\_computer view\_6/21\_2nd state\_18:00.

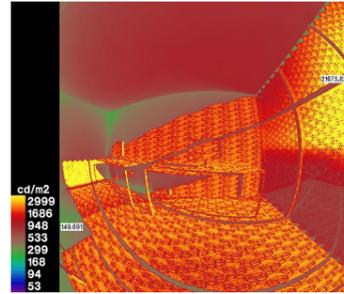


Fig 008 | Tessellate\_computer view\_6/21\_2nd state\_18:00.

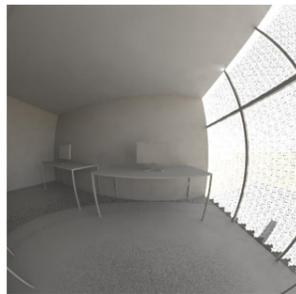


Fig 009 | Tessellate\_computer view\_6/21\_3rd state\_8:00.

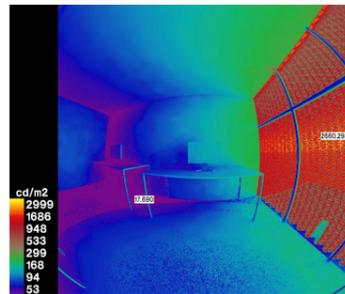


Fig 010 | Tessellate\_computer view\_6/21\_3rd state\_8:00.



Fig 011 | Tessellate\_window view\_6/21\_3rd state\_12:00.

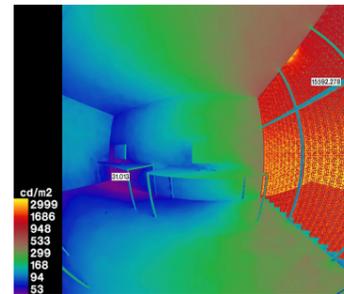


Fig 012 | Tessellate\_window view\_6/21\_3rd state\_12:00.

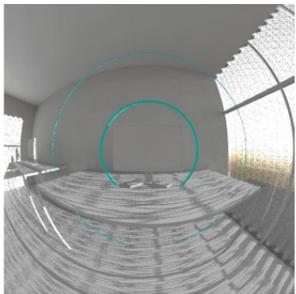


Fig 013 | Tessellate\_computer view\_6/21\_3rd state\_118:00.

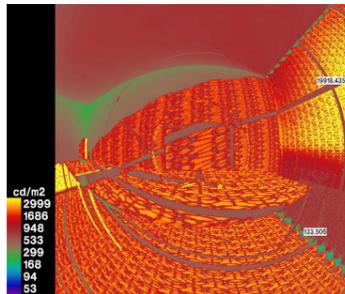


Fig 014 | Tessellate\_computer view\_6/21\_3rd state\_18:00.

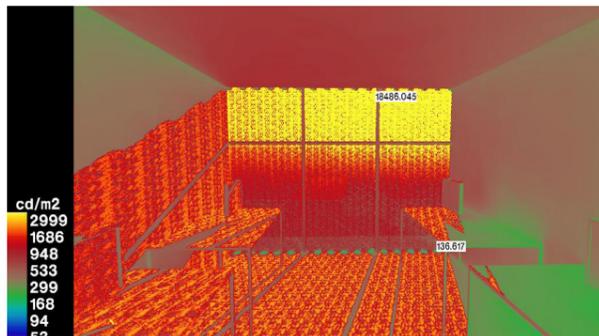


Fig 016 | Tessellate\_interior view\_6/21\_3rd state\_18:00.



Fig 015 | Tessellate\_interior view\_6/21\_3rd state\_18:00.



**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

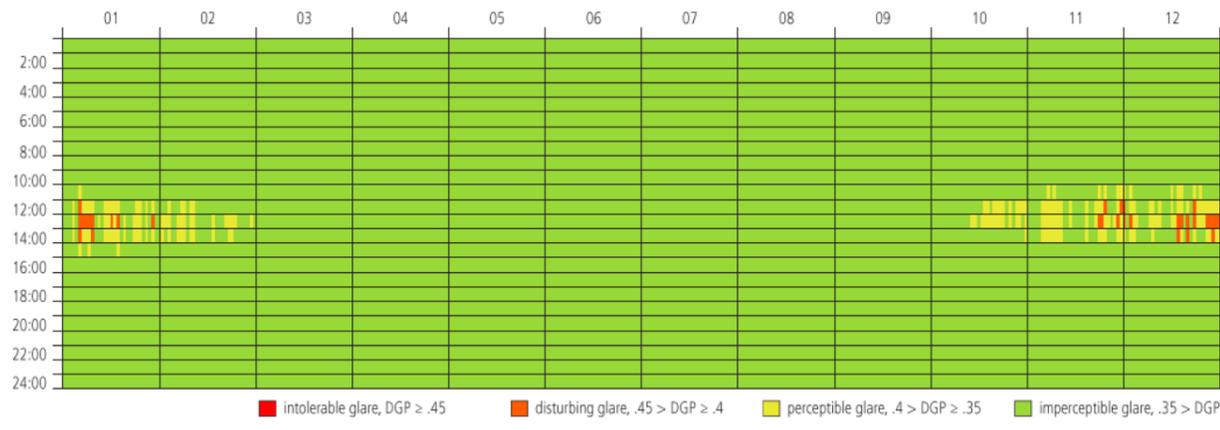
**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**

Hourly values are shown for each view and shading state.

**Base Shading State**

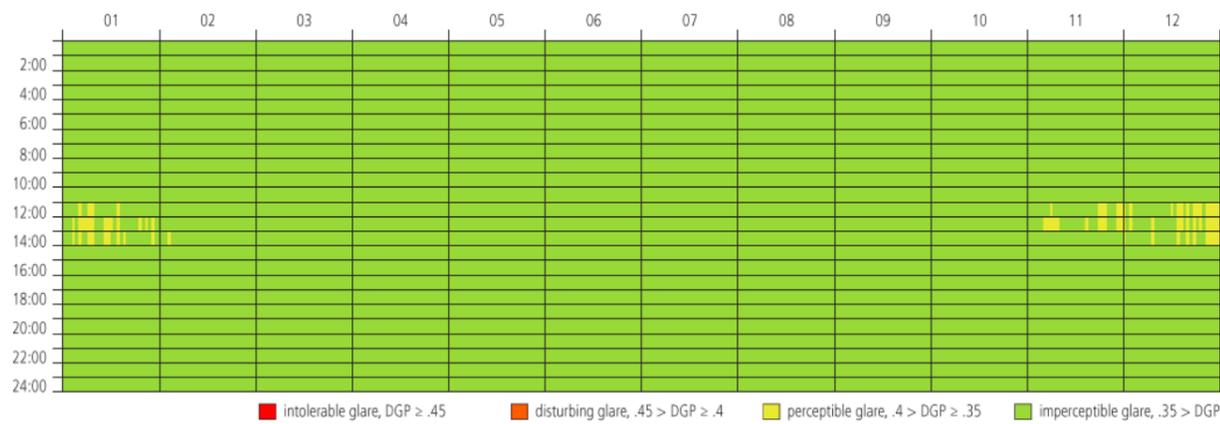
View Name interior



DGP file: gia.dgp

**Shading Group 1; Status 1**

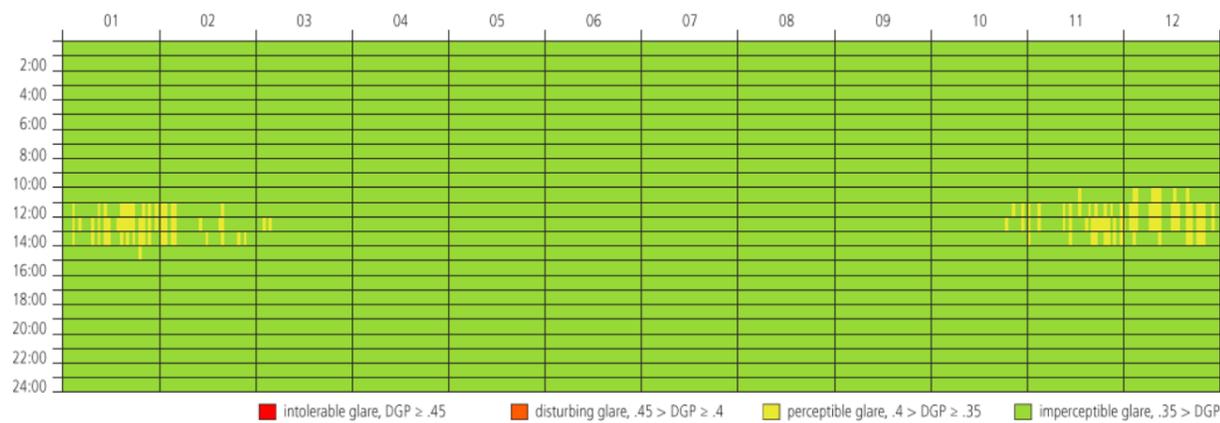
View Name interior



DGP file: SG0BS0.dgp

**Shading Group 1; Status 2**

View Name interior



DGP file: SG0BS1.dgp

**Warnings**

ShadingGroup 1 has no reference sensors.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below

C:\DIVA\temp\gia\gia\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	67% of floor area
Mean Daylight Factor	3.1%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	96% of occupied hours

**Daylight Factor (DF) Analysis:** 47% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 65% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 67% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 84% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 43% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 79% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

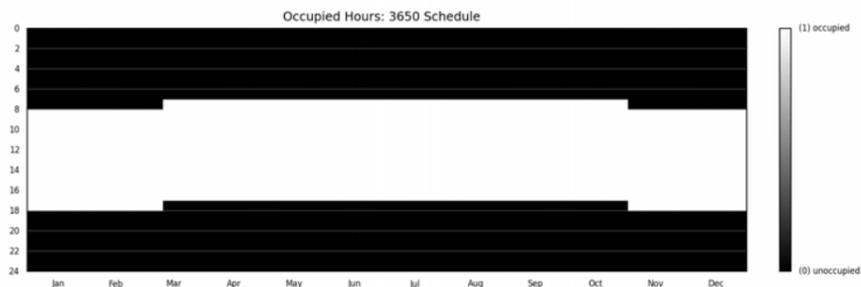
**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.



**Lighting Control:**

There is no electric lighting system specified for the scene.

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**

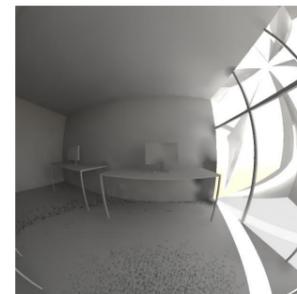
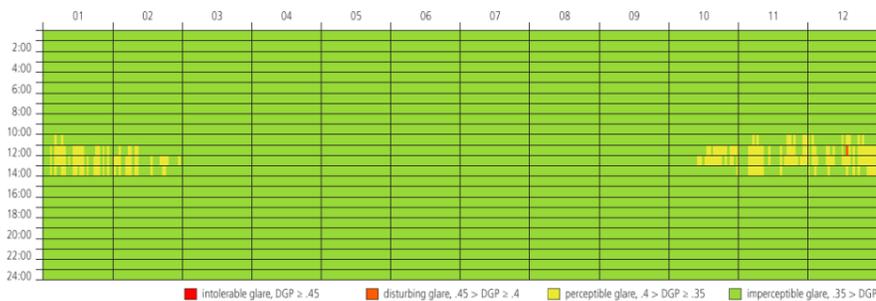
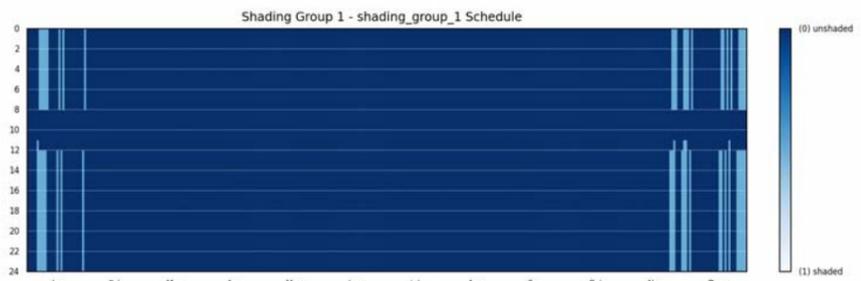


Fig 017 | Al bahar towers\_computer view\_3/21\_1st state\_8:00.

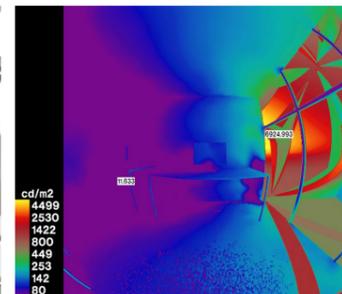


Fig 018 | Al bahar towers\_computer view\_3/21\_1st state\_8:00.

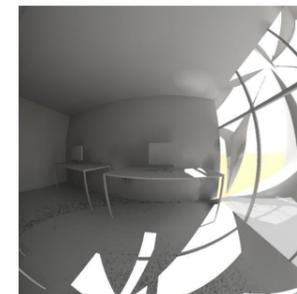


Fig 019 | Al bahar towers\_computer view\_3/21\_1st state\_12:00.

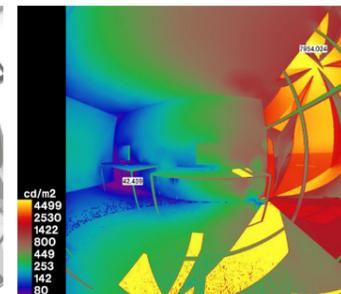


Fig 020 | Al bahar towers\_computer view\_3/21\_1st state\_12:00.

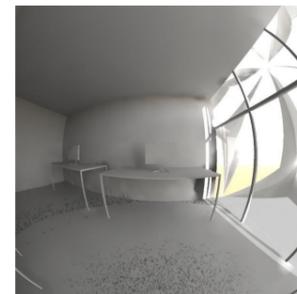


Fig 021 | Al bahar towers\_computer view\_3/21\_1st state\_18:00.

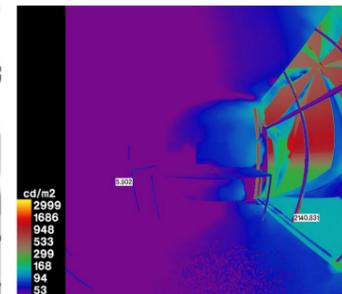


Fig 022 | Al bahar towers\_computer view\_3/21\_1st state\_18:00.

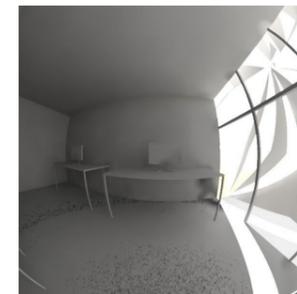


Fig 023 | Al bahar towers\_computer view\_3/21\_2nd state\_8:00.

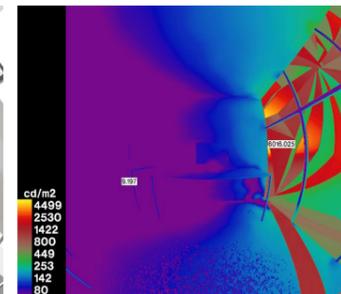


Fig 024 | Al bahar towers\_computer view\_3/21\_2nd state\_8:00.



Fig 025 | Al bahar towers\_computer view\_3/21\_2nd state\_12:00.

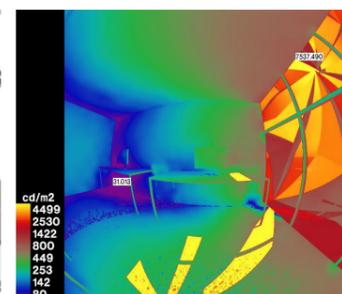


Fig 026 | Al bahar towers\_computer view\_3/21\_2nd state\_12:00.

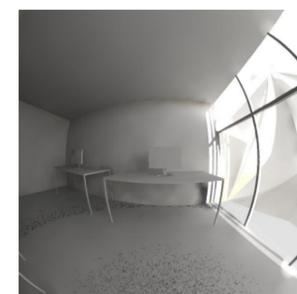


Fig 027 | Al bahar towers\_computer view\_3/21\_2nd state\_18:00.

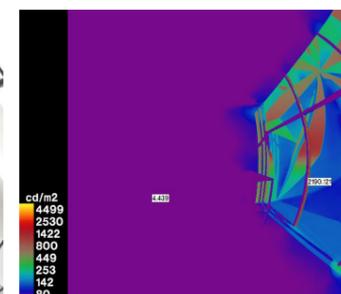


Fig 028 | Al bahar towers\_computer view\_3/21\_2nd state\_18:00.

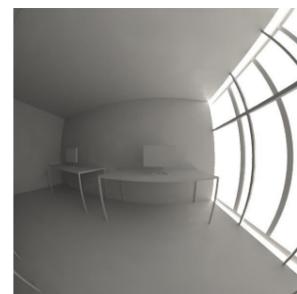


Fig 029 | Al bahar towers\_computer view\_3/21\_1st state\_18:00.

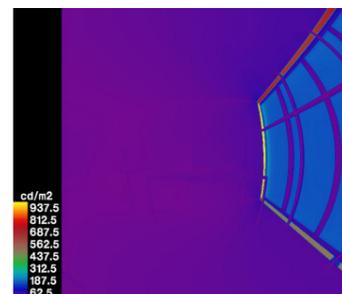


Fig 030 | Al bahar towers\_computer view\_3/21\_1st state\_18:00.

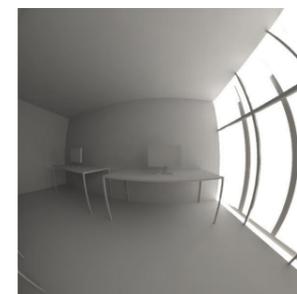


Fig 031 | Al bahar towers\_computer view\_3/21\_2nd state\_8:00.

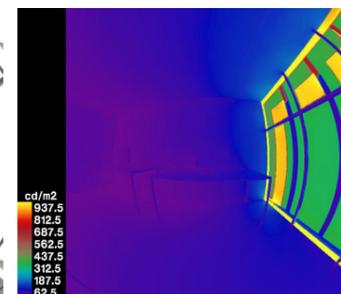


Fig 032 | Al bahar towers\_computer view\_3/21\_2nd state\_8:00.



Fig 033 | Al bahar towers\_computer view\_3/21\_2nd state\_12:00.

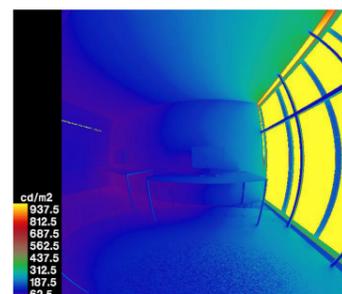


Fig 034 | Al bahar towers\_computer view\_3/21\_2nd state\_12:00.



Fig 035 | Al bahar towers\_interior view\_3/21\_1st state\_8:00.

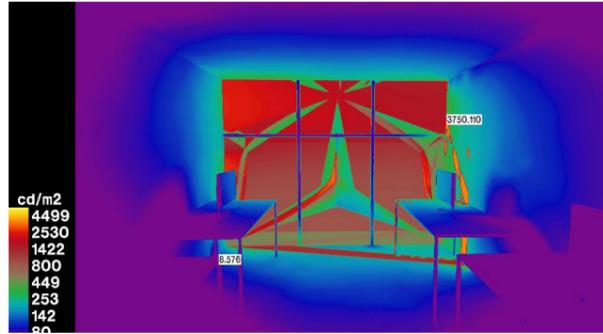


Fig 036 | Al bahar towers\_interior view\_3/21\_1st state\_8:00.



Fig 037 | Al bahar towers\_interior view\_3/21\_1st state\_12:00.

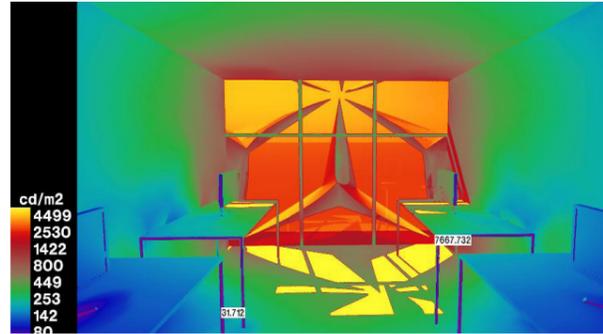


Fig 038 | Al bahar towers\_interior view\_3/21\_1st state\_12:00.



Fig 039 | Al bahar towers\_interior view\_3/21\_1st state\_18:00.

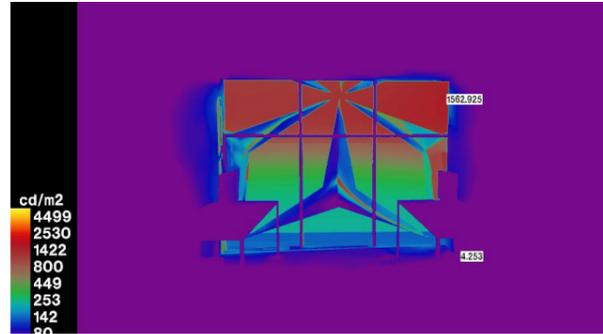


Fig 040 | Al bahar towers\_interior view\_3/21\_1st state\_18:00.



Fig 041 | Al bahar towers\_interior view\_3/21\_2nd state\_8:00.

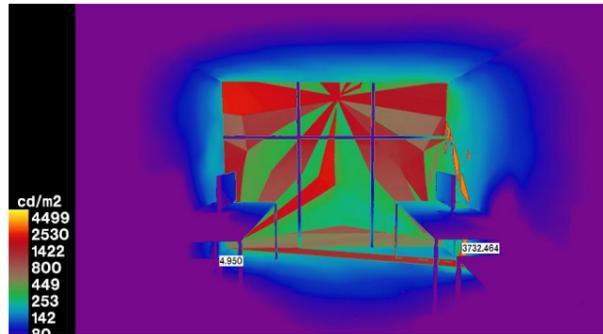


Fig 042 | Al bahar towers\_interior view\_3/21\_2nd state\_8:00.

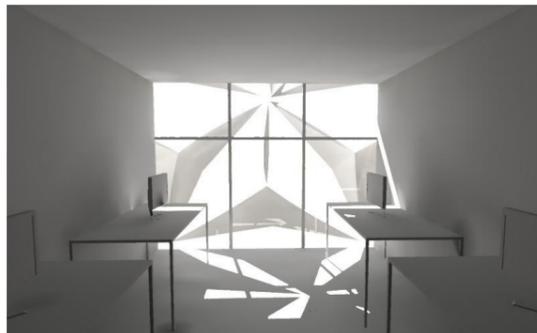


Fig 043 | Al bahar towers\_interior view\_3/21\_2nd state\_12:00.

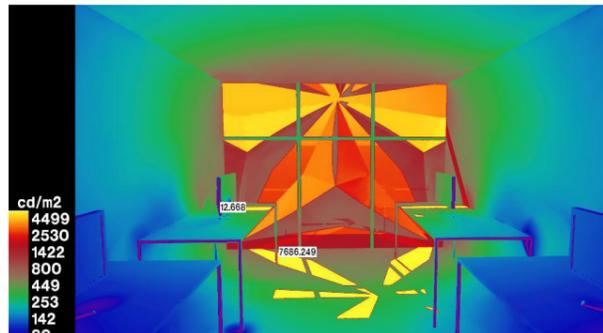


Fig 044 | Al bahar towers\_interior view\_3/21\_2nd state\_12:00.



Fig 045 | Al bahar towers\_interior view\_3/21\_2nd state\_18:00.

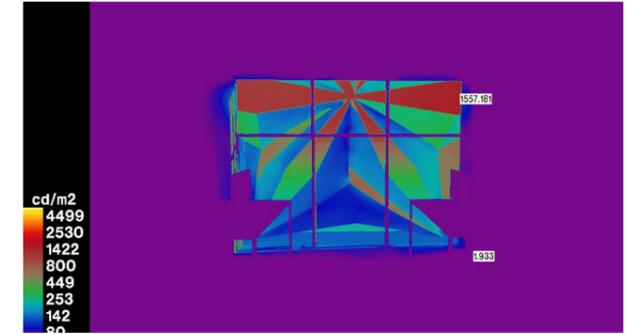


Fig 046 | Al bahar towers\_interior view\_3/21\_2nd state\_18:00.

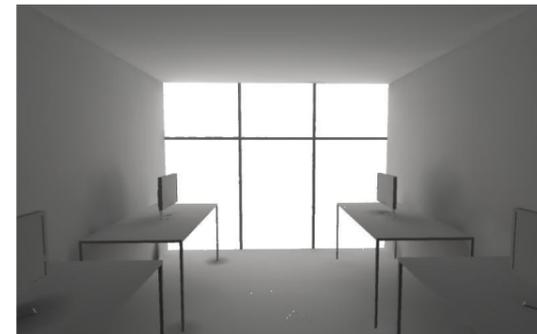


Fig 047 | Al bahar towers\_interior view\_3/21\_3rd state\_12:00.

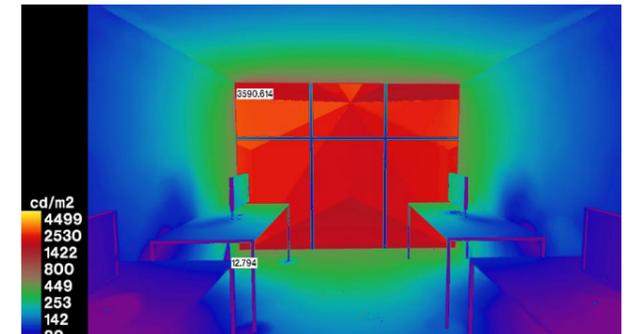


Fig 048 | Al bahar towers\_interior view\_3/21\_3rd state\_12:00.

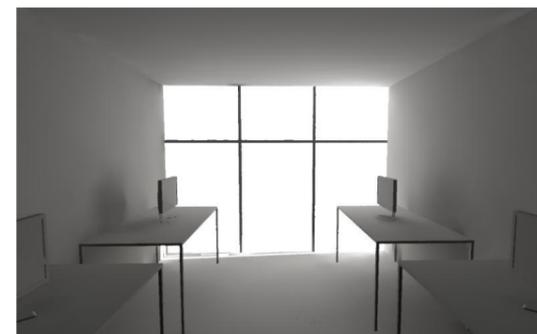


Fig 049 | Al bahar towers\_interior view\_3/21\_3rd state\_18:00.

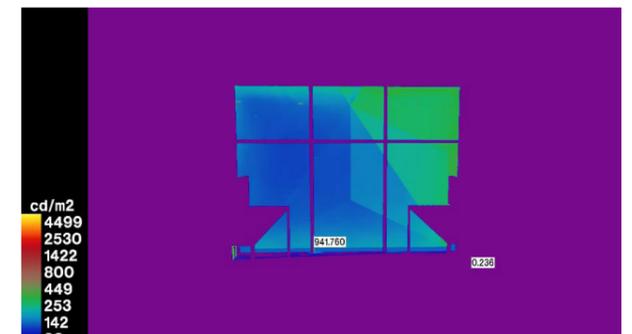


Fig 050 | Al bahar towers\_interior view\_3/21\_3rd state\_18:00.

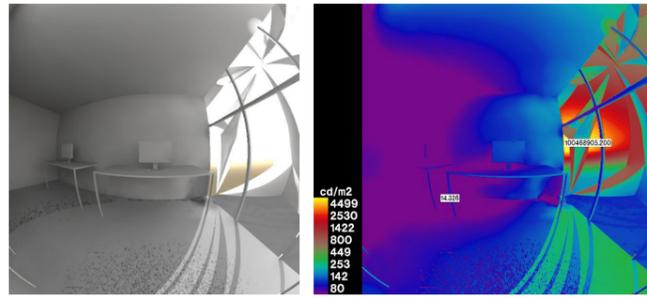


Fig 051 | Al bahar towers\_window view\_12/21\_1st state\_8:00. Fig 052 | Al bahar towers\_computer view\_12/21\_1st state\_8:00.

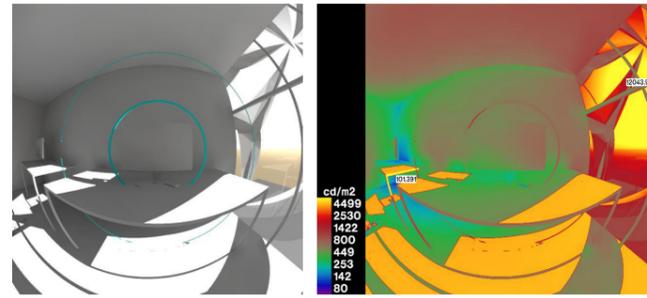


Fig 053 | Al bahar towers\_computer view\_12/21\_1st state\_12:00. Fig 054 | Al bahar towers\_computer view\_12/21\_1st state\_12:00.

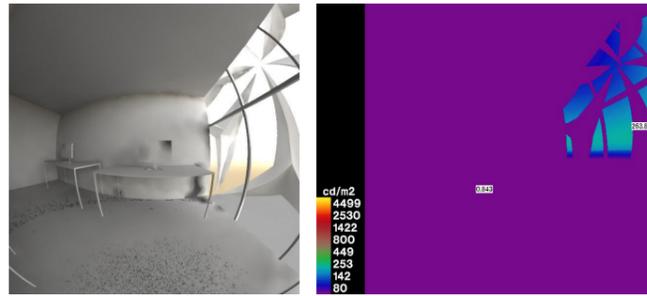


Fig 055 | Al bahar towers\_computer view\_12/21\_1st state\_18:00. Fig 056 | Al bahar towers\_computer view\_12/21\_1st state\_18:00.

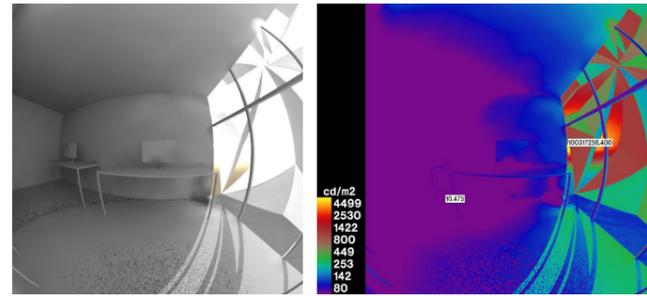


Fig 057 | Al bahar towers\_computer view\_12/21\_2nd state\_8:00. Fig 058 | Al bahar towers\_computer view\_12/21\_2nd state\_8:00.

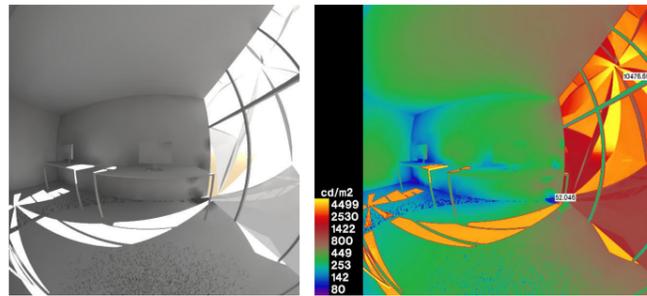


Fig 059 | Al bahar towers\_computer view\_12/21\_2nd state\_12:00. Fig 060 | Al bahar towers\_computer view\_12/21\_2nd state\_12:00.

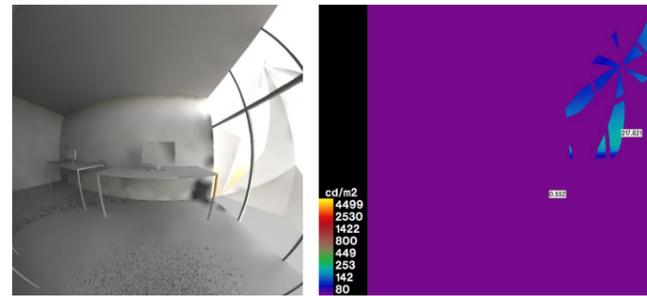


Fig 061 | Al bahar towers\_computer view\_12/21\_2nd state\_18:00. Fig 062 | Al bahar towers\_computer view\_12/21\_2nd state\_18:00.

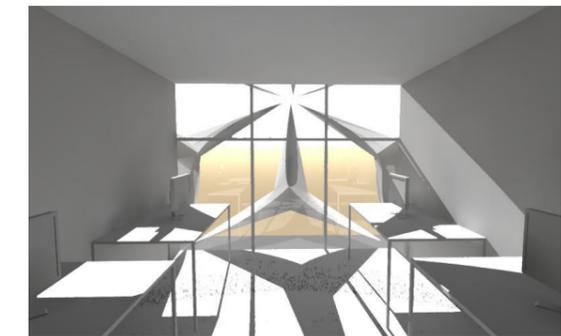


Fig 063 | Al bahar towers\_interior view\_12/21\_1st state\_12:00.

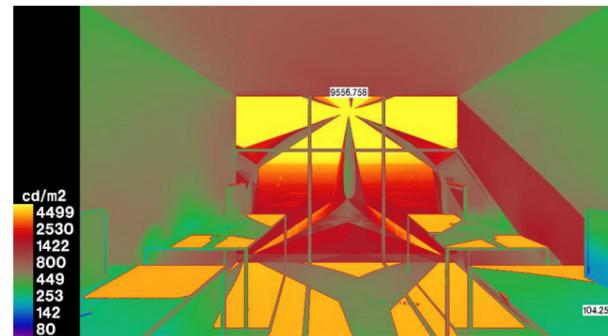


Fig 064 | Al bahar towers\_interior view\_12/21\_1st state\_12:00.



**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

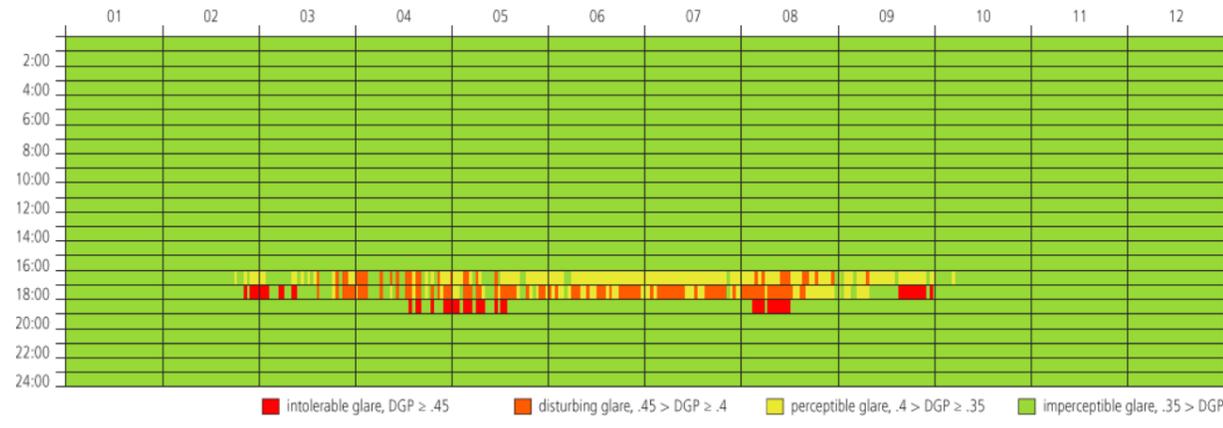
**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**

Hourly values are shown for each view and shading state.

**Base Shading State**

View Name interior



DGP file: albahar\_west.dgp

**Shading Group 1; Status 1**

View Name interior



DGP file: SG0BS0.dgp

**Shading Group 1; Status 2**

View Name interior



DGP file: SG0BS1.dgp

Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\albahar\_west\albahar\_west\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	53% of floor area
Mean Daylight Factor	3.1%
Occupancy	3650 hours per year
Glare	0.2% of occupied hours
Shading Group 1 open	99% of occupied hours

**Daylight Factor (DF) Analysis:** 48% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 56% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 53% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 79% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 34% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 91% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

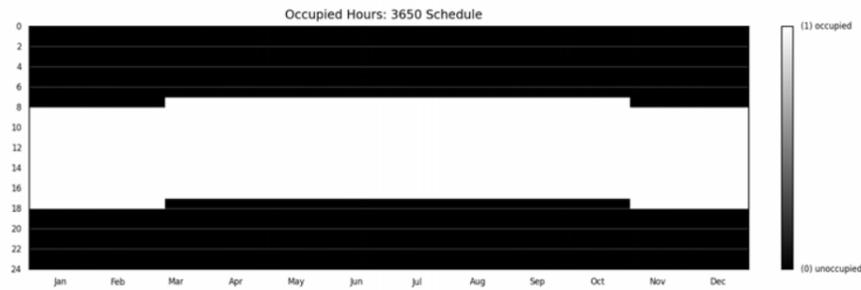
Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.

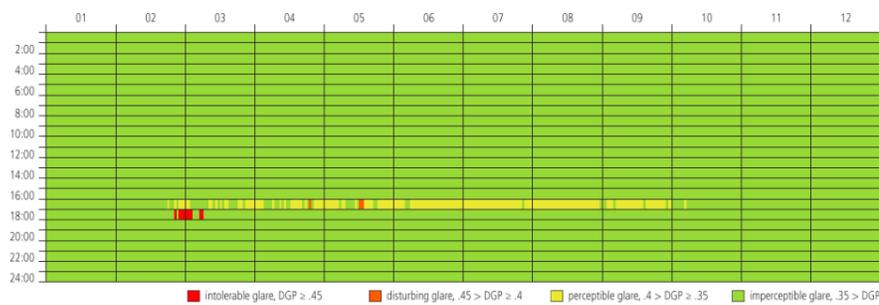


Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



Warnings

No warnings.

Simulation Tips

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

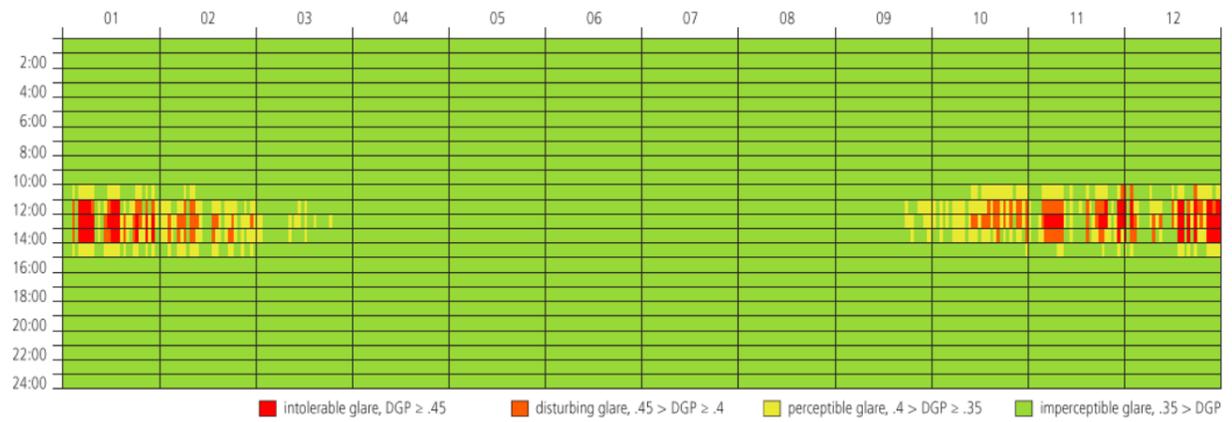
Annual Glare Simulation (eDGPs) Report

Visual Comfort Without Occupant Adaptation

Hourly values are shown for each view and shading state.

Base Shading State

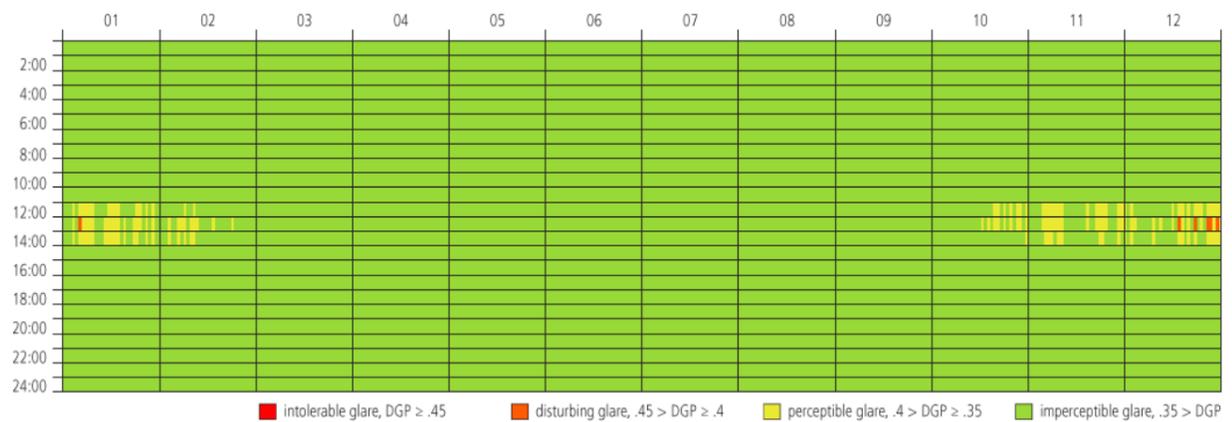
View Name interior



DGP file: cherokee\_south.dgp

Shading Group 1; Status 1

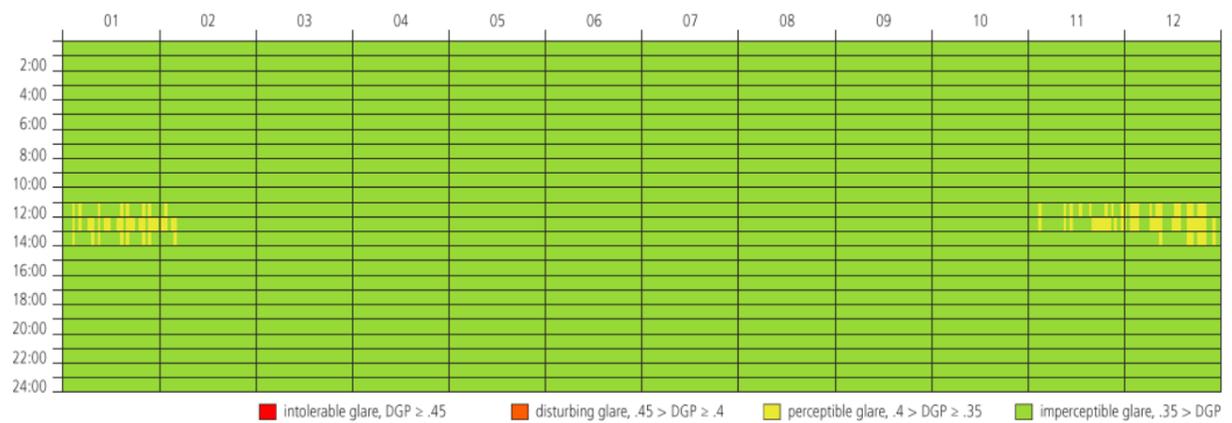
View Name interior



DGP file: SG0BS0.dgp

Shading Group 1; Status 2

View Name interior



DGP file: SG0BS1.dgp

**Warnings**  
ShadingGroup 1 has no reference sensors.

**Simulation Tips**  
Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA  
\temp\cherokee\_south  
\cherokee\_south\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	100% of floor area
Mean Daylight Factor	6.6%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	87% of occupied hours

**Daylight Factor (DF) Analysis:** 78% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone should qualify for the LEED-NC 2.1 daylighting credit 8.1 (see [www.usgbc.org/LEED/](http://www.usgbc.org/LEED/)).

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 87% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 100% for active occupant behavior.

**Continuous Daylight Autonomy (CA) Analysis:** The mean continuous daylight autonomy is 94% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 56% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 62% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

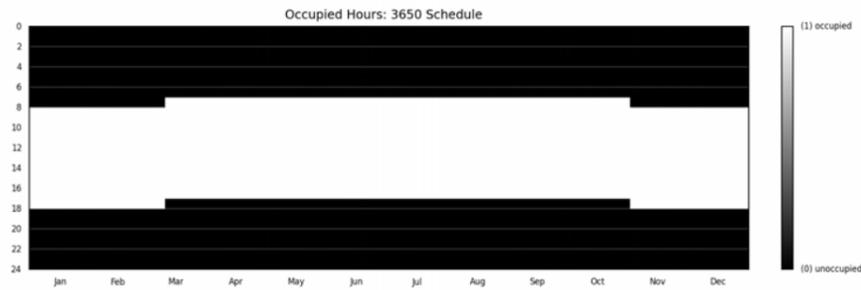
**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.

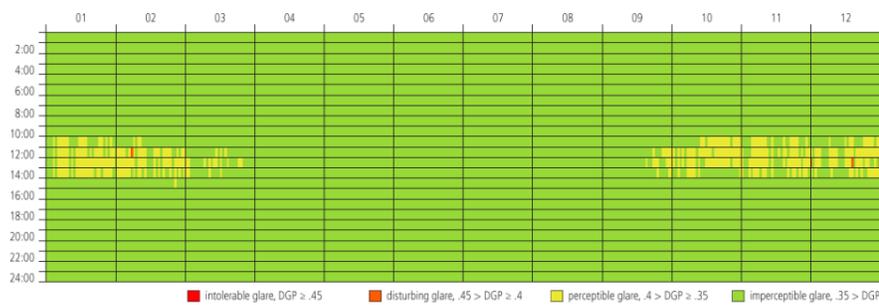


**Lighting Control:**

There is no electric lighting system specified for the scene.

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



**Warnings**  
No warnings.

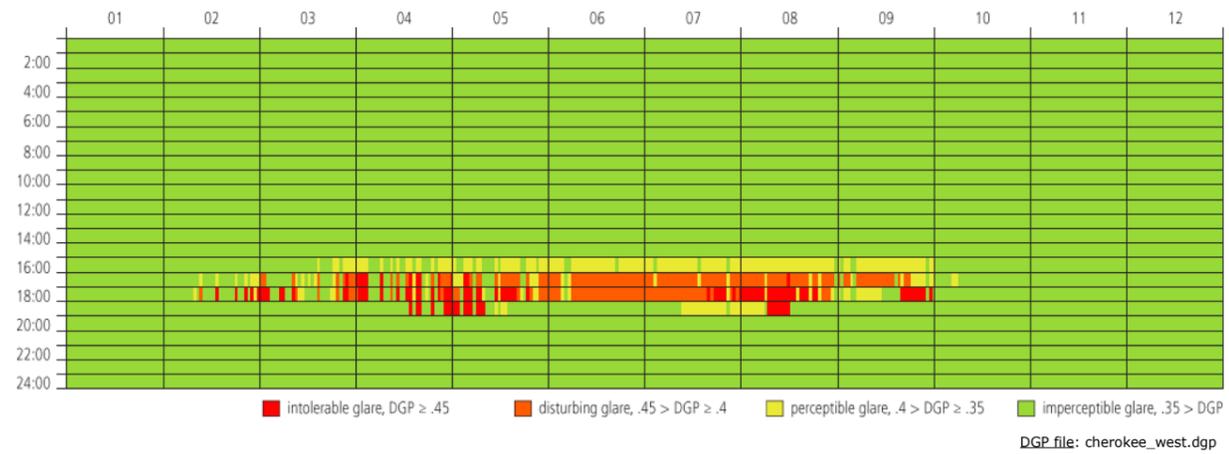
**Simulation Tips**  
You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**  
Hourly values are shown for each view and shading state.

**Base Shading State**

View Name interior



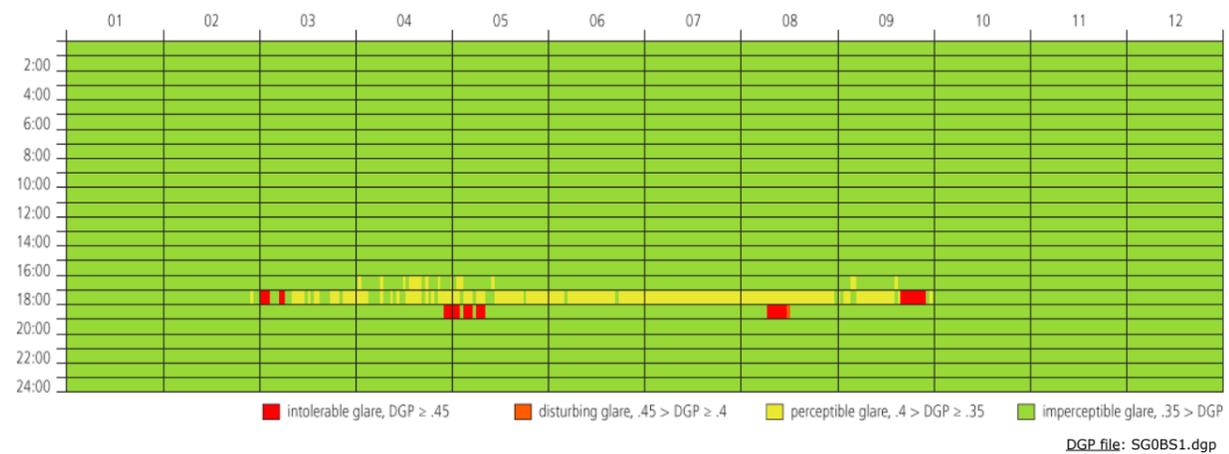
**Shading Group 1; Status 1**

View Name interior



**Shading Group 1; Status 2**

View Name interior



Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIWA  
 \temp\cherokee\_west  
 \cherokee\_west\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	89% of floor area
Mean Daylight Factor	6.6%
Occupancy	3650 hours per year
Glare	0.1% of occupied hours
Shading Group 1 open	96% of occupied hours

**Daylight Factor (DF) Analysis:** 77% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone should qualify for the LEED-NC 2.1 daylighting credit 8.1 (see [www.usgbc.org/LEED/](http://www.usgbc.org/LEED/)).

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 81% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 89% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 92% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 48% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 71% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

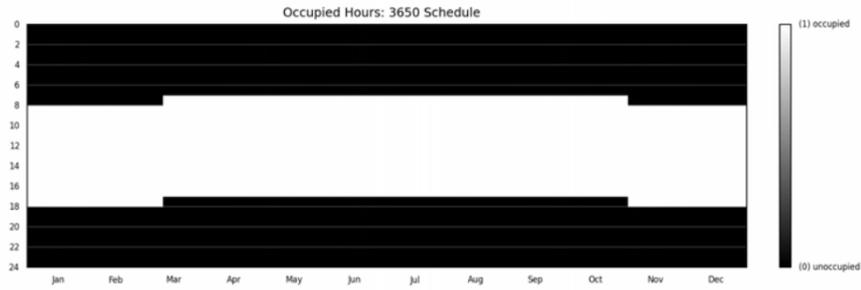
Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.



Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**

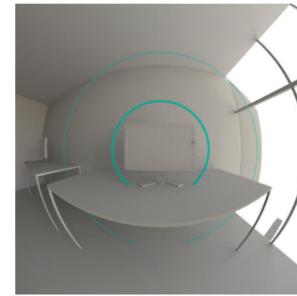
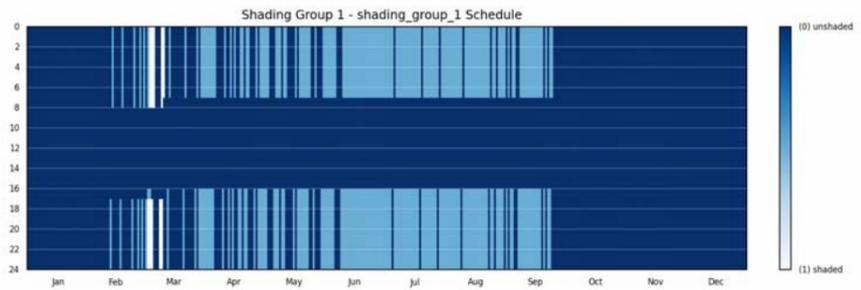


Fig 065 |Cherokee\_computer view\_6/21\_1st state\_8:00.

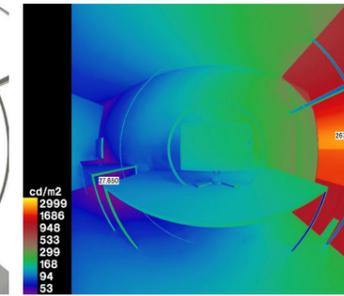


Fig 066 |Cherokee\_computer view\_6/21\_1st state\_8:00.

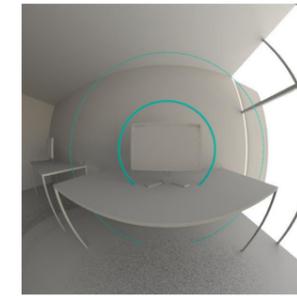


Fig 067 |Cherokee\_computer view\_6/21\_1st state\_12:00.

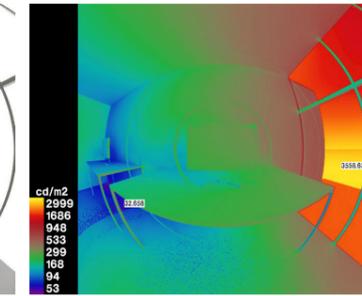


Fig 068 |Cherokee\_computer view\_6/21\_1st state\_12:00.

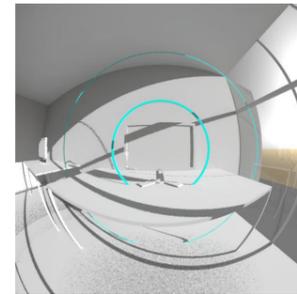


Fig 069 |Cherokee\_computer view\_6/21\_1st state\_18:00.

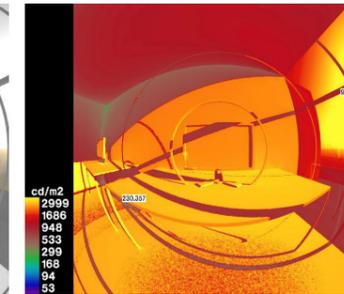


Fig 070 |Cherokee\_computer view\_6/21\_1st state\_18:00.

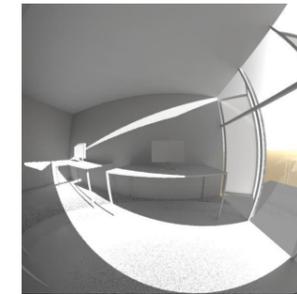


Fig 071 |Cherokee\_computer view\_6/21\_2nd state\_18:00.

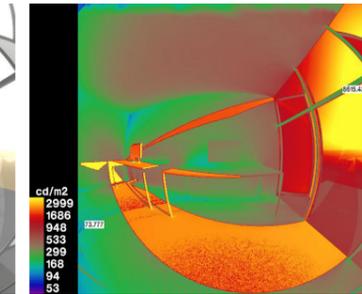


Fig 072 |Cherokee\_computer view\_6/21\_2nd state\_18:00.

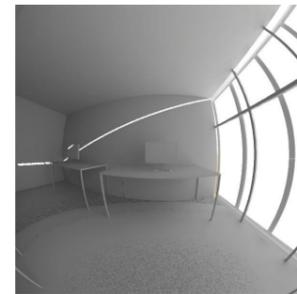


Fig 073 |Cherokee\_computer view\_6/21\_3rd state\_18:00.

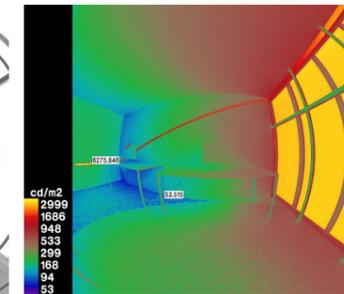


Fig 074 |Cherokee\_computer view\_6/21\_3rd state\_18:00.



Fig 075 | Cherokee\_interior view\_6/21\_1st state\_8:00.

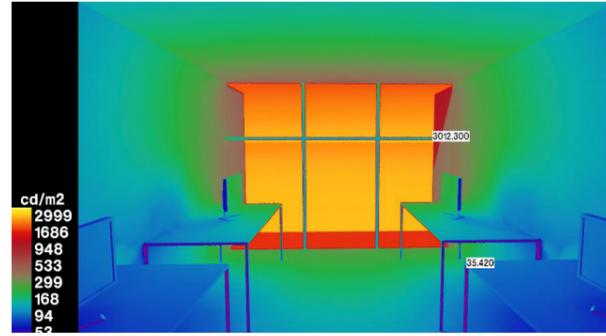


Fig 076 | Cherokee\_interior view\_6/21\_1st state\_8:00.

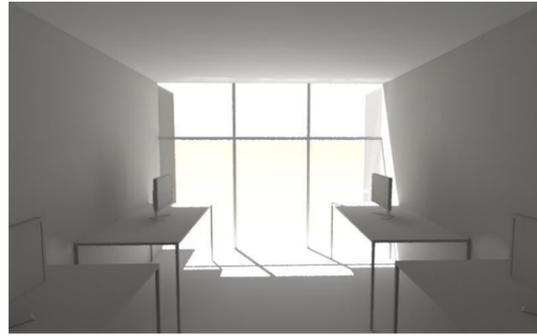


Fig 077 | Cherokee\_interior view\_6/21\_1st state\_12:00.

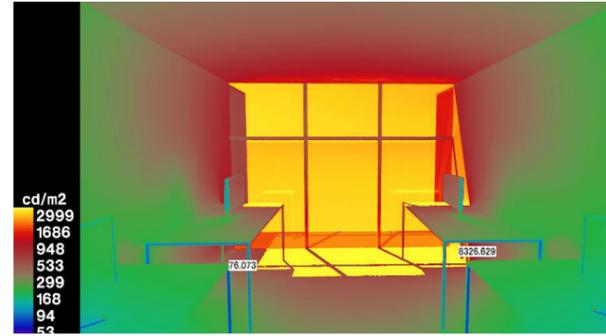


Fig 078 | Cherokee\_interior view\_6/21\_1st state\_12:00.



Fig 079 | Cherokee\_interior view\_6/21\_1st state\_18:00.

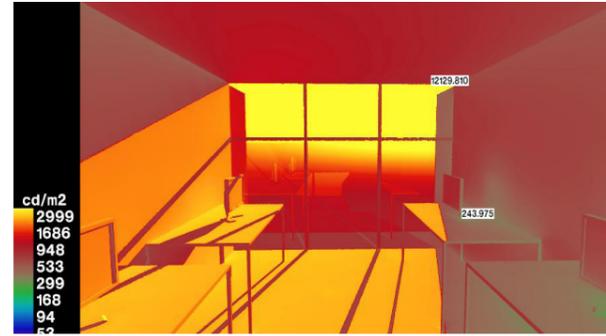


Fig 080 | Cherokee\_interior view\_6/21\_1st state\_18:00.

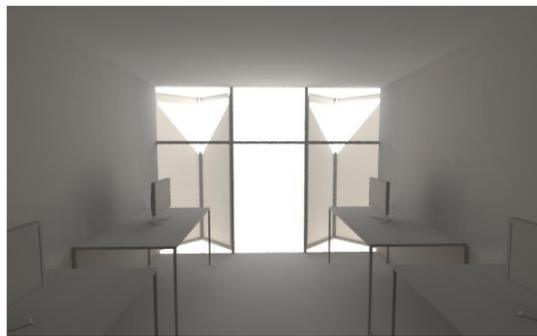


Fig 081 | Cherokee\_interior view\_6/21\_2nd state\_8:00.

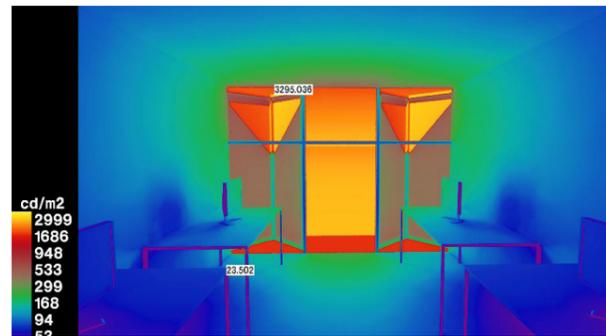


Fig 082 | Cherokee\_interior view\_6/21\_2nd state\_8:00.



Fig 083 | Cherokee\_interior view\_6/21\_2nd state\_12:00.

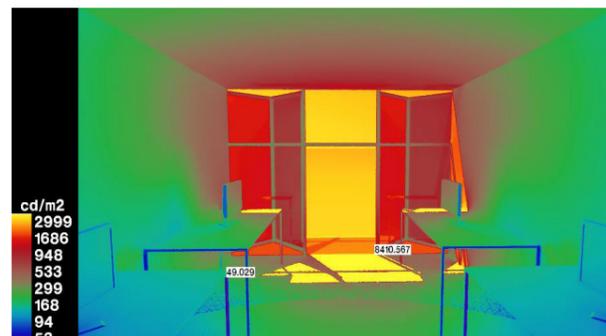


Fig 084 | Cherokee\_interior view\_6/21\_2nd state\_12:00.



Fig 085 | Cherokee\_interior view\_6/21\_2nd state\_18:00.

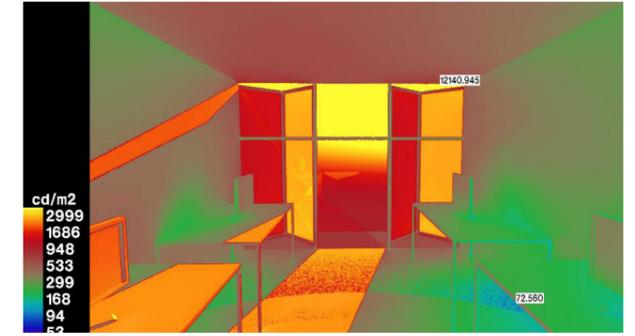


Fig 086 | Cherokee\_interior view\_6/21\_2nd state\_18:00.



Fig 087 | Cherokee\_interior view\_6/21\_3rd state\_8:00.



Fig 088 | Cherokee\_interior view\_6/21\_3rd state\_8:00.

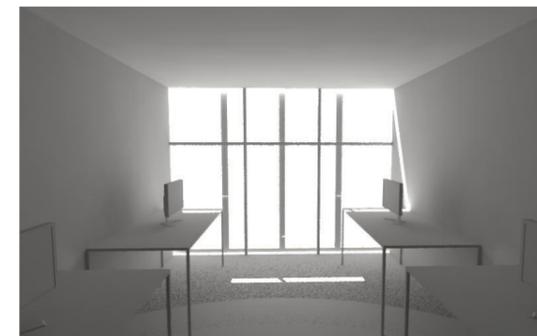


Fig 089 | Cherokee\_interior view\_6/21\_3rd state\_12:00.

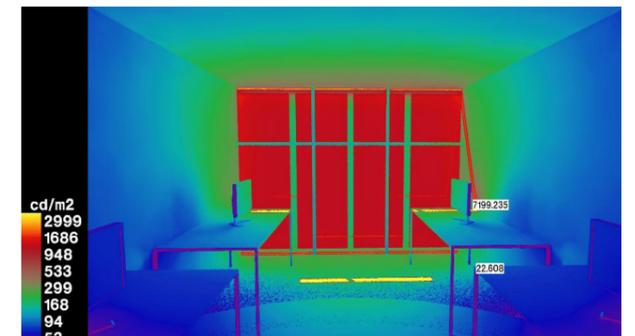


Fig 090 | Cherokee\_interior view\_6/21\_3rd state\_12:00.

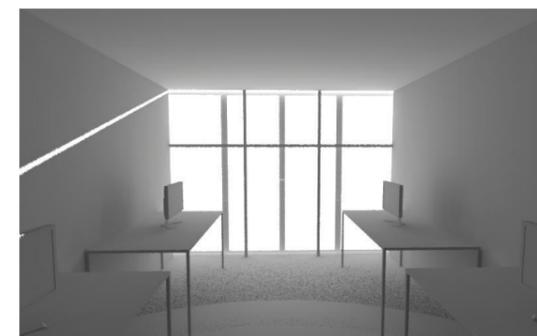


Fig 091 | Cherokee\_interior view\_6/21\_3rd state\_18:00.

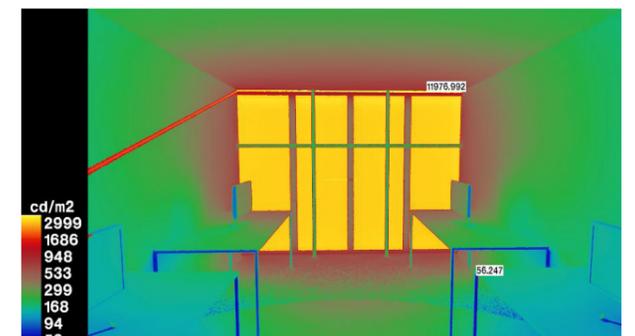


Fig 092 | Cherokee\_interior view\_6/21\_3rd state\_18:00.

Warnings

No warnings.

Simulation Tips

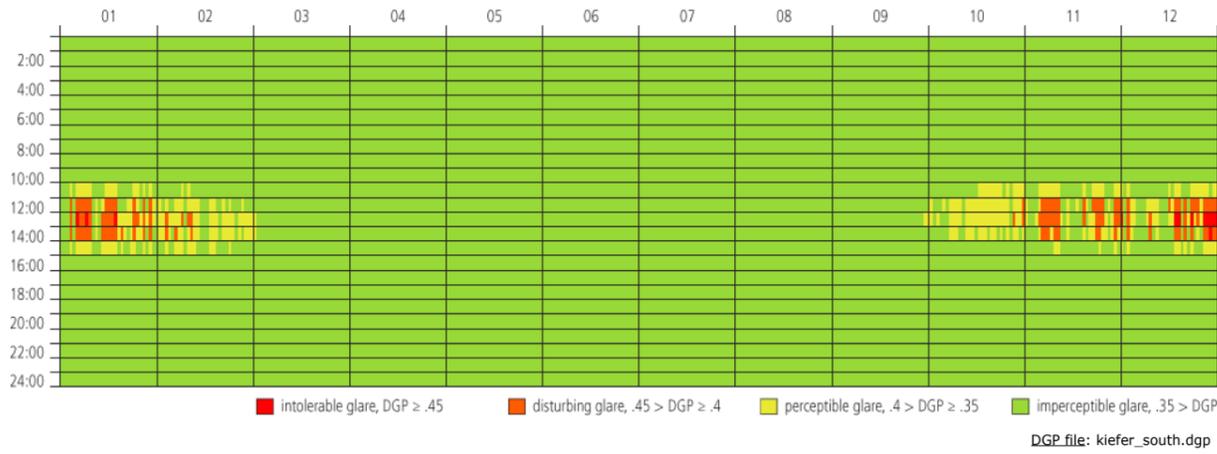
You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

Annual Glare Simulation (eDGPs) Report

Visual Comfort Without Occupant Adaptation  
Hourly values are shown for each view and shading state.

Base Shading State

View Name interior



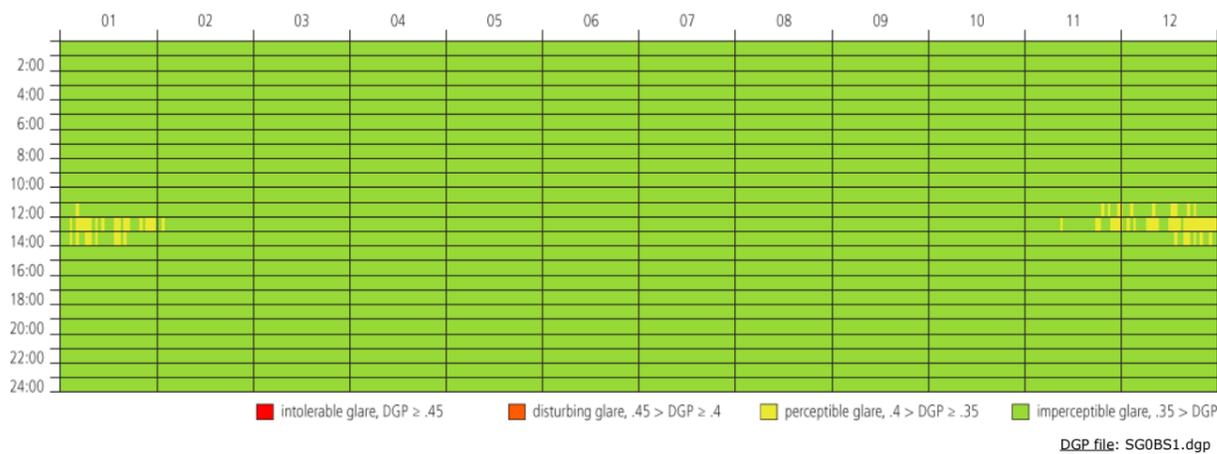
Shading Group 1; Status 1

View Name interior



Shading Group 1; Status 2

View Name interior



Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\kiefer\_south\kiefer\_south\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	98% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	90% of occupied hours

Daylight Factor (DF) Analysis: 69% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 84% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 98% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 33% for active occupant behavior.

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 68% for active occupant behavior.

Electric Lighting Use: The predicted annual electric lighting energy use is:

Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.

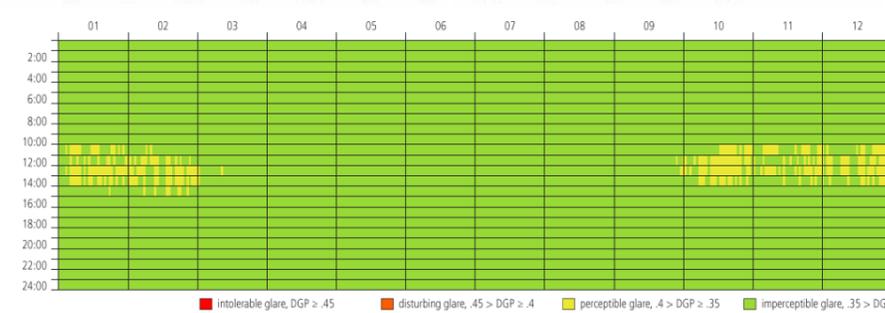


Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



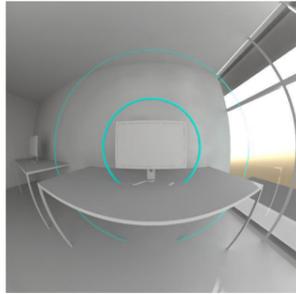


Fig 093 | Kiefer\_computer view\_12/21\_1st state\_8:00.

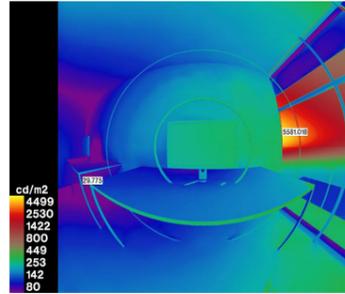


Fig 094 | Kiefer\_computer view\_12/21\_1st state\_8:00.

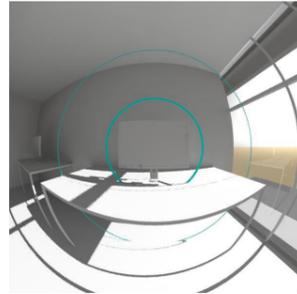


Fig 095 | Kiefer\_computer view\_12/21\_1st state\_12:00.

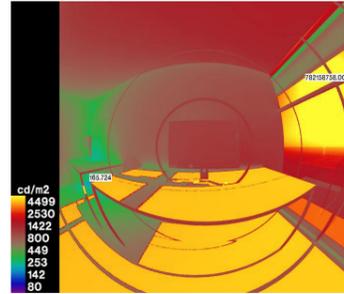


Fig 096 | Kiefer\_computer view\_12/21\_1st state\_12:00.

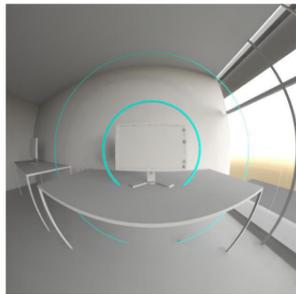


Fig 097 | Kiefer\_computer view\_12/21\_1st state\_18:00.

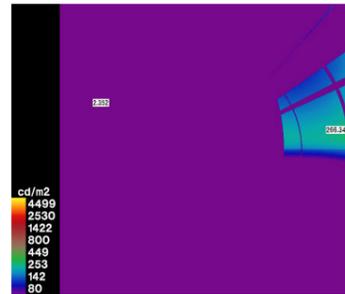


Fig 098 | Kiefer\_computer view\_12/21\_1st state\_18:00.

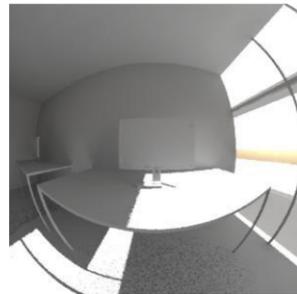


Fig 099 | Kiefer\_computer view\_12/21\_2nd state\_12:00.

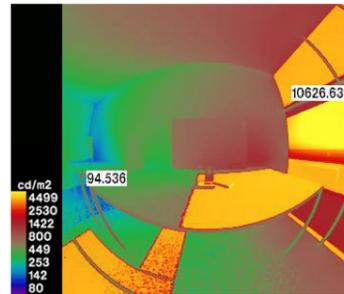


Fig 100 | Kiefer\_computer view\_12/21\_2nd state\_12:00.

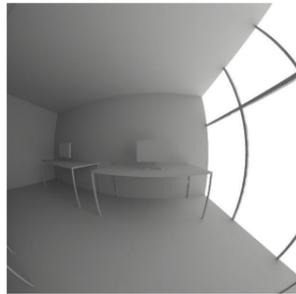


Fig 101 | Kiefer\_computer view\_12/21\_3rd state\_8:00.

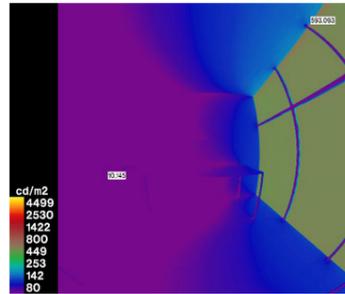


Fig 102 | Kiefer\_computer view\_12/21\_3rd state\_8:00.

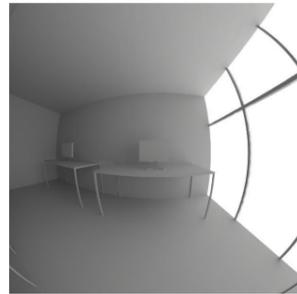


Fig 103 | Kiefer\_computer view\_12/21\_3rd state\_12:00.

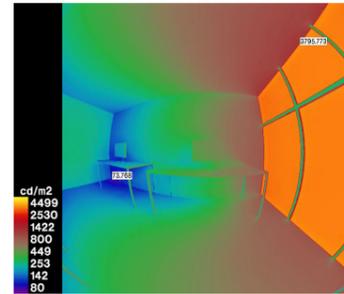


Fig 104 | Kiefer\_computer view\_12/21\_3rd state\_12:00.

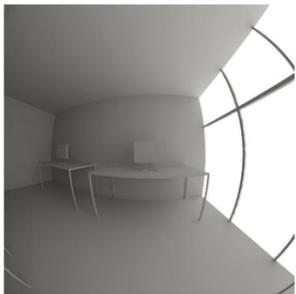


Fig 105 | Kiefer\_computer view\_12/21\_3rd state\_118:00.

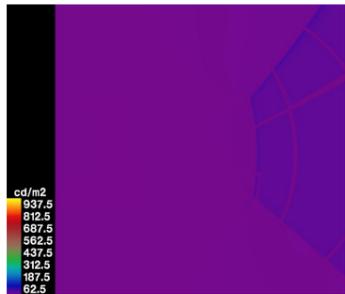


Fig 106 | Kiefer\_computer view\_12/21\_3rd state\_18:00.



Fig 107 | Kiefer\_interior view\_12/21\_1st state\_8:00.

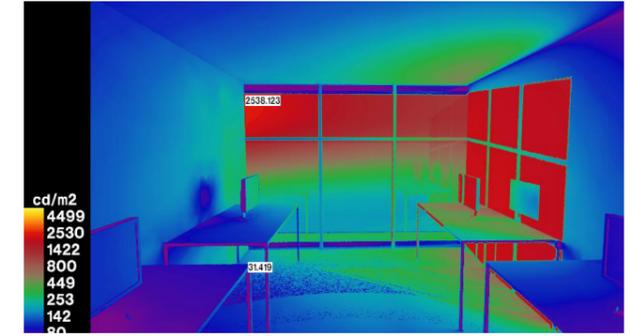


Fig 108 | Kiefer\_interior view\_12/21\_1st state\_8:00.



Fig 109 | Kiefer\_interior view\_12/21\_1st state\_12:00.

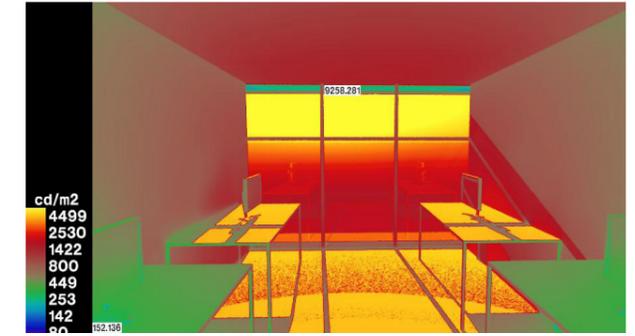


Fig 110 | Kiefer\_interior view\_12/21\_1st state\_12:00.



Fig 111 | Kiefer\_interior view\_12/21\_1st state\_18:00.

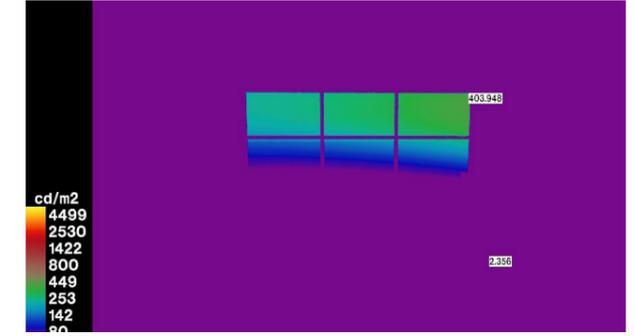


Fig 112 | Kiefer\_interior view\_12/21\_1st state\_18:00.

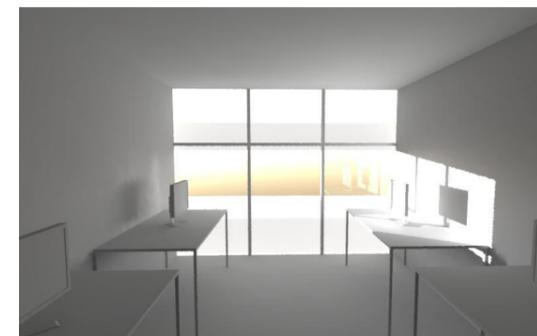


Fig 113 | Kiefer\_interior view\_12/21\_2nd state\_8:00.

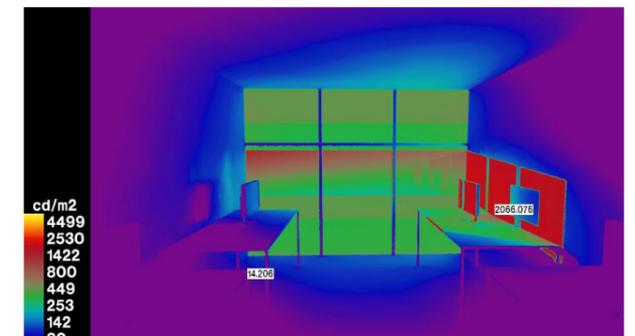


Fig 114 | Kiefer\_interior view\_12/21\_2nd state\_8:00.



Fig 115 | Kiefer\_interior view\_12/21\_2nd state\_12:00.

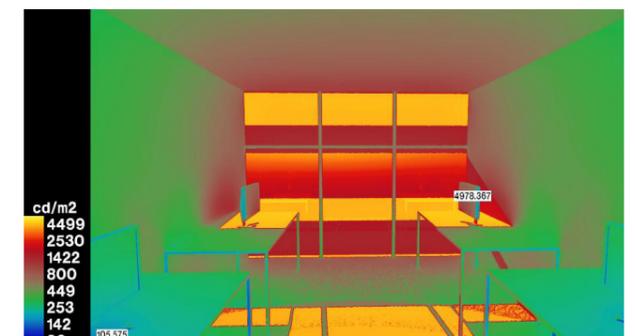


Fig 116 | Kiefer\_interior view\_12/21\_2nd state\_12:00.

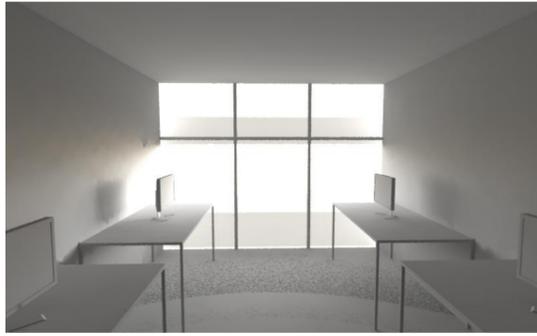


Fig 117 | Kiefer\_interior view\_12/21\_2nd state\_18:00.

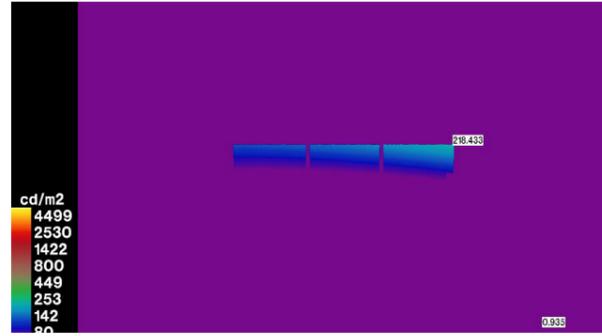


Fig 118 | Kiefer\_interior view\_12/21\_2nd state\_18:00.

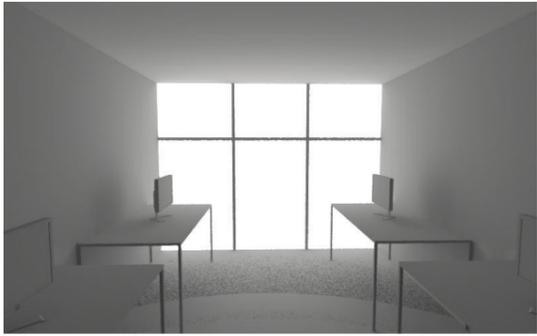


Fig 119 | Kiefer\_interior view\_12/21\_3rd state\_8:00.

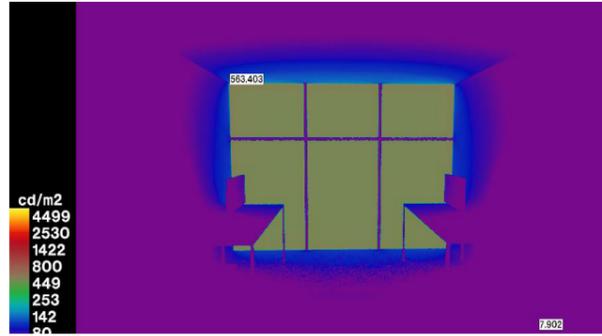


Fig 120 | Kiefer\_interior view\_12/21\_3rd state\_8:00.

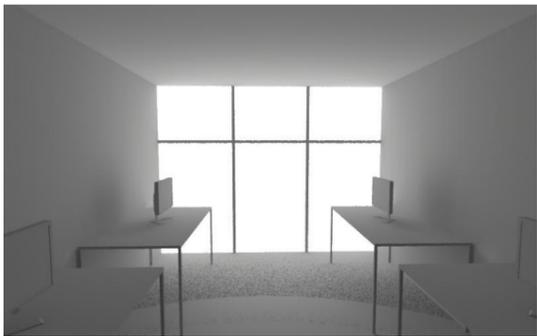


Fig 121 | Kiefer\_interior view\_12/21\_3rd state\_12:00.

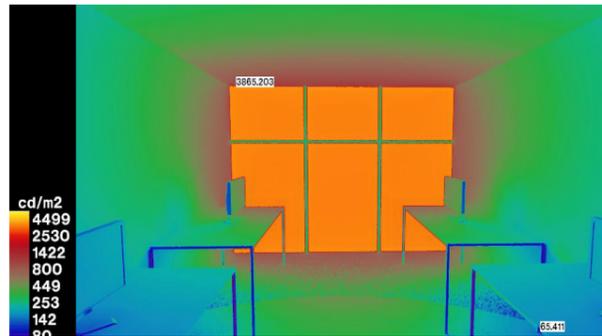


Fig 122 | Kiefer\_interior view\_12/21\_3rd state\_12:00.

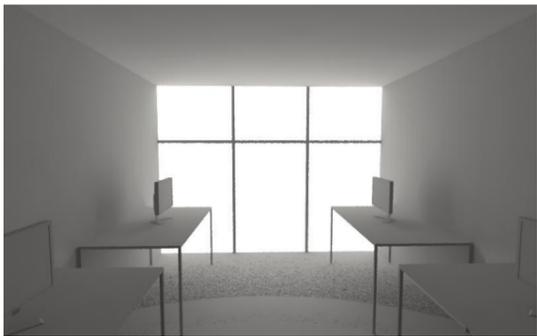


Fig 123 | Kiefer\_interior view\_12/21\_3rd state\_18:00.



Fig 124 | Kiefer\_interior view\_12/21\_3rd state\_18:00.



**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

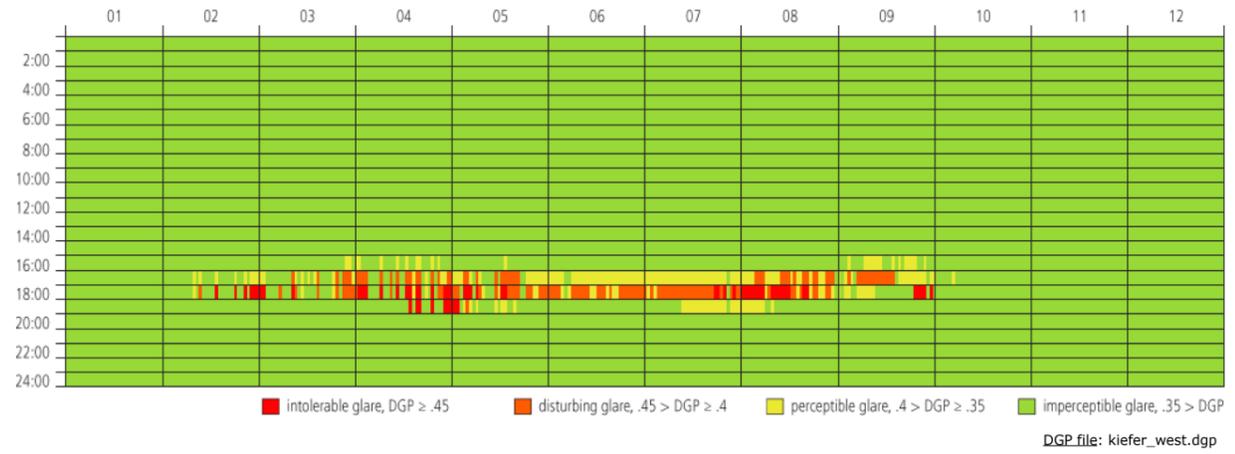
**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**

Hourly values are shown for each view and shading state.

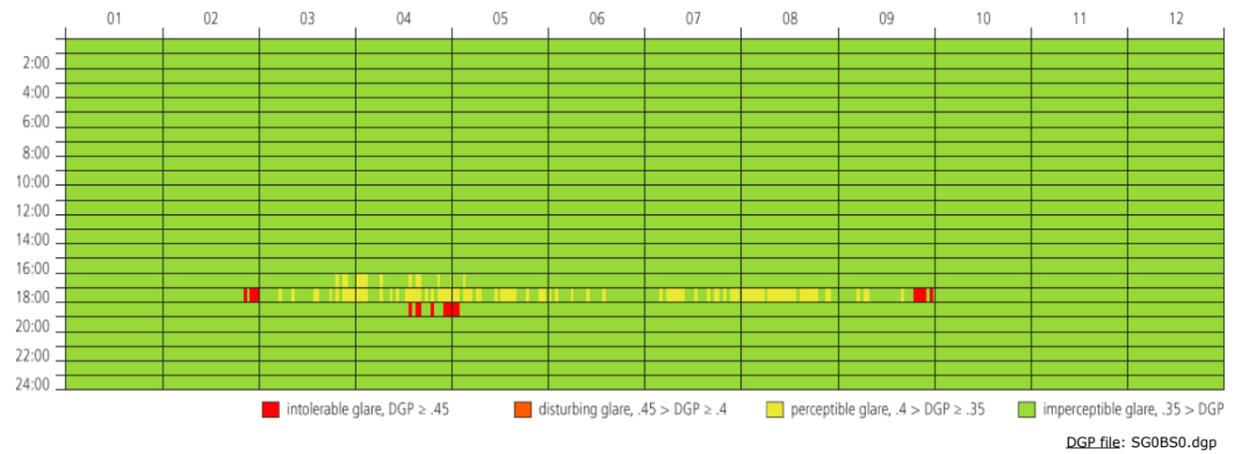
**Base Shading State**

View Name interior



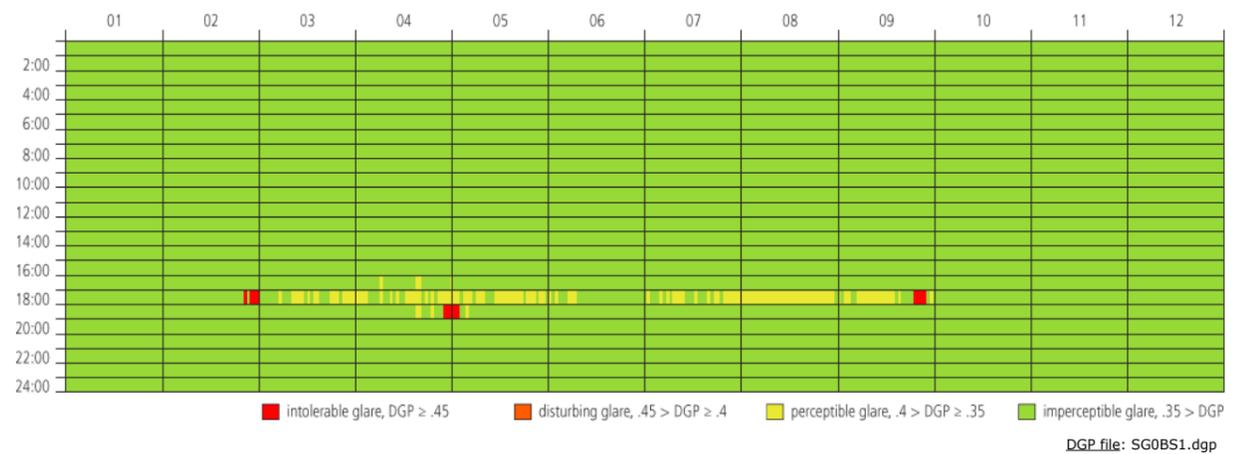
**Shading Group 1; Status 1**

View Name interior



**Shading Group 1; Status 2**

View Name interior



Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\kiefer\_west\kiefer\_west\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	79% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	0.1% of occupied hours
Shading Group 1 open	98% of occupied hours

**Daylight Factor (DF) Analysis:** 69% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 75% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 79% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 90% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 34% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 79% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

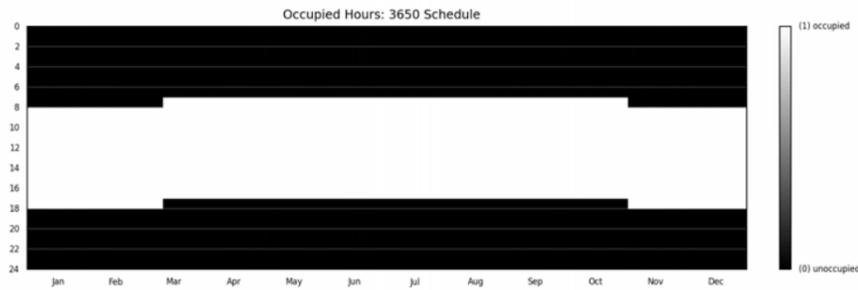
Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.

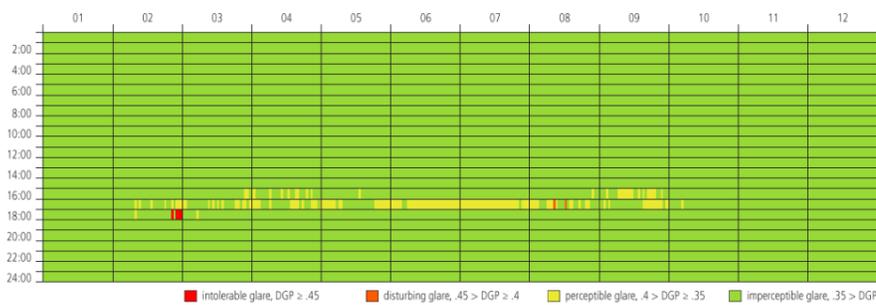
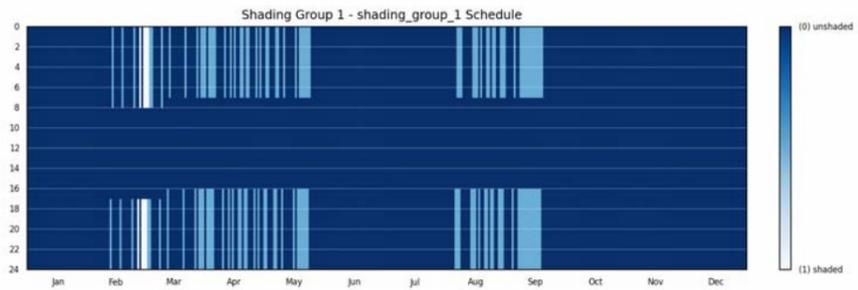


Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



Warnings

No warnings.

Simulation Tips

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

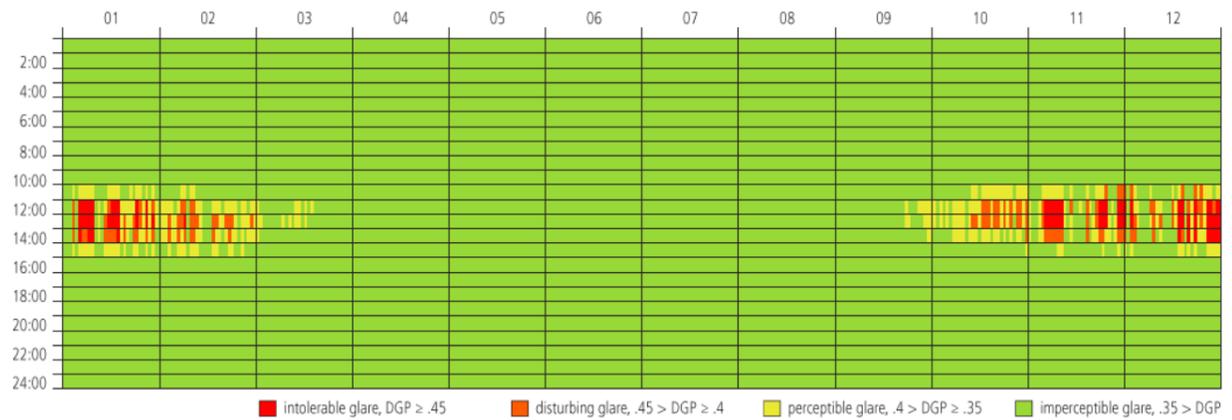
Annual Glare Simulation (eDGPs) Report

Visual Comfort Without Occupant Adaptation

Hourly values are shown for each view and shading state.

Base Shading State

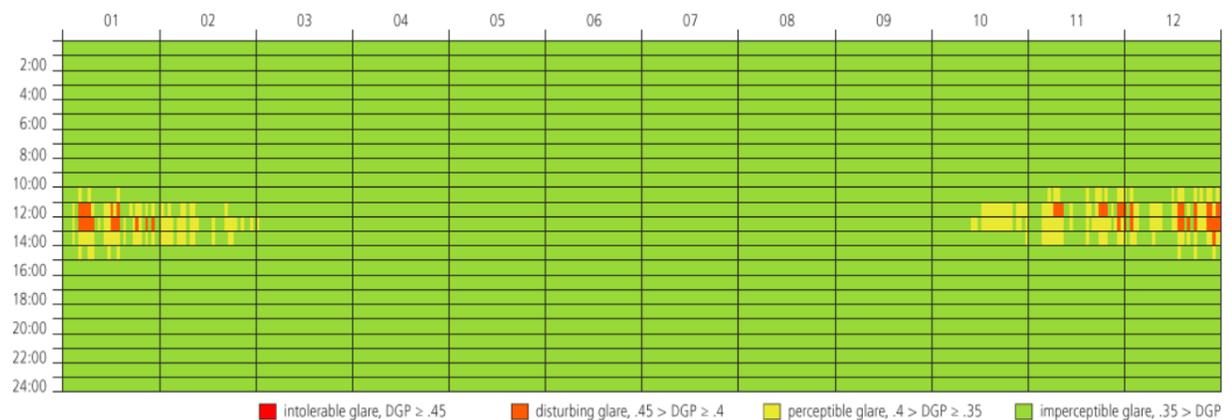
View Name interior



DGP\_file: Q1.dgp

Shading Group 1; Status 1

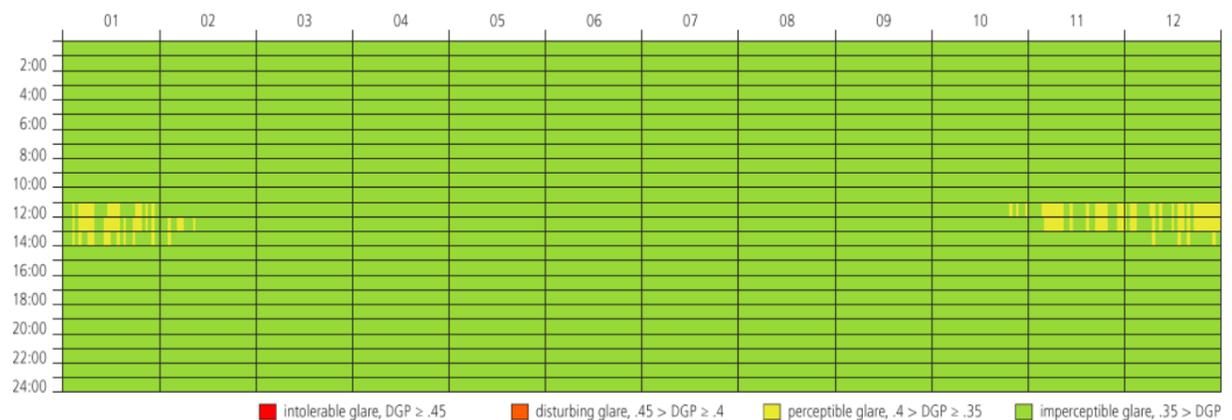
View Name interior



DGP\_file: SG0BS0.dgp

Shading Group 1; Status 2

View Name interior



DGP\_file: SG0BS1.dgp

**Warnings**

ShadingGroup 1 has no reference sensors.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\Q1\Q1\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	99% of floor area
Mean Daylight Factor	5.5%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	86% of occupied hours

**Daylight Factor (DF) Analysis:** 74% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 86% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 99% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 40% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 64% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.

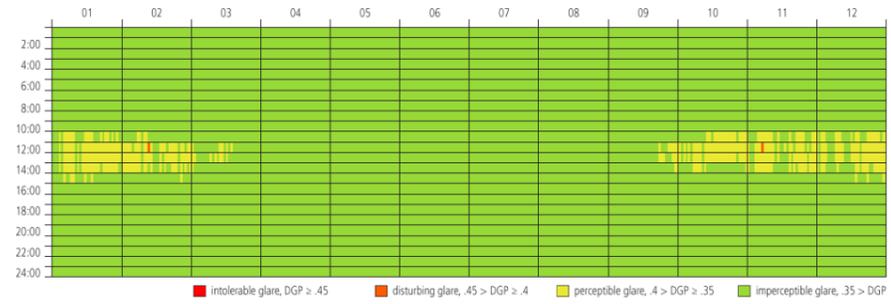


**Lighting Control:**

There is no electric lighting system specified for the scene.

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

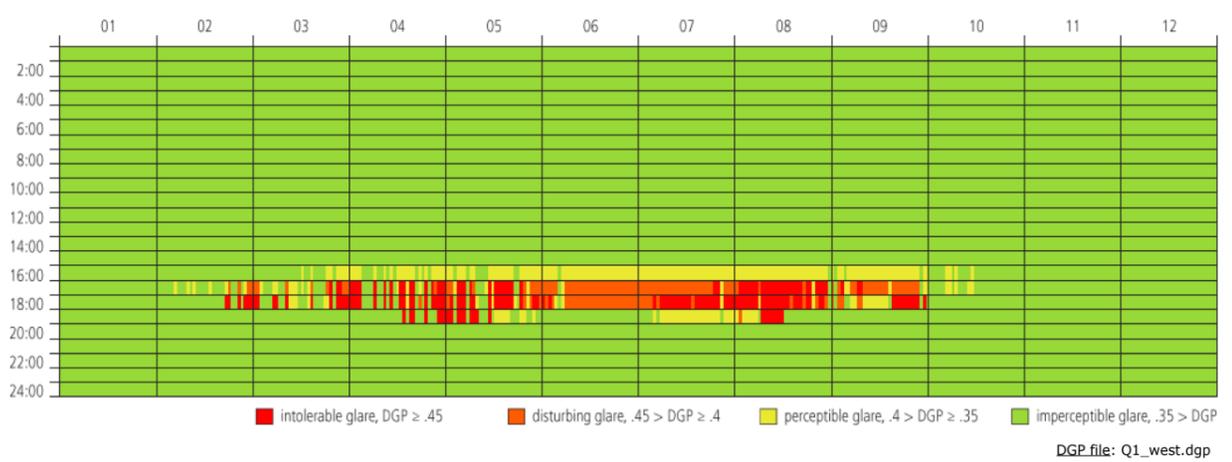
**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**

Hourly values are shown for each view and shading state.

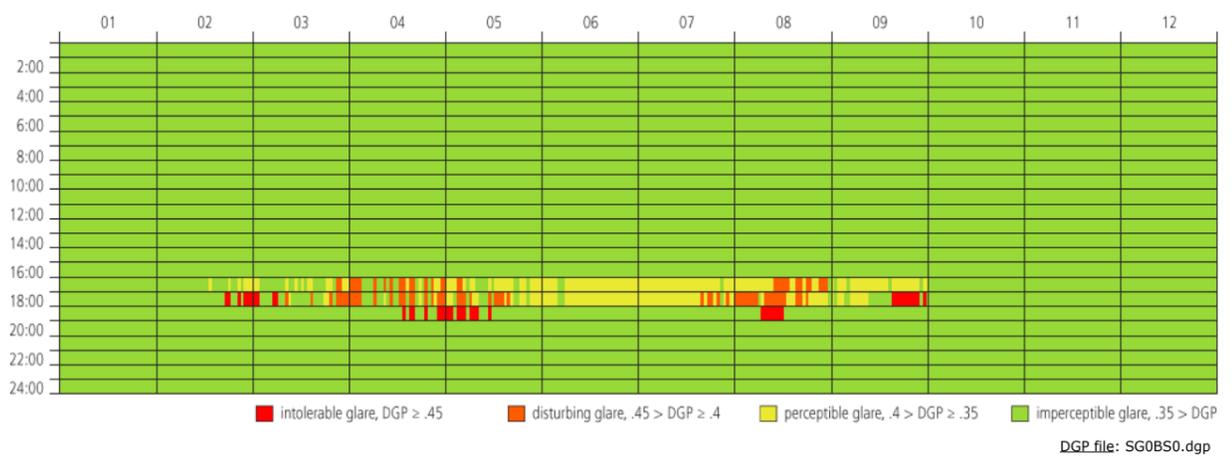
**Base Shading State**

**View Name interior**



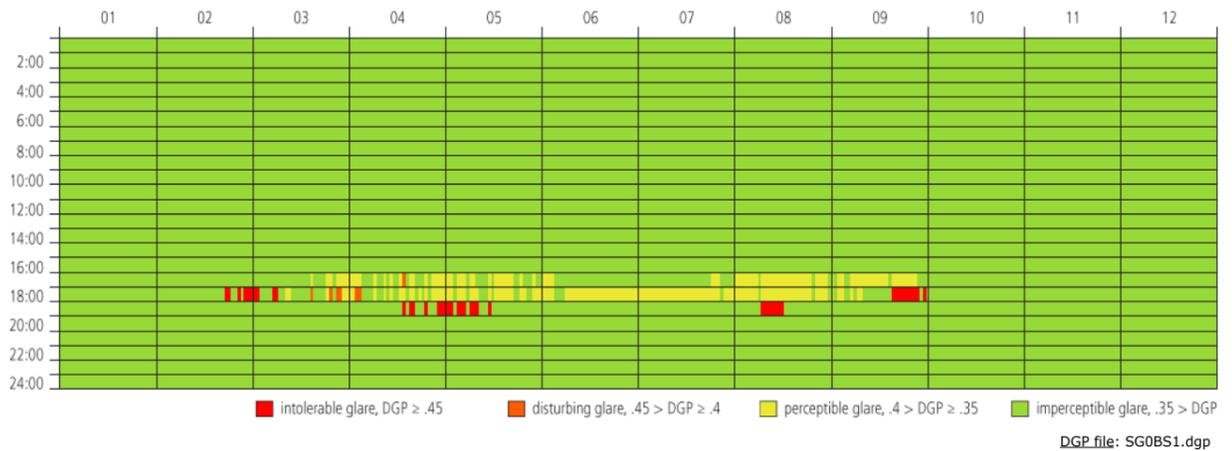
**Shading Group 1; Status 1**

**View Name interior**



**Shading Group 1; Status 2**

**View Name interior**



**Warnings**

ShadingGroup 1 has no reference sensors.

---

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\Q1\_west\Q1\_west\_intgain.csv

Daysim Simulation Report	
Daylit Area (DA <sub>500lux</sub> [50%])	85% of floor area
Mean Daylight Factor	5.5%
Occupancy	3650 hours per year
Glare	0.3% of occupied hours
Shading Group 1 open	95% of occupied hours

**Daylight Factor (DF) Analysis:** 73% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 78% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 85% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 91% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 40% for active occupant behavior

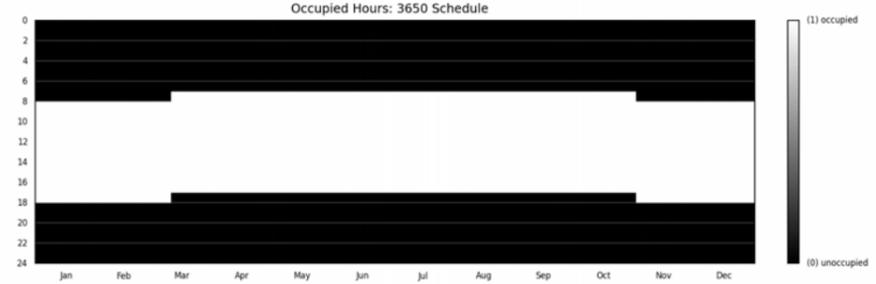
**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 75% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

**Simulation Assumptions**

**Site Description:**  
 The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

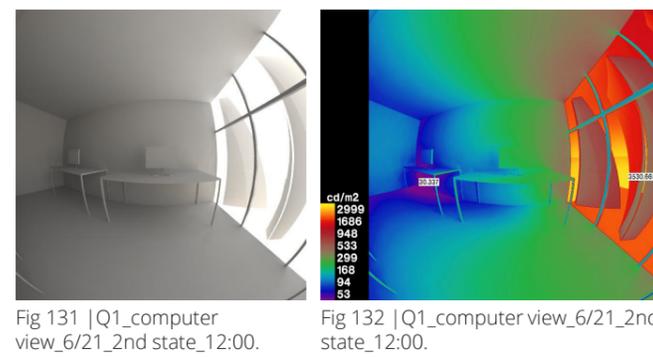
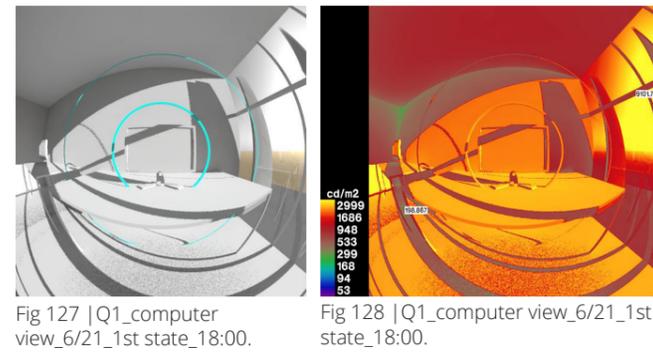
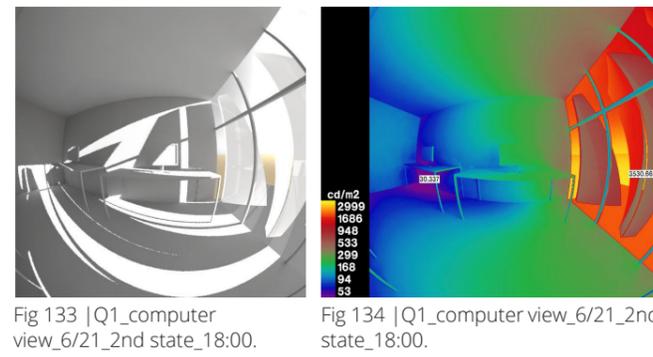
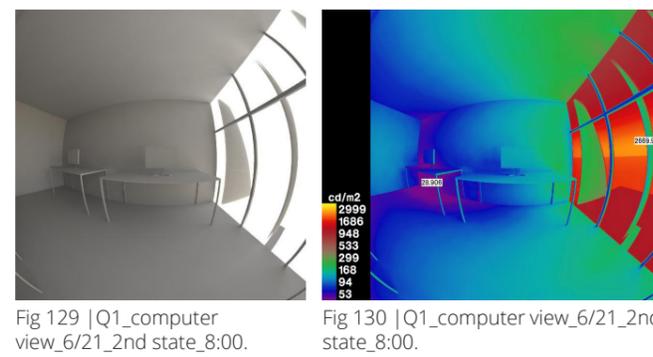
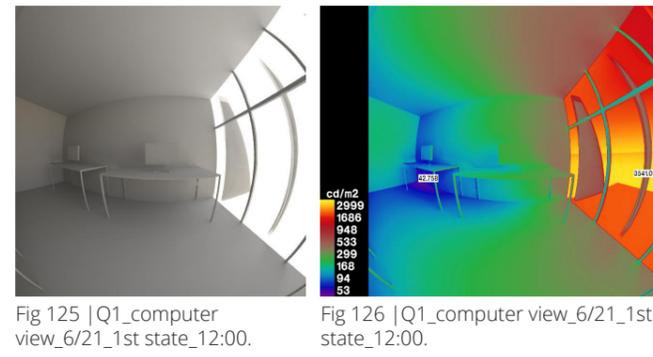
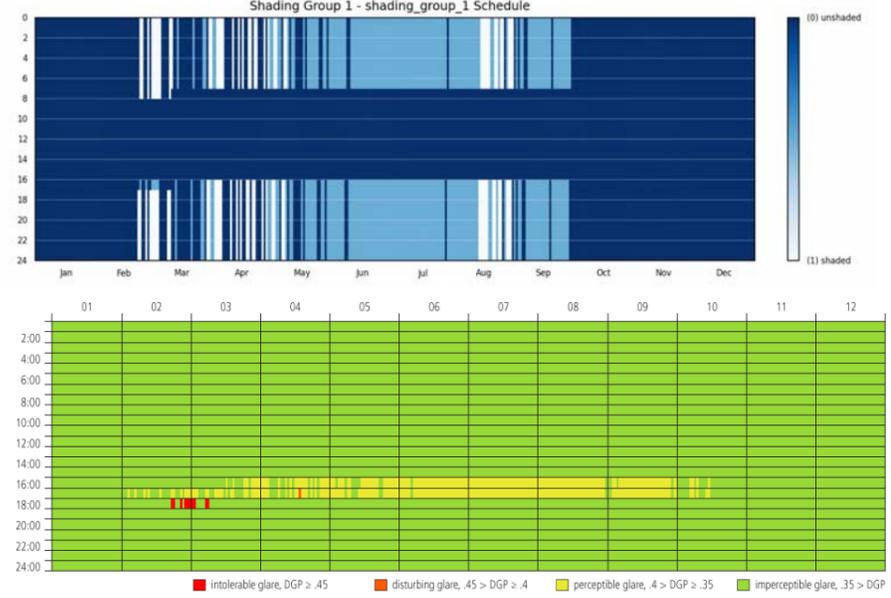
**User Description:**  
 The total annual hours of occupancy at the work place are 3650.



**Lighting Control:**  
 There is no electric lighting system specified for the scene.

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



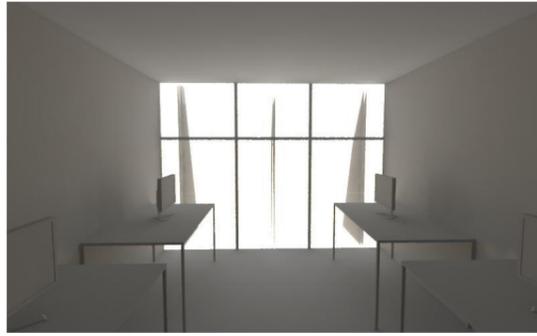


Fig 135 | Q1\_interior view\_6/21\_1st state\_8:00.

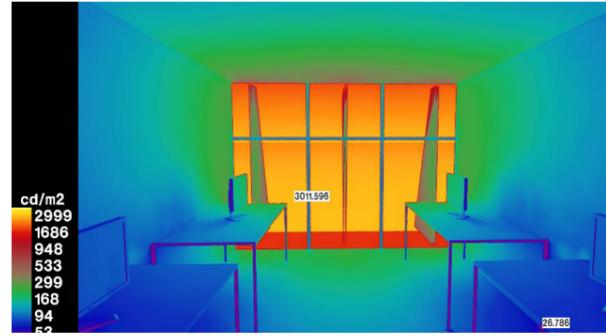


Fig 136 | Q1\_interior view\_6/21\_1st state\_8:00.



Fig 137 | Q1\_interior view\_6/21\_1st state\_12:00.

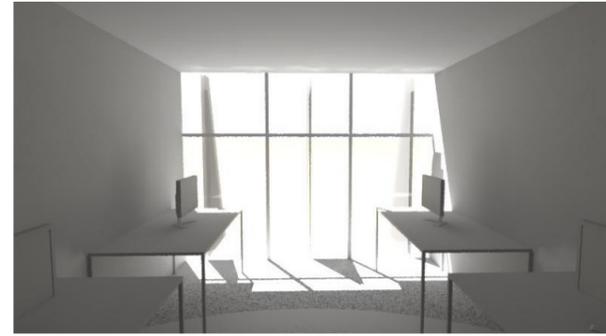


Fig 138 | Q1\_interior view\_6/21\_1st state\_12:00.

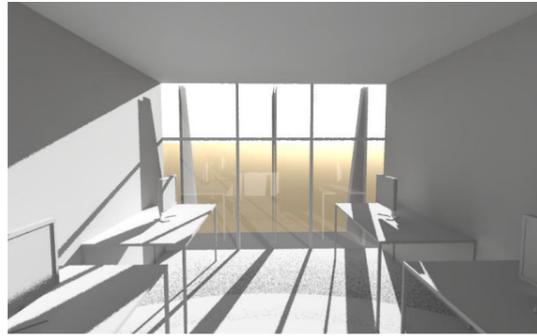


Fig 139 | Q1\_interior view\_6/21\_1st state\_18:00.

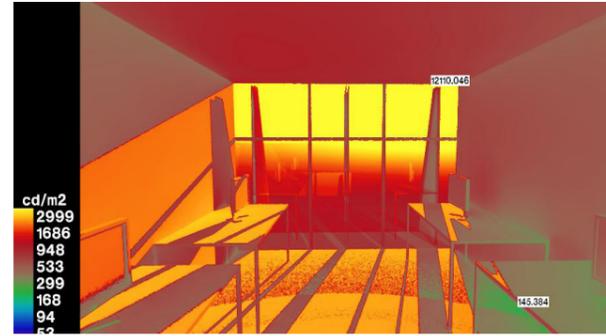


Fig 140 | Q1\_interior view\_6/21\_1st state\_18:00.



Fig 141 | Q1\_interior view\_6/21\_2nd state\_8:00.

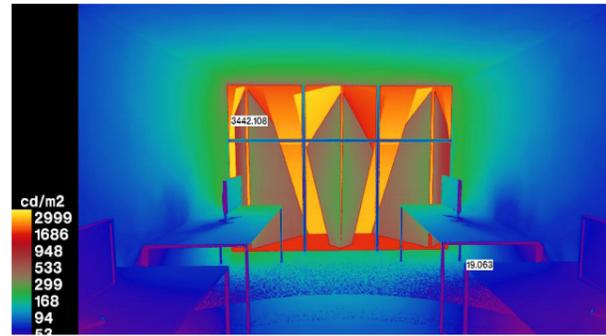


Fig 142 | Q1\_interior view\_6/21\_2nd state\_8:00.

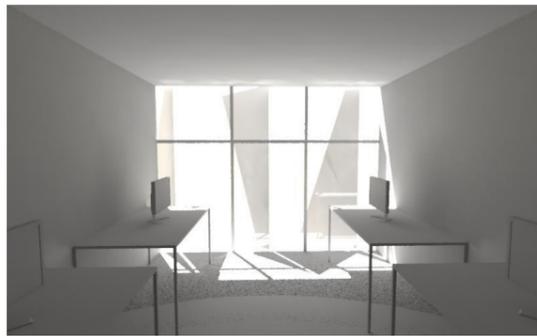


Fig 143 | Q1\_interior view\_6/21\_2nd state\_12:00.

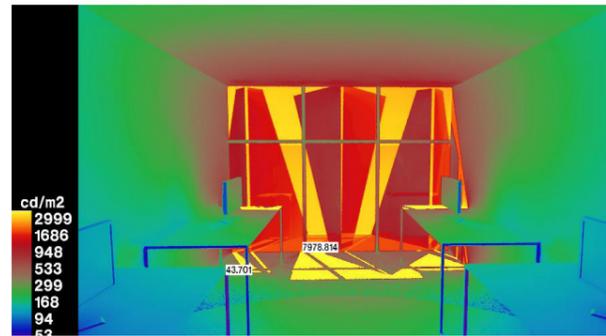


Fig 144 | Q1\_interior view\_6/21\_2nd state\_12:00.



Fig 145 | Cherokee\_interior view\_6/21\_2nd state\_18:00.

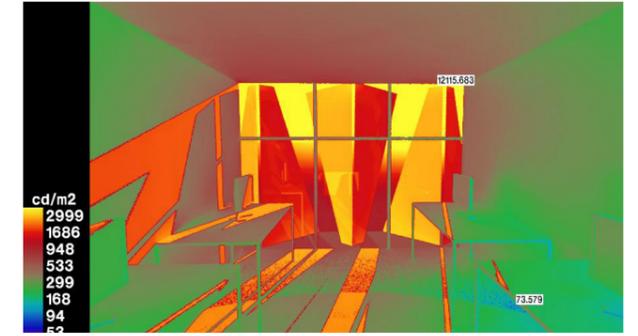


Fig 146 | Cherokee\_interior view\_6/21\_2nd state\_18:00.

Warnings

No warnings.

Simulation Tips

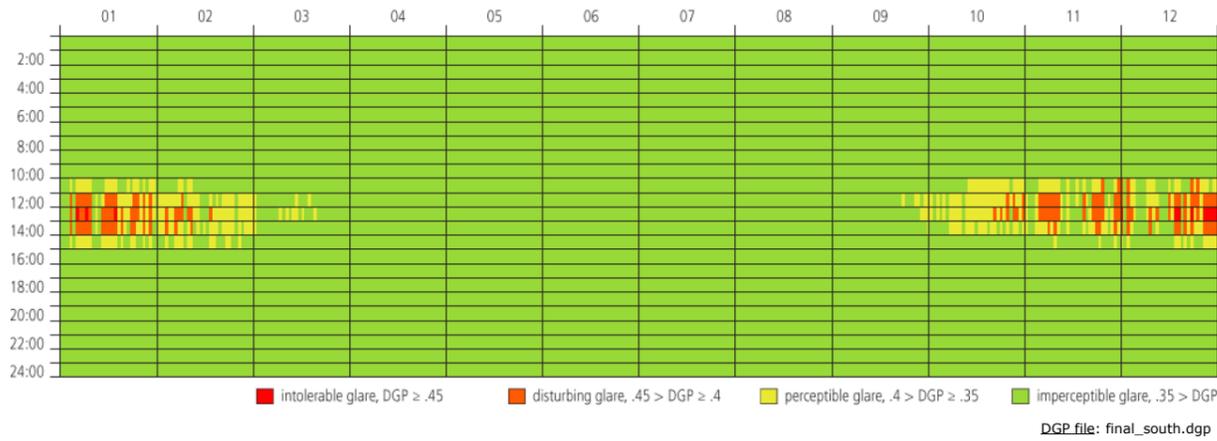
You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

Annual Glare Simulation (eDGPs) Report

Visual Comfort Without Occupant Adaptation  
Hourly values are shown for each view and shading state.

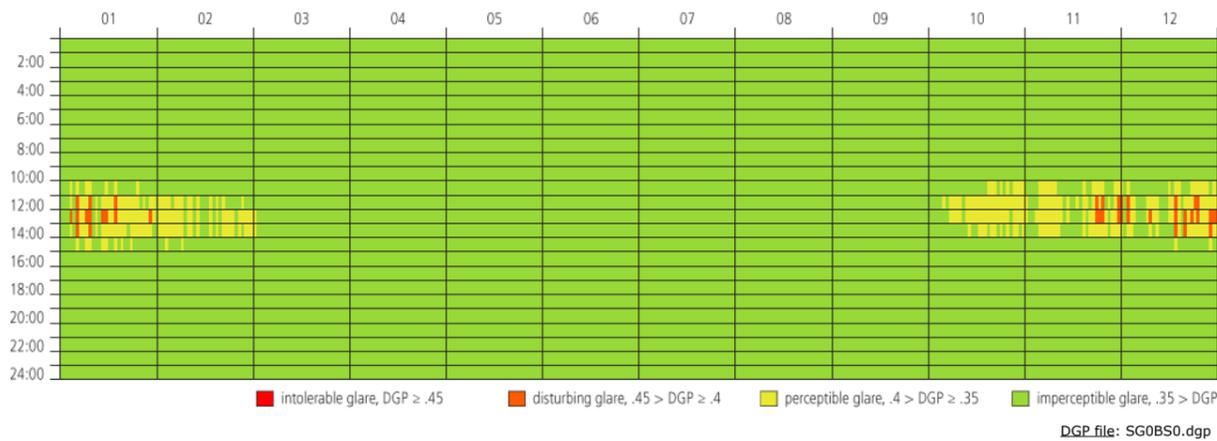
Base Shading State

View Name interior



Shading Group 1; Status 1

View Name interior



Daysim header File: C:\DIVA\temp\final\_south\final\_south.he

Warnings

ShadingGroup 1 has no reference sensors.

Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\final\_south\final\_south\_intgain.csv

Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	100% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	1.0% of occupied hours
Shading Group 1 open	89% of occupied hours

Daylight Factor (DF) Analysis: 70% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 85% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 100% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 33% for active occupant behavior.

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 62% for active occupant behavior.

Electric Lighting Use: The predicted annual electric lighting energy use is:

Simulation Assumptions

Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

User Description:

The total annual hours of occupancy at the work place are 3650.

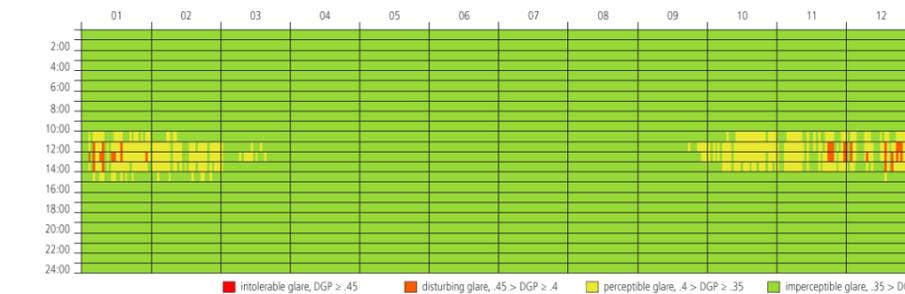


Lighting Control:

There is no electric lighting system specified for the scene.

ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



**Warnings**  
 ShadingGroup 1 has no reference sensors.  
 ShadingGroup 2 has no reference sensors.

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	100% of floor area
Mean Daylight Factor	5.7%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	26% of occupied hours
Shading Group 2 open	35% of occupied hours

**Simulation Tips**  
 Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
 C:\DIVA\temp\final\_south\final\_south\_intgain.csv

**Daylight Factor (DF) Analysis:** 73% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 87% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 100% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 93% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 48% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 47% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

**Simulation Assumptions**

**Site Description:**  
 The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

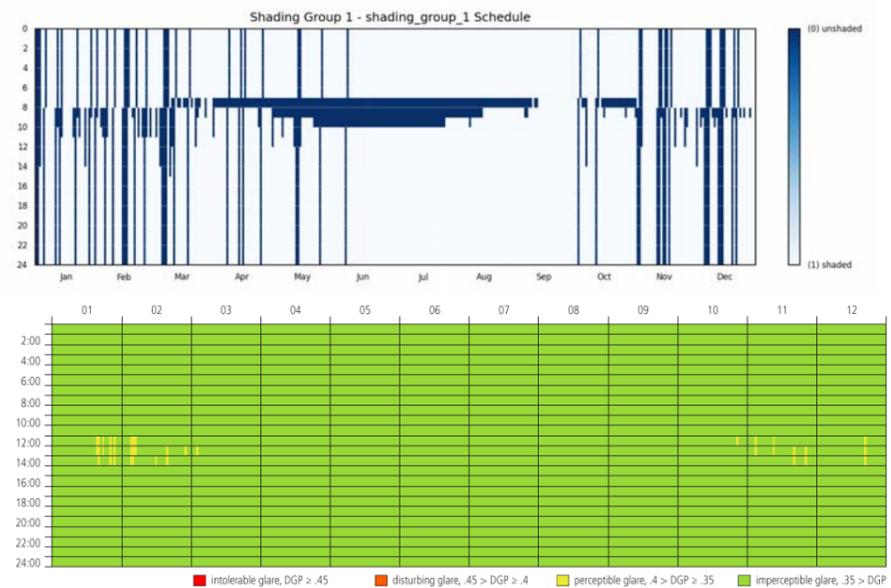
**User Description:**  
 The total annual hours of occupancy at the work place are 3650.



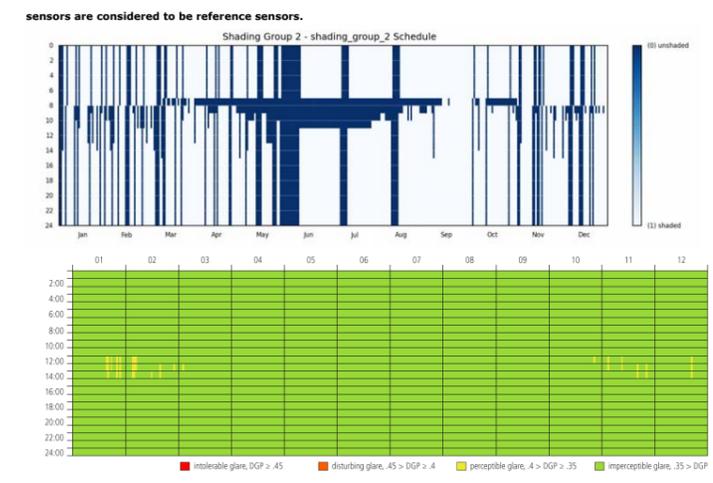
**Lighting Control:**  
 There is no electric lighting system specified for the scene.

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the `Lightswitch_model`. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



- ShadingGroup 2: The system is manually controlled according to the `Lightswitch_model`. **WARNING: Since Shading Group 2 has no reference sensors specified, all sensors are considered to be reference sensors.**



Daysim header File: C:\DIVA\temp\final\_south\final\_south.hea

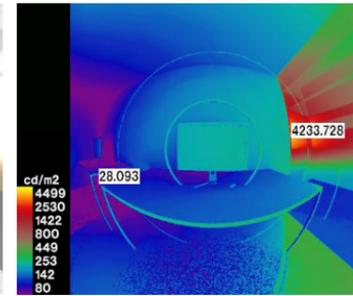
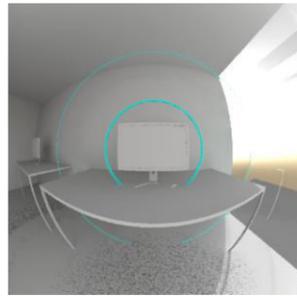


Fig 147 |Prop. system\_s\_computer view\_12/21\_transp\_8:00.

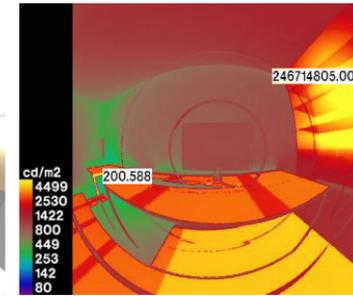
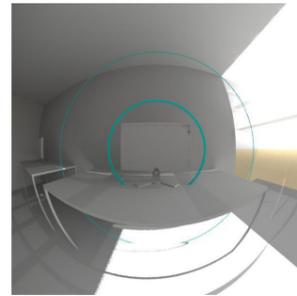


Fig 148 |Prop. system\_s\_computer view\_12/21\_transp\_8:00.

Fig 149 |Prop. system\_s\_computer view\_12/21\_transp\_12:00.

Fig 150 |Prop. system\_s\_computer view\_12/21\_transp\_12:00.

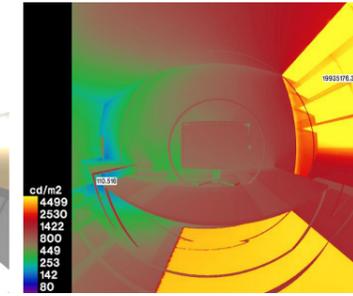
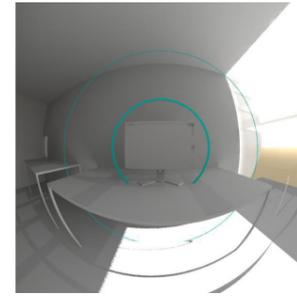


Fig 167 |Prop. system\_s\_comp. view\_12/21\_translucent\_12:00.

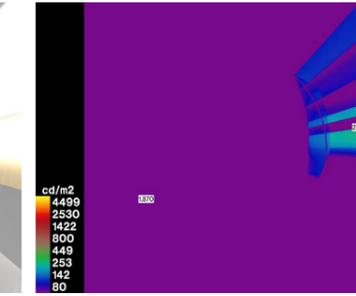
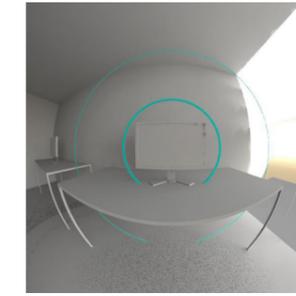


Fig 169 |Prop. system\_s\_comp. view\_12/21\_translucent\_18:00.

Fig 170 |Prop. system\_s\_comp. view\_12/21\_translucent\_18:00.

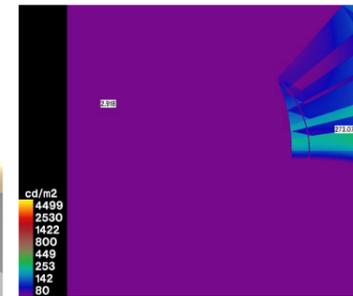
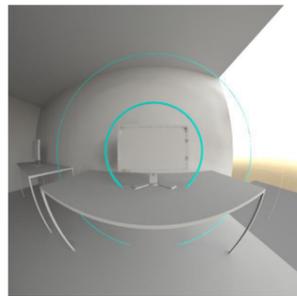


Fig 151 |Prop. system\_s\_comp. view\_12/21\_transp\_18:00.

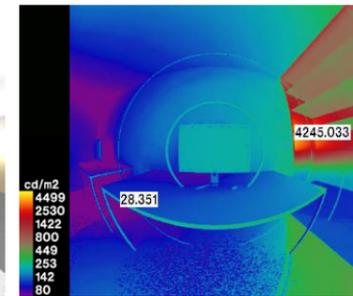
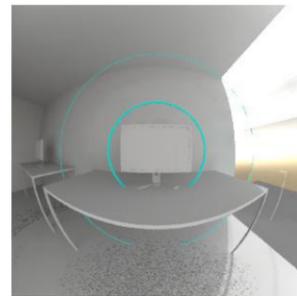


Fig 153 |Prop. system\_s\_comp. view\_12/21\_horiz. transluc. 8:00.

Fig 154 |Prop. system\_s\_computer view\_12/21\_horiz. transluc. 8:00.

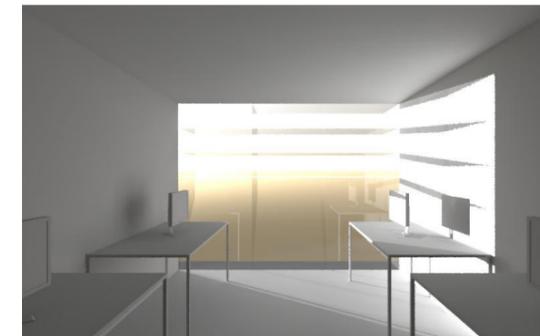


Fig 171 |Prop. system\_s\_interior view\_12/21\_transparent 8:00.

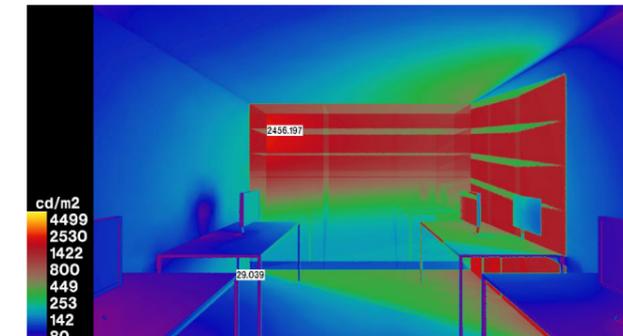


Fig 172 |Prop. system\_s\_interior view\_12/21\_transparent 8:00.

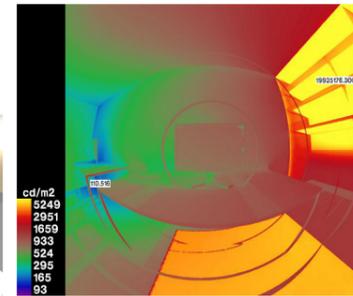
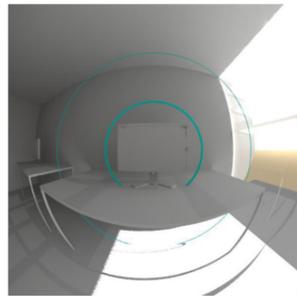


Fig 155 |Prop. system\_s\_comp. view\_12/21\_horiz. transluc. 12:00.

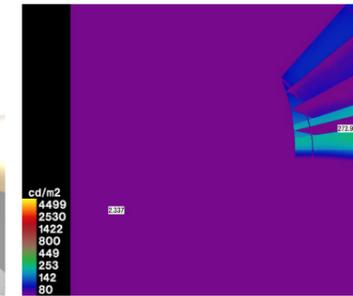
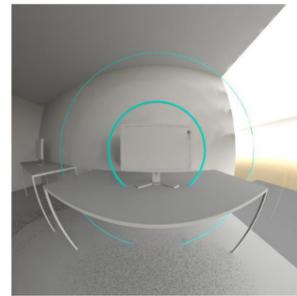


Fig 157 |Prop. system\_s\_comp. view\_12/21\_horiz. transluc. 18:00.

Fig 158 |Prop. system\_s\_comp. view\_12/21\_horiz. transluc. 18:00.

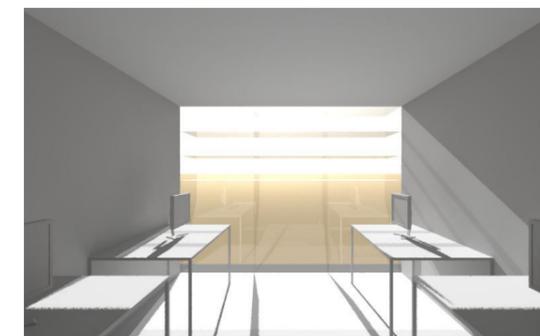


Fig 173 |Prop. system\_s\_interior view\_12/21\_transparent 12:00.



Fig 174 |Prop. system\_s\_interior view\_12/21\_transparent 12:00.

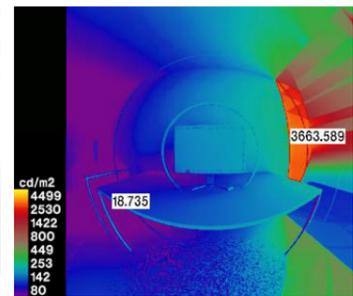
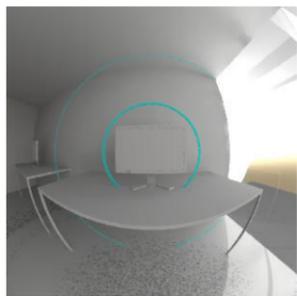


Fig 159 |Prop. system\_s\_comp. view\_12/21\_vertic. transluc. 8:00.

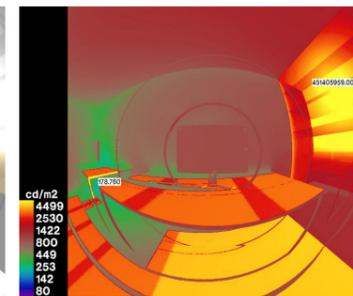
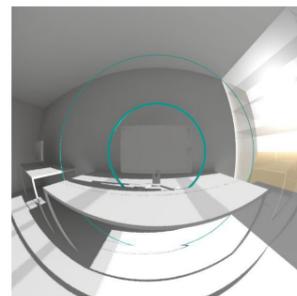


Fig 161 |Prop. system\_s\_comp. view\_12/21\_vertic. transluc. 12:00.

Fig 162 |Prop. system\_s\_computer view\_12/21\_vertic. transluc. 12:00.

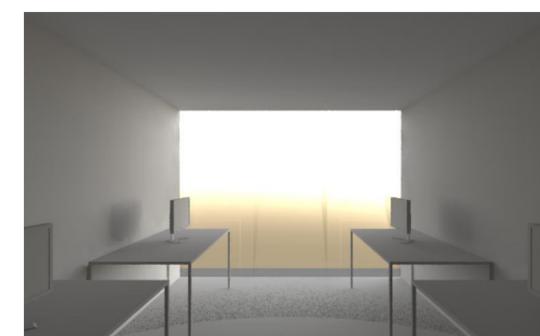


Fig 175 |Prop. system\_s\_interior view\_12/21\_transparent 18:00.

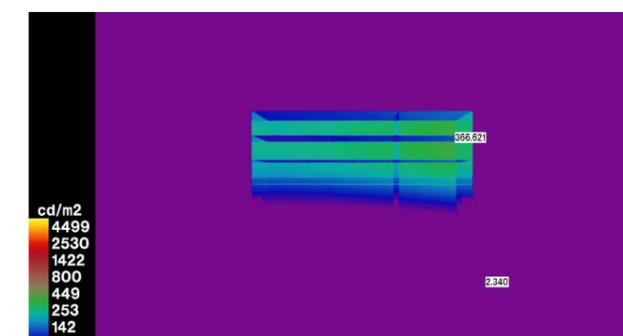


Fig 176 |Prop. system\_s\_interior view\_12/21\_transparent 18:00.

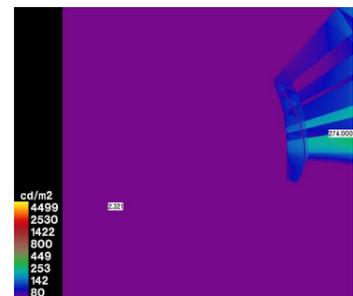
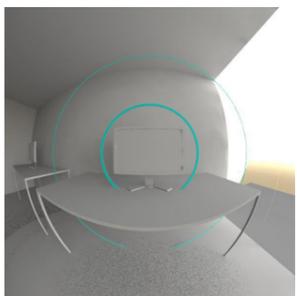


Fig 163 |Prop. system\_s\_comp. view\_12/21\_vertic. transluc. 18:00.

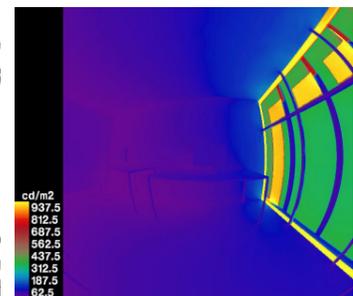


Fig 164 |Prop. system\_s\_computer view\_12/21\_vertic. transluc. 18:00.

Fig 165 |Prop. system\_s\_comp. view\_12/21\_translucent 8:00.

Fig 166 |Prop. system\_s\_comp. view\_12/21\_translucent 8:00.



Fig 177 |Prop. system\_s\_interior view\_12/21\_horiz. translucent 8:00.

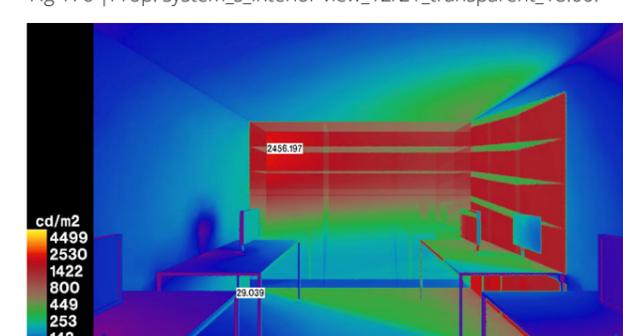


Fig 178 |Prop. system\_s\_interior view\_12/21\_horiz. translucent 8:00.

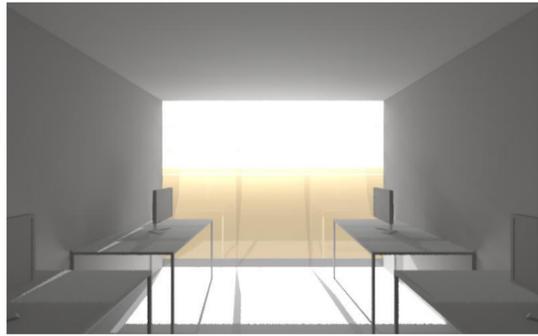


Fig 179 | Prop. system\_s\_interior view\_12/21\_horiz. translucent 12:00.

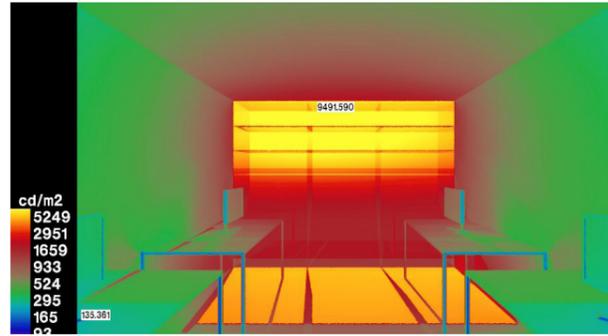


Fig 180 | Prop. system\_s\_interior view\_12/21\_horiz. translucent 12:00.

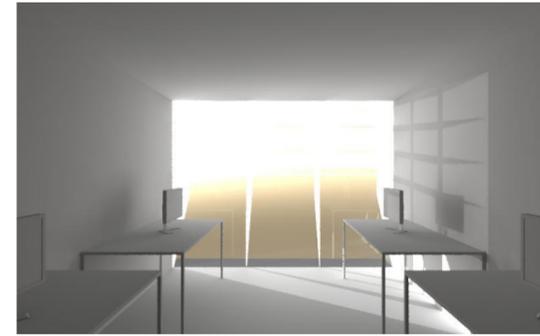


Fig 189 | Prop. system\_s\_interior view\_12/21\_translucent\_8:00.

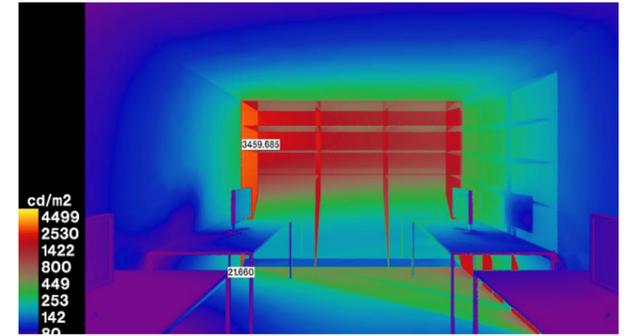


Fig 190 | Prop. system\_s\_interior view\_12/21\_translucent\_8:00.

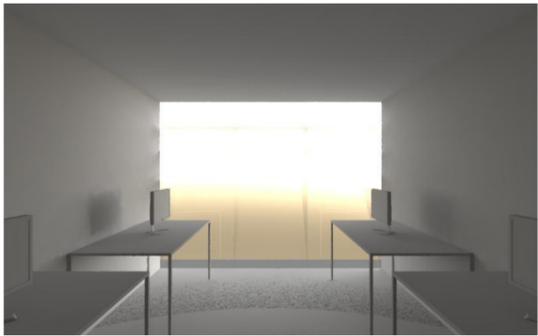


Fig 181 | Prop. system\_s\_interior view\_12/21\_horiz. translucent 18:00.

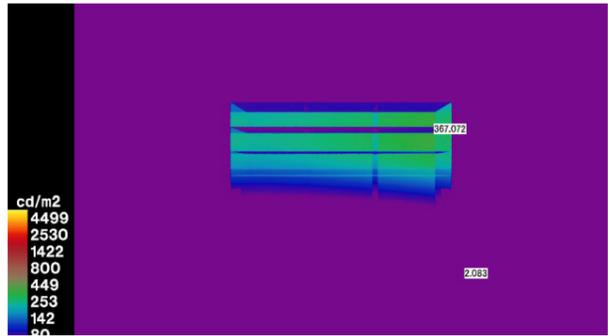


Fig 182 | Prop. system\_s\_interior view\_12/21\_horiz. translucent 18:00.

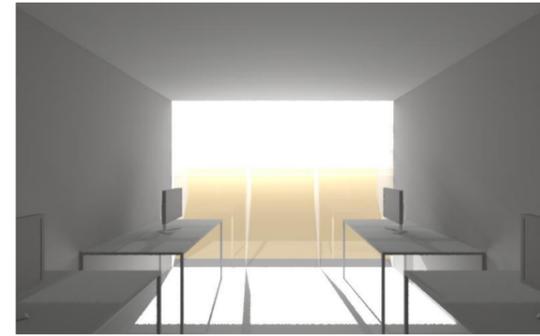


Fig 191 | Prop. system\_s\_interior view\_12/21\_translucent\_12:00.

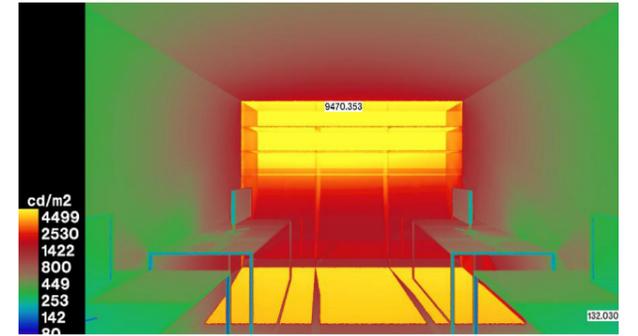


Fig 192 | Prop. system\_s\_interior view\_12/21\_translucent\_12:00.

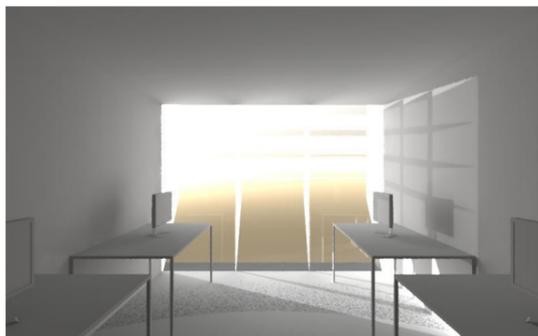


Fig 183 | Prop. system\_s\_interior view\_12/21\_vertical transl\_8:00.

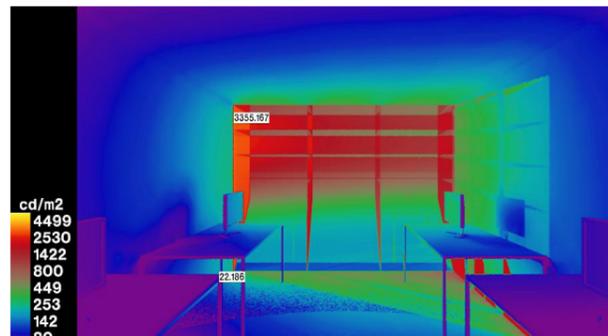


Fig 184 | Prop. system\_s\_interior view\_12/21\_vertical transl\_8:00.

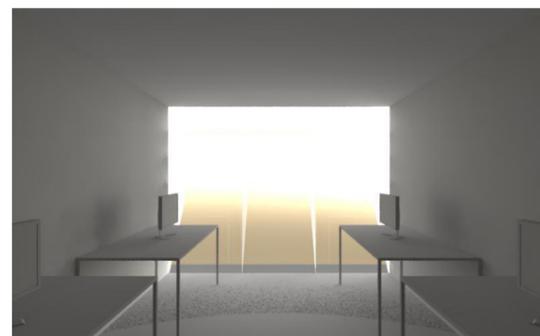


Fig 193 | Prop. system\_s\_interior view\_12/21\_horiz. translucent\_18:00.

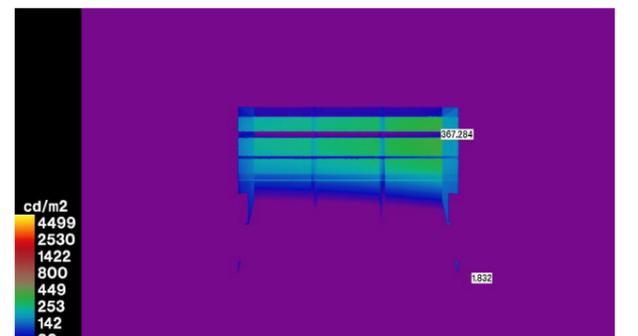


Fig 194 | Prop. system\_s\_interior view\_12/21\_translucent\_18:00.

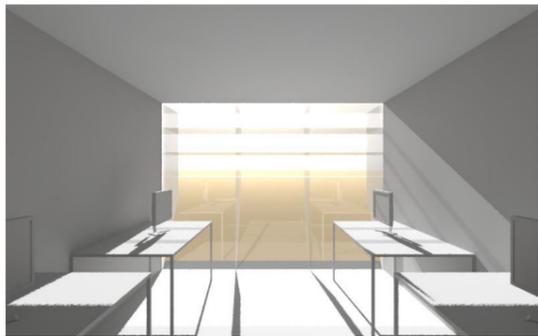


Fig 185 | Prop. system\_s\_interior view\_12/21\_vertical transl\_12:00.



Fig 186 | Prop. system\_s\_interior view\_12/21\_vertical transl\_12:00.

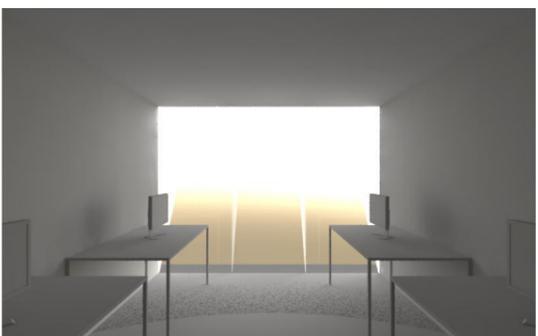


Fig 187 | Prop. system\_s\_interior view\_12/21\_vertical transl\_18:00.

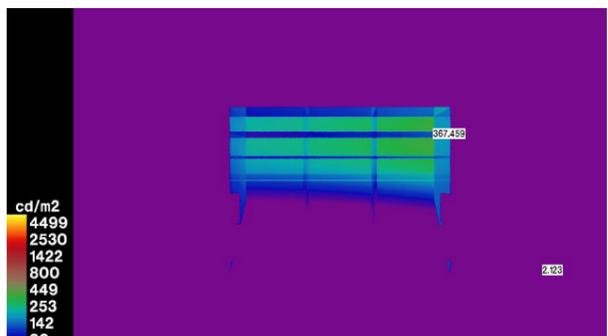


Fig 188 | Prop. system\_s\_interior view\_12/21\_vertical transl\_18:00.

**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

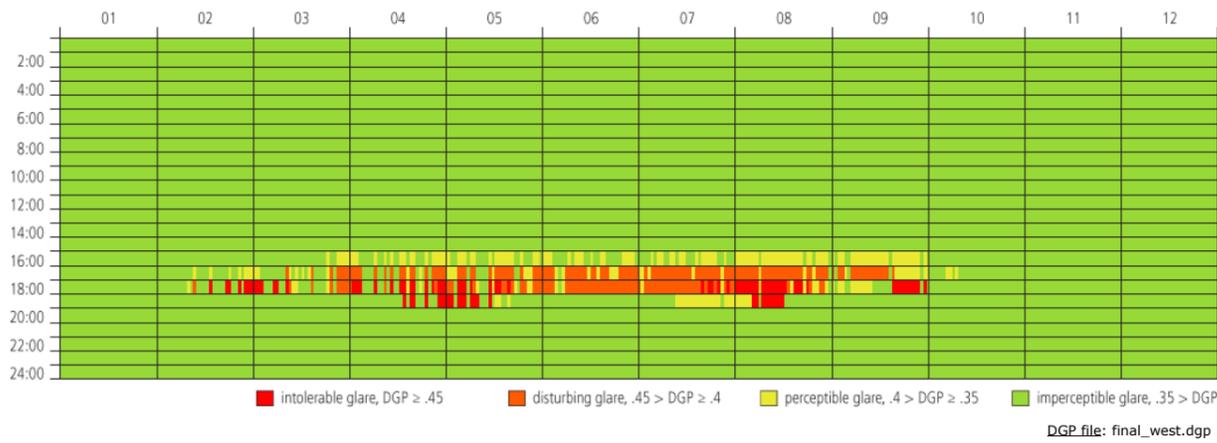
**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**

Hourly values are shown for each view and shading state.

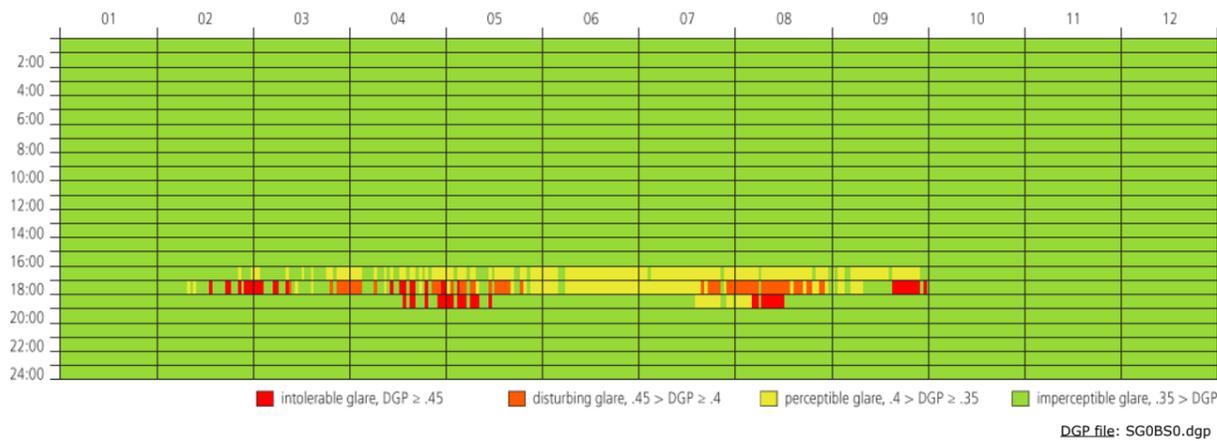
**Base Shading State**

View Name interior



**Shading Group 1; Status 1**

View Name interior



Daysim header File: C:\DIVA\temp\final\_west\final\_west.hea

**Warnings**

ShadingGroup 1 has no reference sensors.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\final\_west\final\_west\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	86% of floor area
Mean Daylight Factor	5.6%
Occupancy	3650 hours per year
Glare	0.3% of occupied hours
Shading Group 1 open	96% of occupied hours

**Daylight Factor (DF) Analysis:** 74% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 78% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 86% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 92% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 38% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 75% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

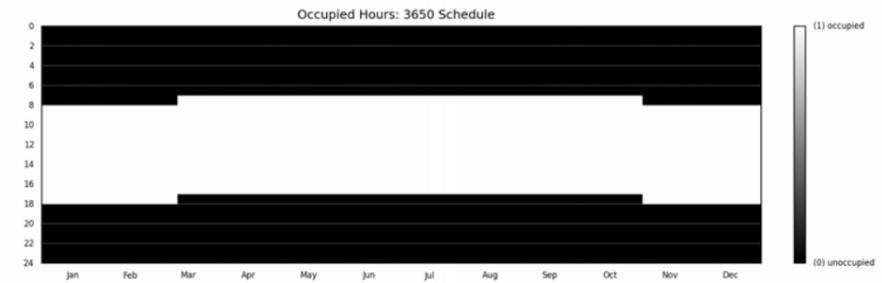
**Simulation Assumptions**

**Site Description:**

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.

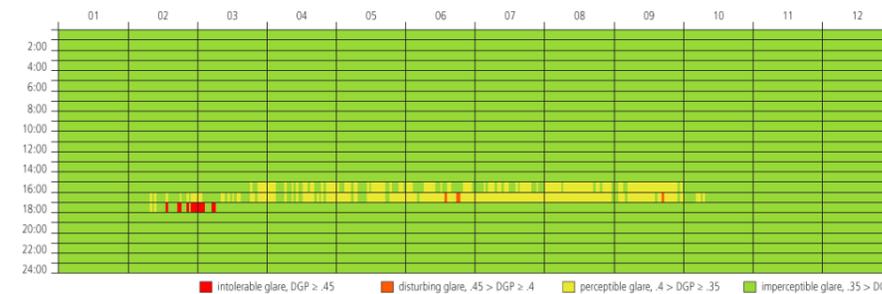


**Lighting Control:**

There is no electric lighting system specified for the scene.

**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**





# Proposed shading system- west (2 shading groups)

# Proposed shading system west (2 shading groups)

### Warnings

ShadingGroup 1 has no reference sensors.  
ShadingGroup 2 has no reference sensors.

### Simulation Tips

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\final\_west\final\_west\_intgain.csv

### Daysim Simulation Report

Daylit Area (DA <sub>500lux</sub> [50%])	87% of floor area
Mean Daylight Factor	5.6%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	66% of occupied hours
Shading Group 2 open	76% of occupied hours

**Daylight Factor (DF) Analysis:** 74% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 79% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 87% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 91% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 37% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 74% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

### Simulation Assumptions

#### Site Description:

The investigated building is located in ATHENS\_GRC (37.90 N/ 23.73 W).

#### User Description:

The total annual hours of occupancy at the work place are 3650.

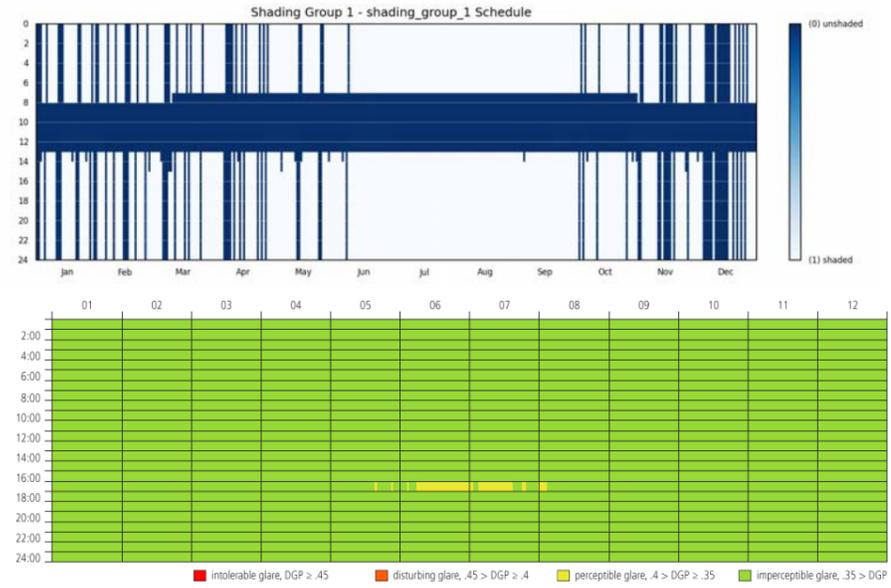


#### Lighting Control:

There is no electric lighting system specified for the scene.

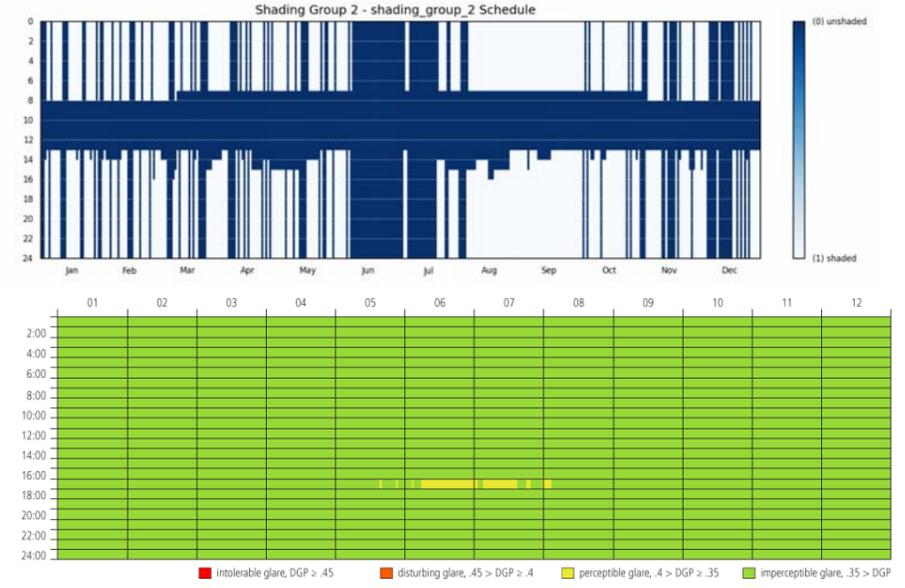
#### ShadingControl:

- ShadingGroup 1: The system is manually controlled according to the Lightswitch model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



- ShadingGroup 2: The system is manually controlled according to the Lightswitch model. **WARNING: Since Shading Group 2 has no reference sensors specified, all**

### sensors are considered to be reference sensors.



Daysim header File: [C:\DIVA\temp\final\\_west\final\\_west.heg](C:\DIVA\temp\final_west\final_west.heg)

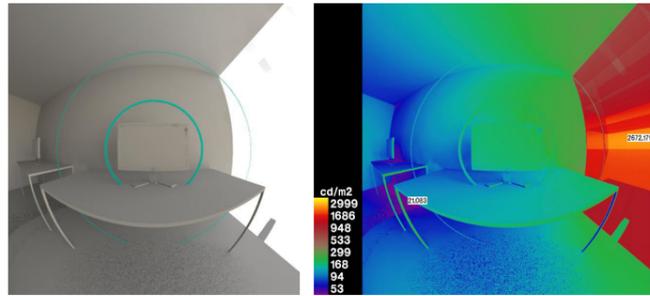


Fig 195 |Prop. system\_w\_computer view\_6/21\_transp\_8:00.

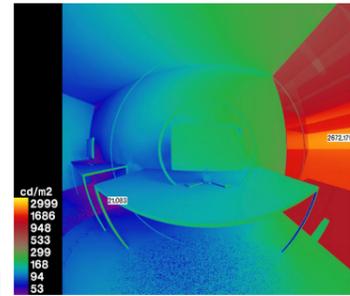


Fig 196 |Prop. system\_w\_computer view\_6/21\_transp\_8:00.

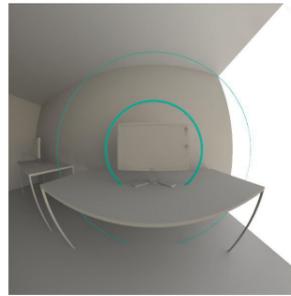


Fig 197 |Prop. system\_w\_computer view\_6/21\_transp\_12:00.

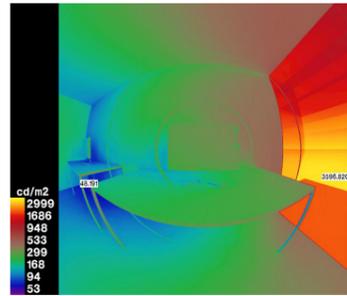


Fig 198 |Prop. system\_w\_computer view\_6/21\_transp\_12:00.

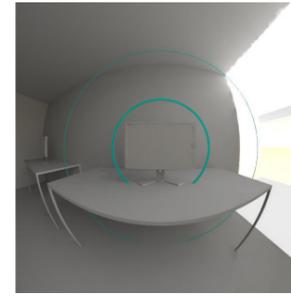


Fig 215 |Prop. system\_w\_computer view\_6/21\_translucent\_12:00.

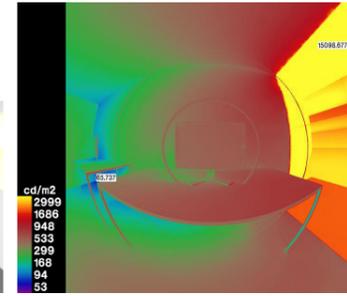


Fig 216 |Prop. system\_w\_computer view\_6/21\_translucent\_12:00.

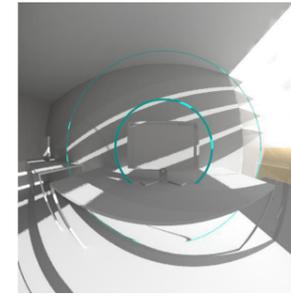


Fig 217 |Prop. system\_w\_computer view\_6/21\_translucent\_18:00.

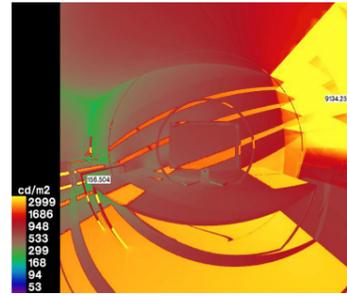


Fig 218 |Prop. system\_w\_computer view\_6/21\_translucent\_18:00.

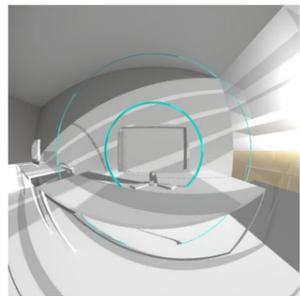


Fig 199 |Prop. system\_w\_computer view\_6/21\_transp\_18:00.

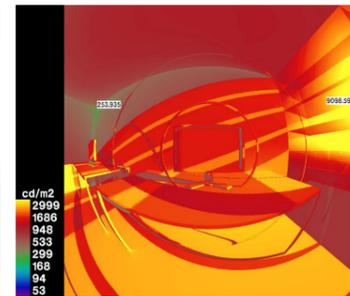


Fig 200 |Prop. system\_w\_computer view\_6/21\_transp\_18:00.

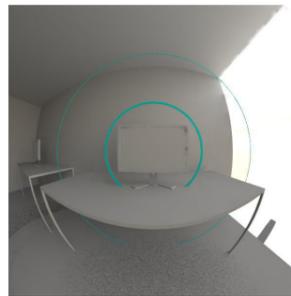


Fig 201 |Prop. system\_w\_computer view\_6/21\_horiz. transluc\_8:00.

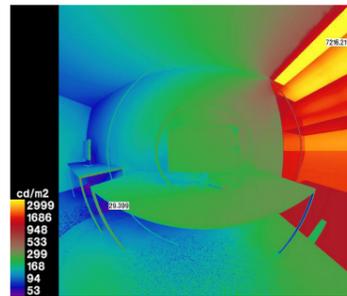


Fig 202 |Prop. system\_w\_computer view\_6/21\_horiz. transluc\_8:00.

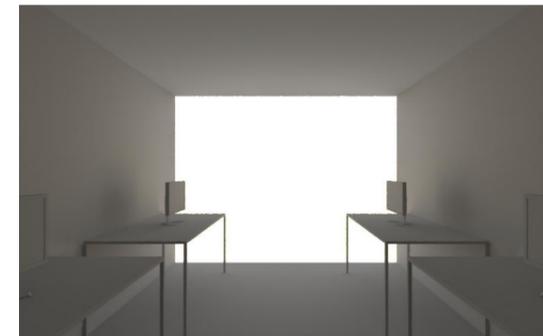


Fig 219 |Proposed system\_w\_interior view\_6/21\_transparent\_8:00.

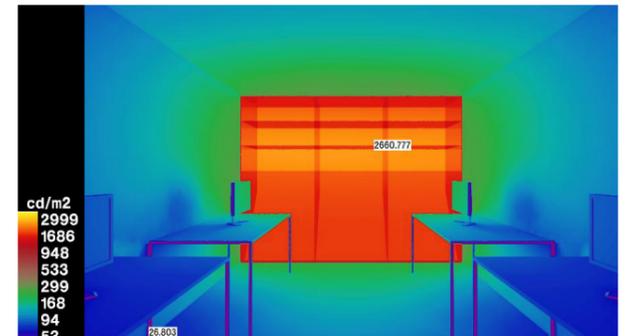


Fig 220 |Proposed system\_w\_interior view\_6/21\_transparent\_8:00.

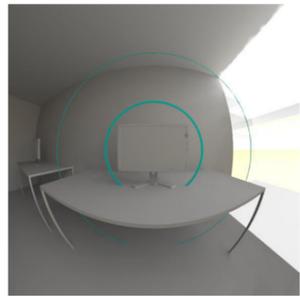


Fig 203 |Prop. system\_w\_computer view\_6/21\_horiz. transluc\_12:00.

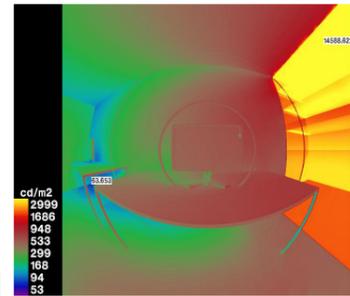


Fig 204 |Prop. system\_w\_computer view\_6/21\_horiz. transluc\_12:00.

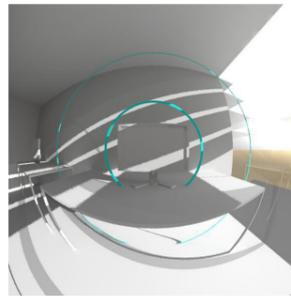


Fig 205 |Prop. system\_w\_computer view\_6/21\_horiz. transluc\_18:00.

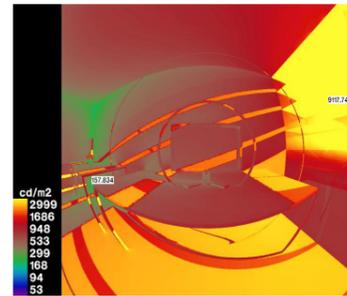


Fig 206 |Prop. system\_w\_computer view\_6/21\_horiz. transluc\_18:00.



Fig 221 |Proposed system\_w\_interior view\_6/21\_transparent\_12:00.

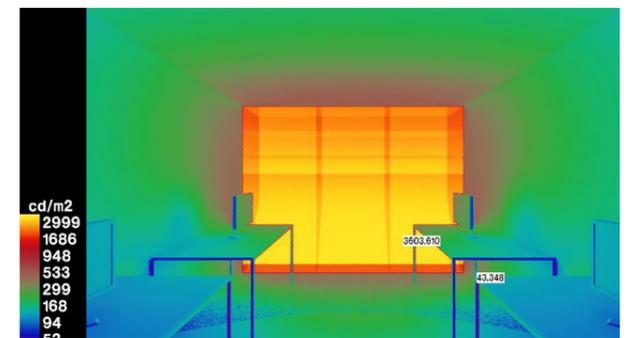


Fig 222 |Proposed system\_w\_interior view\_6/21\_transparent\_12:00.

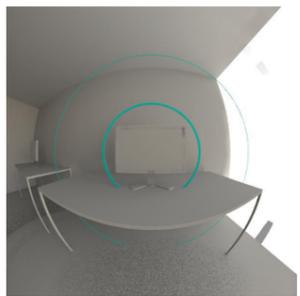


Fig 207 |Prop. system\_w\_computer view\_6/21\_vertic. transluc\_8:00.

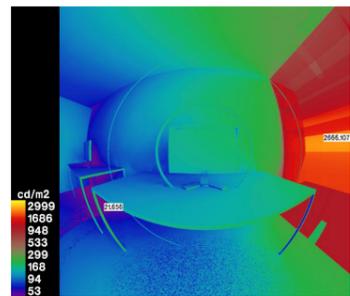


Fig 208 |Prop. system\_w\_computer view\_6/21\_vertic. transluc\_8:00.

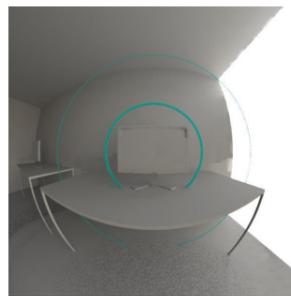


Fig 209 |Prop. system\_w\_computer view\_6/21\_vertic. transluc\_12:00.

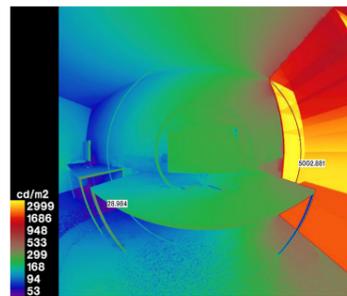


Fig 210 |Prop. system\_w\_computer view\_6/21\_vertic. transluc\_12:00.

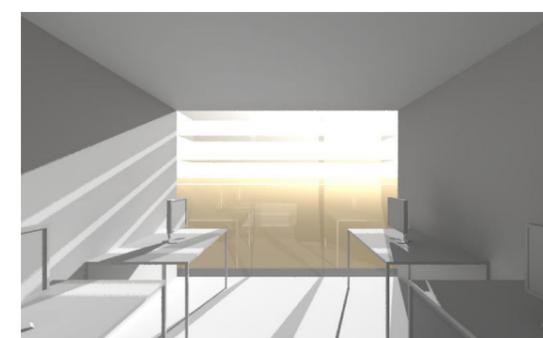


Fig 223 |Proposed system\_w\_interior view\_6/21\_transparent\_18:00.

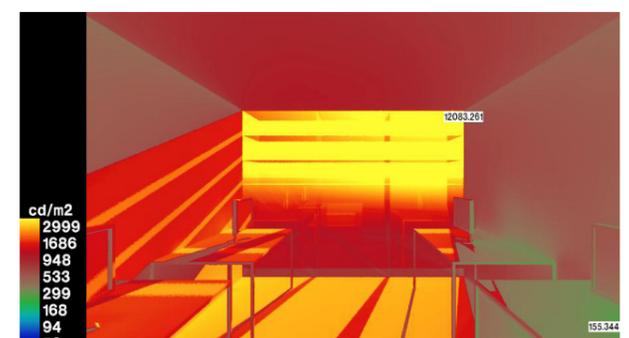


Fig 224 |Proposed system\_w\_interior view\_6/21\_transparent\_18:00.

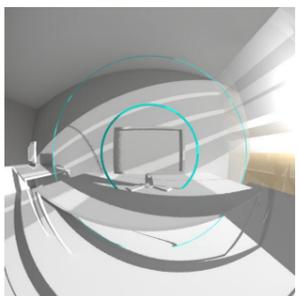


Fig 211 |Prop. system\_w\_computer view\_6/21\_vertic. transluc\_18:00.

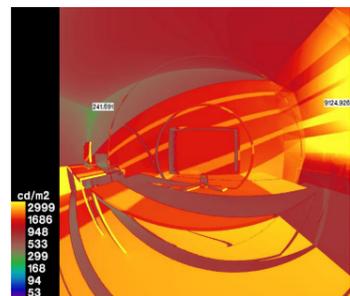


Fig 212 |Prop. system\_w\_computer view\_6/21\_vertic. transluc\_18:00.

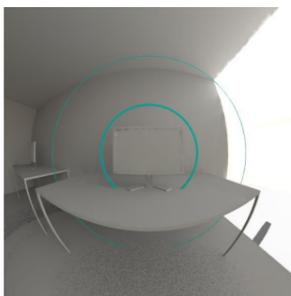


Fig 213 |Prop. system\_w\_computer view\_6/21\_translucent\_8:00.

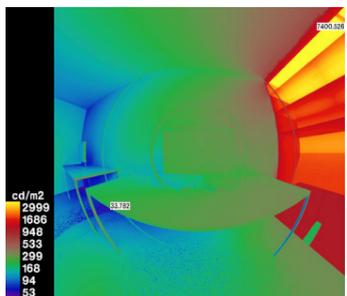


Fig 214 |Prop. system\_w\_computer view\_6/21\_translucent\_8:00.



Fig 225 |Proposed system\_w\_interior view\_6/21\_horiz. translucent\_8:00.

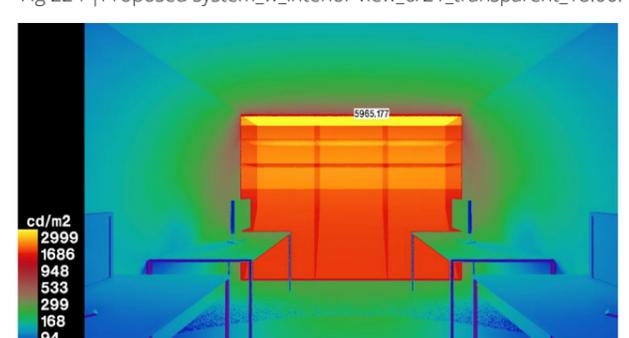


Fig 226 |Proposed system\_w\_interior view\_6/21\_horiz. translucent\_8:00.

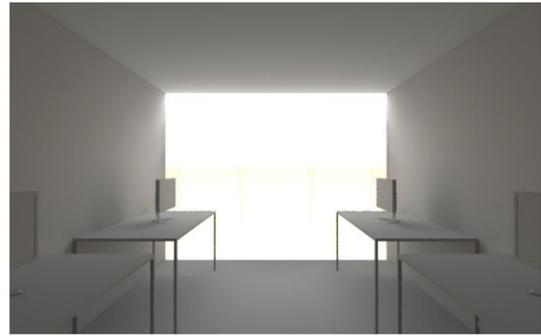


Fig 227 | Proposed system\_w\_interior view\_6/21\_horiz. translucent 12:00.

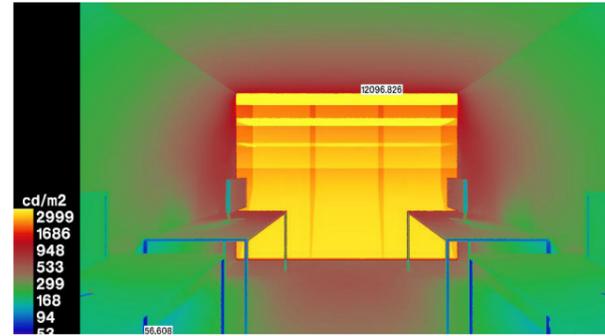


Fig 228 | Proposed system\_w\_interior view\_6/21\_horiz. translucent 12:00.

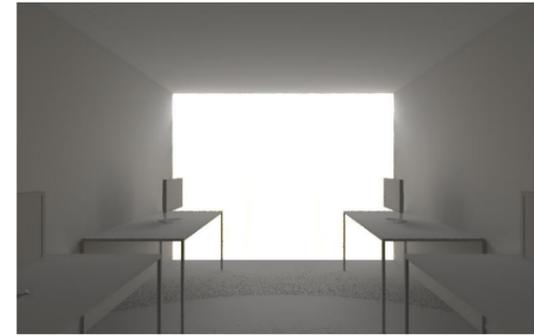


Fig 237 | Proposed system\_w\_interior view\_6/21\_translucent\_8:00.

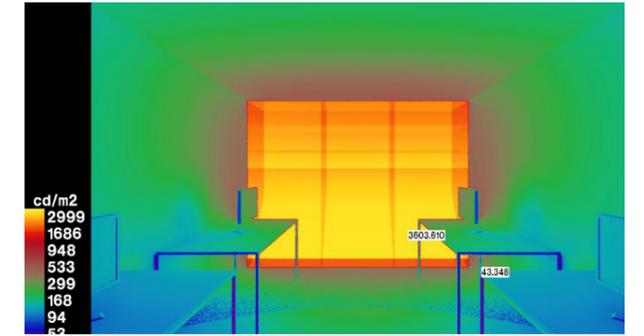


Fig 238 | Proposed system\_w\_interior view\_6/21\_translucent\_8:00.

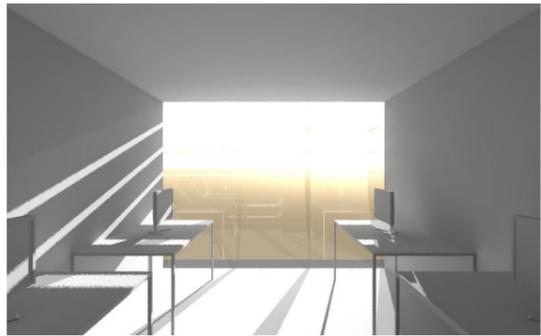


Fig 229 | Proposed system\_w\_interior view\_6/21\_horiz. translucent 18:00.

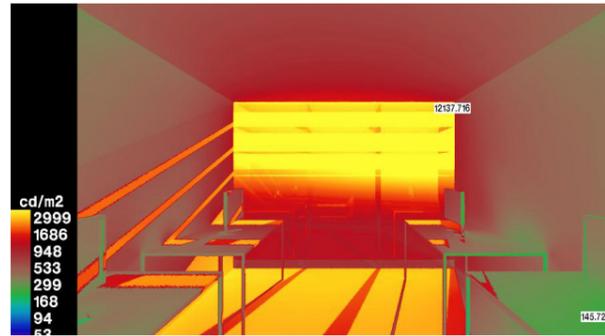


Fig 230 | Proposed system\_w\_interior view\_6/21\_horiz. translucent 18:00.

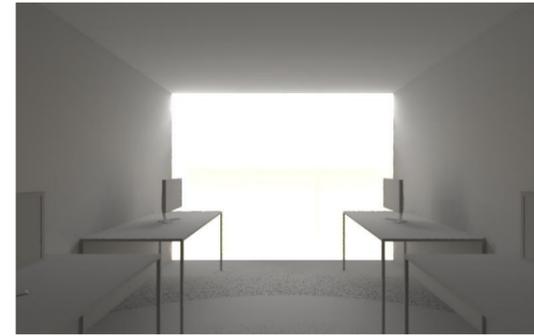


Fig 239 | Proposed system\_w\_interior view\_6/21\_translucent\_12:00.

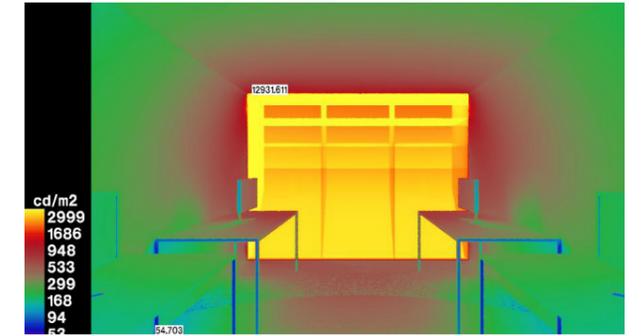


Fig 240 | Proposed system\_w\_interior view\_6/21\_translucent\_12:00.

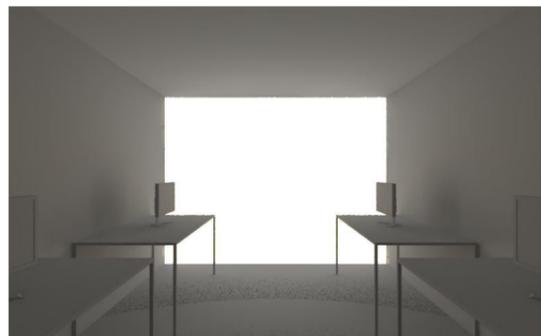


Fig 231 | Proposed system\_w\_interior view\_6/21\_vertical transl\_8:00.



Fig 232 | Proposed system\_w\_interior view\_6/21\_vertical transl\_8:00.

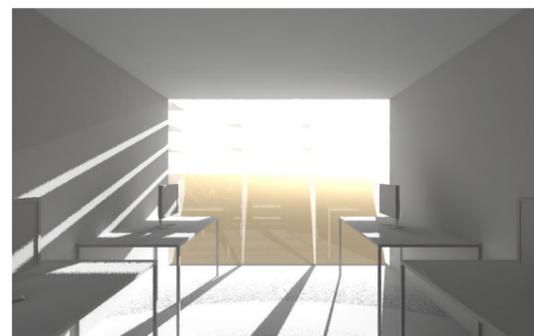


Fig 241 | Proposed system\_w\_interior view\_6/21\_horiz. translucent\_18:00.



Fig 242 | Proposed system\_w\_interior view\_6/21\_translucent\_18:00.

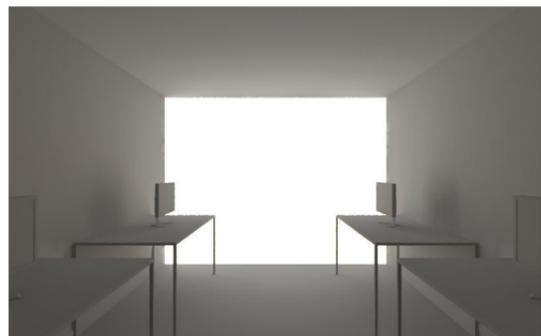


Fig 233 | Proposed system\_w\_interior view\_6/21\_vertical transl\_12:00.

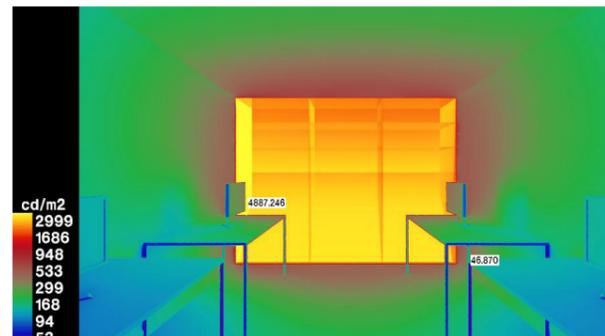


Fig 234 | Proposed system\_w\_interior view\_6/21\_vertical transl\_12:00.

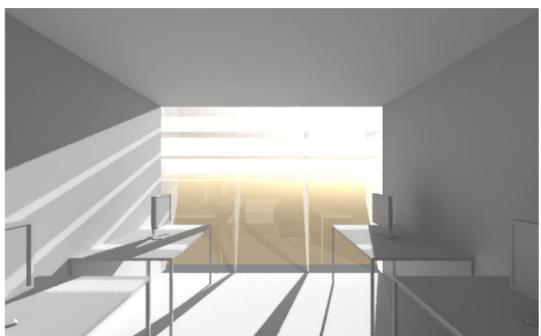


Fig 235 | Proposed system\_w\_interior view\_6/21\_vertical transl\_18:00.

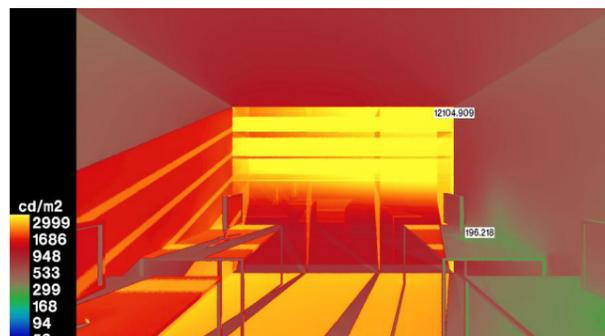


Fig 236 | Proposed system\_w\_interior view\_6/21\_vertical transl\_18:00.



**Warnings**

No warnings.

**Simulation Tips**

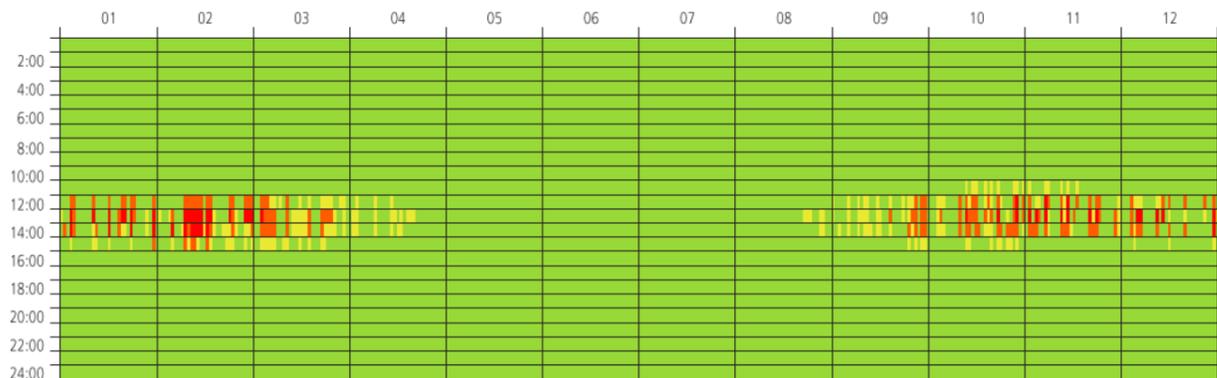
You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**  
Hourly values are shown for each view and shading state.

**Base Shading State**

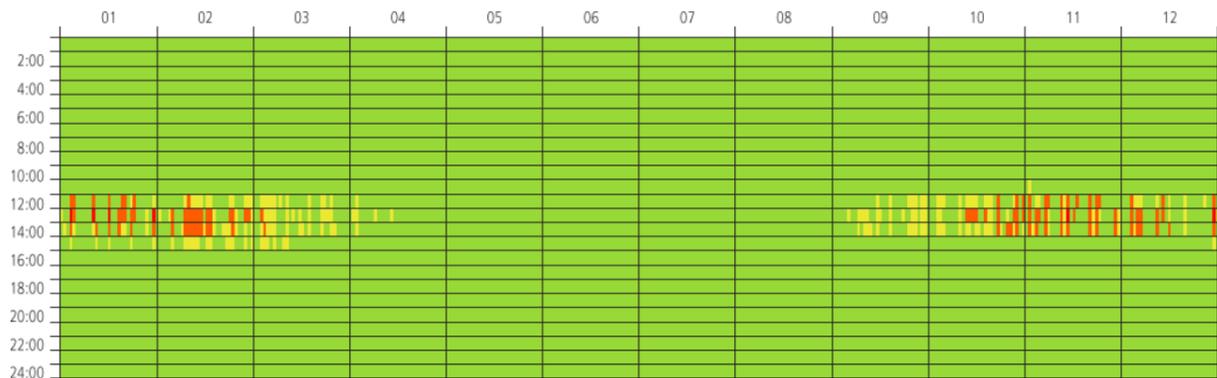
View Name Interior view



■ intolerable glare, DGP ≥ .45 ■ disturbing glare, .45 > DGP ≥ .4 ■ perceptible glare, .4 > DGP ≥ .35 ■ imperceptible glare, .35 > DGP  
DGP file: final\_south.dgp

**Shading Group 1; Status 1**

View Name Interior view



■ intolerable glare, DGP ≥ .45 ■ disturbing glare, .45 > DGP ≥ .4 ■ perceptible glare, .4 > DGP ≥ .35 ■ imperceptible glare, .35 > DGP  
DGP file: SG0BS0.dgp

Daysim header File: C:\DIVA\temp\final\_south\final\_south.he

**Warnings**

ShadingGroup 1 has no reference sensors.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\final\_south\final\_south\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	79% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	2.9% of occupied hours
Shading Group 1 open	86% of occupied hours

**Daylight Factor (DF) Analysis:** 70% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 66% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 79% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 79% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 33% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 69% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

- Lighting Group 1 (manual\_control): 209.4 kWh

**Simulation Assumptions**

**Site Description:**

The investigated building is located in AMSTERDAM\_NLD (52.30 N/ 4.77 W).

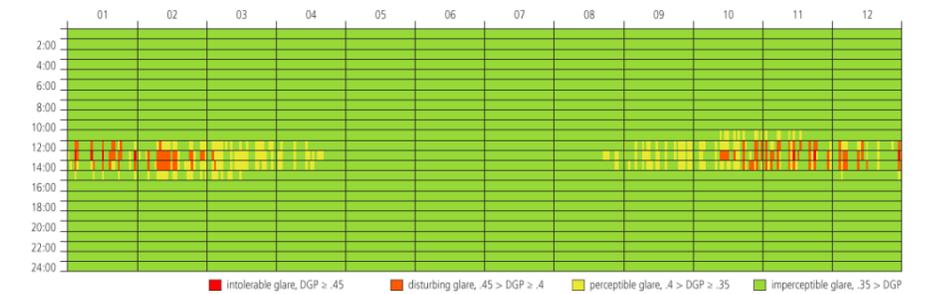
**User Description:**

The total annual hours of occupancy at the work place are 3650.



**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the **Lightswitch** model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



■ intolerable glare, DGP ≥ .45 ■ disturbing glare, .45 > DGP ≥ .4 ■ perceptible glare, .4 > DGP ≥ .35 ■ imperceptible glare, .35 > DGP



**Warnings**  
ShadingGroup 1 has no reference sensors.  
ShadingGroup 2 has no reference sensors.

**Simulation Tips**  
Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below  
C:\DIVA\temp\final\_south\final\_south\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	81% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	0.0% of occupied hours
Shading Group 1 open	48% of occupied hours
Shading Group 2 open	52% of occupied hours

**Daylight Factor (DF) Analysis:** 70% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 67% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 81% for active occupant behavior.

**Continuous Daylight Autonomy (CA) Analysis:** The mean continuous daylight autonomy is 80% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 42% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 63% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

- Lighting Group 1 (manual\_control): 212.7 kWh

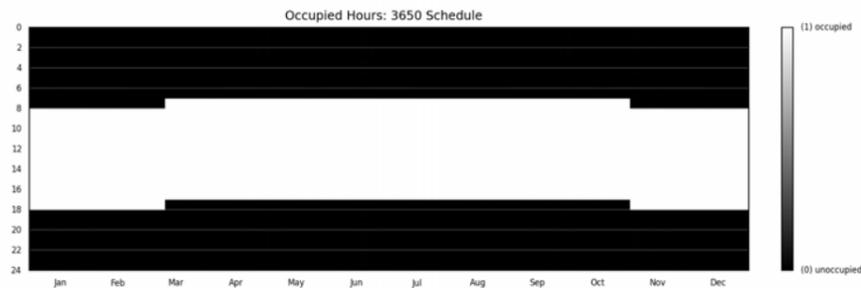
**Simulation Assumptions**

**Site Description:**

The investigated building is located in AMSTERDAM\_NLD (52.30 N/ 4.77 W).

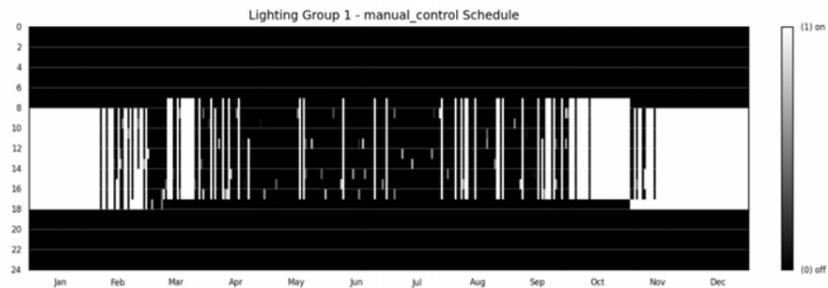
**User Description:**

The total annual hours of occupancy at the work place are 3650.



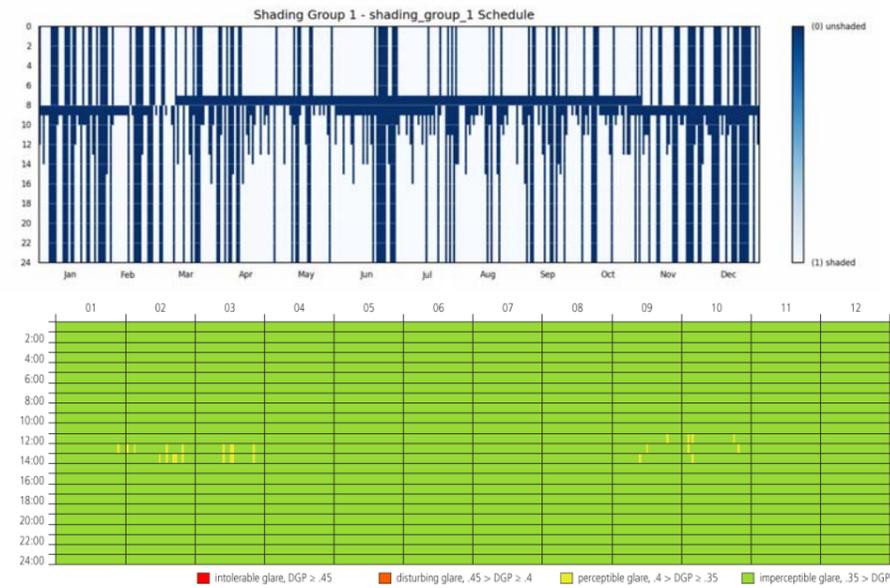
**Lighting Control:**

- Lighting Group 1 (manual\_control): The system has an installed electric lighting power of 120.0W. It is manually controlled with an on/off switch.

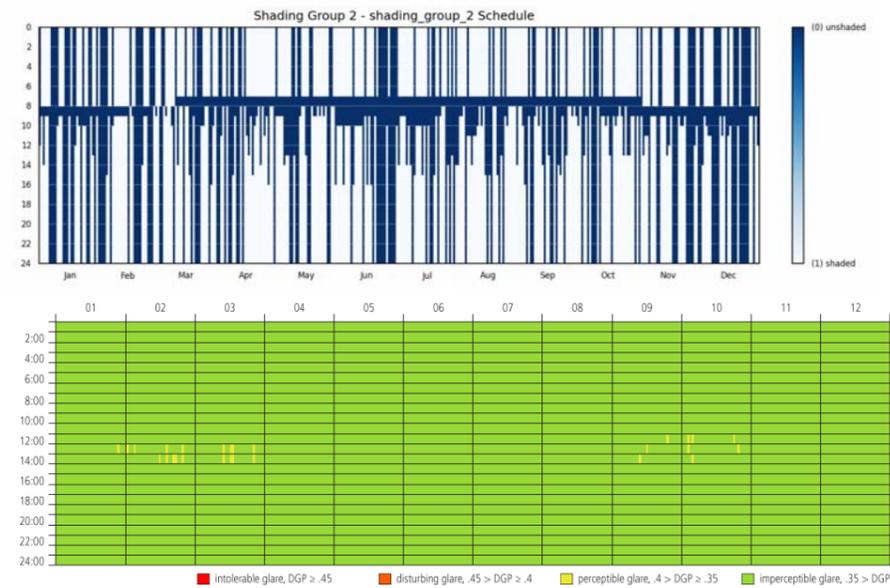


**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



- ShadingGroup 2: The system is manually controlled according to the Lightswitch\_model. **WARNING: Since Shading Group 2 has no reference sensors specified, all sensors are considered to be reference sensors.**



Daysim header File: C:\DIVA\temp\final\_south\final\_south.he



**Warnings**

No warnings.

**Simulation Tips**

You can use the annual glare simulations shown in this file to schedule blind use in Climate-Based (DAYSIM) and Thermal (EnergyPlus) simulations. Just run a Climate-Based simulation with dynamic shading, and the calculated glare will automatically be used as a control.

**Annual Glare Simulation (eDGPs) Report**

**Visual Comfort Without Occupant Adaptation**  
Hourly values are shown for each view and shading state.

**Base Shading State**

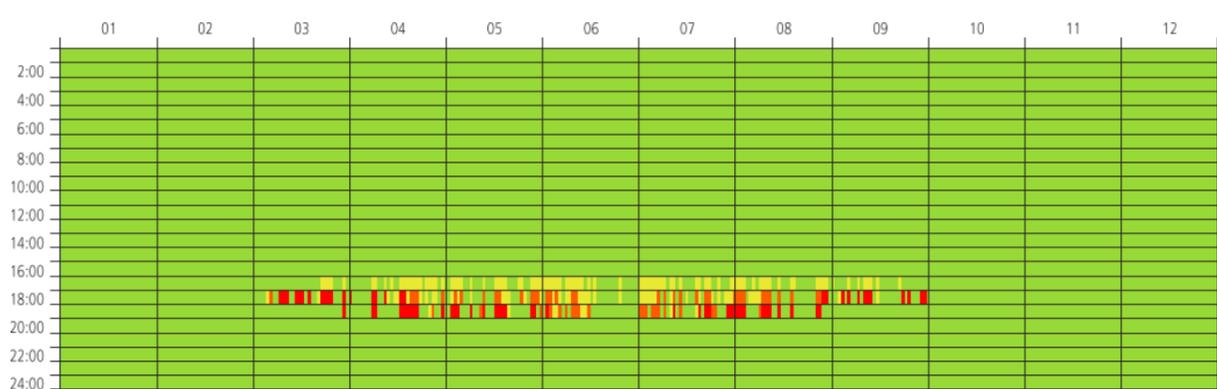
View Name Interior view



intolerable glare, DGP ≥ .45    disturbing glare, .45 > DGP ≥ .4    perceptible glare, .4 > DGP ≥ .35    imperceptible glare, .35 > DGP  
DGP file: final\_west\_holland.dgp

**Shading Group 1; Status 1**

View Name Interior view



intolerable glare, DGP ≥ .45    disturbing glare, .45 > DGP ≥ .4    perceptible glare, .4 > DGP ≥ .35    imperceptible glare, .35 > DGP  
DGP file: SG0BS0.dgp

Daysim header File: C:\DIVA\temp\final\_west\_holland\final\_west\_holland.he

**Warnings**

ShadingGroup 1 has no reference sensors.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below

C:\DIVA\temp\final\_south\final\_south\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	79% of floor area
Mean Daylight Factor	5.1%
Occupancy	3650 hours per year
Glare	2.9% of occupied hours
Shading Group 1 open	86% of occupied hours

**Daylight Factor (DF) Analysis:** 70% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 66% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 79% for active occupant behavior.

**Continuous Daylight Autonomy (DA) Analysis:** The mean continuous daylight autonomy is 79% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 33% for active occupant behavior.

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 69% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

- Lighting Group 1 (manual\_control): 209.4 kWh

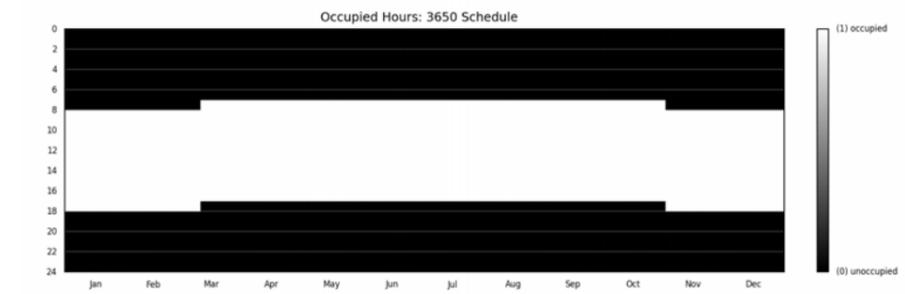
**Simulation Assumptions**

**Site Description:**

The investigated building is located in AMSTERDAM\_NLD (52.30 N/ 4.77 W).

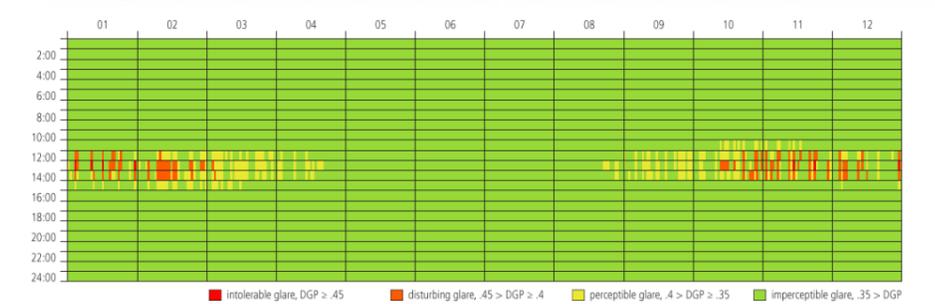
**User Description:**

The total annual hours of occupancy at the work place are 3650.



**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the **Lightswitch** model. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



intolerable glare, DGP ≥ .45    disturbing glare, .45 > DGP ≥ .4    perceptible glare, .4 > DGP ≥ .35    imperceptible glare, .35 > DGP



**Warnings**

ShadingGroup 1 has no reference sensors.  
ShadingGroup 2 has no reference sensors.

**Simulation Tips**

Daysim generates a schedule file, that can be linked to a thermal simulation program. To open file click the link below

C:\DIVA\temp\final\_west  
final\_west\_intgain.csv

**Daysim Simulation Report**

Daylit Area (DA <sub>500lux</sub> [50%])	67% of floor area
Mean Daylight Factor	5.7%
Occupancy	3650 hours per year
Glare	1.0% of occupied hours
Shading Group 1 open	76% of occupied hours
Shading Group 2 open	82% of occupied hours

**Daylight Factor (DF) Analysis:** 75% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

**Daylight Autonomy (DA) Analysis:** The mean daylight autonomy is 60% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 67% for active occupant behavior.

**Continuous Daylight Autonomy (CA) Analysis:** The mean continuous daylight autonomy is 78% for active occupant behavior. The percentage of sensors with a DA\_MAX > 5% is 32% for active occupant behavior

**Useful Daylight Illuminance (UDI):** The percentage of the space with a UDI<sub><100-2000lux</sub> larger than 50% is 80% for active occupant behavior.

**Electric Lighting Use:** The predicted annual electric lighting energy use is:

- Lighting Group 1 (manual\_control): 215.5 kWh

**Simulation Assumptions**

**Site Description:**

The investigated building is located in AMSTERDAM\_NLD (52.30 N/ 4.77 W).

**User Description:**

The total annual hours of occupancy at the work place are 3650.



**Lighting Control:**

- Lighting Group 1 (manual\_control): The system has an installed electric lighting power of 120.0W. It is manually controlled with an on/off switch.



**ShadingControl:**

- ShadingGroup 1: The system is manually controlled according to the `Lightswitch_model`. **WARNING: Since Shading Group 1 has no reference sensors specified, all sensors are considered to be reference sensors.**



- ShadingGroup 2: The system is manually controlled according to the `Lightswitch_model`. **WARNING: Since Shading Group 2 has no reference sensors specified, all sensors are considered to be reference sensors.**



Daysim header File: C:\DIVA\temp\final\_west\final\_west.hea

# B

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## APPENDIX

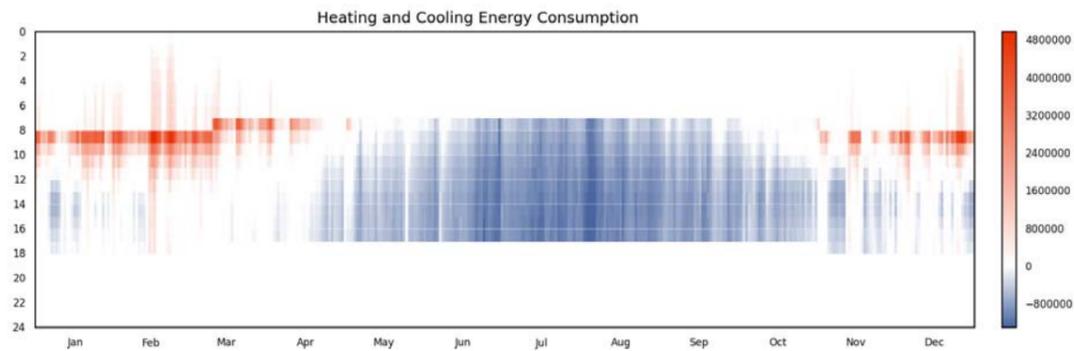
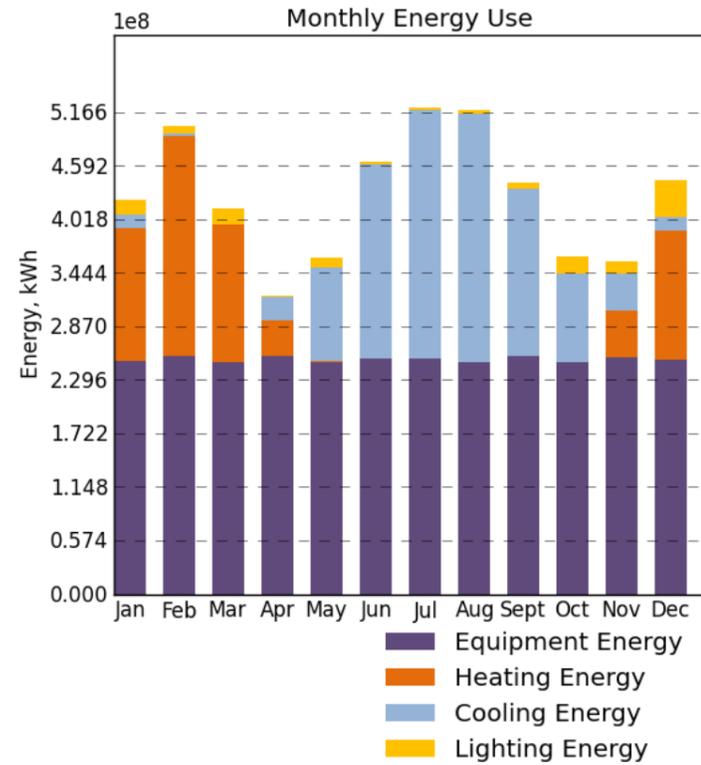


**Warnings**

A record of EnergyPlus warnings and errors is available in the errors output file located at, C:\Users\Stavros\Dropbox\kardoules pantou\Natalia PhD thesis\south\final\_south - DIVA\Thermal\final\_south\_2.err

**Simulation Tips**

**DIVA-Thermal (EnergyPlus) Simulation Report**



**Note: The energy values for HVAC systems in tables below are loads on the system, not actual energy expenditures.**

Program Version: **EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2016.06.08 12:39**

Tabular Output Report in Format: **HTML**

Building: **One Zone Office Model**

Environment: **ATHENS - GRC IWECC Data WMO#=167160**

Simulation Timestamp: **2016-06-08 12:39:16**

[Table of Contents](#)

**Table of Contents**

- [Top](#)
- [Input Verification and Results Summary](#)
- [Climatic Data Summary](#)

**ZoneCoolingSummaryMonthly**

| Environment |

**ZoneHeatingSummaryMonthly**

| Environment |

**SpaceGainsMonthly**

| DIVA PERIMETER\_ZONE |

**WindowReportMonthly**

| EP\_WINDOW\_0 |

[Table of Contents](#)

Report: **Input Verification and Results Summary**

For: **Entire Facility**

Timestamp: **2016-06-08 12:39:16**

**General**

	Value
Program Version and Build	EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2016.06.08 12:39
RunPeriod	ATHENS - GRC IWECC Data WMO#=167160
Weather File	ATHENS - GRC IWECC Data WMO#=167160
Latitude [deg]	37.90
Longitude [deg]	23.73
Elevation [m]	15.00
Time Zone	2.00
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

**ENVELOPE**

**Window-Wall Ratio**

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	10.64	0.00	0.00	10.64	0.00
Window Opening Area [m2]	6.83	0.00	0.00	6.83	0.00
Window-Wall Ratio [%]	64.17	0.00	0.00	64.17	0.00

**Conditioned Window-Wall Ratio**

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	10.64	0.00	0.00	10.64	0.00
Window Opening Area [m2]	6.83	0.00	0.00	6.83	0.00
Window-Wall Ratio [%]	64.17	0.00	0.00	64.17	0.00

**Skylight-Roof Ratio**

	Total
Gross Roof Area [m2]	0.00
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

**PERFORMANCE**

**Zone Summary**

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
DIVA PERIMETER_ZONE	20.90	Yes	Yes	58.52	1.00	10.64	6.83	5.7416	5.00	11.0000
Total	20.90			58.52		10.64	6.83	5.7416	5.00	11.0000
Conditioned Total	20.90			58.52		10.64	6.83	5.7416	5.00	11.0000
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

[Table of Contents](#)

Report: **Climatic Data Summary**

For: **Entire Facility**

Timestamp: **2016-06-08 12:39:16**

**SizingPeriod:DesignDay**

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
None						

**Weather Statistics File**

Proposed shading system-south  
no shading group

Proposed shading system-south  
no shading group

Value
None

Report: **ZoneCoolingSummaryMonthly** [Table of Contents](#)  
 For: **Environment**  
 Timestamp: **2016-06-08 12:39:16**

	ZONE/SYS SENSIBLE COOLING ENERGY [kWh]	ZONE/SYS SENSIBLE COOLING RATE {Maximum}[W]	ZONE/SYS SENSIBLE COOLING RATE {TIMESTAMP}	OUTDOOR DRY BULB {AT MAX/MIN} [C]	OUTDOOR WET BULB {AT MAX/MIN} [C]	ZONE TOTAL INTERNAL LATENT GAIN [kWh]	ZONE TOTAL INTERNAL LATENT GAIN RATE {Maximum}[W]	ZONE TOTAL INTERNAL LATENT GAIN RATE {TIMESTAMP}	OUTDOOR DRY BULB {AT MAX/MIN} [C]	OUTDOOR WET BULB {AT MAX/MIN} [C]
January	12.31	531.25	07-JAN-14:00	16.20	10.53	62.47	252.00	07-JAN-16:30	15.05	10.46
February	2.28	199.14	10-FEB-14:00	16.60	12.66	53.60	252.00	11-FEB-16:30	14.90	9.57
March	0.49	125.45	18-MAR-16:00	17.00	11.02	59.80	252.00	18-MAR-16:30	16.50	10.80
April	20.10	469.21	24-APR-15:00	24.30	16.48	65.76	252.00	29-APR-16:45	21.22	15.35
May	79.56	646.18	07-MAY-13:00	29.00	18.28	75.52	252.00	13-MAY-13:30	22.50	18.83
June	169.23	1038.69	24-JUN-16:00	33.60	20.50	75.33	334.21	30-JUN-07:15	30.20	16.14
July	223.33	1008.62	16-JUL-15:45	35.00	21.88	78.27	306.72	26-JUL-07:15	27.10	19.29
August	228.81	1087.97	06-AUG-14:00	37.20	19.91	78.28	336.14	05-AUG-07:15	30.12	18.56
September	144.76	849.39	18-SEP-14:00	33.60	18.21	75.19	261.55	13-SEP-07:15	24.38	18.52
October	83.68	747.05	09-OCT-14:00	26.40	20.18	74.98	252.00	17-OCT-15:30	23.00	14.56
November	32.11	655.05	08-NOV-13:30	22.10	18.06	65.66	252.00	09-NOV-15:30	20.00	14.87
December	13.30	600.42	31-DEC-14:00	16.80	12.85	62.78	252.00	30-DEC-13:00	16.40	12.04
Annual Sum or Average	1009.96					827.63				
Minimum of Months	0.49	125.45		16.20	10.53	53.60	252.00		14.90	9.57
Maximum of Months	228.81	1087.97		37.20	21.88	78.28	336.14		30.20	19.29

Report: **ZoneHeatingSummaryMonthly** [Table of Contents](#)  
 For: **Environment**  
 Timestamp: **2016-06-08 12:39:16**

	ZONE/SYS SENSIBLE HEATING ENERGY [kWh]	ZONE/SYS SENSIBLE HEATING RATE {Maximum}[W]	ZONE/SYS SENSIBLE HEATING RATE {TIMESTAMP}	OUTDOOR DRY BULB {AT MAX/MIN} [C]
January	36.57	1538.63	17-JAN-08:05	4.33
February	55.67	1621.47	22-FEB-08:05	4.15
March	37.47	1482.82	20-MAR-07:05	6.35
April	10.71	1440.79	02-APR-07:05	6.72
May	0.66	889.80	02-MAY-07:05	11.55
June	0.00	43.94	08-JUN-07:05	17.17
July	0.00	0.00	01-JUL-00:15	26.08
August	0.00	0.00	01-AUG-00:15	25.30
September	0.00	0.00	01-SEP-00:15	23.55
October	0.23	483.64	31-OCT-07:05	13.50
November	12.25	1386.53	15-NOV-08:05	9.65
December	34.90	1601.72	27-DEC-08:05	2.95
Annual Sum or Average	188.47			
Minimum of Months	0.00	0.00		2.95
Maximum of Months	55.67	1621.47		26.08

Report: **SpaceGainsMonthly** [Table of Contents](#)  
 For: **DIVA PERIMETER ZONE**  
 Timestamp: **2016-06-08 12:39:16**

	ZONE PEOPLE TOTAL HEAT GAIN [kWh]	ZONE LIGHTS TOTAL HEAT GAIN [kWh]	ZONE ELECTRIC EQUIPMENT TOTAL HEAT GAIN [kWh]	ZONE GAS EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE HOT WATER EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE STEAM EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE OTHER EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE INFILTRATION SENSIBLE HEAT GAIN [kWh]	ZONE INFILTRATION SENSIBLE HEAT LOSS [kWh]

January	155.50	4.53	71.27	0.00	0.00	0.00	0.00	0.00	47.44
February	140.45	2.32	64.37	0.00	0.00	0.00	0.00	0.00	44.54
March	155.50	3.41	71.27	0.00	0.00	0.00	0.00	0.00	42.84
April	150.48	1.73	68.97	0.00	0.00	0.00	0.00	0.00	33.88
May	155.50	2.82	71.27	0.00	0.00	0.00	0.00	0.09	23.54
June	150.48	0.63	68.97	0.00	0.00	0.00	0.00	3.33	11.06
July	155.50	0.87	71.27	0.00	0.00	0.00	0.00	5.77	5.59
August	155.50	1.18	71.27	0.00	0.00	0.00	0.00	7.18	5.51
September	150.48	1.73	68.97	0.00	0.00	0.00	0.00	1.62	11.17
October	155.50	4.96	71.27	0.00	0.00	0.00	0.00	0.03	24.45
November	150.48	3.75	68.97	0.00	0.00	0.00	0.00	0.00	34.95
December	155.50	11.06	71.27	0.00	0.00	0.00	0.00	0.00	47.35
Annual Sum or Average	1830.84	38.99	839.13	0.00	0.00	0.00	0.00	18.02	332.32
Minimum of Months	140.45	0.63	64.37	0.00	0.00	0.00	0.00	0.00	5.51
Maximum of Months	155.50	11.06	71.27	0.00	0.00	0.00	0.00	7.18	47.44

Report: **WindowReportMonthly** [Table of Contents](#)  
 For: **EP\_WINDOW 0**  
 Timestamp: **2016-06-08 12:39:16**

	WINDOW TRANSMITTED SOLAR [W]	WINDOW TRANSMITTED BEAM SOLAR [W]	WINDOW TRANSMITTED DIFFUSE SOLAR [W]	WINDOW HEAT GAIN [W]	WINDOW HEAT LOSS [W]	INSIDE GLASS CONDENSATION FLAG {HOURS NON-ZERO} [HOURS]	FRACTION OF TIME SHADING DEVICE IS ON {HOURS NON-ZERO} [HOURS]	STORM WINDOW ON/OFF FLAG {HOURS NON-ZERO} [HOURS]
January	106.73	57.11	49.63	71.85	117.81	0.00	0.00	744.00
February	83.29	30.12	53.16	42.45	125.45	0.00	0.00	672.00
March	61.55	5.02	56.53	16.38	101.14	0.00	0.00	744.00
April	67.51	0.70	66.81	28.39	78.11	0.00	0.00	720.00
May	78.99	2.31	76.68	50.49	56.59	0.00	0.00	744.00
June	86.30	4.17	82.13	87.05	34.56	0.00	0.00	720.00
July	83.28	4.25	79.04	98.16	21.68	0.00	0.00	744.00
August	74.64	1.57	73.07	95.81	22.14	0.00	0.00	744.00
September	63.88	0.49	63.39	60.86	37.64	0.00	0.00	720.00
October	83.51	25.96	57.55	65.08	68.69	0.00	0.00	744.00
November	89.24	40.66	48.59	66.35	100.70	0.00	0.00	720.00
December	106.25	58.59	47.66	73.50	121.45	0.00	0.00	744.00
Annual Sum or Average	82.15	19.24	62.91	63.23	73.53	0.00	0.00	8760.00
Minimum of Months	61.55	0.49	47.66	16.38	21.68	0.00	0.00	672.00
Maximum of Months	106.73	58.59	82.13	98.16	125.45	0.00	0.00	744.00

Simulation IDF File: C:\Users\Stavros\Dropbox\kardoules pantou!!!\Natalia PHD thesis\south\final\_south - DIVA\Thermal\final\_south\_2.idf

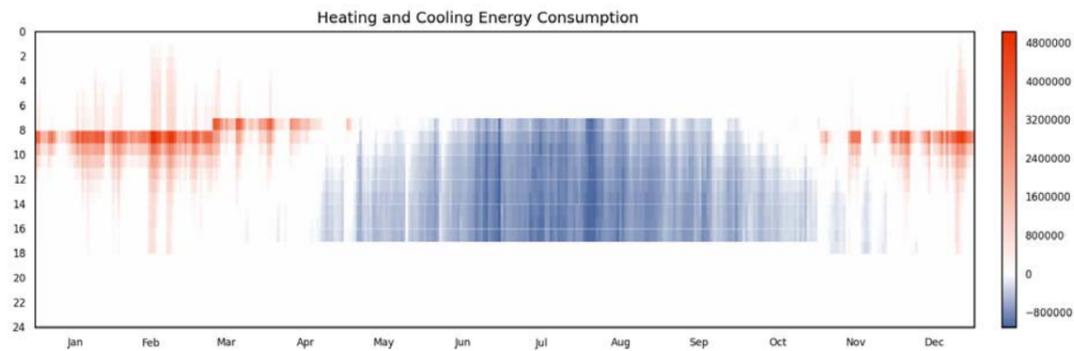
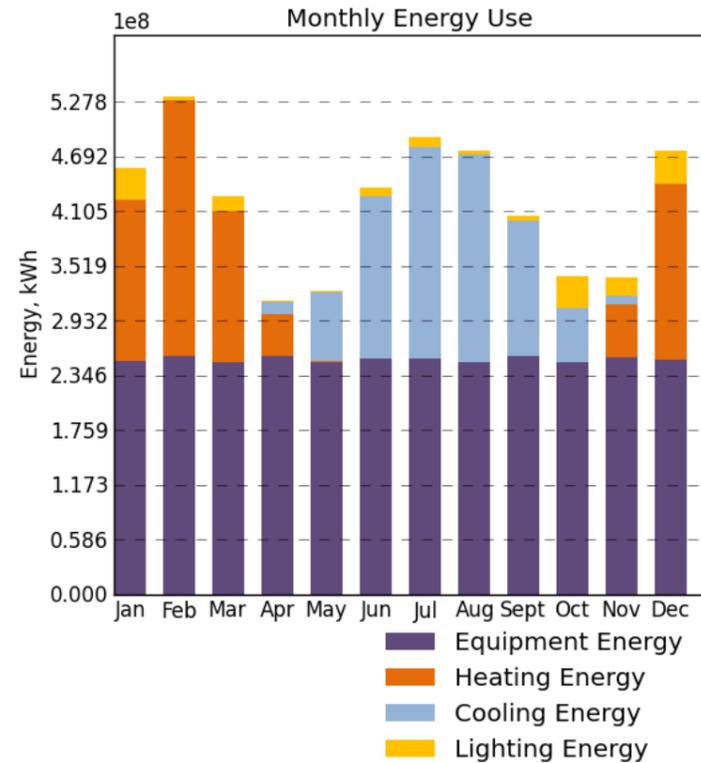


**Warnings**

A record of EnergyPlus warnings and errors is available in the errors output file located at:  
C:\Users\Stavros\Dropbox\kardoules pantou!!!\Natalia PhD thesis\south\final\_south - DIVA\Thermal\final\_south\_2.err

**Simulation Tips**

**DIVA-Thermal (EnergyPlus) Simulation Report**



**Note: The energy values for HVAC systems in tables below are loads on the system, not actual energy expenditures.**

Program Version: **EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2016.06.08 11:17**

[Table of Contents](#)

Tabular Output Report in Format: **HTML**

Building: **One Zone Office Model**

Environment: **ATHENS - GRC IWEC Data WMO#=167160**

Simulation Timestamp: **2016-06-08 11:17:22**

**Table of Contents**

- [Top](#)
- [Input Verification and Results Summary](#)
- [Climatic Data Summary](#)

**ZoneCoolingSummaryMonthly**

| [Environment](#) |

**ZoneHeatingSummaryMonthly**

| [Environment](#) |

**SpaceGainsMonthly**

| [DIVA PERIMETER\\_ZONE](#) |

**WindowReportMonthly**

| [EP\\_WINDOW\\_Q](#) |

Report: **Input Verification and Results Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2016-06-08 11:17:22**

**General**

	Value
Program Version and Build	EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2016.06.08 11:17
RunPeriod	ATHENS - GRC IWEC Data WMO#=167160
Weather File	ATHENS - GRC IWEC Data WMO#=167160
Latitude [deg]	37.90
Longitude [deg]	23.73
Elevation [m]	15.00
Time Zone	2.00
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

**ENVELOPE**

**Window-Wall Ratio**

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	10.64	0.00	0.00	10.64	0.00
Window Opening Area [m2]	6.83	0.00	0.00	6.83	0.00
Window-Wall Ratio [%]	64.17	0.00	0.00	64.17	0.00

**Conditioned Window-Wall Ratio**

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	10.64	0.00	0.00	10.64	0.00
Window Opening Area [m2]	6.83	0.00	0.00	6.83	0.00
Window-Wall Ratio [%]	64.17	0.00	0.00	64.17	0.00

**Skylight-Roof Ratio**

	Total
Gross Roof Area [m2]	0.00
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

**PERFORMANCE**

**Zone Summary**

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Gross Wall Area [m2]	Window Glass Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
DIVA PERIMETER_ZONE	20.90	Yes	Yes	58.52	1.00	10.64	6.83	5.7416	5.00	11.0000
Total	20.90			58.52		10.64	6.83	5.7416	5.00	11.0000
Conditioned Total	20.90			58.52		10.64	6.83	5.7416	5.00	11.0000
Unconditioned Total	0.00			0.00		0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00			

Report: **Climatic Data Summary**

[Table of Contents](#)

For: **Entire Facility**

Timestamp: **2016-06-08 11:17:22**

**SizingPeriod:DesignDay**

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
None						

**Weather Statistics File**

Proposed shading system-south  
1 shading group

Proposed shading system-south  
1 shading group

Value
None

Report: **ZoneCoolingSummaryMonthly** [Table of Contents](#)  
 For: **Environment**  
 Timestamp: **2016-06-08 11:17:22**

	ZONE/SYS SENSIBLE COOLING ENERGY [kWh]	ZONE/SYS SENSIBLE COOLING RATE {Maximum}[W]	ZONE/SYS SENSIBLE COOLING RATE {TIMESTAMP}	OUTDOOR DRY BULB {AT MAX/MIN} [C]	OUTDOOR WET BULB {AT MAX/MIN} [C]	ZONE TOTAL INTERNAL LATENT GAIN [kWh]	ZONE TOTAL INTERNAL LATENT GAIN RATE {Maximum}[W]	ZONE TOTAL INTERNAL LATENT GAIN RATE {TIMESTAMP}	OUTDOOR DRY BULB {AT MAX/MIN} [C]	OUTDOOR WET BULB {AT MAX/MIN} [C]
January	0.00	0.00	01-JAN-00:15	8.30	5.91	57.55	247.51	11-JAN-17:00	14.70	12.81
February	0.00	0.00	01-FEB-00:15	8.60	5.96	50.16	224.69	12-FEB-17:30	15.10	8.97
March	0.18	79.94	24-MAR-16:45	16.70	13.90	57.66	252.00	24-MAR-16:00	16.60	14.03
April	10.67	323.23	24-APR-16:00	23.70	15.84	63.72	252.00	30-APR-16:45	23.07	14.33
May	58.21	511.61	07-MAY-13:00	29.00	18.28	75.03	252.00	30-MAY-14:30	25.00	17.87
June	141.27	953.36	30-JUN-07:05	30.20	16.14	75.26	319.35	30-JUN-07:15	30.20	16.14
July	190.95	850.45	16-JUL-16:00	35.00	22.00	78.20	296.13	26-JUL-07:15	27.10	19.29
August	191.23	970.05	05-AUG-07:05	30.12	18.56	78.22	323.61	05-AUG-07:15	30.12	18.56
September	116.44	707.05	18-SEP-14:00	33.60	18.21	75.16	257.19	13-SEP-07:15	24.38	18.52
October	52.04	488.07	01-OCT-15:00	27.00	19.17	74.89	252.00	02-OCT-14:15	25.75	17.73
November	7.96	233.78	08-NOV-17:00	20.20	15.97	63.29	252.00	07-NOV-17:30	18.10	15.66
December	0.12	81.64	09-DEC-17:15	18.35	15.77	57.53	252.00	09-DEC-17:00	17.00	14.52
Annual Sum or Average	769.07					806.68				
Minimum of Months	0.00	0.00		8.30	5.91	50.16	224.69		14.70	8.97
Maximum of Months	191.23	970.05		35.00	22.00	78.22	323.61		30.20	19.29

Report: **ZoneHeatingSummaryMonthly** [Table of Contents](#)  
 For: **Environment**  
 Timestamp: **2016-06-08 11:17:22**

	ZONE/SYS SENSIBLE HEATING ENERGY [kWh]	ZONE/SYS SENSIBLE HEATING RATE {Maximum}[W]	ZONE/SYS SENSIBLE HEATING RATE {TIMESTAMP}	OUTDOOR DRY BULB {AT MAX/MIN} [C]
January	44.30	1494.09	17-JAN-08:05	4.33
February	64.92	1604.16	16-FEB-08:05	4.60
March	40.98	1468.37	03-MAR-08:05	5.55
April	12.82	1411.58	02-APR-07:05	6.72
May	0.77	921.39	02-MAY-07:05	11.55
June	0.00	46.01	08-JUN-07:05	17.17
July	0.00	0.00	01-JUL-00:15	26.08
August	0.00	0.00	01-AUG-00:15	25.30
September	0.00	0.00	01-SEP-00:15	23.55
October	0.18	342.41	23-OCT-07:05	14.15
November	13.30	1400.11	30-NOV-08:05	9.40
December	48.02	1588.25	27-DEC-08:05	2.95
Annual Sum or Average	225.30			
Minimum of Months	0.00	0.00		2.95
Maximum of Months	64.92	1604.16		26.08

Report: **SpaceGainsMonthly** [Table of Contents](#)  
 For: **DIVA PERIMETER ZONE**  
 Timestamp: **2016-06-08 11:17:22**

	ZONE PEOPLE TOTAL HEAT GAIN [kWh]	ZONE LIGHTS TOTAL HEAT GAIN [kWh]	ZONE ELECTRIC EQUIPMENT TOTAL HEAT GAIN [kWh]	ZONE GAS EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE HOT WATER EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE STEAM EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE OTHER EQUIPMENT TOTAL HEAT GAIN [Invalid/Undefined]	ZONE INFILTRATION SENSIBLE HEAT GAIN [kWh]	ZONE INFILTRATION SENSIBLE HEAT LOSS [kWh]

January	155.50	9.37	71.27	0.00	0.00	0.00	0.00	0.00	43.84
February	140.45	1.05	64.37	0.00	0.00	0.00	0.00	0.00	42.00
March	155.50	4.62	71.27	0.00	0.00	0.00	0.00	0.00	41.34
April	150.48	0.67	68.97	0.00	0.00	0.00	0.00	0.00	32.18
May	155.50	0.38	71.27	0.00	0.00	0.00	0.00	0.09	22.55
June	150.48	2.33	68.97	0.00	0.00	0.00	0.00	3.46	10.11
July	155.50	2.74	71.27	0.00	0.00	0.00	0.00	6.05	4.60
August	155.50	1.27	71.27	0.00	0.00	0.00	0.00	7.43	4.61
September	150.48	1.80	68.97	0.00	0.00	0.00	0.00	1.67	10.56
October	155.50	9.52	71.27	0.00	0.00	0.00	0.00	0.03	23.94
November	150.48	5.41	68.97	0.00	0.00	0.00	0.00	0.00	33.41
December	155.50	9.80	71.27	0.00	0.00	0.00	0.00	0.00	43.60
Annual Sum or Average	1830.84	48.96	839.13	0.00	0.00	0.00	0.00	18.72	312.75
Minimum of Months	140.45	0.38	64.37	0.00	0.00	0.00	0.00	0.00	4.60
Maximum of Months	155.50	9.80	71.27	0.00	0.00	0.00	0.00	7.43	43.84

Report: **WindowReportMonthly** [Table of Contents](#)  
 For: **EP\_WINDOW 0**  
 Timestamp: **2016-06-08 11:17:22**

	WINDOW TRANSMITTED SOLAR [W]	WINDOW TRANSMITTED BEAM SOLAR [W]	WINDOW TRANSMITTED DIFFUSE SOLAR [W]	WINDOW HEAT GAIN [W]	WINDOW HEAT LOSS [W]	INSIDE GLASS CONDENSATION FLAG {HOURS NON-ZERO} [HOURS]	FRACTION OF TIME SHADING DEVICE IS ON {HOURS NON-ZERO} [HOURS]	STORM WINDOW ON/OFF FLAG {HOURS NON-ZERO} [HOURS]
January	17.13	4.11	13.02	2.06	104.35	0.00	526.00	744.00
February	17.03	2.34	14.70	1.34	117.80	0.00	473.00	672.00
March	15.07	0.51	14.56	1.06	102.24	0.00	585.00	744.00
April	15.07	0.24	14.83	2.83	77.56	0.00	592.00	720.00
May	28.78	0.71	28.07	15.83	52.16	0.00	536.00	744.00
June	26.39	1.20	25.19	33.65	26.86	0.00	608.00	720.00
July	23.01	1.23	21.78	40.43	15.06	0.00	655.00	744.00
August	12.26	0.45	11.81	33.33	14.83	0.00	696.00	744.00
September	6.51	0.16	6.35	10.76	29.44	0.00	700.00	720.00
October	10.96	1.65	9.30	5.02	59.21	0.00	644.00	744.00
November	15.51	3.11	12.40	5.36	89.04	0.00	528.00	720.00
December	14.38	3.77	10.61	1.76	108.01	0.00	534.00	744.00
Annual Sum or Average	16.85	1.62	15.23	12.87	66.07	0.00	7077.00	8760.00
Minimum of Months	6.51	0.16	6.35	1.06	14.83	0.00	473.00	672.00
Maximum of Months	28.78	4.11	28.07	40.43	117.80	0.00	700.00	744.00

Simulation IDF File: C:\Users\Stavros\Dropbox\kardoules pantou!!!\Natalia PHD thesis\south\final\_south - DIVA\Thermal\final\_south\_2.idf

# C

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## APPENDIX

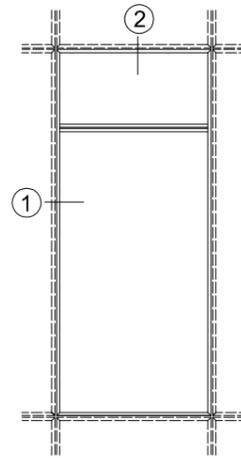
	Items	Quantity	Units	Price (€)/unit	Price (€)	Price per façade surface (€ /m <sup>2</sup> )
1	Glass sheets - PDLC film	19.82	m <sup>2</sup>	500 - 750 <sup>[1]</sup>	9,910 - 14,865	
	Aluminum cap rails	77	m	8.9 <sup>[2]</sup>	685	
	T profile steel	55.62	Kg	1.5 - 2.5	83.48 - 139.13	
	Cables	35	m	13 <sup>[3]</sup>	455	
	<b>Total system cost</b>				<b>11,133.48 - 16,144.13</b>	<b>533 - 772 €/m<sup>2</sup></b>
2	Acrylic sheets PDLC film	19.82	m <sup>2</sup>	300 <sup>[4]</sup> 150 - 300 <sup>[5]</sup>	8,900 - 11,900	
	Aluminum cap rails	77	m	8.9 <sup>[2]</sup>	685	
	T profile steel	55.62	Kg	1.5 - 2.5	83.48 - 139.13	
	Cables	35	m	13	455	
					<b>11,110.48 - 14,166.13</b>	<b>531 - 678 €/m<sup>2</sup></b>
3	Hor.   glass sheets - PDLC Vert.   Satin float glass sheets	12.96 6.86	m <sup>2</sup>	500 - 750 <sup>[1]</sup> 300 - 500	8,538 - 13,150	
	Aluminum cap rails	52	m	8.9 <sup>[2]</sup>	462	
	T profile steel	55.62	kg	1.5 - 2.5	83.48 - 139.13	
	Cables	35	m	13	455	
	<b>Total system cost</b>				<b>10,163.28 - 14,420.93</b>	<b>486 - 690 €/m<sup>2</sup></b>
4	Satin float glass sheets	19.82	m <sup>2</sup>	300 - 500	5,946 - 9,910	
	T profile steel	55.62	Kg	1.5 - 2.5	83.48 - 139.13	
	Cables	35	M	13	455	
	<b>Total</b>				<b>6,484.48 - 10,504.13</b>	<b>310 - 503 €/m<sup>2</sup></b>

- [1] Dream Glass, Madrid, Spain  
[2] S3i GROUP, Haworth, England  
[3] East African Cables  
[4] TAP Plastics

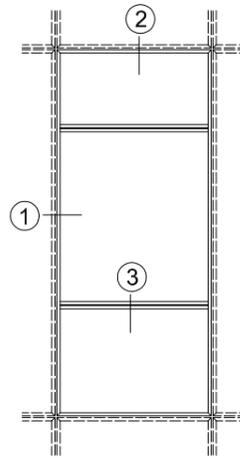
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## APPENDIX

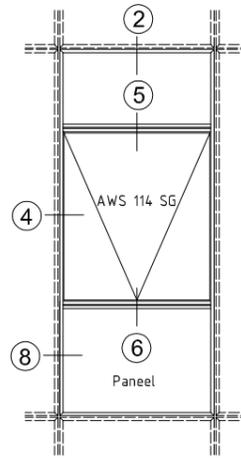
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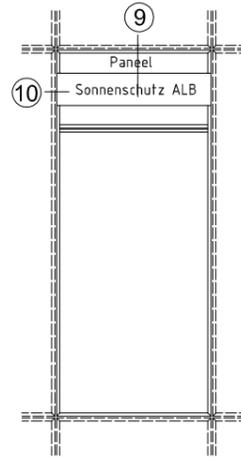
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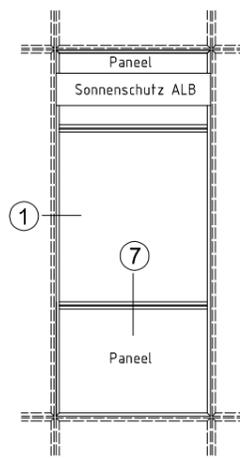
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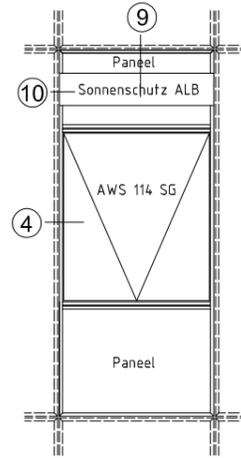
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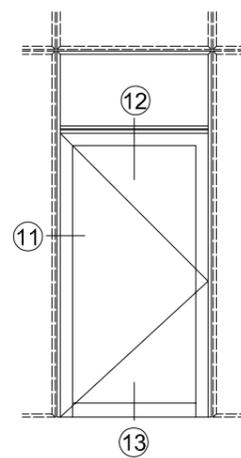
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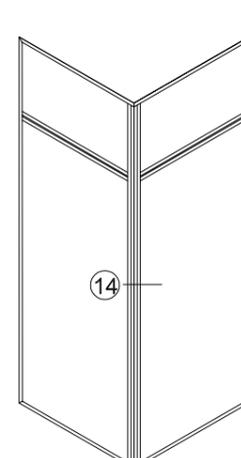
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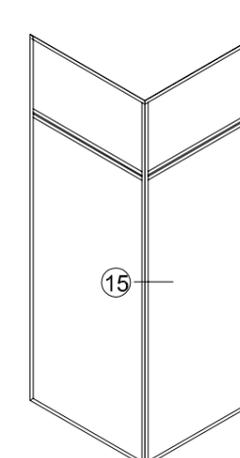
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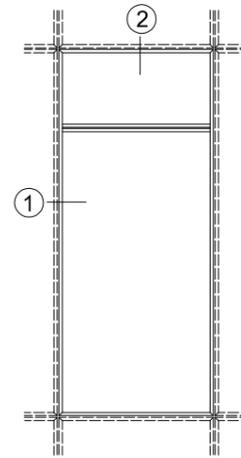
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90° corner



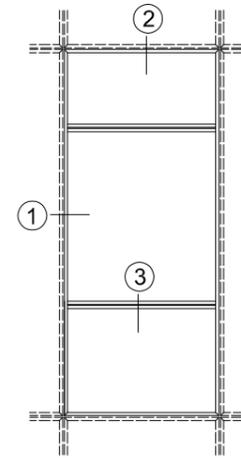
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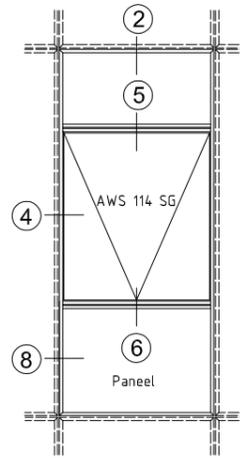
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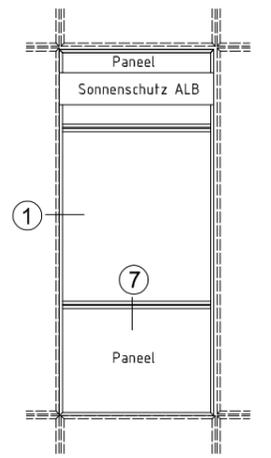
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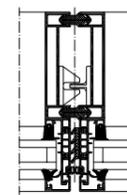
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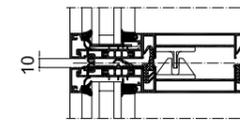
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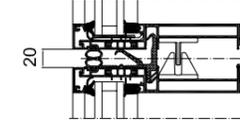
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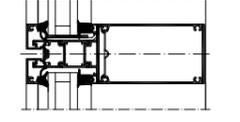
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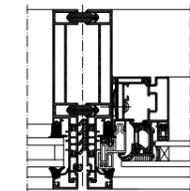
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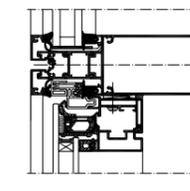
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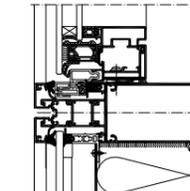
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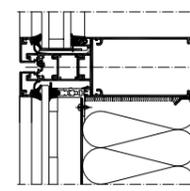
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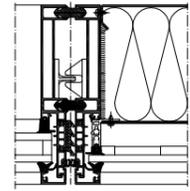
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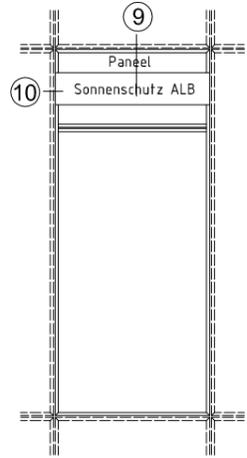


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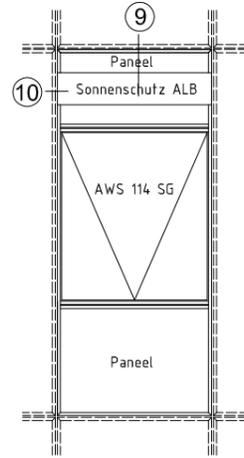


Sonnenschutz  
solar shading

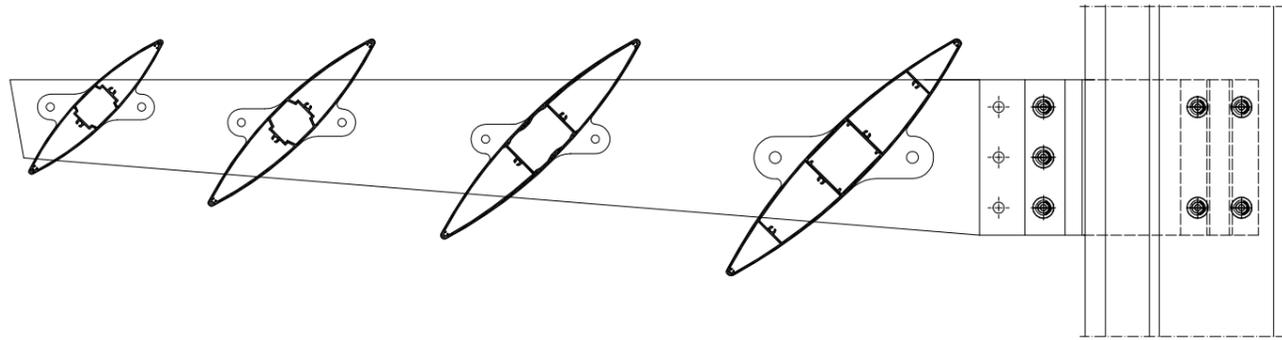
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standard unit with ALB



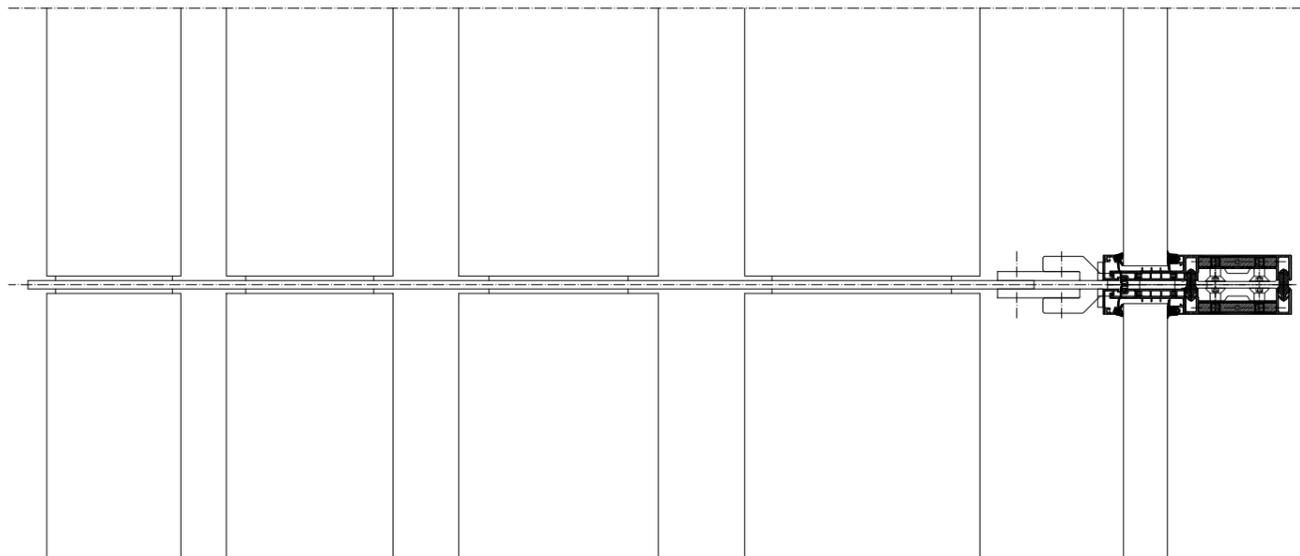
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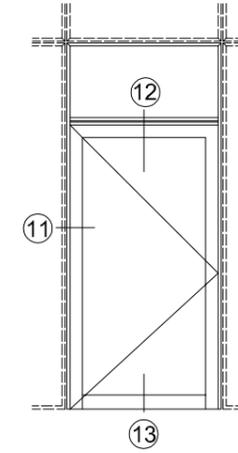


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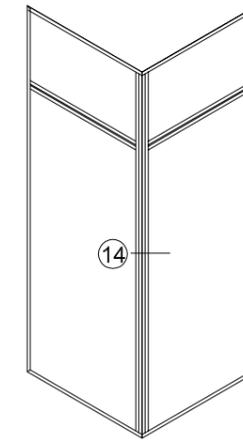


Tür / 90 ° Ecke  
door / 90 ° corner

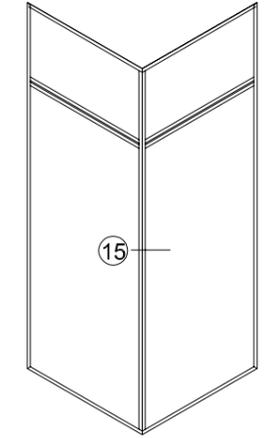
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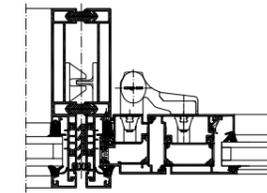
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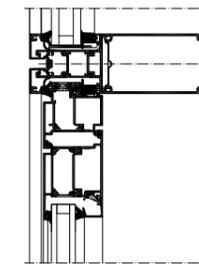
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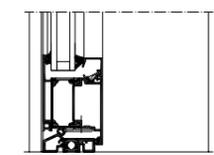
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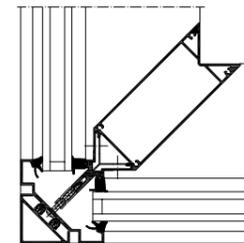
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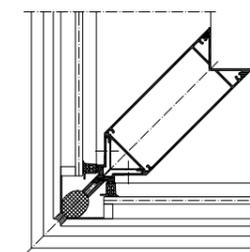
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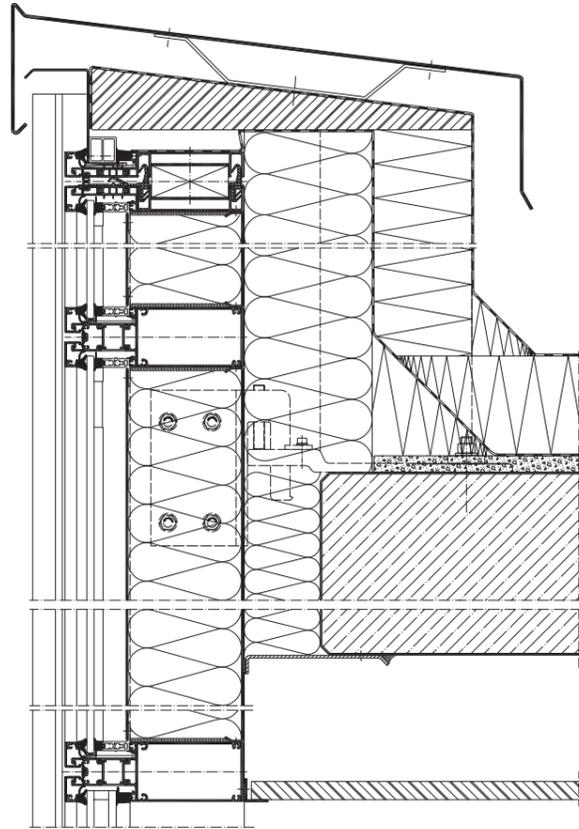


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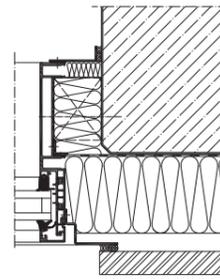


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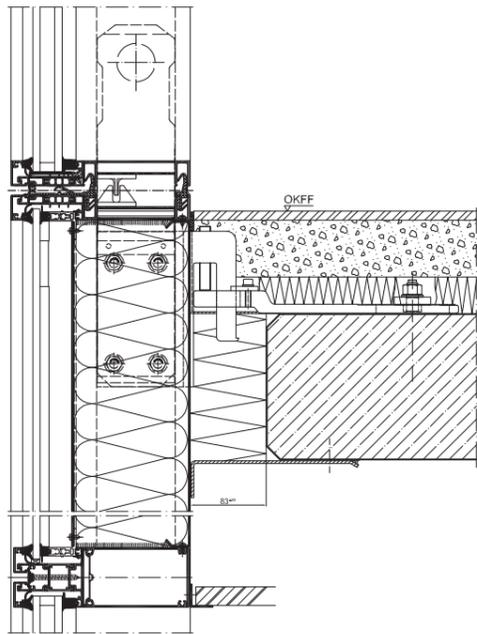




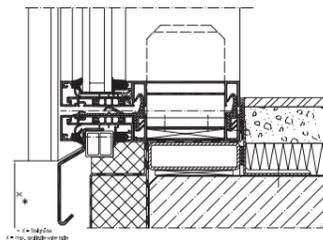
Oberer Anschluss  
Top attachment



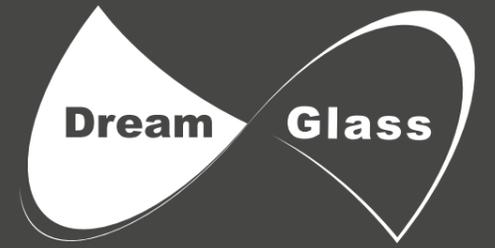
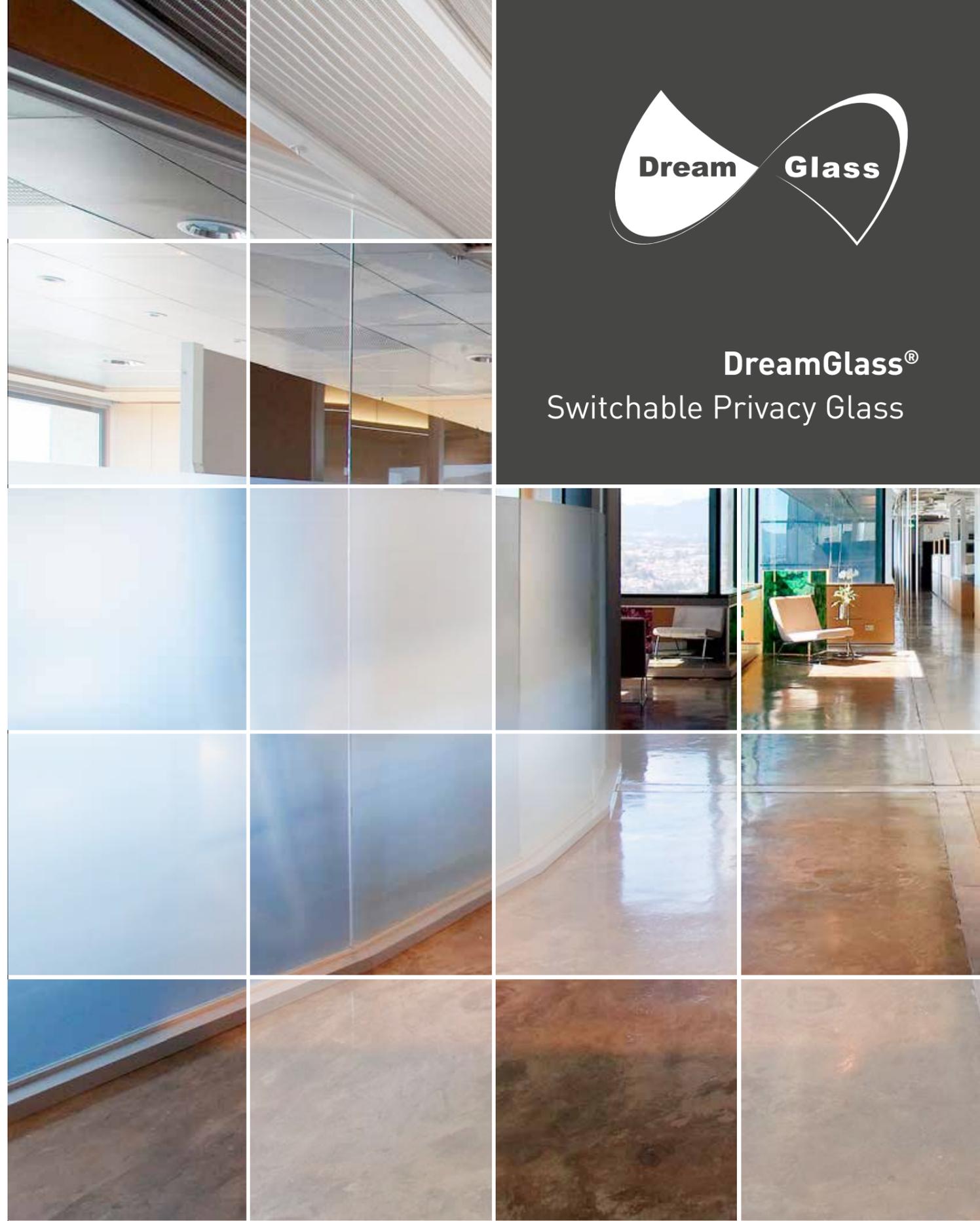
Seitlicher Anschluss  
Side wall attachment



Anschluss Geschossdecke  
attachment intermediate floor



Unterer Anschluss  
Sill attachment



DreamGlass®  
Switchable Privacy Glass

PRODUCT CATALOGUE

[www.dreamglassgroup.com](http://www.dreamglassgroup.com)

# Privacy is yours with the flick of a switch

GOING FROM CLEAR GLASS TO OPAQUE IS AS EASY AS TURNING ON A LIGHT.

An essential contemporary design element, glass separates interior spaces without blocking natural light or obstructing your view. There are trade-offs, however: conventional glass sacrifices privacy or requires the integration of additional design elements - such as blinds, curtains and roller shades - which detract from its otherwise pristine aesthetic.

**DreamGlass®** radically changes the privacy landscape of interior design. This glass features an "inbuilt privacy system" which can be instantly activated or turned off with the simple flick of a switch.



- DUAL USAGE**  
Privacy or transparency? The power to choose is yours.
- INSTANT PRIVACY**  
Effortlessly achieve privacy in mere milliseconds.
- EASY TO CLEAN**  
While curtains and blinds collect dirt and dust, DreamGlass® requires only the occasional wipe down.
- NO MOVING PARTS**  
Unlike other privacy systems, durable DreamGlass® has no pulleys, strings, chains or get stuck.
- CONVENIENCE**  
Flashes deliver every time and a 5-year guarantee. What's more convenient than that?
- MAINTENANCE? WHAT MAINTENANCE?**  
No moving parts means maintenance-free enjoyment.

**WHY CHOOSE DREAMGLASS® OVER OTHER PRIVACY SOLUTIONS?**

Why invest time and money into buying or fixing traditional privacy systems when **DreamGlass®** offers superior innovation, reliability and cost efficiency?

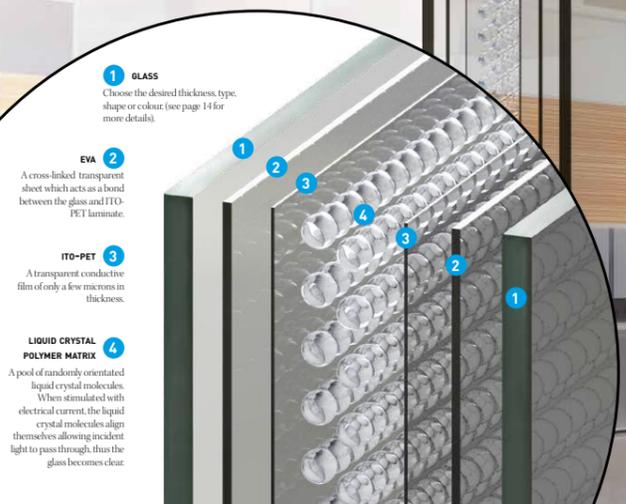
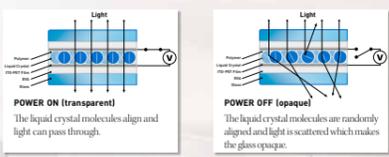
While mechanical methods are destined to fail, **DreamGlass®** delivers a sophisticated and timeless modern design solution.

**DREAMGLASS® OFFERS UNPARALLELED AMBIENCE AND FUNCTIONALITY**

# Real glass, real privacy

ENJOY ALL OF THE ADVANTAGES OF REAL GLASS WITH A NEXT GENERATION, BUILT-IN PRIVACY SYSTEM.

**DreamGlass®** puts privacy at your fingertips through the power of electricity. Switch the current off and the glass turns opaque. Reactivate the current and the glass reverts to a clear, transparent view. This ingenious technology involves a film of dispersed liquid crystal in a polymer matrix pressed between two glass sheets. When a small current is applied to the liquid crystal, its molecules align allowing light to pass through. When the current is disconnected, the molecules immediately disarrange for instantaneous and total privacy.



## CONTROL YOUR DREAMGLASS® IN MULTIPLE WAYS

- MOTION SENSOR**  
Combine with motion sensors to alter privacy depending on the detection of a physical presence.
- SMART PHONE AND COMPUTER**  
Control remotely via smartphone app, laptop or any computer system.
- DIMMER**  
Programmatically adjust to your desired level of privacy from transparent to opaque through dimmer controls.
- DOMOTICS**  
Integrate with home automation systems.
- REMOTE CONTROL**  
Remotely control glass panels via remote controls.

# What's your desired level of privacy?

- **JUST A BIT?**  
utilize dimmable transparency/opacity
- **TOTAL?**  
enjoy privacy at its best
- **PARTIAL?**  
selectively block a chosen area
- **FORM?**  
merge style and substance with stripes and other decorative techniques
- **CORPORATE BRANDING?**  
embed your company logo or slogan
- **FUNCTION?**  
create privacy partitions and foster natural light flow



## OUR CUTTING EDGE MANUFACTURING PROCESS DELIVERS BESPOKE DESIGNS AND SOLUTIONS.

State-of-the-art technology allows our production team to accommodate the comprehensive range of design needs. And each and every **DreamGlass®** is customized for the perfect fit.

Moveable glass doors, curved partitions, tinted, fire rated and even bullet proof glass can all be manufactured with **DreamGlass®**.

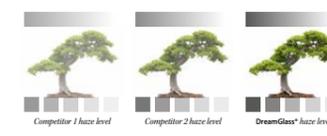
But that's not all. The inner switchable film can differ in size and shape from the glass surface. Want to integrate your company logo or other custom design? These creative visual effects and more are possible with **DreamGlass®**.



**TINTED AND BULLET PROOF?**  
Switchable, tinted glass that's also bullet proof? Not a problem with DreamGlass®. Want it curved or cut to custom shapes? If you can imagine it we can do it. Anything is possible with DreamGlass®.

## TRUE TRANSPARENCY

UP TO 30-50% LESS HAZE THAN COMPETITORS! NOW WE'RE TALKING.  
Most switchable glass manufacturers offer high privacy and low transparency or low privacy and high transparency. **DreamGlass®** uses the two extremes to deliver high privacy levels when OFF and high transparency levels when ON.



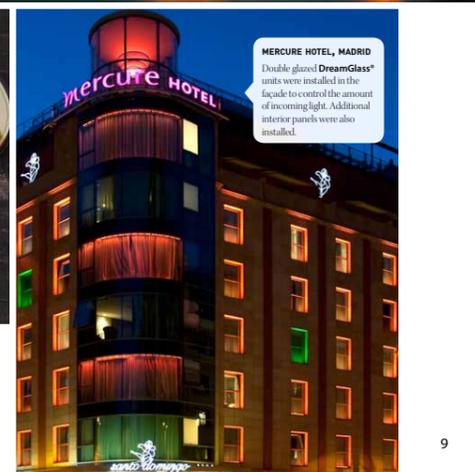
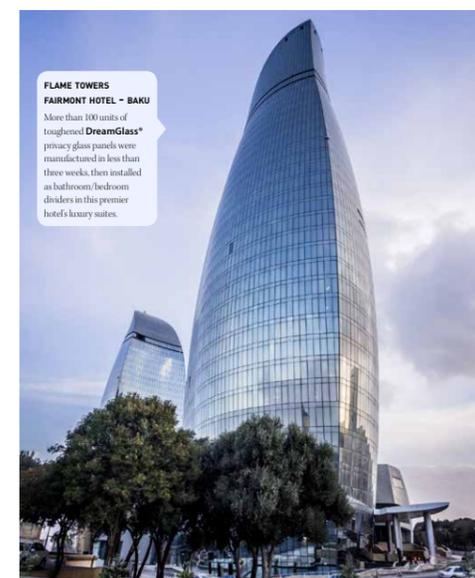
**UNPARALLELED PRECISION CUTTING**  
**Dream Glass Group** is a leader in the area of privacy film cutting (PDLIC Film). We've done away with conventional cutting techniques and pioneered innovative new ways to deliver precision cut shapes, holes and edges. The result? A perfect, clean edge at every level of cutting pattern complexity.

# International Outreach

## DREAMGLASS® FOR THE WORLD

An exceptional product and commitment to consummate service allows us to deliver premier solutions for the world's most complex design challenges. But our promise to you doesn't end there. We offer a fast turnaround time in any region of the whole world while ensuring on-time and on-budget international delivery.

At the heart of the **DreamGlass®** ethos is a core commitment to research and development, customer service and exceptional design consultancy. Ten years of scientific study dedicated to the PDLIC Field has prepared us to accept even the most sophisticated projects.



- NESPRESSO · VOLKSWAGEN · ROCA · CBRE · QATAR FOUNDATION · LA CAIXA · ALLIANZ  
ROLLS ROYCE · DUBAI BANK · FAIRMONT · W HOTELS · MOVEMPICK HOTELS · PARADORES

# DreamGlass®: business and hospitality industry applications

DREAMGLASS® REVOLUTIONIZES TRADITIONAL INTERIOR ARCHITECTURE.

DreamGlass® delivers a whole new world of efficiency and ambiance for offices and hotel rooms. Replace traditional walls with spaciousness, open views for the essence of comfort and wellbeing. DreamGlass® welcomes natural sunlight into every hotel bathroom and interior office area with no compromise of privacy.

The dual functionality of transparency and privacy seamlessly integrates with contemporary open plan designs for a visionary new solution to traditional design and architecture challenges.



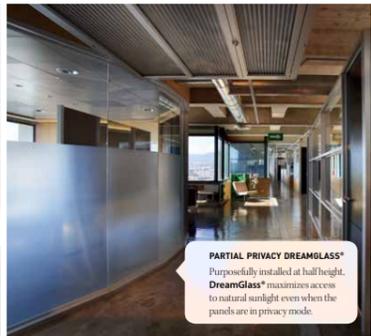
**BOARD CONFERENCE ROOM**  
DreamGlass® panels, which can be dimmed for optimal privacy, separate this conference room from the presidential office suite.



**BATHROOM-BEDROOM PARTITION**  
The entire bathroom wall of this hotel room has been replaced with DreamGlass® panels for an intriguing blend of privacy and transparency.



**PARTITION SCREEN**  
A large partition screen delivers privacy and separation while maintaining the open plan architecture of this office area.



**PARTIAL PRIVACY DREAMGLASS®**  
Purposely installed at half height, DreamGlass® maximizes access to natural sunlight even when the panels are in privacy mode.



**FRAMELESS MEETING ROOMS**  
The large frameless glass fronts of the meeting room and adjacent office creates options for openness and privacy while highlighting the spaces chic interior design.

## ENDLESS APPLICATION POSSIBILITIES



# Technical specifications

QUALITY WITHOUT COMPROMISE.

DreamGlass® can be engineered to meet your specific needs through any imaginable configuration, ranging from low-iron glass to colour tinted, curved, double glazed, fire rated, bullet proof and shaped glass.

Its superior quality, accompanied by unrivalled customer service with the industry's shortest lead times, make the DreamGlass® name synonymous for quality without compromise.



**IN-HOUSE R&D DEPARTMENT**  
Our own talented R&D department is constantly working to enhance our available glass product line while assessing the market and customer needs. Furthermore, our available glass is tested under the most adverse climatic conditions in our high-tech laboratory for guaranteed performance in any setting.

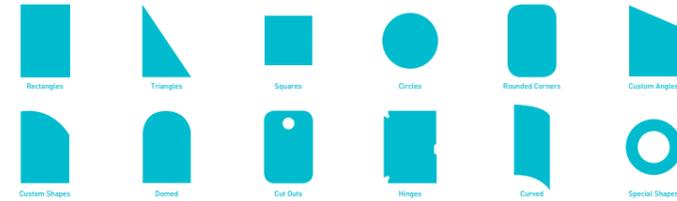


**QUALITY TESTING**  
We go to great lengths to ensure the highest quality for our DreamGlass® products. This means investing heavily in sophisticated equipment and rigorous methods, such as weathering and UV degradation, to allow for testing under the most demanding and extreme scenarios.

TECHNICAL DATA		
Environment	Storage	-20° C to 50° C
	Operation	-10° C to 50° C
Electrical Properties	Operating Voltage	70 - 80V AC
	Operating Frequency	50 - 60 Hz
	Power Consumption	< 8 W/m²
	Switching Time	< 0.1 seconds
Optical Properties	Total Transmittance OFF state	60% ±3%
	Direct Transmittance OFF state	0.3%
	Total Transmittance ON state	> 77%
	Haze ON state	< 8%

The above figures are recommended for guide purposes only. DGG reserves the right to amend information without prior notice.

DREAMGLASS® CAN BE MANUFACTURED AND CUT TO MOST SIZES AND SHAPES



ASSURING QUALITY, FUNCTIONALITY AND SAFETY



## THE DETAILS THAT MAKE DREAMGLASS® THE UNRIVALLED MARKET LEADER

DREAMGLASS®	PHYSICAL, OPTICAL AND ACOUSTIC PROPERTIES						DESIGN OPTIONS					CERTIFICATIONS			WARRANTY	
	Construction	max. size	haze	UV protection	db Rating Rw (1)	colour tinted	curved	shapes	sand blasted	screen printed	patterned	CE	ISO 9001:2008	ISO 10140-2:2011		IPx7
<b>4 + 4 mm</b>	4 mm low iron glass + 0,4 mm EVA + PDLIC + 0,4 mm EVA + 4 mm low iron glass	1.500 x 3.500 mm	< 8%	> 98%	36	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
<b>5 + 5 mm</b>	5 mm low iron glass + 0,4 mm EVA + PDLIC + 0,4 mm EVA + 5 mm low iron glass	1.500 x 3.500 mm	< 8%	> 98%	37	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
<b>6 + 6 mm</b>	6 mm low iron glass + 0,4 mm EVA + PDLIC + 0,4 mm EVA + 6 mm low iron glass	1.500 x 3.500 mm	< 8%	> 98%	38	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
<b>8 + 8 mm</b>	8 mm low iron glass + 0,4 mm EVA + PDLIC + 0,4 mm EVA + 8 mm low iron glass	1.500 x 3.500 mm	< 8%	> 98%	39	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
<b>custom configurations</b>	non-standard compositions	1.500 x 3.500 mm	subject to composition	> 98%	subject to composition	✓	✓	✓	✓	✓	✓	✓	optional	optional	✓	✓
<b>double/triple glazing</b>	standard double glazed units or triple glazed units	1.500 x 3.500 mm	subject to composition	> 98%	subject to composition	✓	✓	✓	✓	✓	✓	✓	optional	optional	✓	✓
<b>bullet proof</b>	combinations of DreamGlass® with bullet proof glass and interlayers	1.500 x 3.500 mm	subject to composition	> 98%	subject to composition	✓	✓	✓	✓	✓	✓	✓	optional	optional	✓	✓

(1) In accordance with the standard UNE-EN ISO 10140-2:2011

# DreamGlass®: healthcare, automation, transport and architectural applications

THE ADAPTABLE, INFINITE USES OF DREAMGLASS®.

It's no surprise that DreamGlass® has become the healthcare sector's preferred choice: in simplest terms, it's the most hygienic privacy system available. After all, what hospital curtain can outperform the ease of maintenance and disinfectability of DreamGlass®?

DreamGlass® partitions also allow natural daylight to flow freely into hospital interiors creating a soothing atmosphere that fosters recovery.

Transport, automation and architecture industries also benefit from the infinite potential of DreamGlass®. Dynamically adjustable sunroofs and skylights are increasingly valued sought after 21st century accessories.



**TRANSIT INTERIORS**  
Privacy partitions, as in this illustration of a cockpit separated from a passenger area, are a superior solution for the automotive, marine, rail and aviation sectors.



**EXHIBITION CENTERS**  
DreamGlass® was skillfully used to create ingenious visual effects as part of this architectural arts exhibition.

## ENDLESS APPLICATION POSSIBILITIES



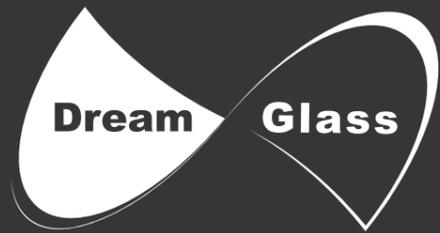
**INTENSIVE CARE UNITS**  
Hermetic doors can be fitted with DreamGlass® to offer a hygienic and efficiently controlled environment for patients who are isolated from external contact. This reduces the risk of infection and other health hazards.



**OPERATING ROOMS**  
Consulting doctors, nurses and other healthcare practitioners can advise and monitor surgical teams without even having to enter the operating room.



**PRIVACY FLOORS IN DUPLEX APARTMENTS**  
DreamGlass® converts a simple floor into a dynamic solution by illuminating the lower level with natural daylight while granting instant upper level privacy.



### 5 YEAR WARRANTY

*An extraordinary product deserves an extraordinary warranty.*

## ABOUT DREAM GLASS GROUP

Dream Glass Group (DGG) was founded in 2004 in Madrid, Spain with the mission to supply high quality switchable privacy glass with the best quality, guaranteed customer service and satisfaction to its global clientele. To maintain its position as a leading switchable privacy glass manufacturer, DGG extensively invests in R&D.



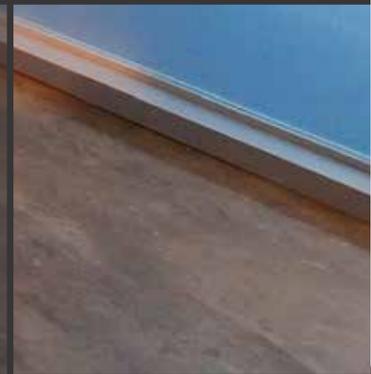
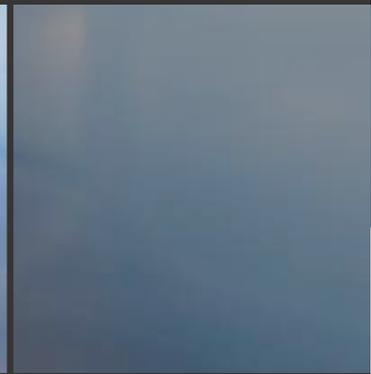
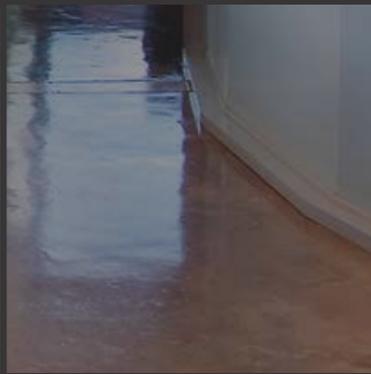
### IN-HOUSE R&D DEPARTMENT

*DGG's in-house R&D group guarantees outstanding quality and functionality.*



### WORLDWIDE DISTRIBUTION

*An international sales team is qualified to handle projects in multiple languages, including English, Spanish, Italian, French, Portuguese, Arabic and Mandarin.*



## CLEANING MANUAL DREAMGLASS®

### Cleaning DreamGlass® panels

1. Clean the glass, when in OFF position (translucent state), with a dry or slightly humid (water) cloth, or with a window-cleaning fluid that doesn't contain alcohol, ammonia or acetones. Be sure that the window-cleaning fluid does not reach the borders of the glass panel. The Film interlayer will dissolve if it comes in contact with window-cleaning products that contain the previously mentioned products. Hence, the affected zone would remain clear/translucent and defective from that moment on.
2. Before turning the glass panel ON again (transparent state), be sure that all borders of the glass are completely dry.
3. DreamGlass® Warranty is not applicable to defective glass panels which have been cleaned in an inappropriate way or have been in contact with incompatible products like those mentioned in Point 1.



