DAYLIGHT IN OFFICES

A comparison between the Dutch and European standards for daylight in buildings

M.L. Zoutendijk
Graduation thesis

DAYLIGHT IN OFFICES

A comparison between the Dutch and European standards for daylight in buildings

Master (MSc) thesis
April 2018

Master of Science
in Architecture, Urbanism & Building Sciences
Building Technology – Sustainable Design

Author
M.L. (Lianne) Zoutendijk, BSc
4218663

First supervisor
Dr. G.J. (Truus) Hordijk – Building Physics

Second supervisor
Ir. P. (Paul) de Ruiter – Design informatics
Dr.ir. P. (Pirouz) Nourian – Design informatics

Guest supervisor
Ing. G. (Gertjan) Verbaan – (DGMR)

Delegate of the Board of Examiners
Drs. D.J. (Dirk) Dubbeling – OTB
Drs. C.P. (Kees) Dol – OTB

TU Delft

Delft University of Technology
Faculty of Architecture and the Built Environment
Julianalaan 134
2628 BL Delft
The Netherlands

PREFACE

This graduation research is the final part of the master track of Building Technology for my Master of Architecture, Urbanism and Building Sciences at the Delft University of Technology. During the past years of my study, I developed a special interest in light, especially daylight. I discovered that light has a great influence on the ambience of a building and also on people's well-being.

I believe that as a designer or building engineer, one has the responsibility to design healthy and comfortable buildings. The exact effects of daylight on health and comfort are still being investigated. But it is generally known that daylight influences it a lot. Therefore, designers should always consider daylight during the design process. The problem is that they do not always know how. The standards for daylight in buildings vary and recommend different levels of daylight quality.

With this research I hope to give designers insight in the standards for daylight in buildings and the daylight quality they should aim for.

Therefore this research is all about that daylight quality.

I would like to thank some people who helped me to successfully finish this project. Firstly, thanks to my mentors, Truus Hordijk, Pirouz Nourian and Paul de Ruiter. They all provided me with lots of knowledge and skills and helped me with the process of this research.

I would like to thank Gertjan Verbaan as my mentor, and the other colleagues at DGMR for sharing their knowledge and experiences and for making my time at DGMR a very pleasant and informative experience.

Finally I want to thank my family and friends, especially Matthijs, for their interest and support during the full process of this graduation project.

ABSTRACT

The current Dutch standard for daylight in buildings does not assure good daylight quality. Designers therefore often do not know when a building has good daylight quality and how they can design a visually comfortable and healthy building.

The new European standard for daylight in buildings is more elaborative and recommends a higher daylight quality. When this standard is introduced, the assessment method must be adopted in the Dutch building regulations. The assessment method however differs a lot from the current Dutch assessment method, which makes it difficult to compare the standards and determine the exact differences.

To make it easier to design buildings with good daylight quality, the goal of this research was to establish a set of recommendations. For these recommendations, it was necessary to compare the Dutch and European standards. Three aspects of the standards were considered in this research: the requirements, the assessment methods and the effects on daylight quality.

Literature review on the standards gave insight in the requirements and assessment methods. The most obvious difference was that the European standard is more elaborative and assess, besides daylight, also sunlight, glare and view. Another big difference is that the Dutch standard is normative and the European standard descriptive. Both standards do not consider the orientation of a building and opposite obstructions.

After a literature study, two case studies were performed. The assessment of daylight in a basement showed that a space that meets the Dutch standard, can have a really bad daylight quality. It also led to the orientation factor which can be used to convert simulated daylight factors. This can be useful to gain insight in the amount of daylight in a space in common situations when the sky is not completely clouded and sunlight influences the daylight quality a lot.

The second case had quite good daylight quality, but still did not meet the European standard. There is not enough daylight, at the south east side there is too much glare, and at the north west side there is not enough exposure to sunlight.

The last part of the research was a systematic study. Variants were simulated according to the Dutch and European standard. Variants with a minimum daylight area from the Dutch standard had a bad daylight quality and showed that the window shape influences the access of daylight. In almost all other variants with bigger windows, higher reflection factors, or less obstructions, it was not possible to meet the European standard on both side of the building. This means that in a dense area the European standard is almost unachievable. Because of the many influencing factors, there is no clear relation between the equivalent daylight area and the daylight factor.

For designers it is recommended that they consider the orientation, surroundings and reflection factors, even though it is not required according to the standards. This gives a more realistic insight in the daylight quality. Rooms should comply with a minimum daylight factor of 0.8% in 50% of the area and an average daylight factor of 1.5% also in 50% of the area. Besides the amount of daylight, sunlight, glare and view also influence the daylight quality and should be taken into account during the design process.

Of course, there might be more factors that should be considered by designers. Those are not mentioned in this research, but can be investigated in future research.

GLOSSARY

LIST OF SYMBOLS

Derived from the Dutch standard NEN 2057 (Nederlands Normalisatie Instituut, 2011):

$A_{e,i}$	equivalent daylight area	[m²]
$A_{d,i}$	area of daylight opening i	[m²]
$C_{b,i}$	obstruction factor of daylight opening i	[-]
$C_{u,i}$	external reduction factor of daylight opening i	[-]
C_{LTA}	reduction factor for translucent materials with a LTA value less than 0.60	[-]
LTA	light transmission coefficient	[%]
$A_{net,i}$	total area of the external structure	[m²]
$A_{gross,i}$	translucent area of the external structure	[m²]

Derived from the European standard EN 17037 (European Committee for Standardization, 2017):

p	maximum grid cell size	[m]
d	longer dimension of the calculation area	[m]
α_s	solar azimuth (measured clockwise from due North)	[°]
γ_s	solar altitude	[°]
φ	geographical latitude of the site	[°]
δ	declination of the sun	[°]
ω	hour angle	[h]
TST	true solar time	[h]
LT	the local clock time	[h]
δ_s	longitude of the standard meridian	[°]
ET	equation of time	[h]
DGP	daylight glare probability	[-]
DGP_s	simplified daylight glare probability	[-]
E_v	illuminance at eye level	[lux]
L_s	luminance of the glare source	[cd/m²]
P	position index	[-]
ω_s	solid angle subtended by the glare source	[-]
i	number of glare sources	[-]
α	view angle to the window	[°]
g	height of the window	[m]
r	distance to the window s	[m]
D_T	target daylight factor	[%]
D_{TM}	minimum target daylight factor	[%]

Derived from the research report on the Dutch and European standards for daylight (Ridder, Boer, & Verbaan, 2018):

$D_{T,av}$	average target daylight factor	[%]

CONTENT

1. Introduction

1.1 BACKGROUND

The current Dutch standard for daylight, NEN 2057 *'Daglichtopeningen in gebouwen'*, describes the assessment for daylight access in a room. The requirements regarding daylight are given in section 3.11 of the Dutch building regulations called the *'Bouwbesluit'*, which also refers to NEN 2057.

This standard does not always assure good visual quality and comfort. One of the reasons for this is that in some situations the described methods for assessment are not applicable. In other situations, the incoming amount of daylight is still very little. Besides this, there is no attention to other aspects of visual comfort than the minimum amount of daylight.

For these reasons it might be necessary to revise the current Dutch standard.

The new European standard for daylight in buildings, *EN 17037 Daylight of buildings*, does take more aspects into account and is applicable in many more situations. But one drawback could be that there is no distinction made between different building functions or building occupants. Therefore, research is needed to investigate the exact differences between the Dutch and the European standard and to determine the advantages of both standards.

1.2 RESEARCH FRAMEWORK

1.2.1 PROBLEM STATEMENT

The Dutch and European standards for daylight in buildings have different assessment methods. For the Dutch standard, the geometry of buildings and rooms must be assessed, while for the European standard the amount of daylight inside buildings must be assessed. These different assessment methods lead to different sorts of requirements and recommendations. Therefore, the standards are not directly comparable. Besides that, the effects of the standards are not completely known. The Dutch standard does not mention the amount of daylight directly and the European standard is relatively new and therefore not completely investigated yet.

This causes uncertainty among designers about which recommendations they should follow to design a building, with healthy and comfortable use of daylight.

1.2.2 OBJECTIVES

General objective

Because designers do not know how to design buildings with good daylight quality, a set of recommendations is needed, of which the effects are known. Proposing this set of recommendations is therefore the main objective of this research. The recommendations will be based on the Dutch and European standards and may contain elements from those standards. The set of recommendations can be used on its own. However, it can also be seen as advisory supplements to the Dutch standard.

Sub-objectives

Necessary for the establishment of the recommendations is a comparison between the Dutch and European standard.

Due to the different assessment methods, both the requirements and the effects of the Dutch and European standards will differ, and therefore all three should be investigated:

- Firstly, both the Dutch and the European assessment methods should be investigated and described. The differences should be established, so a comparison of the two assessment methods can be made.
- Secondly, the requirements in both the Dutch and the European standard should be investigated and the differences between them should be described and analysed.
- Lastly, the effects on the daylight quality of the Dutch and European standards should be investigated and compared.

1.2.3 Constraints

This research focuses on offices in the Netherlands and on Dutch employees, designers and engineers. Only the assessment methods, requirements and effect on daylight quality will be investigated. Therefore, all non-visual effects, like thermal and biological effects are disregarded. Only the amount and quality of daylight, sunlight, glare and view will be investigated.

1.2.4 Research questions

In order to meet the objective, the following research question is formulated:

What are the main differences between the Dutch and the European standards for daylight in buildings?

The will be investigated on three subjects: the assessment methods, the requirements, and the visual effects.

The sub-objectives will be achieved by investigating the following sub-questions.

- What is the assessment method for the Dutch standard for daylight in buildings?
- What is the assessment method for the European standard for daylight in buildings?
- What are the differences between the assessment methods of the Dutch and European standards for daylight in buildings?
- What are the requirements of the Dutch standard for daylight in buildings?
- What are the requirements of the European standard for daylight in buildings?
- What are the differences between the requirements of the Dutch and European standards for daylight in buildings?
- What are the effects on the daylight quality of the Dutch standard for daylight in buildings?
- What are the effects on the daylight quality of the European standard for daylight in buildings?
- What are the differences between the effects on the daylight quality of the Dutch and European standards for daylight in buildings?

1.2.4 Approach

Report structure

The report will be divided into sections that are related to the different parts of the research. There will be a section about the assessment methods of the standards, a section about the requirements given in the standards, and a section about the effects the standards have on daylight quality. At the end of each sections the questions regarding the topic of the section will be answered shortly. In the final conclusions all answers will be answered in depth.

Execution plan

Figure 1 on the next page shows a flowchart of the full research process. The research is separated into three main parts, in order to answer the research questions.

The research starts with a literature study. With this study both the assessment methods and the requirements of the Dutch and European standards will be investigated and compared.

To determine the effects that the standards have on daylight quality, case studies and a systematic study will be used. The cases will be measured, simulated and tested according to the Dutch and European standard. They will be investigated on the extent to which they meet the standards. For the systematic study one of the cases will be elaborated. Several variants will be modelled and simulated. They will also be tested according to the Dutch and European standards. Together, the case studies and systematic study will provide insight in the differences between the effects of the Dutch and European standard on the daylight quality.

When the differences between the Dutch and European standards for daylight in buildings regarding the assessment method, requirements and effects on the daylight quality are determined, the set of recommendations can be established. The recommendations can be inspired by the current Dutch and European standards for daylight in buildings, but also by other building standards, recommendations or guidelines.

Relevance

Daylight has a big influence on the living quality of the indoor environment, in which people spend 80-90% of their time. It therefore also affects people's well-being a lot. Authorities, architects and engineers might want to realize a healthier built environment, but they often do not know which standards or guidelines they should use. With this research the differences between and the effects of the Dutch and European standard will become clearer. This, in combination with the recommendations that will be established, will make it easier to design buildings with good daylight quality.

Because of the influence daylight has on people, in the end this research is not only beneficial for designers, but also for building occupants, employers, health institutions, and more.

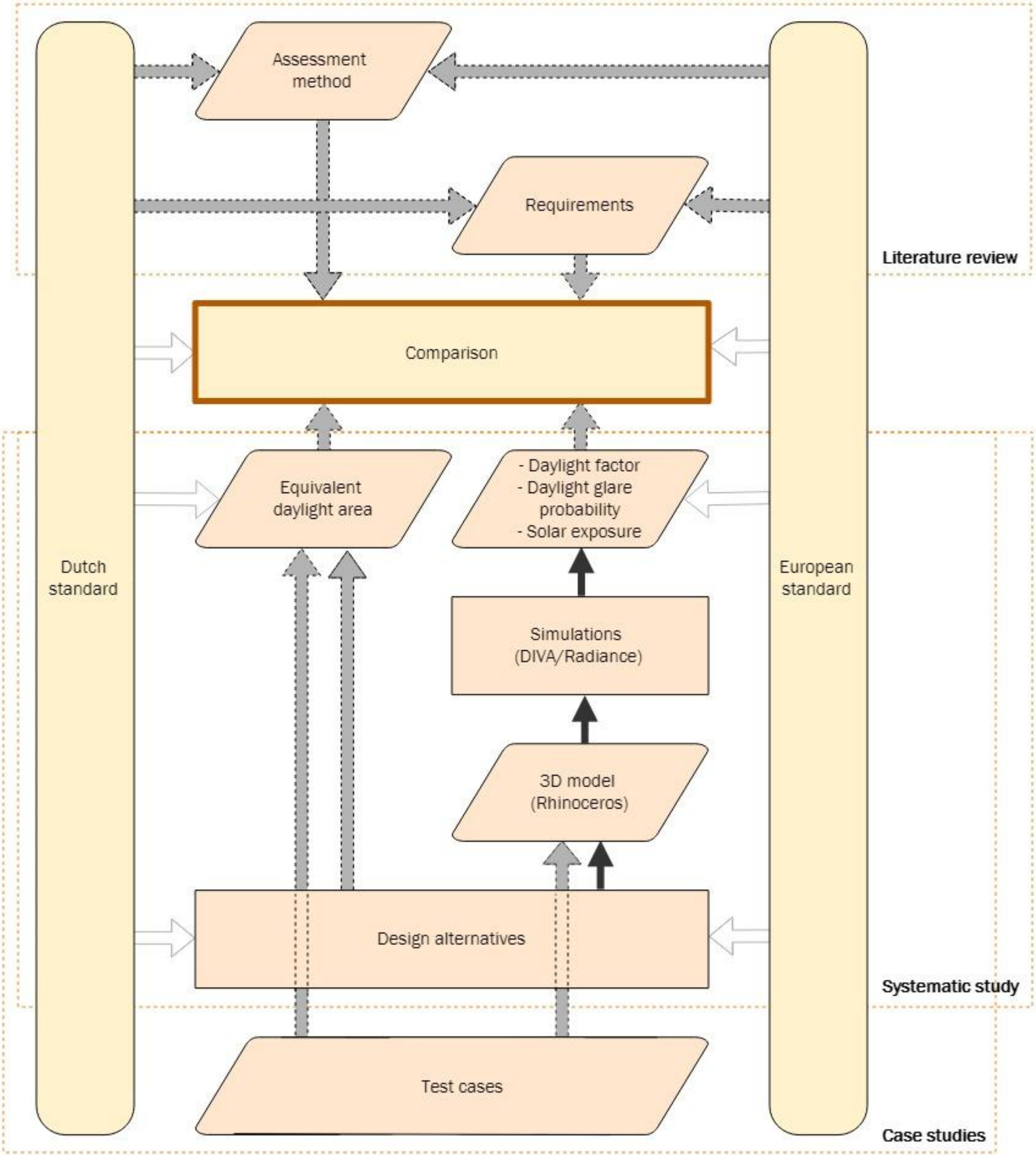


Fig. 1: The research process

2. Standards for daylight in buildings

When building a new office, it is obligated to comply with the Dutch building regulations called the '*Bouwbesluit'*. In section 3.11, the section about daylight, it gives the required equivalent daylight area for several building functions. The equivalent daylight area is the total daylight area above 60 cm from the floor, reduced by some reduction factors. For these reduction factors, the '*Bouwbesluit'* refers to NEN 2057. This is a standard established by the Dutch Normalisation Institute (NEN), and describes the method to assess daylight in buildings. The Dutch requirements and assessment method are described in paragraph 2.1.

The new European standard that is currently being drafted, will change the Dutch building regulations regarding daylight when it is finished and introduced. The Dutch standard will then have to adopt the assessment method described in the European standard. This method assesses the daylight factor instead of the equivalent daylight area. The change will be quite big, because the standard will not be normative anymore, but descriptive.

Both standards do not consider the orientation, because the equivalent daylight area and the daylight factor are independent of the orientation. Also opposite buildings on other parcels are not considered. The Dutch standard explicitly states to disregard them, and the European standard does not mention opposite obstructions at all.

2.1 THE DUTCH STANDARD

2.1.1 REQUIREMENTS

The Dutch requirements regarding daylight in buildings are described in section 3.11 of the *'Bouwbesluit'* and are last modified in 2012. For these requirements, several use functions are distinguished. The required equivalent daylight areas are given in table 1.

	Relative equivalent daylight area [%]	Absolute equivalent daylight area [m²]
Living	10	0.5
Gathering		
a) childcare	5	0.5
b) others	-	-
Cell	3	0.15
Healthcare	5	0.5
Industry	-	-
Office	**2.5**	**0.5**
Lodging	-	-
Education	5	0.5
Sport	-	-
Shopping	-	-
Others	-	-

Table 1. Required equivalent daylight areas; relative, as a percentage of the floor area, and absolute.

2.1.2 ASSESSMENT

In the Dutch standard for Daylight in buildings the equivalent daylight area is determinative. This is calculated with equation (1).

$$A_{e,i} = A_{d,i} \cdot C_{b,i} \cdot C_{u,i} \cdot C_{LTA} \quad (1)$$

In which:

$A_{e,i}$ is the equivalent daylight area of daylight opening i [m²];
$A_{d,i}$ is the area of daylight opening i [m²];
$C_{b,i}$ is the obstruction factor of daylight opening i [-];
$C_{u,i}$ is the external reduction factor of daylight opening i [-];
C_{LTA} is the reduction factor for translucent materials with a LTA value less than 0.60 [-].

$$C_{LTA} = LTA\ translucent\ material\ /0.60$$

For materials with $LTA \geq 0.60$, $C_{LTA} = 1$.

In order to determine the equivalent daylight area of a space, all equivalent daylight areas n in that particular space are added together, as is done in equation (2).

$$A_e = \sum_{i=1}^{n} A_{e,i} \quad (2)$$

In which:

A_e is the equivalent daylight area of a space, in m².

In the following paragraphs the assessment of the area, obstruction factor, and external reduction factor are described.

Assessment of the area of daylight area *i*

The assessment of the area of a daylight opening differs, depending on the angle of inclination. The three categories are given in figure 2. Daylight areas can be vertical, inclining inwards and inclining outwards. On vertical facades and facades that incline inwards the projection surface is located at the inside of the facade. On outwards inclining facades, the projection surface is located on the vertical plane that cuts the facade through the lowest point of the daylight opening.

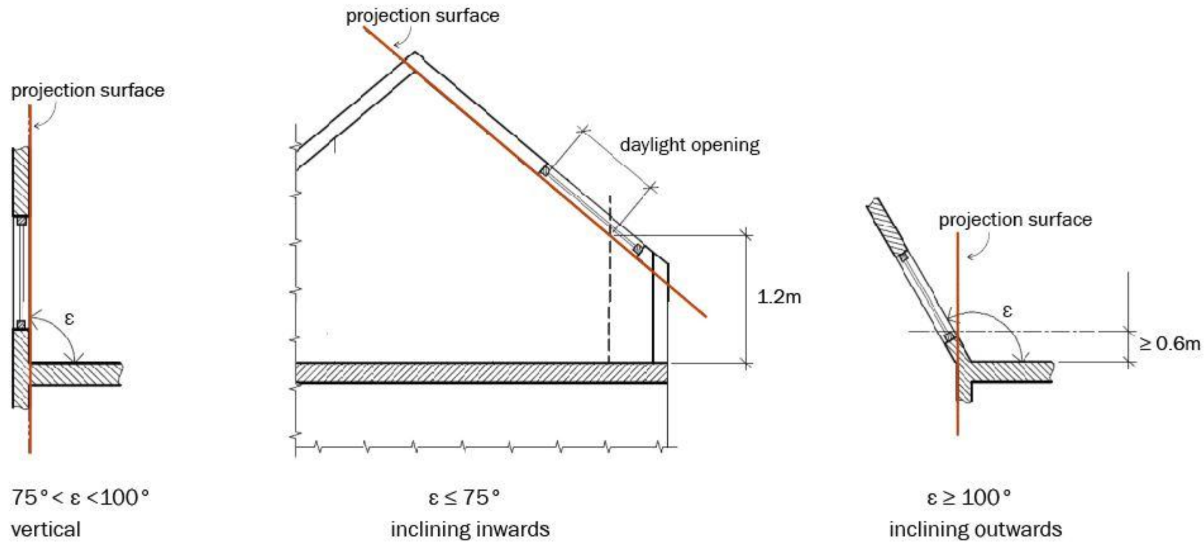


Fig.2 Inclination and projection surfaces

For the assessment of the area of a daylight opening the window is projected perpendicular on the projection surface. The bottom of the daylight opening is in general located at the bottom of the window. The bottom of vertical and outwards inclining daylight openings is located at a height of at least 0.6 m. The minimum height for the bottom of inwards inclining daylight openings is 1.2 m. The top of the daylight opening is located at the top of the window or at the bottom of a possible canopy. When the daylight opening is composed of multiple windows, the projection of each window must cut the line through the middle of the daylight opening or be located completely below that line. Windows that are located completely above the middle of the daylight opening can only be added to the daylight opening if the area of those windows is less than 20% of the daylight opening.

Assessment of the obstruction factor of daylight area *i*

Obstructions are divided in two categories: canopies and all other obstructions. The obstructions which are not canopies are taken into account when they are located in the α-zone. This is defined by an angle of 100°, perpendicular to the projection surface, as is shown in figure 3a. The obstruction angle α is the angle between the plane through the top of obstruction and the bottom of the daylight opening and the horizontal plane through the bottom of the daylight opening. This is shown in figure 3b. If the plane through the top of obstruction and the bottom of the daylight opening cuts a canopy, obstruction angle α is reduced to the plane that cuts through any part of the canopy. When the obstruction angle α is smaller than 20°, it is equalised to 20°.

In the case of multiple obstructions, the obstruction that causes the highest obstruction angle is taken into account or a different method is used. This method divides the α-zone in ten parts of 10°. Then the maximum obstruction angle of each part is determined. The average of the ten angles is the obstruction angle α of daylight opening i.

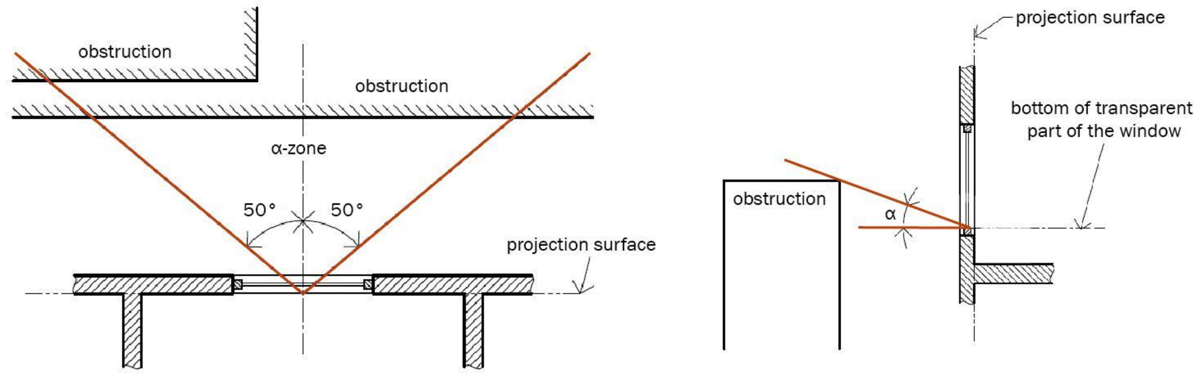


Fig. 3: The α-zone and obstruction angle α

Canopies are considered when they are located in the β-zone. This is defined by an angle of 120°, perpendicular to the bottom of the daylight opening and through its middle, as is shown in figure 4. The obstruction angle β is the angle between the projection surface and the plane through the middle of the daylight opening that cuts through any part of the canopy. This is shown in figure 4. Daylight openings that incline outwards always have an obstruction angle β.

When there are multiple canopies, the biggest obstruction angle is taken into account or the β-zone is divided in eight parts of 15°. The average of the eight obstruction angles is the obstruction angle β of daylight area i.

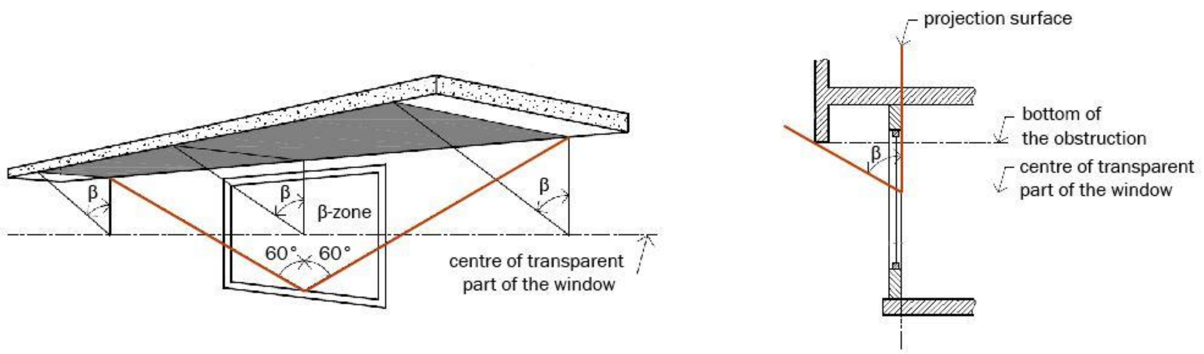


Fig.4 The β-zone and obstruction angle β

When obstruction angles α and β are determined the obstruction factor can be found in a table.

Assessment of the external reduction factor of daylight area i

When there is an external separation structure in front of the daylight area, the external reduction factor is calculated with equation (3).

$$C_{u,i} = LTA \cdot \frac{A_{net,i}}{A_{gross,i}} \qquad (3)$$

In which:

$C_{u,i}$	is the external reduction factor of daylight opening i [-];
LTA	is the light transmission coefficient [%];
$A_{net,i}$	is the total area of the external structure [m2];
$A_{gross,i}$	is the translucent area of the external structure [m2].

The total area of the external structure that is considered is defined by four planes:

- the two planes that define the α-zone;
- the plane through the top of obstruction and the bottom of the daylight opening;
- the plane through the middle of the daylight opening that cuts through any part of the canopy.

The translucent area of the external structure is the area of the translucent parts of the external structure in between the four planes.

The elaborated assessment method

For the situations for which the earlier described assessment method for the obstruction factor is not applicable, there is a method in which the access of daylight is simulated. This method is not applicable for outwards inclining daylight openings. For the simulation, standard reflection factors, obstructions and the climatic situation are given. In this situation, the illuminance on an unobstructed horizontal plane is calculated. This is converted to a reference illuminance E_z. Then the illuminance on the window, E_m, is calculated. If $E_m/E_z \geq 0.15$ the obstruction factor $C_{b,i}$ is calculated with equation (4).

$$C_{b,i} = 0.32 \cdot I_n \cdot (E_m/E_z) + 0.81 \qquad (4)$$

This obstruction factor $C_{b,i}$ is then used in equation (1) to calculate the equivalent daylight area.

2.2 THE EUROPEAN STANDARD

The European standard for daylight in buildings considers four aspects: the amount of daylight, sunlight, glare and view. For the assessment of each aspect several methods are described. Paragraph 2.2.2 contains those methods. The standard also gives recommendations for each aspect. A distinction is made between three levels: minimum, medium and high. This research only considers the minimum recommended levels, which are defined in paragraph 2.2.1.

2.2.1 REQUIREMENTS

Daylight

For the provision of daylight distinction is made between daylight openings in facades and daylight openings in roofs. In the case of openings in the facade the illuminance during 50% of daylight hours should be 300 lux over 50% of the space and 100 lux over 95% of the space. This means that the daylight factor in the Netherlands should be at least 2.1% in 50% of the area and 0.7% in 95% of the area. In spaces with rooflights the illuminance over 95% of the space during 50% of daylight hours should be 300 lux. This results in a daylight factor of 1.7% in the Netherlands.

Exposure to sunlight

The minimum recommendation for exposure to sunlight is that rooms should receive sunlight for at least 1.5 hours on at least one day between February 1st and March 21st. Cloudless sky conditions should be assumed.

Glare

The minimum requirement for glare protection is that the daylight glare probability does not exceed a value of 0.45 in more than 5% of the occupation time of the relevant space.

View

There are a few requirements regarding view. Firstly, view windows should have dimensions that result in a view angle of 14°. Secondly the outside distance of a view should be at least 6 m. Lastly, from the three layers sky, landscape and ground, at least the landscape layer should be visible from at least 75% of the utilised area.

2.2.2 ASSESSMENT

Daylight

To meet the requirements for the provision of daylight, a minimum illuminance level should occur over a stated part of the reference plane, during a stated amount of daylight hours.

This can be validated in two ways. The first is through performing calculations of indoor illuminances on the reference plane over a full year, using time steps of one hour or less. For this, detailed, hourly, daylight information on site is required. It can also be estimated by the calculation of daylight factors over the entire reference plane, under standard CIE overcast sky. For this last method, the minimum illuminance values are converted to target daylight factors D_T that depend on the location and therefore are given for 33 capital cities of CEN national members. For the determination of the diffuse horizontal illuminance, standardised climate files are used.

For the calculations using daylight factors any reliable method that is based on the ISO 15469:2004 standard overcast sky can be used. The daylight factors must be predicted across a grid of points on a plane 0.85 m above the floor. The ratio of length and width of a grid cell should be between 0.5 and 2 and the maximum grid size can be calculated with equation (5).

$$p = 0.5 \cdot 5^{log_{10}(d)} \qquad (5)$$

In which:

p	is the maximum grid cell size [m];
d	is the longer dimension of the calculation area, except for when the ratio of the longer to the shorter side is 2 or more [m]. When the calculation area is located in a room a band of 0.5 m from the walls is excluded from the calculation area.

$p \leq 10\ m$

Exposure to sunlight

The exposure to sunlight must be checked at a reference point at the centre of the window and at the inner surface of the aperture. The reference point is at least 1.2 m above the floor and 0.3 m above the window sill, if present. From this point, it is necessary to identify the visible part of the sky to know for which amount of time the sun reaches the reference point on a selected date.

There are two methods for the assessment of sunlight. The first one uses software to generate images towards the outside. These could either be 180° angle images or images with a cylindrical projection. If generated in the correct way, these images can be compared to sun path diagram that applies for the correct location.

The other method uses manual geometric constructions and requires the critical azimuths α_s and solar altitudes γ_s. The minimum values for these angles define the start and end of the possible duration of exposure to sunlight. Obstructions with an elevation higher than the solar altitude also limit the possible duration of exposure to sunlight. The azimuth α_s can be calculated with equation (6) and the solar altitude γ_s with equation (7).

$$\alpha_s = 180° \pm \cos^{-1} \frac{\sin\gamma_s \cdot \sin\varphi - \sin\delta}{\cos\gamma_s \cdot \cos\varphi} \qquad (6)$$

In which

α_s	is the solar azimuth (measured clockwise from due North) [°];
γ_s	is the solar altitude [°];
φ	is the geographical latitude of the site [°];
δ	is the declination of the sun [°].

$$\gamma_s = \sin^{-1}(\cos\omega \cdot \cos\varphi \cdot \cos\delta + \sin\varphi \cdot \sin\delta) \qquad (7)$$

In which

γ_s	is the solar altitude [°];
ω	is the hour angle, $\omega = (12.00h - TST) \cdot 15°$ [h];
φ	is the geographical latitude of the site [°];
δ	is the geographical longitude of the East or West of Greenwich [°].

The true solar time can be calculated with equation (8).

$$TST = LT + \frac{\delta_s - \delta}{15} + ET \qquad (8)$$

In which

TST	is the true solar time [h];
LT	is the local clock time [h];
δ	is the geographical longitude of the East or West of Greenwich [°];

δ_s	is the longitude of the standard meridian [°];
ET	is the equation of time [h].

For the 33 capital cities of CEN national members the minimum solar altitude is given. Solar altitudes below those are neglected.

The duration of exposure to sunlight is estimated by the period in which the sun reaches the reference point.

Glare

For the assessment of glare the daylight glare probability (DGP) is used. This DGP can be calculated with equation (9).

$$DGP = 5.87 \cdot 10^{5} \cdot E_v + 9.18 \cdot 10^{-2} \cdot log\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1.87} \cdot P_i^2}\right) + 0.16 \qquad (9)$$

In which:

E_v	is the illuminance at eye level [lux];
L_s	is the luminance of the glare source [cd/m2];
P	is the position index [-];
ω_s	is the solid angle subtended by the glare source [-];
i	is the number of glare sources [-].

For the calculation of the DGP the worst-case position should be investigated. The DGP must not exceed a stated value in more than 5% of the occupation time.

For side-lit spaces with shading devices a simplified annual glare evaluation method can be applied. Shading devices with tilting curtain will not exceed a DGP of 0.35 in more than 5% of the occupation time when the device can be operated by the occupant, the visual transmittance of the curtain material is zero and in the fully closed and extended position there is no gap in the curtain. For shading devices with a fabric or non-fabric curtain glare protection classes are defined. For several situations the recommended classes are given in order to not exceed a stated DGP in more than 5% of the reference usage time. For non-diffusing glazing devices with a low or variable light transmittance pre-calculated DGP-values that will not be exceeded during more than 5% of the usage time are given. These DGP-values are depending on the transmittance properties of the glazing and the frequency of the occurrence of the sun in the field of view.

Glare can also be assessed by measurements. In that case the testing position should be a current used position or a position that might be used and have a glare problem. Measurements should be taken with cloudless sky condition and a critical solar altitude. Shading devices should be tested in automatic mode or in closed position if the device can be manually controlled. The measurement device should face towards the façade, parallel to the floor and towards the azimuth direction of the sun. The height of the device should be in the eye level of a specific task or at a height of 1.2 m. The DGP can be measured with a HDR camera with fish-eye lens or approximated using an illuminance meter and a spot illuminance meter. When the sun disk is invisible or specular reflectance not occurring, the DGP can be calculated with equation (10).

$$DGP_s = 6.22 \cdot 10^{-5} \cdot E_v + 0.184 \qquad (10)$$

In which:

DGP_s	is the simplified daylight glare probability [-];
E_v	is the vertical illuminance at eye level [lux];

When the sun disk is visible or specular reflectance might cause glare, the solid angle can be assessed with equation (11) and (12).

$$\frac{\alpha}{2} = \tan^{-1}\left(\frac{g}{2r}\right) \quad (11)$$

In which:

α	is the view angle to the window [°];
g	is the height of the window [m];
r	is the distance to the window [m].

$$\omega_s = 2\pi\left(1 - \cos\left(\frac{\alpha}{2}\right)\right) \quad (12)$$

In which:

ω_s	is the solid angle [-];
α	is the view angle to the window [°].

When the sun disk can be seen and is not changed by the shading device, a solid angle of $7 \cdot 10^{-5}$ sr should be used.

View

For the estimation of the view, a few parameters should be considered. The first are the dimensions of view windows and the outside distance of the view, which can both easily be measured. The estimation of view width, number of layers and quality of the environmental information is more complicated. The view width is determined by the ratio between the depth of the occupied area of a space a, the width of a space b, and the total width of the windows b_w. For several situations, these are shown in figure 5. Figure 6 shows the ratio between the three factors for a view width of 14°.

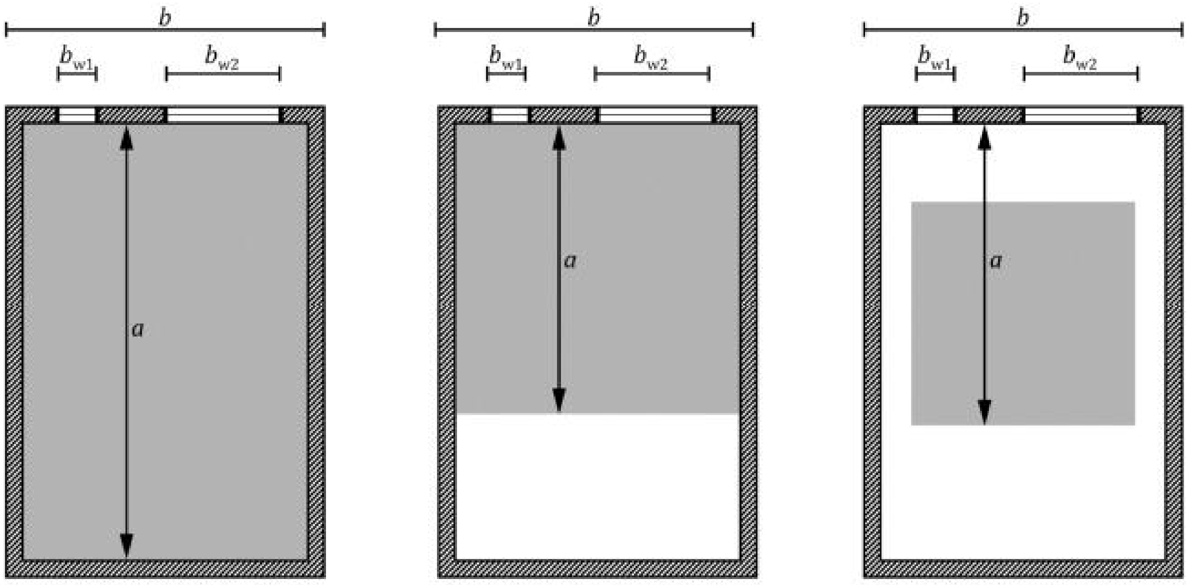


Fig. 5: The depth of the occupied area, the width of the area and the total width of the windows

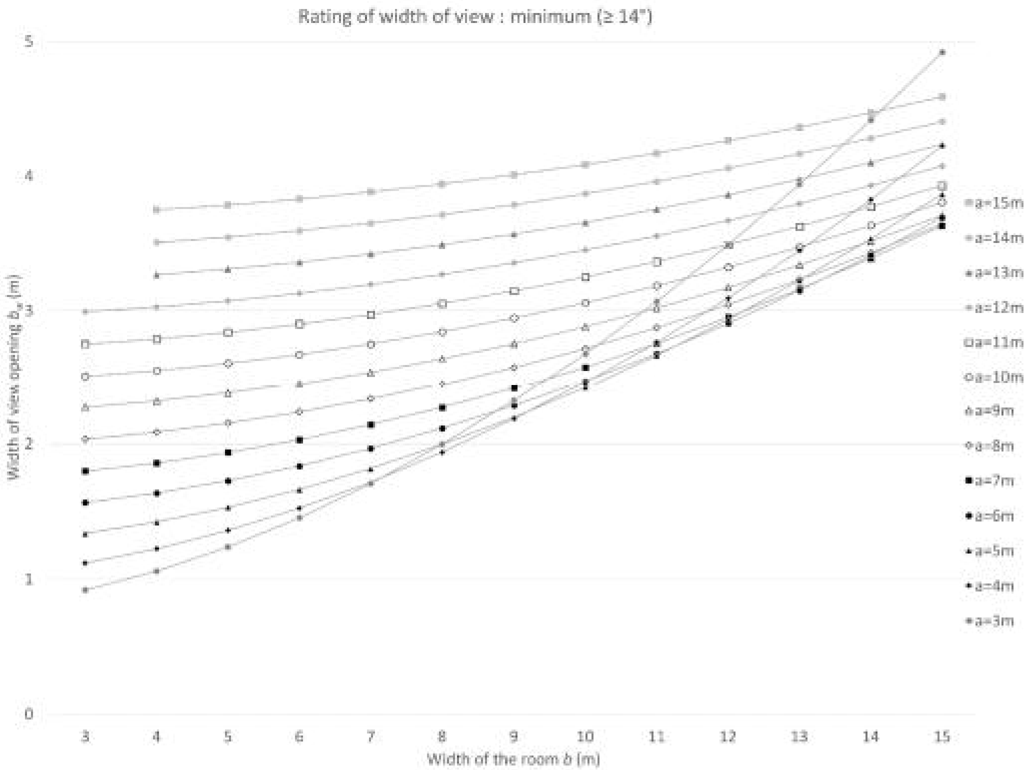


Fig. 6: The ratio between the depth and width of a space and the width of the view opening for a view width of 14°.

The view quality depends on the presence of environmental information, such as location, time, weather, nature and people. Also, the visibility of the sky-, landscape- and ground layer should be considered.

One way to judge the quality of the view is the projection method. This method uses a fish-eye projection from points where people are sitting or standing, perpendicular to the facade. All obstructions in the view should be considered.

Another way to judge the view quality is the no-sky or no-ground line concept. Those lines are the dividers between the parts of a space from where the sky or ground is visible from a height of 1.20 m and from where it is not visible on that height. The no-sky and no-ground lines are shown in figure 6.

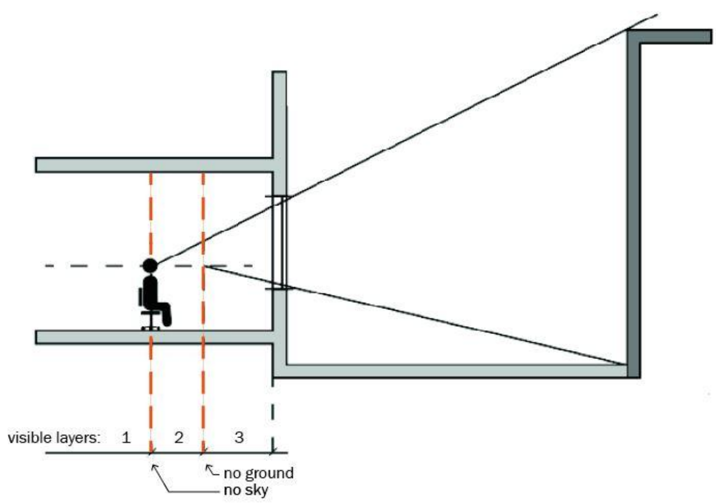


Fig. 7: Cross-section showing the no-sky and no-ground lines

2.3 Other guidelines and recommendations

2.3.1 TNO-norm

In the Dutch building regulations, insolation is not included. However, there is a standard that some municipalities use to assess the insolation. This standard is called the *'lichte TNO-norm'*. It is met when insolation is possible for at least two hours on the days between February 19 and October 21 (3DL, n.d.)(HBA, 2017).

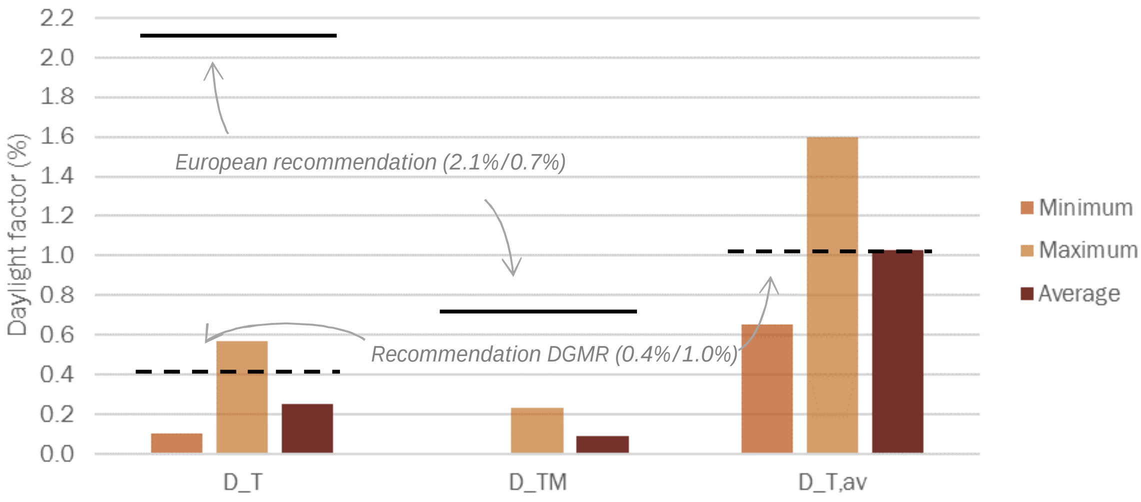
This *'lichte TNO-norm'* is similar to the European standard. The differences are the duration of insolation, and the amount of days on which insolation should be possible. The duration of insolation should be two hours per day according to the *'lichte TNO-norm'*., and 1.5 hours per day according to the European standard. And for the European standard enough insolation should be possible on only one day (at least) between February 1 and March 21, while for the *'lichte TNO-norm'* it should be possible on each day between February 19 and October 21.

The fact that for the European standard enough insolation on only one day is sufficient, makes it easier to assess insolation according to the European standard. Because of the shorter duration it is also easier to comply with it.

2.3.2 The new Dutch standard proposal

Because the Dutch standard probably has to change, research is done on how the current minimum equivalent daylight area can be converted to a minimum daylight factor (Ridder, Boer, & Verbaan, 2018). This research is carried out by DGMR, and mainly consists of a variant study, case studies and a proposal. The variants all have the minimum required equivalent daylight area and different obstructions. Also the effects of the window shape is investigated. For the variants the minimum and average daylight factor in 50% of the area (D_T, $D_{T,av}$) and the minimum daylight factor in 95% of the area (D_{TM}) are determined. The minimum, maximum and average levels are given in graph 1. The results of the variants with the same obstructions, but different window shapes, are averaged.

The graph shows that the levels recommended by the European standard are not met. A target daylight factor D_T of 0.4% can be compared to the minimum equivalent daylight area. Because the depth of the room influences the daylight factor in a room a lot, an average target daylight factor $D_{T,av}$ of 1% is recommended (Ridder, Boer, & Verbaan, 2018).



Graph 1: Recommended daylight factors

2.4 Elaboration on the standards

The difference that immediately stands out is that the European standard is more comprehensive than the Dutch standard. Exposure to sunlight, glare and view are not mentioned in the Dutch standard. Besides that, the Dutch requirements must be met in order to get a building permit, while the European standard only gives recommendations about the amount of daylight, sunlight, glare and view.

Another big difference is that the Dutch standard requires to use the equivalent daylight area to assess daylight and the European standard requires to use the daylight factor. This leads to a totally different assessment method. In case of the Dutch standard, one could assess daylight by hand, while for the assessment of the, for the European standard required daylight factor, simulation software is necessary.

There are a few more differences in the assessment methods of both standards. Firstly the *'Bouwbesluit'* states to ignore obstructions on other parcels but use a minimum obstruction angle α of 20° instead. This ensures that the equivalent daylight area will not change too much when the surroundings of a building change. When in the original situation the obstruction angle is smaller than 20°, the actual equivalent daylight area will be larger than the calculated equivalent daylight area and stay approximately the same when new buildings get built. But when in the original situation the obstruction angle is bigger than 20°, the actual equivalent daylight area will be smaller than the calculated equivalent daylight area. This means that the amount of daylight also will be smaller than expected with the same equivalent daylight area.

According to the European standard one should make a representative 3D computer model to assess daylight. Logically the surroundings are then also considered. It however is not clear whether a current situation should be used, because the surroundings might change. In that case the daylight factor might be too low.

A representative 3D computer model also includes representative reflection factors. The standard does recommend ranges for the reflection factors of walls, floors, and ceilings, but one may deviate from those ranges. This means that higher reflection factors can be used for the simulation, while they might change during the use of a building. The actual amount of daylight in a room then might be too low.

the light transmittance of the glass also is of course taken into account with the simulation of the daylight factor. Therefore, the European standard does consider the light transmittance. But the *'Bouwbesluit'* states that the light transmittance must be at least 0.6 and that it can be disregarded in the calculation of the equivalent daylight area. The minimum light transmittance is not a problem, but the light transmittance can still be included in the calculation of the equivalent daylight area.

3. Case studies

To investigate the effects the Dutch and European standards have on the daylight quality, two case studies are performed and elaborated in this chapter. Both cases meet the Dutch standard, but they do not meet every aspect of the European standard. Especially the first case has a bad daylight quality, and the second case also could be better.

The second case also shows that the orientation and the surroundings of a building influence the daylight quality. However, both are not mentioned in the Dutch nor European standard. An orientation factor can be used to investigate a more realistic, actual daylight factor, for example for days on which the sky is not completely overcast and direct sunlight influences the amount of light in a room.

3.1 METHODOLOGY

3.1.1 MEASUREMENTS

All measurements are taken according to the Dutch standard NEN 1891. This standard describes the way light inside buildings should be measured. The grid described in the European standard is bigger and therefore less accurate. The Dutch standard gives a method to determine the grid, starting with an equation for the grid size. This equation is derived from CIE S 005-1992.

$$p = 0.2 \cdot 5^{log(d)} \quad (13)$$

in which

p is the maximum grid size, but ≤ 10 meter.

d is the length of the longest side of the measuring area, unless the shorter side is more than twice as short as the longer side of the area.

The measuring area is the same as the floor area of the room that is measured, but excludes the area less than 0.5 m from the walls. The amount of points in the direction of the longer side is d/p. The amount of points is then used to calculate the real distance between the points in the direction of the longer side of the room. Lastly the length of the shorter side of the room is divided by this distance between the points to calculate the amount of points in the other direction. All measuring points in the grid are placed at a height of 0.75 m above the floor, according to the Dutch standard and on desk level. Incoming daylight from below this level will not contribute much to the daylight factors.

The working areas, which normally need a smaller grid, are not taken into account for these measurements. This way the results can be easily compared to the results of the simulations which are done with the same grid. Because the main goals of the measurements are the validation of the simulation and the estimation of the amount of light in the area, the measurements are taken only once.

During the measurements, the horizontal illuminance in the point is measured with a lux meter. At the same time, the illuminance outside is also measured. This is done at a point with the least obstructions as possible. For each measuring point the external illuminance is measured. Thereby the daylight factor can be calculated using equation (14).

$$DF = E_e/E_i \cdot 100\% \quad (14)$$

in which

DF is the daylight factor.

E_i is the internal illuminance.

E_e is the external illuminance.

3.1.2 SIMULATIONS

Simulations are done to determine the amount of daylight, sunlight and glare in a room. The software used for the simulations is Rhinoceros, with a plug-in DIVA. Rhinoceros is used to model the rooms, and DIVA simulates daylight with Radiance, a ray-tracing program.

Models must exist of surfaces that are well connected. Materials are submitted in DIVA for each layer in Rhinoceros. The weather file that is used has to be the one for the location that is closest to the location of the simulated building. Weather files are available for three Dutch locations: Amsterdam, Beek and Groningen.

Simulation options

DIVA gives different options for the simulations. For the case studies, the daylight factor and the daylight glare probability will be simulated and a fish-eye projection will be made to investigate the duration of sunlight exposure.

Radiance parameters

For all simulations the Radiance parameters are very important settings. The applicable parameters are the ambient bounces, ambient accuracy, ambient resolution, ambient divisions and the ambient super-samples. The values that are used are given in table 2 and explained in appendix A.

Parameter		Min.	Fast	Accurate	Very accurate	Max.	Used
-ab	ambient bounces	0	0	2	**5**	8	5
-aa	ambient accuracy	0.5	0.2	**0.15**	**0.08**	-	0.1
-ar	ambient resolution	8	32	**128**	**512**	-	300
-ad	ambient divisions	0	32	**512**	**2048**	4096	1024
-as	ambient super-samples	0	32	**256**	512	1024	256

Table 2: Used Radiance parameters.

Daylight factor

Besides the radiance parameters, for the daylight factor only the geometric density must be set. This is set to the maximum of 100 for the most refined resolution. In the other simulations the same geometric density is used.

Daylight glare probability

To assess glare an annual glare calculation is executed. This calculation uses an annual hourly occupancy schedule. Because the glare will be evaluated according to the European standard the occupancy schedule is also set according to this standard. The reference usage time is the time between 8 am and 6 pm on weekdays. This was not one of the standard schedules, so therefore a custom schedule file is made. Considering the European standard, the worst-case scenario is assessed. Therefore the 'adaptive visual comfort' is set to unadaptable. This way the simulations automatically use the viewports with the worst glare condition.

Duration of sunlight exposure

To determine the duration of sunlight exposure in a room, a fisheye visualisation is made. For the purpose of this visualisation the image quality, sky condition, date and time do not matter. The view direction of the image must be exactly vertical and upward. This way, after mirroring the image, the angles of the fisheye projection correspond with the angles of a sunpath diagram. Because DIVA cannot visualise images in which the view direction is the same as the view up, the y-axis of the model, instead of the z-axis, is set as the view up. To set the view up, it is added to the Radiance parameters like '*-vu 0 1 0*'. This is shown in figure 8c.

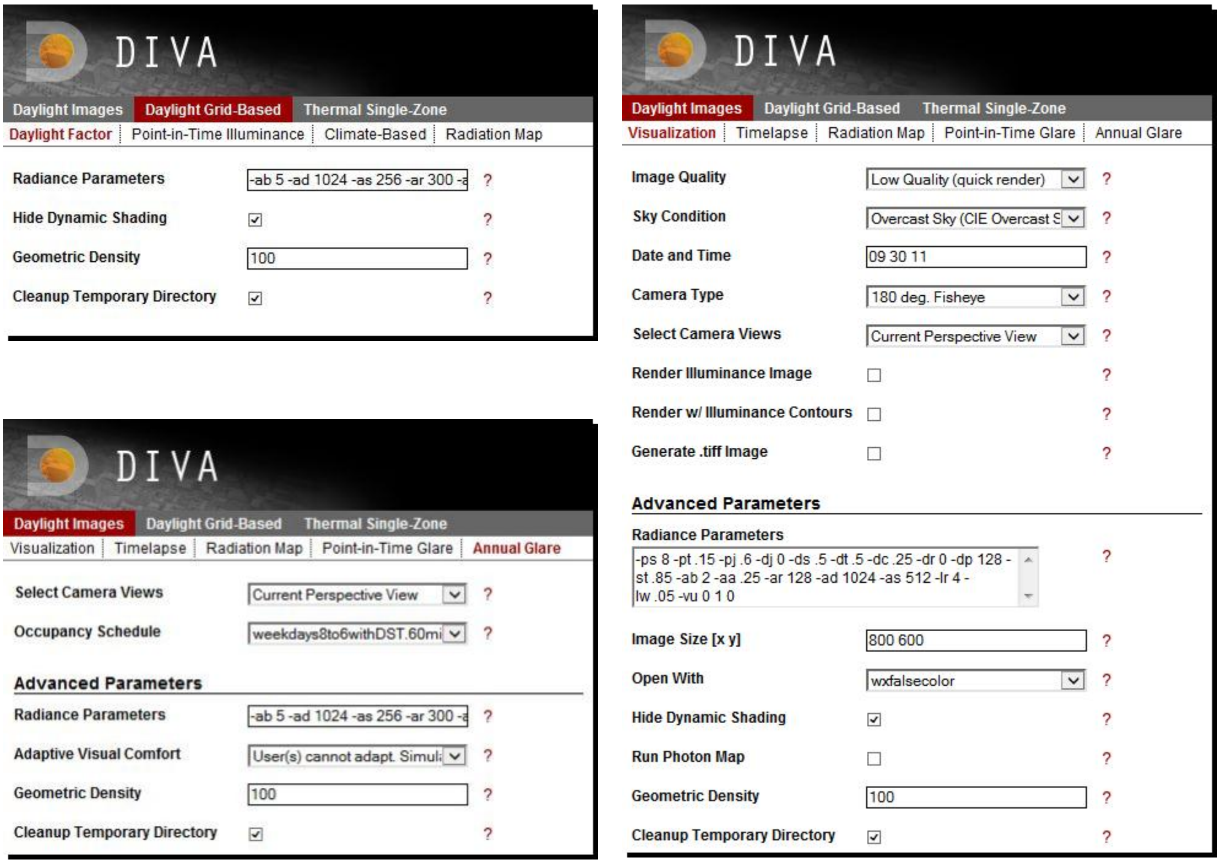


Fig. 8: The settings for the calculation of the daylight factor and the daylight glare probability and the visualisation of the duration of sunlight exposure.

3.2 BASEMENT BASISWEG AMSTERDAM

The first case is a room in the basement of an office building at the Basisweg in Amsterdam. The basement is mainly used for installations and the distribution of mail and goods. A small area however is used as an office space for approximately ten employees. This area is divided into several rooms separated by walls which are partly opaque and partly transparent. One of the rooms has a window in a window well. This is the only opening through which daylight can enter the office area. The room with the window is investigated through measurements, simulations and observations and is tested according to the Dutch and European standards. The room has a length of 10.5 m, a width of 7 m, and a floor area of 65.5 m^2 and is shown in figure 9, 10 and 11.

Fig. 9: The window well and the window with closed louvres.

Fig. 10: The room in the office area in the basement and the window with opened louvres.

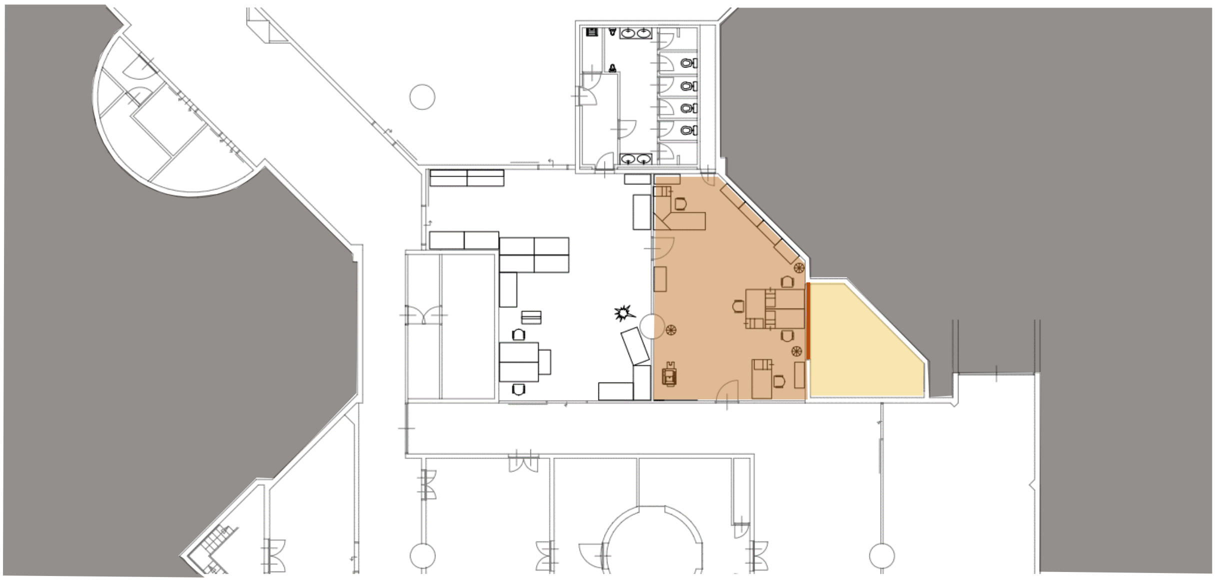


Fig. 11: A part of the office area in the basement, the room with the window and the window well.

3.2.1 MEASUREMENTS

Measuring points

The grid of measuring points in the room is calculated according to the method described in paragraph 3.1. The grid size is $0.2 \cdot 5^{log(9.5)} = 0.965$ m. This results in ten measuring points with a distance of 0.95 m between them in the longer direction and 6 points with a distance of 1 m between them in the shorter direction. Because the room is not rectangular the grid exists of fifty measuring points, shown in figure 12. The illuminance is measured at a height of 0.75 m, using a tripod or the desks in the room.

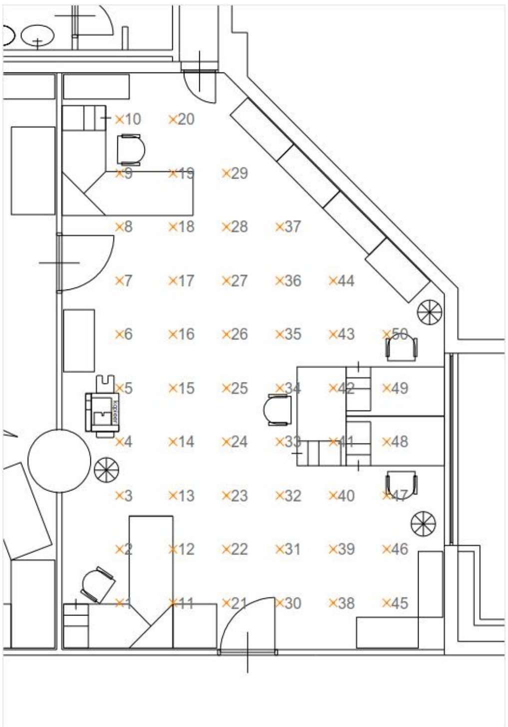


Fig. 12: The grid of measuring points inside the room.

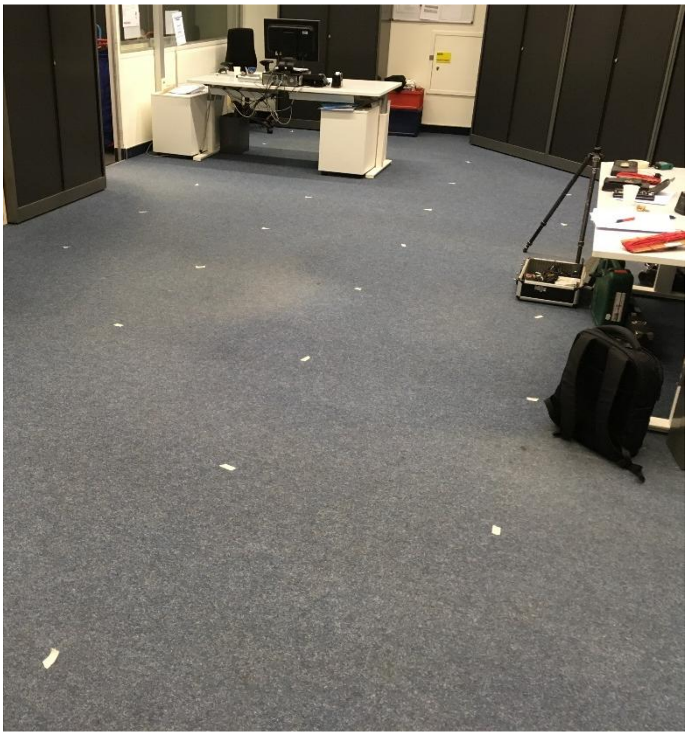


Fig. 13: The measuring points marked on the floor or on desks.

Besides the illuminance inside the room, the illuminance outside is also measured. This is done next to the building, on the place with the least obstructions.

Time

The measurements were taken on the 30th of September 2017 between 10:30 am and 12:00 am. At that time there was a completely overcast sky, which means there were no big fluctuations in the illuminance.

Equipment

For the measurements two lux meters with photometric sensors were used. The sensor for the measurements inside the room was placed on a tripod or on the desks, while the lux meter stayed in the same placed during all measurements. Hereby the illuminance was not influenced by the presence of the researcher.

Results

The measured illuminance values are given in appendix B1. There the daylight factor is also calculated. Therefore, the results of the measurements can be used to validate the simulations.

3.2.2 SIMULATIONS

With simulations, the amount of daylight, sunlight and glare in the room is determined according to the method described in paragraph 4.1.2.

The model

The room and all spaces around it through which light can travel from or to the examined office room, are modelled in Rhinoceros. The outside of the building is given in figure 14 and the modelled part of the basement is given in figure 15.

The analysis nodes in the model are placed on the same grid that is used for the measurements. The weather file that is used is the file with data for Amsterdam.

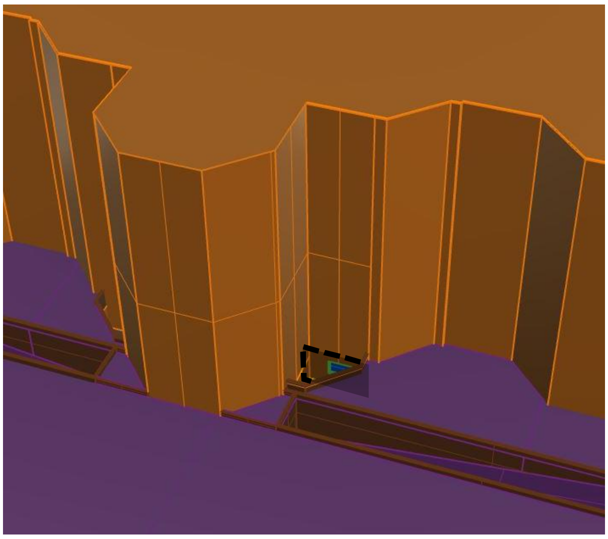


Fig. 14: The outside of the building and the place of the office room and the window well.

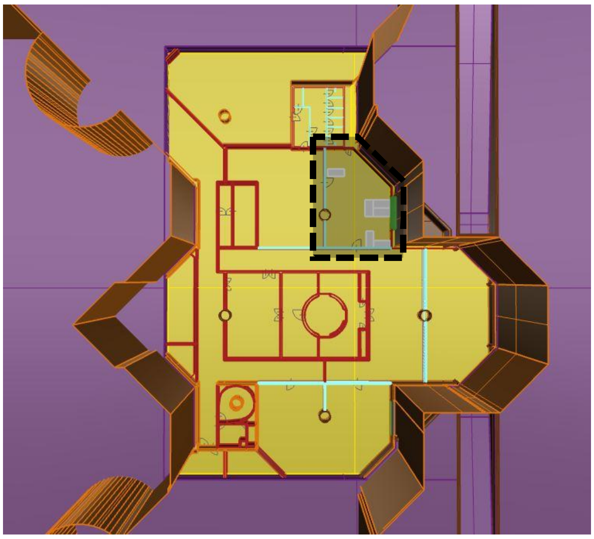


Fig. 15: The modelled part of the basement and the place of the office room. The ceiling in the basement and the roof are not shown, but are present in the model.

Materials

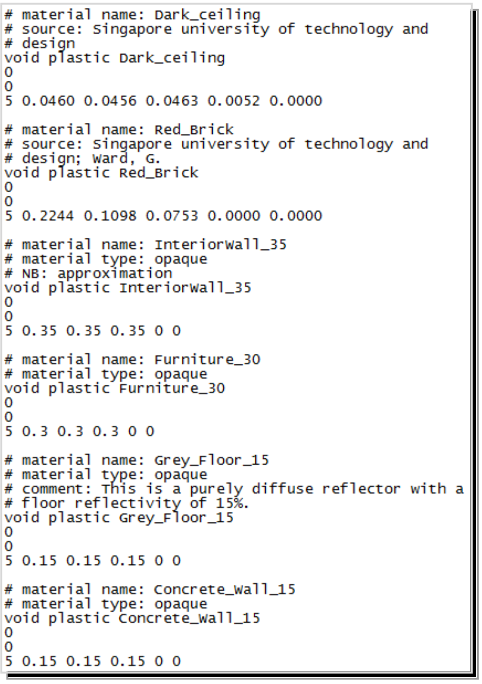
Initially only the standard materials in DIVA were used. Those materials have standard reflection factors or light transmittances. With the standard materials and settings described in paragraph 4.1.2 the daylight factors did not correspond with the daylight factors that were calculated with the measured illuminances. The reason for this is that the materials in the room were not comparable with the standard materials or there were obstructions in the room that were not taken into account in the model. In reality the ceiling and the floor were darker and therefore have lower reflection factors than the standard materials in DIVA. For the floor an approximation is made based on the characteristics of a dark grey floor that was measured and defined by the Singapore University of Technology and Design (2017). This defined floor has a reflectance of 16.36% and is quite smooth. Because carpet floors like the floor in the office room, generally reflect less light than smoother floors, a reflection factor of 15% is used for the floor. Also for the ceiling a material defined by the Singapore University of Technology and Design is used (2017). This is a dark ceiling with a reflectance of 5%. Figure 16 shows the reflectance of blue, green and red light for all custom materials.

For the façade the characteristics of red bricks are used. The defined material has a reflectance of 13.8%. The concrete walls are modelled with a reflectance of 15%, based on the characteristics of a concrete street curb with a reflectance of 15.3% (Singapore University of Technology and Design, 2017).

The reflection factors of the interior walls and desks are probably correct, but because of the many obstructions like black cabinets against the walls and computers on the desks, the reflection factor of the materials are adjusted. An approximated factor of 0.5 is used to scale the reflection factor of generic white interior walls (70%) to the reflection factor of the walls in the office room, taking the obstructions into account (35%). For the desks the reflection factor of generic furniture (50%) is scaled with an approximated factor of 0.6 to the reflection factor of the desks, considering the obstructions on them (30%).

Glazing

In the model two types of glass are used. The glass in the interior walls is a clear double pane. Therefore the standard DIVA material with a visual transmittance of 80% is used. For the double pane glass in the window not only the visual transmittance of the glass, but also dirt on the window is considered. This results in a visual transmittance of 65%. All materials used in the model are shown in figure 17.



```
# material name: Dark_ceiling
# source: Singapore university of technology and
# design
void plastic Dark_ceiling
0
0
5 0.0460 0.0456 0.0463 0.0052 0.0000

# material name: Red_Brick
# source: Singapore university of technology and
# design; Ward, G.
void plastic Red_Brick
0
0
5 0.2244 0.1098 0.0753 0.0000 0.0000

# material name: InteriorWall_35
# material type: opaque
# NB: approximation
void plastic InteriorWall_35
0
0
5 0.35 0.35 0.35 0 0

# material name: Furniture_30
# material type: opaque
void plastic Furniture_30
0
0
5 0.3 0.3 0.3 0 0

# material name: Grey_Floor_15
# material type: opaque
# comment: This is a purely diffuse reflector with a
# floor reflectivity of 15%.
void plastic Grey_Floor_15
0
0
5 0.15 0.15 0.15 0 0

# material name: Concrete_Wall_15
# material type: opaque
void plastic Concrete_Wall_15
0
0
5 0.15 0.15 0.15 0 0
```

Fig. 16.: The custom materials

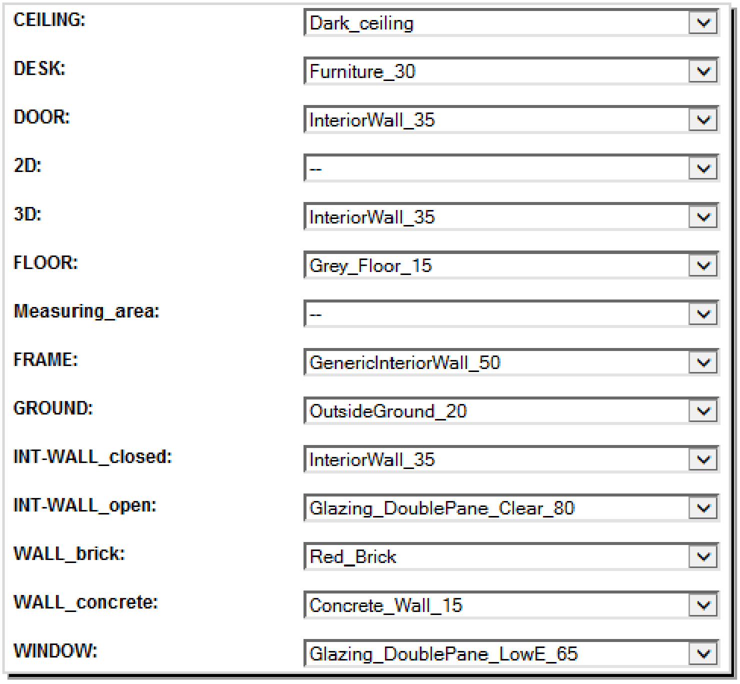
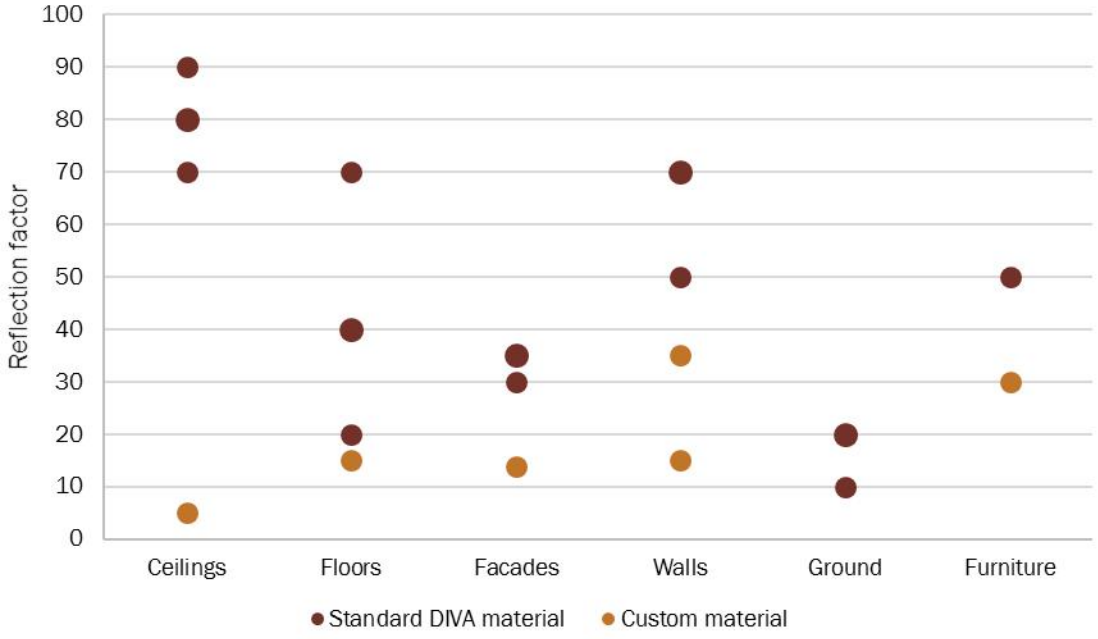


Fig. 17: Materials for each layer



Graph 2: The reflection factor of standard materials from DIVA and custom materials.

Results

The results of all simulations are given in appendix B2.

Daylight

The daylight factor in the room is very low. In more than half of the simulation nodes, it is approximately 0%. The highest values are located directly in front of the window and range from 1.7% to 2.5%. Around the brightest points the daylight factor is lower than 1%. The distribution of light in this simulation is approximately the same as the measurements showed. The simulated daylight factor however is higher than the measured daylight factor. This could be caused by the fact that in reality, even without taking sunlight into consideration, windows with different orientations receive different amounts of daylight. Tregenza and Wilson (2011) use an orientation factor to caluculate the actual daylight factor. This orientation factor is multiplied with the simulated daylight factor.

For this research the same orientation factor is used as Trengenza and Wilson used for London, despite of the different location. The difference can be neglected because the difference in altitude is not bigger than 0.86°(Marsh, 2014). With the orientation factor taken into account, the daylight factors in the room are almost the same as the measured daylight factors. The highest simulated daylight factor is then 1.9% and corresponds with the measured 1.7%. Because the daylight factors are comparable, the simulations can be used to assess the exposure to sunlight and the daylight glare possibility.

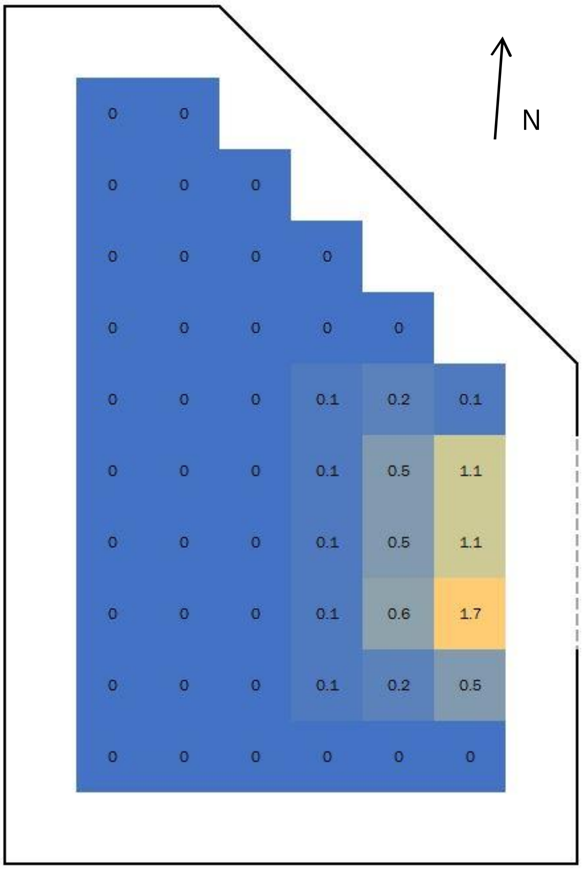


Fig. 18: The measured daylight factor.

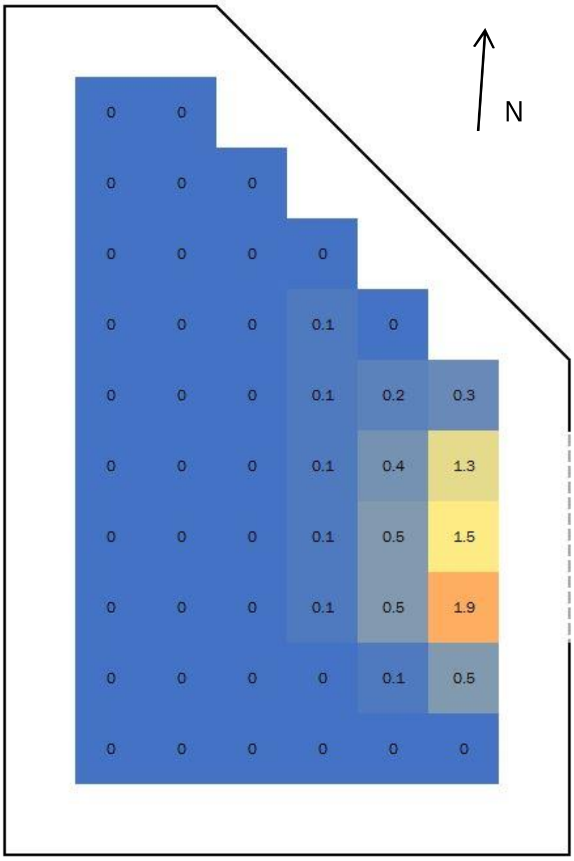


Fig. 19: The simulated daylight factor converted with the orientation factor

Glare

DGP values higher than 0.45 only occur between 8 am and 10 am from April to July. The time it occurs is only 2.2% of the occupation time.

Sunlight

The mirrored fisheye projection with the sunpath diagram as overlay, shows that no direct sunlight enters the room on March 21. The walls of the window well and the façade block a large part of the sky.

View

The view distance from the window in this office room is maximum 5.2 m. The graph in appendix B2 shows that with a window width of 3.4m, the view angle is wider than 14º. From every point in the room the window well is visible, which means that at least the landscape layer is visible.

3.2.3 MEETING THE STANDARDS

Dutch standard

According to the Dutch regulations, the equivalent daylight area in the office room must be 2.5% of the floor area. This floor area is 65.5 m2, which means that the equivalent daylight area must be 1.64 m2.

The equivalent daylight area is calculated with equation (1), which is elaborated in paragraph 2.1.1. There is no transparent or translucent external structure, so the external reduction factor $C_{u,i}$ is 1.

The window has a height of 1.5 m and a width of 3.5 m. Therefore, the area of the daylight opening $A_{d,i}$ is 5.25 m2.

To determine the obstruction factor $C_{b,i}$, the obstruction angles α and β must be measured. For the obstruction angle α the α-zone is divided into ten sections, of which the biggest obstruction angle is determined, shown in figure 20 and 21 and in table 3. The obstruction angle β is also determined and given in table 3.

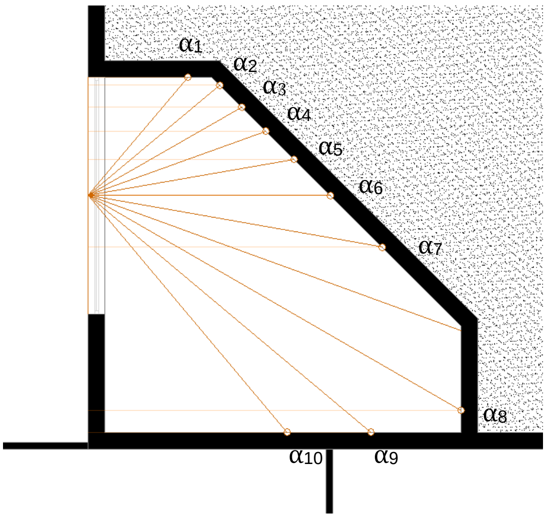


Fig. 20: The obstructions angles α in plan

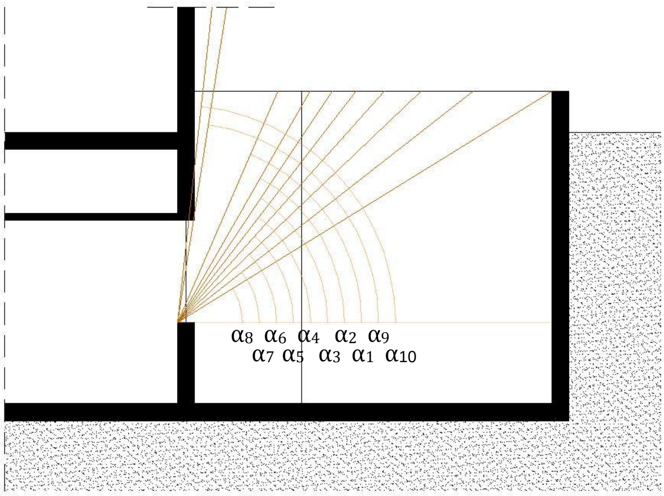


Fig. 21: The obstructions angles α in section

Section	*α [°]*	*Section*	*α [°]*		*α [°]*	*β [°]*
1	56.87	6	32.19			
2	49.18	7	27.41			
3	44.80	8	22.26			
4	40.65	9	83.42			
5	36.52	10	85.92	*Average*	48	31

Table 3: Obstruction angles

According to table 1c in the Dutch standard NEN2057, with these obstruction angles, the obstruction factor $C_{b,i}$ is 0.52. Multiplied with the window area $A_{d,i}$, this gives an equivalent daylight area of 2.73 m2.

$$A_{e,i} = A_{d,i} \cdot C_{b,i} \cdot C_{u,i} = 5.25 \cdot 0.52 \cdot 1 = 2.73\, m^2$$

This equivalent daylight area is bigger than the required equivalent daylight area of 1.64 m2, which means that the office room in the basement meets the Dutch standard.

European standard

Daylight

Looking at the daylight factor converted with the orientation factor, in only 6% of the space the daylight factor is higher than 0.7%. The daylight factor is never higher than 2.1%. This means that the office room does not meet the European standard regarding the amount of daylight.

Sunlight

Because of the absence of direct sunlight in the room, it also does not meet the standard regarding the exposure to sunlight.

Glare

The daylight glare probability is higher than 0.45 in less than 5% of the occupation time. Therefore the glare probability in the room complies with the European standard.

View

Because the view distance is shorter than 6m, the room does not meet all requirements regarding view in the European standard. The view angle and visible layers are sufficient.

3.2.4 Observations

During the measurements in the room a few things stood out. The first thing that was noticed, was how dark the room is, especially in the corners far from the window. Therefore it is logical that most desks were standing near the window. Some desks however stood in the corners. From those desks there was almost no view to the outside. From behind the desks in front of the window people can look outside, but the view is directly blocked by the window well. Therefore there is almost no environmental information visible. The lack of view and light in the room make it an visually uncomfortable room.

3.3 DGMR OFFICE CASUARIESTRAAT THE HAGUE

One of the offices of DGMR is located on the first three floors of a six-story building in The Hague. The exterior and interior of the building is shown in figure 22 and 23. Employees work alone or with one or two colleagues in separated rooms at the north-west side and south-east side of the building. Almost all rooms have the same dimensions: 3.6 x 5.4 m. There are a few exceptions where in most cases only the length of the room differs. Almost all rooms have the same windows and therefore the same daylight area of 3.9 m^2. For this research the exceptions are neglected.

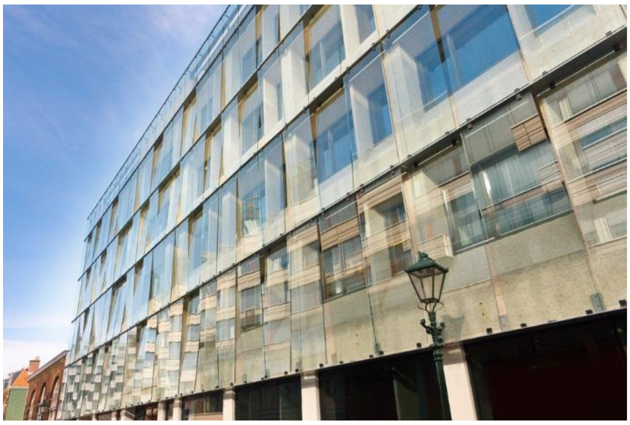


Fig. 22: The exterior of the office building in The Hague at the north-west side of the building.

Fig. 23: The second floor of the office, with rooms at both sides of the building.

For this case study the amount of daylight in two rooms at different sides of the building is measured and simulated and employees from all floors are questioned using a questionnaire. The two rooms are also tested according to the Dutch and European standards.

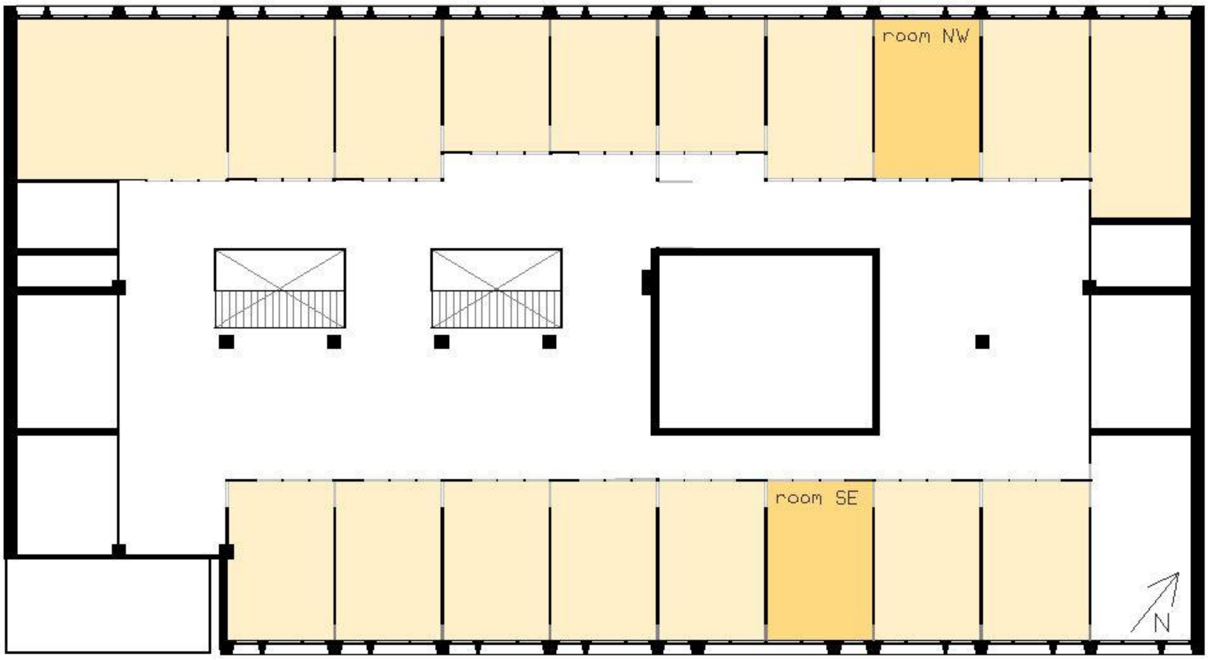


Fig. 24: Rooms on the second floor used by DGMR employees and the two rooms that are measured and simulated.

3.3.1 MEASUREMENTS

Measuring points

The grid of measuring points in each room is calculated according to the method described in paragraph 3.2.1. The grid size is $0.2 \cdot 5^{log(4.4)} = 0.563$ m. This results in eight measuring points with a distance of 0.55 m between them in the longer direction and 5 points with a distance of 0.52 m between them in the shorter direction. In each room the grid therefore exists of forty measuring points, shown in figure 25. The illuminance is measured at a height of 0.75 m, using a tripod or the desks in the room.

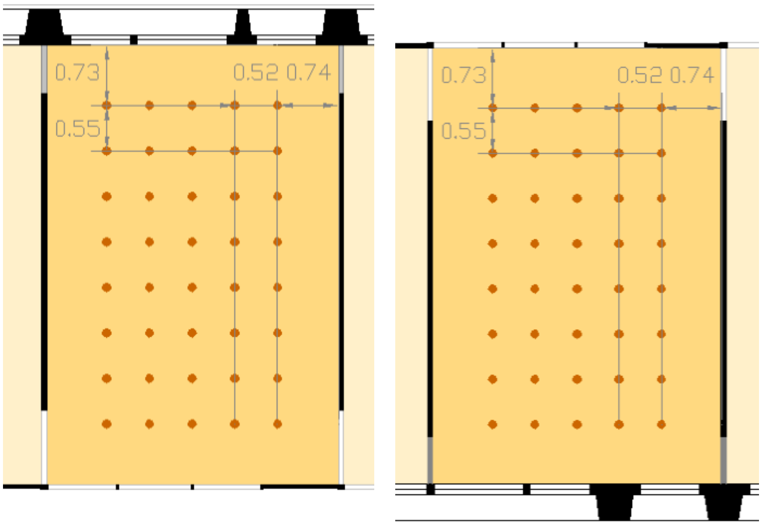


Fig. 25: Measuring grid in both rooms.

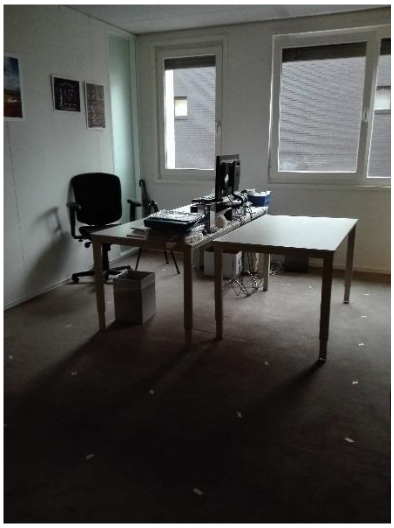


Fig. 26.: Measuring grid in room SE.

Besides the illuminance inside the room, the illuminance outside is also measured. This is done directly outside the window, 0.5 m from the façade, and in streets and areas with as least obstructions as possible. The daylight factor then can be calculated through the ratio between the illuminance inside and in front of the façade and the ratio between the illuminance in front of the façade and in the open field.

Time and circumstances

The measurements were taken on the 16th of November 2017 between 10:15 am and 11:30 am. The sky was overcast, which means there were no big or sudden fluctuations in the illuminance. The results however do show differences in the external illuminances, which means that the sky was not completely overcast and the internal illuminance is influenced by weather changes.

The electrical lights in the rooms that were measured, were turned off. The lighting in the corridor was also turned off, but in the other rooms the lights could not be switched off, because they were occupied by employees. Because of the translucent and transparent panels in the walls between the rooms, some electrical light from adjacent rooms entered the investigated rooms.

Equipment

For the measurements, a lux meter with photometric sensor was used. The sensor for the measurements inside the room was placed on a tripod or on the desks. The lux meter was read a few meters away from the sensor. Hereby the influence of the presence of the researcher was as little as possible.

Results

The measured illuminance values and the calculated daylight factors are given in appendix C1. These results can be used to validate the simulations.

In both rooms the measuring points near the windows have the highest daylight factors. At the north-west side the highest daylight factor is 4.2%. At the south-east side the highest value is 8.2%. The points near the corridor in both rooms have the same lowest value of 0.2%. In both rooms the light is distributed quite evenly, except for the area in front of the window in room SE.

3.3.2 SIMULATIONS

Simulations are again used to determine the amount of daylight, sunlight and glare in the rooms. The method for these simulations is the same as for the simulations of the other case.

The model

From the building the facades, roof, and first three floors are modelled in Rhinoceros. The analysis nodes are placed on the same grid used for the measurements and the weather file that belongs to Amsterdam is used.

Figures 27 and 28 show the Rhinoceros model.

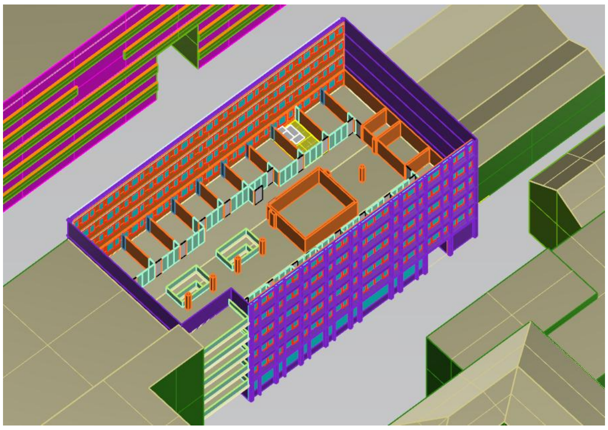


Fig. 27: The office from the South

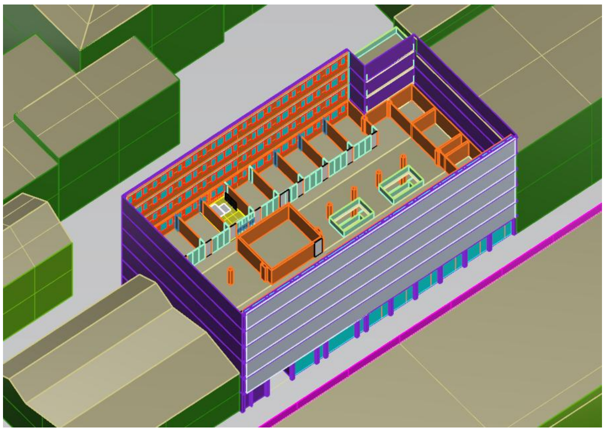


Fig. 28: The office from the North

Materials

The materials that were initially used, were the standard materials in DIVA. But after the first simulations, the results did not match with the measurements. Therefore, many simulations with other materials were performed. In the end no set of materials could make the simulation results match the measurements. This was caused by the measuring method. Because the internal and external illuminances were not measured at the same time, the daylight factors could differ from reality. Because it is unknown whether the results of the measurements were correct, they can not be compared to the simulation results. Therefore, the simulations are performed with the standard materials that match with the actual materials. The used materials are shown in figure 29.

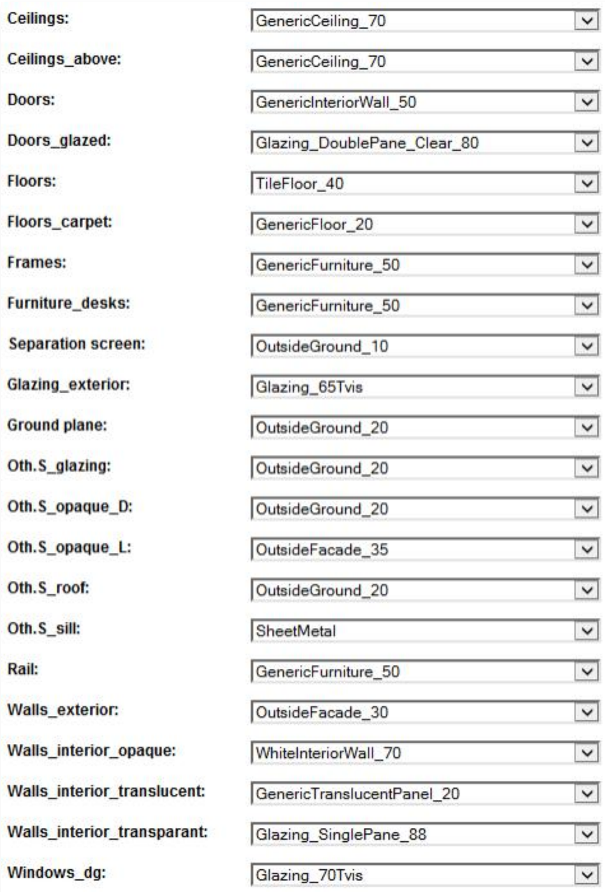


Fig. 29: The materials used for the simulations

Results

The results of all simulations are given in appendix C2.

Daylight

Figure 30 shows the daylight factors in room NW and room SE. The daylight factors in both rooms differ a lot from each other, because at the northwest side of the building the external glass panes reduce the amount of incoming light. In room NW the daylight factors range from 0.13% to 3.01%, while in room SE they range from 0.34% to 10.61%. The minimum daylight factor in 95% of the room is 0.14% in room NW and 0.36% in room SE. In 50% of the room the minimum daylight factor is respectively 0.36% and 1.92%. Especially in room SE the daylight factors in the row in front of the window differ. This is caused by the orientation of the room and the presence of transparent and translucent panels in the separation walls. Near the transparent panels the daylight factors are higher, because they let trough more light.

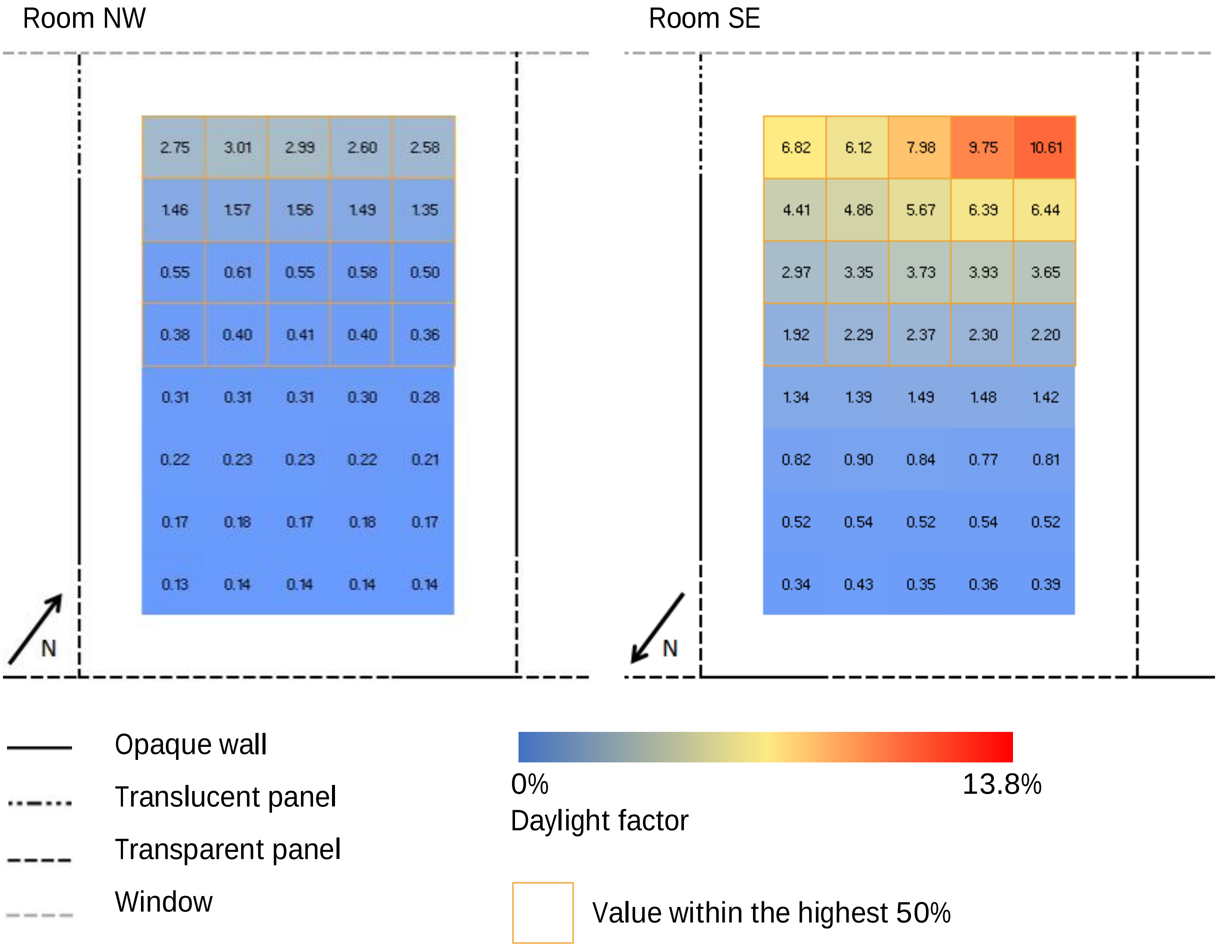


Fig. 30: Daylight factors in room NW and room SE

These simulation results do not match the calculated daylight factors. Using an orientation factor will not help, because the calculated daylight factors are higher than the simulated daylight factors. This is probably caused by the measuring method. The internal and external illuminance were not measured simultaneously, while they can change every minute when the sky is not completely overcast. Afterwards some more measurements were taken, which show that the method indeed is not accurate. The results are given in appendix C2.

Glare

In room NW the DGP is never higher than 0.45. In room SE the DGP is higher than 0.45 during 9.89% of the occupation time.

Sunlight

In room NW direct sunlight enters during 0.2 hours on March 21. For room SE this is 2.7 hours.

View

In both rooms the view distance is bigger than 6m. Because the width of the windows is larger than 1.5m, the view angle is wider than 14° in both rooms. Besides that, from the entire rooms at least the landscape layer is visible.

3.3.3 MEETING THE STANDARDS

Dutch standard

The equivalent daylight area must be 2,5% of the floor area, which is 19.44m². So the equivalent daylight area must be 0.486m². This is less than 0.5m² and therefore the minimum equivalent daylight area of 0.5m² applies.

Tables 4 and 5 show the obstruction angles, obstruction factors, the actual daylight area, the reduction factor and the equivalent daylight area.

	NW	SE
β_1	38.89°	41.47°
β_2	38.89°	41.47°
β_3	38.89°	41.47°
β_4	31.29°	22.65°
β_5	31.29°	22.65°
β_6	31.29°	22.65°
β_7	31.29°	22.65°
β_8	15.08°	22.65°
$\beta_{average}$	32.11°	29.71°
α	20°	20°
$C_{b,i}$	**0.74**	**0.75**

Table 4: The obstruction angles α and β and the obstruction factor of room NW and room SE.

	NW	SE
$A_{d,i}$	3.9 m	3.9 m
$C_{b,i}$	0.74	0.75
$C_{u,i}$	0.65	-
$A_{e,i}$	**1.88 m²**	**2.93 m²**

Table 5: The actual daylight area, the obstruction factor, the reduction factor and the equivalent daylight area of room NW and room SE.

In both rooms the equivalent daylight area is bigger than 0.486m², and therefore they comply with the Dutch standard.

European standard

Daylight

The minimum daylight factors in 95% of the area 0.14% and 0.36% do not meet the European standard of 0.7%. The minimum daylight factors in 50% of the area of 0.36% and 1.92% also do not meet the European standard.

Glare

In room NW the DGP never reaches a value of 0.45 and therefore room NW complies with the standard regarding glare. In room SE the DGP is higher than 0.45 during more than 5% of the occupation time and therefore room SE does not comply with the European standard.

Sunlight

Room NW does not receive sunlight for at least 1.5 hours, and therefore also does not meet the European standard. Room SE does receive sunlight for more than 1.5 hours, and therefore meets the European standard regarding sunlight.

View

Because the view distance is longer than 6m, the view angle wider than 14°, and the landscape layer is visible in the entire rooms, both rooms meet the European standard regarding view.

3.3.4 OBSERVATIONS

During the research much time was spent in room NW and not all results match the experiences. The amount of daylight in the room for example feels like it is enough, while it does not meet the standard by far. Also, the results regarding glare are surprising, because glare was perceived multiple times, for multiple hours, when the sky was clear. Glare was then perceived through reflections on the opposite building. The view also meets the standard, but is perceived as uncomfortable by multiple employees. The main reasons for this are that there is almost no movement visible and the opposite building is quite close to the room.

3.4 Findings

3.4.1 Basement Basisweg

It is very notable that the dark space meets the Dutch standard. It shows that the Dutch standard does not assure good daylight quality. It is therefore not surprising that the daylight factors in the room were too low. It however is remarkable that the uncomfortable view almost complies with the European standard. If the window well had been slightly bigger, the view distance would have been sufficient, just as the other aspects regarding view, that the European standard considers.

An orientation factor is necessary to match the calculated and simulated daylight factors. Even then the results can differ around 20%. What probably caused the different daylight factors, is the fact that, in reality, the sky is not completely overcast. This means that direct sunlight might reflect into the room and contribute to the daylight factor. For the simulations a completely overcast sky is used. While the simulations give the correct daylight factors without the influence of direct sunlight, it is good to use an orientation factor to investigate the common situations in which the sky is not completely clouded.

3.4.2 Office DGMR

This office that has quite good daylight quality, does not meet the European standard. At both sides there is not enough daylight, at the south east side there is too much glare, and at the north west side there is not enough exposure to sunlight. This shows that the amounts of sunlight and glare depend on the orientation, but experience shows that surrounding buildings also influence both aspects. Buildings can of course block sunlight, but they can also reflect it, after which it can cause glare.

Measurements for the determination of the daylight factors should be taken simultaneously. Even on cloudy days the external illuminance, and therefore also the internal illuminance, can differ every minute.

4. SYSTEMATIC STUDY

With a systematic study the effects that the Dutch and European standards have on daylight quality will be investigated and compared. Variants are designed as modifications of the office of DGMR in The Hague. All variants are assessed according to the Dutch and European standard. And the recommendations from the European standard turned out to be hardly achievable.

This study also shows that there is no clear relation between the amount of daylight in a room and the daylight factor.

4.1 Research design

4.1.1 Variant categories

For this systematic study, variants of the current office building of DGMR in The Hague are simulated. Alterations will primarily be made in order to meet the Dutch or European standards. Other alternatives can also be simulated to investigate the difference between the standards.

The variants will be subdivided into three categories:

0. Original design
   The current designs of the office building and the surrounding buildings are used.
1. Minimal window area according to the Dutch standard
   Several variants with the minimal daylight area according to the Dutch standard are modelled and simulated. Only realistic alterations will be made, which means that facades, obstructions, reflection factors and the lay-out of the office rooms can be altered, provided that they do not change the load bearing structure of the office building itself and the surrounding buildings. All surrounding building must preserve the original appearance from the street.
2. Minimal daylight factors according to the European standard
   Through the simulation of several variants, a variant with the minimal daylight factors will be designed. Initially the alterations made, will be realistic, just like the alterations for the minimal daylight area. More alterations however might be useful to investigate what is necessary to meet the European standard. In that case, all elements of the buildings can be changed, but the effects of each alteration must be clear. Therefore, for each alteration, different models and simulations are used.

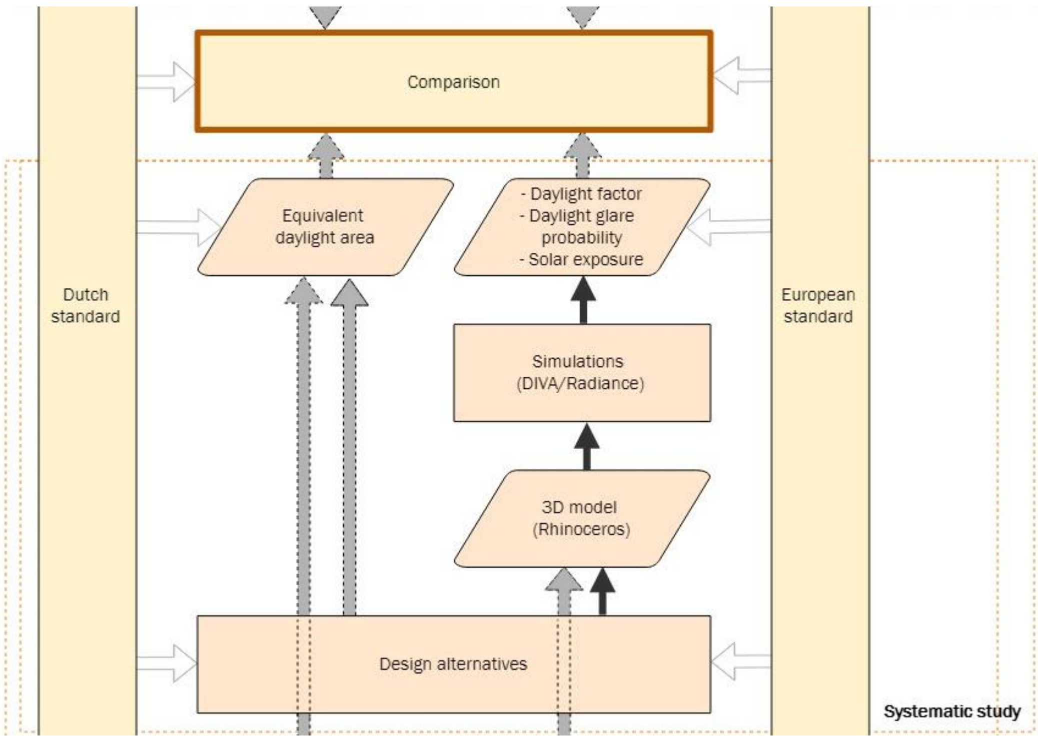


Fig. 31: The process of the systematic study.

An overview of the variants is given in table 6. All variants are also elaborated in the following paragraphs.

0.0	Original design with actual/realistic reflection factors
1	Minimal window area according to the Dutch standard
1.1	’’ with a square window in the centre of the façade
1.2	’’ with a vertical window in the centre of the façade
1.3	’’ with a vertical window on one side of the façade
1.4	’’ with a horizontal window
1.5	’’ without the external glass panes
2	Minimal daylight factor according to the European standard
2.1	Maximum daylight factor, only without the external glass panes
2.2	’’, with maximum reflection factors
2.3	’’, with less separation walls and bigger rooms
2.4	’’, without surrounding buildings
2.5	’’, with the maximum window arae
2.6	’’, with a thinner façade

Table 6: The predefined variants

4.1.2 Simulations

For the simulations the same settings and parameters are used as for the case studies. Those are elaborated in chapter 3, and shortly given in table 7 and figure 32. Also the Rhinoceros model from the case study is used and adjusted for the variants. Only the windows in room NW and room SE are adjusted and therefore the amount of light coming through the panels in the separation walls is the same. When changing the external glass panes or the structure of the façade, the whole façade gets changed.

For all variants the daylight factors, duration of solar exposure and the exceedance time of a daylight glare probability of 0.45 is simulated or calculated. This way all requirements regarding daylight, sunlight and glare can be investigated.

Parameter		Used value
-ab	Ambient bounces	5
-aa	Ambient accuracy	0.1
-ar	Ambient resolution	300
-ad	Ambient divisions	1024
-as	Ambient super-samples	256

Table 7: Radiance parameters

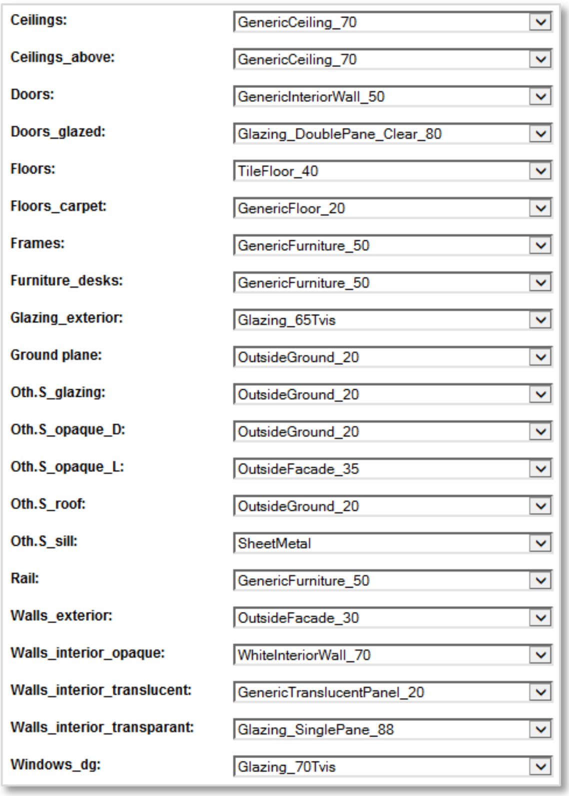


Fig. 32: Used materials

4.2 VARIANTS

4.2.1 CATEGORY 0, ORIGINAL DESIGN

This first variant is the current situation. The 3D model in Rhinoceros is practically the same as the model used for the case study, but simplified. Temporary elements like separation screens and sun shading are not taken into account in this study, because they will also not be taken into account during the assessment of actual designs. Both rooms are 3.6 m wide and 5.4 m deep.

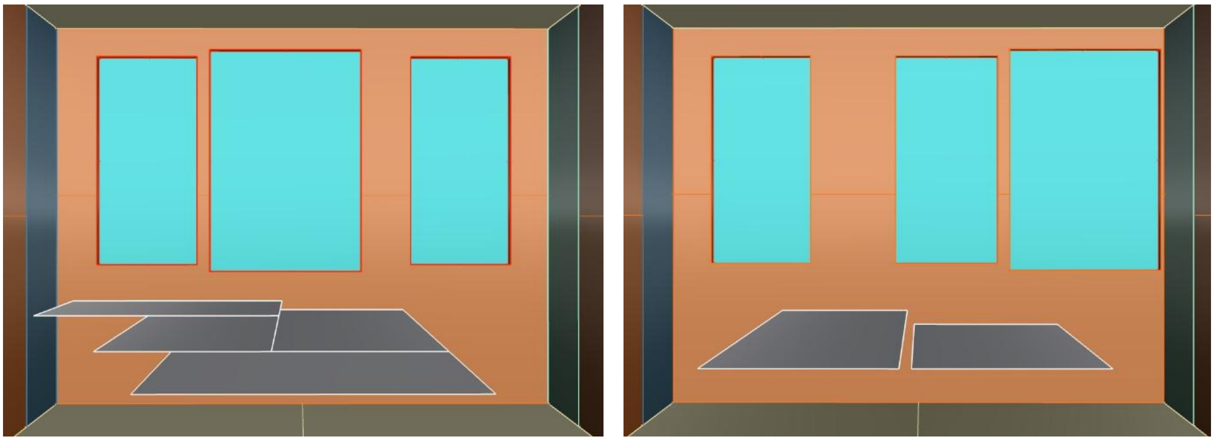


Fig. 33: The original facades in room NW (left) and room SE (right).

Equivalent daylight area

The equivalent daylight area is calculated with the method described in paragraph 2.2. In the following tables the obstruction angles, obstruction factors, reduction factors and daylight areas are given. For the reduction factor of the external glazing is assumed that the glass panes cover the entire façade. Therefore, the reduction factor is the same as the light transmittance of the glass panes.

	NW	SE
β_1	38.89°	41.47°
β_2	38.89°	41.47°
β_3	38.89°	41.47°
β_4	31.29°	22.65°
β_5	31.29°	22.65°
β_6	31.29°	22.65°
β_7	31.29°	22.65°
β_8	15.08°	22.65°
$\beta_{average}$	32.11°	29.71°
α	20°	20°
$C_{b,i}$	**0.74**	**0.75**

Table 8: The obstruction angles α and β and the obstruction factor of room NW and room SE.

	NW	SE
$A_{d,i}$	3.9 m	3.9 m
$C_{b,i}$	0.74	0.75
$C_{u,i}$	0.65	-
$A_{e,i}$	**1.88 m²**	**2.93 m²**

Table 9: The actual daylight area, the obstruction factor, the reduction factor and the equivalent daylight area of room NW and room SE.

4.2.2 CATEGORY 1, MINIMAL DAYLIGHT AREA (DUTCH)

In this category, five variants with the minimal daylight area according to the Dutch standard will be simulated. For the first variant the rooms have square windows on the eye level of a sitting person and in the centre of the façade. The second and third variants have vertical windows with maximal height. The windows in variant 1.2 are placed in the centre of the façade. The windows in variant 1.3 are placed at the right or left side of the façade. Variant 1.4 has a horizontal window on the eye level of a sitting person. Variant 1.5 has the same square windows as variant 1.1, but the external glass panels at the northwest side of the building are not modelled and simulated.

Calculation of the daylight area

For the variants in this category, the actual window area must be calculated. These window areas depend on the equivalent daylight area, the presence of the external glass panes and the obstruction factors. The equivalent daylight area and the presence of external glass panes is for all variants the same, but the obstruction angles differ. These angles are also not definable before the location of the window is known, which depends on the size of the window. To make an estimation of the necessary actual window area, for all variants the same obstruction angles are used. Figure 34 shows variants 1.1 to 1.4, with the distances from the centre of the windows to

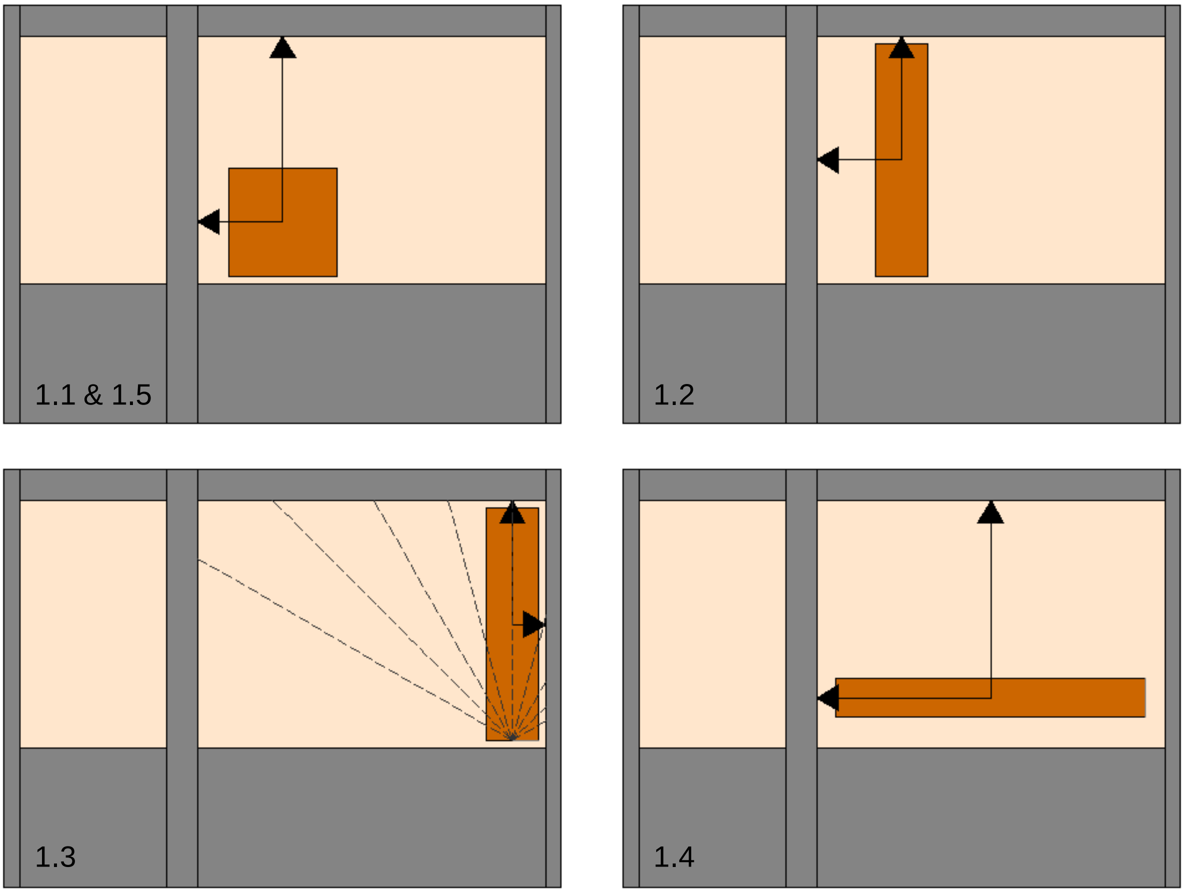


Fig. 34: The façades of variants 1.1, 1.2, 1.3 and 1.4 with the distances from the centre of the window to the obstructions.

the obstructions. In variant 1.3 these distances are the smallest, which means that the obstructions angles are the biggest. For this variant the obstruction angles are measured and used for the calculation of the window area of all variants in this category.

For the windows, the least favourable dimensions are assumed. In this case applies that the narrower the window is, the bigger the obstruction angles are. Therefore a window with a height of 1.5m and a width of 0.33m is assumed. This gives a window with approximately the minimal required area of 0.5m². In a model with such windows in both room NW and room SE, the obstruction angles are measured. These are given in table 10, with the average obstruction angle β, obstruction angle α, and obstruction factor $C_{b,i}$. Obstruction angle α has the minimal value of 20°, because there are no opposite obstructions on the parcel.

	NW	SE
$\boldsymbol{\beta_1}$	31.29°	40.03°
$\boldsymbol{\beta_2}$	31.29°	40.03°
$\boldsymbol{\beta_3}$	31.29°	40.03°
$\boldsymbol{\beta_4}$	31.29°	40.03°
$\boldsymbol{\beta_5}$	55.54°	22.65°
$\boldsymbol{\beta_6}$	55.54°	22.65°
$\boldsymbol{\beta_7}$	55.54°	22.65°
$\boldsymbol{\beta_8}$	55.54°	22.65°
$\boldsymbol{\beta_{average}}$	43.42°	31.34°
$\boldsymbol{\alpha}$	20°	20°
$\boldsymbol{C_{b,i}}$	0.67	0.74

Table 10: The obstructions angles α and β and the obstruction factor of room NW and room SE.

The external glass panes at the northwest side of the building have a light transmittance of approximately 0.65, which gives an extra reduction factor $C_{u,i}$ of 0.65.

The equivalent daylight area must be 2.5% of the floor area: $A_{e,i}$ = (3.6 · 5.4) · 0.025 = 0.486 m^2. This all together gives for room NW an actual daylight area of 1.12 m²:

$$A_{d,i} = {}^{A_{e,i}}/_{C_{b,i} \cdot C_{u,i}}$$

$$A_{d,i} = {}^{0.5}/_{0.67 \cdot 0.65} = 1.12\ m^2$$

Room SE has the same floor area but no external glass panes. Therefore, the actual daylight area is 0.66 m²:

$$A_{d,i} = {}^{A_{e,i}}/_{C_{b,i}}$$

$$A_{d,i} = {}^{0.5}/_{0.74} = 0.66\ m^2$$

	NW	SE
$\boldsymbol{A_{d,i}}$	1,12 m²	0,66 m²
$\boldsymbol{C_{b,i}}$	0.67	0.74
$\boldsymbol{C_{u,i}}$	0.65	-
$\boldsymbol{A_{e,i}}$	0,486 m²	0,486 m²

Table 11: The actual daylight area, the obstruction factor, the reduction factor and the equivalent daylight area of room NW and room SE.

For variant 1.5 the external glass panes are taken out of the model. Therefore there is no reduction factor $C_{u,i}$. Because the construction elements for the glazing are also removed, the obstruction angles and the obstruction factor differ from variants 1.1 to 1.4. Those are given in table 12.

	NW	SE
β_1	22.65°	40.03°
β_2	22.65°	40.03°
β_3	22.65°	40.03°
β_4	22.65°	40.03°
β_5	55.54°	22.65°
β_6	55.54°	22.65°
β_7	55.54°	22.65°
β_8	55.54°	22.65°
$\beta_{average}$	39.10°	31.34°
α	20°	20°
$C_{b,i}$	0.70	0.74
$C_{u,i}$	-	-
$A_{d,i}$	0,69 m^2	0,66 m^2
$A_{e,i}$	0,486 m^2	0,486 m^2

Table 12: The obstructions angles α and β and the obstruction factor of room NW and room SE in variant 1.5.

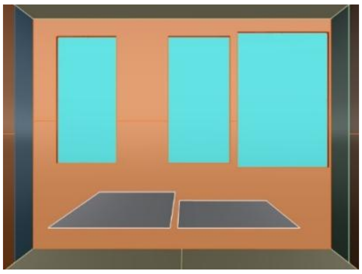
All variants are shown in figure 35. The calculation of the daylight areas is given in appendix D1.

4.2.3 Category 2, minimal daylight factor (European)

In category 2, six variants will be assessed according to the Dutch and European standards. All variants are designed to reach the highest daylight factors possible, but in each variant only one element is changed. In variant 2.1 the external glass panes are removed. Variant 2.2 has maximum reflection factors on all surfaces. In variant 2.3 some separation walls are removed, so the rooms are twice as wide. Variant 2.4 is simulated without the surrounding buildings. For the last two variants, the structure of the façade is adapted. In variant 2.5 the rooms have maximum daylight area. In variant 2.6 the façade is thinner.

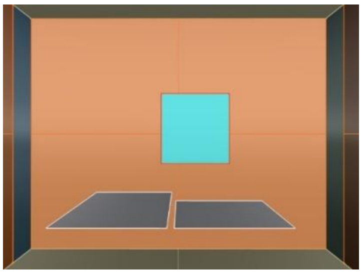
Appendix D1 contains the obstruction angles, obstruction factors, reduction factors, and daylight areas of the variants.

Category 0

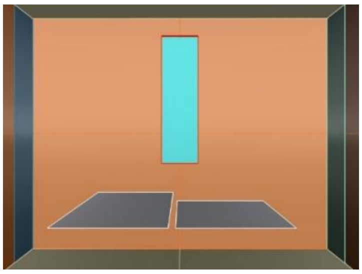


0.0
Original situation

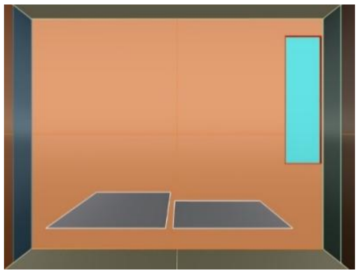
Category 1 – Dutch standard



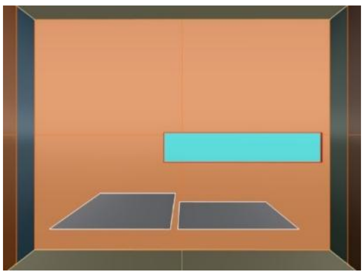
1.1
Min. $A_{e,i}$ / square



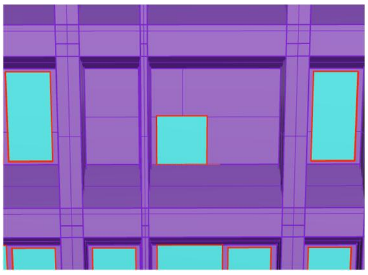
1.2
Min. $A_{e,i}$ / vertical / centre



1.3
Min. $A_{e,i}$ / vertical / side



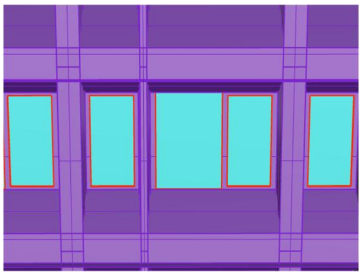
1.4
Min. $A_{e,i}$ / horizontal



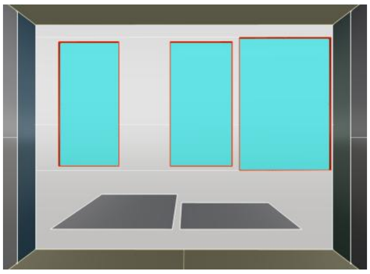
1.5
Min. $A_{e,i}$ / square / no ext. glass

Fig. 35:: An overview of all variants

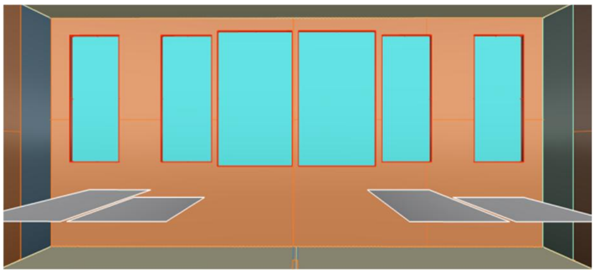
Category 2 – European standard



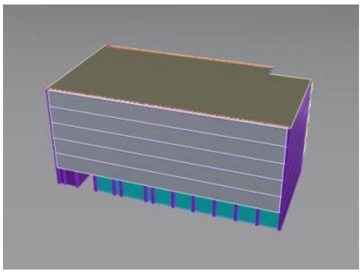
2.1
No ext. glass



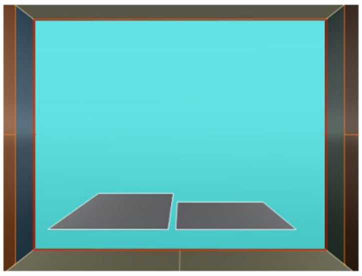
2.2
Higher relection factors



2.3
Less separation walls



2.4
No surroundings



2.5
Fully glazed

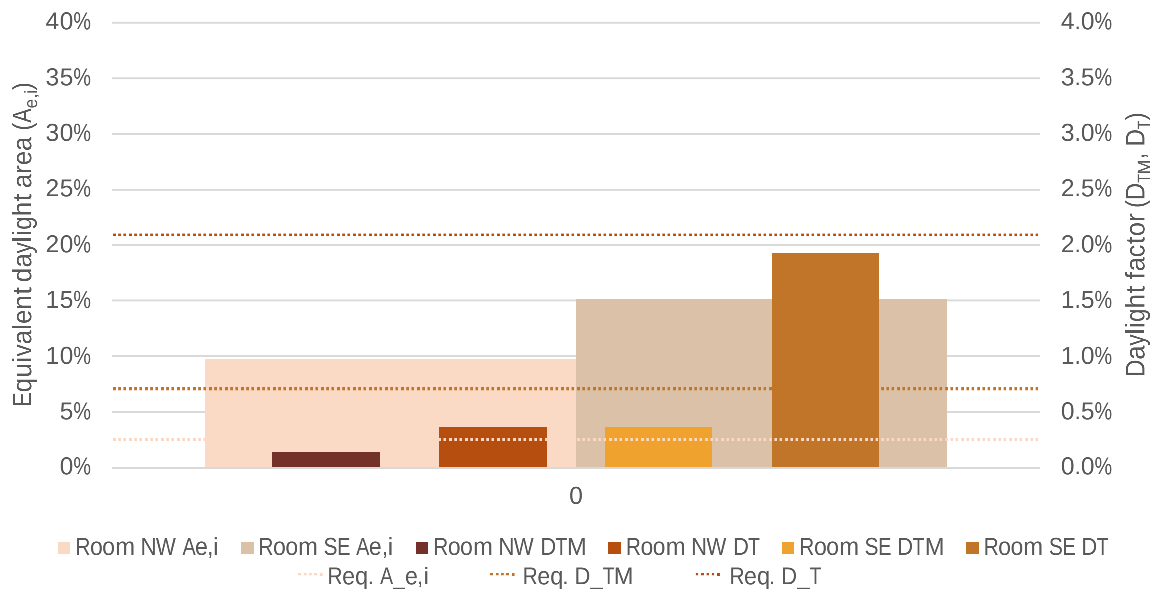
2.6
Thinner facade

4.3 Results

In this paragraph the results will be summarised and discussed. All results are documented in appendix D2.

4.3.1 Category 0 – original situation

In the original situation, variant 0.0, the equivalent daylight area is 9.7% in room NW and 15.1% in room SE. This is respectively 4 and 6 times bigger than the required equivalent daylight area according to the Dutch standard. The minimum daylight factor in 95% of the area (D_{TM}) is 0.14% in room NW and 0.36% in room SE. In the brightest 50% of the area the minimum daylight factor (D_T) is 0.36% in room NW and 1.92% in room SE. All these daylight factors do not meet the required values according to the European standard. Especially in room NW, they should be almost six times as high. In room SE the minimum daylight factor in 50% of the area is almost high enough, but the minimum daylight factor in 95% of the area should be twice as high.

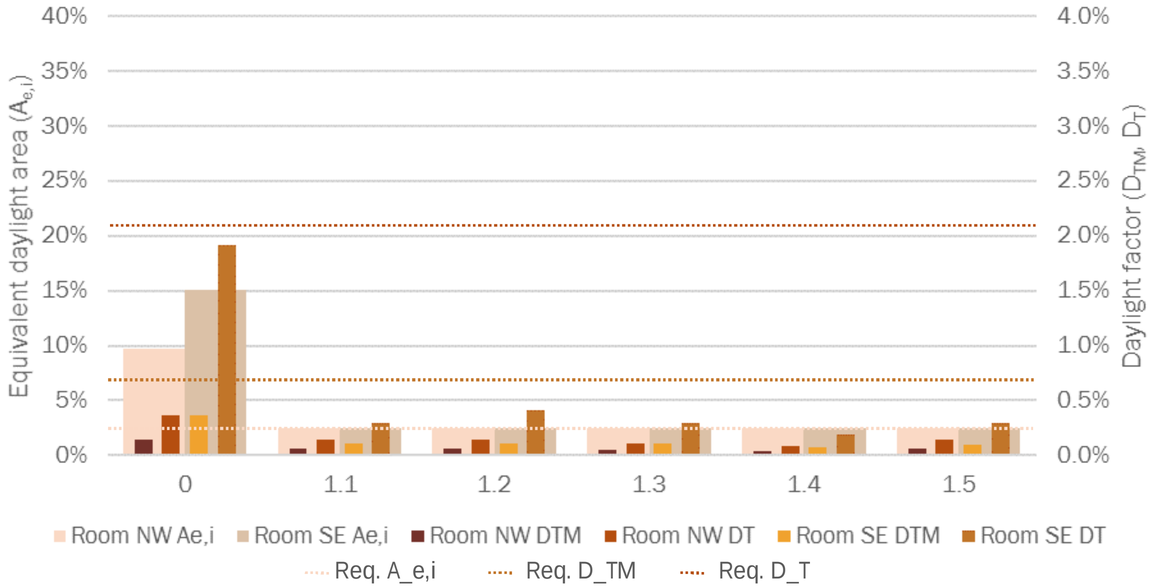


Graph 3: Daylight factors in the original situation

4.3.2 Category 1 - minimal daylight area

In this category all variants have the minimum required equivalent daylight area of 2.5%. The shape and size of the windows differ per variant.

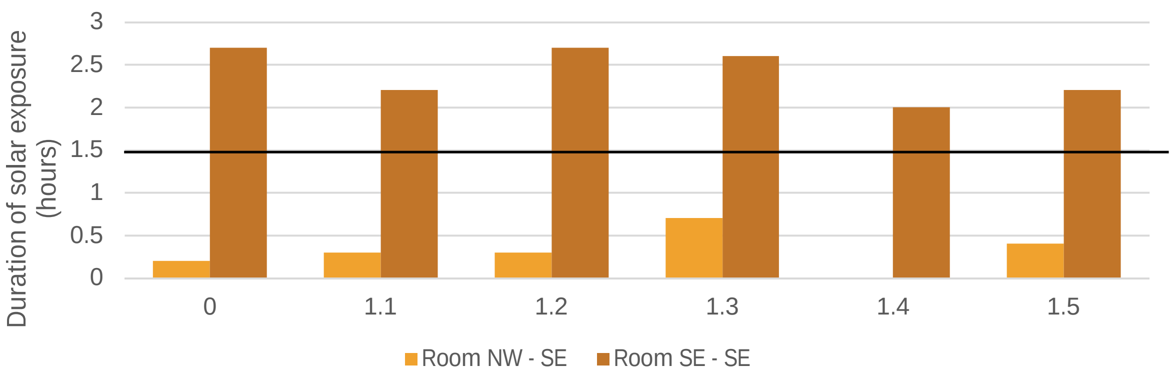
Daylight



Graph 4: Daylight factors in category 1

All variants have approximately the same minimum target daylight factors. Only variant 1.4 has a significant lower value in room SE. This is caused by the shape of the window, which is wide, with a height of only 35cm. This variant also has the lowest target daylight factors in 50% of the area. At the southeast side variant 1.2 has the highest target daylight factors in 50% of the area. This is the variant with the high, narrow window in the centre of the façade, through which a higher and brighter part of the sky is visible. Because of the orientation this difference is smaller at the northwest side of the building. There the square window in the centre gives the highest minimum daylight factor in 50% of the area. The high, narrow window near a separation wall gives lower daylight factors, because the light is only distributed to one side. The results of variant 1.1 and 1.5 are approximately the same, which means that the presence of external glass panes is correctly taken into account with the calculation of the equivalent daylight area.

Duration of solar exposure

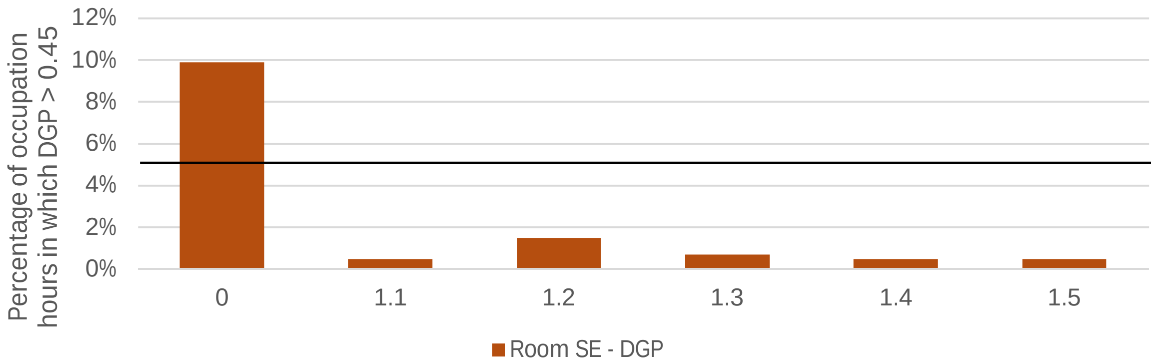


Graph 5: Solar exposure (SE) in category 1

In all variants the duration of exposure to direct sunlight is less than 1.5 hours in room NW and more than 1.5 hours in room SE. In general, the longer, narrower windows gain more direct sunlight. At the northwest side the long, narrow window in variant 1.3 gains more sunlight, because it is located closer to the end of the opposite building.

Glare

The daylight glare probability does not exceed a value of 0.45 in more than 1.5% of time in every variant. It increases with the height of a window, and when the window is closer to the viewpoint. Therefore variant 1.2 and 1.3, with long, narrow windows, have higher glare probabilities than the other variants. And because the window in variant 1.2 is closer to the viewpoint than the window in variant 1.3, the daylight glare probability also increases.

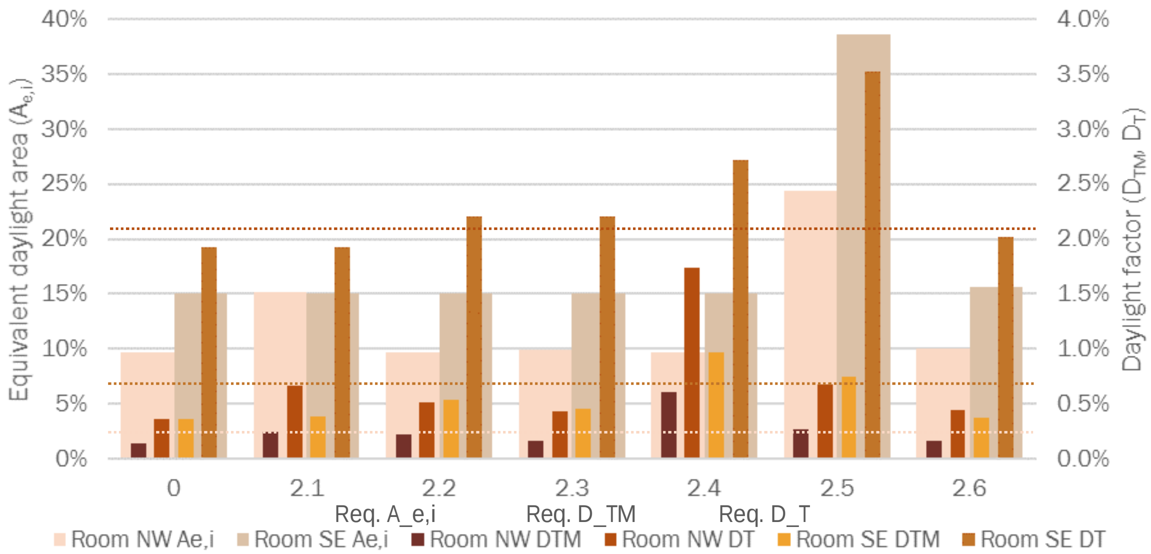


Graph 6: DGP in category 1

4.3.3 Category 2 - Minimal daylight factor

The variants in this category are designed to gain as much daylight as possible. The equivalent daylight area therefore can differ in this category, just like the materials and structural and spatial design of the building.

Daylight



Graph 7: Daylight factors in category 2

The first variant, 2.1, shows that without the external glass panes the equivalent daylight area in room NW is approximately 1.5 times as big as in the original situation. The daylight factors however are approximately 1.8 times as big. The extra light at the northwest side of the building also influences the amount of daylight at the southeast side, because it travels through the glass separation walls. The daylight factors in variant 2.1 are therefore slightly higher than the daylight factors in variant 0.0. With higher reflection factors in variant 2.2, the equivalent daylight area stays the same. The daylight factors however do increase.

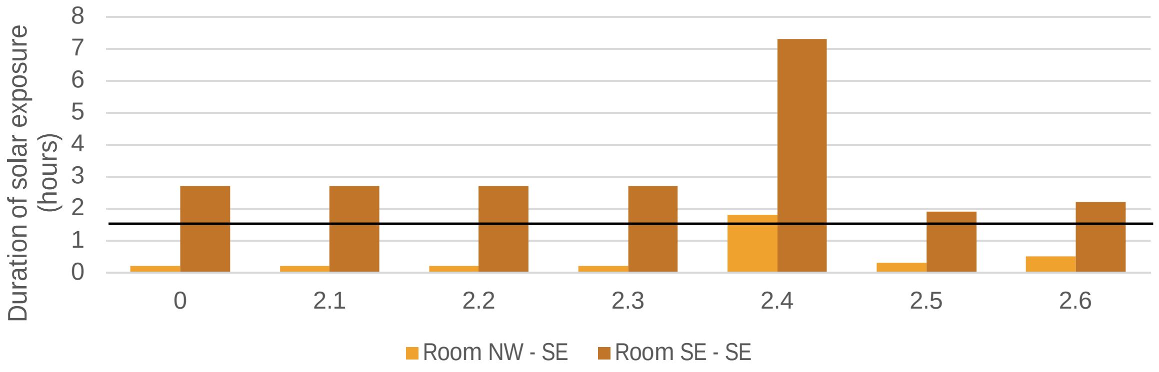
In the bigger rooms of variant 2.3, which are relatively less deep, the equivalent daylight areas and minimum daylight factors do not change much. The daylight factors in the middle of the rooms however are higher than in the original situation.

The surrounding buildings, which are removed in variant 2.4, influence the minimum daylight factors the most. Without them the minimum daylight factors are 4 to 6 times as high in room NW and 1.5 times as high in room SE. This also shows that the orientation of a room does influence the daylight factors.

In variant 2.5, with a fully glazed facade, the equivalent daylight areas are twice as big as in the original situation. The same applies to the daylight factors which are also approximately twice as big as in the original situation.

With the thinner facade in variant 2.6, both the equivalent daylight area and the daylight factors are slightly bigger.

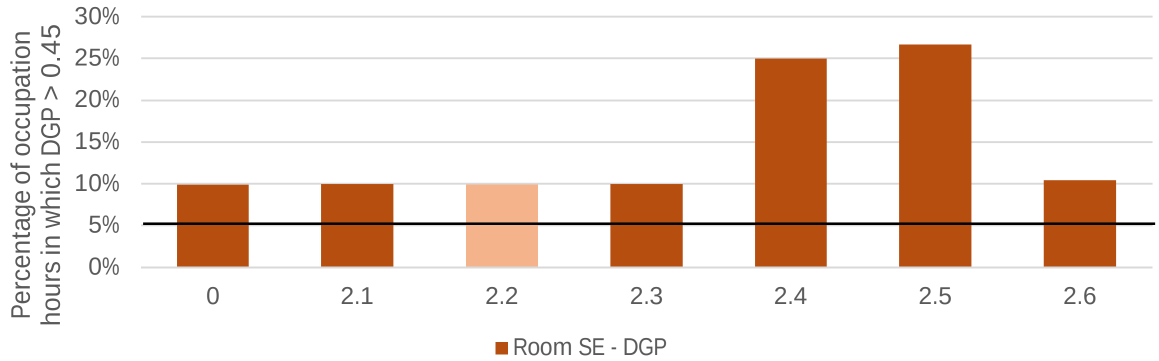
Duration of solar exposure



Graph 8: Solar exposure (SE) in category 2

In all variants in this category, in room SE the duration of exposure to direct sunlight in longer than 1.5 hours, and in room NW it is shorter. Variant 2.4 is an exception. Because the surrounding buildings do not block the sun in this variant, even at the northwest side the duration of solar exposure is 1.8 hours.

Glare

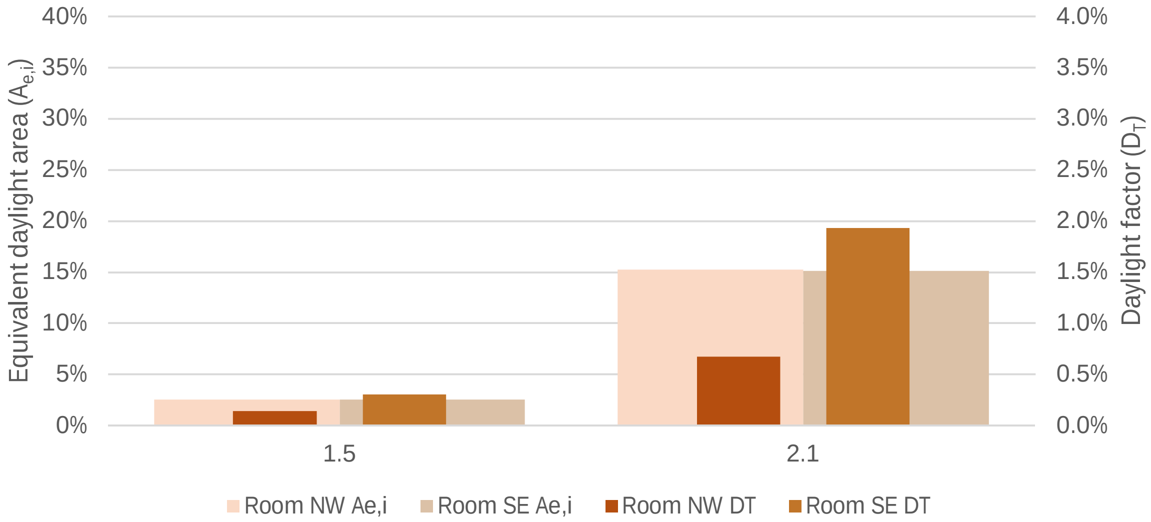


Graph 9: DGP in category 2

Because the windows are bigger in this category, in all variants the daylight glare probability exceeds a value of 0.45 in more than 5% of the occupation time. This is especially the case with the fully glazed facade, and the absence of surrounding buildings.

4.3.4 Overall results

Orientation



Graph 10: Daylight factors in variants with no external glass panes

As shown in graph 10, the differences between the target daylight factor in room NW and room SE are quite big. These are results from variants with no external glass panes. Therefore, the differences are not caused by the external glass panes. With an equivalent daylight area of 2.5% (variant 1.5) the target daylight factor in room SE are twice as high as the minimum daylight factors in room NW. When the equivalent daylight area is approximately 15% (variant 2.1), the target daylight factor in room SE is almost three times as high as the minimum daylight factors in room NW. The differences can be caused by the orientation and the surrounding buildings.

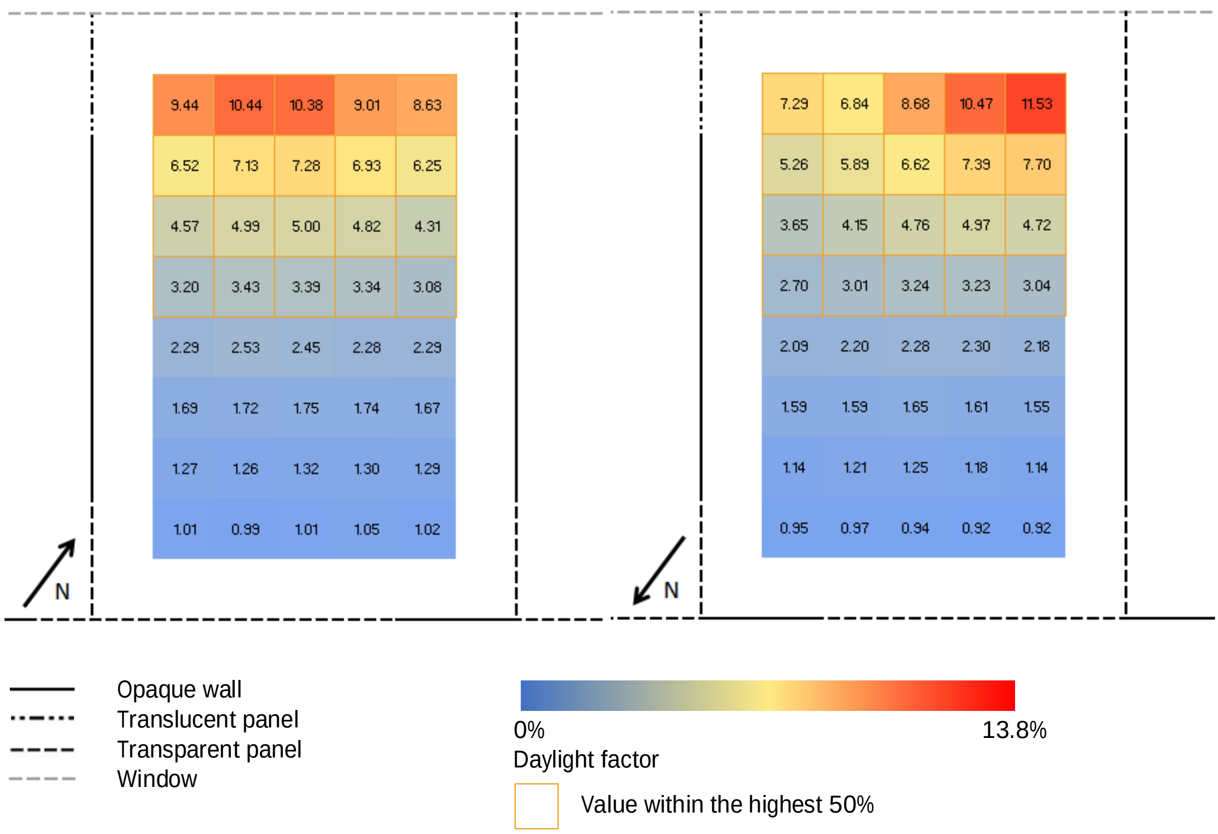
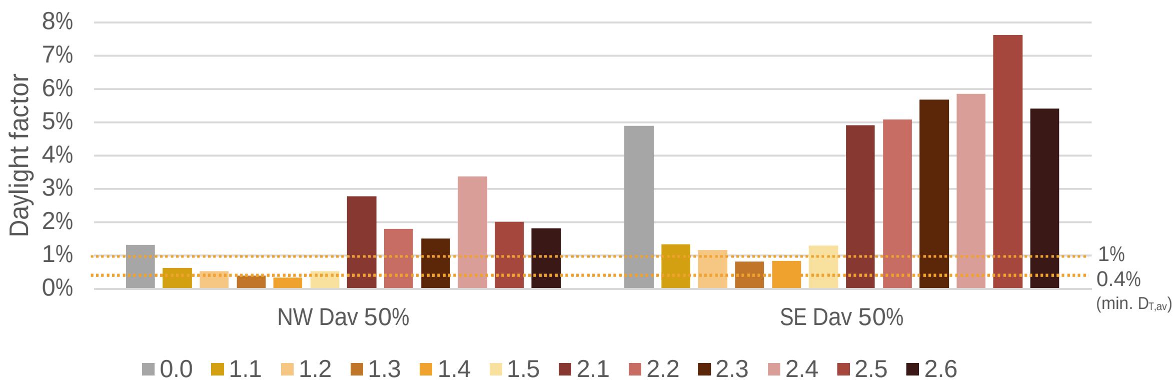


Fig. 36:: The daylight factor in the variant with no glass panes and no surroundings

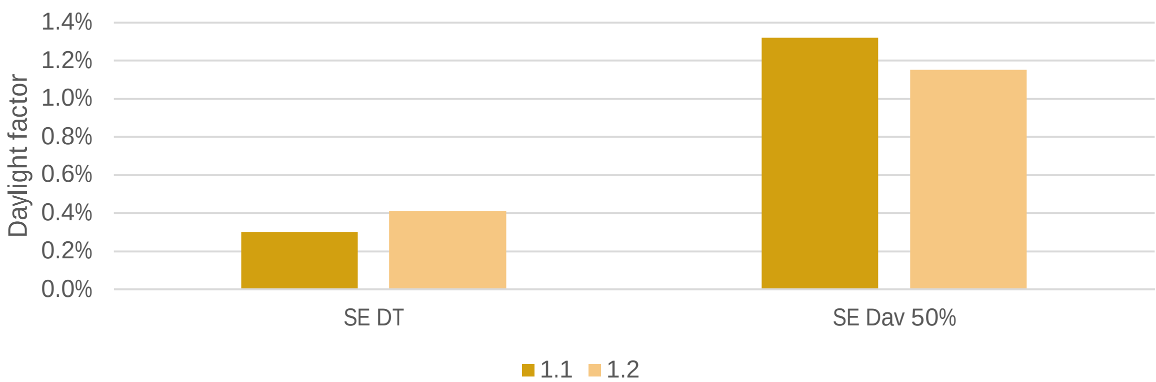
To investigate the influence of the orientation more, another variant with no glass panes and no surroundings is simulated. In this variant the daylight factors in both rooms should be approximately the same, because theoretically the orientation does not influence the daylight factor. The results of the simulation is shown in figure 36. The target daylight factor is higher in room NW. This means that there is something else in the building that influences the daylight factor. This might be the columns in the façade or the foils on the glass separation walls. When simulating with a completely overcast sky, the orientation does not influence the daylight factors much. In reality this might differ, when direct sunlight is reflected into a room.

Average daylight factors in 50% of the area



Graph 11: Average daylight factors

The average daylight factors in 50% of the area is in some variants more than 1.0%. This is the level recommended for a new Dutch standard. This level is met in the variants in category 0 and 2, with equivalent daylight areas of 9.7% or more.



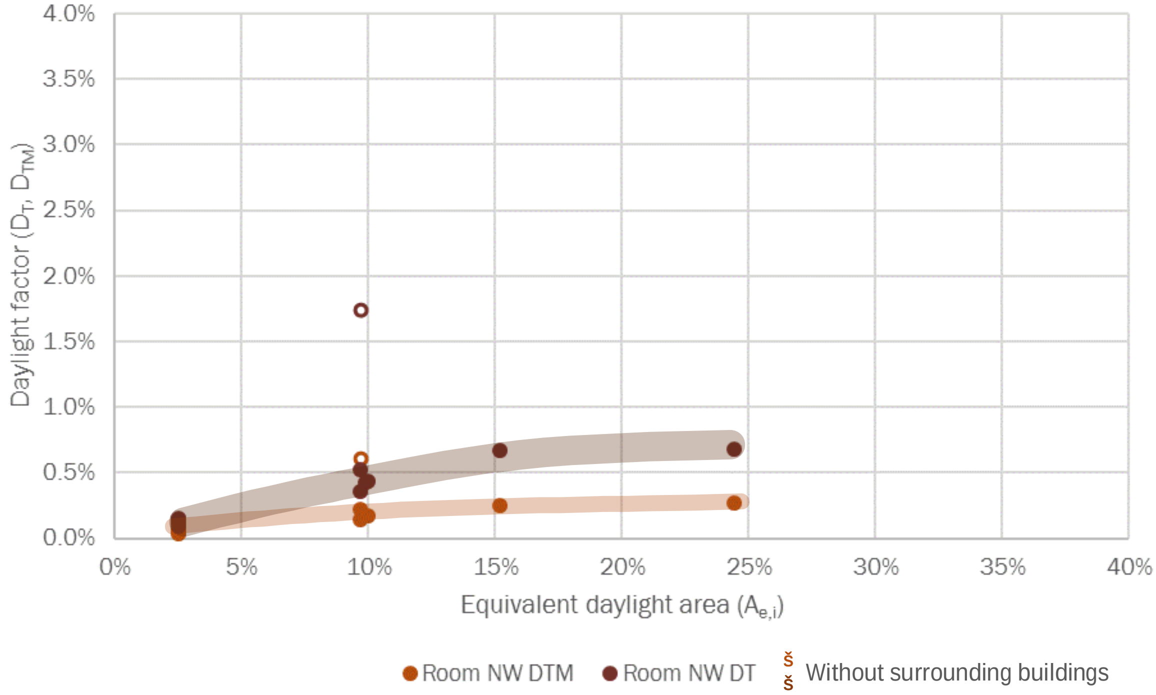
Graph 12: Average daylight factors in variant 1.1 and 1.2

Remarkable are the results of variant 1.1 and 1.2. The target daylight is higher in variant 1.2 and the average daylight factor in 50% of the area is higher in variant 1.1. It therefore is recommended to look at the average daylight factor in a room, besides the target daylight factor. A high target daylight factor does not assure daylight quality in the whole room.

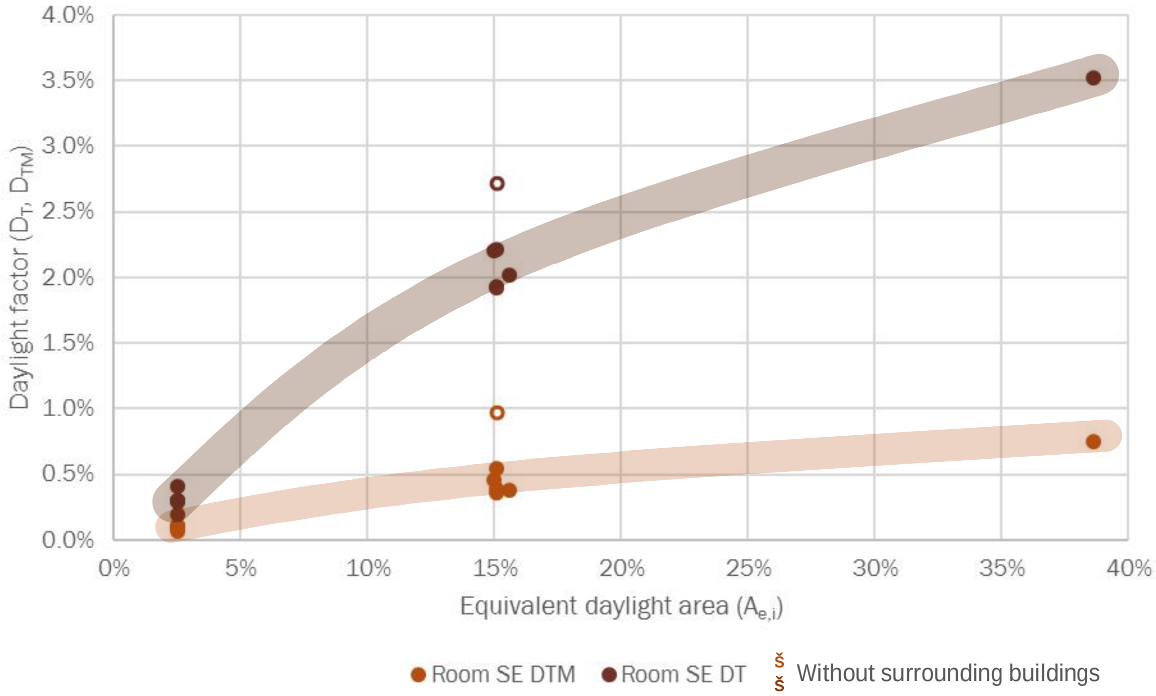
Relation between equivalent daylight area and daylight factor

Graphs 13 and 14 show the relation between the equivalent daylight area and the minimum daylight factors. Only the daylight factors of the variant without surrounding buildings are significantly higher than the other variants with approximately the same equivalent daylight area.

Extrapolation of the results show that the minimum daylight factor in 95% of the area will probably not get much higher than 1% when the equivalent daylight area increases. The minimum daylight factor in 50% of the area can get much higher. Especially with a beneficial orientation and a larger distance from surrounding buildings.



Graph 13: The relation between equivalent daylight area and daylight factor



Graph 14: The relation between equivalent daylight area and daylight factor

4.4 FINDINGS FROM THE SYSTEMATIC STUDY

Firstly, the variants in category 1 show the big difference between the required levels of daylight of the Dutch and European standard. They do not reach the recommended levels of daylight of the European standard by far.

With the variants in the category 2 is tried to reach the target daylight factor and the minimum target daylight factor in several ways. In most variants the minimum target daylight factor of 0.7% is not met. The target daylight factor of 2.1% is met more often, but also only at the south east side of the building. This shows that it is almost impossible to meet the European standard.

The results also show that the daylight factors depend on much more factors than the daylight area only. Therefore, there is no clear relation between the equivalent daylight area and minimum daylight factors. The factors that influence the daylight factors the most, besides the daylight area, are the surroundings, orientation and the window shape. The surroundings block much light, which makes it difficult to reach sufficient levels of daylight in dense areas. The orientation of a building mainly influences the amount of sunlight and glare, but also the amount of daylight. And the shape of the windows influences the view and amount of daylight, sunlight and glare. Vertically longer windows let through more light and wider windows give a wider view.

Because there are more factors that influence the amount of daylight in a room, there is no clear relation between the daylight area and the daylight factor.

5. Conclusions & Recommendations

In this part of the report the research questions will be answered and the recommendations for designers will be established. The main research question is

What are the main differences between the Dutch and the European standards for daylight in buildings?

Three aspects were considered while investigating this question: the assessment method, the requirements and the visual effects. First the assessment method and requirements will be discussed, then the visual effects. Following the conclusions, the recommendations for designers will be given.

At last there will be a discussion on the research and potential following research.

5.1 CONCLUSIONS

5.1.1 DIFFERENCES REGARDING THE ASSESSMENT METHODS AND REQUIREMENTS

The Dutch standard for daylight in buildings assesses the geometric design of a building. In contrast to the European standard, which describes required quantities and qualities of daylight, sunlight and view, the Dutch standard describes how one should design the geometry of a space, and assumes with that geometry the space will have a sufficient amount of daylight. In other words, the Dutch standard is normative, while the European standard is descriptive. The part of the European standard about glare however is normative, like the Dutch standard.

Another big difference is that the European standard takes more aspects than only daylight into account, namely sunlight, glare and view. The Dutch standard does not give requirements for those aspects.

The European standard also gives the designer more freedom, because the recommendations are no hard requirements, which the Dutch standard gives. It also does not give minimum obstructions and limits for the reflection factors, which are included in the Dutch assessment method. For the European assessment, realistic values that match with the current or known future situation should be used.

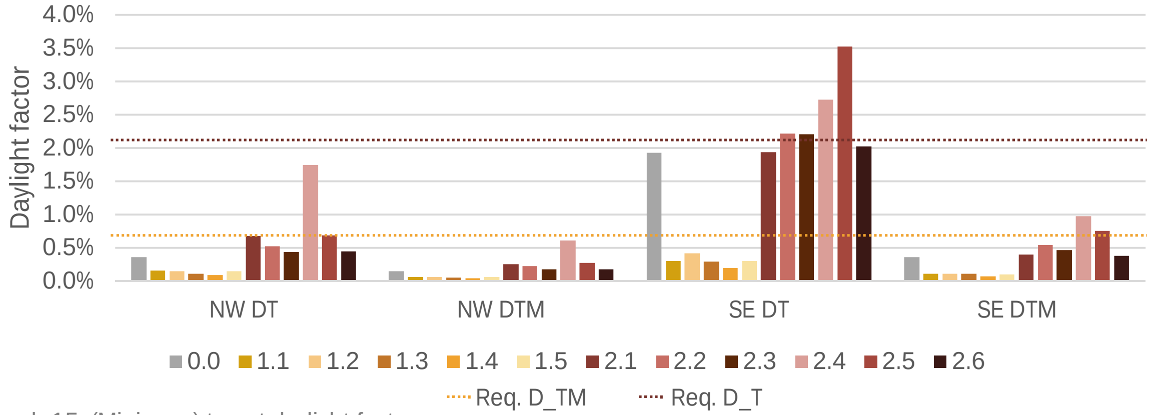
Both standards do have multiple requirements for one aspect of daylight. The Dutch standard for example requires a minimum equivalent daylight area of 2.5% of the floor area, but the equivalent daylight area cannot be smaller than $0.5m^2$. The European standard gives a target daylight factor of 2.1% for 50% of the area and a minimum target daylight factor of 0.7% for 95% of the area.

From the case studies and systematic study can also be concluded that the Dutch standard can be met easily, because all variants and even the dark basement comply with the standard. The recommended level of the European standard is almost impossible to meet, especially the minimum target daylight factor for 95% of the area, but the target daylight factor for 50% of the area is also hard to reach.

5.1.2 Differences regarding the visual effects of the standards

The results of the case studies and systematic study show that the Dutch standard does not assure a good visual climate. There still can be too little light, no exposure to sunlight and an unsatisfying view. This was the case in the basement at the Basisweg in Amsterdam, and in the room at the northwest side of the DGMR office in The Hague.

In contrast to this, the recommendations from the European standard are too high, especially in dense areas with many surrounding buildings. The minimum target daylight factor of 0.7% is never met in all variants of the systematic study. And for the target daylight factor of 2.1% the daylight openings should be abnormally big.



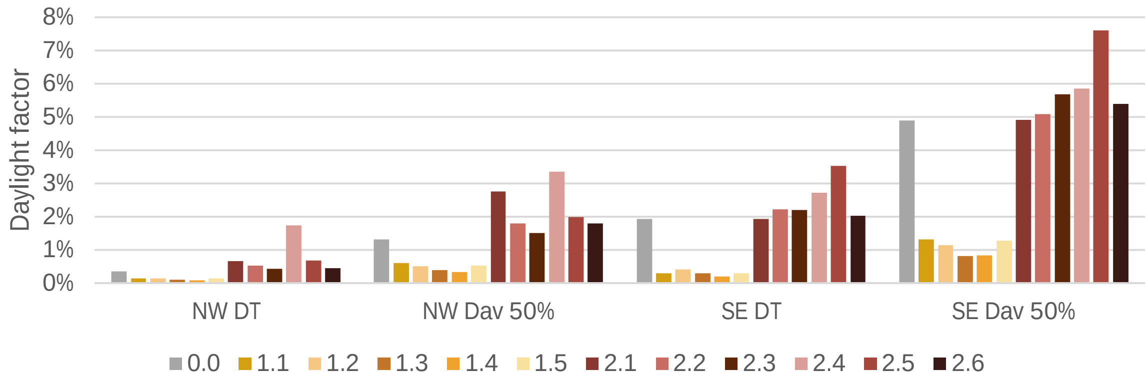
Graph 15: (Minimum) target daylight factors

With these large amounts of daylight, the glare probability also gets higher. To decrease this probability, shading should be applied.

Comparing the equivalent daylight area and the daylight factor, it can be concluded that in many cases the target daylight factor can reach a level of 0.4%, as is stated in the research report for a new Dutch standard. At the north west side however, this target daylight factor is still not reached with the minimum required equivalent daylight area of 2.5%.

A more achievable target daylight factor for rooms with an equivalent daylight area of 2.5% is 0.2% (shown in graph 16). This is not even close to the recommended daylight factor of 2.1%.

The average target daylight factor in rooms that meet the Dutch standard, can be 0.4%. For rooms that meet the European standard, the average target daylight factor can be 1.5%.



Graph 16: (Average) target daylight factors

5.1.3 SET OF RECOMMENDATIONS FOR THE DESIGNER

As a designer one should know that the requirements in the Dutch standard do not assure good daylight quality and the recommendations regarding daylight in the European standard are almost unachievable in a dense environment. Therefore, some other recommendations are established.

- Firstly, it is important to always consider the specific situation and the possibilities for a building or site. The surroundings and orientation have a big influence on the daylight quality in a room, but can not be changed.
- Because the sky is almost never completely clouded, the orientation should be taken into account. For example with the use of an orientation factor when simulating daylight factors.
- With simulations, it is good to use standard materials with standard reflection factors. Materials can change and the furniture or decorations can also change the reflection from the surfaces in a room. This way it is most likely that the daylight quality will stay sufficient in the future.
- Also, the surroundings of a building can change. Therefore, it is recommended to use minimum obstructions for the assessment of daylight.
- The shape of a window influences the incoming daylight and view. The vertically longer the window, the more light comes through. But for a better view the windows should be wider.
- A minimum daylight factor in a certain part of the occupied area does assure a certain level of daylight, but can be misleading. Therefore, it is good to also assess the average daylight factor in a (part of the) room.
- It is recommended to comply with a minimum daylight factor of at least 0.8% in 50% of the area. This is possible for most situations. In many cases it can even be much higher.
- For the average daylight factor in 50% of the area it is recommended that it is at least 1.5%. This can also be much higher, depending on the surroundings and orientation.
- Besides the amount of daylight, it is important to also consider exposure to sunlight, glare and view. The access of much daylight can for example cause a chance of glare. In that case shading should be applied.
- Lastly, it is important to realise that simulations are approximations. They are no guarantee for daylight quality in reality, but they give good insight in the daylight quality and the factors that influence it.

5.2 Discussion

The aspects that are investigated in this research are quite limited. Therefore, there are a few aspects that are not or barely mentioned, which however are interesting. This means that some recommendations might have negative effects that were not considered in this research. To be able to establish recommendations that assure good daylight quality much other research is needed.

One thing that is shortly investigated, but can be elaborated more, is the influence of the orientation on the daylight quality. Results showed that with the simulation of daylight factors, there is no influence from the orientation. The measured and calculated daylight factors however are influenced by the orientation. And in general, the orientation is very important for the experience of daylight. This however could be investigated more in depth in following research.

For the establishment of the recommended levels of daylight, research in combination with personal experiences is used. The recommendations however are mainly based on assumptions and could be substantiated or validated. In that case not only the experience of daylight can be considered, but also the effects on the health and productivity of building occupants. For this, research is necessary to gain insight in the effects of daylight on health in general and more specific the effects of daylight in buildings. This way the sufficient amount of daylight can be determined. Distinction can be made between different building functions and different building occupants. Also, the amount of time people spent indoors influences the effects of daylight on them. Because there are so many influencing factors, much research can be done on this topic.

The European standard does not distinguish different building functions. The Dutch standard does, and therefore research similar to this, but for other functions might be useful for the implementation of the European assessment method in the Dutch building regulations.

Something else that must be considered when designing daylight openings, are other physical effects like thermal and energetic effects. It would be good to investigate those effects in other following research.

6. References

6.1 BIBLIOGRAPHY

3DL. (n.d.). *TNO norm bezonning*. Retrieved from 3DL: https://www.3dl.nl/informatie/TNO_norm_bezonning

Aries, M., Aarts, M., & Hoof, J. v. (2015). *Daylight and health: A review of the evidence and consequences for the built environment.* Lighting research & Technology, 6-27.

Baker, N., & Steemers, K. (2002). *Daylight Design of Buildings*. London: James & James.

BRIS. (2012). *Afdeling 3.11. Daglicht*. Retrieved from Bouwbesluitonline: https://www.bouwbesluitonline.nl/Inhoud/docs/wet/bb2012/hfd3/afd3-11

DIVA4Rhino. (2018). *DIVA User Guide*. Retrieved from DIVA for Rhino: http://diva4rhino.com/user-guide

European Committee for Standardization. (2016, July). *prEN 17037 Daylight in Buildings*.

European Committee for Standardization. (2017, February). *CEN/TC 169/WG 11 - Daylight - N 0133.*

European Committee for Standardization. (2017, March). *CEN/TC 169/WG 11 - Daylight - N 0135.*

European Committee for Standardization. (2017, March). *CEN/TC 169/WG 11 - Daylight - N 0136.*

Fokkema & partners. (2011). *DGMR Den Haag*. Retrieved from Fokkema & partners: http://www.fokkema-partners.nl/projects/chronological/all/casuariestraat-dgmr

HBA. (2017). *TNO Normen*. Retrieved from Handel Bouw Advies: http://www.handelbouwadvies.nl/tno-normen/

Hellinga, H. (2013). *Daylight and View: The influence of windows on the visual quality of indoor spaces.* Delft: Delft University of Technology.

Marsh, A. (n.d.). *2D Sunpath*. Retrieved from Andrew Marsh: http://andrewmarsh.com/apps/releases/sunpath2d.html

Nederlands Normalisatie Instituut. (2011, June). *NEN2057 Daglichtopeningen in gebouwen - Bepaling van de equivalente daglichtoppervlakte van een ruimte.*

Nederlands Normalisatie Instituut. (2011, December). *NEN 2057/C1 Daglichtopeningen van gebouwen - Bepaling van de equivalente daglichtoppervlakte van een ruimte (Correctieblad)*.

Reinhart, C. (2010). *Tutorial on the Use of Daysim Simulations for Sustainable Design.* Cambridge: Harvard Design School.

Ridder, H., Boer, E., & Verbaan, G. (2018). *Onderzoek daglichtnorm - Beleidsonderzoek Europese Daglichtnorm.* DGMR.

Singapore Universtity of Technology and Design. (2017). *Lighting Materials for Simulation*. Retrieved from Lighting materials: http://www.lighting-materials.com/

Tregenza, P., & Wilson, M. (2011). *Daylighting - Architecture and Lighting Design.* Glasgow: Bell & Bain.

6.2 Figures

Figure 2	Derived from Nederlands Normalisatie Instituut (2011) and edited
Figure 3	Derived from Nederlands Normalisatie Instituut (2011) and edited
Figure 4	Derived from Nederlands Normalisatie Instituut (2011) and edited
Figure 5	Derived from European Committee for Standardization (2017) and edited
Figure 6	Derived from European Committee for Standardization (2017) and edited
Figure 7	Derived from European Committee for Standardization (2017) and edited
Figure 22	Derived from Fokkema & Partners (2011)

All other figures are made by the author.

APPENDICES

A. Radiance parameters

The Radiance parameters are determined with the use of the online manual for DIVA, experiences of colleagues and a short literature study. An explanation of the parameters is given below.

Ambient bounces (ab)

The ambient bounces (ab) parameter describes the amount of diffuse reflections that will be calculated before a ray path is discarded. A value of 5 is enough for a standard room. When a room gets more complicated, the ab-value must be higher. This however will increase the simulation time significantly.

Ambient accuracy (ac) and Ambient resolution (ar)

The ambient accuracy (aa) and ambient resolution (ar) influence the luminance distribution in a room. Together with the dimension of a room, they determine how fine this distribution is calculated.

Ambient divisions (ad)

This parameter determines the amount of rays that will be sent out of a surface point during the calculation. When the brightness in a room varies a lot, this parameter needs to be high.

Ambient super samples (as)

In areas with a high brightness gradient, extra rays can be sent out from a surface point. This value determines the amount of extra rays.

(Reinhart, 2010) (DIVA4Rhino, 2018)

B1. Basement Basisweg – Results measurements

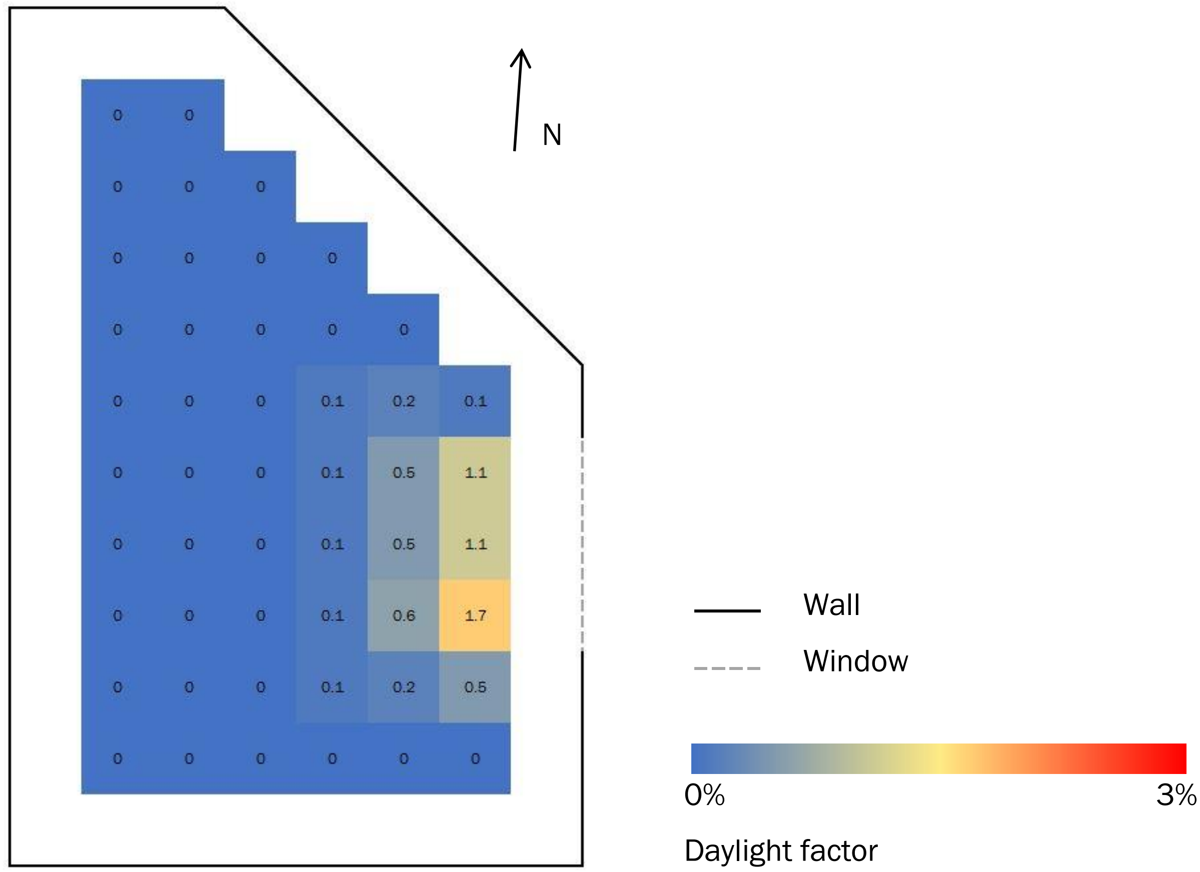
E_e is the external illuminance in the open field.

E_i is the internal illuminance, measured at the grid points, at a height of 0.75 m.

DF is the daylight factor. $DF = E_i / E_{e,2} \cdot 100\%$

Measuring point	External illuminance (E_e) [lux]	Internal illuminance (E_i) [lux]	Daylight Factor (DF) [%]	Measuring point	External illuminance (E_e) [lux]	Internal illuminance (E_i) [lux]	Daylight Factor (DF) [%]
1	9130	0.45	0.00	26	10210	2.56	0.03
2	9120	0.63	0.01	27	10000	1.45	0.01
3	9180	0.81	0.01	28	9800	0.62	0.01
4	9290	0.82	0.01	29	9610	0.37	0.00
5	9410	0.65	0.01	30	9430	1.47	0.02
6	9520	0.56	0.01	31	9280	5.63	0.06
7	9610	0.46	0.00	32	9180	11.76	0.13
8	9670	0.35	0.00	33	9180	10.27	0.11
9	9770	0.21	0.00	34	9160	6.98	0.08
10	9950	0.15	0.00	35	9100	5.4	0.06
11	10190	0.6	0.01	36	8980	2.48	0.03
12	10400	0.87	0.01	37	8770	0.74	0.01
13	10560	1.23	0.01	38	8620	3.66	0.04
14	10760	1.35	0.01	39	8500	19.18	0.23
15	10850	1.25	0.01	40	8360	49.1	0.59
16	10920	1.05	0.01	41	8170	39.3	0.48
17	10930	0.76	0.01	42	7990	37.3	0.47
18	10870	0.52	0.00	43	7820	17.5	0.22
19	10790	0.34	0.00	44	7710	1.69	0.02
20	10780	0.29	0.00	45	7640	1.31	0.02
21	10770	1.18	0.01	46	7590	37.9	0.50
22	10770	1.76	0.02	47	7560	131.7	1.74
23	10730	4.95	0.05	48	7540	79.3	1.05
24	10610	3.91	0.04	49	7530	81.5	1.08
25	10430	2.9	0.03	50	7510	4.07	0.05

The internal and external illuminances and the daylight factor for each measuring point.



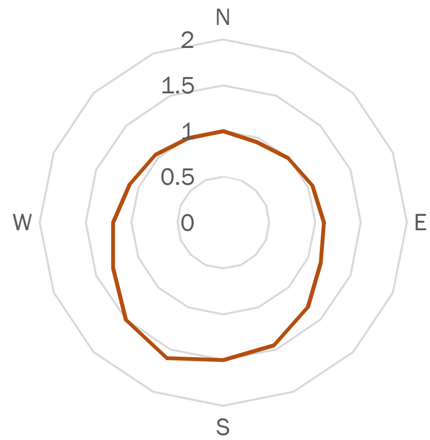
The daylight factor in the office in the basement.

B2. Basement Basisweg – Results simulations

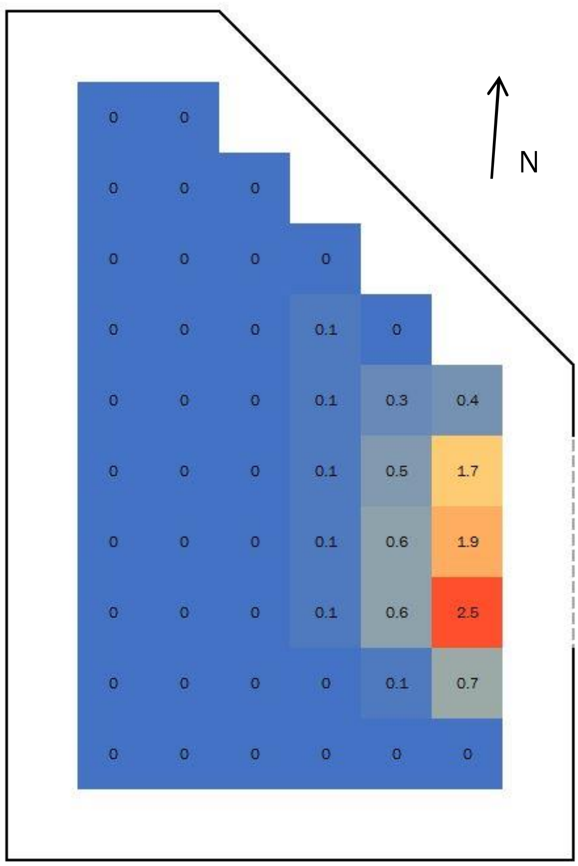
Daylight

Measuring point	Measured Daylight Factor [%]	Simulated Daylight Factor [%]	Daylight Factor, with orientation factor [%]	Measuring point	Measured Daylight Factor [%]	Simulated Daylight Factor [%]	Daylight Factor, with orientation factor [%]
1	0.0	0.0	0.0	26	0.0	0.0	0.0
2	0.0	0.0	0.0	27	0.0	0.0	0.0
3	0.0	0.0	0.0	28	0.0	0.0	0.0
4	0.0	0.0	0.0	29	0.0	0.0	0.0
5	0.0	0.0	0.0	30	0.0	0.0	0.0
6	0.0	0.0	0.0	31	0.1	0.0	0.1
7	0.0	0.0	0.0	32	0.1	0.1	0.1
8	0.0	0.0	0.0	33	0.1	0.1	0.1
9	0.0	0.0	0.0	34	0.1	0.1	0.1
10	0.0	0.0	0.0	35	0.1	0.1	0.1
11	0.0	0.0	0.0	36	0.0	0.1	0.0
12	0.0	0.0	0.0	37	0.0	0.0	0.0
13	0.0	0.0	0.0	38	0.0	0.0	0.0
14	0.0	0.0	0.0	39	0.2	0.1	0.2
15	0.0	0.0	0.0	**40**	**0.6**	**0.6**	**0.6**
16	0.0	0.0	0.0	**41**	**0.5**	**0.6**	**0.5**
17	0.0	0.0	0.0	**42**	**0.5**	**0.5**	**0.5**
18	0.0	0.0	0.0	**43**	**0.2**	**0.3**	**0.2**
19	0.0	0.0	0.0	44	0.0	0.0	0.0
20	0.0	0.0	0.0	45	0.0	0.0	0.0
21	0.0	0.0	0.0	**46**	**0.5**	**0.7**	**0.5**
22	0.0	0.0	0.0	**47**	**1.7**	**2.5**	**1.7**
23	0.0	0.0	0.0	**48**	**1.1**	**1.9**	**1.1**
24	0.0	0.0	0.0	**49**	**1.1**	**1.7**	**1.1**
25	0.0	0.0	0.0	**50**	**0.1**	**0.4**	**0.1**

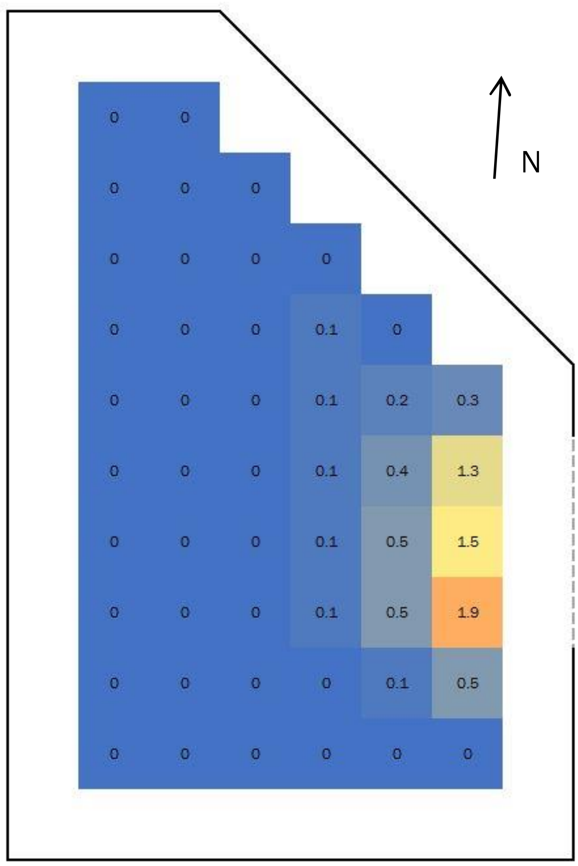
Measured, simulated and converted daylight factors.



Orientation factor

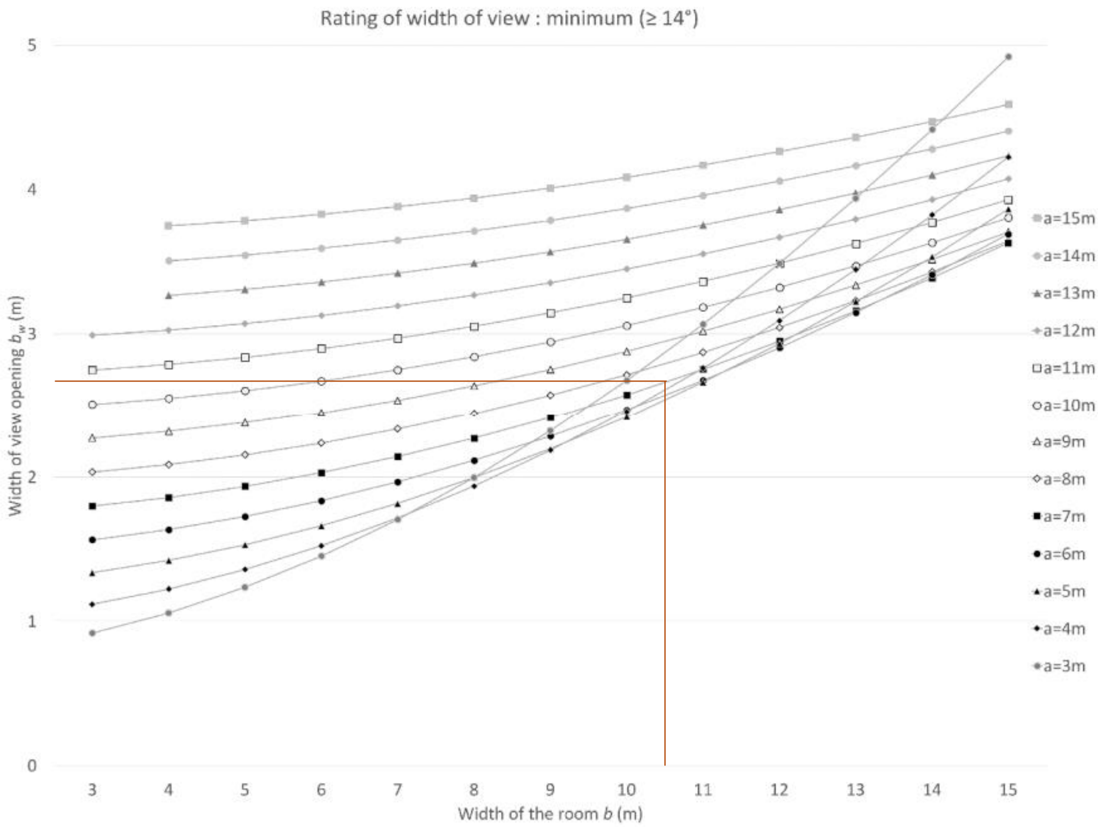


Simulated daylight factor



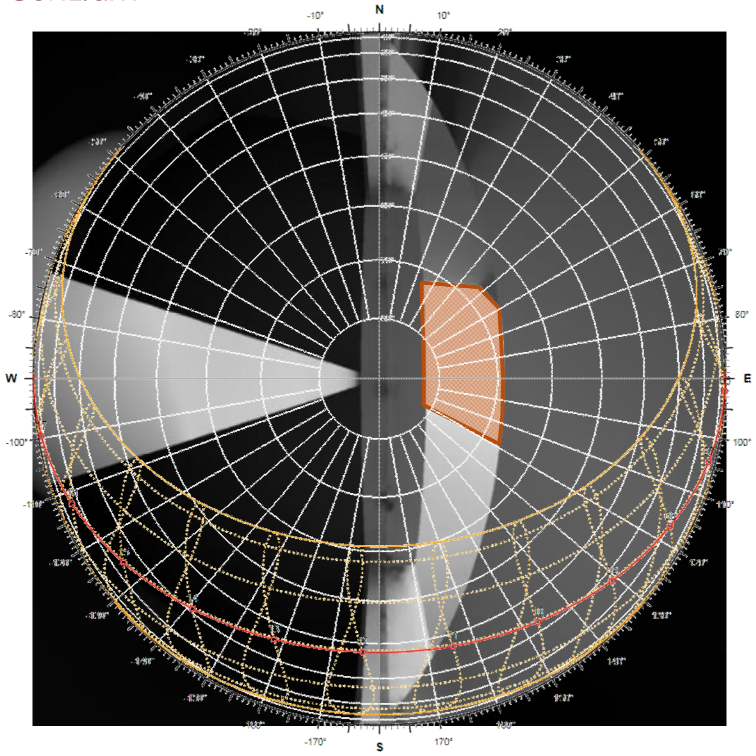
Simulated daylight factor converted with the orientation factor

VIEW

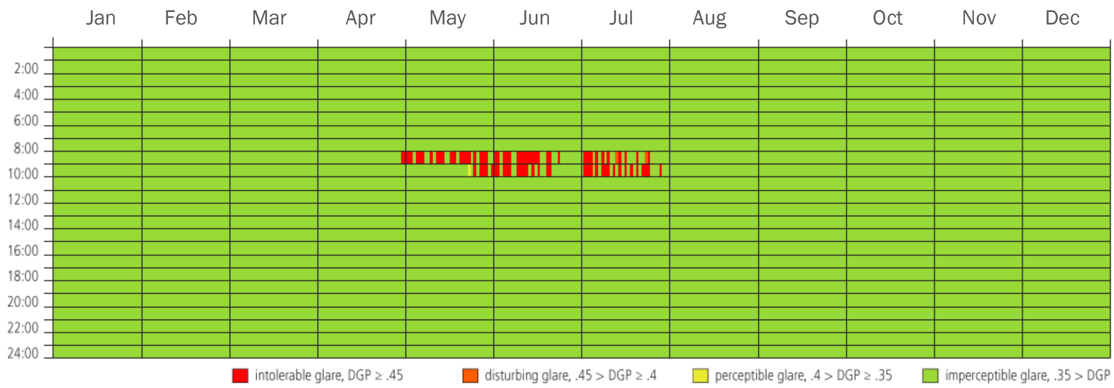


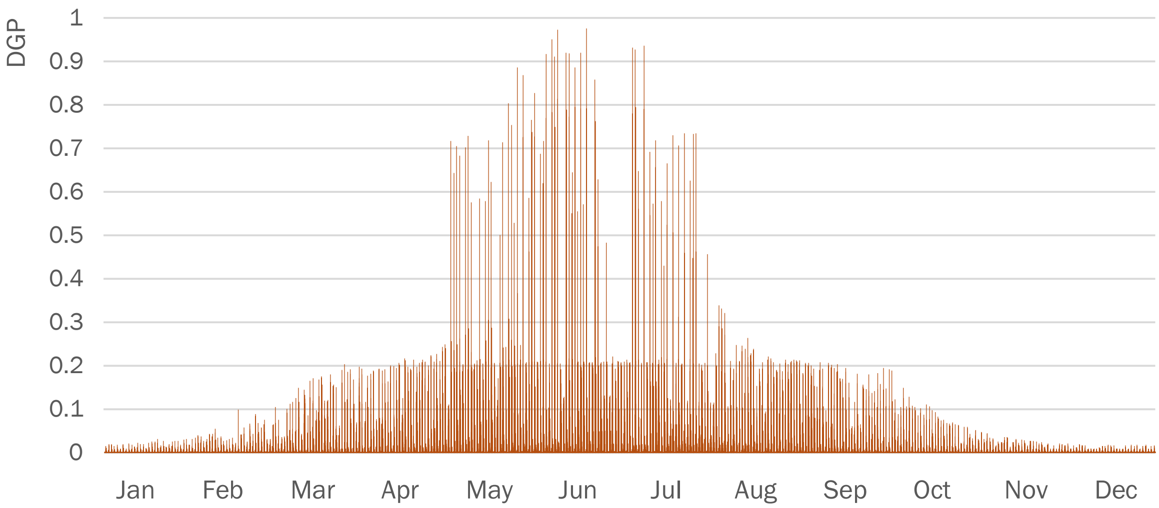
- The view distance is shorter than 6m.
- The view angle is wider than 14º , because the window is wider than 2.7m.
- The landscape layer is visible from 75% of the utilised area.

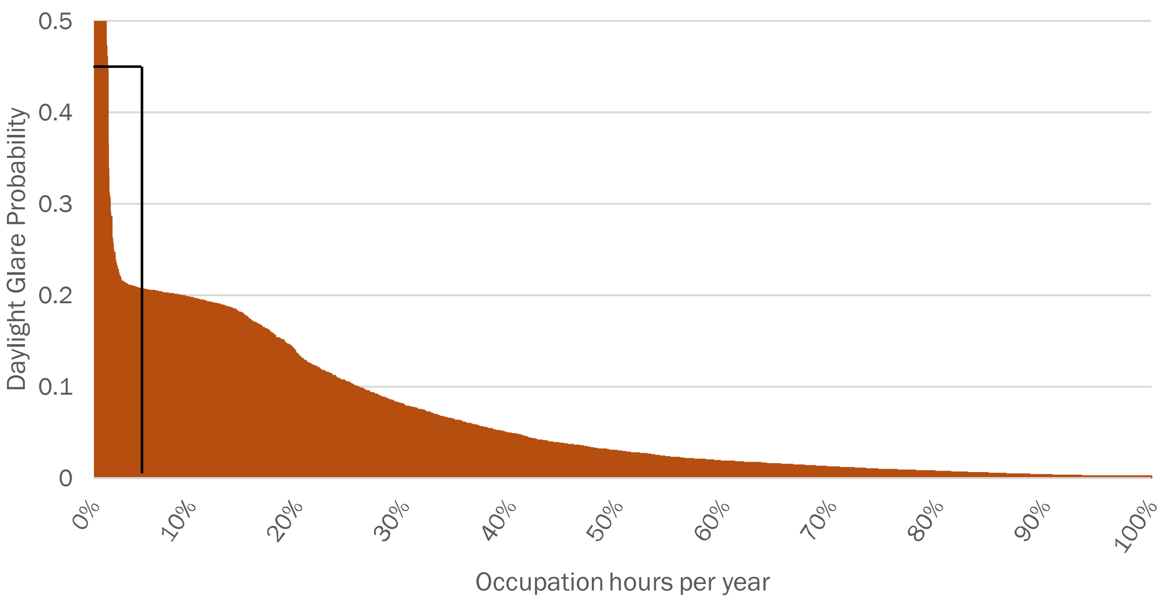
SUNLIGHT



GLARE


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00
intolerable glare, DGP ≥ .45
disturbing glare, .45 > DGP ≥ .4
perceptible glare, .4 > DGP ≥ .35
imperceptible glare, .35 > DGP


DGP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daylight Glare Probability
0.5
0.4
0.3
0.2
0.1
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Occupation hours per year

C1. Office DGMR – Results measurements

E_i is the internal illuminance, measured at the grid points, at a height of 0.75 m.

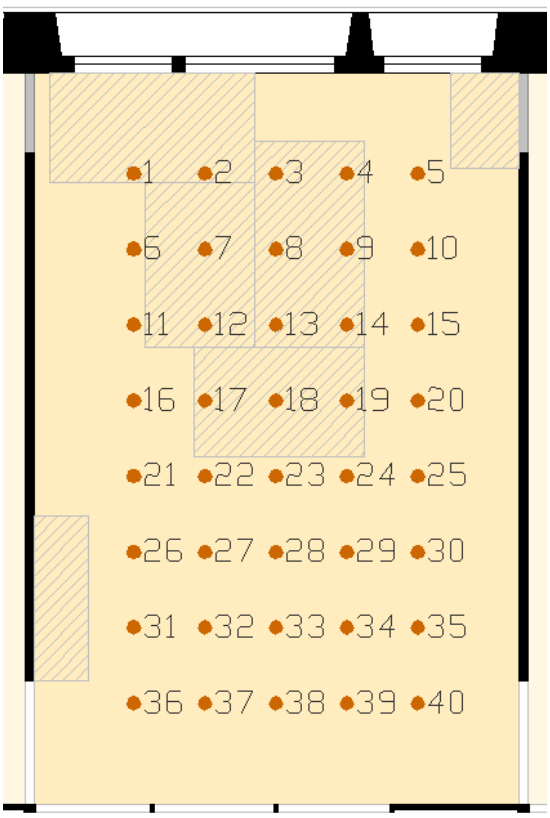
$E_{e,1}$ is the measured and interpolated external illuminance, measured directly in front of the windows. This external illuminance was measured right before the measurements inside for the point that was measured first and right after the measurements for the point that was measured last. For all other points, the values are interpolated. To calculate the ratio F_E, this external illuminance is measured again right before the measurements in the open field.

$E_{e,unobstructed}$ is the unobstructed external illuminance, measured in the open field with the least possible obstructions.

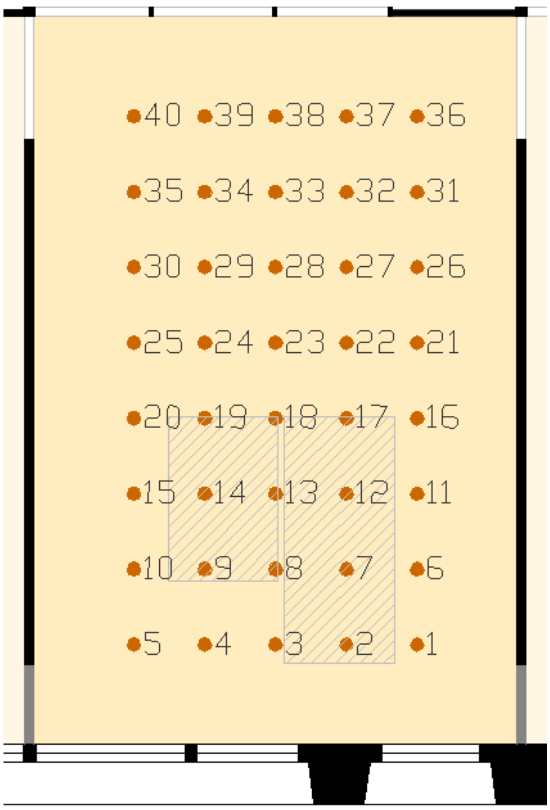
F_E is the ratio between the illuminance right outside the window and the unobstructed external illuminance. $F_E = E_{e,unobstructed}/E_{e,1}$. This ratio is used to calculate the external illuminance $E_{e,2}$.

$E_{e,2}$ is the calculated external illuminance,

DF is the daylight factor. $DF = E_i/E_{e,2} \cdot 100\%$



The grid points in room NW.



The grid points in room SE.

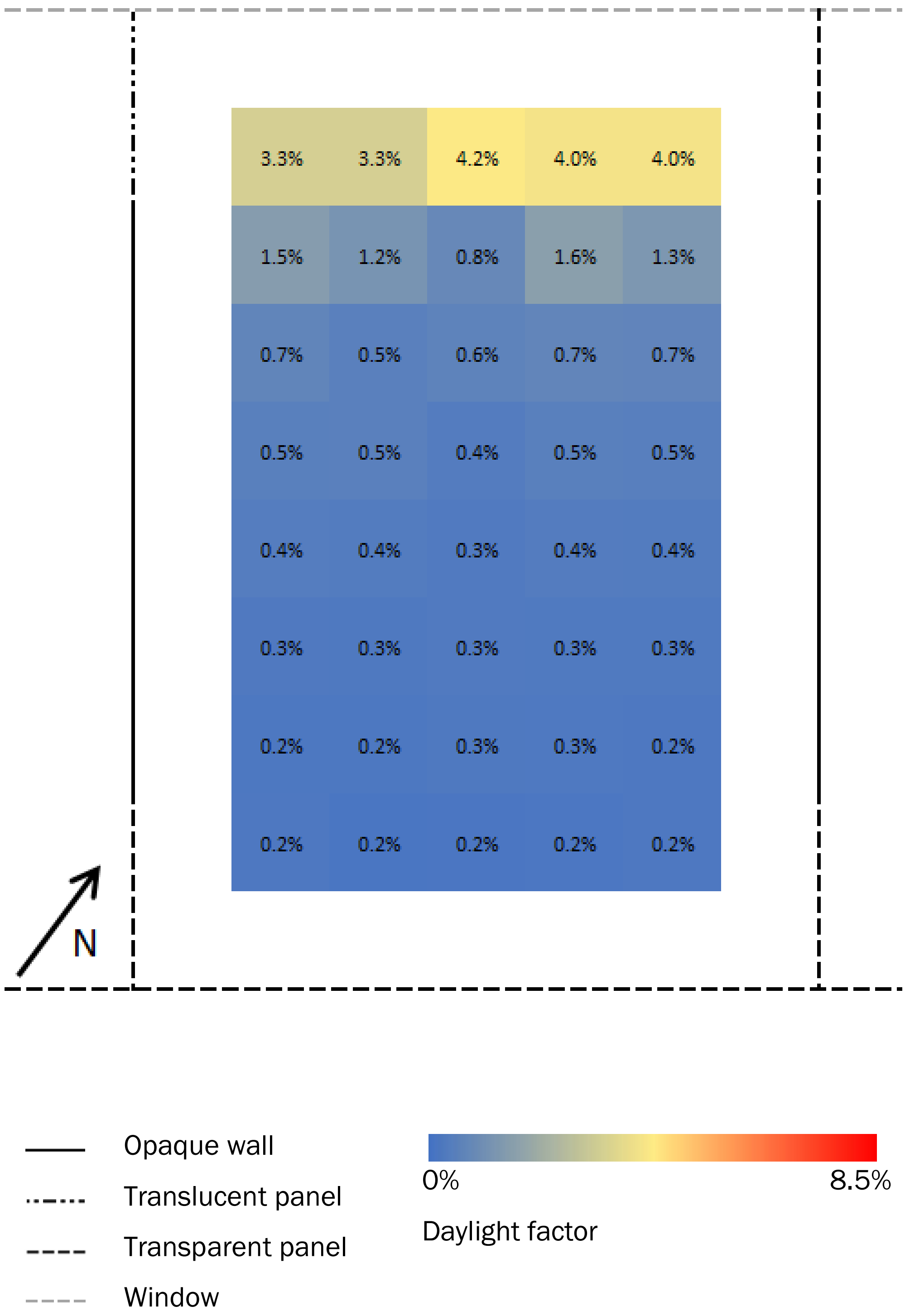
NORTH-WEST

$E_{e,1}$	[lux]	1525.1
$E_{e,unobstructed}$	[lux]	5840
F_E	[-]	3.829

The ratio between external illuminances at the north-west side of the building.

Measuring order				*Grid point order*				
pnt	E_i [lux]	$E_{e,1}$ [lux]	$E_{e,2}$ [lux]	pnt	E_i [lux]	$E_{e,1}$ [lux]	$E_{e,2}$ [lux]	DF [%]
1	71.6	574.4	2199	1	71.6	574.4	2199	3.3%
2	75.7	591	2262	2	75.7	590.9	2262	3.3%
6	33.9	607	2325	3	164.5	1018.7	3900	4.2%
11	16.1	624	2388	4	163.7	1068.0	4089	4.0%
16	12.1	640	2451	5	153.3	1002.2	3837	4.0%
21	9.9	657	2514	6	33.9	607.3	2325	1.5%
26	7.1	673	2577	7	32.1	722.5	2766	1.2%
31	5.9	690	2640	8	31.4	1035.1	3963	0.8%
36	6.2	706	2703	9	64.4	1084.5	4152	1.6%
7	32.1	722	2766	10	47.4	985.7	3774	1.3%
12	14.7	739	2829	11	16.1	623.8	2388	0.7%
22	10.3	755	2892	12	14.7	738.9	2829	0.5%
27	8.0	772	2955	13	24.1	1051.6	4026	0.6%
32	6.4	788	3018	14	29.1	1100.9	4215	0.7%
37	4.7	805	3081	15	24.6	969.3	3711	0.7%
24	11.8	821	3144	16	12.1	640.2	2451	0.5%
29	9.2	838	3207	17	22.4	1150.3	4404	0.5%
34	8.5	854	3270	18	16.7	1133.8	4341	0.4%
39	6.6	871	3333	19	21.1	1117.4	4278	0.5%
40	8.1	887	3396	20	16.8	952.8	3648	0.5%
35	8.5	903	3459	21	9.9	656.7	2514	0.4%
30	10.2	920	3522	22	10.3	755.4	2892	0.4%
25	12.9	936	3585	23	13.9	1216.1	4656	0.3%
20	16.8	953	3648	24	11.8	821.2	3144	0.4%
15	24.6	969	3711	25	12.9	936.4	3585	0.4%
10	47.4	986	3774	26	7.1	673.1	2577	0.3%
5	153.3	1002	3837	27	8.0	771.8	2955	0.3%
3	164.5	1019	3900	28	14.0	1199.7	4593	0.3%
8	31.4	1035	3963	29	9.2	837.7	3207	0.3%
13	24.1	1052	4026	30	10.2	919.9	3522	0.3%
4	163.7	1068	4089	31	5.9	689.6	2640	0.2%
9	64.4	1084	4152	32	6.4	788.3	3018	0.2%
14	29.1	1101	4215	33	12.2	1183.2	4530	0.3%
19	21.1	1117	4278	34	8.5	854.1	3270	0.3%
18	16.7	1134	4341	35	8.5	903.5	3459	0.2%
17	22.4	1150	4404	36	6.2	706.0	2703	0.2%
38	7.7	1167	4467	37	4.7	804.8	3081	0.2%
33	12.2	1183	4530	38	7.7	1166.7	4467	0.2%
28	14.0	1200	4593	39	6.6	870.6	3333	0.2%
23	13.9	1216.1	4656	40	8.1	887.0	3396	0.2%

The internal and external illuminances and the daylight factor in room NW. Orange values are interpolated.



The daylight factor in room NW.

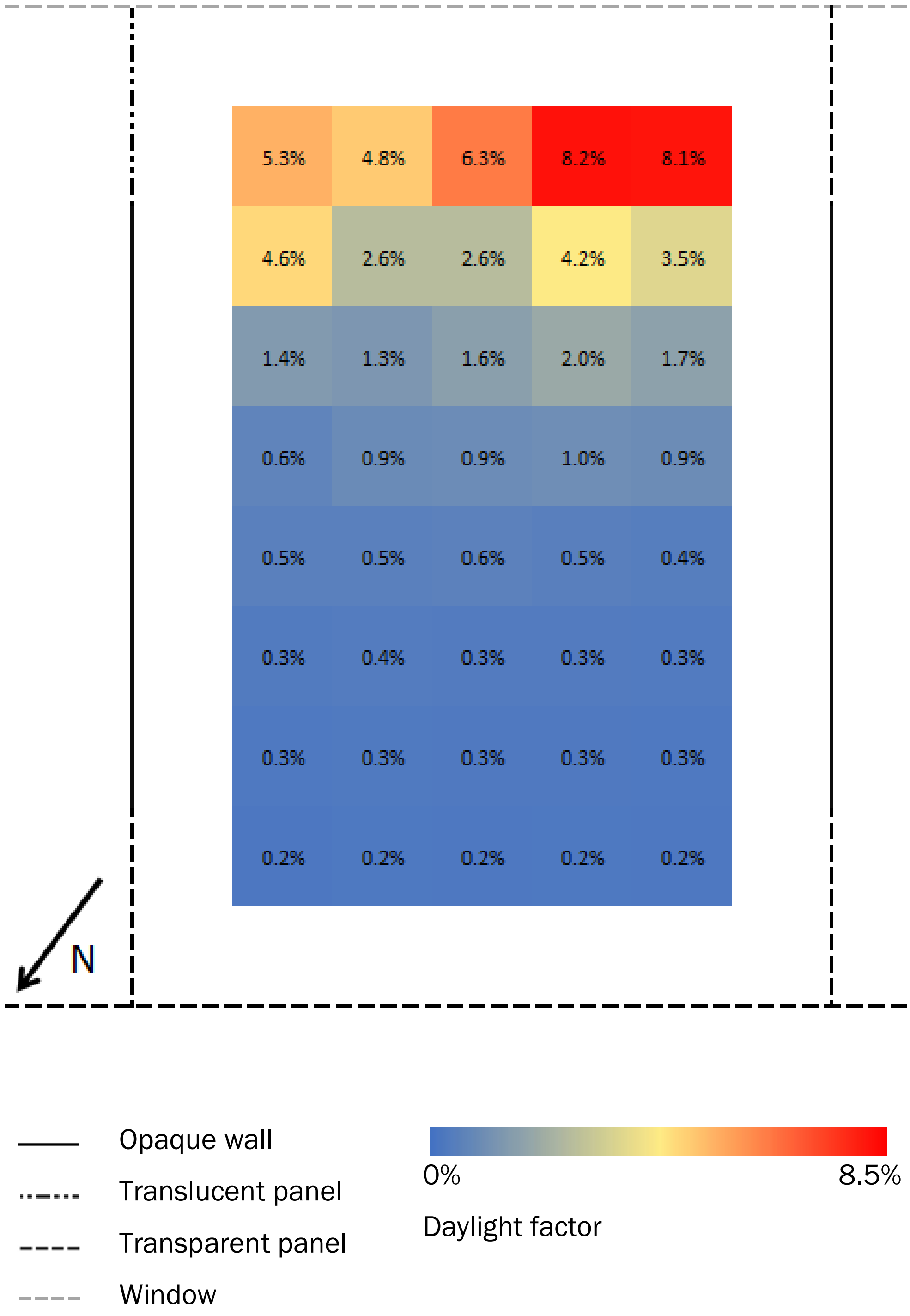
South-east

$E_{e,1}$	[lux]	3460
$E_{e,unobstructed}$	[lux]	5840
F_E	[-]	1.688

The ratio between external illuminances at the south-east side of the building.

Measuring order				*Grid point order*				
pnt	E_i [lux]	E_e 1 [lux]	E_e 2 [lux]	pnt	E_i [lux]	E_e 1 [lux]	E_e 2 [lux]	DF [%]
5	326.0	2370	4001	1	312.3	3482.8	5879.0	5.3%
4	333.2	2406	4061	2	293.9	3590.5	6060.8	4.8%
10	145.6	2442	4122	3	392.4	3698.2	6242.5	6.3%
15	70.3	2478	4182	4	333.2	2405.9	4061.2	8.2%
20	39.5	2514	4243	5	326.0	2370.0	4000.6	8.1%
25	18.4	2549	4304	6	267.3	3446.9	5818.4	4.6%
30	14.3	2585	4364	7	156.9	3554.6	6000.2	2.6%
35	11.4	2621	4425	8	161.6	3662.3	6181.9	2.6%
40	10.8	2657	4485	9	268.8	3770.0	6363.7	4.2%
19	45.1	2693	4546	10	145.6	2441.8	4121.7	3.5%
24	22.3	2729	4607	11	81.7	3411.0	5757.8	1.4%
29	16.0	2765	4667	12	77.1	3518.7	5939.6	1.3%
34	13.0	2801	4728	13	98.0	3626.4	6121.4	1.6%
39	11.8	2837	4788	14	123.3	3734.1	6303.1	2.0%
18	44.3	2873	4849	15	70.3	2477.7	4182.3	1.7%
23	27.3	2908	4909	16	35.3	3231.5	5454.8	0.6%
28	17.2	2944	4970	17	45.6	3052.0	5151.8	0.9%
33	13.9	2980	5031	18	44.3	2872.6	4848.9	0.9%
38	11.9	3016	5091	19	45.1	2693.1	4545.9	1.0%
17	45.6	3052	5152	20	39.5	2513.6	4242.9	0.9%
22	26.3	3088	5212	21	28.3	3267.4	5515.4	0.5%
27	19.5	3124	5273	22	26.3	3087.9	5212.4	0.5%
32	15.1	3160	5334	23	27.3	2908.5	4909.5	0.6%
37	13.4	3196	5394	24	22.3	2729.0	4606.5	0.5%
16	35.3	3232	5455	25	18.4	2549.5	4303.5	0.4%
21	28.3	3267	5515	26	18.8	3303.3	5576.0	0.3%
26	18.8	3303	5576	27	19.5	3123.8	5273.0	0.4%
31	14.8	3339	5637	28	17.2	2944.4	4970.1	0.3%
36	11.7	3375	5697	29	16.0	2764.9	4667.1	0.3%
11	81.7	3411	5758	30	14.3	2585.4	4364.1	0.3%
6	267.3	3447	5818	31	14.8	3339.2	5636.6	0.3%
1	312.3	3483	5879	32	15.1	3159.7	5333.6	0.3%
12	77.1	3519	5940	33	13.9	2980.2	5030.7	0.3%
7	156.9	3555	6000	34	13.0	2800.8	4727.7	0.3%
2	293.9	3590	6061	35	11.4	2621.3	4424.7	0.3%
13	98.0	3626	6121	36	11.7	3375.1	5697.2	0.2%
8	161.6	3662	6182	37	13.4	3195.6	5394.2	0.2%
3	392.4	3698	6243	38	11.9	3016.1	5091.3	0.2%
14	123.3	3734	6303	39	11.8	2836.7	4788.3	0.2%
9	268.8	3770	6364	40	10.8	2657.2	4485.3	0.2%

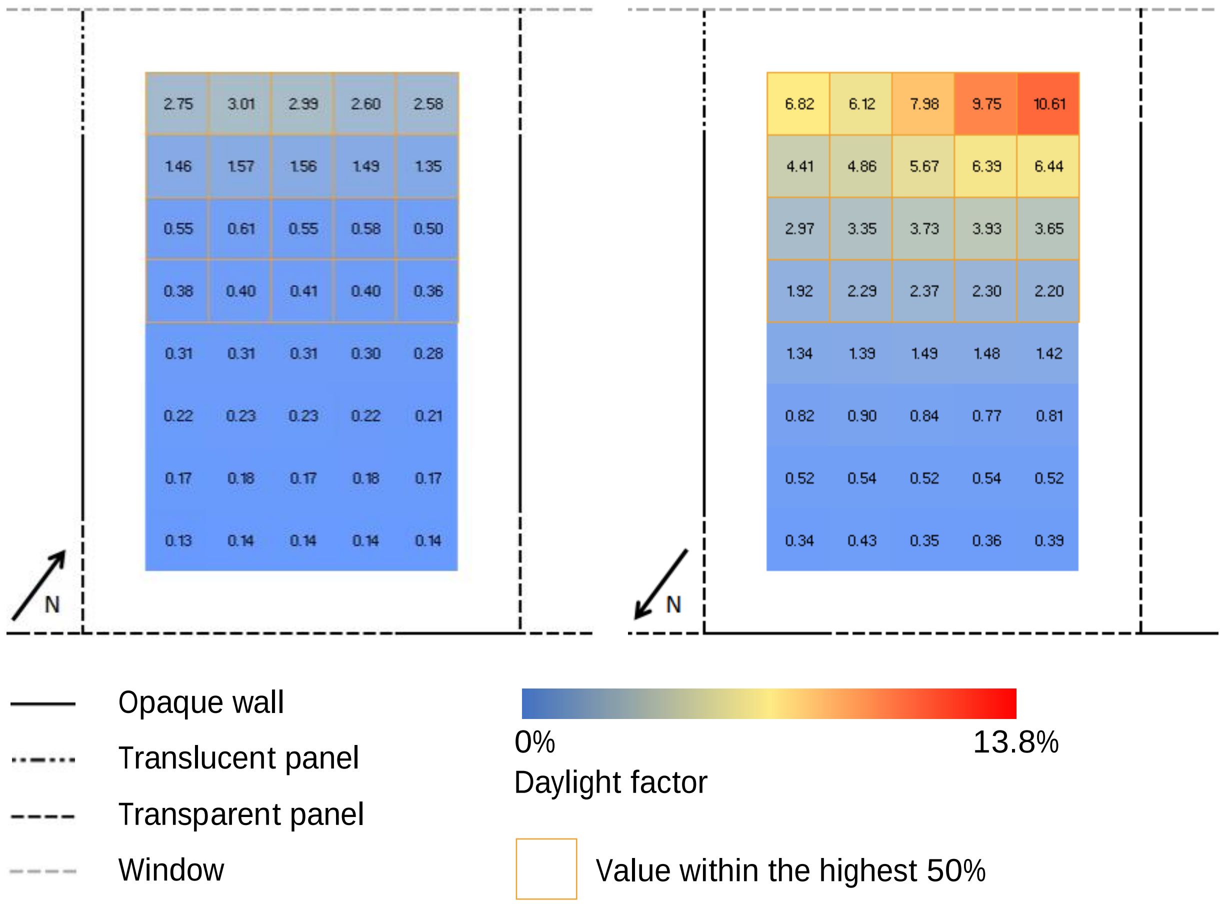
The internal and external illuminances and the daylight factor in room SE. Orange values are interpolated.



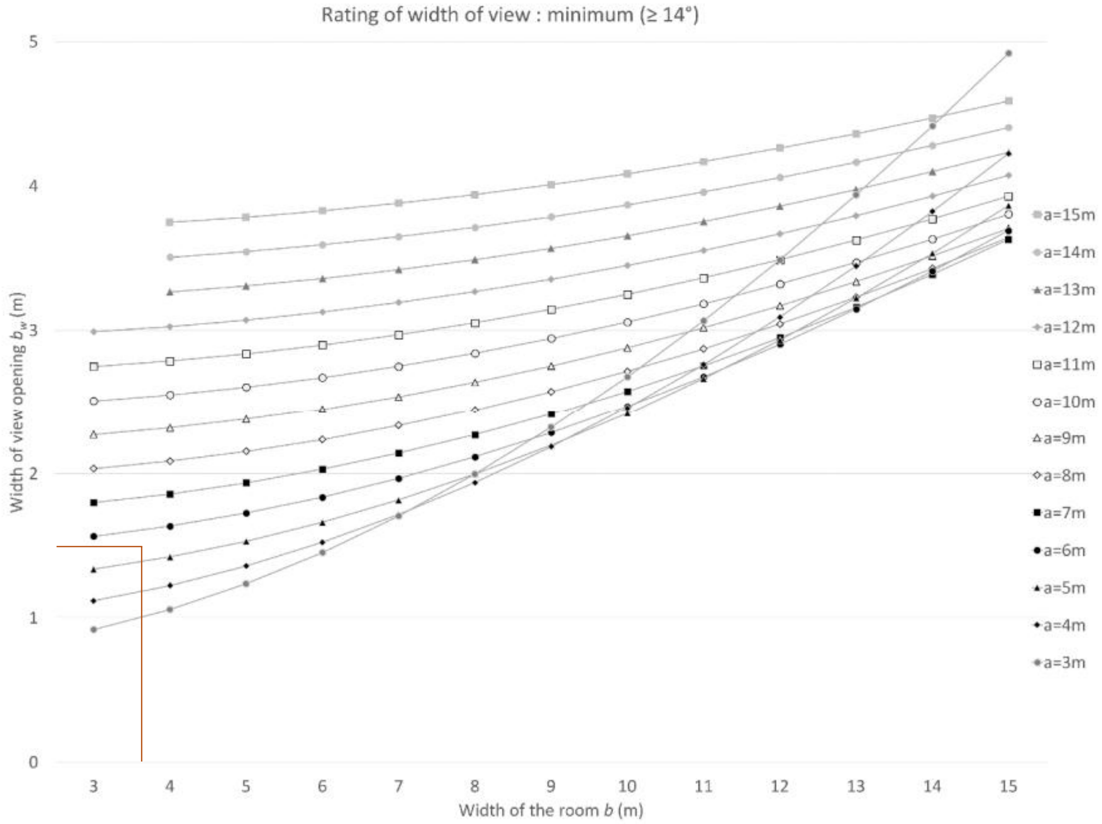
The daylight factor in room SE.

C2. Office DGMR – Results simulations

Daylight

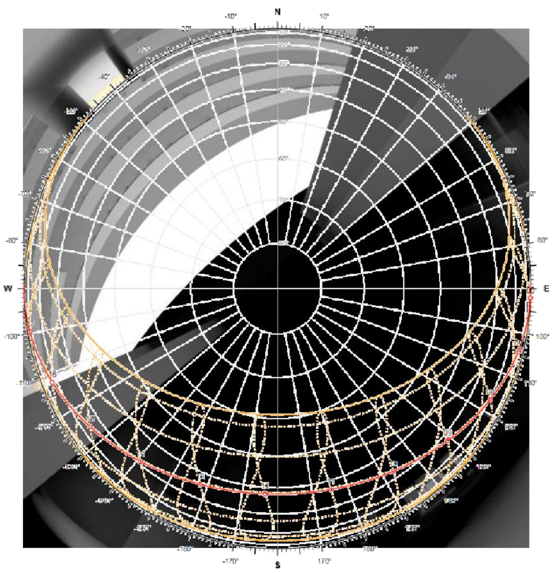


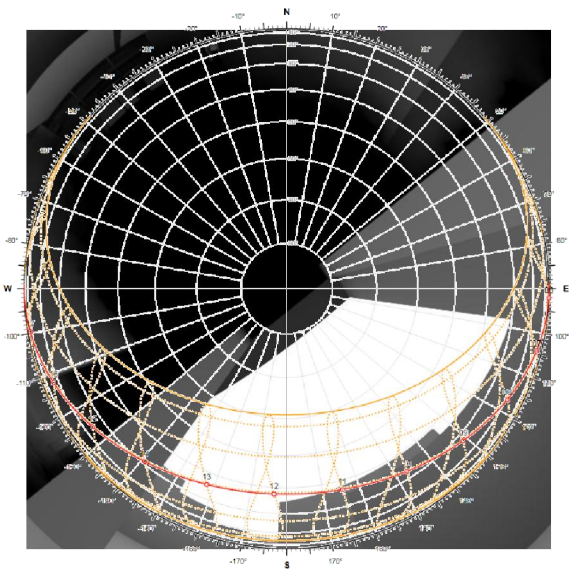
VIEW



- The view distance is longer than 6m.
- The view angle is wider than 14^{o}, because the view width is larger than 1.5m according to the figure above.
- The landscape layer is visible from 75% of the utilised area.

SUNLIGHT

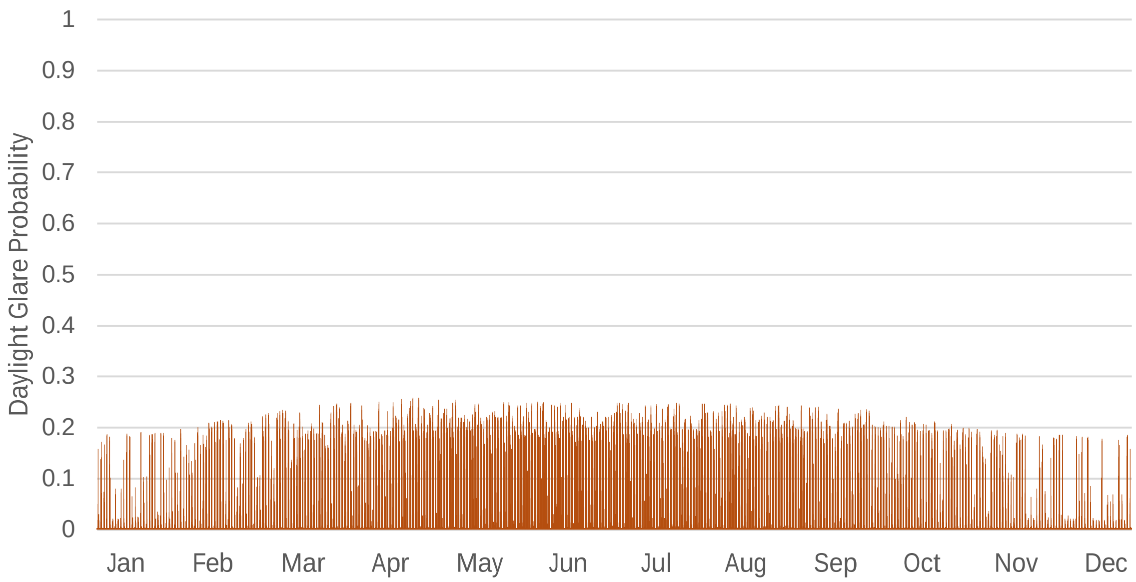


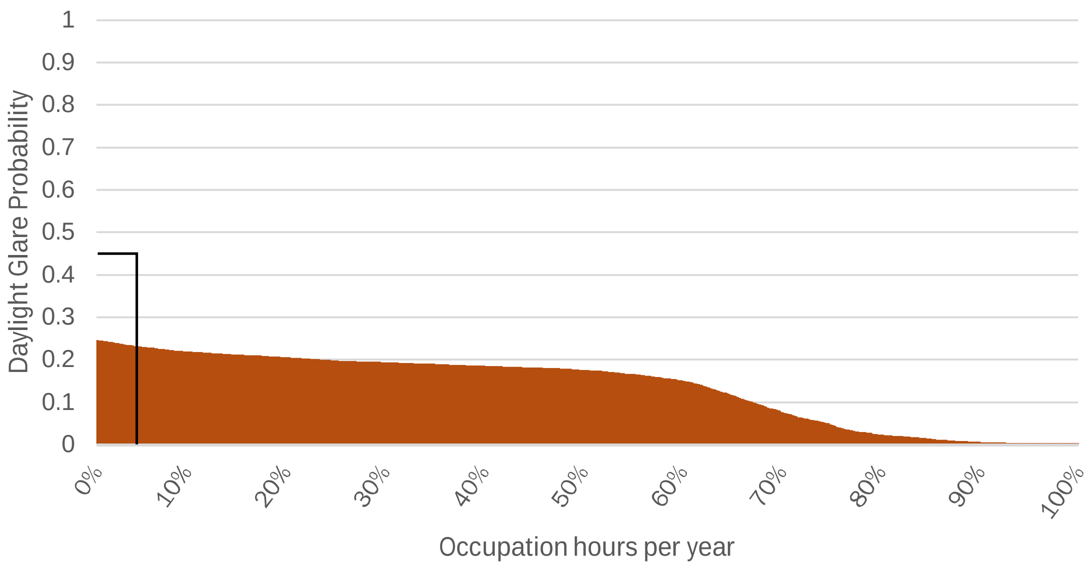


NW: 0.2 hours SE: 2.7 hours

GLARE

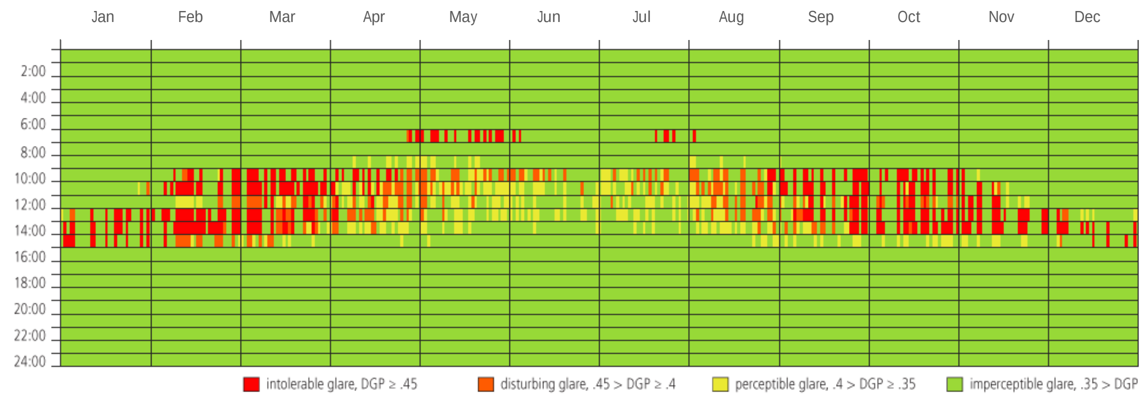
Room NW



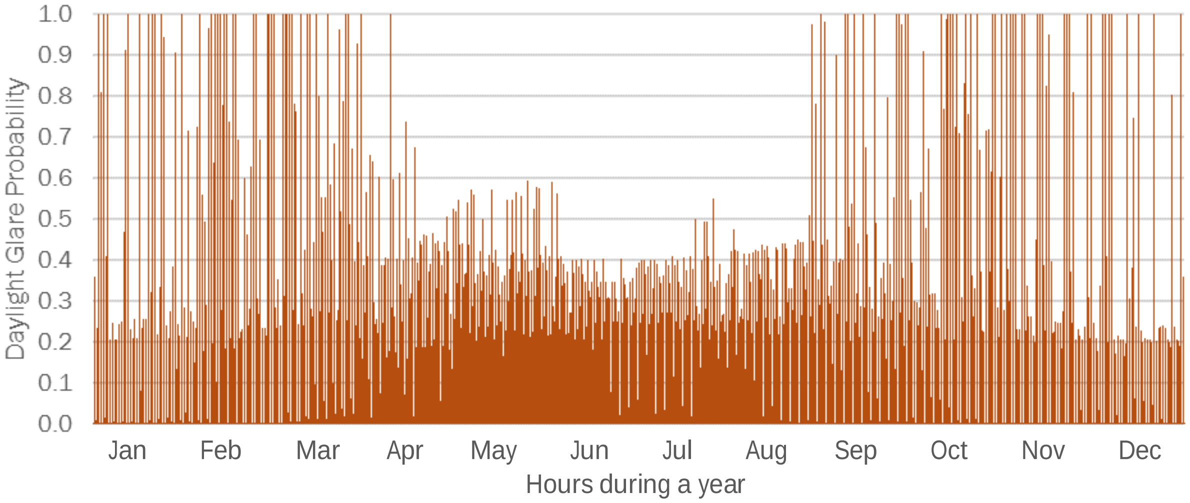


During **0%** of the occupation hours, the DGP is higher than 0.45.

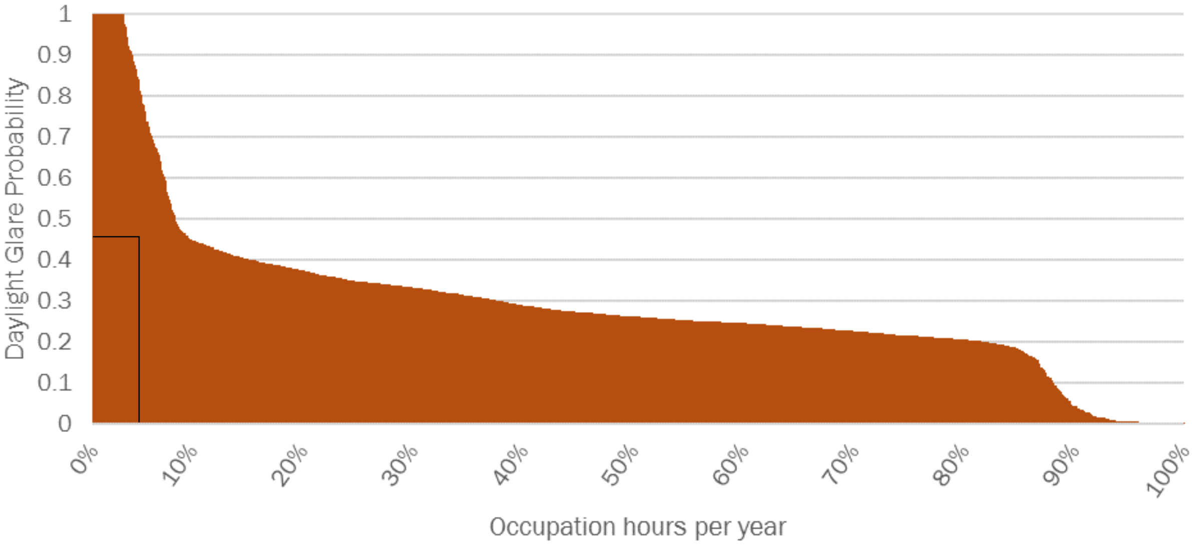
Room SE



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year



Daylight Glare Probability during a percentage of the occupation hours per year

During **9.89%** of the occupation hours, the DGP is higher than 0.45.

Verification of the measuring method

Internal illuminance	External illuminance	Daylight factor
23.4 lux	4830 lux	0.48%
26.4 lux	5540 lux	0.48%
42.7 lux	6570 lux	0.65%
45.0 lux	7350 lux	0.61%

Extra measurements were taken to confirm that the used method was inaccurate. The internal illuminance was measured at one of the grid points on a desk. 8 minutes later the external illuminance was measured. This is repeated three times. The daylight factors vary 0.17%, which seems little, but is almost 25%.

It shows that when the internal and external illuminance are not measured simultaneously, the calculated daylight factors are unreliable.

	NW	SE
Variant 1.1 , minimal daylight area / square / centre		
$A_{e,i}$	0.486 m²	0.486 m²
$A_{d,i}$	1.12 m²	0.66 m²
Window height	1.06 m	0.82 m
Window width	1.06 m	0.82 m
Variant 1.2, minimal daylight area / vertical / centre		
Variant 1.3, minimal daylight area / vertical / side		
$A_{e,i}$	0,486 m²	0,486 m²
$A_{d,i}$	1,12 m²	0,66 m²
Window height	1.5 m	1.5 m
Window width	0.75 m	0.44 m
Variant 1.4, minimal daylight area / horizontal / centre		
$A_{e,i}$	0.486 m²	0.486 m²
$A_{d,i}$	1.12 m²	0.66 m²
Window height	0.59 m	0.35 m
Window width	1.9 m	1.9 m
Variant 1.5 , minimal daylight area / square / centre / without external glass panes		
$A_{e,i}$	0,486 m²	0,486 m²
$A_{d,i}$	0.69 m²	0,66 m²
Window height	0.83 m	0.82 m
Window width	0.83 m	0.82 m

Daylight areas and window dimensions of variants in category 1.

	Room NW	Room SE
Variant 2.1 , maximum daylight factor / without external glass panes		
β_1	38.89°	41.47°
β_2	38.89°	41.47°
β_3	38.89°	41.47°
β_4	22.65°	22.65°
β_5	22.65°	22.65°
β_6	22.65°	22.65°
β_7	22.65°	22.65°
β_8	15.08°	22.65°
$\beta_{average}$	27.79°	29.71°
α	20°	20°
$C_{b,i}$	0.76	0.75
$C_{u,i}$	-	-
$A_{d,i}$	3.9 m	3.9 m
$A_{e,i}$	2.96 m²	2.93 m²
Variant 2.2 , maximum daylight factor / maximum reflection factors		
β_1	38.89°	41.47°
β_2	38.89°	41.47°
β_3	38.89°	41.47°
β_4	31.29°	22.65°
β_5	31.29°	22.65°
β_6	31.29°	22.65°
β_7	31.29°	22.65°
β_8	15.08°	22.65°
$\beta_{average}$	32.11°	29.71°
α	20°	20°
$C_{b,i}$	0.74	0.75
$C_{u,i}$	0.65	-
$A_{d,i}$	3.9 m	3.9 m
$A_{e,i}$	1.88 m²	2.93 m²
Variant 2.3 , maximum daylight factor / less separation walls		
β_1	38.89°	41.47°
β_2	38.89°	41.47°
β_3	38.89°	41.47°
β_4	22.34°	21.72°
β_5	22.34°	21.72°
β_6	22.34°	21.72°
β_7	22.34°	21.72°
β_8	15.08°	21.72°
$\beta_{average}$	27.64°	29.13°
α	20°	20°
$C_{b,i}$	0.76	0.75
$C_{u,i}$	0.65	-
$A_{d,i}$	7.8 m	7.8 m
$A_{e,i}$	3.85 m²	5.85 m²
Variant 2.4, maximum daylight factor / without surrounding buildings		
β_1	38.89°	41.47°
β_2	38.89°	41.47°
β_3	38.89°	41.47°
β_4	31.29°	22.65°
β_5	31.29°	22.65°
β_6	31.29°	22.65°

$\boldsymbol{\beta_7}$	31.29°	22.65°
$\boldsymbol{\beta_8}$	15.08°	22.65°
$\boldsymbol{\beta_{average}}$	32.11°	29.71°
α	20°	20°
$\boldsymbol{C_{b,i}}$	0.74	0.75
$\boldsymbol{C_{u,i}}$	0.65	-
$\boldsymbol{A_{d,i}}$	3.9 m	3.9 m
$\boldsymbol{A_{e,i}}$	1.88 m²	2.93 m²
Variant 2.5, maximum daylight factor / maximum window area		
$\boldsymbol{\beta}$	23.75°	16.81°
α	20°	20°
$\boldsymbol{C_{b,i}}$	0.77	0.79
$\boldsymbol{C_{u,i}}$	0.65	-
$\boldsymbol{A_{d,i}}$	7.6 m	7.6 m
$\boldsymbol{A_{e,i}}$	3.80 m²	6.00 m²
Variant 2.6, maximum daylight factor / thinner facade		
$\boldsymbol{\beta_1}$	22.84°	12.15°
$\boldsymbol{\beta_2}$	22.84°	12.15°
$\boldsymbol{\beta_3}$	22.84°	12.15°
$\boldsymbol{\beta_4}$	22.57°	12.15°
$\boldsymbol{\beta_5}$	22.57°	28.86°
$\boldsymbol{\beta_6}$	22.57°	28.86°
$\boldsymbol{\beta_7}$	22.57°	28.86°
$\boldsymbol{\beta_8}$	22.57°	28.86°
$\boldsymbol{\beta_{average}}$	22.67°	20.51°
α	20°	20°
$\boldsymbol{C_{b,i}}$	0.77	0.78
$\boldsymbol{C_{u,i}}$	0.65	-
$\boldsymbol{A_{d,i}}$	3.9 m	3.9 m
$\boldsymbol{A_{e,i}}$	1.95 m²	3.04 m²

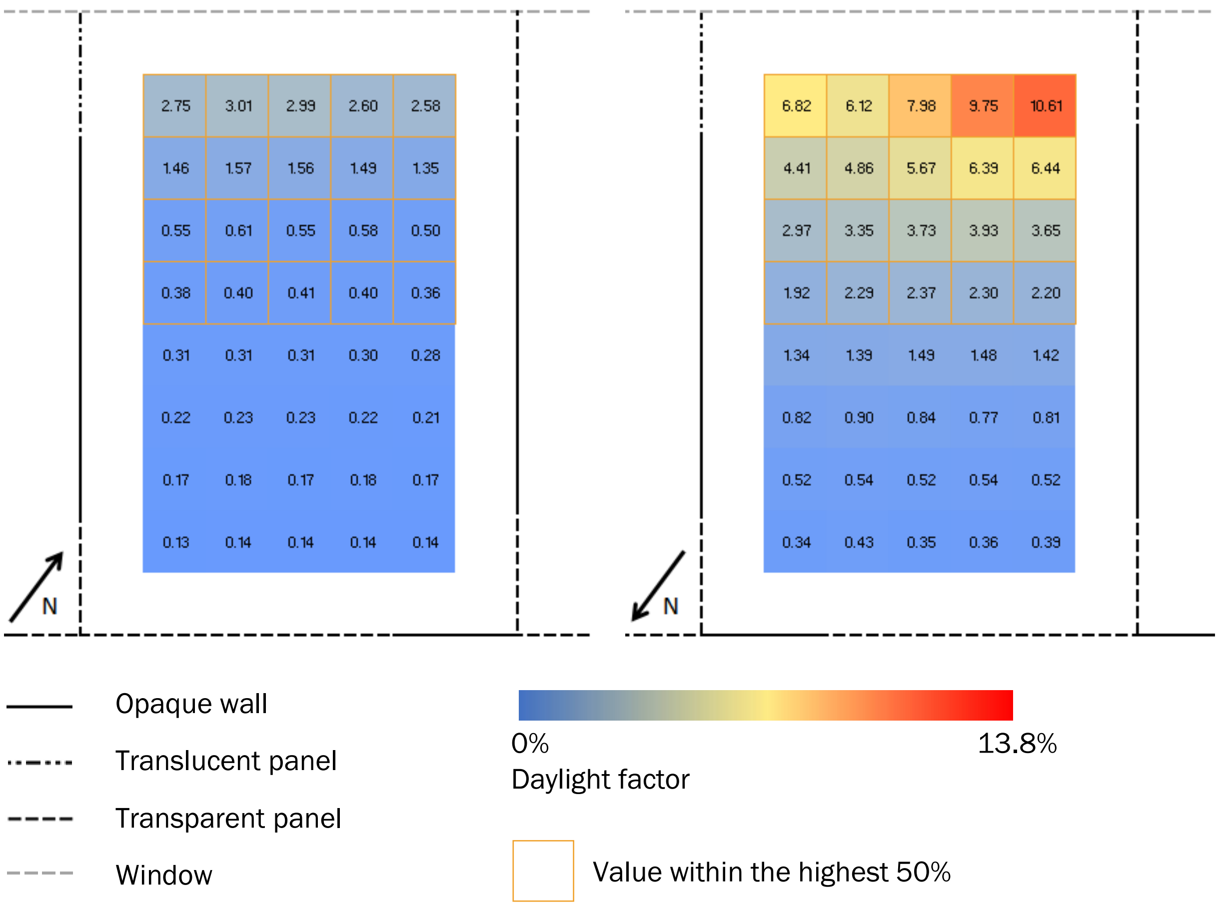
Obstruction angles, obstruction factors, reduction factors, and daylight areas of the variants in category 2.

D2. Systematic study – Results

Variant 0.0, current situation

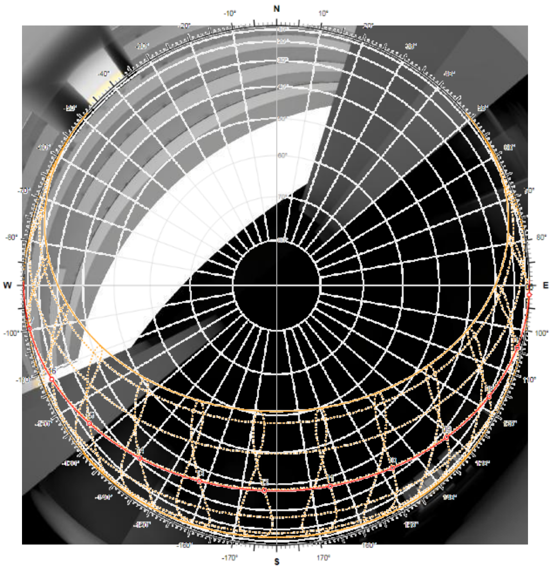
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.88 m^2	2.93 m^2
		9.7%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.14%	0.36%
	in 50% of the occupated area	0.36%	1.92%
Percentage of occupation hours when DGP > 0.45			9.89%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

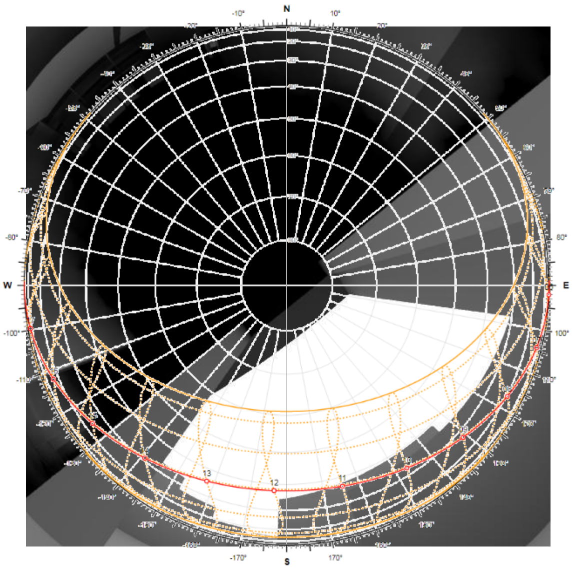
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.14%	0.36%
	in 50% of the occupated area (D_T)	0.36%	1.92%

Sunlight

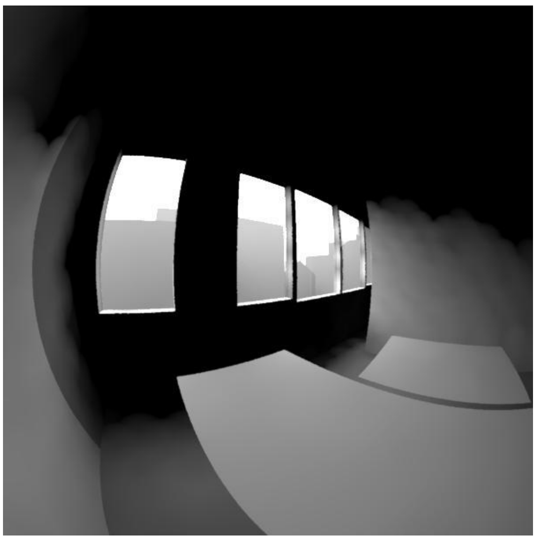




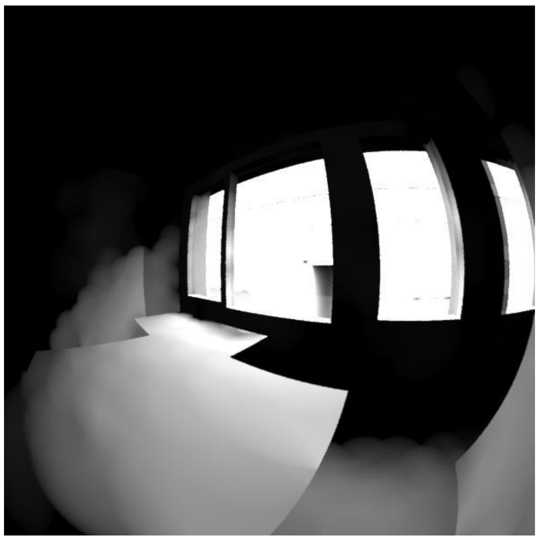
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.2 hours	2.7 hours

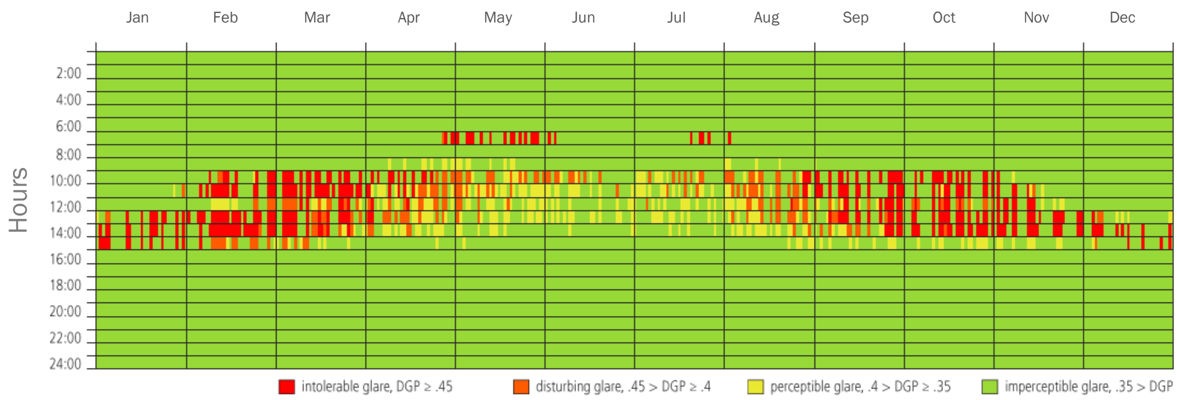
Glare



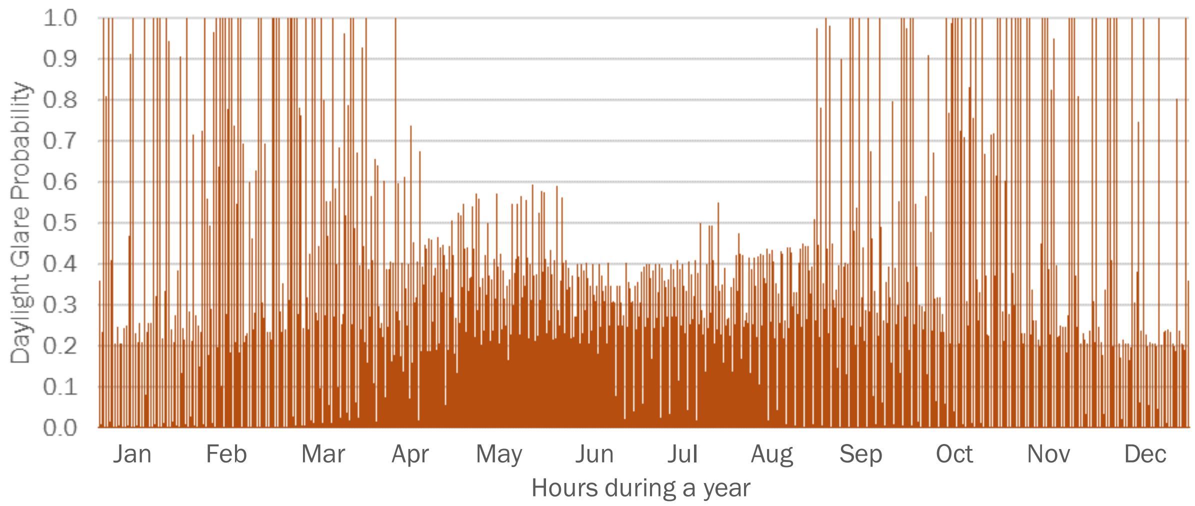
NW



SE



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

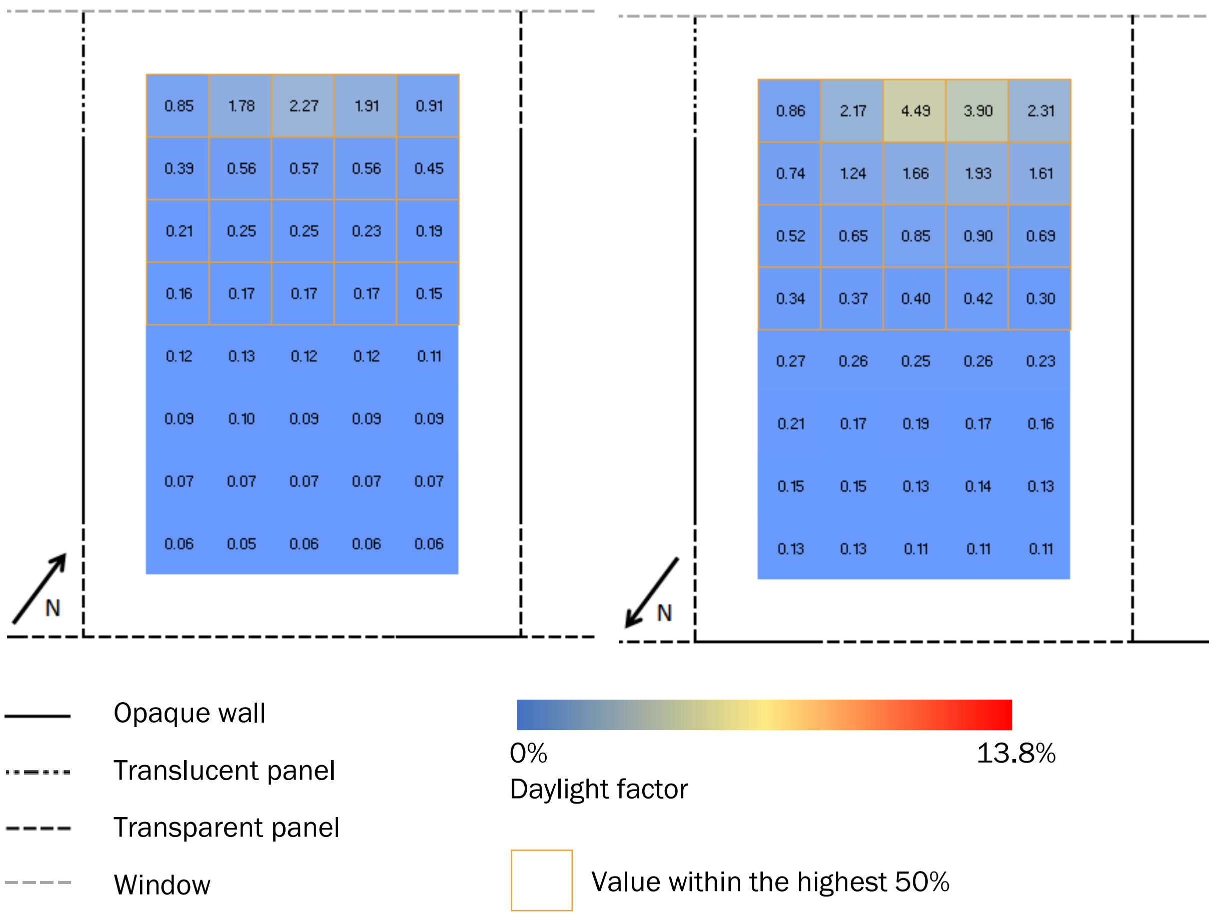
Daylight Glare Probability during a percentage of the occupation hours per year

During **9.89%** of the occupation hours, the DGP is higher than 0.45.

Variant 1.1 , minimal daylight area (Dutch) / square / centre

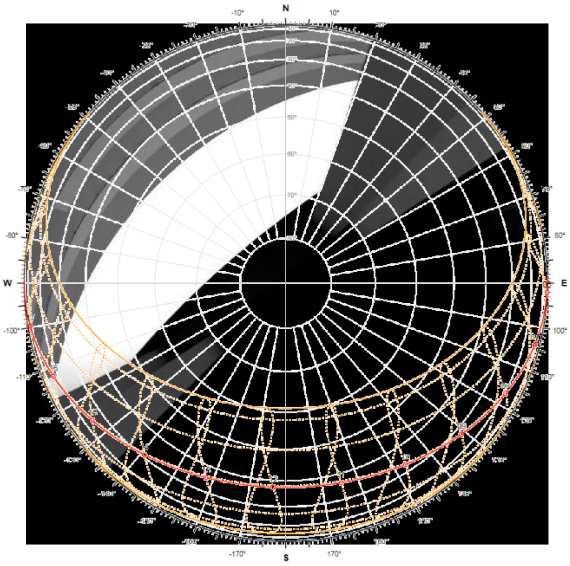
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m^2	0.66 m^2
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.06%	0.11%
	in 50% of the occupated area	0.15%	0.30%
Percentage of occupation hours when DGP > 0.45			0.46%
Duration of exposure to direct sunlight		0.3 hours	2.2 hours

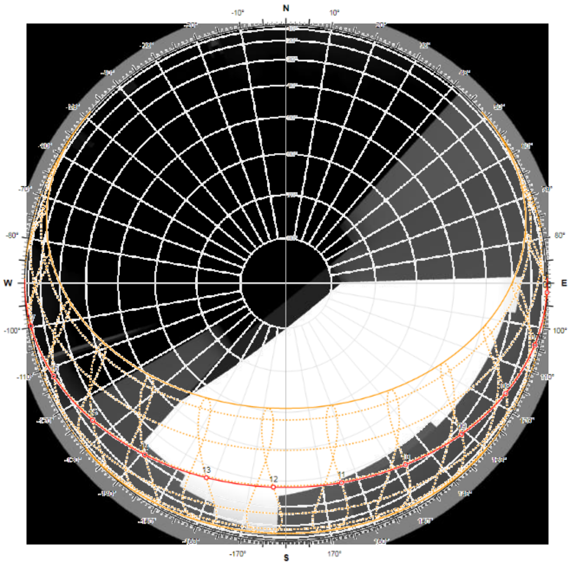
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.06%	0.11%
	in 50% of the occupated area (D_T)	0.15%	0.30%

Sunlight



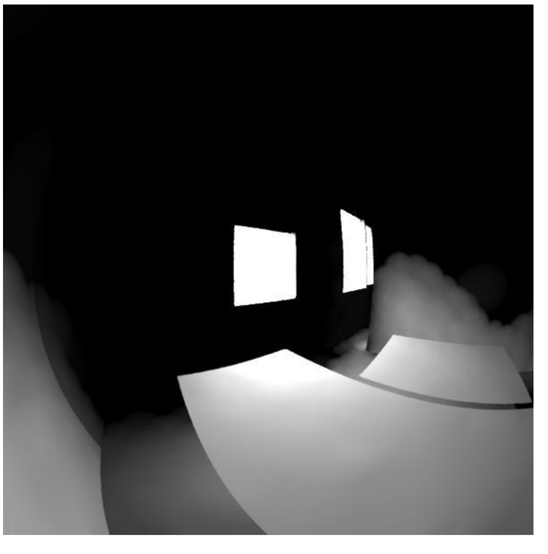


Sun path on March 21

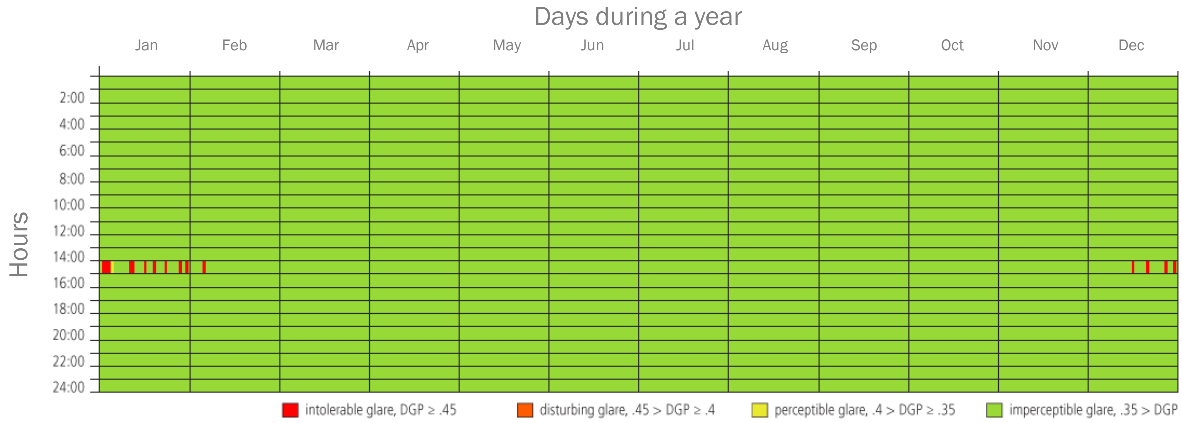
	Room NW	Room SE
Duration of exposure to direct sunlight	0.3 hours	2.2 hours

Glare

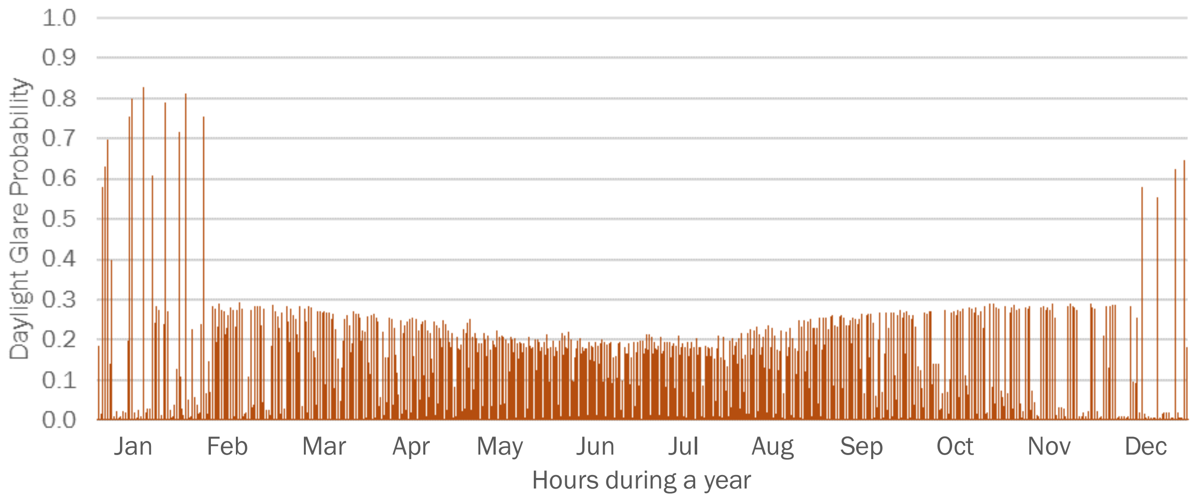
NW



SE



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

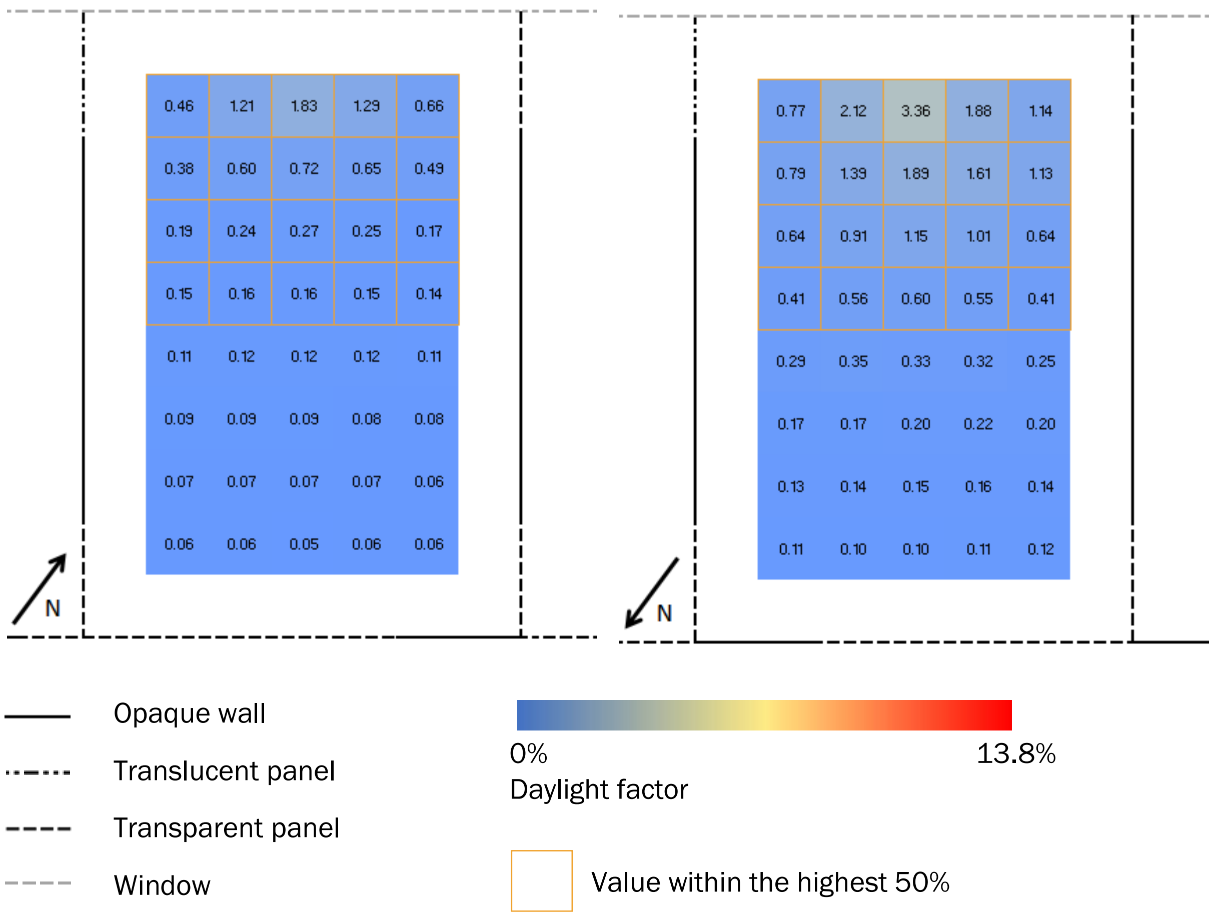
Daylight Glare Probability during a percentage of the occupation hours per year

During 0.46% of the occupation hours, the DGP is higher than 0.45.

Variant 1.2, minimal daylight area (Dutch) / vertical / centre

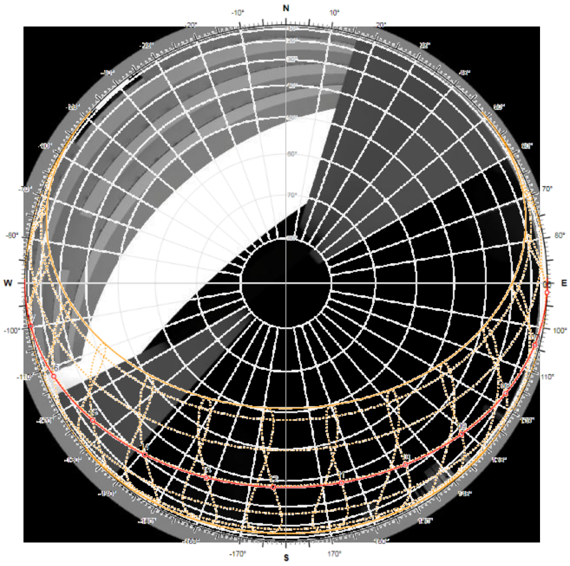
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.06%	0.11%
	in 50% of the occupated area	0.14%	0.41%
Percentage of occupation hours when DGP > 0.45			1.49%
Duration of exposure to direct sunlight		0.3 hours	2.7 hours

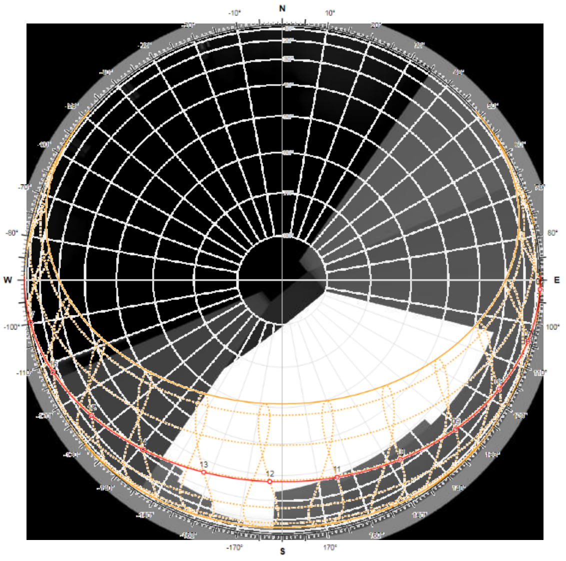
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.06%	0.11%
	in 50% of the occupated area (D_T)	0.14%	0.41%

Sunlight

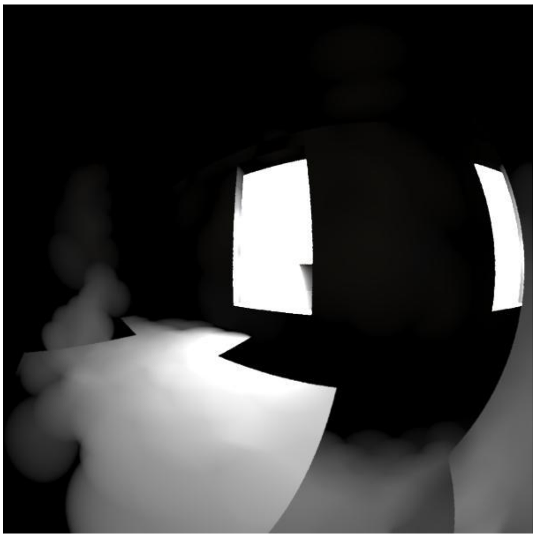




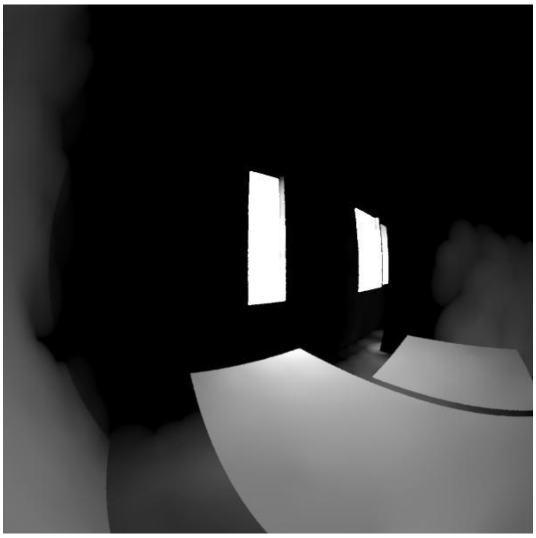
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.3 hours	2.7 hours

Glare

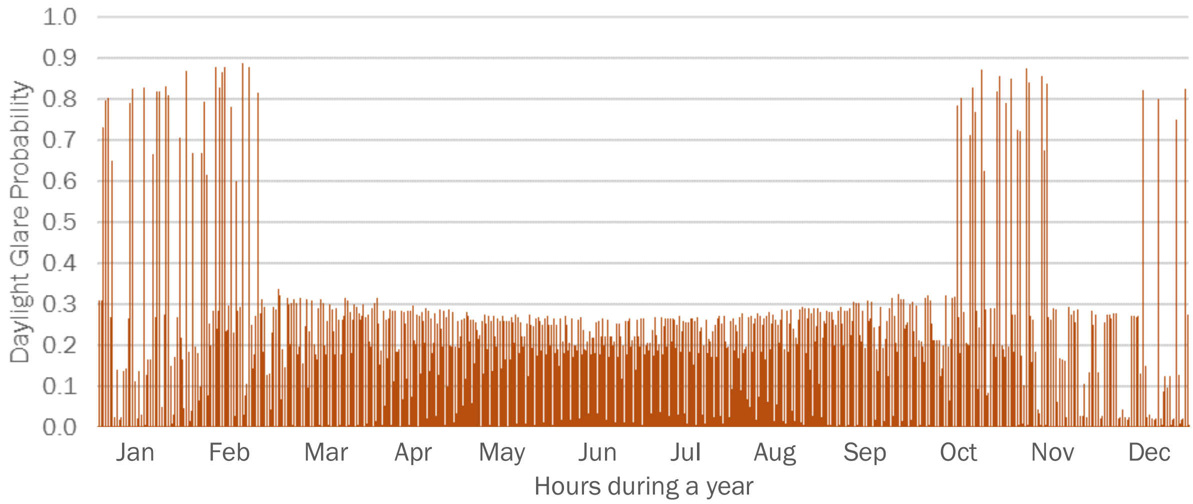


NW

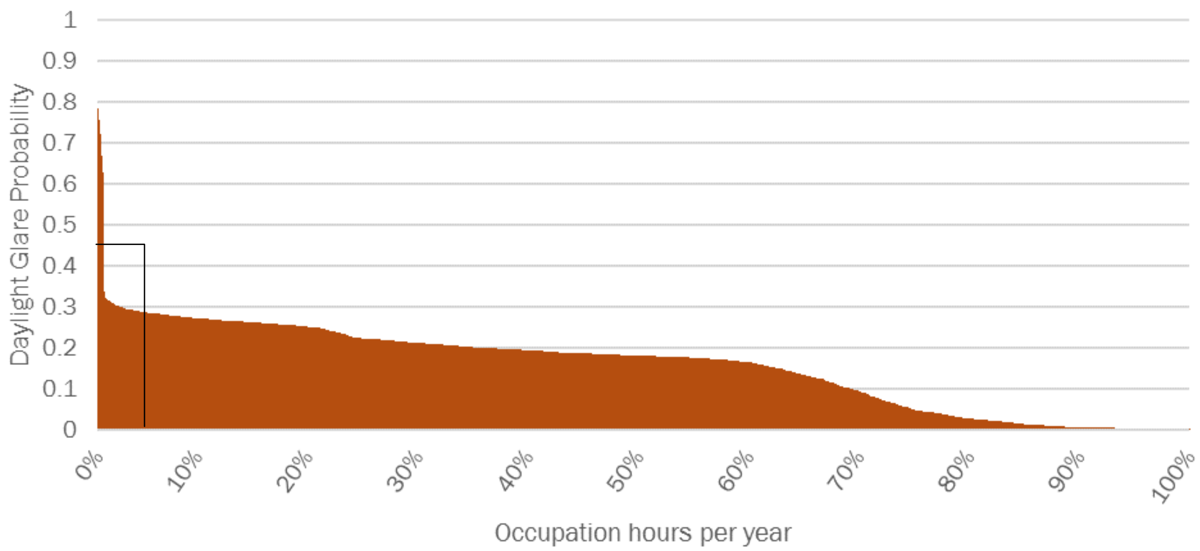


SE

Daylight Glare Probability during the year and day



Daylight Glare Probability during the year



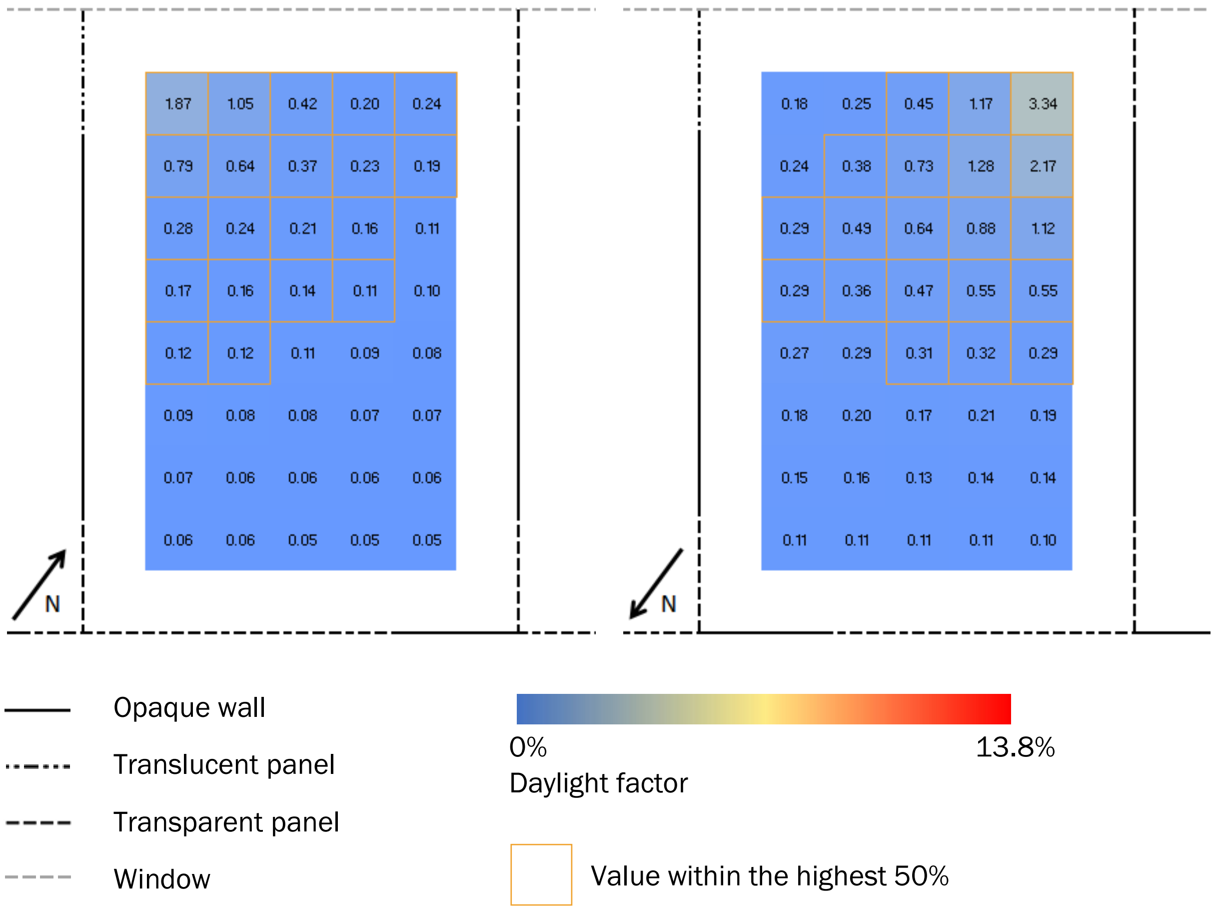
Daylight Glare Probability during a percentage of the occupation hours per year

During **1.49%** of the occupation hours, the DGP is higher than 0.45.

Variant 1.3, minimal daylight area (Dutch) / vertical / side

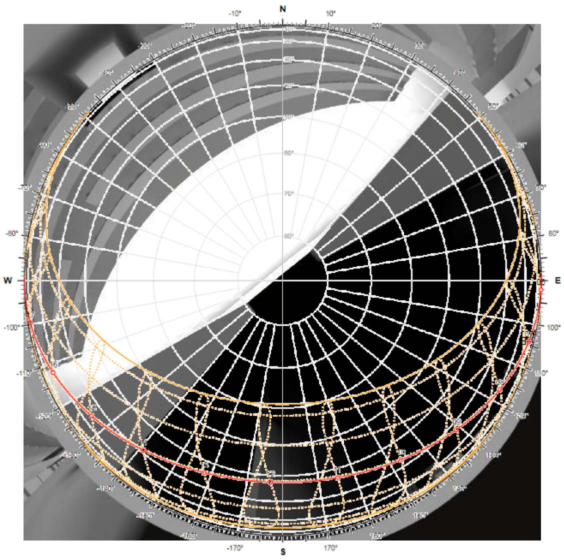
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.05%	0.11%
	in 50% of the occupated area	0.11%	0.29%
Percentage of occupation hours when DGP > 0.45			0.69%
Duration of exposure to direct sunlight		0.7 hours	2.6 hours

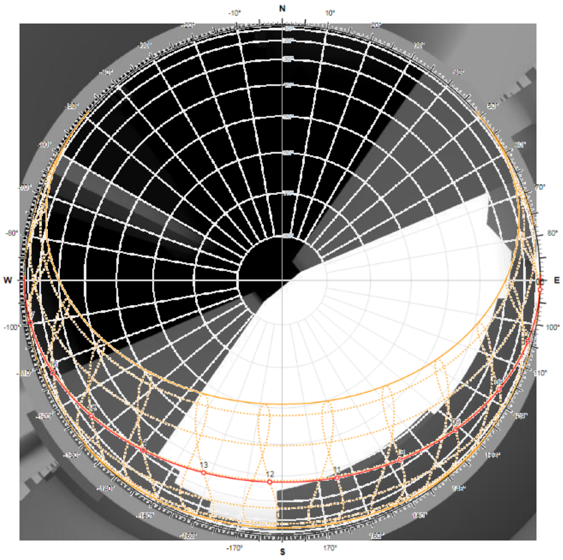
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.05%	0.11%
	in 50% of the occupated area (D_T)	0.11%	0.29%

Sunlight

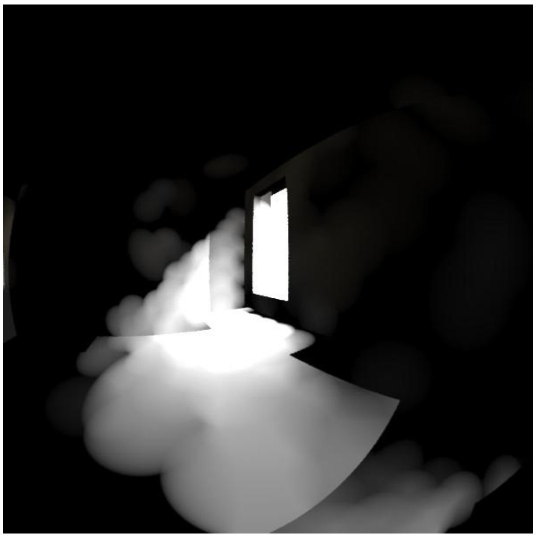




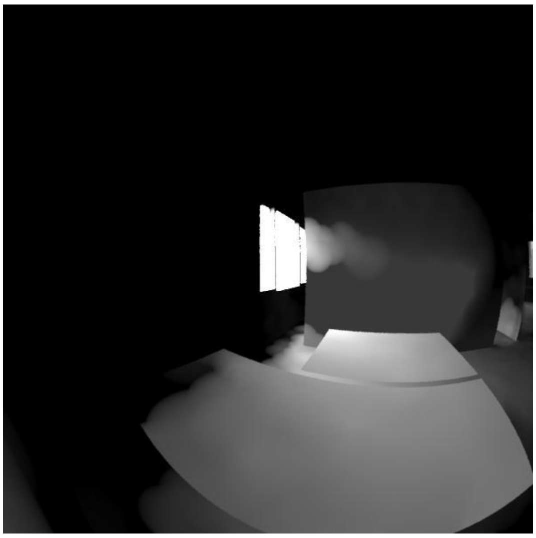
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.7 hours	2.6 hours

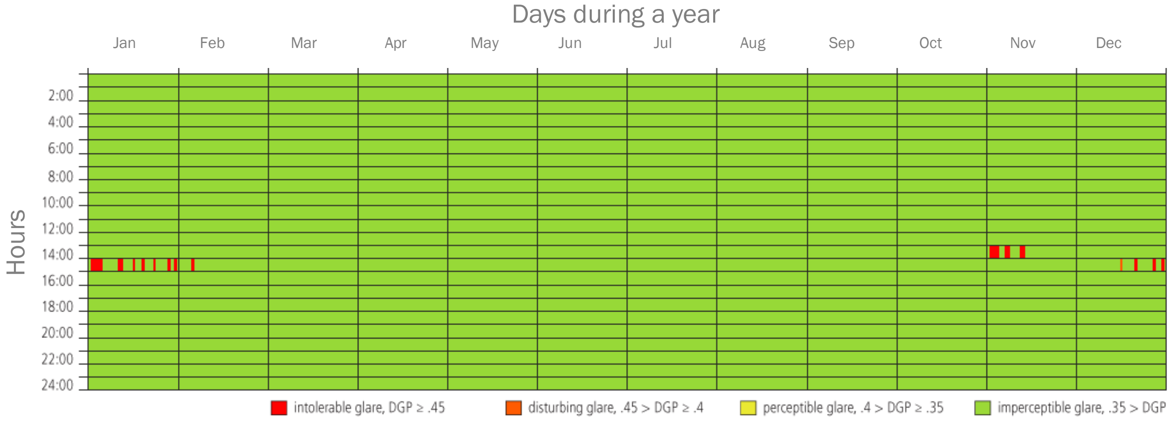
Glare



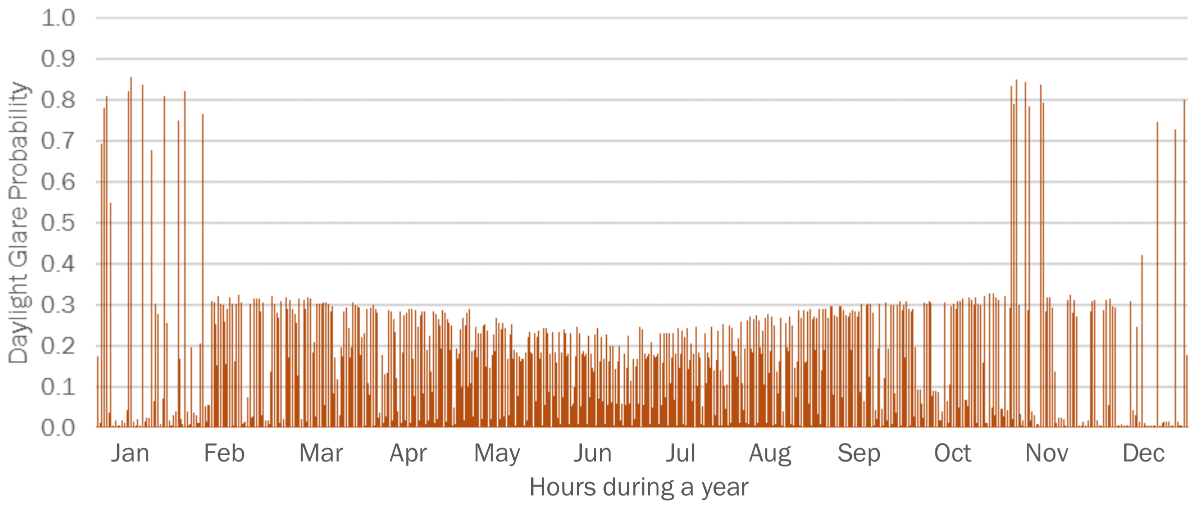
NW



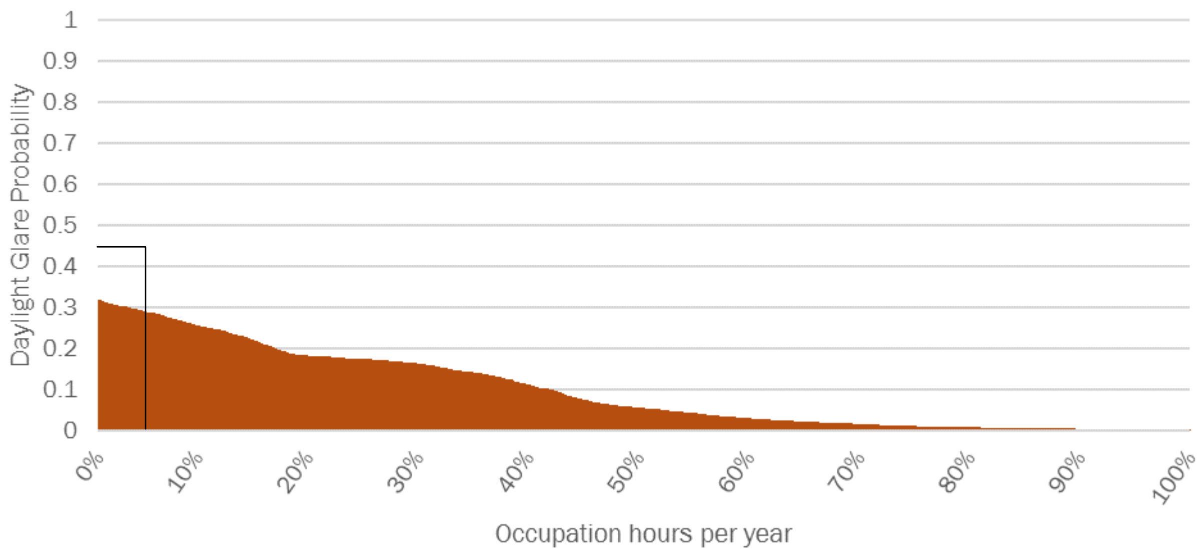
SE



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year



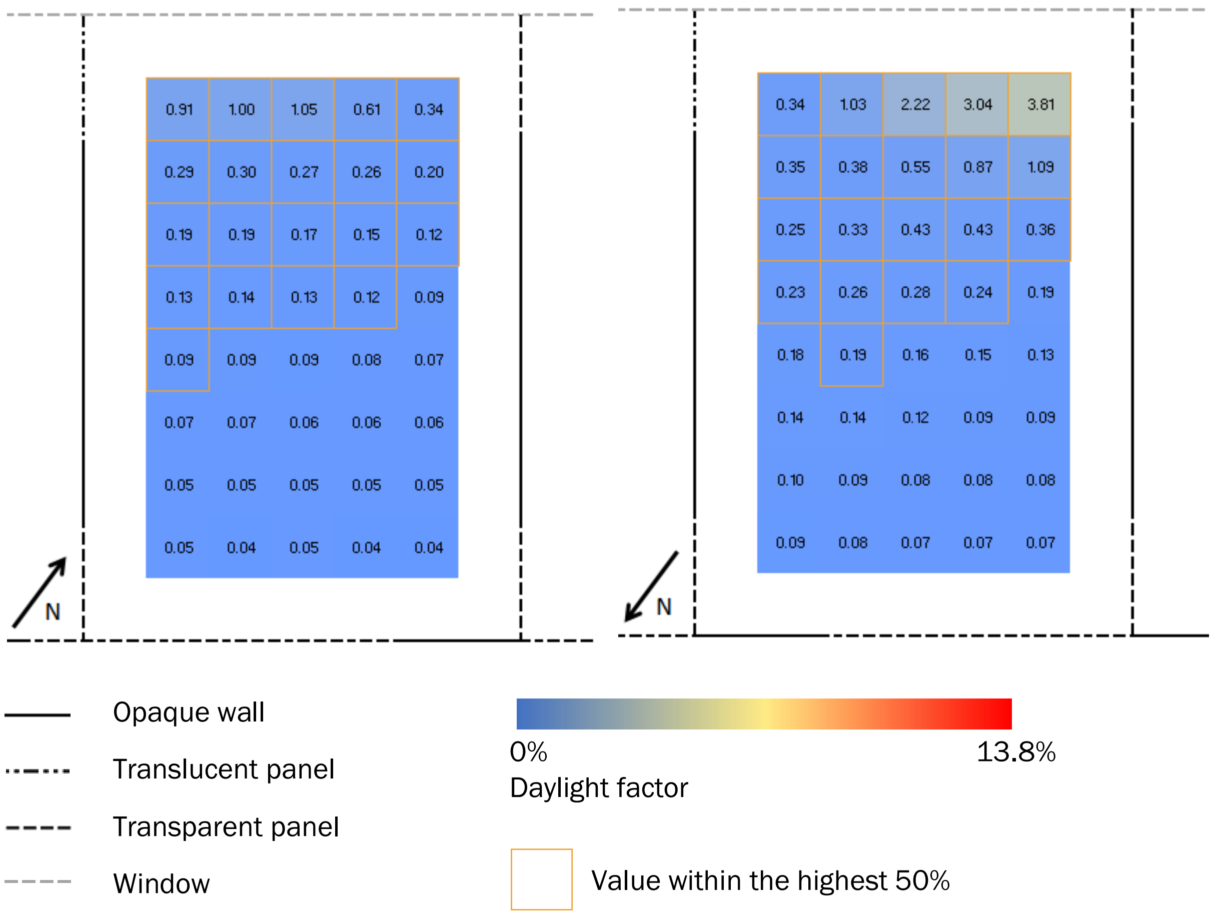
Daylight Glare Probability during a percentage of the occupation hours per year

During **0.69%** of the occupation hours, the DGP is higher than 0.45.

VARIANT 1.4, MINIMAL DAYLIGHT AREA (DUTCH) / HORIZONTAL / CENTRE

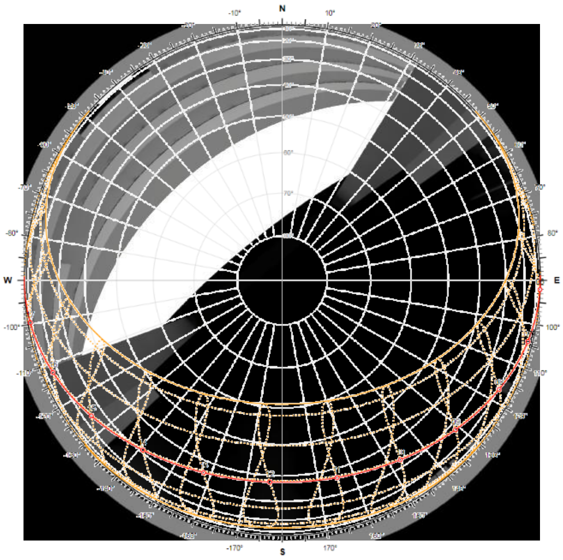
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.04%	0.07%
	in 50% of the occupated area	0.09%	0.19%
Percentage of occupation hours when DGP > 0.45			0.46%
Duration of exposure to direct sunlight		0 hours	2 hours

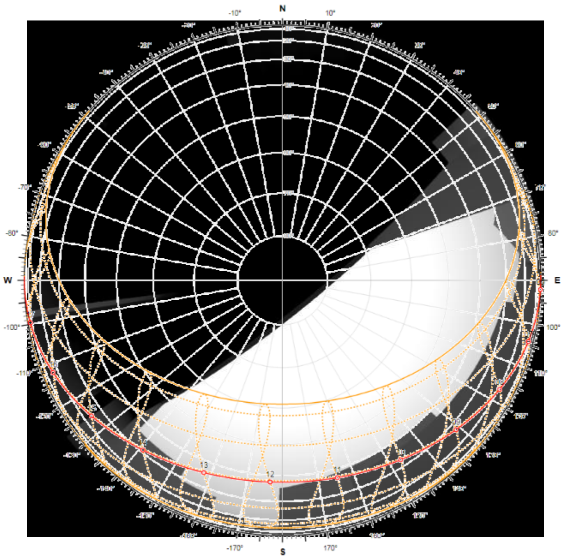
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.04%	0.07%
	in 50% of the occupated area (D_T)	0.09%	0.19%

Sunlight

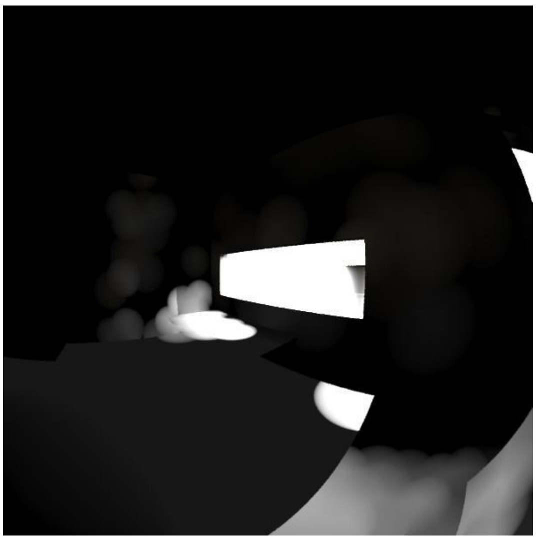




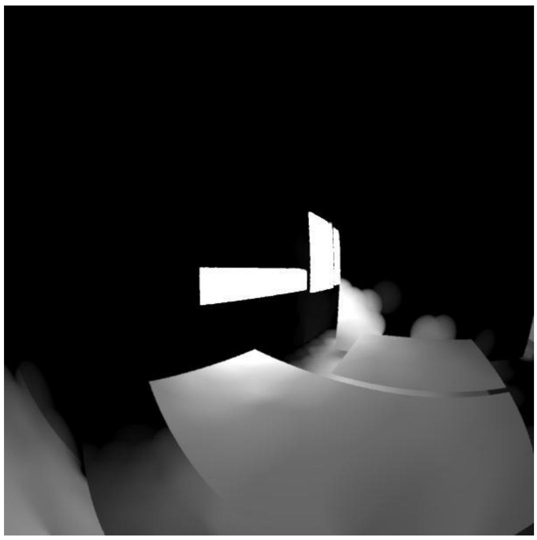
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0 hours	2 hours

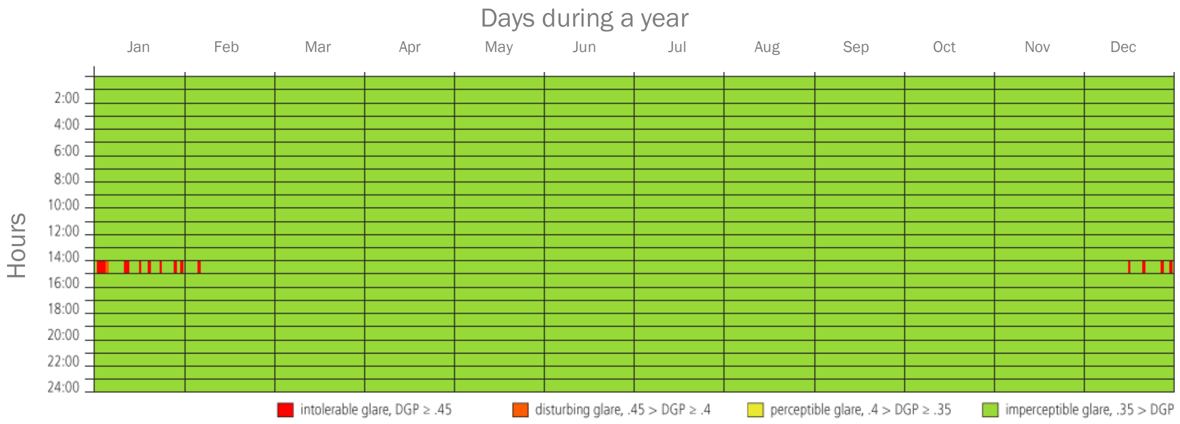
Glare



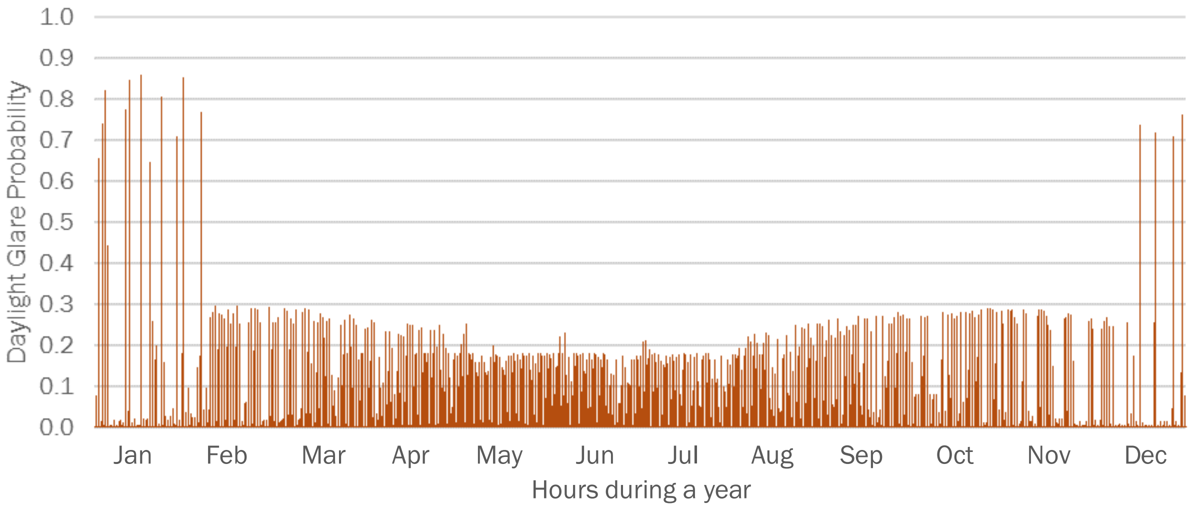
NW



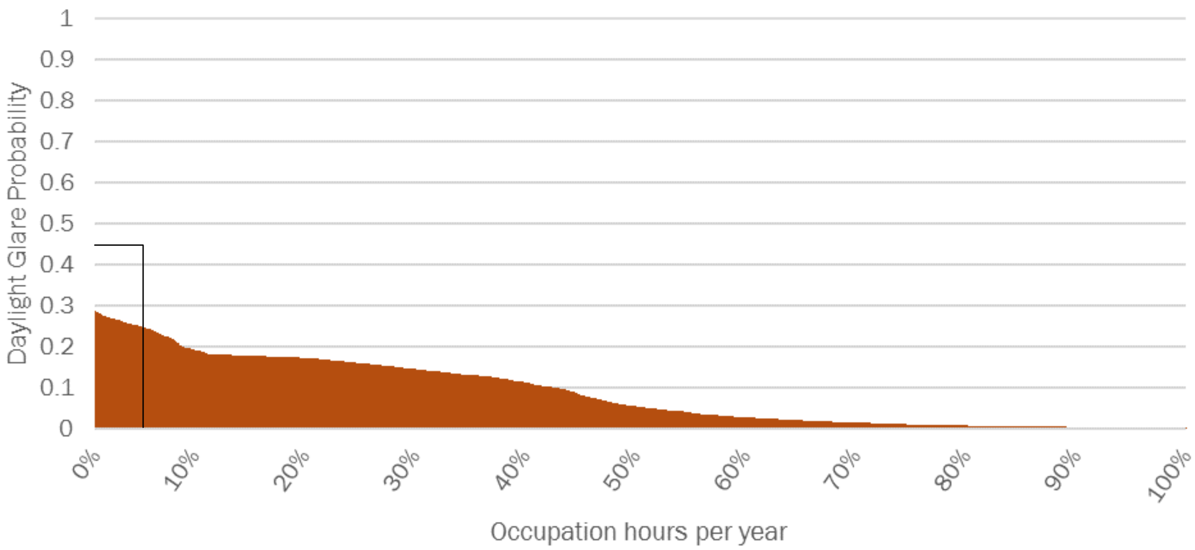
SE



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year



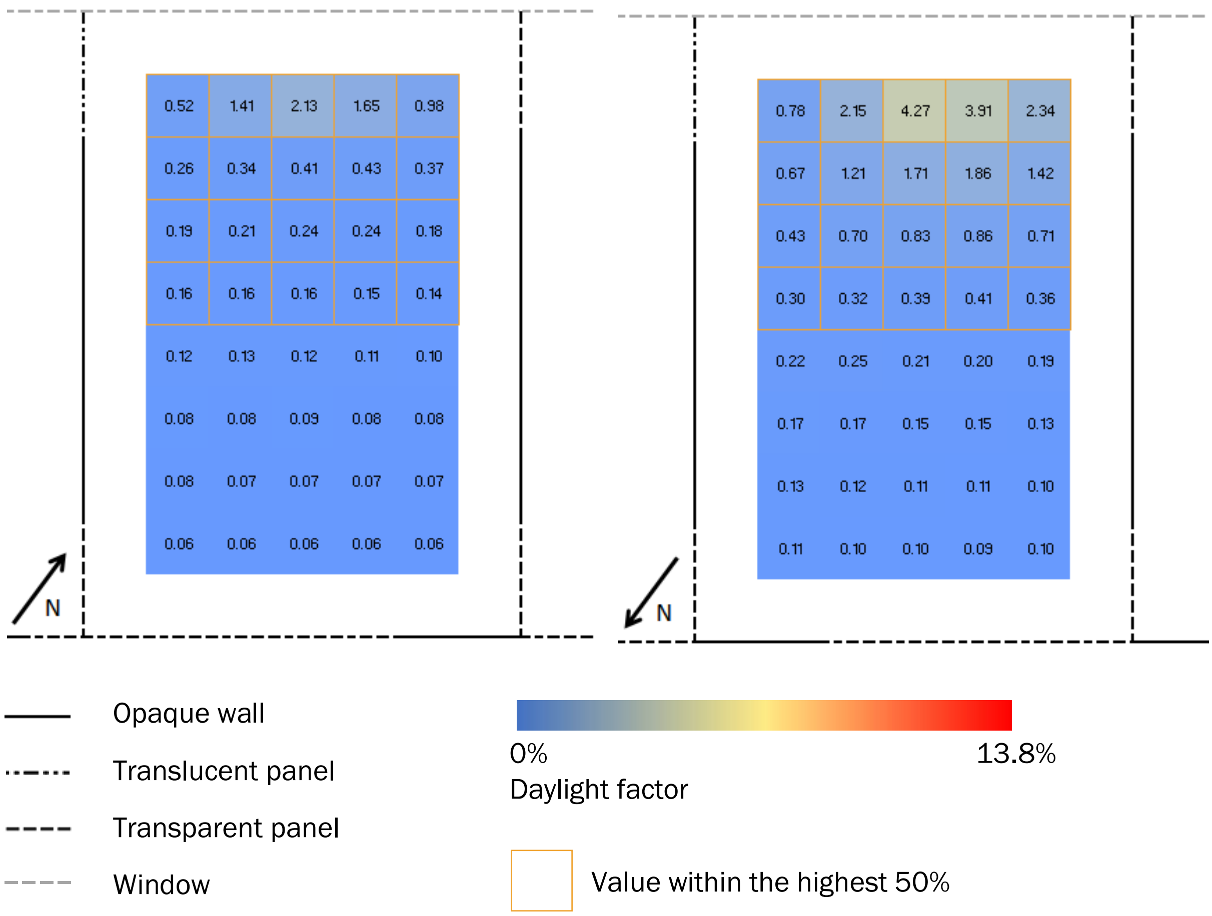
Daylight Glare Probability during a percentage of the occupation hours per year

During **0.46%** of the occupation hours, the DGP is higher than 0.45.

VARIANT 1.5 , MINIMAL DAYLIGHT AREA (DUTCH) / SQUARE / CENTRE / WITHOUT EXTERNAL GLASS PANES

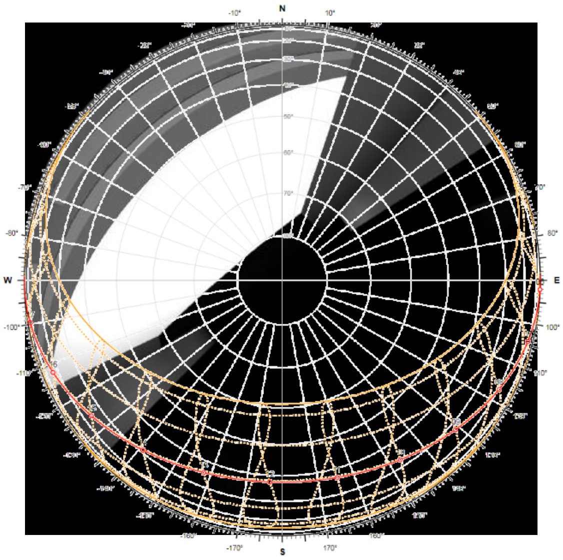
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.06%	0.10%
	in 50% of the occupated area	0.14%	0.30%
Percentage of occupation hours when DGP > 0.45			0.46%
Duration of exposure to direct sunlight		0.4 hours	2.2 hours

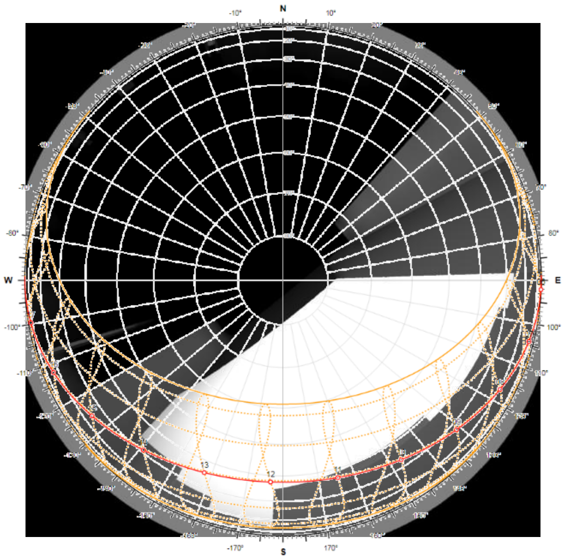
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.06%	0.10%
	in 50% of the occupated area (D_T)	0.14%	0.30%

Sunlight

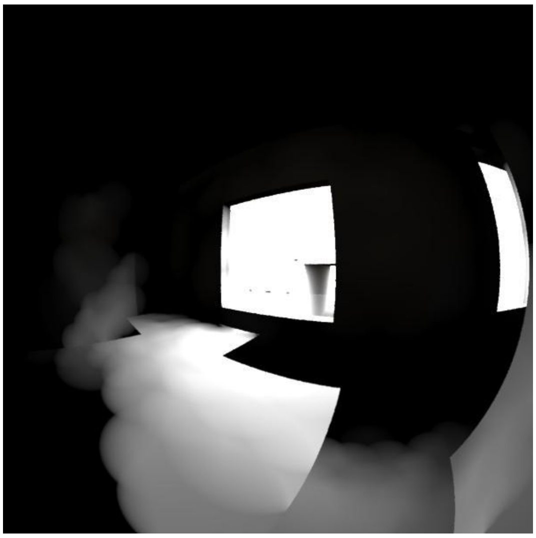




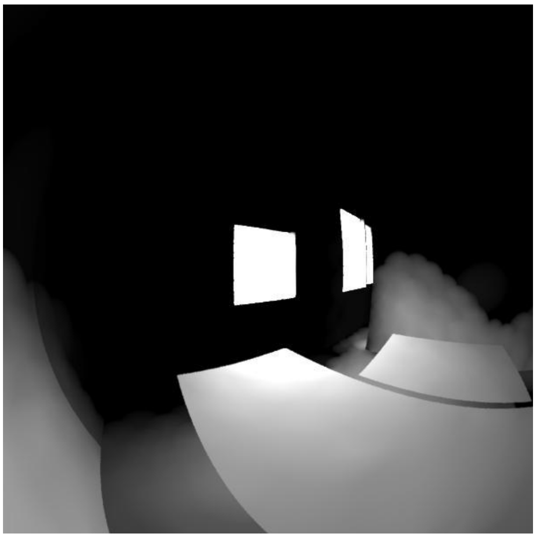
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.4 hours	2.2 hours

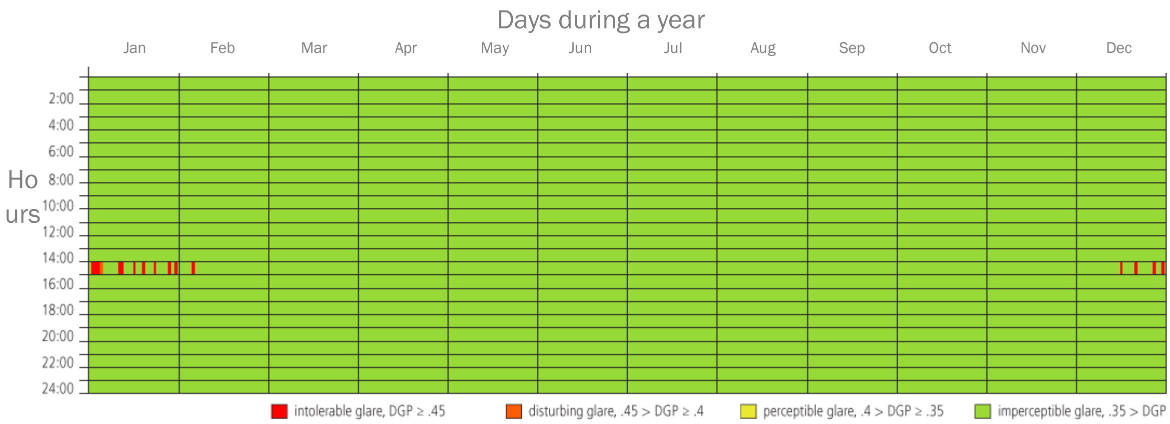
Glare



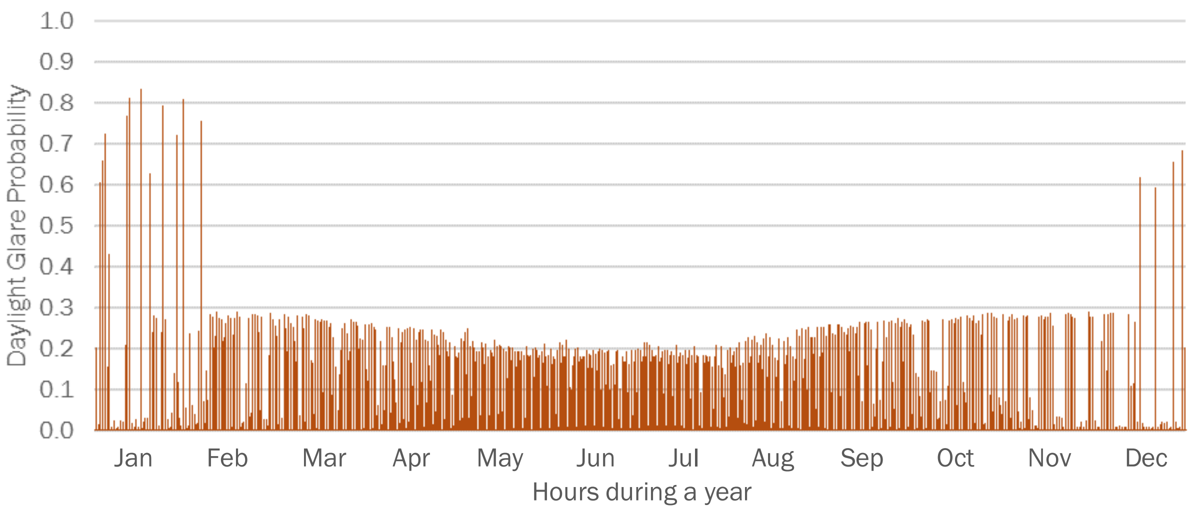
NW



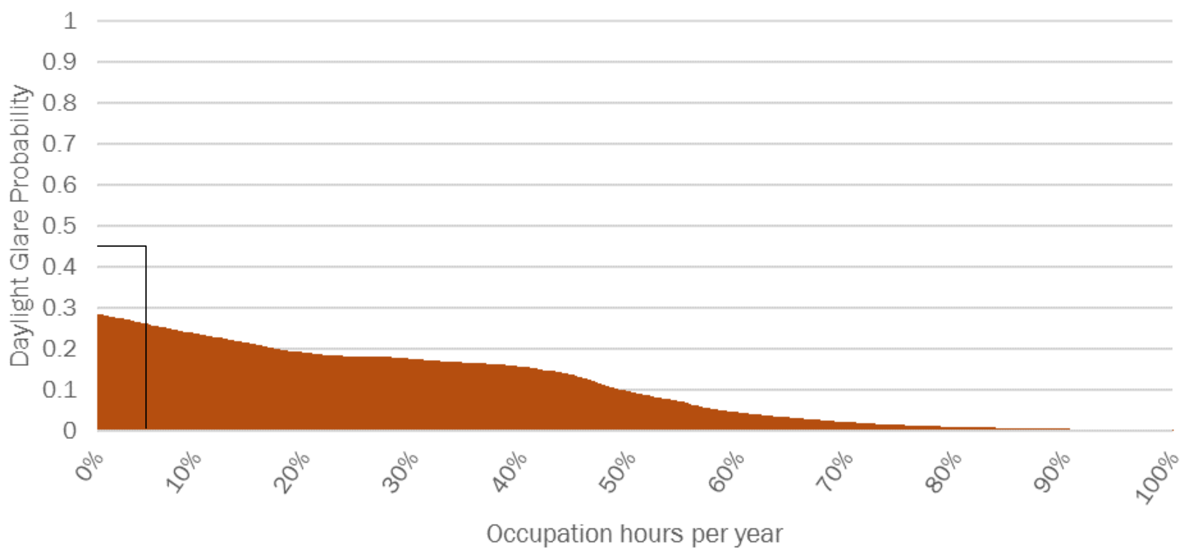
SE



Graph ..: Daylight Glare Probability during the year and day



Graph ..: Daylight Glare Probability during the year



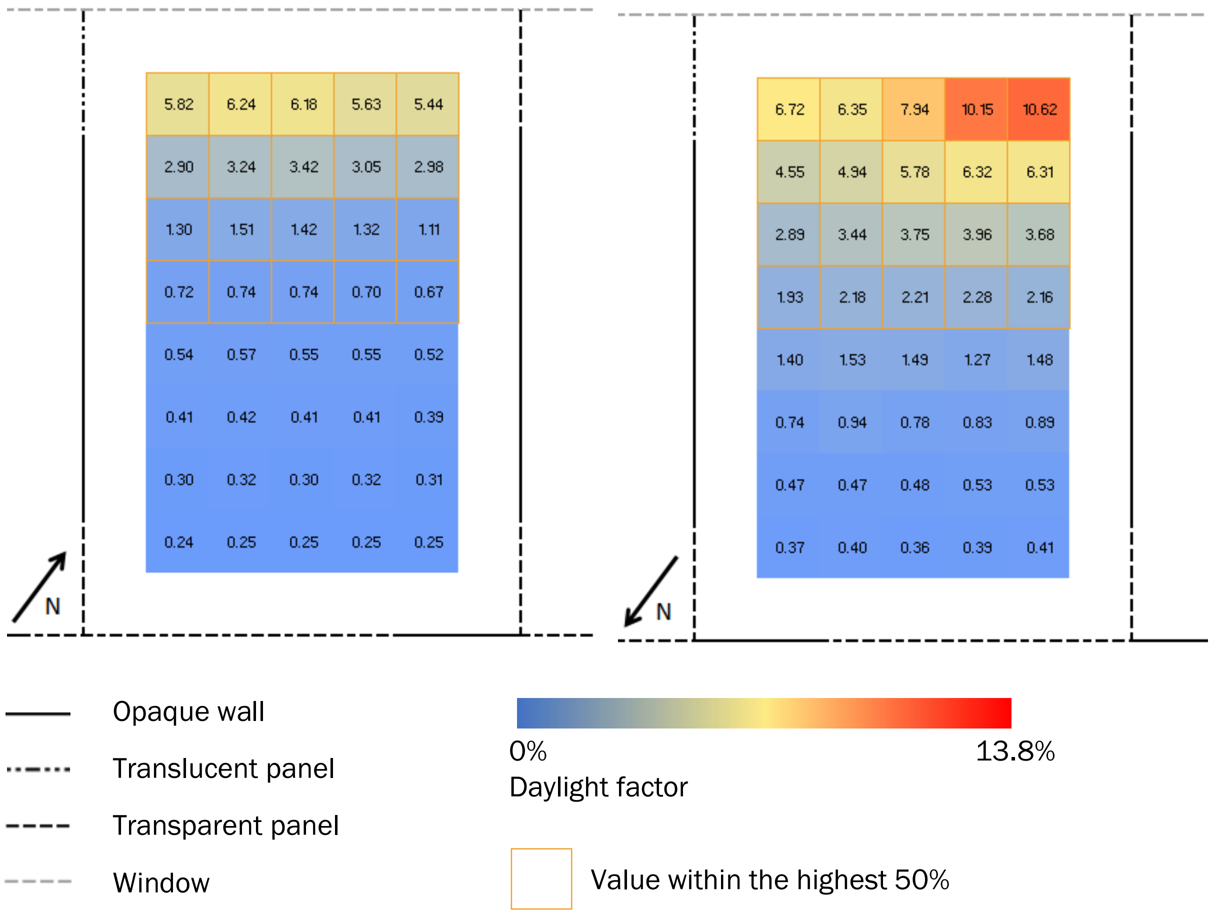
Graph ..: Daylight Glare Probability during a percentage of the occupation hours per year

During **0.46%** of the occupation hours, the DGP is higher than 0.45.

VARIANT 2.1 , MAXIMUM DAYLIGHT FACTOR / WITHOUT EXTERNAL GLASS PANES

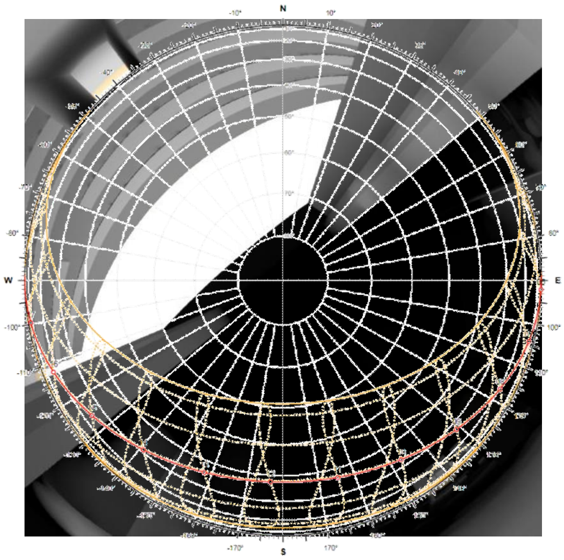
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		2.96 m^2	2.93 m^2
		15.2%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.25%	0.39%
	in 50% of the occupated area	0.67%	1.93%
Percentage of occupation hours when DGP > 0.45			9.92%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

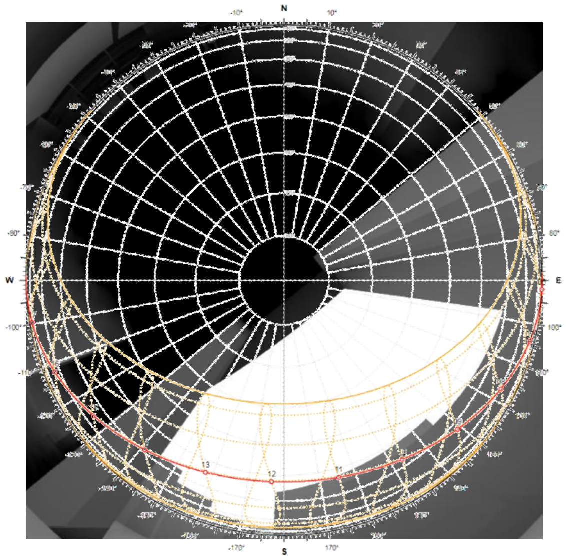
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.25%	0.39%
	in 50% of the occupated area (D_T)	0.67%	1.93%

Sunlight

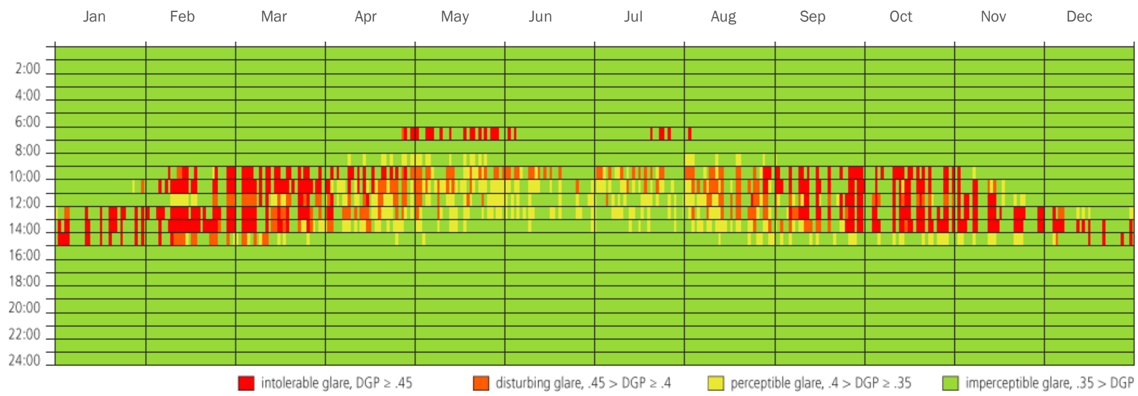




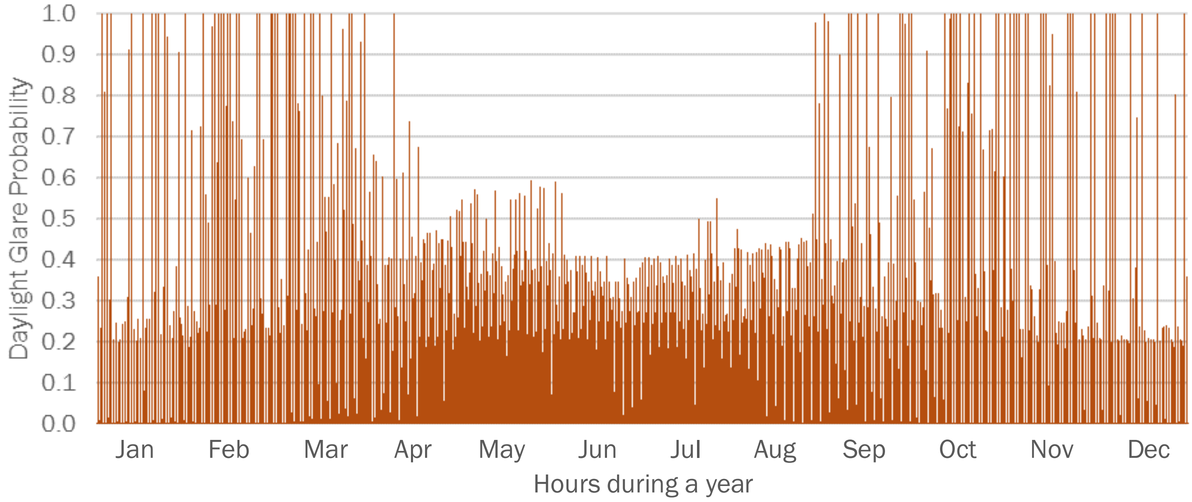
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.2 hours	2.7 hours

Glare



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

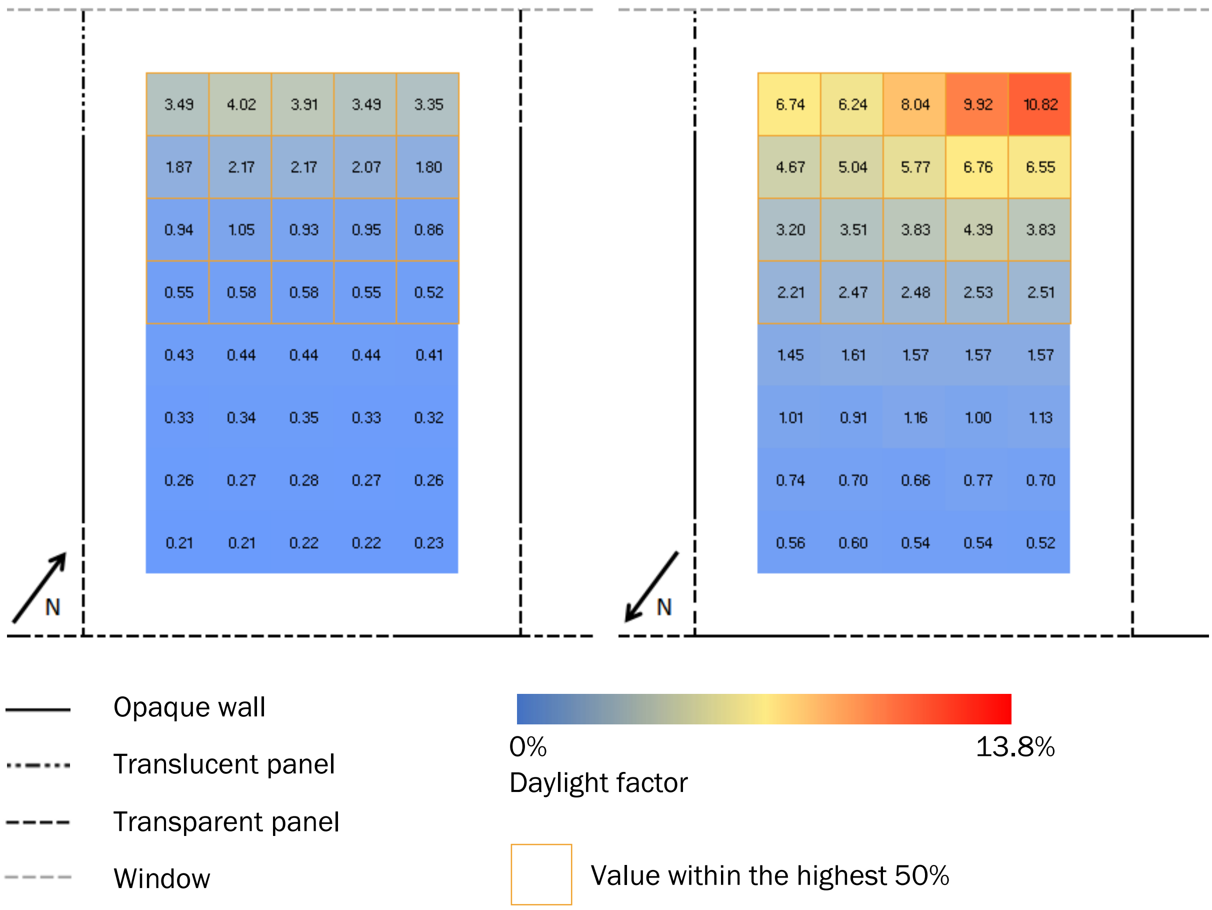
Daylight Glare Probability during a percentage of the occupation hours per year

During 9.92% of the occupation hours, the DGP is higher than 0.45.

VARIANT 2.2 , MAXIMUM DAYLIGHT FACTOR / MAXIMUM REFLECTION FACTORS

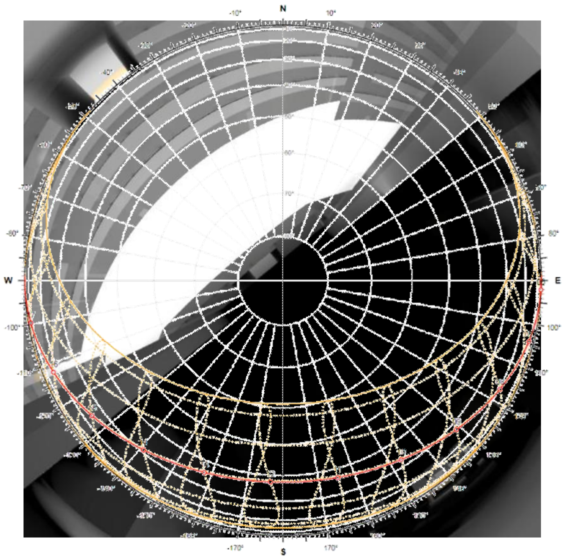
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.88 m²	2.93 m²
		9.7%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.22%	0.54%
	in 50% of the occupated area	0.52%	2.21%
Percentage of occupation hours when DGP > 0.45			..%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

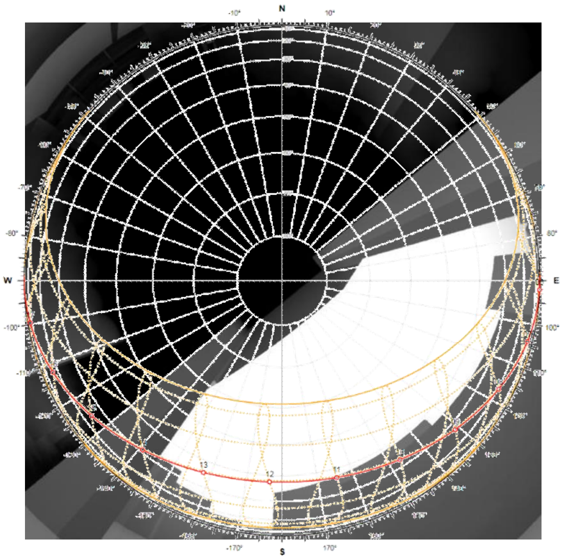
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.22%	0.54%
	in 50% of the occupated area (D_T)	0.52%	2.21%

Sunlight





Sun path on March 21

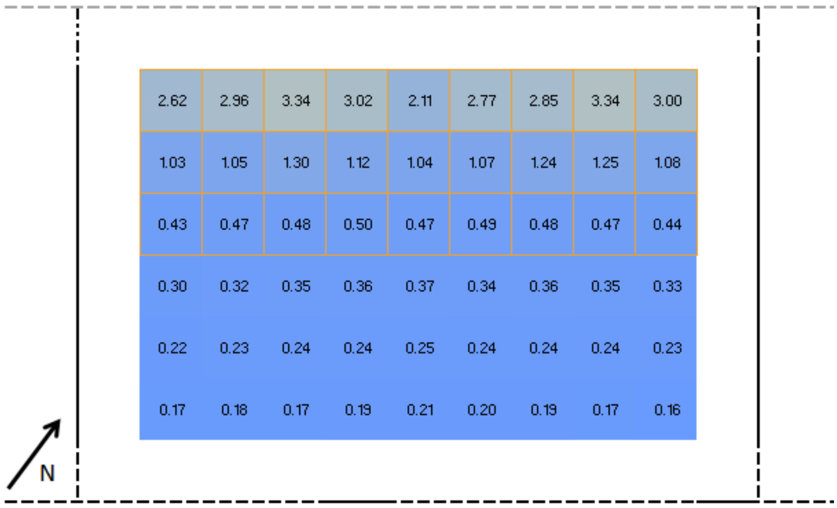
	Room NW	Room SE
Duration of exposure to direct sunlight	0.2 hours	2.7 hours

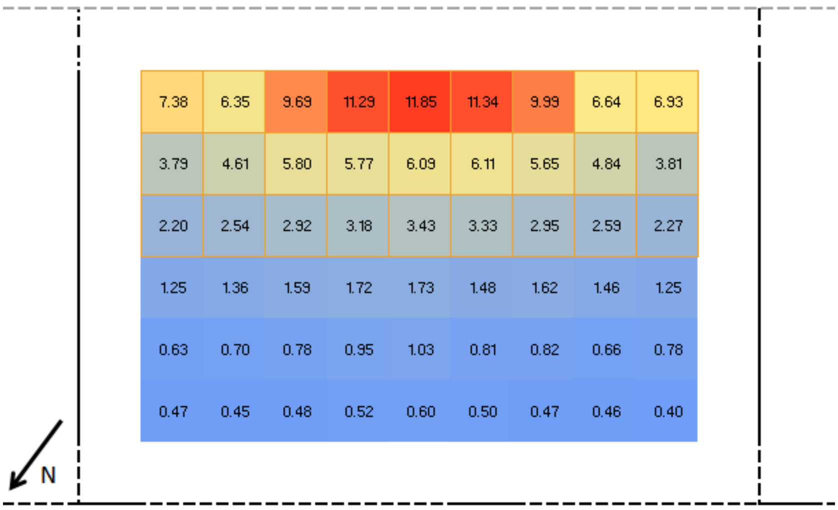
VARIANT 2.3 , MAXIMUM DAYLIGHT FACTOR / LESS SEPARATION WALLS

...

		Room NW	Room SE
Dutch standard			
Equivalent daylight area		3.85 m²	5.85 m²
		9.9%	15.0%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.17%	0.46%
	in 50% of the occupated area	0.43%	2.20%
Percentage of occupation hours when DGP > 0.45			9.92%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

Daylight factor





Opaque wall

Translucent panel

Transparent panel

Window

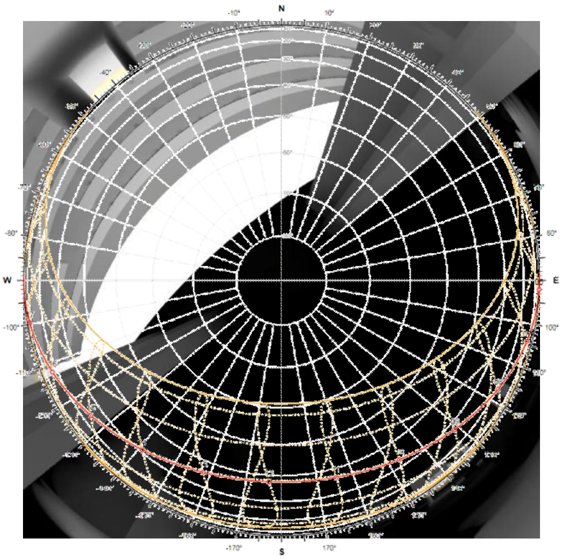
0% 13.8%

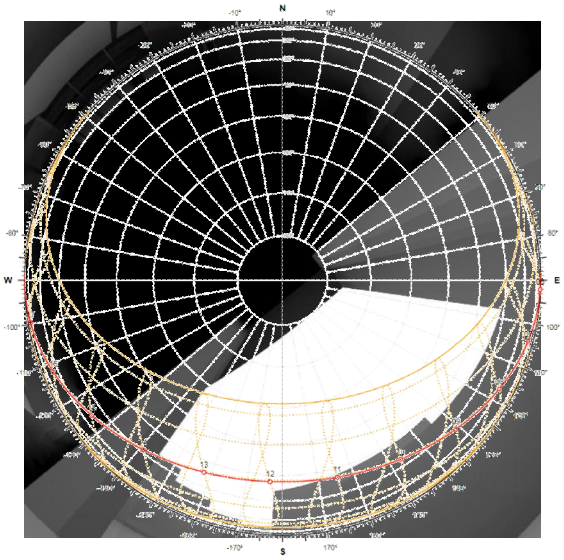
Daylight factor

Value within the highest 50%

		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.17%	0.46%
	in 50% of the occupated area (D_T)	0.43%	2.20%

Sunlight

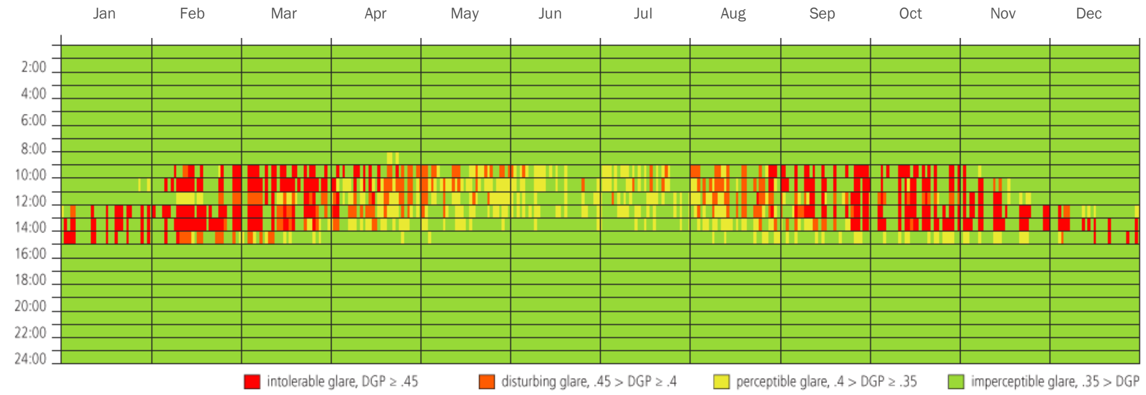




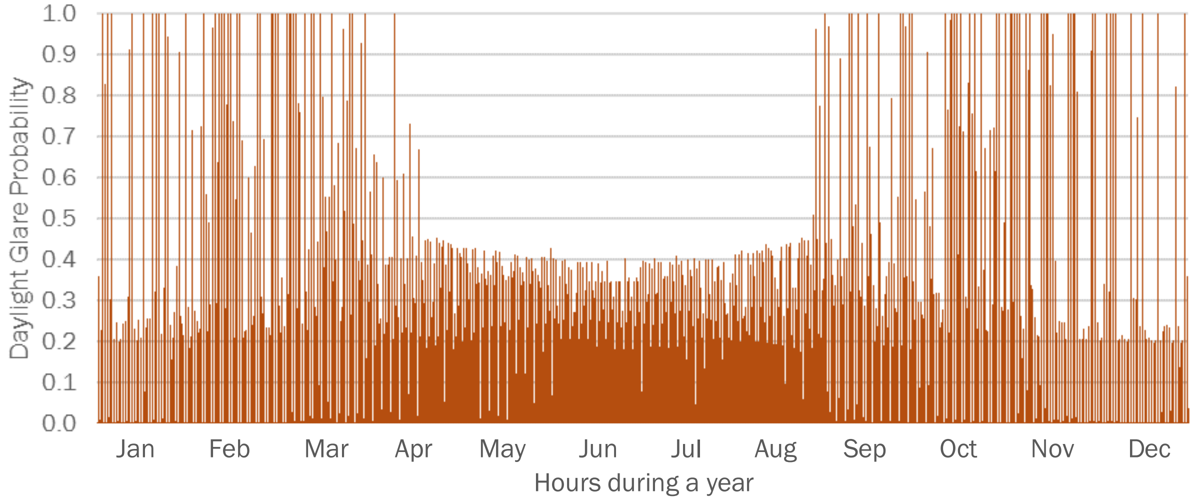
 Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.2 hours	2.7 hours

Glare



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

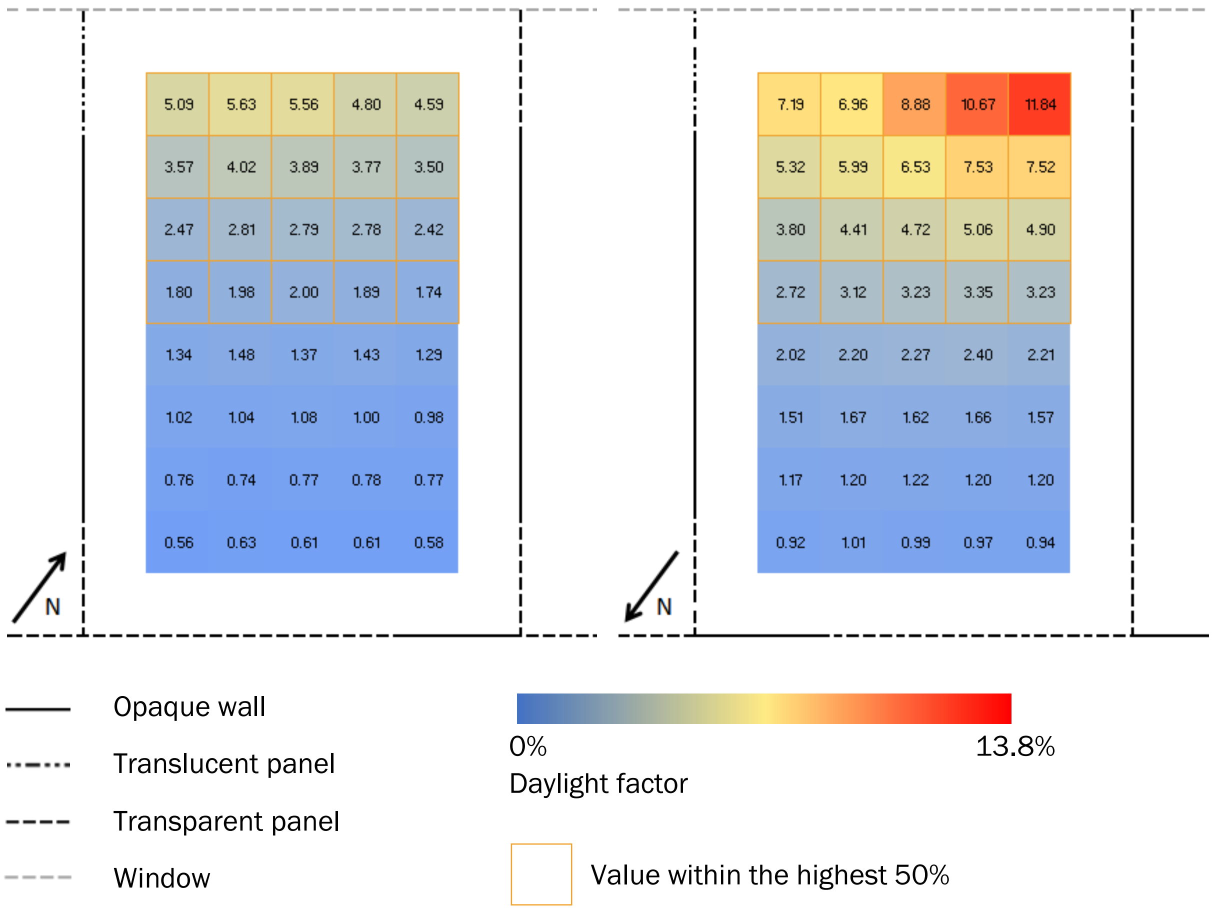
Daylight Glare Probability during a percentage of the occupation hours per year

During 9.92% of the occupation hours, the DGP is higher than 0.45.

VARIANT 2.4, MAXIMUM DAYLIGHT FACTOR / WITHOUT SURROUNDING BUILDINGS

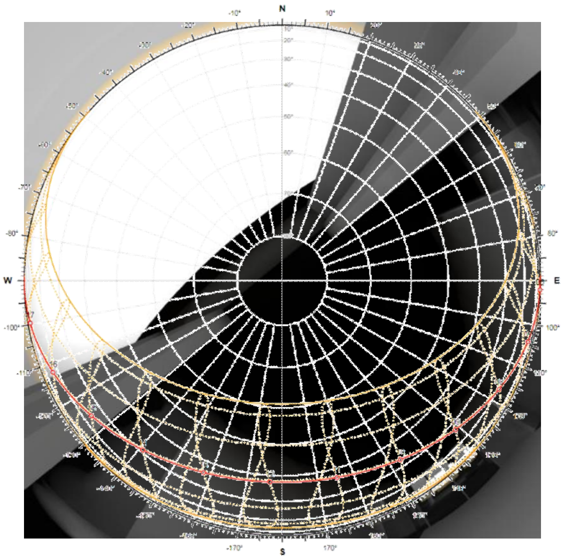
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.88 m²	2.93 m²
		9.7%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.61%	0.97%
	in 50% of the occupated area	1.74%	2.72%
Percentage of occupation hours when DGP > 0.45			24.94%
Duration of exposure to direct sunlight		1.8 hours	7.3 hours

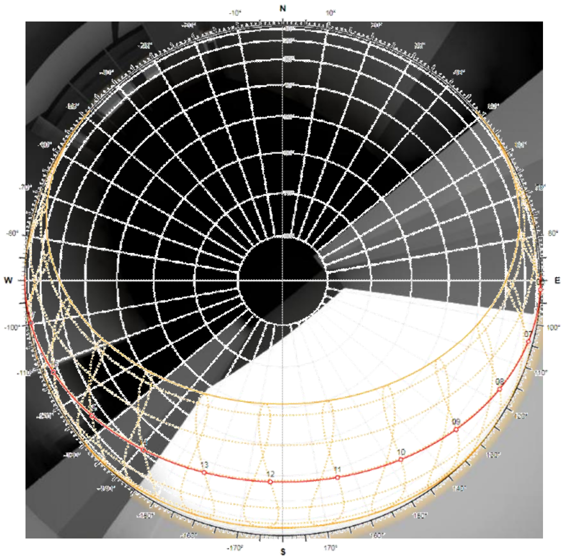
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.61%	0.97%
	in 50% of the occupated area (D_T)	1.74%	2.72%

Sunlight

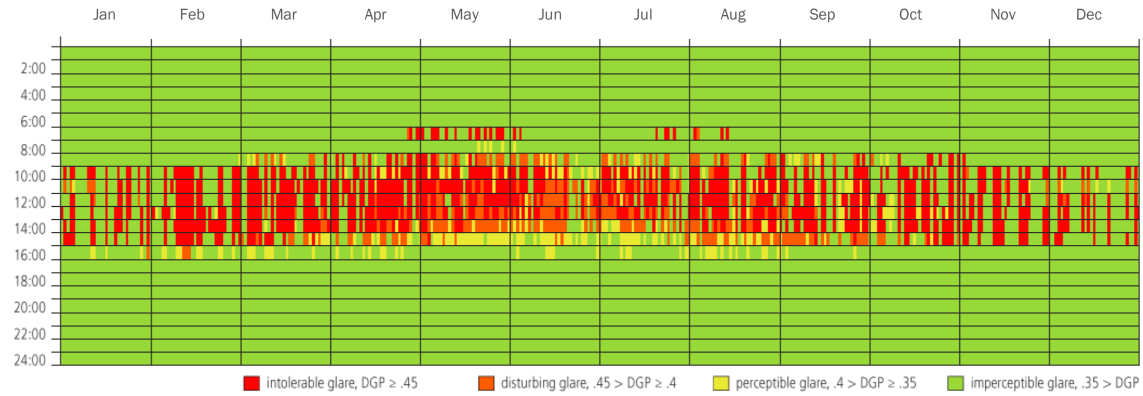




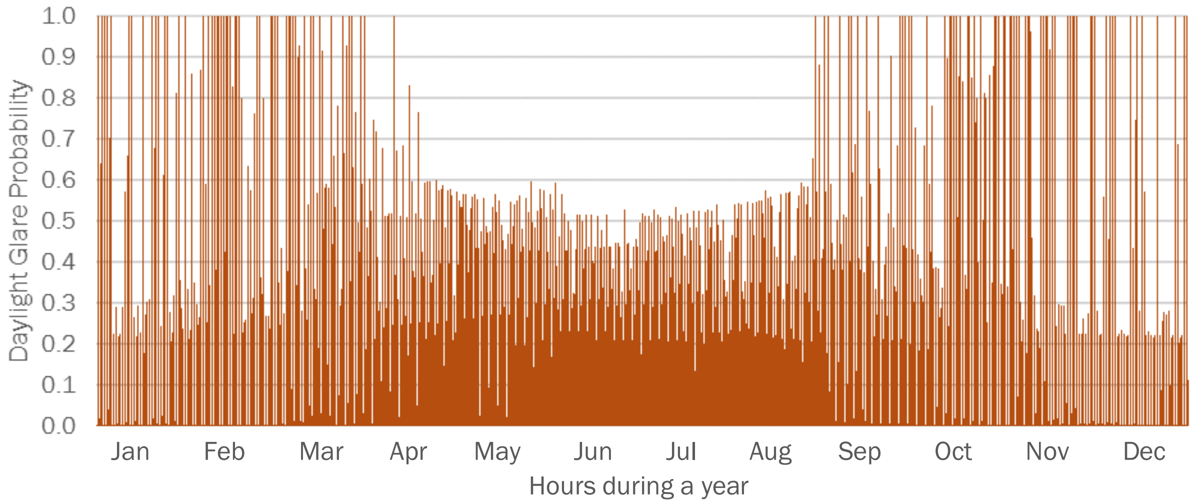
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	1.8 hours	7.3 hours

Glare



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

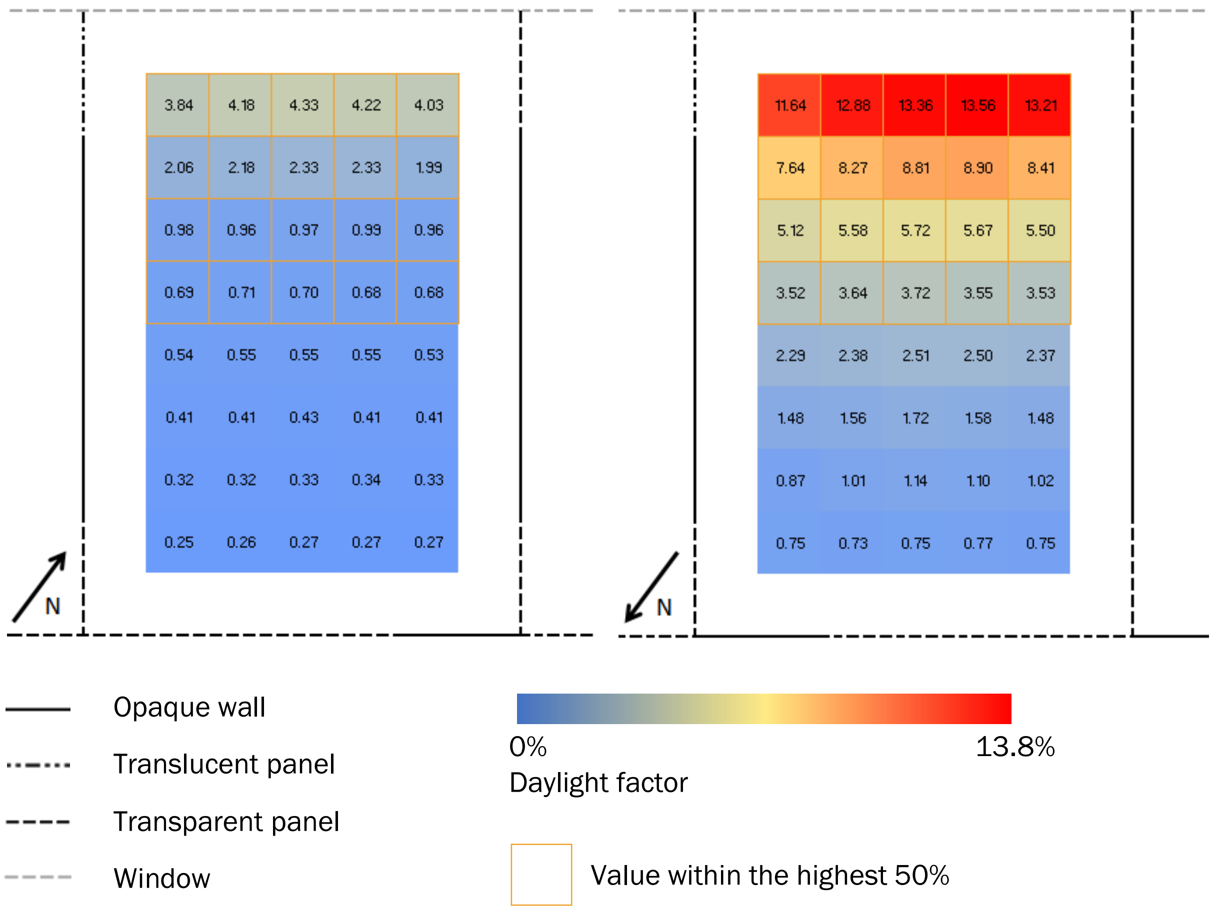
Daylight Glare Probability during a percentage of the occupation hours per year

During 24.94% of the occupation hours, the DGP is higher than 0.45.

VARIANT 2.5, MAXIMUM DAYLIGHT FACTOR / MAXIMUM WINDOW AREA

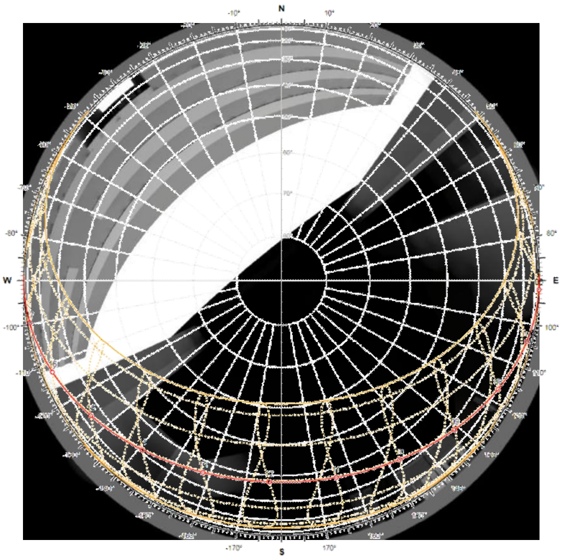
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		3.80 m² 19.5%	6.00 m² 30.9%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.27%	0.75%
	in 50% of the occupated area	0.68%	3.52%
Percentage of occupation hours when DGP > 0.45			26.63%
Duration of exposure to direct sunlight		0.3 hours	1.9 hours

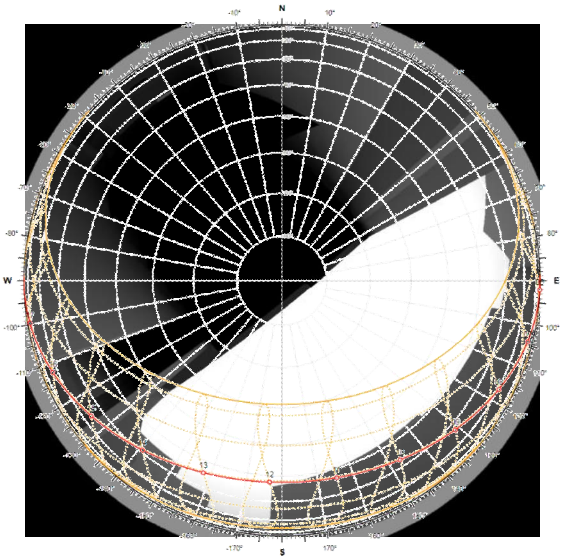
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.27%	0.75%
	in 50% of the occupated area (D_T)	0.68%	3.52%

Sunlight

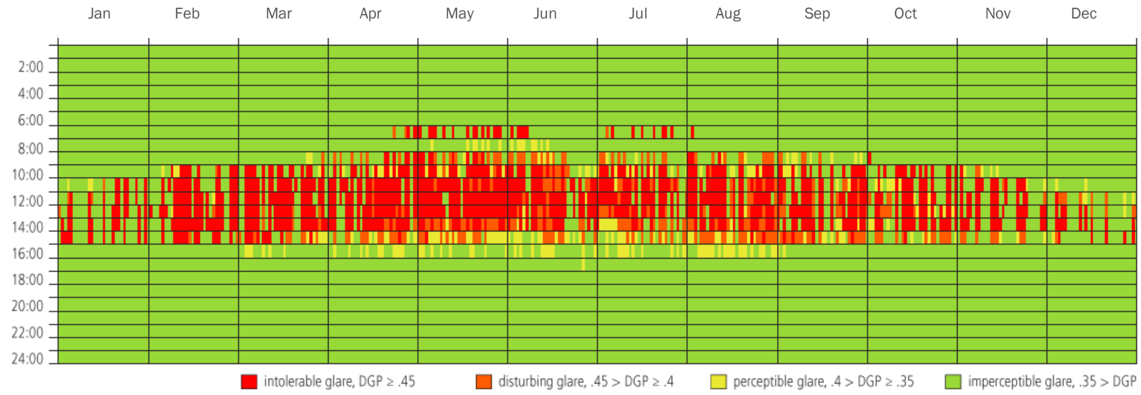




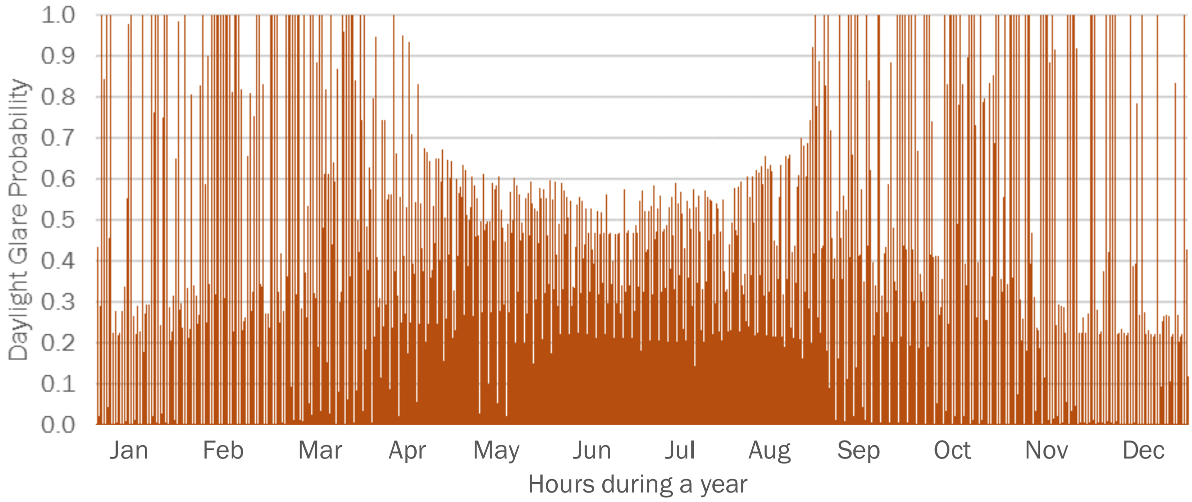
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.3 hours	1.9 hours

Glare



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

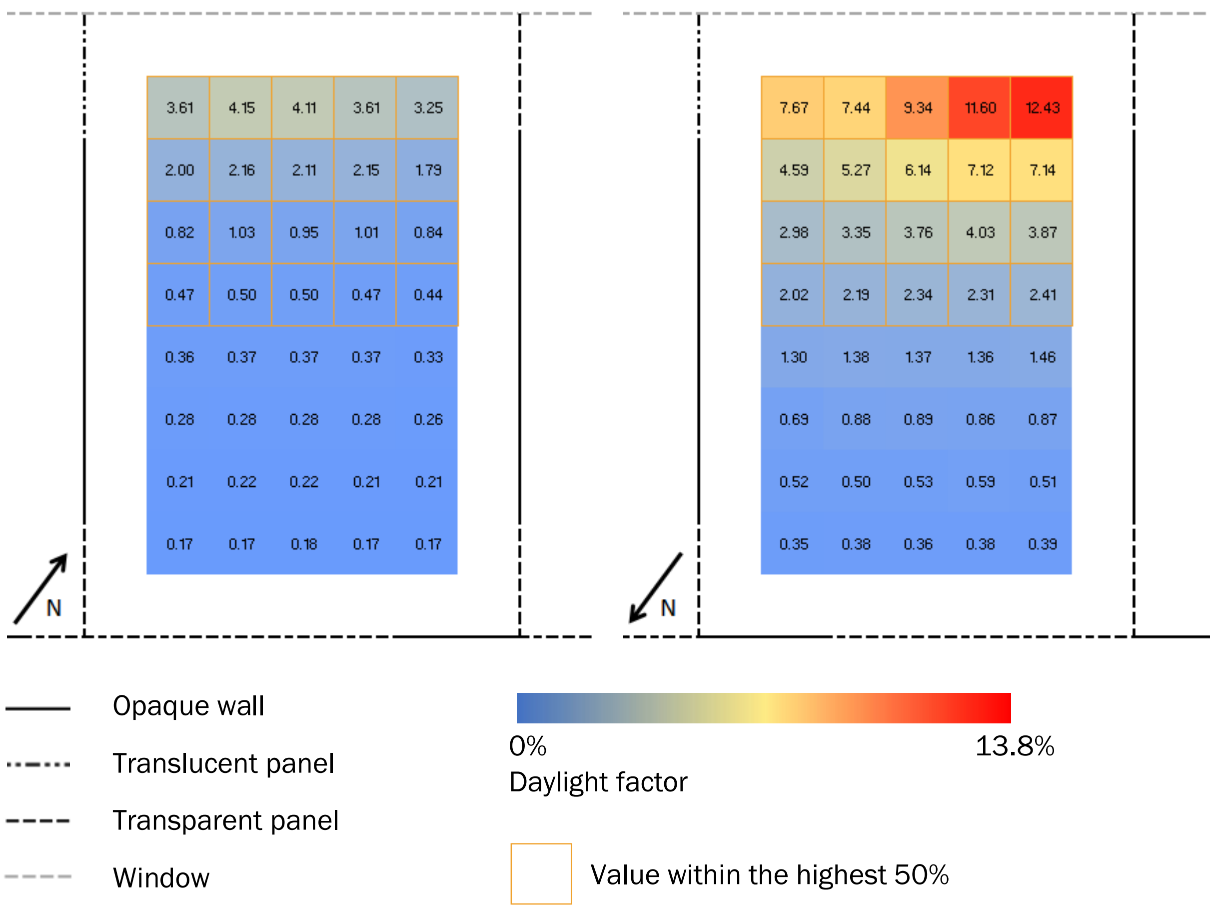
Daylight Glare Probability during a percentage of the occupation hours per year

During 26.63% of the occupation hours, the DGP is higher than 0.45.

VARIANT 2.6, MAXIMUM DAYLIGHT FACTOR / THINNER FACADE

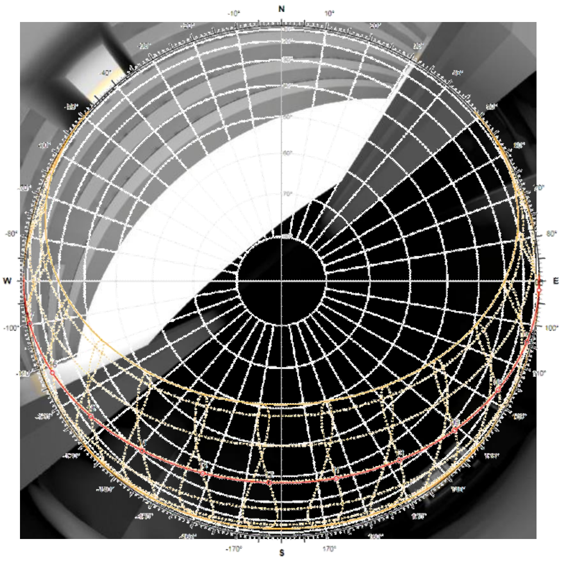
		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.95 m²	3.04 m²
		10.0%	15.6%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.17%	0.38%
	in 50% of the occupated area	0.44%	2.02%
Percentage of occupation hours when DGP > 0.45			10.38%
Duration of exposure to direct sunlight		0.5 hours	2.2 hours

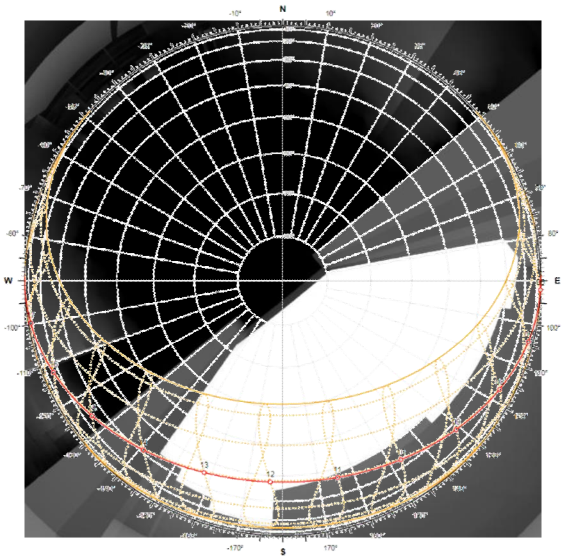
Daylight factor



		Room NW	Room SE
Minimal daylight factor	in 95% of the occupated area (D_{TM})	0.17%	0.38%
	in 50% of the occupated area (D_T)	0.44%	2.02%

Sunlight

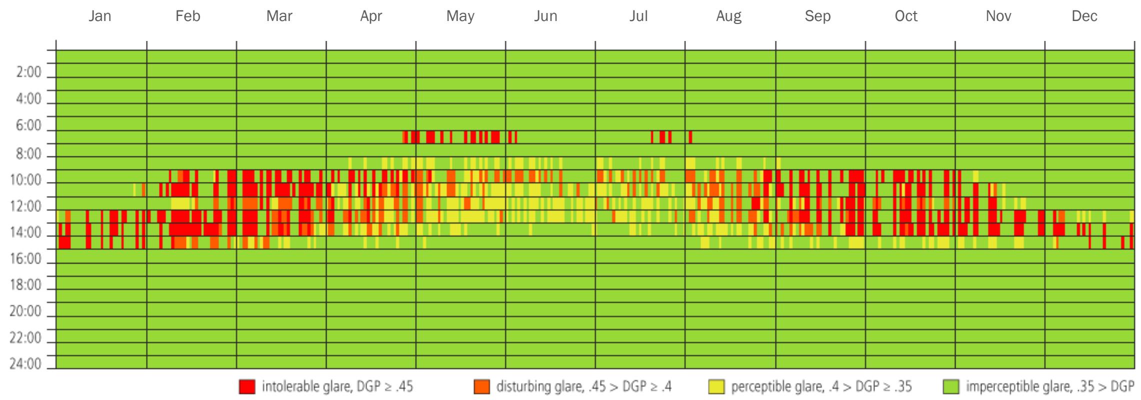




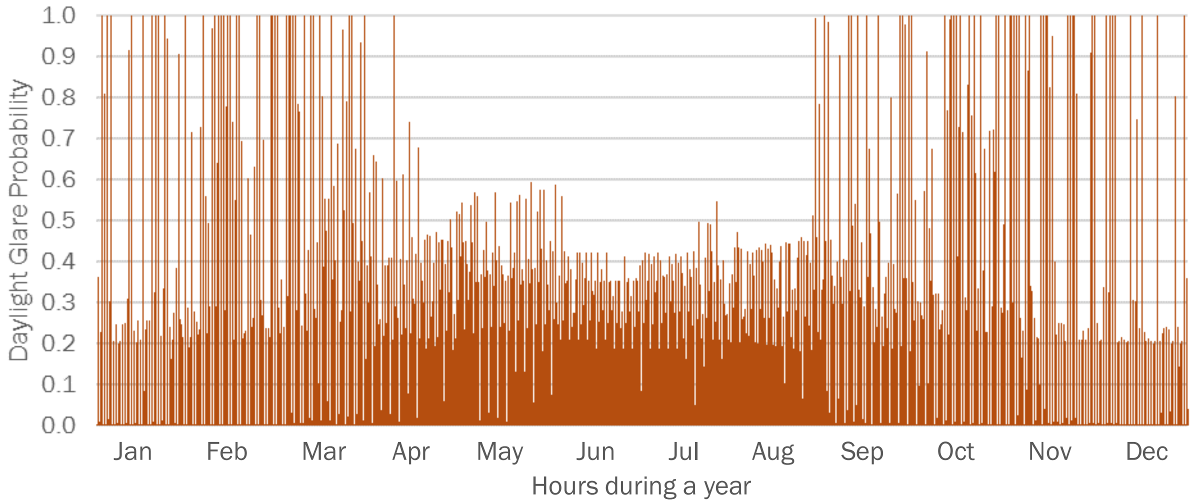
Sun path on March 21

	Room NW	Room SE
Duration of exposure to direct sunlight	0.5 hours	2.2 hours

Glare



Daylight Glare Probability during the year and day



Daylight Glare Probability during the year

Daylight Glare Probability during a percentage of the occupation hours per year

During 10.38% of the occupation hours, the DGP is higher than 0.45.

D3. Systematic study – Results overview

0.0		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.88 m²	2.93 m²
		9.7%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.14%	0.36%
	in 50% of the occupated area	0.36%	1.92%
Percentage of occupation hours when DGP > 0.45			9.89%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

1.1		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.06%	0.11%
	in 50% of the occupated area	0.15%	0.30%
Percentage of occupation hours when DGP > 0.45			0.46%
Duration of exposure to direct sunlight		0.3 hours	2.2 hours

1.2		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.06%	0.11%
	in 50% of the occupated area	0.14%	0.41%
Percentage of occupation hours when DGP > 0.45			1.49%
Duration of exposure to direct sunlight		0.3 hours	2.7 hours

1.3		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.05%	0.11%
	in 50% of the occupated area	0.11%	0.29%
Percentage of occupation hours when DGP > 0.45			0.69%
Duration of exposure to direct sunlight		0.7 hours	2.6 hours

1.4		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.12 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.04%	0.07%
	in 50% of the occupated area	0.09%	0.19%
Percentage of occupation hours when DGP > 0.45			0.46%
Duration of exposure to direct sunlight		0 hours	2 hours

1.5		Room NW	Room SE
Dutch standard			
Equivalent daylight area		0.69 m²	0.66 m²
		2.5%	2.5%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.06%	0.10%
	in 50% of the occupated area	0.14%	0.30%
Percentage of occupation hours when DGP > 0.45			0.46%
Duration of exposure to direct sunlight		0.4 hours	2.2 hours

2.1		Room NW	Room SE
Dutch standard			
Equivalent daylight area		2.96 m²	2.93 m²
		15.2%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.25%	0.39%
	in 50% of the occupated area	0.67%	1.93%
Percentage of occupation hours when DGP > 0.45			9.92%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

2.2		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.88 m²	2.93 m²
		9.7%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.22%	0.54%
	in 50% of the occupated area	0.52%	2.21%
Percentage of occupation hours when DGP > 0.45			..%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

2.3		Room NW	Room SE
Dutch standard			
Equivalent daylight area		3.85 m²	5.85 m²
		9.9%	15.0%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.17%	0.46%
	in 50% of the occupated area	0.43%	2.20%
Percentage of occupation hours when DGP > 0.45			9.92%
Duration of exposure to direct sunlight		0.2 hours	2.7 hours

2.4		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.88 m²	2.93 m²
		9.7%	15.1%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.61%	0.97%
	in 50% of the occupated area	1.74%	2.72%
Percentage of occupation hours when DGP > 0.45			24.94%
Duration of exposure to direct sunlight		1.8 hours	7.3 hours

2.5		Room NW	Room SE
Dutch standard			
Equivalent daylight area		3.80 m²	6.00 m²
		19.5%	30.9%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.27%	0.75%
	in 50% of the occupated area	0.68%	3.52%
Percentage of occupation hours when DGP > 0.45			26.63%
Duration of exposure to direct sunlight		0.3 hours	1.9 hours

2.6		Room NW	Room SE
Dutch standard			
Equivalent daylight area		1.95 m²	3.04 m²
		10.0%	15.6%
European standard			
Minimal daylight factor	in 95% of the occupated area	0.17%	0.38%
	in 50% of the occupated area	0.44%	2.02%
Percentage of occupation hours when DGP > 0.45			10.38%
Duration of exposure to direct sunlight		0.5 hours	2.2 hours

	ROOM NW				ROOM SE				
	$A_{e,i}$	D_{TM}	D_T	SE	$A_{e,i}$	D_{TM}	D_T	SE	DGP < 0.45
0.0	9.7%	0.14%	0.36%	0.2h	15.1%	0.36%	1.92%	2.7h	9.89%
1.1	2.5%	0.06%	0.15%	0.3h	2.5%	0.11%	0.30%	2.2h	0.46%
1.2	2.5%	0.06%	0.14%	0.3h	2.5%	0.11%	0.41%	2.7h	1.49%
1.3	2.5%	0.05%	0.11%	0.7h	2.5%	0.11%	0.29%	2.6h	0.69%
1.4	2.5%	0.04%	0.09%	0.0h	2.5%	0.07%	0.19%	2.0h	0.46%
1.5	2.5%	0.06%	0.14%	0.4h	2.5%	0.10%	0.30%	2.2h	0.46%
2.1	15.2%	0.25%	0.67%	0.2h	15.1%	0.39%	1.93%	2.7h	9.92%
2.2	9.7%	0.22%	0.52%	0.2h	15.1%	0.54%	2.21%	2.7h	
2.3	9.9%	0.17%	0.43%	0.2h	15.0%	0.46%	2.20%	2.7h	9.92%
2.4	9.7%	0.61%	1.74%	1.8h	15.1%	0.97%	2.72%	7.3h	24.94%
2.5	19.5%	0.27%	0.68%	0.3h	30.9%	0.75%	3.52%	1.9h	26.63%
2.6	10.0%	0.17%	0.44%	0.5h	15.6%	0.38%	2.02%	2.2h	10.38%

	ROOM NW				ROOM SE			
	D_T	$D_{av\ 50\%}$	D_{TM}	$D_{av\ 95\%}$	D_T	$D_{av\ 50\%}$	D_{TM}	$D_{av\ 95\%}$
0.0	0.36%	1.31%	0.14%	0.76%	1.92%	4.89%	0.36%	2.84%
1.1	0.15%	0.61%	0.06%	0.35%	0.30%	1.32%	0.11%	0.75%
1.2	0.14%	0.51%	0.06%	0.29%	0.41%	1.15%	0.11%	0.67%
1.3	0.11%	0.39%	0.05%	0.23%	0.29%	0.81%	0.11%	0.49%
1.4	0.09%	0.33%	0.04%	0.20%	0.19%	0.83%	0.07%	0.47%
1.5	0.14%	0.52%	0.06%	0.30%	0.30%	1.28%	0.10%	0.71%
2.1	0.67%	2.76%	0.25%	1.57%	1.93%	4.91%	0.39%	2.85%
2.2	0.52%	1.79%	0.22%	1.05%	2.21%	5.08%	0.54%	3.02%
2.3	0.43%	1.50%	0.17%	0.88%	2.20%	5.68%	0.46%	3.30%
2.4	1.74%	3.36%	0.61%	2.15%	2.72%	5.85%	0.97%	3.67%
2.5	0.68%	1.99%	0.27%	1.19%	3.52%	7.61%	0.75%	4.52%
2.6	0.44%	1.80%	0.17%	1.03%	2.02%	5.40%	0.38%	3.09%

E. Reflection

The following paragraphs will reflect on the full graduation project. It will describe the process and approach of the research, but also the impact of the results of this project.

Position in the studio

In the sustainable design graduation studio, this project is mostly related to the section of climate design. Along with for example thermal and acoustical comfort, visual comfort is one of the most important topics within the section of climate design. And for this project it is also one of the objectives to make recommendations for designers and engineers, in order for them to be able to design visually comfortable offices.

This research however investigates more than visual comfort only. It investigates the influence of the Dutch and European building standards on the access of daylight, exposure to sunlight, view and glare. Besides that, this part is not only about buildings physics, but also about the use of simulation software. Therefore, the project is also related to design informatics.

Approach

For the various parts of the research, the approach differs. The part about the assessment methods and requirements of the Dutch and European standards, is investigated with a literature review. This is compared with own experiences during the other parts of the research. By reviewing the standards and evaluating them, not only the differences but also the advantages and disadvantages are made clear.

The effects on daylight quality are investigated with case studies and a systematic study, in which several variants are assessed according to the Dutch and European standards. Both studies showed that the ways the Dutch and European standard affect the daylight quality differ a lot. The systematic study particularly, showed the extent of the differences and it showed which factors influence the amount of daylight, sunlight, glare and view. These insides were very useful for the establishment of the recommendations.

The approach changed a little during the process, because the initial objectives were too ambitious. This led to some uncertainties, unnecessary research and delay of the project. The change of the second supervisor also contributed to this. This setback however made the final approach clearer and achievable.

Research and design

For this graduation project, designing was not one of the objectives. However, for the systematic study, several variants were designed. For each variant, one aspect of the original design was changed. By assessing and simulating the designs, research is done. This might resemble research by design. It however is not, because design was no substantial part of the research.

Application in practice

This research can be used for several purposes. The first focusses on designers. They can use the recommendations that are established at the end of the research, during the design process to design a building with good daylight quality. The recommendations can also be used in several ways. For example, to improve the assessment or simulation of a design or to determine the appropriate daylight quality of a room.

This conclusions from this research can also be used for the establishment of new standards or guidelines.

SUSTAINABLE AND SOCIAL IMPACT

Generally speaking, this graduation project affects the daylight quality in buildings. With good daylight quality, rooms can be lit more naturally, instead of artificially. This not only decreases the energy use, but also contributes to a healthier indoor environment. Therefore, building occupants, employers, health institutions and more will benefit from this research.