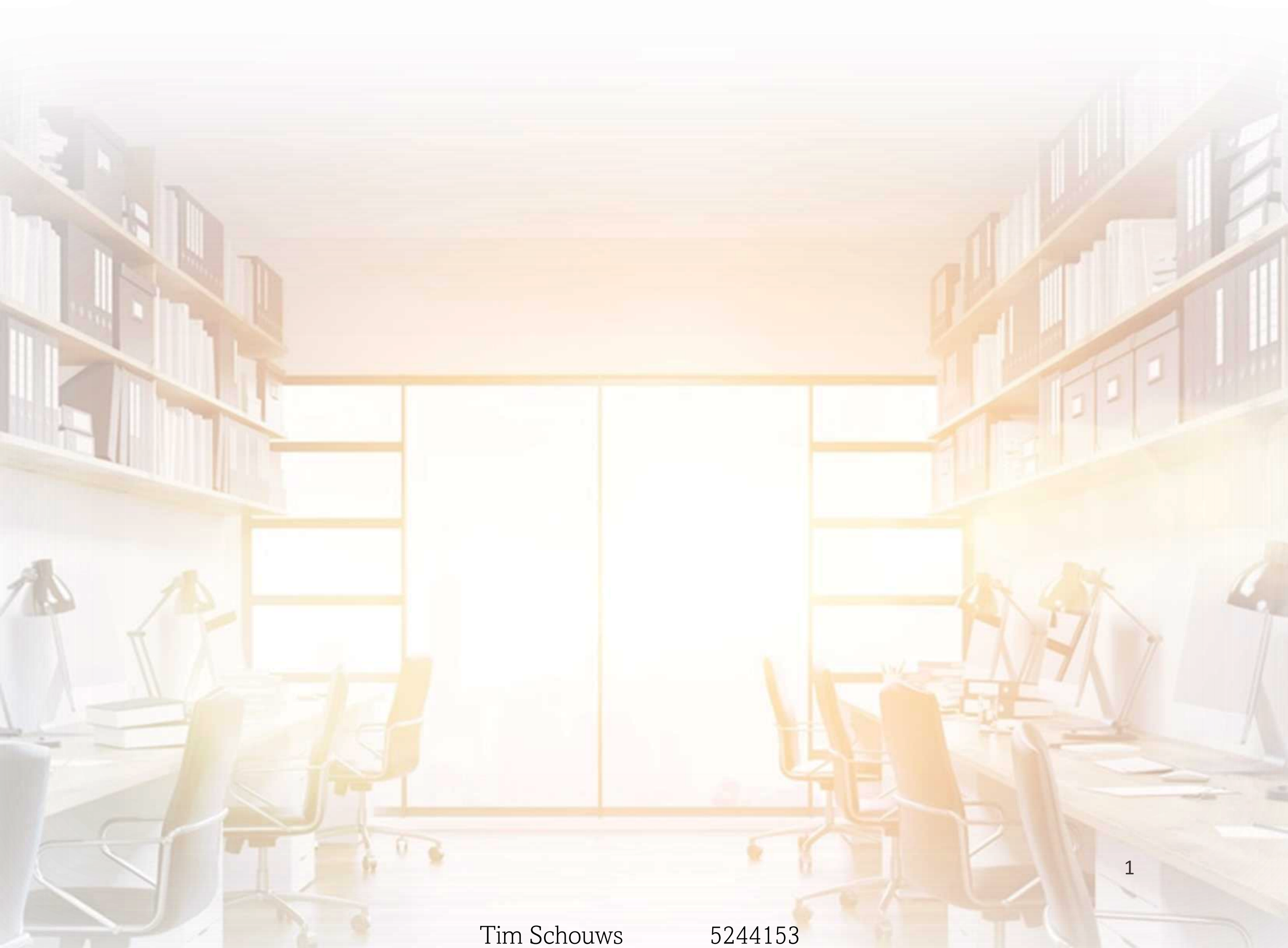
Measuring Daylight: the New European Standard and the effect on Green Building Certificates

A study about the effect of EN-17037 on green certificates



Tim Schouws 5244153

Colophon

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Personal Details

Student:	Tim Schouws
Student number:	5244153

Graduation Details

University:	Delft University of Technology
Faculty:	Architecture and the Built Environment
Master:	Building Technology
1st Mentor:	Dr. E. (Eleonora) Brembilla
2nd Mentor:	Dr. P. (Pirouz) Nourian
Delegate of the board examiners:	Prof.Dr. J.E. (Jantien) Stoter
	Dr. J.L. (John) Heintz

TU Delft

Delft University of Technology

Abstract

In 2018, a new standard was released for daylight in buildings: EN 17037. This is the first standard for daylight in buildings for Europe. In the Netherlands it will replace the NEN 2057. The determination method for daylight provision for EN 17037 is based on internal illuminance. Additional ambitions for the design quality factors: view, direct sunlight and the prevention of glare have been added to the standard. A sustainable design is all about balancing daylight performance and energy consumption. Large windows will cause the building to overheat and use too much cooling energy. Too small windows will result in low levels of daylight availability and visual comfort. For this reason, it was still unclear whether it is possible to achieve these new recommendations for daylight and at the same time meet the energy requirements for Green building certificates, such as BREEAM and LEED. The main aim of this research was therefore to investigate how much influence the European standard has on the energy consumption of a typical office building and whether the requirements for BREEAM and LEED can still be met.

The analysis shows that the European standard has an influence on the daylight and energy credits for BREEAM and LEED. For the daylight credits this standard has a positive influence. For the minimum performance level for daylight provision for the European standard this is not yet enough to meet the requirements for the performance outcome for daylight provision for BREEAM and LEED. For BREEAM, this is mainly due to the uniformity ratio which is not sufficient for most variants, and for LEED the sDA percentage is often not enough for 3 points. For BREEAM and LEED, the variants only meet the requirements if the medium and high recommendation levels for the European standard are met. However, the ASE is often too high for a design that meets the high performance level for EN 17037. It should also be taken into account that when a certain performance level for daylight provision has been achieved for the European standard using method 2 (based on internal illuminance per hour for a typical year) this same variant will usually score lower with method 1 (based on daylight factors).

The energy consumption goes up when the recommendation level for the European standard is higher. When comparing the average energy consumption of variants with the minimum performance level for the European norm with the high performance level, the total energy consumption goes up 8.33 kWh/m^2 . These values can be higher or lower with different orientations. To reduce the negative impact of the European standard on BREEAM and LEED, certain parameters for the design can be chosen differently. The most important parameters for meeting the high-performance level and minimizing primary fossil energy consumption is the window-to-wall ratio and width/depth ratio. To find a balance between daylight and energy consumption, the optimal width/depth ratio is between 1.33 and 0.75. The optimum window-to-wall ratio is between 40% and 60%. The daylight performance measure will not increase much after a WWR of 60% and the energy consumption increases the most after passing the window-to-wall ratio of 40%. To reduce the cooling consumption and ASE even more, designers can consider the introduction of overhangs in the façade, or other interventions that reduce the window SHGC. In most cases this will cause the heating consumption to increase, but the cooling consumption decreases more.

This study has shown that the European standard has an influence on green building certificates, but this influence does not have to be too big if the parameters are chosen correctly.

Keyword: EN 17037, BREEAM, LEED, Daylight provision, Energy consumption

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Glossary

Symbol	Name of quantity	Unit
Ev	Vertical illuminance at eye level	lx
Ftime	Fraction of time for which a given value of illuminance is exceeded	
ETM	Target minimum illuminace	lx
ET	Target illuminance	lx
Fplane	Fraction of the reference plane for target illuminance level	%
D	Daylightfactor	%
DGP	Daylight glare probability	
DGPe < 5 %	DGP-value, that is not exceeded in more than 5 % of the occupation time	
Dt	Target daylight factor	%
DTM	Minimum target daylight factor	%
Ev,d,med	Median diffuse horizontal skylight illuminanc	lx
Fplane,%	Fraction of the reference plane for target illuminance level	%

Abbreviation	Name
BENG	Bijna energie neutrale gebouwen
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
PMV	Predicted Mean Vote
PPD	Predicted Percentage of People Dissatisfied
WWR	Window to Wall Ratio
sDA	Spatial Daylight Autonomy
ASE	Annual Sunlight Exposure
Als	Loss area
Ag	Use area
SHGC	Solar Heat Gain Coefficient
VLT	Visible light transmittance
PCI	Performance cost index
PCIt	Performance cost index target
BBUEC	Baseline Building Unregulated Energy Cost
BBREC	Baseline Building Regulated Energy Cost
BPF	Building Performance Factor
BBP	Baseline Building Performance
aa	ambient accuracy
ab	ambient bounces
ad	ambient divisions
as	ambient super-samples
ar	ambient resolution
EN	European norm
HVAC	Heating, Ventilation, Air conditioning and Cooling
PSZ-AC	Packaged Single Zone Air Conditioner

1. Introduction

Daylight plays a vital role in regulating the circadian rhythm of humans. The term circadian rhythm refers to a 24-hour internal clock that coordinates many processes in the body, including sleep. Insufficient daylight can affect a person's mood and even lead to depression. This can cause all kinds of health problems. Many people in the Netherlands do not get enough daylight, because nowadays an average of 90 percent of the Dutch population spend their time indoors (RTLNieuws, 2019).

Since daylight is so important, a requirement for daylight in buildings has been included in the Dutch Building regulations. The Building Regulations in the Netherlands sets requirements for the minimum amount of daylight in buildings. This determination method can be found in NEN 2057 (NEN, 2011). NEN 2057 describes a method for determining the equivalent daylight surface for a room in a building. This is the daylight opening multiplied by the reduction factors from the standard. An occupied room has an equivalent daylight surface in m^2, which is a percentage of what the floor area of that occupied room is. For example, for an office function the daylight surface must be 2.5% of the total floor surface, where the minimum area is 0.5 m^2 (Duvast, 2016).

A newer standard is now released for daylight in buildings: NEN-EN 17037. Although some considerations were included in the previous version, a more qualitative method was missing. The determination method of EN 17037 is based on internal illuminance. Additional ambitions for the design quality factors view, direct sunlight and the prevention of glare have been added to the standard. These design parameters were missing from NEN 2057. The daylight standard EN 17037 for determining daylight was published at the beginning of 2018. For this reason, the Dutch Standardization Institute (NEN) has withdrawn NEN 2057 (this is mandatory for conflicting EU standards). However, the building regulations will probably continue to refer to this standard withdrawn by the NEN until 2021. After that, it will refer to the European determination method. The level of minimum daylight factors to be applied has not yet been determined (velux, n.d.).

This new standard can become a challenge when designing a sustainable building. To comply with the recommendation level for daylight provision for the European standard, the window-to-wall ratio may have to be quite high. Designing a sustainable design is all about balancing daylight performance and energy consumption. Too much glass will cause the building to overheat and use too much cooling energy. Too little glass will result in low levels of daylight availability and visual comfort.

For a sustainable design, it is important that a design reduces the need for electric lighting, prevents overheating in the summer and creates a proper and adequate visual connection with the outside world.

Problem definition

As described above, the new European standard is the first European standard that deals exclusively with daylight in buildings. But in order to achieve the requirements for the European standard for daylight provision, it is likely that the openings in the building will also have to be enlarged. However, there is usually a balance to be struck between the opening in the building for the health of the user and the energy consumption of a building. With meeting the requirements for the standard, the building maybe use too much energy to comply with BREEAM and LEED. Is it still possible to comply with energy-related aspects for green certificates when certain recommendation levels are pursued?

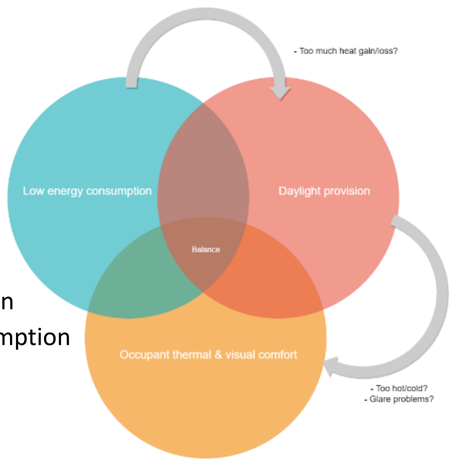


Figure 1, Balancing between daylight and energy consumption

Research Question

How does the European standard for daylight in buildings influence the energy performance of an office building and what influence does this have on the BREEAM and LEED certificates?

Sub Questions

1. What requirements does the new European standard set for daylighting in buildings?
2. What is the difference between the requirements of the European standard for daylight in buildings and the BREEAM and LEED requirements for daylight in buildings?
3. How does the European standard for daylight in buildings influence the energy performance in buildings and what influence does this have on the BREEAM and LEED certificates?
4. What requirements can be proposed in order to still be able to comply with the green certificates, but also to guarantee sufficient daylight in buildings?

Aim

The main objective of this research is to investigate how much influence the different daylighting advice levels for the European standard have on the achievement of green certificates such as BREEAM and LEED. Advice can be given for architects and designers who intend to obtain a sustainability certificate, whereby it can be used at an early stage in the design process. What design input should be paid extra attention to, if a high recommendation level for the European standard is also desired, but the primary fossil energy use is as low as possible. This allows a good balance to be found between sufficient daylight in buildings and the energy use of a sustainable building. This will provide insight into the influence of the choice between Minimum, Medium and High performance levels for daylight provision and the effect on the feasibility of green building certificates.

Objectives

- Which design inputs are important in order to meet the requirements for a high recommendation level for daylight provision, but also a design that uses as little primary fossil energy as possible and thus achieves as many credits as possible for LEED and BREEAM
- Demonstrate the difference between the BREEAM and LEED daylight requirements and the requirements of EN 17037.
- To gain insight into how much the three different levels in the European standard have an influence on the window to wall ratio and energy consumption in offices. You can see what the influence will be on the BREEAM and LEED certification.
- To show whether the EN 17037 high recommendations level for daylight provision can be achieved in the Netherlands for a standard office and what it takes to achieve it
- To show the difference between the first method, based on daylight factor values and the second method, based on internal illuminance per hour for a typical year for the European standard. A recommendation is given for which variant is the best method to use in different design situations.

Constraints

This study will mainly focus on one function: an office. This means that the different floor plan dimensions are based on the dimensions of a standard office in the Netherlands. The general results for the European standard can be used for any function. The results for energy consumption will be slightly different due to the different occupancy schemes, climate zone and baseline values for LEED. For BREEAM the daylight requirements are also slightly higher for schools. Only the requirements of the Dutch BREEAM will be used. From the new European standard (NEN 17037) only the design parameter: daylight requirements will be considered. The other 3 subjects will only be explained in the first sub-question. They will not be examined further as they fall outside the scope of this study.

Step-by-step approach

The following steps will be taken for this research. These steps are also shown in Figure 2:

• Step 1: Analyzing the requirements included in the European standard for daylight in buildings. Journal paper and academic research projects will also be analyzed to see what has already been researched and how this research can complement the previous ones.

• Step 2: Analyzing BREEAM and LEED. Which categories are affected by the new European standard and how much stricter are the NEN recommendations for daylight compared to the certificates? This step also examines the requirements of BREEAM and LEED for obtaining points for the energy part and the requirements of LEED for calculating the baseline model reference value for the energy credits.

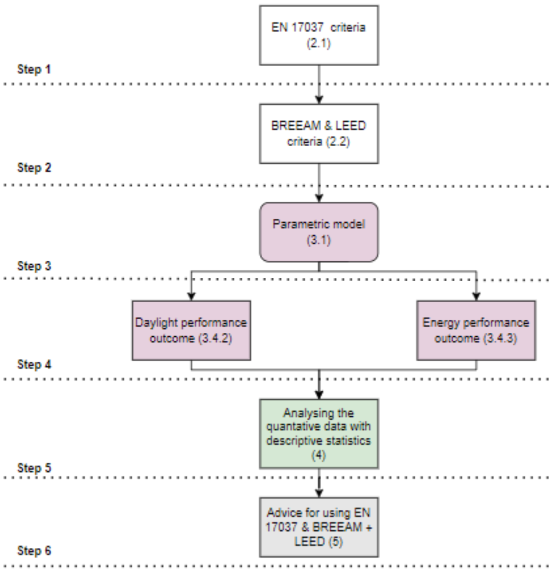


Figure 2, Research methodology

• Step 3: A simulation-based methodology with a single-zone approach is used to analyze simulate the amount of daylight and energy consumption of all the variants. A parametric model for an office is created in grasshopper. With the help of different room parameters, eight different orientations and three different context, different scenarios are created. The sizes of the rooms are based on a grid size that is often used for office spaces in the Netherlands. Eight different orientations for a multi-story building are considered. The other parameters are made with the help of the Building Decree, BREEAM and LEED and other standards. With the help of 3Dbag viewer, three different types of context are loaded into Grasshopper to simulate three different environment in the Netherlands.

• Step 4: The simulations are started and the results are saved in a csv file using the Colibri plug-in in grasshopper. Since some simulations cannot be run simultaneously, because results from another simulation are used, the ASE and DF will be simulated first. The results of the ASE simulations are used to calculate the sDA and the recommendation levels for the European standard. With the daylight results completed, first the baseline model for LEED is calculated and then the proposed energy consumption results.

• Step 5: The quantitative data will be analyzed with the help of descriptive statistics. The two different methods for daylight provision for the European standard will also be compared with each other. The data are ordered and the characteristics of the dataset are summarized. This helps to understand and describe the characteristics of the dataset.

.• Step 6: Providing recommendations that can be used to design a floor plan for a sustainable building where a good balance has been found between the various recommendations of EN 17037 and the energy use of a sustainable building.

Relevance of research

Scientific relevance

Since the new NEN standard for daylight was only released in 2018, not many studies have been done yet. The scientific relevance of this research consists of the fact that it complements the previous conducted research. Paule and Flourentzos (2019) reported that the objective set by the European standard is demanding. They show that the requirements can lead to an increase in the building energy consumption. However, this study did not include blinds because it is not a requirement of the European standard. With this study, blinds are included and this study can complement the research of Paule and Flourentzos. With this research a conclusion can be drawn how much influence the European standard has on green certificates with respect to energy consumption. The study also examined lighting, but did not use the blinds. For this research, the blinds will also be included to study the impact on lighting consumption. It also shows how much stricter the European standard is compared to the BREEAM and LEED requirements for daylight in buildings and which design parameter has the most influence.

In another paper by Paulet (2018) it is mentioned that sometimes method 1 is better and other times the method 2 gives a better outcome. This study will also determine if there is any difference between the use of Method 1 and Method 2.

Societal relevance

It will be investigated how much influence this standard has on green building certificates. The conclusion of this report can serve as advice for professionals, such as architects and building engineers, who will have to deal with the new standard. In this study, the difference between the first method and the second method is investigated on the basis of various variables. Advice is given on which approach gives a better result and what influence this has on the energy consumption of the building. It can also be used to determine which recommendations should be used in the building code. This research is socially relevant because it investigates the relationship between the recommendation levels of the European standard and the inverse relationship between the energy consumption of heating and cooling and the use of lighting. The addition of this research is that the energy use of lighting is also included when the blinds are closed due to too much direct sunlight. In this way, a better estimate can be made of the subsequent energy consumption of the building.

2. Literature Review

2.1 EN 17037

A new European standard for daylighting in buildings was released in 2018. This is the first European standard that deals exclusively with the design of daylighting in buildings. This new standard replaces several standards from different European countries since there was not yet a European standard for daylight. The Netherlands has gone along with this new standard and the NEN-EN 17037 is the result of this. This standard includes four performance criteria: Daylight recommendations, View, direct sunlight and the prevention of glare. The standard states that a minimum performance must be achieved for each area. In addition to the minimum level, there are also two other achievement levels that can be achieved: medium and high (velux, n.d.).

2.1.1 Daylight provision

The first performance criterion concerns the amount of daylight in buildings. The availability of daylight is important for users to be able to perform tasks in a building. In addition, this will also reduce the need for artificial lighting (Bernard & Flourentzos, 2019). The tables for daylight recommendations (table 1 and 2) from the NEN indicate recommendations for target illuminance (Et) and the minimum target illuminance (Etm) within a room. The reference plane of the room is 0,85 meters above the floor with an offset distance of 0,5 meter from the walls. Table 1 and 2 show the recommendations for vertical and horizontal openings. The minimum level of recommendation for target illuminance is 300 lux, which must be achieved over 50% of the reference plane within a room during 50% of the daylight hours. The minimum target illuminance is 100 lux over 95% of the indicated reference plane within a room. For the recommendation level of medium and high, the target and minimum target illuminance is higher. The target illuminance (ET) for medium is 500 lux and for high 750 lux (NEN, 2018).

Level of recommendation for vertical and inclined daylight opening	Target illuminance ET lx	Fraction of space for target level Fplane,%	Minimum target illuminance ETM lx	Fraction of space for minimum target level Fplane,%	Fraction of daylight hours Ftime,%
Minimum	300	50%	100	95%	50%
Medium	500	50%	300	95%	50%
High	750	50%	500	95%	50%

Table 1, Recommendation for vertical daylight openings

If there is any doubt as to whether an opening is in a vertical/inclined plane or a horizontal plane, each opening is considered horizontal. The recommendation for a horizontal daylight opening is shown in table 2.

Level of recommendation for vertical and inclined daylight opening	Target illuminance ET lx	Fraction of space for target level Fplane,%	Fraction of daylight hours Ftime,%
Minimum	300	95%	50%
Medium	500	95%	50%
High	750	95%	50%

Table 2, Recommendation for Horizontal daylight opening

Two methods can be used to calculate the daylight provision. The second method is explained on the previous page. The first method uses daylight factors. The daylight factor indicates how much light enters a room from an unobstructed overcast sky through a daylight opening. The daylight factor is indicated in percentages. A certain target daylight factor and minimum target daylight factor must be achieved in order to meet the recommendation levels for daylight provision. The recommended daylight factors for the different recommendation levels are based on the recommended target illuminance and minimum target illuminance from method two. The target daylight factor and minimum target daylight factor are calculated just like the target illuminance and minimum target illuminance for a part of the reference plane. The daylight factor has been calculated with the median external diffuse illumination and this value is different for each country. This is stated for thirty-three capitals in EN 17037 and for Amsterdam the median external diffuse illuminance is 14400 lux. In order to meet the minimum recommendation level, the following target daylight factor and minimum target daylight factor over part of the reference plane will have to be achieved.

$$D_t = \frac{\text{Illuminance Level}}{E\text{v,d,med}} \quad = \quad \frac{300\ \text{lux}}{14400} \times 100\% = 2{,}1\ \%$$

$$D_{tm} = \frac{\text{Illuminance Level}}{E\text{v,d,med}} \quad = \quad \frac{100\ \text{lux}}{14400} \times 100\% = 0{,}7\ \%$$

The table below shows the other values that are required for the medium and high-performance level.

Nation	Capital	Geographical latitude ϕ [°]	Median External Diffuse Illuminance Ev,d,med	D to exceed 100 lx	D to exceed 300 lx	D to exceed 500 lx	D to exceed 750 lx
The Netherlands	Amsterdam	52.3	17600	0.70%	2.10%	3.50%	5.20%

Table 3, Values for the daylight factor based on the location

2.1.2 Recommendations for view out

The second performance criterion is for view out. The users of a building will be positively influenced if they have a wide clear view to the outside of the building. If all three layers specified in the standard are visible when looking outside, this will have a positive effect on the user in the building. For example, this will have a positive impact on the reading achievement in a classroom (Kuhlenengel et al.,2019). The European NEN gives three recommendations for views from vertical, inclined and horizontal openings. The level of recommendation for view looks at the following three criteria: the horizontal viewing angle, outside distance to major obstructions and the number of layers that are visible. The three layers that can be seen when looking outside are: the sky, landscape (urban or nature) and the ground. The requirements for the minimum level are, if you are closer than 6 meters from the facade, the horizontal viewing angle must be greater than fourteen degrees and at least the landscape layer must be visible (NEN, 2018).

Level of recommendation for view out	Horizontal sight angle	Outside distance of the view	Number of layers to be seen from at least 75 % of utilized area: ▪ Sky ▪ landscape (urban and/or nature) ▪ ground
Minimum	≥ 14°	≥ 6,0 m	At least landscape layer is included
Medium	≥ 28°	≥ 20,0 m	Landscape layer and one additional layer is included in the same view opening
High	≥ 54°	≥ 50,0 m	all layers are included in the same view opening

Table 4, Assessment of the view outwards

2.1.3 Sunlight exposure

The third performance criterion is for exposure to sunlight. Providing a room with sunlight is essential for hospitals and residential building and is very important for people's well-being. The level of exposure is assessed by calculating how much sunlight a room receives on a selected date between February 1 and March 21 in one day. The minimum duration of sunlight to be received is reported in table 5. The minimum recommendation for exposure to sunlight is one and a half hours a day and for the highest recommendation level it is 4 hours a day. The assessment for the selected date is performed from a reference point on the inner face of the selected aperture. This reference point is located in the middle of the width of the opening. The reference point is at least 1.2 m above the floor and 0.3 m above the windowsill (NEN, 2018).

Level of recommendation for exposure to sunlight	Sunlight exposure
Minimum	1,5 h
Medium	3,0 h
High	4,0 h

Table 5, Recommendation for sunlight exposure

2.1.4 Glare protection

The last performance criterion is protection from glare. Glare can be caused by a direct view of the sun or its reflections from inside a building. Even small effects can accumulate and lead to fatigue during a working day (R.G.Hopkinson, 2003). For the different levels, the probability of glare caused by daylight should not exceed the values mentioned in table 6 for more than 5% of the time that the space is in use. Threshold values for the different recommendation levels of protection against glare are presented in the table below. The minimum recommendation for glare protection is that the space in question does not exceed a value of 0.45 for more than 5% of the time that the room is in use. For medium, this value is lower and should not exceed 0.4. For high, the value should not be more than 0.35 (NEN, 2018).

Level of recommendation for glare protection	DGPe < 5 %
Minimum	0,45
Medium	0,4
High	0,35

Table 6, Proposed different levels of threshold DGPe < 5 % for glare protection

2.1.5 Calculation method for daylight provision

This study will focus on the first performance criterion of the EN 17037: daylight provision. To calculate daylight provision there are several requirements in the NEN, such as standard reflection factors, grid size and two different methods that can be used to assess daylight within a room. The following two methods are therefore both used in this study and the results are compared with each other and with the outcome from the green certificates:

Method 1 uses daylight factors. The daylight factor method evaluate the daylight indoor/outdoor ratio. The daylight factor is calculated with a CIE standard overcast sky.

Method 2 is a detailed daylight calculation method in which the hourly daylight illuminance is calculated for a typical year. This is done using the hourly sky and sun conditions, derived from climate files used for simulation corresponding to the location.

Default Reflectance values

To get the right results from a simulation, the reflection coefficients are very important and must be considered carefully. The NEN recommends a standard reflection coefficient of 0.2 for the floor, 0.5 for the walls and 0.7 for the ceiling.

Calculation Grids

The illuminance and daylight factors are calculated for a reference plane situated 0.85 m above the floor of the selected room. Preference is given to square grid cells, the maximum grid size of which is calculated as follows:

$p = 0{,}5 \times 5 \log10(d)$

In which

$p \leq 10$ m

d: is the longest dimension of the selected area (m), but if the ratio of the long to short sides is

is 2 or more, then d becomes the shortest dimension of the area and p is the maximum grid cell size.

The nearest whole number that is equal to or greater than d/p determines the number of points in the

relevant dimension.

A band of 0.5 meters from the walls should not be included as part of the area (NEN, 2018).

2.1.6 Research already been done on EN 17037

In order to establish what has already been researched, all relevant research about the EN 17037 were examined. The most relevant studies for this study will be discussed below. One study on the European norm states that the objective for daylight provision is quite demanding and the consequences on the design of buildings are far from neutral (Bernard & Flourentzos, 2019). Since this research will mainly be about the first recommendations (recommendation for daylight provision), only the studies about the 1st performance criterion will be discussed.

The first research that will be discussed is from the company DGMR. In this study the new European standard is compared with the current Dutch building decree and what the difference is between the two. Various variants were calculated and then compared with the Dutch building regulations. Also, different obstacles in front of the building were included in the study. The result was that for almost all variants the daylight provision was not enough for the minimum performance level for the European norm, but complied with the Buildings Decree. It will also be more difficult for deeper spaces to meet the requirement compared to the current Building Decree (DGMR,2021).

Paule and Flourentzou conducted a study into 4 different locations and the effect on the daylight provision inside a room. This involved looking at four locations, based on latitudes and what the window to floor ratio (WFR) does to the performance level for daylight provision inside a room. As a result, with a WFR of 24% in Oslo, the ranking for daylight provision is minimum and in Athens the ranking was Medium. The selected WFR percentage was also used to calculate the energy consumption of the room which is shown in figure 3.

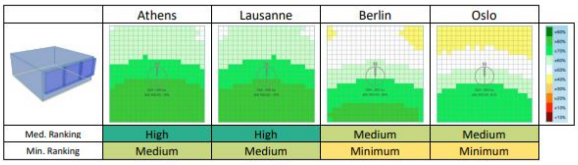


Figure 3, Daylight provision for a south oriented room (WFR = 24%) (Bernard & Flourentzos, 2019)

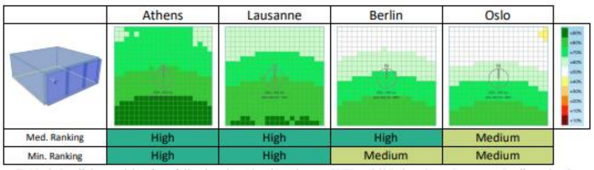


Figure 4, Daylight provision for a fully glazed south oriented room (WFR = 34%) (Bernard & Flourentzos, 2019)

In the second example, the WFR is increased to 34%, where the façade consists entirely of glass. In Oslo, the minimum ranking for daylight provision is then still medium and in Athens it is high enough for the high recommendation level. Since Amsterdam is at almost the same latitude of Berlin, the maximum achievable recommendation level may be medium for this study. Looking at the energy consumption, the largest increase in heat demand with a WFR factor of 34% is 7.5 kWh/m2 for a room in Oslo and the largest increase in cooling demand is in Athens. In no case does lighting demand decrease more than 1 kWh/m2, regardless of location and orientation (Bernard & Flourentzos, 2019).

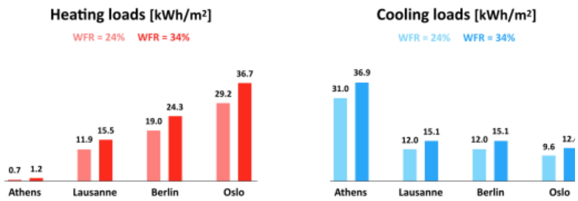


Figure 5, Heating & Cooling loads (Bernard & Flourentzos, 2019)

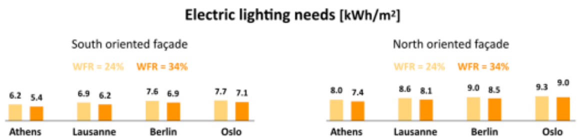


Figure 6, Electric lighting needs (Bernard & Flourentzos, 2019)

The previous studies show that with a higher recommendation level, energy consumption will also increase. To complement the studies, several analyses have been performed that have not been explored in the above studies. The study looks at how easy it is to meet the different performance levels for daylight provision for a room in Amsterdam and what the influence of the different performance levels will be on energy use and green building certificates. Not only method 1 will be used, as mentioned above, but also method 2 in which they are compared with each other. Together with the studies as described above, a clear conclusion can be formed about the EN 17037.

2.2Green certificates

2.2.1 BREEAM and LEED

There is more focus on sustainability in building development when compared to the past. In order to study the impact of the daylighting requirements of the NEN 17037 on green building certificates, the requirements of the EN 17037 are compared with the impact on the two most important green certificates. The most common sustainability certificates, used to assess the sustainability of a design are Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM). BREEAM and LEED are sustainability labels for realizing sustainable buildings with minimal environmental impact. What these certificates entail and what the criteria are for obtaining a good certification is explained below. The two labels consist of assessment systems whereby a rating is obtained by collecting credits. The labels cover environmental aspects such as materials, energy, water, pollution, indoor environmental quality and building site. The most critical point in both certificates is energy consumption, as most points can be obtained in this category. The final score for both certificates is converted into a qualification, which can be seen in the tables below.

Pass	≥ 30%
Good	≥ 45%
Very Good	≥ 55%
Excellent	≥ 70%
Outstanding	≥ 85%

Table 7, BREEAM-qualification

Certified	40-49
Silver	50-59
Gold	60-79
Platinum	80+

Table 8, LEED-qualification

To achieve this qualification, a project can obtain 48 individual assessment credits for BREEAM in nine environmental categories, plus one category for innovation. For each credit, a certain number of points are available. For LEED, this is broken down into 7 environmental categories.

Land use and ecology	8%
Water	7%
Energy	20%
Materials	13%
Health and wellbeing	19%
Transport	6%
Waste	6%
Pollution	10%
Managment	11%
Innovation	10%

Table 9, BREEAM Categories

Sustainable sites	24	22%
Water efficiency	11	10%
Energy and atmosphere	33	30%
Materials and resources	13	12%
Indoor environmental quality	19	17%
Innovation and design	6	5%
Regional priority	4	4%
	110	100%

Table 10, LEED Categories

The categories that are affected by the new European norm are Energy and Health and Wellbeing (LEED: Indoor environmental quality). These two categories play a key role in obtaining a good qualification, as they take represent 39% of the total score for BREEAM and as much as 47% for LEED. If a project scores poorly in these categories, it is almost impossible to obtain a good score.

2.2.2 LEED, daylight

First, the daylight requirements for LEED are explained. This is measured in a different way than for the European standard. For LEED, 3 points can be achieved for visual comfort and daylight provision. To achieve these points, the spatial daylight autonomy and annual sunlight exposure as defined in IES LM-83-12 must be calculated for each regularly occupied room. Lighting Measurement 83 (LM-83) was published in 2013 by the Illuminating Engineering Society of North America (IES). This is the first evidence-based annual performance measurement for daylight in the lighting industry (van den Wymelenberg & Mahic, 2016). All criteria applicable to LEED are listed in the LM-83-12 and are summarized below.

- Spatial daylight autonomy

The first metric is about spatial daylight autonomy. This metric is about the adequacy of ambient light in indoor environments. It is used as a measure of whether there is sufficient daylight in a regularly occupied space. It is defined as the percentage of occupied hours per year, when the minimum illuminance can only be maintained by daylight. In contrast to the daylight factor, sDA takes into account all daylight conditions of a typical year. The threshold of this metric is 300 lux on a horizontal plane 800 mm above the finished floor. The 50% in $sDA_{300,\ 50\%}$ indicates that the analysis points in the analysis area meet or exceed 300 lux for at least 50% of the analysis period. The results of the different analysis points are then collected and can be reported as an area ratio whether it meets the requirements.

There are two levels of criteria indicating that the spatial daylight autonomy in indoor environments is sufficient. The two levels are: Preferred and Nominally Accepted. The criteria for Preferred and Nominally Accepted are as follows:

- For the analysis area to be rated as favorable, the spatial daylight autonomy must meet or exceed 75% of the analysis area.

- For nominally accepted, spatial daylight autonomy must meet or exceed 55% of the analysis area (Society, 2012).

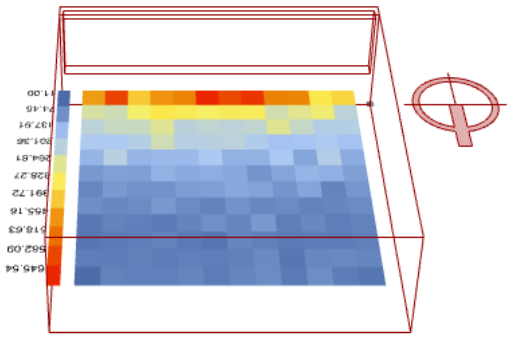


Figure 7, Example of Spatial daylight Autonomy (simulation with Grasshopper)

- Analyse period

The analysis period is not the same as the European standard. The analysis period is fixed and is from 8 am till 6 pm. This amounts to an analysis period of 10 hours per day. These 10 hours have been chosen as a reasonable approximation of normal working hours (Society, 2012).

- Grid

A fixed value is also chosen for the grid size and is not calculated with a formula like the European standard. The points in the grid must be no more than 60 cm apart from each other with a minimum of 30 cm and a maximum of 60 cm from the wall. The grid is located at a height of 80 cm above the finished floor. This distance was chosen because this distance is small enough to make accurate simulations and reduces the simulation time by a factor of four compared to a grid size of 30 cm. A larger grid of 60 cm would mean that the accuracy is less accurate (society, 2012).

- Blinds

For the sDA simulations, blinds must be included in the calculation. These blinds operate every hour to block direct sunlight if the analyze points receive too much. The blinds will close to ensure that no more than 2% of the analysis points receive 1000 lux of direct sunlight. The shading does not need to be modulated if no shading is used in the design or if the annual sunlight exposure for the analysis area meets the criteria for nominally acceptable. For analysis areas between 46,5 m2 and 83 m3 the blinds shall close when more than 5 analysis points receive too much direct sunlight. For analysis areas between 18,5 m2 and 46,5 m2 the blinds shall close when 3 or more analysis points receive more than 1000 lux of direct sunlight. For areas smaller than 18,5 m2 , the blinds will close when one analysis point receives too much direct sunlight.

When using white blinds, a VLT diffuse distribution of 20% can be used for sunlight. For the VLT of dark colors, a visible light transmission of 10% is recommended (Society, 2012).

- Default reflection factors

If the reflection values are not yet known, the following standard reflection values can be used (society, 2012).:

- 20% floor
- 50% Walls
- 70% ceiling
- 50% furniture

Since only the default ceiling reflection factor is lower than that is prescribed by the European standard, the reflection factor of LEED (70%) is used when calculating the hourly daylight illuminance.

- Annual Sunlight Exposure

The second metric is about Annual Sunlight Exposure. This metric looks at visual discomfort in indoor spaces. It is used as a check-and-balance for sDA rather than as a stand-alone statistic. ASE is defined as the percentage of an analysis area that is greater than a specified direct sunlight illuminance for a specified number of hours per year. Sunlight exposure is calculated before the blinds are turned on. The purpose is to determine at what times sunlight may cause glare. If more than 10% of the analysis points receive more than 1000 lux or more than 250 hours of direct sunlight per year, it must be demonstrated how the design will prevent glare. The analysis period is the same as that of the sDA (10 hours per day). Areas with less than 7% $ASE_{1000.250h}$ are given a neutral assessment. Areas with less than 3% $ASE_{1000,250h}$ are considered clearly acceptable (Society, 2012).

With the raytracing software Radiance (Ward, 1985), the direct sunlight can be calculated using a zero bounce simulation. It can be calculated whether a sensor receives more than 1000 lux for more than 250 hours per year. This simulation can also be used to generate the operating schedules of blinds for sDA. The same reference plane is used for the grid as for the sDA. The maximum distance between the analysis points is also 60 cm for ASE.

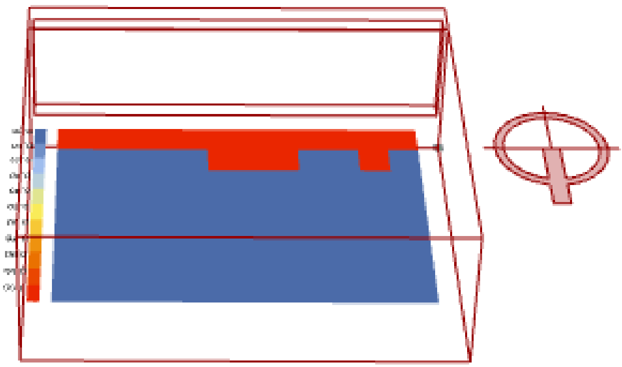


Figure 8, Example of Annual Sunlight Exposure (simulation with Grasshopper)

Points

For LEED, three methods can be chosen to demonstrate that there will be sufficient daylight for the proposed design. For the first method, the $sDA_{300/50\%}$ and $ASE_{1000,250}$ are calculated as mentioned in the previous pages. For the second method, the amount of daylight is calculated for two different times on a clear day. It must be demonstrated that the illuminance at both 9 a.m. and 3 p.m. is between 300 and 3000 lux. The two days chosen for the simulation must fall within 15 days of 21 September and within 15 days of 21 March. The simulation does not require the use of blinds. For the third option, the illuminance has to be measured on site. These values must be between 300 and 3000 lux. Since a comparison with EN 17037 will be made, option 1 will be the best option as it is calculated for a typical year. The only difference is that for LEED daylight is analyzed for the working hours (8 am-6pm) and for EN 17037 the daylight hours are used for the occupancy schedule.

A maximum of 3 points can be obtained for option 1. For the minimum points, daylight autonomy of 300 lux for 50% of the occupancy schedule must be achieved for at least 40% of the room. To obtain 3 points, 300 lux must be achieved for at least 50% of the analysis period for more than or equal to 75% of the analysis area. The distribution of points is also shown in Table 11

Percent of area meeting sDA requirement	Points available
The average sDA300/50% value for the regularly occupied floor area is at least **40%**	1 point
The average sDA300/50% value for the regularly occupied floor area is at least **55%**	2 points
The average sDA300/50% value for the regularly occupied floor area is at least **75%**	3 points

Table 11, sDA requirement for LEED

In addition, no more than 10% of a room may have direct sunlight in excess of 1000 lux for a maximum period of 250 hours per year (ASE1000/250) (ArchEcology, 2017). If this is more than 10%, the designer must show how glare will be prevented, to prevent reduction of points.

2.2.3 BREEAM, daylight

For BREEAM there are several performance criterion for daylight. The performance criterion consists of the following three parts: Preventing of glare, daylight provision, view towards outside. The requirement for daylight provision is determined in accordance to the old NEN standard (NEN 2057). The points for daylight provision are determined on the basis of the average daylight factor of a room. This is the same performance measure as method 1 for the European standard.

The daylight factor is today the most widely used daylight measure due to its simplicity. The daylight factor is the ratio between the light level in a building and the light level outside under an CIE overcast sky. The daylight factor is calculated using the formula below.

$$DF = \frac{\text{Einternal}}{\text{Eexternal}} x100\%$$

DF = Daylight factor (%)

Einternal = Horizontal illuminance of reference point indoors (lux)

Eexternal = Horizontal illuminance of reference point indoors (lux)

The biggest weakness of the daylight factor is that the orientation of the building has no influence on the daylight factor. The other weakness of the daylight factor method is that the overcast sky tends to underestimate the luminance near the horizon (Reinhart & Herkel, 1999).

For various functions, the average daylight factor is determined for a minimum usable area per occupied space. For most rooms, an average daylight factor of 2.0% must be achieved for 80% of the room in order to obtain one daylight point. For a teaching space, this is even 5% for 80% of the selected space. There must also be a uniformity ratio of at least 0.3. The minimum usable area of an occupied space is determined by not include a band of 0.5 meters from the walls in the area . This was done to meet the requirements for EN 17037 while comparing the results with BREEAM.

Daylight entry			
Function	Average daylightfactor/ function	minimum usable surface (m2) per occupied space	Points
Office spaces	2,00%	80%	1
Teaching spaces	5,00%	80%	1
Living space	2,00%	80%	1

Table 12, Daylight factor based on function

2.2.4 BREEAM, energy

The energy rating for BREEAM and LEED will also be influenced by the requirements of the European Daylighting Standard. If the window to wall ratio is increased to meet a higher performance level for daylighting, the overall U-value of a façade will also be affected. This will affect the overall energy consumption of the building and therefore the points for LEED and BREEAM. Below will be explained how a proposed design can earn points for LEED and BREEAM for the energy category.

BREEAM In the energy category for BREEAM, 15 points can be obtained. This will encourage the designer to design a building with the lowest possible $C0_2$ emissions. The calculation of the energy performance is based on BENG 1 and BENG 2, determined according to NTA 8800 (NEN, 2022). When the primary fossil energy use is calculated, it is compared to a reference value. Primary fossil energy use is the amount of energy from non-renewable sources required to meet the energy demand. Renewable energy may be deducted from primary fossil energy use. It is the sum of primary energy use for heating, cooling, hot water preparation and fans. For non-residential buildings, lighting also counts towards primary energy consumption (RFO, 2017).

The reference value is based on the function of the design. Table 13 shows the reference value for an office. To determine the geometry ratio, the usable area (Ag) and loss area (Als) are divided by each other and it is checked whether this is higher or lower than 1.8. For this study, all variants are less than 1.8 for Als/Ag and for BENG 1, 90 kWh/m^2 will be used as reference value.

Function	Als/Ag	Energy requirement (kWh/m2 yr) (BENG-1)	Primary fossil energy consumption (kWh/m2 yr) (BENG -2)
Office	< 1,8	90	40
	> 1,8	90+30*(Als/Ag-1,8)	

Table 13, Energy requirement for an office

Based on the tables below, points can be awarded for improvement over the primary fossil energy consumption of the reference value. The first 10 points are awarded when the primary energy use is smaller than the reference value in percentages. The other 5 can be obtained by subtracting the primary fossil energy consumption in kWh from the reference value.

Points	Reduction of primary fossil energy consumption (BENG 2) compared to reference value
1	10%
2	20%
3	30% (required for Very Good)
4	40%
5	50%
6	60% (required for Excellent)
7	70%
8	80%
9	90%
10	100% (required for Outstanding)

Table 14, Reduction of primary fossil energy consumption (percentage)

Points	Reduction of primary fossil energy consumption (BENG 2) compared to reference value
1	-10 kWh/m2.yr
2	-20 kWh/m2.yr
3	-30 kWh/m2.yr
4	-40 kWh/m2.yr
5	-50 kWh/m2.yr

Table 15, Reduction of primary fossil energy consumption (fixed number)

2.2.5 LEED, Energy

For LEED, 18 points can be earned in the energy category. These reference values must be determined according to the ASHRAE 90.1 standard. This standard provides the minimum requirements for an energy efficient design. Based on the proposed design and all rooms, a reference value is calculated using the ASHRAE 90.1 standard. This is not a fixed number like BREEAM, but will change as the surfaces of the design changes.

An energy simulation will determine the sustainability of the building by comparing it to a reference model. Efficiency measures focus on reducing energy consumption and HVAC-related strategies. Points can be calculated by calculating the performance cost index of the building and comparing it to the performance cost index target calculated using ASHRAE Standard 90.1-2016, Annex G. How to calculate this will be discussed on the next page. The PCI target for compliance with the code is a function of the building type, climate zone and the ratio of regulated to non-regulated energy expected to be used by the baseline building. The PCI of the proposed building should be less than or equal to the PCI_T. The improvement over the performance cost index target determines the number of points based on the table below. The renewable energy generated on site can be deducted from the proposed energy cost and greenhouse gas emissions. A maximum of 18 points can be earned in total in this category.

New construction	Points BD+C
5%	1
10%	2
15%	3
20%	4
25%	5
30%	6
35%	7
40%	8
45%	9

Table 16. Points for percentage improvement in energy performance

New construction	Points BD+C
5%	1
10%	2
16%	3
24%	4
32%	5
40%	6
50%	7
65%	8
80%	9

Table 17. Points for percentage improvement in energy performance

- Regulated and unregulated energy

For LEED, regulated and unregulated energy must be calculated for the baseline model. The total operational energy consumption of a building consists of regulated and unregulated energy. Regulated energy is the energy consumption in a building of controlled fixed building installations and devices. This is for example heating, cooling, hot water, ventilation and lighting.

Unregulated energy consists of energy consumed by a process that is not controlled. This is the energy consumption that is not required by the building code. It can include IT equipment, lifts, escalators, laptops and other devices. In some buildings, unregulated energy can amount to as much as 50% of total energy consumption. Unregulated energy can usually only be identified late in the design process (Buildings, 2020).

- Calculating the baseline design model

The reference model is calculated using the ASHRAE Standard 90.1-2016, Annex G. The reference model is used to evaluate a proposed building for energy efficiency using energy simulations. The requirements in Appendix G for energy simulation are listed below:

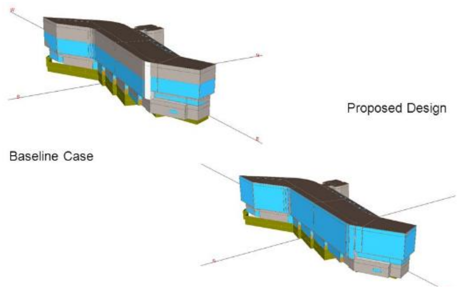


Figure 9. Example of baseline case and proposed design (CTTC, 2014)

  - The floor area of the baseline design model is the same as the floor area of the proposed design. The proposed design may be modified from the basic design model in the following respects: Properties and surfaces of the shell, window openings, walls, lighting, and HVAC system, types and controls.
  - The schematics of the basic design model must be the same as those of the proposed design.
  - The building envelope must have the same floor area and building dimensions in the proposed design compared to the baseline model. The orientation of the baseline model is the same as the actual orientation.
  - Lighting schedules for automatic lighting controlled by occupancy sensors shall be simulated every hour by the lighting schedule based on the reduction factors of the occupancy sensors and the room type
  - The thermal blocks for the HVAC zones in the proposed design are the same as in the base model (Kim, 2020).
  - The baseline energy use for the baseline building is calculated by taking the real orientation and rotated orientations of: 90, 180 and 270. The average of these orientations is taken as the baseline value.
- Building envelope

For the calculation of the basic model, the facade surfaces must be known and equal to the proposed design. The U-factor for the base model is derived from the climate zone in which the design is located. The climate zone that most closely matches the climate in Amsterdam is 4C (Salem, Oregon). Based on this climate zone, the U-factors for the different building elements can be extracted from tables. These numbers for climate zone 4 are shown in the table below.

Climate Zone	U -factor			
	Roof insulation	Wall	Floor	Doors
4	0.063	0.124	0.052	0.7

Table 18, U-factor baseline model

For the basic model, it is also indicated how the building layers should be modelled. The structure is determined by the climate zone and the function of the building. The following structures for the different elements are used in the modelling of the base model.

Construction	Thickness (Inch)	Conductivity (Btu/h ft F)	Density (lb/ft²)	Specific Heat (Btu/lb F)	R-value (ft²·°F·h/ Btu)	U-Factor
Exterior air film					0.17	
Roofing membrane					0.00	
R/15 Continious insulation	3.6	0.02	1.8	0.29	15.00	
Steel deck	0.06	26	480	0.10	0.00	
Interior air film					0.61	
Total for assembly					10.78	0.063

Table 19, Building Wall Construction Assemblies

Construction	Thickness (Inch)	Conductivity (Btu/h ft F)	Density (lb/ft²)	Specific Heat (Btu/lb F)	R-value (ft²·°F·h/ Btu)	U-Factor
Air film					0.17	
Stucco	0.4	0.42	116	0.2	0.08	
Gypsum board	0.625	0.093	50	0.2	0.56	
					6.00	
Gypsum board	0.625	0.093	50	0.2	0.56	
Interior air film					0.68	
Total for assembly					8.05	0.124

Table 20, Exterior Floor Construction Assemblies

Construction	Thickness (Inch)	Conductivity (Btu/h ft F)	Density (lb/ft²)	Specific Heat (Btu/lb F)	R-value (ft²·°F·h/ Btu)	U-Factor
Interior air film					0.92	
Carpet and pad					1.23	
Concrete	4	1.33	140	0.2	0.25	
R/19 insulation between joints					16.37	
Metal deck	0.06	26	480	0.1	0.00	
Semi-exterior air film					0.46	
Total for assembly					19.23	0.052

Table 21, Roof construction Assemblies

For doors, a U value of 0.7 must be used. For windows, the U-factor and SHGC are specified in the table below. The visible transmission must be equal to 1.1 x the SHGC. For the variants used in this study, this corresponds to a VLT of 0.43

Climate zone	U-factor		SHGC					
	Vertical	Horizontal	0-10%	10.1-20%	20.1-30%	30.1-40%	0-2%	2.1-5%
4	0.57	0.69	0,39	0.39	0.39	0.39	0.49	0.39

Table 22, Fenestration U-factor and SHGC

HVAC systems

The HVAC systems for the basic model are determined according to the type of building, the size of the building and the climate zone. The diagrams shall be the same as the proposed design. However, the setpoint of the dry bulb temperature may deviate from the base model if it can be shown that equivalent thermal comfort is maintained. For climate zone 4 a Packaged Single Zone Air Conditioner (PSZ-AC) is used. A PSZ AC system consists of the following systems:

System No.	System type	Fan control	Cooling type	Heating type
3 – PSZ AC	Packaged roof top air conditioner	Constant volume	Direct expansion	Fossil fuel furnace

Table 23, HVAC system

- Calculating the performance cost index

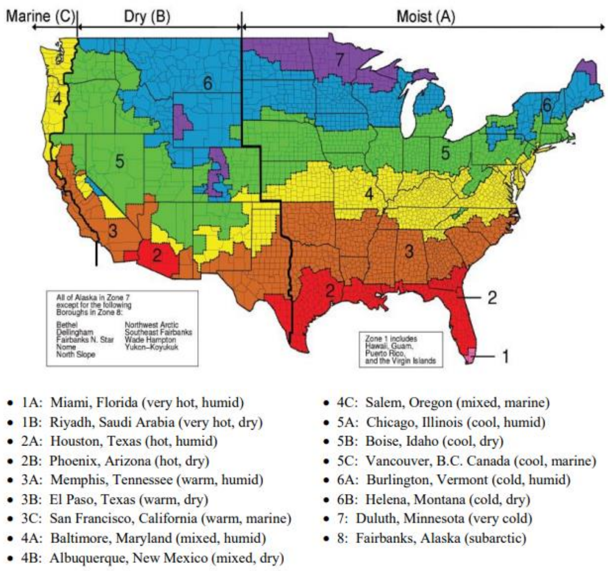
The performance requirement for the proposed design must demonstrate that the PCI is below a target PCI (PCI_t). The proposed design must exceed the proposed performance. Thus, it must have lower energy costs per year compared to the baseline. To calculate the PCI, the following formula should be used (Rosenberg & Hart, 2016).

$$\text{Performance Cost Index} = \frac{\text{Proposed Building Performance}}{\text{Baseline Building Performance}}$$

Proposed Building Performance = The annual energy cost for a proposed design calculated according to Standard 90.1, Appendix G

Baseline Building Performance = The annual energy cost for a baseline design calculated according to Standard 90.1, Appendix G

For the calculation of the baseline model, 16 prototype buildings were developed, representing the majority of the commercial building stock. For each prototype, a set of requirements was developed for the 17 different climate zones in the United States. This combination of prototypes, climate locations and standard editions results in 1088 individual building models with different energy costs.



Building Type	Prototype building
Office	Small Office
	Medium Office
	Large Office
Retail	Stand-Alone Retail
	Strip Mall
School	Primary School
	Secondary School
Healthcare/hospital	Outpatient Health Care
	Hospital
Lodging/hotel	Small Hotel
	Large Hotel
Warehouse	Warehouse
Restaurant	Fast Food Restaurant
	Sit-Down Restaurant
Apartment (Multi-family)	Mid-Rise Apartment
	High-Rise Apartment

Figure 10, Climate zone united States

(Rosenberg & Hart, 2016)

Table 24, Building types ASHRAE 90.1-2016

(Rosenberg & Hart, 2016)

The annual design energy cost is determined using the state's average energy price, as published by the Energy Information Administration (EIA). For the state of Salem, Oregon, this is $0.088.kwh. Oregon was chosen because it is most similar to the Dutch climate. The climate in Oregon is a mixed, maritime climate. Amsterdam also has a maritime climate. It is strongly influenced by its proximity to the sea. The driest month of the year has an average monthly precipitation of at least 30 mm and that the precipitation is spread roughly throughout the year.

The following formula can be used to calculate the PCI target for the baseline building.

$$PCIt = \frac{(\mathrm{BBUEC}\ + (\mathrm{BPF}\ \cdot\ \mathrm{BBREC}))}{\mathrm{BBP}}$$

PCI_t = The maximum Performance Cost Index target for a proposed design

BBUEC = Baseline Building Unregulated Energy Cost

BBREC = Baseline Building Regulated Energy Cost

BPF = Building Performance Factor (BPF) from Tables 25 (0,58)

BBP = Baseline Building Performance. The annual energy cost of the baseline building design in which both regulated and non-regulated energy consumption are added together (Rosenberg & Hart, 2016).

The building performance factor is determined based on the climate zone and the building type. In this case, it is 4C for the climate zone (Salem, Oregon) and the function is an office, so the building performance factor is 0.58.

Building Type	Climate Zone 0A & 1A	0A & 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Building Type Average
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61	0.60
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53	0.57
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51	0.50
Healthcare	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56	0.56
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68	0.61
Hotel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58	0.62
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67	0.61
Apartment	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80	0.76
All Others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52	0.58

Table 25, Building performance factor based on climate zone and building type

For LEED, credits can be obtained for percentage improvements compared to the standard. For example, if one has 20% less energy costs, LEED awards eight points. The improvement compared to the standard can be calculated using the following formula:

$$PCI = \frac{\mathrm{PCIt}\ -\ \mathrm{PCI}}{\mathrm{PCIt}}$$

%Improvement = the target percent improvement over the baseline building

PCI = the Performance Cost Index

PCIt = the Performance Cost Index Target

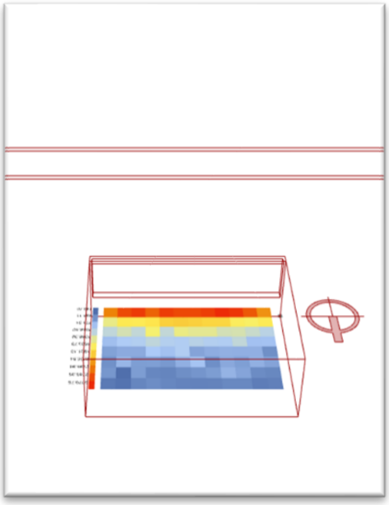
As the section above explains how the daylight and energy points are calculated for BREEAM, LEED and EN 17037, an example variant is shown on the next page. One variant has been selected for the analysis, but all other variants will be calculated in the same way.

Variant 0896

Performance criteria

EN 17037 (method 2): Medium

Minimum		Medium		High	
ET	ETM	ET	ETM	ET	ETM
True	True	True	True	True	False



LEED : 3 Points

sDA300,50%: 87,5%

ASE1000,250h: 16%

EN 17037 (method 1): Minimum

Minimum		Medium		High	
DT	DTM	DT	DTM	DT	DTM
True	True	False	False	False	False

BREEAM: 0 points

Daylightfactor (>2%): 4,45

Uniformity ratio (>0.30): 0,29

Proposed building energy consumption

Cooling energy demand = 4,287 kWh/m2

Heating energy demand = 19,647 kWh/m2

Ventilation energy demand = 23,72 kWh/m2

Lighting energy demand = 2,715 kWh/m2

Electric equipment = 25,649 kWh/m2

Pump energy demand = 4,501 kWh/m2

Water energy demand - 4,501 kWh/m2

Total energy demand = 85 ,019 kWh/m2

Pv panels = 20 kWh

Example BREEAM

Points are awarded on the basis of the improvement in primary fossil energy consumption compared to the reference value weighted by surface area.

Primary fossil energy use = 39,37 kWh/year

Reference value Office = 40 kWh/year

Reduction from the reference value (-) = 40 -39,37 = 0.63 kWh/year reduction

$$\text{Reduction from the limit value (\%)} = \frac{0.63\,\frac{\text{kWh}}{\text{y}}}{40\,\frac{\text{kWh}}{\text{y}}} * 100 = 1{,}58\%$$

Result: 0 Points

Example LEED

Location	= Climate zone 4C
Price / kwh	**=** $0.088/kWh
Building performance factor (table 25)	**=** 0.58
Proposed building performance	**=** 85,019-20=65,019 kWh
Baseline building performance (BBP)	= 120,956 kWh
Baseline building regulated energy cost (BBREC)	= 25,649 kWh
Baseline building unregulated energy cost (BBUEC)	**=** 146,61 kWh

Step 1.

$$\text{Performance Cost Inde}x\ (PCI) = \frac{65{,}019}{146{,}61\ \text{kWh}} = 0{,}44$$

Step 2.

$$\text{PCI}t = \frac{(\text{BBUEC}\ + (\text{BPF}\ \cdot\ \text{BBREC}))}{\text{BBP}}$$

$$PCIt = \frac{25{,}649\ + (0{,}58\ \cdot 120{,}956))}{146{,}605} = 0{,}653$$

Average of the chosen orientation plus the 3 other orientations; = 0,65

Step 3.

$$Improvement\ beyond\ code = \frac{\text{PCIt}\ -\ \text{PCI}}{\text{PCIt}} * 100$$

$$Improvement\ beyond\ code = \frac{0{,}65\ - 0{,}44}{0{,}65} * 100 = 32{,}31\%$$

Result: The proposed design is 32,31% better than the base

LEED: 11 Points

In this paragraph it became clear that if a higher recommendation level is achieved for daylight provision for the European standard, the total energy consumption of the building will probably increase. The requirements for the high recommendation level for daylight provision is a target illuminance of 750 lux and a minimum target illuminance of 500 lux. This can have an effect on obtaining sufficient credits for the daylight and energy part for BREEAM and LEED. Therefore, this research investigates: *How does the European standard for daylight in buildings influence the energy performance in buildings and what influence does this have on the BREEAM and LEED certificates?*

Using baseline models and values, the outcomes for green buildings certificates are calculated for different variants when meeting the different requirements for daylight provision for the European standard. To complement the previous studies, blinds are also applied, as this is mandatory for LEED . In order to better analyze the lighting energy consumption, daylight-sensitive dimmers and illuminance sensor are used.

From the literature review, it also becomes clear that there are different performance requirements for daylight provision used for BREEAM and LEED compared to the European standard. Therefore, this research also examines whether there is much difference between the performance measures for daylight for the green building certificates and the European standard.

3. Methodology

In the previous paragraph, the requirements of the European norm and the two green building certificates were examined. In the next section, all simulation assumptions, the flowchart for Grasshopper and the reliability of the results are explained. Using this paragraph and paragraph 2, all simulations can be performed and the results are show in paragraph 4.

3.1. Simulation assumptions

For the simulation inputs, all fixed inputs are discussed first. These are mainly all simulation assumptions for installations, the occupancy schedule and the location of the study. After this, the variable inputs are discussed. The variable inputs are changed in order to analyze the differences in outcome performance. In this study, the variable inputs are: width, depth, orientation, WWR, glass characteristics, context and the depth of fixed shading devices.

3.1.1 Fixed input

Since this study examines light-related aspects from EN17037, fixed inputs are chosen for the installations. These numbers are based on the most sustainable installations that can be used in a building without compromising the comfort of the user. For the cooling and heating of the building, an Aquifer thermal energy storage system is used. This is a sustainable energy supply in which the heat pump use a fluid flowing through the ground heat exchanger as their source for heating and cooling. For ventilation, mechanical ventilation was chosen. The lighting consists of LED lighting, because this consumes the least energy. For the simulation, the settings belonging to these installations are used. The other settings are based on Dutch standards, BREEAM requirements or commonly used parameters as reported in literature.

Heating and cooling

For BREEAM, there are a number of points to be earned for thermal comfort. Thermal comfort describes the sensation of when a person should not be warmer or colder. This is subjective because it depends on individual perception. Thermal comfort is affected by physical activities, clothing, and fluctuations in thermal environmental factors. When one deviates from this value, there is a loss of performance that should be noted. The Predicted Mean Vote (pmv) is described in the ISO 7730 (NEN, 2005). The aim of PMV is to predict an average value of votes of a group of residents on a seven-point scale for thermal sensation. Thermal equilibrium is achieved when the thermal internal heat production is equal to the heat loss (Guenther, 2021).

-3	-2	-1	0	1	2	3
Very cold	Cold	Slightly cold	Neither hot or cold	Slightly hot	Hot	Very hot

Table 26, Thermal sensitivity

The Predicted Percentage of Dissatisfied (PPD) quantitatively predicts the percentage of dissatisfied persons. The graph below shows the agreement between PMV and PPD. For BREEAM, the temperature range of -0.5 < PMV < +0.5 must be achieved for all accommodation areas during 95% of the usage time. This means that only 10% of a large group of people are dissatisfied with the temperature.

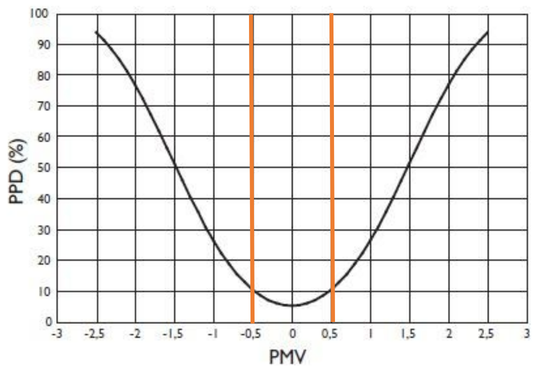


Figure 11, PPD as a function of PMV (BeSWIC, n.d.)

The cooling and heating setpoint will be determined according to the European standards of EN 15251. There are 3 categories for the operative temperature for hourly energy calculations. The category I: heating ranges 21.0-23.0°C and cooling 23.5-25.5°C, category II: heating ranges 20.0-24.0°C and cooling 23.0-26.0 °C, and category III: heating ranges 19.0-25.0°C and cooling 22.0-27.0°C. In most spaces, set point for temperature for heating is close to 20°C and for cooling not above 26°C. In this simulation, these numbers will therefore be maintained (BEDNAROVA, 2014).

Ventilation

The amount of air exchange was determined according to the NEN standard 1087 (NEN, 2019). The same requirements have been applied for the BREEAM credits. This is 60 m^3/h per person for an office. A minimum capacity of the blow-down ventilation per occupied space is 6 dm^3/s per m2 of floor area. The air velocity of the fresh air supply is not higher than 0.2 m/s.

Occupancy schedule

For the baseline model for ASHREA 90.1 2016, the occupancy schedule of a small office should be used. These occupancy schedule values are mentioned in the ASHREA 90.1 standard. For the proposed design the same occupancy schedule will be used. The occupancy schedule of a small office is shown in figure 12 for a weekday. On weekends, no one will be present.

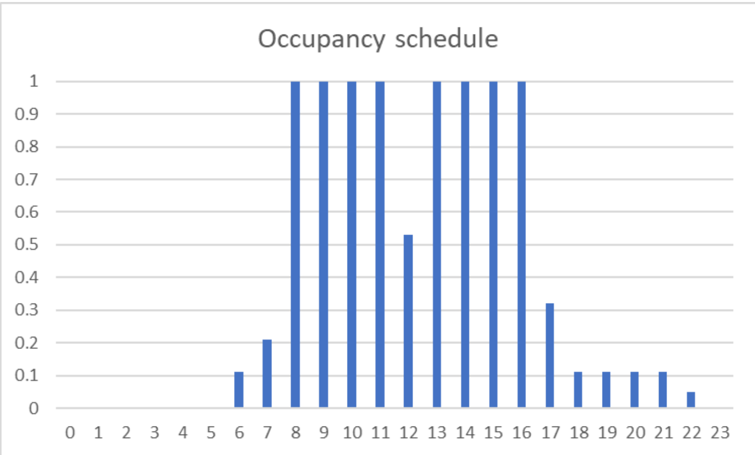


Figure 12, Occupancy schedule for a small office

R-value and U-value

The R-value is the thermal resistance of a structure and indicates its insulating capacity. The higher the R-value, the less heat is lost through the structure. Building codes in the Netherlands state that floors must have a minimum R-value of 3.5 m^2K/W , roofs 6 m^2K/W and facades 4.5 m^2K/W. For the windows, the U-value is prescribed in the Dutch Building Decree. This is the rate of heat transfer through a structure. For window frames and curtain walls, the building code states that they may have an average U-value of no more than 1.65 W/m2.K. An individual element may have a maximum value of 2.2 W/m2.K. The facade elements of the entire building may therefore not exceed an average U-value of 1.65 W/m2.K.

Since most sustainable buildings use a higher R-value to lose less heat, the energy consumption is examined with the R-value based on the passive house principle. The goal of the passive house principle is to achieve an energy efficient home. As a rule of thumb, an R-value of 8.0 m^2K/W is used for the floor, walls and roof (ph building consultancy, n.d.).

Location and weather file

In order to simulate the annual amount of daylight in a building, it is first necessary to know the amount of solar radiation at the building site for a year. These data are usually provided in the form of typical meteoritical years. They include annual profiles of outdoor climate data such as ambient temperature, wind direction and speed, precipitation, and direct and diffuse irradiance. The climate data for this project was downloaded from the Energyplus website and used for method 2 for EN 17037 and LEED. Amsterdam is used for the location. Amsterdam has a marine west coast climate influenced by the North Sea and westerly winds. The average annual temperature for Amsterdam is 13^{o} C and it receives 435 mm of rain per year.

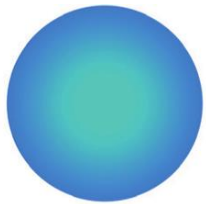


Figure 13, CIE overcast Sky (Thompson, 2011)

Two methods can be used to calculate the daylight provision for the European standard. The two methods are explained below:

In the first method, the daylight factor is calculated using a method based on ISO 15469 (ISO, 2004) with a CIE overcast sky. The luminance of a standard overcast sky changes with latitude. It is three times as bright in the zenith as it is near the horizon. With the CIE overcast sky, the position of the sun has no effect, nor does the orientation of the building.

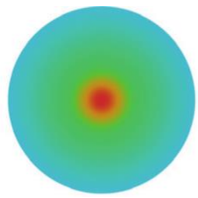


Figure 14, Perez sky (Thompson, 2011)

The second method is a detailed daylight calculation method where values for the internal daylight illuminance per hour are calculated for a typical year. If the room contains shading devices, this should be included in the simulation. For the minimum requirement, the target illuminance must then be reached 300 lux for 50% of the room for 2190 hours on the reference plane.

3.1.2 Variable inputs

To clarify the influence of EN 17037 on BREEAM and LEED, different variants are simulated to calculate the performance outcome. These different variants are created by using different parameters, context and orientation. The use of these parameters will result in different performance outcomes. The variable inputs that will be used are explained below.

<u>Orientation of the building</u>

The orientation of the building is important to get enough daylight, but also affects the risk of glare and overheating of the building. Glazing facing north will only receive indirect sunlight. A south-facing façade will again provide good daylighting, but there is a high risk of overheating the building and glare from the low sun in the winter months. Thus, nine different orientations will be considered. With these different orientations, two scenarios for a building can be created later. The different orientations can be seen below.

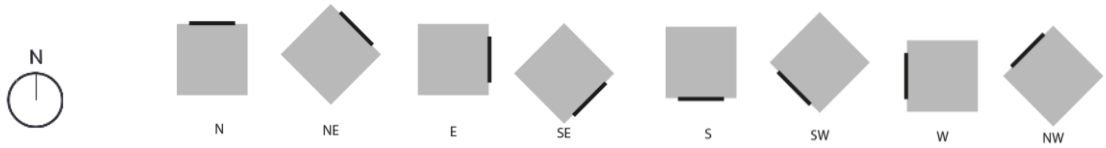


Figure 15, Orientation of the building

<u>Width, Depth and Height of the room</u>

The width, depth and height affect the amount of daylight that falls on a reference surface. The deeper the space, the lower the average daylight factor in the space becomes. Almost every office building built after 1970 in the Netherlands has a grid of 1.80 and multiples thereof. A room for 4 people usually has a size of 3.6 x 5.4 meters (Lansink, 2019). The width and depth are thus chosen between multiples of 1.80 meters up to a maximum of 7.2 meters. The height of a room is 2.6 meter. This is the minimum height for an office according to the Building Code.

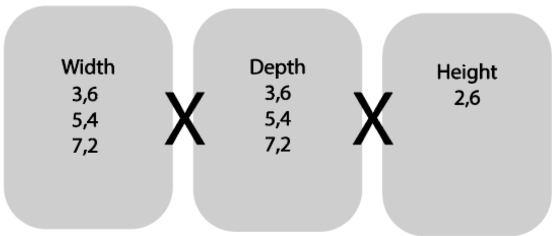


Figure 16, Width, Depth & height parameters

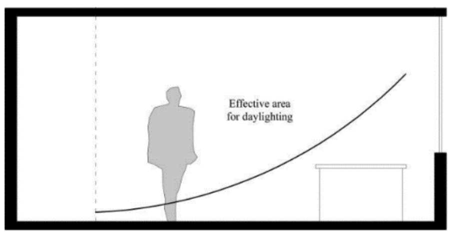


Image 17, Room depth as an effective area for daylighting (Ayoosu, n.d.)

Glass characteristics

In recent years, the specifications of glass have improved significantly. There are now high-quality glazing systems on the market that dramatically reduce a building's energy consumption. There are many points to consider when choosing glazing and can ultimately reduce HVAC costs by 10%-40% (Ander, 2016).

The most important aspects of glass characteristics are the U-value, the Solar Heat Gain Coefficient and the Visible Light Transmittance. The properties of glass can be changed by tinting the glass or applying different coatings and films.

Solar Heat Gain Coefficient (SHGC)

The SHGC indicates how much solar energy on the window passes through as heat. As the SHGC increases, so does the potential solar gain. The SHGC is a ratio between 0 and 1. SHGC= 0 means that no heat will pass through the window. With an SHGC of 1, it means that all solar energy is transmitted through the window as heat.

In buildings with high air conditioning loads, windows with low SHGC values are desirable. Buildings where passive solar heating is required, high SHGC values are important.

Visible Light Transmittance (VLT)

VLT indicates the percentage of the visible part of the solar spectrum that is transmitted through a particular glass product. In general, a high visible glass transmittance (> 70%) is desired, especially for daylighting (Ander, 2016).

Type window	U-value	VLT	SHGC
Double glazing high VLT, high SHGC	1,1	77	60
Double glazing high VLT, low SHGC	1,1	68	37

Table 27, Glass specifications

WWR

In a building, windows are considered weak points in the envelope because of their lower resistance to heat transmission. By increasing the window-to-wall ratio, this will have a positive effect on the daylight factor in the room. However, this may lead to an increase in energy consumption for cooling or heating. In this study, the WWR varies from 10-100% with 10% increments to investigate the effect of WWR on energy consumption and daylight factor. Figure 18 shows the different window-to-wall ratios.

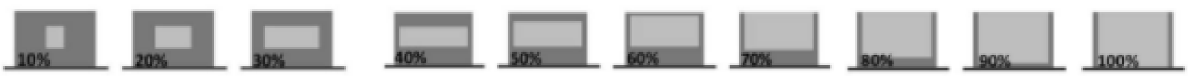


Figure 18, Different window to wall ratios

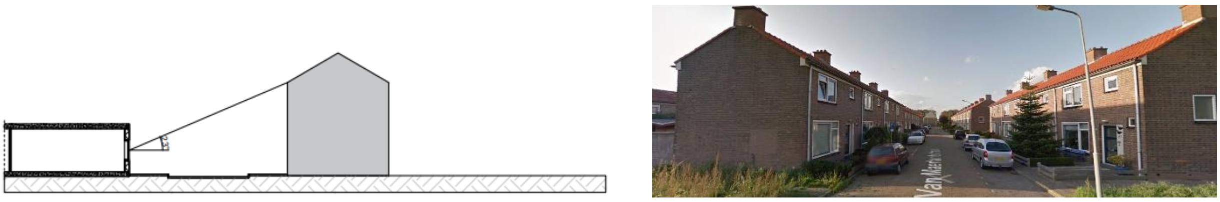
Lighting

Lighting represents a significant part of energy costs in most of the building buildings. To analyze the effect of the European standard on lighting energy costs, daylight-sensitive dimmers and illuminance sensor are used in the simulation. According to the literature, this can save up to 60% of lighting energy costs (Tsangrassoulisa, et al., 2017). The illuminance is set at 300 illuminance. This is sufficient for simple office work and for reading surfaces that need to be illuminated. For the lighting power density 10 W/m^2 will be used (Archtoolbox, 2021).

Context

Since a high urban density can have a negative effect on daylight provision inside a building. Three different kinds of context are included in the study. Context with a minor obstruction, limited obstruction and significant obstruction are used in this simulation. The different kind of context are based on common buildings in a city, such as residential housing and apartment blocks. The context consists of models that actually exists and was loaded into grasshopper with the help of 3D bag (tudelft3d, 2021). 3D bag is an up-to-date dataset of 3D building models of the Netherlands. The models are generated by combining two open data sets: the building data from the BAG and the height data from the AHN. You can see the three different contexts in the images below.

Context 01, Small obstruction



Context 02, Limited obstruction

Context 03, Significant obstruction

Figure 19, Three different kind of context used in this study

Depth of the Fixed shading devices

Since fixed shading in front of the façade can also be applied, three different scenarios are also set for this. The first scenario is where there is no fixed shading, the second is small shading in front of the facade (0.3m) and the last is a significant fixed shading (1.2m), like a balcony.

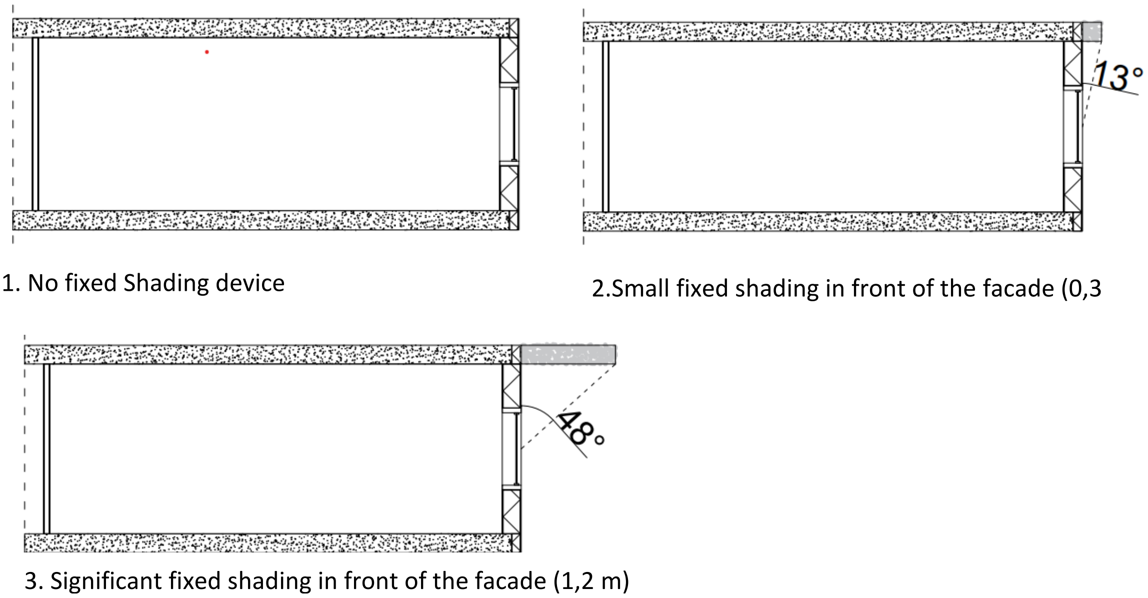


Figure 20, Depth fixed shading

With the mentioned orientations and three different contexts, different scenarios can be created. A simple square building mass will be used for this research. Six different scenarios can be created, which are shown below. It is assumed that the buildings consist of a core with office spaces surrounding the core, so that each orientation can be analyzed. By adjusting the width/depth, WWR, fixed shading and glass characteristics of the different scenarios, we can see what this does to performance outcome of the office spaces with the different contexts.

The first two scenarios consist of two buildings where one is oriented towards the N/E/S/W and the other building is oriented towards the NE/SE/SW/NW, with no obstruction around the building.

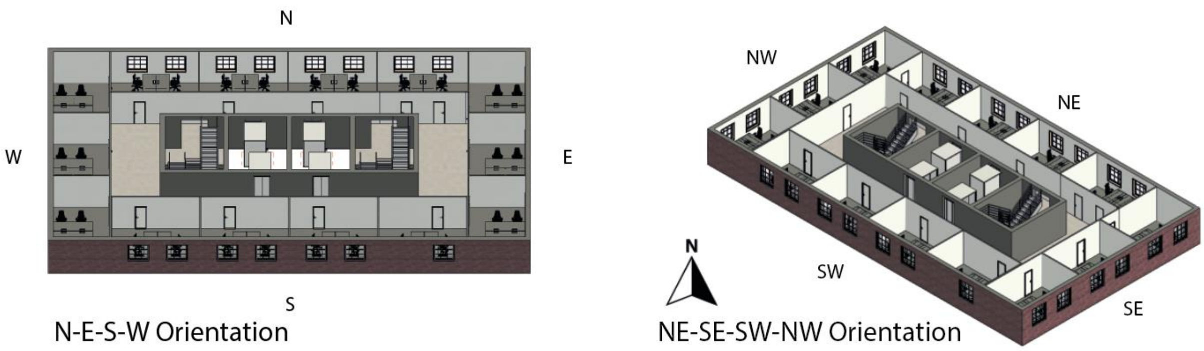


Figure 21, Scenario 1 and 2

For the other four scenarios, the difference between the previous ones is that there are 2 different conext around the building. For two scenarios, these are housing blocks and for the last two, the sunlight is blocked by four apartment buildings. The orientation is the same as the one mentioned above.

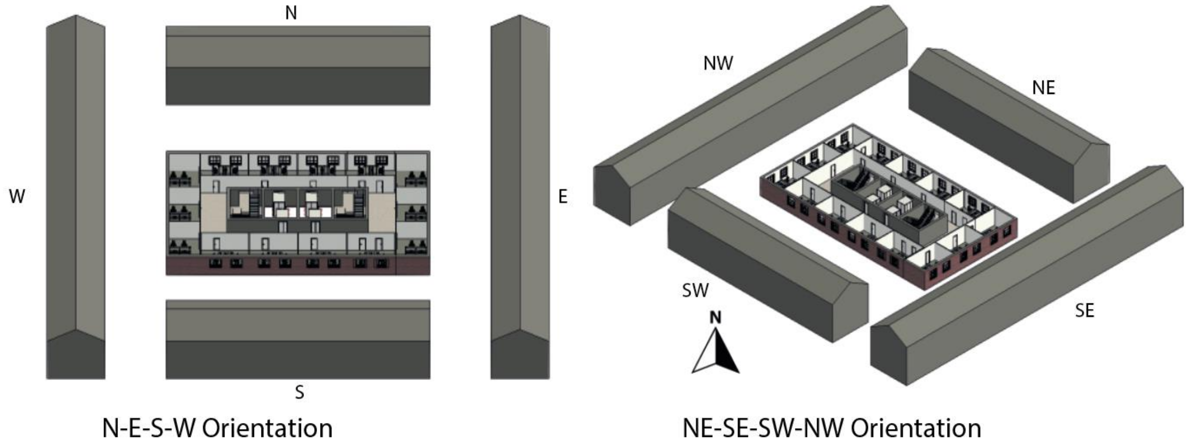


Figure 22, Scenario 3 and 4

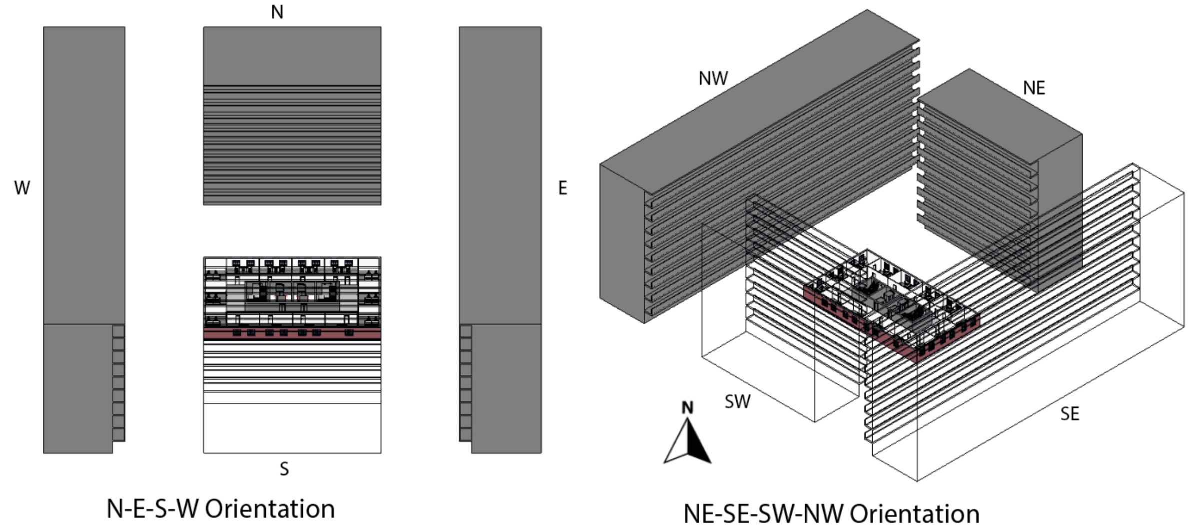


Figure 23, Scenario 5 and 6

3.2 Software

To perform the simulations, Grasshopper is being used. Grasshopper is a visual programming language and environment that runs within Rhinoceros Computer-Aided Design (CAD) application. The program is mainly used to build parametric algorithms (Wikipedia, 2021). The latest version of Rhino (7) is used to run grasshopper. When writing algorithms in Grasshopper, it is possible to install additional plugins. Since it is an open-source code, other programmers can share their plugins publicly. The following plugins will be used in this research.

Ladybug

With the ladybug plugin, the weather data of a location can be visualized and analyzed. This can be done by importing an Energyplus weather file and analyzing them with the Ladybug tool. It also supports the evaluation of design options through solar radiation studies, rendering analysis and modeling of sunlight hours. This is important when simulating daylight in buildings (food4rhino, n.d.).

Figure 24, Ladybug (Ladybug, n.d.)

Honeybee

With Honeybee, daylight simulations and energy models can be made. It creates, executes and visualizes the results of the daylight and energy simulation. This simulation can be linked to CAD and visual script interfaces such as Grasshopper and Rhino. This is done with the help of Radiance and Openstudio (Ladybug tools, n.d.).

Radiance is a program for analyzing daylight in a design. It uses ray tracing techniques to calculate radiation values. This is the amount of light that passes through a specific point in a specific direction. It uses a hybrid approach of deterministic and stochastic raytracing to get an accurate result in a reasonable amount of time (Radiance-online, 1997). This is further explained in 3.3.

Openstudio is a collection of software tools to support energy modeling with Energyplus and advanced lighting analysis with Radiance.

Figure 25, Honeybee

(Honeybee, n.d.)

TT toolbox

Grasshopper data can be streamed to Microsoft Excel spreadsheets using TT toolbox. It is also possible with the Colibri plugin that comes with the TT toolbox to generate datasets for Design Explorer. Design explorer is an open source tool for exploring design variants. The different variants can be visualized and filtered. The Colibri workflow consists of two phases, iteration and aggregation. The iterator component controls the sliders so that all steps can be completed in an automated manner. The aggregator collects the input from the iterator, the output, generates images and writes all data to a data.csv file. The images and csv file can be uploaded into drive and opened in Design explorer to visualize and filter the different ones (Tomasetti, 2017).

Figure 26, Colibri (Colibri, n.d.)

Pollination

With the Pollination plugin, the simulations for the Ladybdug tool can be run on the cloud instead of on a local computer. Hundreds of iterations can be simulated in parallel. All inputs and outputs can be loaded back into grasshopper later. In the pollination plugin several standard recipes for energy, daylight and comfort simulations can be used that are also used for Ladybug and Honeybee (Pollination, n.d.).

Figure 27, Pollination

(Pollination, n.d.)

3.3 Daylight simulation settings

Before the design variants are calculated, the accuracy and reliability of the results of one variant is tested. It is checked whether the radiance parameters are set correctly and the outcome is accurate. When the settings are too low it can affect the accuracy of the results, but too high and the radiance parameters can drastically increase the simulation time. When the radiance parameters are set and the results are accurate, the outcome is checked whether the same daylight and energy results are achieved using a different Rhino plugin. This ensures that the results are reliable and all other variants can be calculated.

- Radiance parameters

As mentioned in section 3.1, Honeybee and Ladybug use Radiance for their daylight calculation engine. Radiance uses a hybrid approach of deterministic and stochastic raytracing to get an accurate result in a reasonable amount of time. The idea behind backward ray tracing is to simulate individual light rays in space from a point of interest. The individual light rays are traced until they hit a light source or another object. An advantage of backward ray tracing is that the computation times are less than forward ray tracing. This is because the amount of light that falls into the room is only calculated for the selected rooms. (Reinhart, 2010).

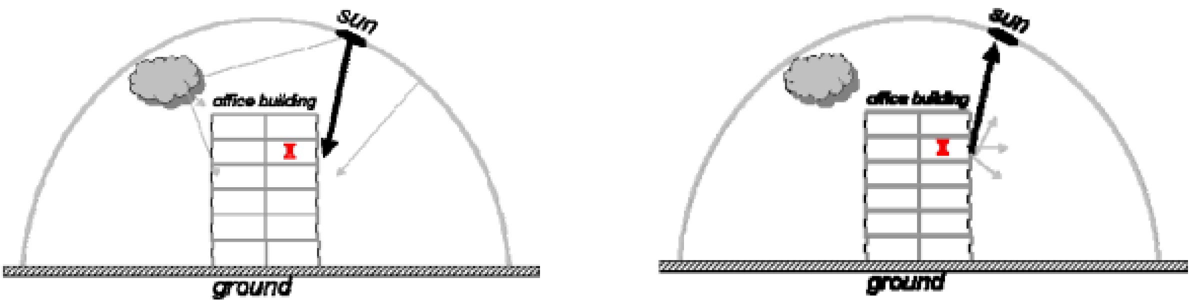


Figure 28, Forward and backward raytracing (Reinhart, 2010)

To make a simulation, a few settings for the radiance simulation parameters needs to be entered. An incorrect setting of some simulation parameters may compromise the accuracy of the simulation. The program will not report that a number of settings are wrong or what the accuracy of the simulation is. Returning the settings to the highest settings will dramatically increase the simulation time (see table 28). The most important parameters are explained on the next page.

Parameter	Change	Potential CPU overhead
ad ambient divisions	512 to 1024 i.e. doubling	x 2
aa ambient accuracy	0.2 to 0.1 i.e. halving	x 4
	no interpolation 0	x a lot?
ar ambient resolution	32 to 64 i.e. doubling	x 4
	unlimited resolution 0	x a lot?

Table 28, Potential CPU overhead
(Mardaljevic, 2014)

- aa: ambient accuracy and ar: ambient resolution

The ambient accuracy is the maximum permissible error in the interpolation of the indirect irradiance. Normally, a number between 0 and 0.1 is chosen, with lower values giving greater accuracy. Halving the aa leads to a doubling of the simulation time. The ambient resolution determines the distance between ambient calculations by determining the maximum density of ambient values to be used in interpolation, with other parameters also affecting the scale over which interpolation may take place.

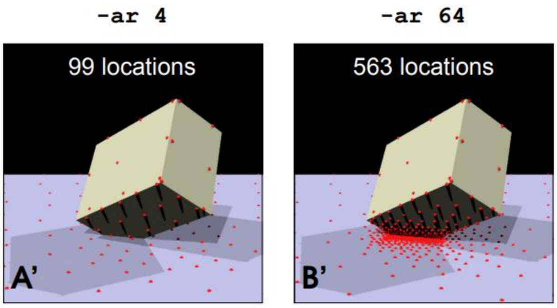


Figure 29, Ambient resolution

(Mardaljevic, 2014)

The combination of these two parameters with the maximum scene dimension provides a measure of how finely the luminance distribution in a scene is calculated (Reinhart, 2010).

- ab: ambient bounces (number of inter-reflections to take into account)

This parameter describes the number of diffuse interreflections that will be calculated before a path is ignored. The number of ambient bounces depends on the type of building and the daylight system. An ab-value of 5 is sufficient for reliable results for most standard rooms without complicated facades. With blinds, this parameter should be set higher because rays can be reflected several times before finding their way out (Reinhart, 2010).

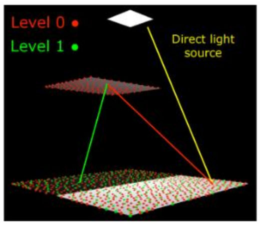


Figure 30, Ambient bounces (Mardaljevic, 2014)

- ad: ambient divisions (number of rays in the sampling hemisphere)

The ambient division parameter determines the number of sample rays that are sent out from a surface point during an ambient calculation. Improving the ambient divisions yields a smoother shadow at a higher calculation cost. The ambient division and super sample parameter can help to reduce noise in the calculation, as shown in figure 31. Higher ambient division values will reduce the patchiness. However, it will quadruple the computation time (Reinhart, 2010).

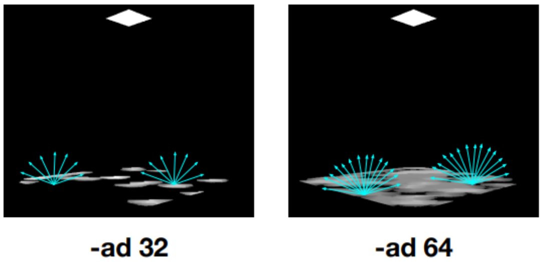


Figure 31, Ambient divisions (Mardaljevic, 2014)

- as: ambient super-samples (additional rays for highly varying regions)

Ambient super-samples is used to sample additional rays in the divided hemisphere that appear to have a large variation. It is usually set to about half the ambient divisions. Ambient sampling parameter greater than zero determines the number of extra rays that are sent in sample areas with a high brightness gradient (Reinhart, 2010).

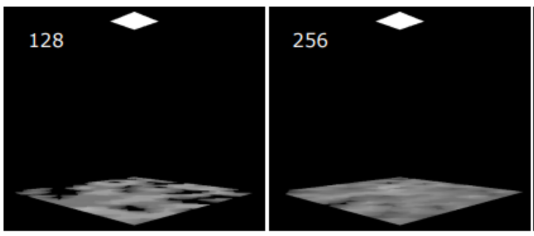


Figure 32, Ambient super-samples (Mardaljevic, 2014)

- Convergence test

Since it is important that the radiance parameters are chosen correctly so that the result are accurate and stable in different runs, a convergence test was performed. The test consists of running several simulations and gradually increasing the resolution process by changing one parameter each time. The radiance parameter is changed till the performance outcome reaches a plateau. It was decided to do this for the deepest and narrowest variant in this study (3.5 x 7.2 x 2.6 m), in which daylight has to reflect several times in order to reach deep into the room. Since the issue is the adequacy of the ambient light and no rendering is required, the ambient parameter need not be too high. The parameters that have been chosen are colored in green in the table. For the ambient bounces, five ambient bounces were chosen, because it is easy to see that the performance outcome still changes significantly if the ab is lower than five. For ad+as and aa, the settings were chosen at which the graph reaches a plateau, which can be seen in figures 33 and 35.

Ambient division (ad) and ambient super-samples (as)

ab	aa	ar	ad	as	DF	
1	0.4	8	32	16	1,435	1,4
1	0.4	8	64	32	1,339	1,3
1	0.4	8	128	64	1,404	1,4
1	0.4	8	256	128	1,479	1,5
1	0.4	8	512	256	1,501	1,5

Ambient resolution (ar)

ab	aa	ar	ad	as	DF	
1	0.4	8	256	128	1,479	1,5
1	0.4	16	256	128	1,477	1,5
1	0.4	32	256	128	1,474	1,5
1	0.4	64	256	128	1,420	1,4
1	0.4	128	256	128	1,488	1,5

Ambient accuracy

ab	aa	ar	ad	as	DF	
1	0.4	32	256	128	1,501	1,5
1	0.2	32	256	128	1,471	1,5
1	0.1	32	256	128	1,457	1,5
1	0.05	32	256	128	1,438	1,4

Ambient bounces

ab	aa	ar	ad	as	DF	
1	0.1	32	256	128	1,501	1,5
2	0.1	32	256	128	1,683	1,7
3	0.1	32	256	128	1,895	1,9
4	0.1	32	256	128	1,955	2,0
5	0.1	32	256	128	2,001	2,0

Table 29, Radiance parameters convergence test

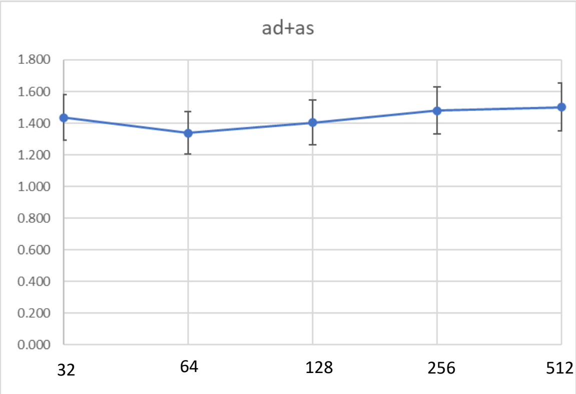


Figure 33, Ambient divisions and ambient super-samples

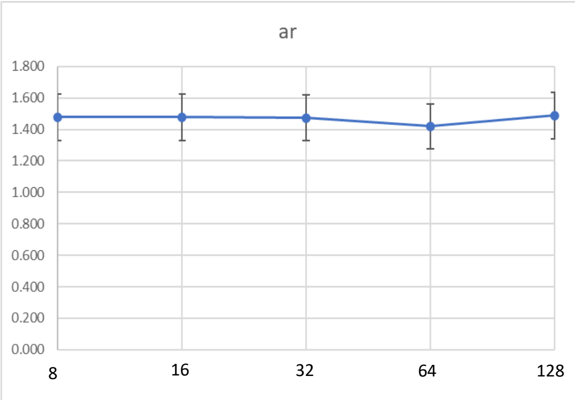


Figure 34, Ambient resolution

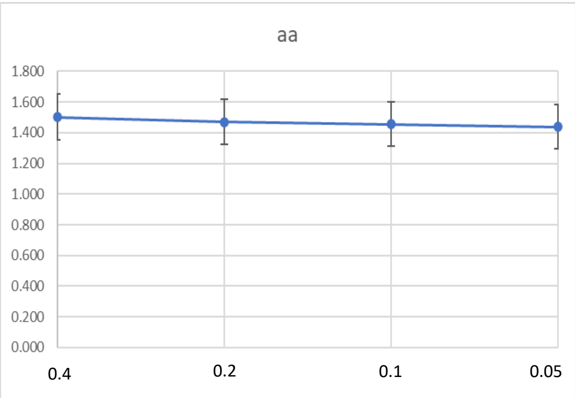


Figure 35, Ambient accuracy

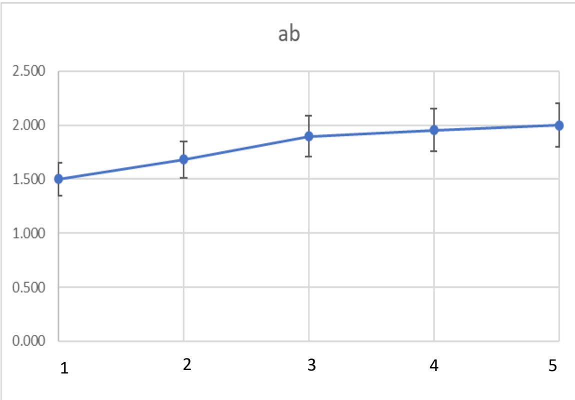


Figure 36, Ambient bounces

- Inter-model comparison

To see if the results of the Grasshopper model are credible, one variant is examined and the results are compared with the results from Climate Studio. Climate Studio is a plugin for Rhino 3D that also uses Radiance-based path tracing. The setup instructions are simple, requiring only that the location, materials, grid and occupied areas be entered. If the results match, the Grasshopper workflow can be used to calculate all other variants. Again, the deepest variant is chosen. The parameters of the variant can be seen in table 30. The following performance outcomes are used to compare the results of the different plugins: daylight factor, illuminance, sDA, ASE and the results of EN 17037. Most percentage differences between the results are below 5%, so it can be considered reliable. The only outcome that is above 5% is ASE. This can be explained by the fact that ASE is measured at each grid point if it is above 250 hours. For each row, the results are close to each other as they are equally deep in the room and only the points near the walls are a little lower. If the second row of grid points with Climate studio fall just below 250 hours and with Grasshopper above 250 hours, the difference between the two models is immediately very large.

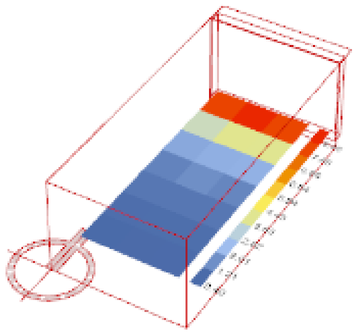


Figure 37, Reference model

Simulation	
Width	3600
Depth	7200
Height	2600
SHGC	0,6
VLT	0,77
WWR	0.90
Context	1
Shading	0

Table 30, Parameters of the variant

Program	DF	Uniformity	sDA, without blinds	ASE	sDA, with blinds	300lux.50	500lux.50	750lux.50
Climate studio	2,25	0,22	57,10%	14,30%	33,30%	49,36%	34,41%	19,59%
Grasshopper workflow	2,259	0,177	53,30%	8,33%	35%	45%	33,30%	23,30%
Difference	0,009	-0,043	-3,80%	-5,97%	1,70%	-4,36%	-1,11%	3,71%

Table 31, Performance outcome comparison with Climate Studio

3.4 Grasshopper workflow

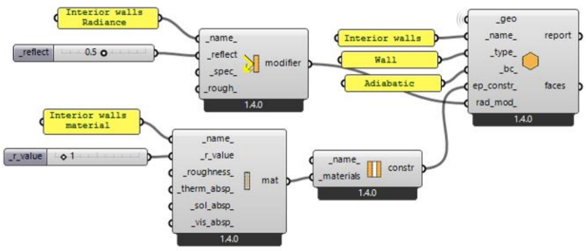
With all the simulations assumptions explained, the last step is to set up the Grasshopper file. This is explained with the help of a flowchart. The flowchart is divided into three parts: setting up the shoebox model, daylight calculation and energy calculation. The entire flowchart can be found in appendix A.

3.4.1 Setting up the model

Shoebox model

To calculate the different energy and daylight variants, a shoebox model will be parametrically modified. A shoebox model is used so that different variants can be evaluated quickly to see which parameters and context have the greatest impact. Using a larger model will only increase the simulation time. The shoebox is created using three dimensions in the x, y and z direction. The box consists of four walls, the floor and the ceiling. The floor, ceiling and three of the four walls are adiabatic boundaries. An adiabatic boundary is one in which there is no heat or mass transfer. It can be seen as an infinite insulation value (buildinggreen, n.d.).

This is done because it is assumed that these building elements are connected to other well-insulated heated spaces. As a result, little thermal transfer between these boundaries will take place. Using the component *honeybee face*, all values are assigned for the opaque construction such as the R-value of the façade and whether it is an adiabatic boundary (figure 38).



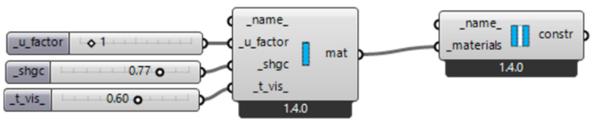


Figure 38, Opaque construction

Figure 39, Window construction

To model the opening, the size determined by the ratio of the glass to the façade (WWR). This is done with the Honeybee component *Apertures by ratio*. The sill height is set to 900 mm and the window height to 1300 mm. For a grid size greater than 3600 mm, the window is divided into two windows. This is more realistic in an office, as daylight will be better distributed in the room. This makes no difference to the energy simulation because the ratio of the opening to the façade remains the same, and therefore the total U-value of the façade will remain the same.

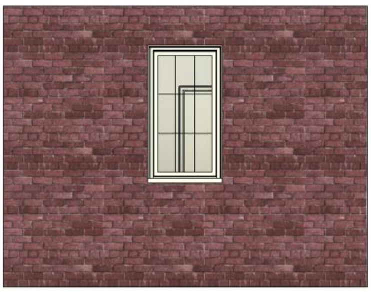


Figure 40, 10% ratio with 3.6 width

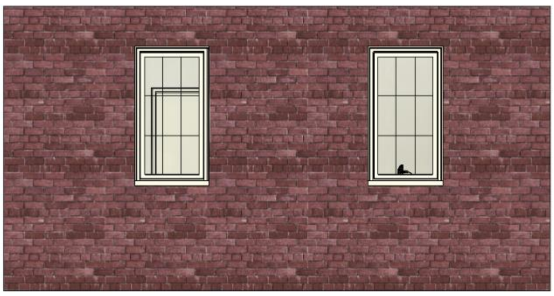


Figure 41, 10% ratio, width 5400 mm

Once this has been determined, the properties of the glazing are assigned in Grasshopper with the *HB window construction* component (figure 39). The assigned properties are the U-factor of the glazing, the solar heat gain coefficient and the visible light transmission coefficient. Since the façade has a certain thickness and will block some of the direct sunlight, a border shade is added around the window with a depth of 300 mm.

Context

To simulate the shoebox in the three environments, three different contexts are added using 3Dbag viewer. With small context models, there is no need to simplify the models for the simulation time. The simulation time will not decrease drastically when simplifying the model. For example, for the apartment building, the 3Dbag model consists of 588 shades and the simplified version of eight shades. However, the simulation time is only 0.22 seconds different.

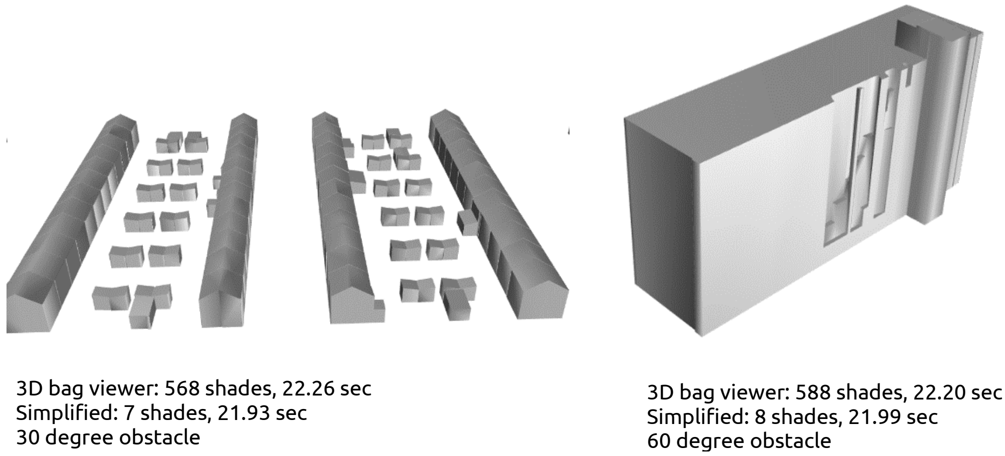


Figure 42, Different kind of context imported with 3D bag in Grasshopper

Grid

The final step for setting up the model is to add a sensor grid. The height at which the grid is placed depends on which performance result is being calculated. For BREEAM 850 mm above the finished floor must be maintained and for LEED this is 800 mm. The distance between the grid points depends on the green certificate and the building code. If only BREEAM is chosen, the formula of EN 17037 can be chosen. For LEED the distance must be less than 600 mm. As the outcome for the variants with the formula of EN 17037 is higher than 600 mm, a distance of 500 mm is used for the comparison of LEED with EN 17037. This distance is chosen because for EN17037 a strip of 500 mm must be subtracted from the wall.

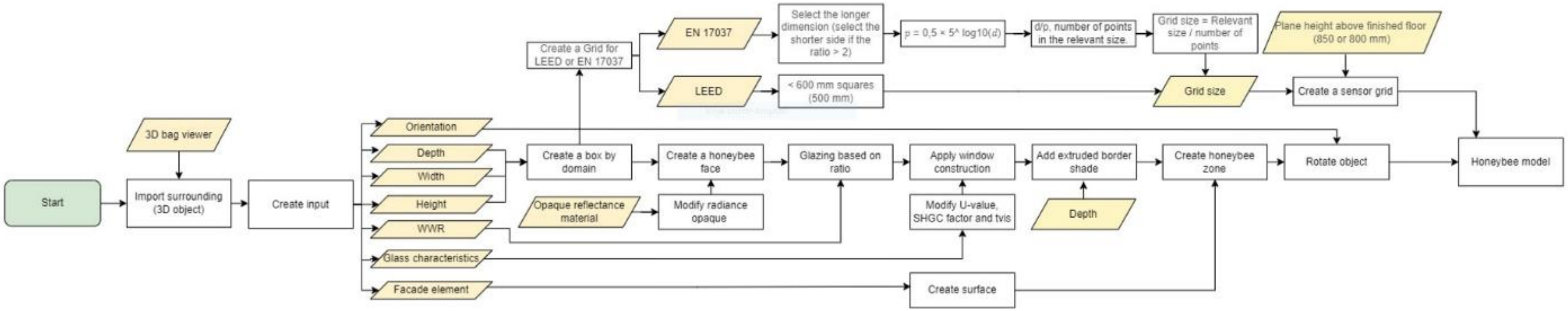


Figure 43, Flowchart part 1 (setting up the model)

3.4.2 Workflow Daylight

Weather file

EN 17037 requires a certain indoor illuminance to be achieved for part of a reference plane for at least half of the daylight hours. Since daylight hours vary from country to country, hourly weather data from the location is used. The weather data from Energyplus is downloaded for this study in Grasshopper. This file contains files with an annual time series of 8760 hours with values for diffuse horizontal illuminance. These values are then ranked from highest to lowest and the highest 4380 hourly values are extracted. Using the highest hourly values, an occupancy schedule is created in which only the availability of daylight in a room is calculated during these 4380 hourly values. The occupancy schedule is used to calculate the annual daylight metrics.

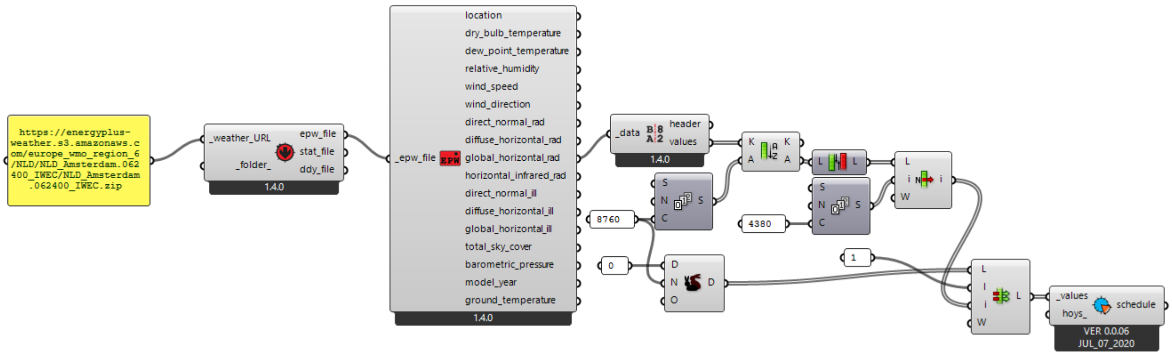
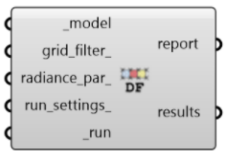


Figure 44, Daylight schedule

For the daylight factor this is based on the availability of diffuse sky light for the location in question. There is no need to create an occupancy schedule anymore, since the outdoor illuminance will always be the same. For the NEN, the Median External Diffuse Illuminance has been used to calculate the daylight factor required to comply with the recommendation levels for the European standard. For Amsterdam is the Median External Diffuse Illuminance 14400 lux.

Daylight factor

In order to meet the daylight requirements for BREEAM and method 1 of EN 17037, the daylight factor will have to be calculated. This is done in Grasshopper with the *HB daylight factor* component. This only requires the input of the model and the grid, as discussed above. The workflow is explained per certificate below:



Daylight factor (DF)
Input:
-Model
-Grid

EN17037 (Method 1) In order to comply with the European standard, 50% and 95% of the grid points are considered to meet the minimum requirements for the different recommendation levels. For the minimum daylight factor (50% of the plane), the results of each grid point are ranked and the highest of half of all grid points is checked to see if it meets the minimum requirements for the daylight factor. This can also be seen in the flow chart below for method one of the European Standard

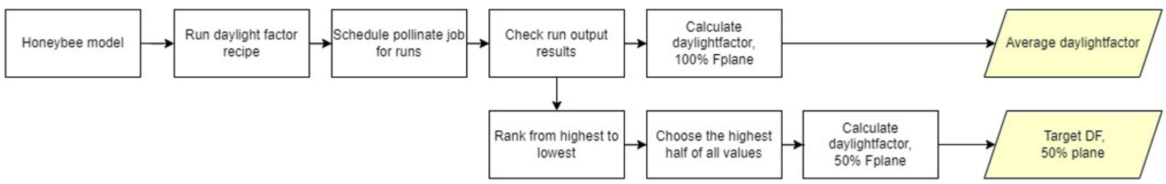


Figure 45, Flowchart EN 17037 (Method 1)

BREEAM For BREEAM, the average daylight factor of the grid must be higher than 2.0%. The uniformity ratio is also calculated in the room by calculating the minimum point daylight factor and comparing it with the average daylight factor. This should be at least 0.3 times the relevant average daylight factor. If this is met, the daylight requirements for BREEAM are met.

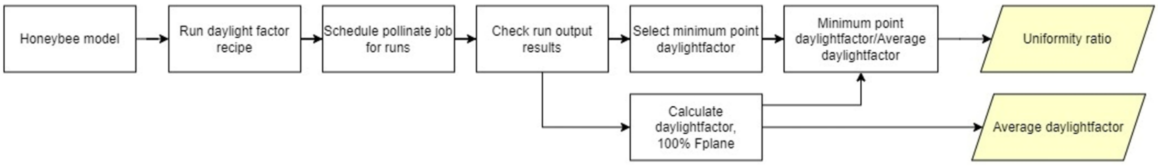
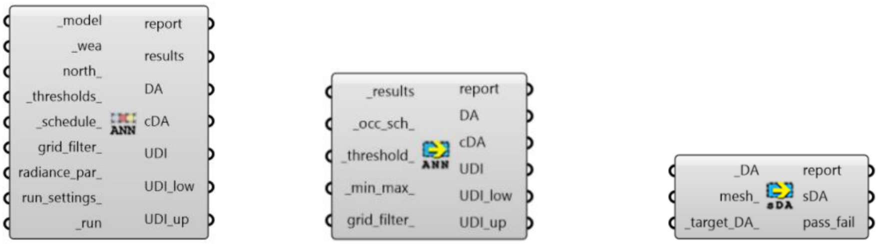


Figure 46, Flowchart BREEAM

EN17037 (Method2) In order to check which daylighting performance level the different variants meet with method 2, an annual daylight recipe in Grasshopper is used. Using the weather input, model, grid and radiance parameters the hourly illuminance for each sensor is calculated. Using the thresholds based on the performance levels of NEN 17037 and the schedule based on the daylight hours, the Daylight Autonomy results are calculated in percentages. The daylight autonomy indicates the percentage of occupied hours that each sensor receives more than the illuminance threshold. The daylight autonomy target is based on the target illuminance level (50% of the reference plane) and the minimum target illuminance level (95% of the reference plane). For the target illuminance, the results for each grid point are ranked and half of all values are included for the target level.



Hourly illuminance
Input:
-Weather (Amsterdam)
- Model
- Grid
- Radiance parameters

Calculate annual daylight metrics from a result
Input:
- Threshold for daylight autonomy in lux (100,300,500,750 lux)
- Occupancy schedule

Calculate spatial daylight Autonomy from list of daylight autonomy values
Input:
- DA
- Target DA: Minimum target value for daylight autonomy

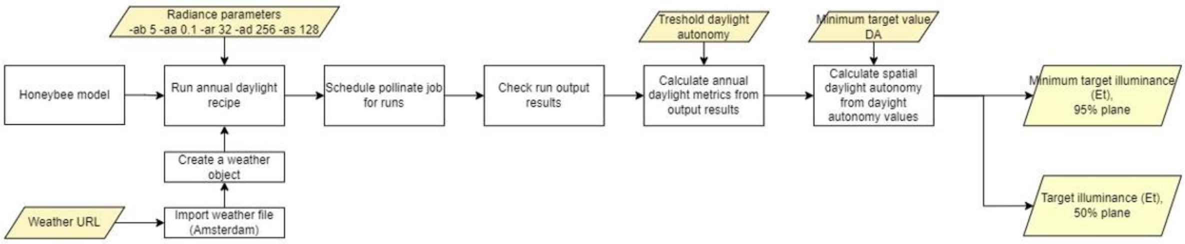


Figure 47, Flowchart EN 17037 (method 2)

LEED (sDA and ASE) To see whether the variants also meet LEED's daylight requirements, the annual daylight recipe is used to calculate sDA and ASE. However, the calculation does not follow exactly the same workflow as for the European standard. For the sDA simulation, the blind schedule must be included in the simulation. The flow chart will consist of two parts where first the ASE is calculated and the results are used for the sDA calculation. A blind schedule has to be created whereby the blinds will close if 2% of all of the grid points receive more than 1000 lux of direct sunlight. Since for ASE, only direct sunlight is considered and no blind schedule is used, the blind schedule is also calculated during this simulation. The only difference with the calculation of the sDA and ASE is that for the ASE calculation, the ambient bounces are set to 0 and for sDA this is set to 5 ambient bounces. As a result, diffuse light is not included in the ASE calculation and only direct sunlight is considered. With these results, the following workflow is used to calculate the ASE in percentage of the floor area and the blind schedule as 8760 values of zeros and ones.

For the second calculation, the hourly illuminance in a room is calculated on the basis of the annual daylight recipe. The radiance settings are reset to five ambient bounces, which means that diffuse light is also included in the calculation. When the blinds are closed, diffuse light can still enter the room. Therefore, a diffuse light transmission distribution of 20% visible light is used for when the blinds are closed. The blinds schedule obtained from the ASE simulation consists of a list of 8760 values consisting of 100% and 20% values representing visible light transmission for the closed and open position of the blinds. This list is multiplied by the results of the hourly illuminance of the room with five ambient bounces. With these results, the daylight autonomy of the room can be calculated by looking at the percentage that the sensors receive in excess of the illuminance threshold. With this percentage, the performance criteria for LEED can be calculated. A total of three points can be achieved. The sDA300/50% value for the regularly occupied floor area must be at least be 75% for 3 points.

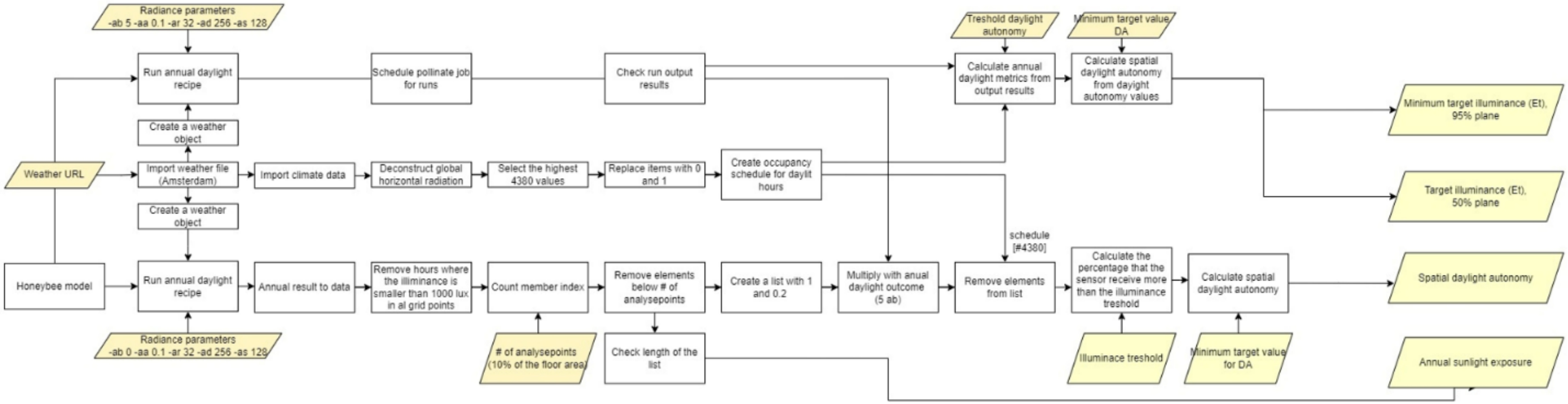


Figure 48, Flowchart LEED

3.4.3 Workflow energy

LEED BASELINE model, For LEED, the base model will first have to be simulated in order to calculate the energy efficiency of the proposed shoebox model. To calculate this, the Grasshopper component *construction set by climate* is used. The input for this component is *vintage: ASHRAE 90.1 2016, climatezone: 4 - Mixed* and *construction type: Mass*. The output of this Grasshopper component is a construction set according to ASHREA 90.1 that can be used for the baseline model. This construction set contains the established values for the construction components, such as the U-value, SHGC and VLT values of the glass.

To create a room to calculate the energy values, a program for the rooms will also have to be created. To make a standard office where the program is based on the ASHRAE 90.1 requirements, the *HB building program component* can be used. For this study the building program: small office in Grasshopper was chosen, which contains a standard program for a standard small office. This program contains information about grids and loads, such as the occupancy load and the infiltration load. These values are based on the ASHRAE 90.1-2016 requirements.

For the climate system of the baseline model, a standard HVAC system can be chosen using the grasshopper component *HB all-air HVAC*. The climate zone and this building type is used to select the HVAC system for the baseline model. For this study, the PSZ-AC with a fossil fuel furnace should be selected. The efficiency is based on ASHRAE 90.1 2016. With the construction set and the HVAC system assigned, the energy consumption can be calculated. With results of the baseline energy calculation, the PCI_t, the unregulated and regulated costs for every variant can be determined. With this PCI_t, the improvement above the code can later be calculated with the corresponding energy efficiency score.

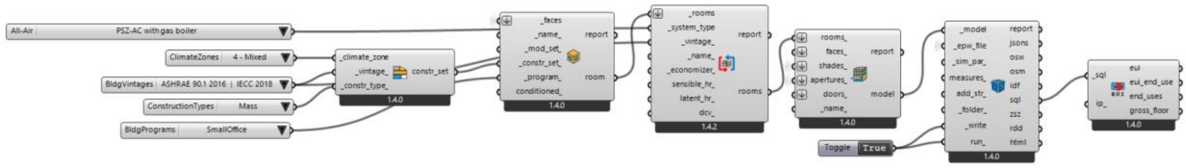


Figure 49, Grasshopper workflow baseline model

BREEAM and LEED, Proposed model: The same workflow can be used for BREEAM and LEED. The difference with the Baseline model is that the HVAC systems are not already designated, but are based on the systems in the proposed design. For the construction set, only the U-values of the construction elements will be changed. For the opaque materials this is an RC value of 8 and for the window the U-value is 1.1 W/mk2 with different SHGC and VLT values . The system type is a ground source heat pump. This can be assigned with the *HB Heatcool HVAC* component. With all systems and loads assigned, just like the baseline model, the energy consumption of the different shoebox models will be calculated. With these values, the improvement beyond code can be calculated for the energy categories of BREEAM and LEED.

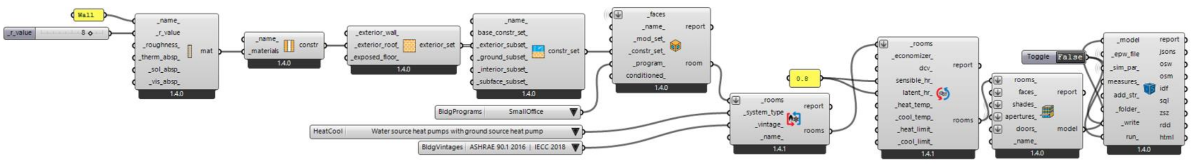


Figure 50, Grasshopper workflow proposed model

HVAC assumptions

For the proposed design, the small office program of ASHREA 90.1 is partly used. The program is taken apart and for infiltration, ventilation, heating setpoints and cooling setpoints the values are changed to the values of more sustainable installations, discussed in 3.1 . The other values are kept the same as the values established in the ASHRAE 90.1. For lighting, the Grasshopper component *daylight control schedule* is used, whereby illuminance setpoint is set at 300 lux. This component creates a daylight control schedule so that the illuminance in the room is always 300 lux. The blind control schedule is taken into account by changing the daylight control schedule to 1 when the blinds are closed, which means that the lights are on. With these schedules, a program can be created for the proposed energy model.

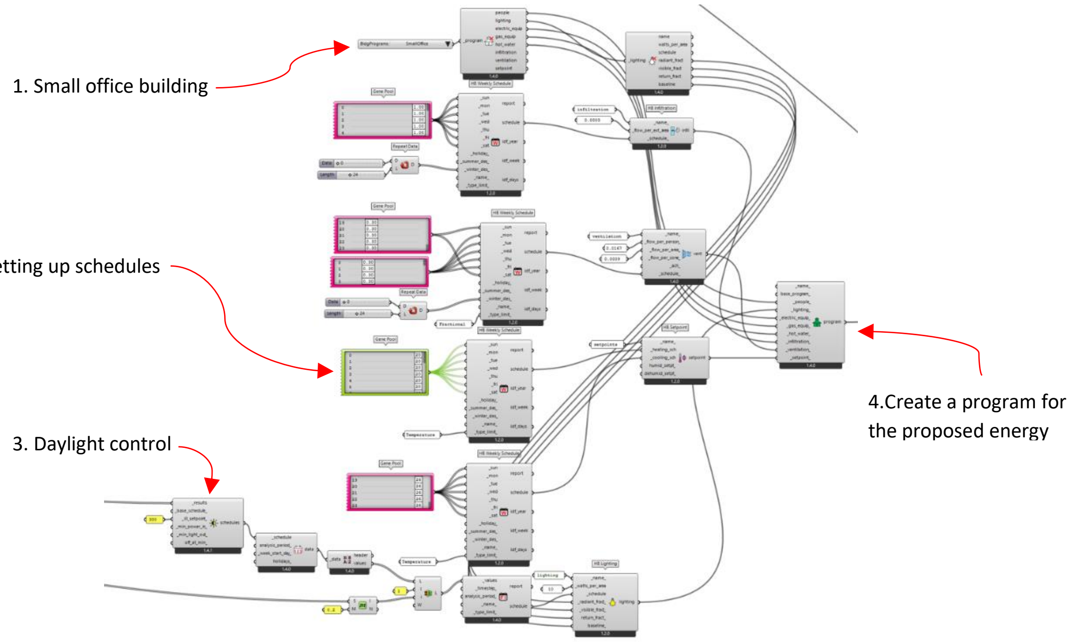


Figure 51, HVAC grasshopper

For BREEAM, the total energy consumption in kWh is compared to the reference value (40 kWh) and points are awarded if the consumption is under the reference value. For LEED, using the proposed building performance and the calculated PCI_t, the improvement beyond code can be calculated and the improvement points will be awarded for the energy efficiency category for LEED.

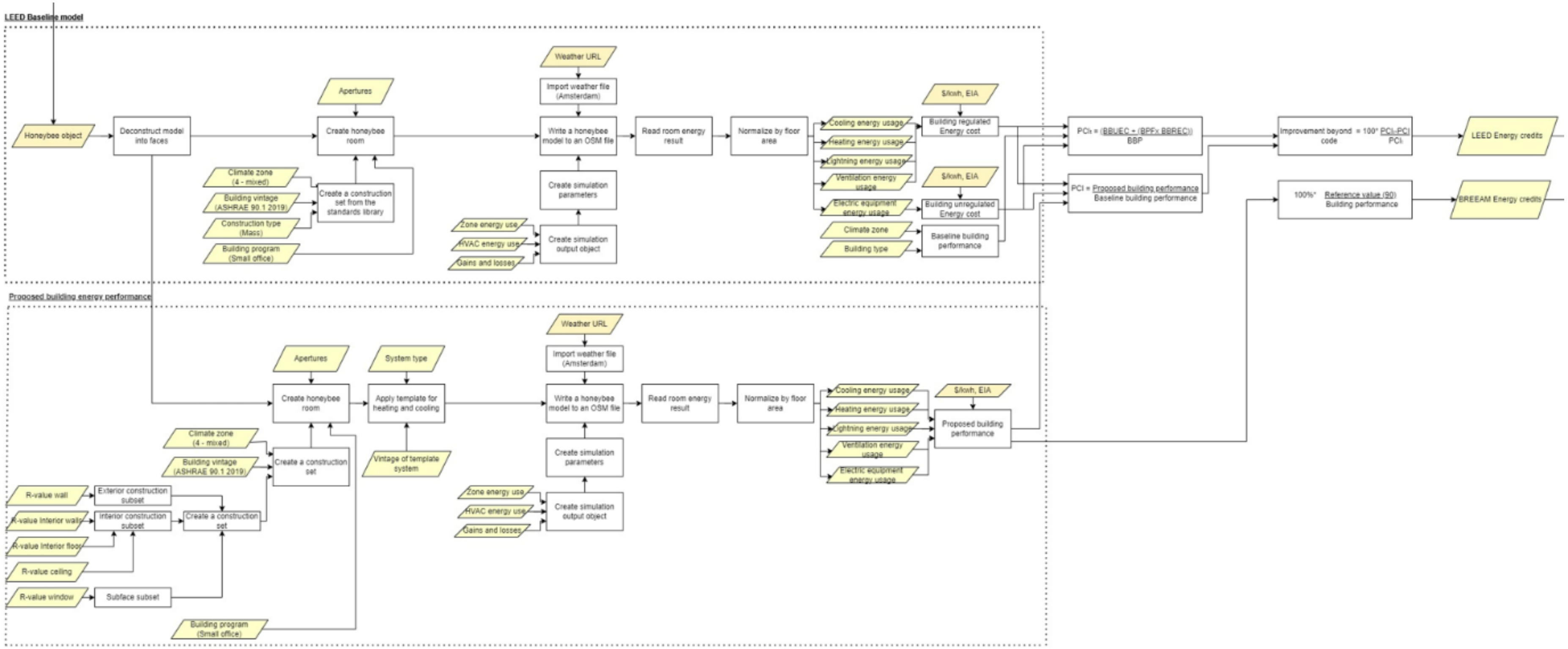


Figure 52, Grasshopper workflow (Energy model)

3.5 Performance measures

Once the shoebox has been made, the materials and systems have been allocated and the correct radiance settings have been set, the different variants can be calculated. Several performance measures will be saved for later analysis. Different performance measures are stored for daylight (method 1), daylight (method2) and the energy calculation. The tables below show what is stored, in which paragraph the performance measurement is explained and which certificate it concerns. For the target and minimum target performance, separate records are made per variant whether the target performance meets the requirements and whether the minimum target performance meets the requirements. This makes it possible to check later whether the shoebox model is too deep and a performance level cannot be achieved or whether the entire room receives not enough daylight.

Measurement		Description	Paragraph	Certificate
1.	Average daylight factor	Average internal illuminance on the reference plane, expressed as a percentage, under a free CIE standard Overcast Sky	2.2.3	**BREEAM**
2.	Uniformity ratio	The ratio between the minimum daylightfactor and the average daylightfactor		
3.	Target daylightfactor	Determined daylight factor for more than 50% of the total work area	2.1.1	**EN 17037**
4.	Minimum target daylightfactor	Determined daylight factor for more than 95% of the total work area		

Table 32,Daylight provision method 1 (EN 17037 and BREEAM)

Measurement		Description	Paragraph	Certificate
1.	ASE$_{1000,250h}$	The percentage of the workspace that receives at least 1000 lux of direct sunlight for at least 250 occupied hours per year.	2.2.2	**LEED**
2.	sDA$_{300,50\%}$	What percentage the work surface receives at least 300 lux for 50% of the occupied time.		
3.	Blind schedule	A list of 8760 hourly values indicating when to close the blinds because 2% of grid points receive more than 1000 lux		
4.	Target illuminance	Defined target illuminance for more than half of the daylight hours, for more than 50% of the total work area	2.1.1	**EN 17037**
5.	Minimum target illuminance	Defined target illuminance for more than half of the daylight hours, for more than 95% of the total work area		
7.	Performance level	Three performance levels for which specific recommendations apply		

Table 33, Daylight provision method 2 (EN 17037 and LEED)

Regarding to the performance measures for energy consumption, different performance measures are calculated for the two different certificates. For BREEAM, only the total energy consumption of the proposed building will give performance credits, but the consumption of the different HVAC components is also interesting to analyze. For LEED, several performance measurements are calculated to determine the improvement beyond code

	Measurement	Description	Paragraph	Certificate
1.	Baseline energy performance	Baseline building total energy performance (kWh)	2.2.5	**LEED**
	Energy use intensity	Consumption of the different HVAC systems for the baseline design		
	BBREC	Baseline building regulated energy cost		
	BBUEC	Baseline building unregulated energy cost		
2.	Proposed building performance	The annual energy performance for the proposed building in kWh		
	Proposed building performance ($)	The annual energy performance for the proposed building in $		
	PCI	Performance cost index		
	Improvement beyond code	Percentage improvement over baseline building	2.2.4/ 2.2.5	**LEED/ BREEAM**
	Proposed building performance (kWh)	The annual energy performance for the proposed building in kWh	2.2.4.	**BREEAM**
	EUI-End Use	Consumption of the different HVAC systems for the proposed design		

Table 34, Energy consumption

3.6 Data collection

After all performance measures of one variant have been calculated, it can be executed parametrically and the different iterations can be exported. This is done using TT-tooblox and Colibri. Using Colibri, all performance measures of the different variants are streamed to an Excel spreadsheet. A csv file is created and a 3D object for visualization as a .json format is created.

3.7 Data analysis

In the next step, after all performance measures for each variant have been collected, the data is analyzed and the characteristics of the data set are summarized. The analyses consist mainly of descriptive statistics. In this process, the data are ordered and the characteristics of the dataset are summarized. This helps to understand and describe the characteristics of the dataset. The first analysis consists of describing the characteristics of the daylight dataset, such as the mean of a performance outcome or the relationship between different performance outcomes. The frequency distribution for certain performance outcomes and parameters are also analyzed and summarized in graphs and tables. These analyses are also done for energy and total points for BREEAM and LEED. The results of these analyses are discussed in the next section.

4 Results

This section presents the results obtained from the simulation runs described in the previous chapter. The daylight results will be discussed first. Second, the energy results are visualized using tables and graphs. Next, the influence of the European standard on the daylight and energy results is examined. Finally, it is investigated how the outcome performance of the different scenarios can be improved by using other parameters.

4.1 Daylight provision

The simulations obtained 12.968 results using different orientations and context, which are described in section 2 and five different parameters: width, depth, window ratio, fixed shading, and glass characteristics. Five performance outcomes for daylight are of interest: SDA, ASE, DF, Uniformity Ratio and the performance level for the European Standard . For the daylight factor, 1621 results were obtained because this method is not affected by the orientation of the model. On the following pages, the overall results for the European Standard, LEED and BREEAM were first analyzed separately and then compared with each other.

4.1.1 EN 17037

It will first be examined whether there are orientations in which rooms do not meet the different recommendation levels of the European standard and whether the orientation has a significant influence on the results.

Figures 53 and 54 show the results of all the variants and how many variants meet the criterion of a certain performance level for EN 17037. Figure 53 and 54 shows that, percentage-wise, more variants score below the minimum performance requirement with method 1(DF) than with method 2 (based on internal illuminance per hour for a typical year). For all variants calculated with method 1, 2% meets the criterion for a high performance level, 6.85% for medium, 22.40% for minimum and 68.64% are below the minimum requirement. For the second method on average across all orientations, 6.16% meets the daylight criterion for a high recommendation level, 9.38% for medium, 27.25% for minimum and 57.21% the amount of daylight is too low to meet the minimum requirement of the European standard.

Figure 54 also shows that the orientation influences the outcome of the second method, albeit very little. Since the simulation does not require the use of blinds, the number of variants that qualify for the high performance level is highest for the south-east and south-west orientation. For south-east, 7.16% qualify for the high performance level and 6.92% for south-west. The northern orientation has the most variants scoring lowest in performance levels, with only 5.06% qualifying for the highest recommendation.

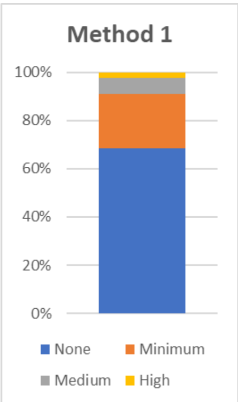


Figure 53, Performance level (Method 1)

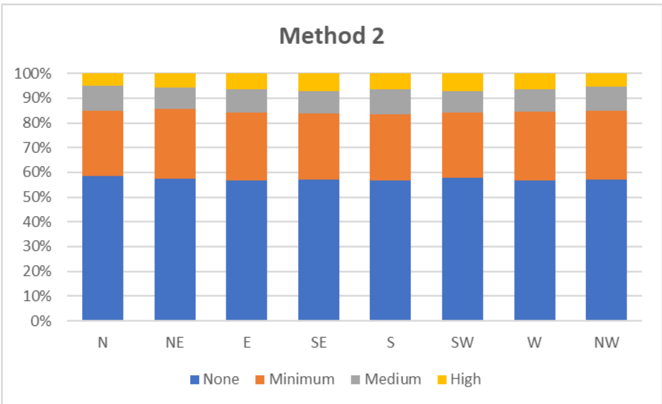


Figure 54, Performance level (Method 2)

As mentioned earlier, there are two methods to calculate the performance level for the European standard. The first method is a simpler method, but the second method gives more accurate results (Kingspan, 2019). To compare the two different methods, the results of method 2 are first sorted according to the performance level achieved and the orientation. With the different variants sorted by performance level and orientation, it is possible to see what the performance level will be, calculated with method 1 compared to method 2. For the medium performance level, calculated with method 2, 32% of the variants with method 1 will reach the same performance level. The same applies to minimum and high, where 57.7% for minimum and 40.5% for high will reach the same performance level with method 1 compared to method 2. Almost no variant scores higher than the performance level calculated with method 2 compared to method 1.

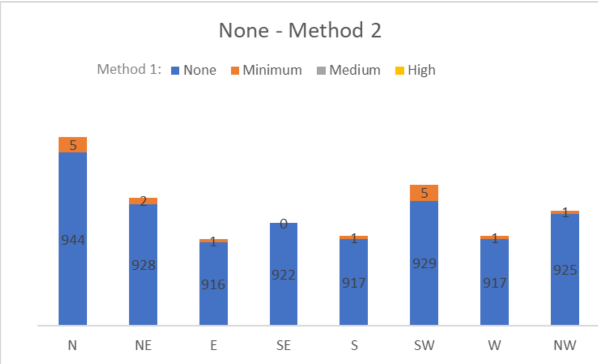


Figure 55, None performance level: method 2, compared to method 1

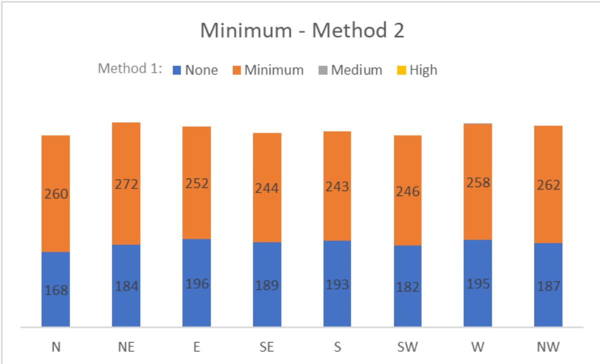


Figure 56, Minimum Performance level method 2, compared to method 1

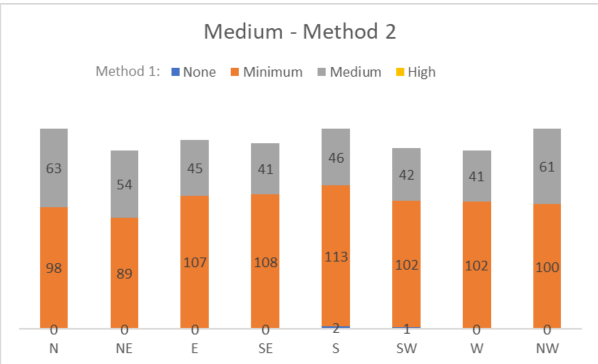


Figure 57, Medium performance level method 2, compared to method 1

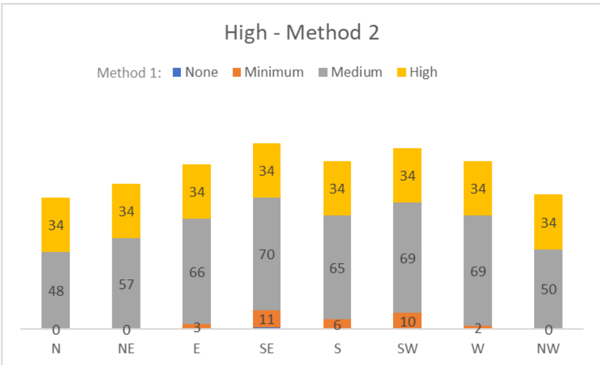


Figure 58, High performance level method 2, compared to method 1

4.1.2 LEED

For LEED, first the average of the SDA and ASE for the different orientations is examined. This makes it clear what most variants score and whether there is much difference between the different orientations.The blinds were included in the calculation for sDA. Figure 59 shows in percentages how many of the variants achieve 3,2,1 and 0 points for the different orientations. The figure also shows that the south-west, south and south-east score the least points compared to the other orientations. The graph shows a different distribution than the previous graph for the European standard. The fewest points are scored here for the south. Figure 60 shows that the blinds are the most closed for these three orientations. This explains the lower scores.

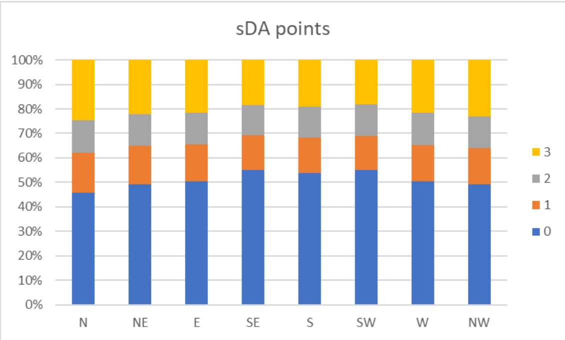


Figure 59, sDA points

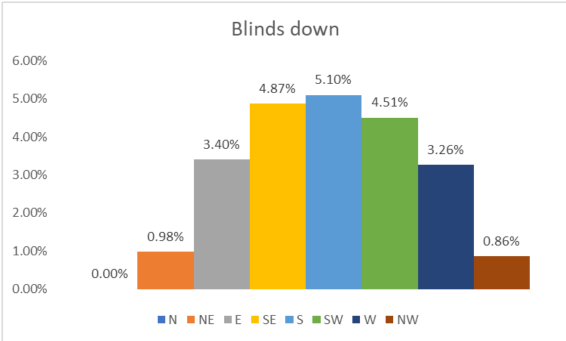


Figure 60, Blinds down schedule

Figure 61 shows the average ASE for all orientation and that for most orientations the ASE is clearly acceptable. Only for the South-East, South and South-West is the ASE above 10%. For the south-east orientation, 30.9% is above 10% ASE, 19.5% for south and 25.9% for south-west. For all other orientations, the ASE is low enough and no additional measures need to be taken. For the East and West orientation, some variants are nominally acceptable. This is where the ASE is between three and seven percent of the surface.

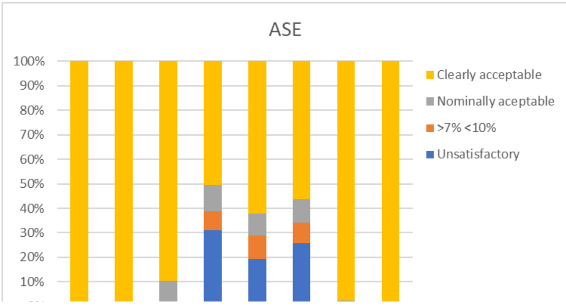


Figure 61, Annual sunlight exposure

4.1.3 BREEAM and Method 1

To achieve the minimum performance level with method 1 for the European standard, the target daylight factor must be 0.7% and the minimum target daylight factor 2.1%. For BREEAM the average daylight factor must be higher than 2% and the uniformity ratio must be equal to or higher than 0.3. Figure 63 shows that 29% of all variants meet the BREEAM's daylighting requirements. When analyzing all the variants, 699 meet the average daylight factor of 2% for BREEAM. However, of the variants in which the average daylight factor is higher than 2%, 474 variants only meet the uniformity ratio higher than 0.3. The variants that meet the high and medium performance level for the European standard also all meet the BREEAM requirements for daylight and uniformity ratio. For minimum performance level of the European standard, 88 out of 363 do not meet the uniformity ratio and 11 do not meet the daylight factor.

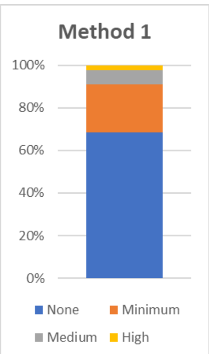


Figure 62, EN 17037 results (method 1)

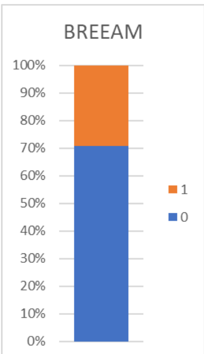


Figure 63, BREEAM results

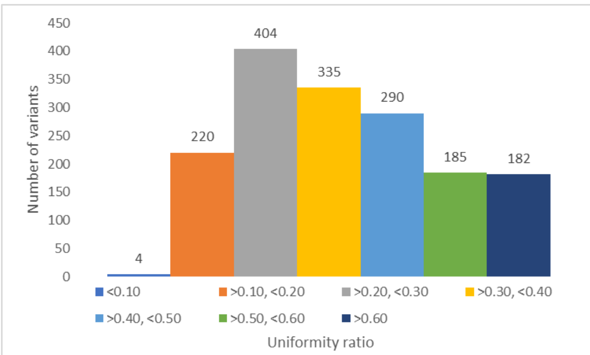


Figure 64, Uniformity ratio

4.2 Energy

This section first examines the overall results for energy consumption of all variants. On the following pages, the total energy consumption will be analyzed, so that it is possible to see later how it can be reduced by using various parameters. The three main performance outcome of the analysis for energy are heating, cooling and lighting. Figure 65 shows the overall energy consumption of all variants. It can be seen that the energy consumption increases when the orientation is changed from north to south. The average energy consumption is the highest for the variants oriented towards the South-East direction. The reason why the energy consumption increases can be seen in figures 66 and 67. Solar heat gains are greater if the building is oriented towards the south, so that the cooling consumption will increase, but the heating consumption will decrease. The decrease in average heating consumption is only less than the increase in average cooling. The lighting will also consume more energy if the room is oriented towards the south. This is because the blinds are down more during the year, so the light stays on to meet the 300 lux requirement in the office.

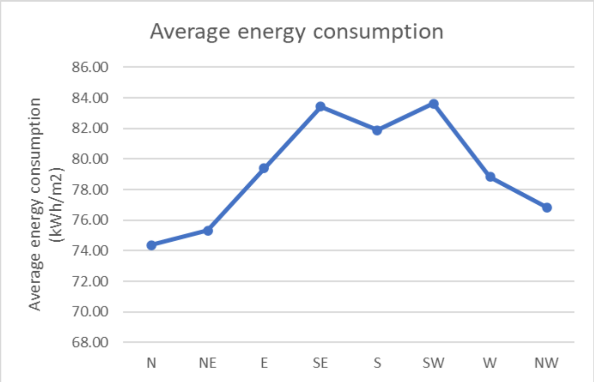


Figure 65, Average energy consumption

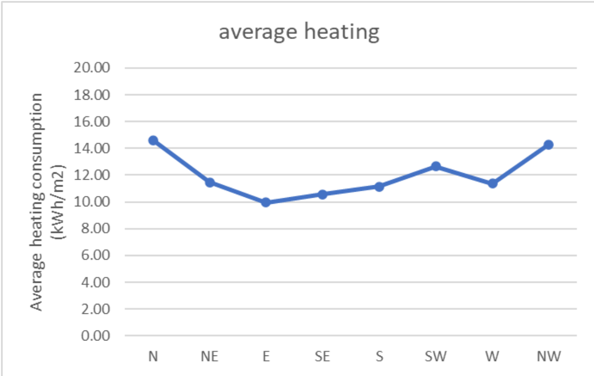


Figure 66, Average heating consumption

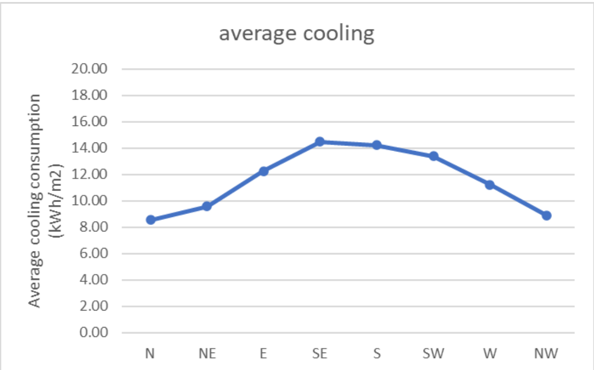


Figure 67, Average cooling consumption

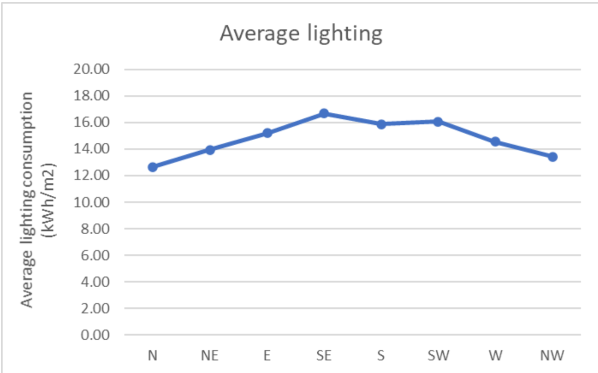


Figure 68, Average lighting consumption

For LEED, the proposed building performance is compared with the baseline model and after that the points for energy can be calculated. Table 42 shows the average, maximum and minimum PCR_t values of all variants. When the energy consumption for the proposed building is lower than these values, points are awarded. The average reference value of all variants to get points for LEED must be lower than 94.5 kWh. Since these values change when the proposed building changes, this value is different for each variant. The maximum baseline value of all variants to improve is 239.35 kWh and the minimum baseline value is 69.72 kWh. This is still less strict than the reference value for BREEAM.

Average PCR	Max PCR	Min PCR	Average (kWh)	Max (kWh)	Min (kWh)
0.66	0.69	0.62	94.50	239.35	69.72

Table 42, Baseline model reference values

4.3 Effect of the European norm on BREEAM and LEED

On the previous pages it became clear that not many variants meet the high recommendation level. This section looks at how the different recommendation levels for the European standard affect LEED and BREEAM. Figure 69 shows the average points of all variants for BREEAM and LEED for daylight provision compared to the recommendation levels for the European standard. If the medium and high daylight provisions requirements for the European standard are met, almost all variants achieve all the points for the green building certificates. For BREEAM the average number of points for all variants is 0.97 for medium and 1.00 for high, where 1 is the highest point achievable. For LEED this is for medium 2.99 and for high 3.00, where 3 is the highest point achievable. For minimum, the average points for LEED are 1.93 and for BREEAM 0.51. Thus, meeting the medium and high recommendation level will also be enough to achieve the maximum number of points for BREEAM and LEED.

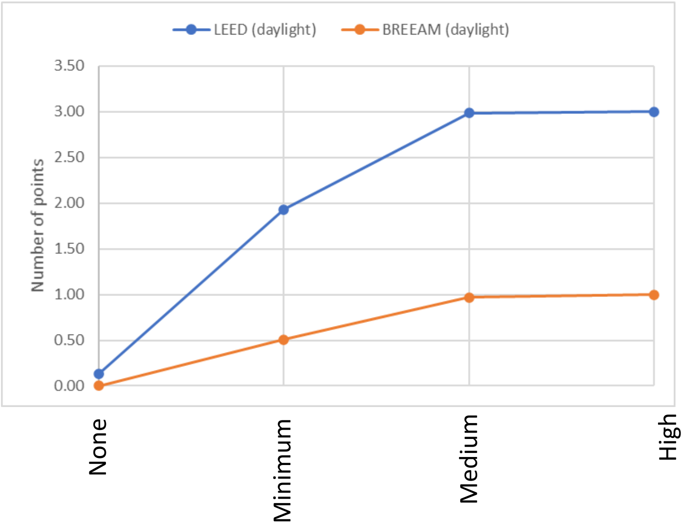


Figure 69, Average LEED and BREEAM points compared to EN 17037 recommendation levels for daylight provision

Since several points can be achieved for LEED, the following part examines what the average sDA is for an orientation, when a certain recommendation level is reached. Since LEED uses a blind scheme and the European standard does not require the use of a blind scheme, the graph shows a different relationship. Below, the two different performance measures are compared. The graph shows the average of the different orientations, the four performance levels for the European Standard for daylight provision, and the percentages of spatial daylight autonomy. Figure 70 shows the average sDA of all variants that meet a given performance requirement for the European standard. The figure shows that when the performance requirements for medium and high are met, a score of 3 points is usually achieved for LEED. The average sDA is 94% of the area when daylighting is sufficient for the medium performance level for the European standard. For the medium variants, there is only 1.6% that does not score three points for LEED. This is due to the orientation and the blind schedule. It is also still possible to achieve an SDA above 75% with a minimum performance level for the European standard. Although the average of all variants is below 3 points.

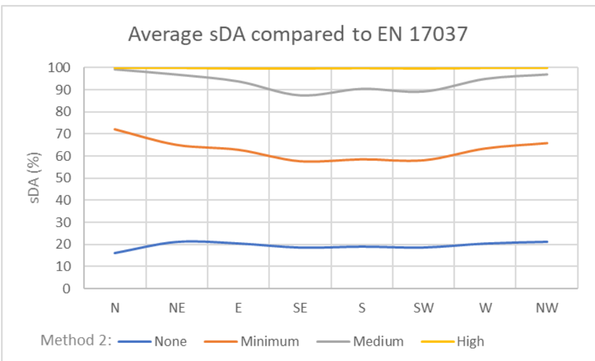


Figure 70, Average sDA compared to EN 17037

Figures 71 and 72 show the average and maximum ASE of all variants. These values are divided into how well they score for the European standard for daylight provision. The graph clearly shows that the higher the performance level, the higher the ASE will be. This is due to the higher window-to-wall ratio the variants need to have to meet the European standard. Figure 71 also shows that most of the variants that comply with medium and high and have an orientation between 90 and 215 degrees, the ASE is unsatisfactory for the user of the building. Figure 72 also shows that even though there is not enough daylight to meet the minimum performance level, the ASE can still be too high. However, for each performance level there are also variants with an ASE of 0. This is for example for a room of 3.6x3.6 m and a 1.2 meter fixed shading in front of the facade. Various parameters can be adjusted in order to meet the high recommendation level, but also keeping the ASE as low as possible.

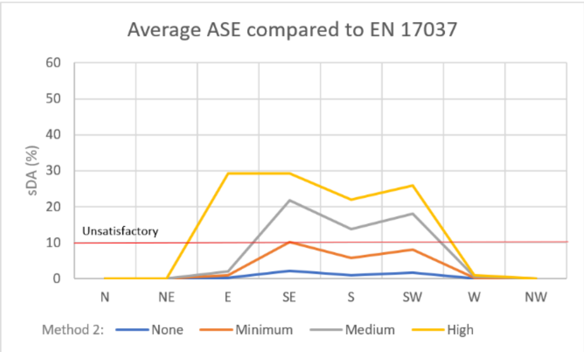


Figure 71, Average ASE compared to EN 17037

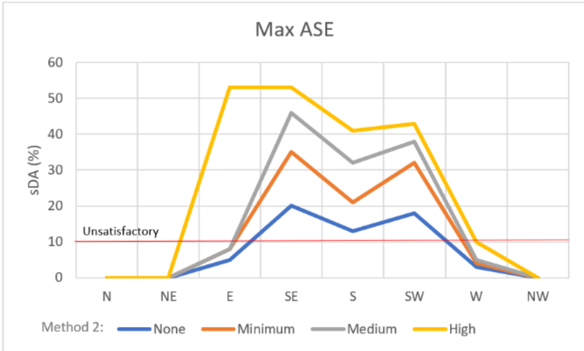


Figure 72, Maximum ASE compared to EN 17037

To see how much influence, the European standard has on the energy points for LEED and BREEAM , the average energy consumption of a variant that meets a certain performance level for EN 17037 is examined. Below are the different performance levels broken down into the three performance levels mentioned in the European norm and one for the variants where the daylight provision is not enough for the minimum performance level (None). The figure shows that the higher the performance level is, the higher the average energy consumption of all the variants will be. Compared to the variants below the minimum performance level, the heating consumption increases by 1.83 kWh/m^2 and the cooling consumption by 0.89 kWh/m^2. If the average energy consumption of Medium is compared with minimum, the energy consumption increases by 3.79 kWh/m^2 for heating and 0.89 kWh/m^2 for cooling. The biggest increase can be seen between medium and High where the cooling consumption increases by 4.74 kWh/m^2 and heating consumption by 1.2 kWh/m^2. The cooling and heating consumption increases because the window-to-wall ratio will be higher. When the window-to-wall ratio increases, the U-value of the total façade will increase, which will also lead to an increase in heating consumption. The cooling consumption will also increase, because when the WWR increases, the amount of solar loads increases. The average energy costs for lighting go down with a higher performance level for EN 17037. However, the reduction in energy costs is less than the increase for cooling and heating. Comparing the medium and high recommendation level, the lighting consumption will also increase a little bit because the blinds are closed more often.

- Minimum

Cooling: + 1,83 kWh/m^2
Heating: + 3,9 kWh/m^2
Lighting: - 2,9 kWh/m^2

- Medium

Cooling: + 0,89 kWh/m^2
Heating + 3,79 kWh/m^2
Lighting: -0,35 kWh/m^2

- High

Cooling: + 1,20 kWh/m^2
Heating: + 4,74 kWh/m^2
Lighting: + 0,19 kWh/m^2

Table 43, Increase in HVAC consumption compared to the previous recommendation level

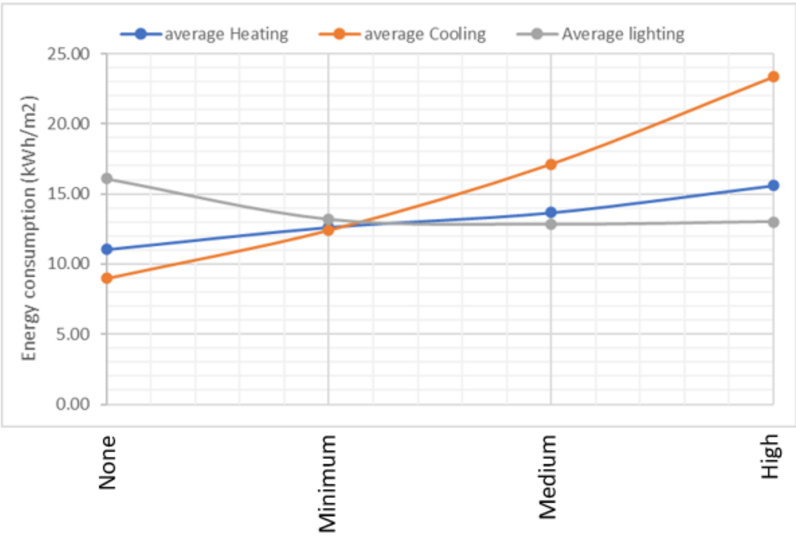


Figure 73, HVAC energy consumption compared to EN 17037 recommendation levels

- Minimum

Total + 2,11 kWh/m^2

- Medium

Total + 5,40 kWh/m^2

- High

Total + 8,33 kWh/m^2

Table 44, Increase in energy consumption compared to the previous recommendation level

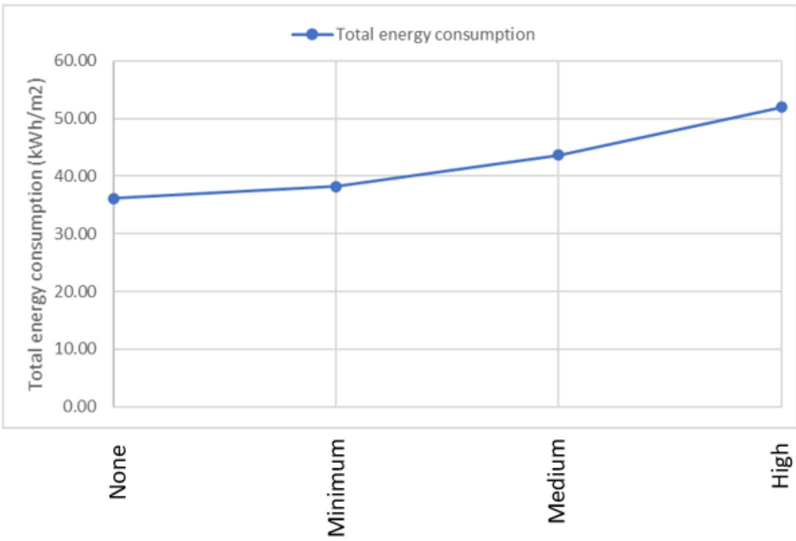


Figure 74, Total energy consumption compared to EN 17037 recommendation levels

Table 44 showed that the average energy consumption increases when the variant meets a higher recommendation level. Table 45 shows the average points compared to the recommendation level. For LEED, the average number of points increases up to medium and then decreases again at high. This can be explained by the fact that the variants of medium and minimum have other surface areas than the variants below minimum. Therefore, the baseline reference value is different and despite the higher energy consumption the points will still go up. BREEAM is more reliable to analyze as the reference value remains the same. For BREEAM, which is based on a fixed reference value, the number of points will only decrease when a higher recommendation level is scored. When using relatively efficient heating and cooling systems, such as a heat pump, the designer will not lose many points.

<u>BREEAM</u>
Minimum
- 1.01 points
- Medium

-0.66 points
- High

-0.43 points

<u>LEED</u>

- Minimum

- 1.01 points
- Medium

-0.66 points
- High

-0.43 points

Table 45, Increase in points compared to the previous recommendation level

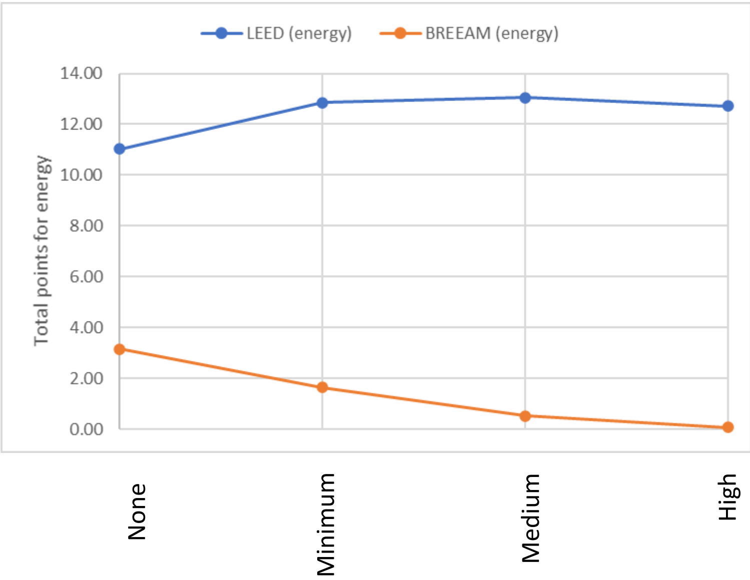


Figure 75, Average LEED and BREEAM energy points compared to EN 17037 recommendation levels for daylight provision

4.4 Influential parameters

In the previous sections it became clear that the European recommendation levels for daylight provision influence the daylight and energy catogory for BREEAM and LEED. In order to see which parameters are important to achieve a certain performance level for the European norm, the parameters of the variants that meet a certain performance level are analyzed. It is also examined if a negative influence on BREEAM and LEED can be avoided or reduced by using other parameters. Tables 35-37 show the three performance levels with all parameters, orientations and context of the variants. The red colored parameters, context and orientations are the parameters that do not occur in all variants for the chosen recommendation level. As an example, for a minimum performance level, there are no variants that have a WWR of 0.1 and 0.2 (table 37). Based on the three tables, the width/depth ratio and the window-to-wall ratio are the most important parameters. These are the red colored parameters. The context also has a profound influence on the final performance level. For the high performance level, there are no variants that meet these criteria if the width/depth ratio is equal to or greater than 0,5 or 0,67. This equates to a size of 3,6x5,4 m, 3,6x7,2 m or 3,6x7,2 m. The room is too deep to receive 500 lux for 95% of the reference plane. For the WWR, this should not be less than 0.4 and for context, an apartment block will block too much light. Consequently, the criteria for the high performance level cannot be met. For the performance level medium, the WWR shall not be less than 0.3 and the width to depth ratio shall not be greater than 0,5. For the minimum performance level, only the variants with a window-to-wall ratio lower than 0.3 are not sufficient.

High							
Width	Depth	Width/de	WWR	Orientation	VLT	Shading	Context
3600	3600	0,5	0,1	N	0,68	0	0
5400	5400	0,67	0,2	NE	0,77	1	1
7200	7200	0,75	0,3	E		2	2
		1	0,4	SE			
		1,33	0,5	SE			
		1,5	0,6	SW			
		2	0,7	W			
			0,8	NW			
			0,9				
			0,95				

Table 35, Different parameters for the high performance level

Medium							
Width	Depth	Width/de	WWR	Orientatio	VLT	Shading	Context
3600	3600	0,5	0,1	N	0,68	0	0
5400	5400	0,67	0,2	NE	0,77	1	1
7200	7200	0,75	0,3	E		2	2
		1	0,4	SE			
		1,33	0,5	SE			
		1,5	0,6	SW			
		2	0,7	W			
			0,8	NW			
			0,9				
			0,95				

Table 36, Different parameters for the medium performance level

Minimum							
Width	Depth	Width/de	WWR	Orientatio	VLT	Shading	Context
3600	3600	0.5	0.1	N	0.68	0	0
5400	5400	0.67	0.2	NE	0.77	1	1
7200	7200	0.75	0.3	E		2	2
		1	0.4	SE			
		1.33	0.5	SE			
		1.5	0.6	SW			
		2	0.7	W			
			0.8	NW			
			0.9				
			0.95				

Table 37, Different parameters for the minimum performance level

Tables 46 and 47 show the parameters of the top 2% of all variants scoring best for BREEAM and LEED. For BREEAM it can be seen that some parameters for width, depth and context are missing. The width/depth ratio is between 0.75 and 1.33. For a room too deep, the uniformity ratio will not be enough and when the floor ratio compared to the facade area is too high, the heating and cooling loads will increase. For context, only context 0 appears in the parameters. For LEED, only Width/depth ratio greater than one, WWR ratio lower than 0.3 and North orientation are missing.

BREEAM								
Width	Depth	Width/de	WWR	Orientation	VLT	SHGC	Shading	Context
3600	3600	0,5	0,1	N	0,68	0,37	0	0
5400	5400	0,67	0,2	NE	0,77	0,6	1	1
7200	7200	0,75	0,3	E			2	2
		1	0,4	SE				
		1,33	0,5	SE				
		1,5	0,6	SW				
		2	0,7	W				
			0,8	NW				
			0,9					
			0,95					

Table 46, Parameters for the top 2% for BREEAM

LEED								
Width	Depth	Width/de	WWR	Orientatio	VLT	SHGC	Shading	Context
3600	3600	0,5	0,1	N	0,68	0,37	0	0
5400	5400	0,67	0,2	NE	0,77	0,6	1	1
7200	7200	0,75	0,3	E			2	2
		1	0,4	SE				
		1,33	0,5	SE				
		1,5	0,6	SW				
		2	0,7	W				
			0,8	NW				
			0,9					
			0,95					

Table 47, Parameters for the top 2% for LEED

In the following section, the influence of various parameters on the daylight performance measures is examined. For this purpose, a standard office was chosen with dimensions of 5.4 meters by 5.4 meters with a window-to-wall ratio of 60%. The performance outcome with these parameters is seen as 0 and when some of the parameters are changed of the reference office, the performance outcome will change and the change range is than calculated. For the reference office, the following other parameters and a context were chosen as zero point.

Width	Depth	Height	Orientatie	VLT	SHGC	WWR	Shading	Context
5400	5400	2600	180	0,77	0,60	60%	0	1

Table 38, Parameters reference office

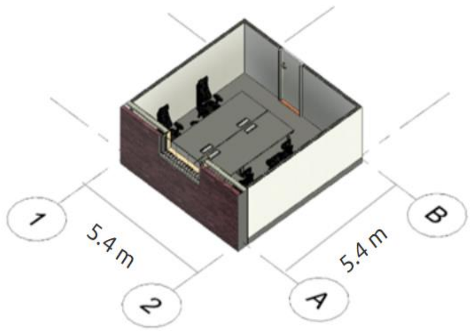


Figure 76, Reference office

To investigate the influence of the parameters, one parameter is slowly increased and decreased for each variant. The results of the various daylight performance measures are recorded in a table. For example, to examine the influence of the depth of the building, the parameters are first increased from 3.6 meters to 5.4 meters and finally increased to 7.2 meters, as shown in table 39. The 5.4 meter is seen as standard and it is examined what the difference is in outcome performance if this is increased to 7.2 meter. By tracking the results, the degree of change can be studied. For the sDA, changing the depth from 5.4 meters to 3.6 meters will improve the sDA by 59.92%.

Depth									sDA		ASE		EN 17037		AVG		UNI		EN 17037 (DF)	
5400	3600	2600	180	0,77	0,60	60%	0	1	85	-59.92%	17	-41.67%	2	-100.00%	17	-402.96%	0.43	-95.45%	2	-100.00%
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	1	0.00%	3.38	0.00%	0.22	0.00%	1	0.00%
5400	7200	2600	180	0,77	0,60	60%	0	1	37.5	29.44%	8	33.33%	0	100.00%	2.35	30.47%	0.16	27.27%	0	100.00%
									Min	-59.92%		-41.67%		-100.00%		-402.96%		-95.45%		-100.00%
									Max	29.44%		33.33%		100.00%		30.47%		27.27%		100.00%
									Change range	89.37%		75.00%		200.00%		433.43%		122.73%		200.00%

Table 39, Sensitivity analysis of the depth of a room on different outcome

Table 39 show that sDA is most affected by the window-to-wall ratio and the depth of a room. The sDA will increase from 3.13% to 60.94% when changing the window-to-wall ratio from 10% to 95% with increments of 10%. The table also shows that sDA changes the most between the WWR of 0.10 and 0.60. After that, the sDA percentage will increase less because the glass surface is below the reference plane.

ASE is influenced by various parameters. The orientation has the biggest influence on the ASE as can be seen in the graphs of section 4.1.2. The other parameters that also have a profound influence are context, shading and window to wall ratio. This is because these parameters and context can block a lot of direct sunlight. Depth and the width do not have much influence on direct sunlight since direct sunlight only enters the room near the façade.

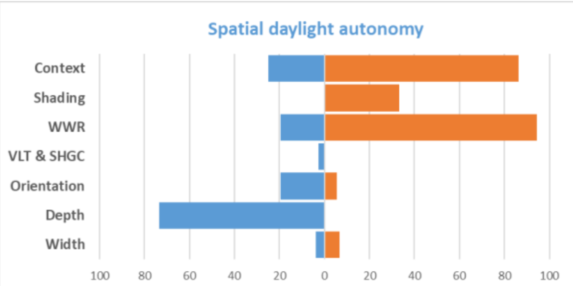


Figure 77, Sensitivity result spatial daylight autonomy

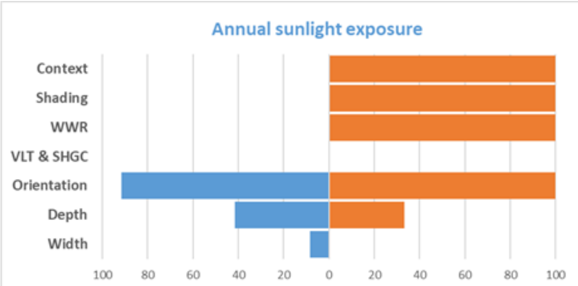


Figure 78, Sensitivity result Annual sunlight exposure

The sensitivity results for the average daylight factor and the uniformity ratio are shown below. The average daylight factor is most influenced by the window to wall ratio with the largest changes occurring between the WWR of 0.10 and 0.60. The uniformity ratio is influenced most by the depth of the room. The context of the design and the length of the fixed shading in front of the façade also influence the uniformity ratio. Daylight does not penetrate too far into the room which further reduces the minimum daylight factor point and therefore the uniformity ratio.

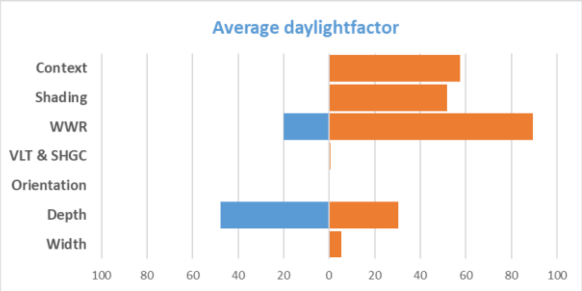


Figure 79, Sensitivity result average daylight factor exposure

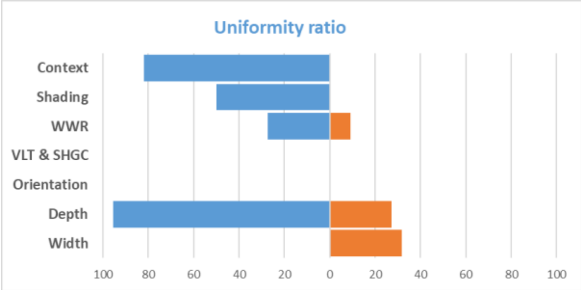


Figure 80, Sensitivity result uniformity ratio

For heating, cooling and lighting, the influence of different parameters is also investigated. Using the same reference office, the extent to which the performance measures change when one parameter is changed, is examined. Figures 81 and 82 show that the heating and cooling are most influenced by the orientation. This became also clear in paragraph 4.2 where the energy consumption is highest in a room oriented to the South. Figure 83 shows that the lighting is influenced most by the orientation of the room and the window to wall ratio. Since the orientation of a space often cannot be easily changed in a design because the building is placed on a designated site, the following pages look at what can be done to keep the performance outcome as low as possible. The following pages look at what can be done to keep the performance outcome as low as possible

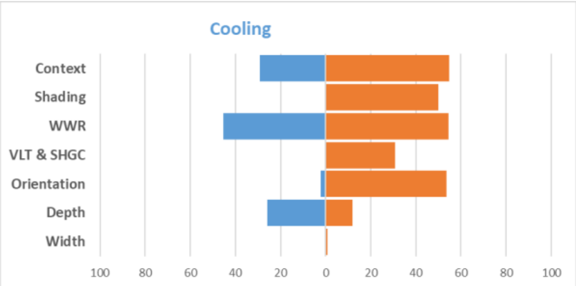


Figure 81, Sensitivity result cooling

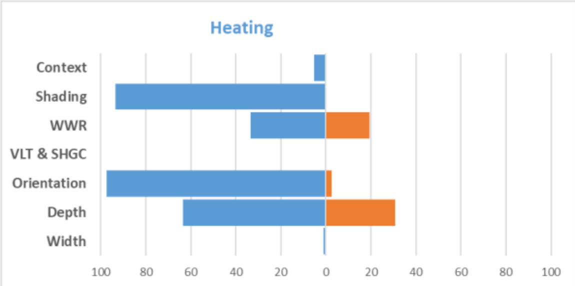


Figure 82, Sensitivity result heating

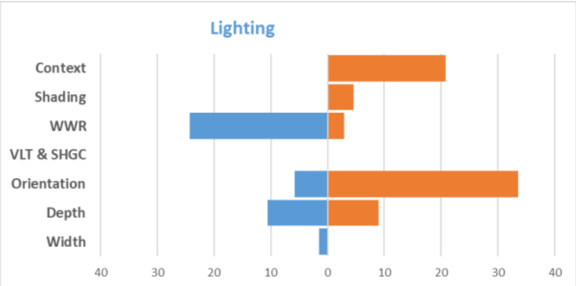
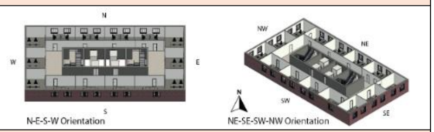


Figure 83, Sensitivity result lighting

- Width depth ratio

Figure 77-80 on the previous page clearly shows that the width of the room does not have much influence on the various daylight performances. Depth, on the other hand, has a major influence on the daylight outcome. In order to better analyse this parameter, the width/depth ratio is analysed. There is a clear correlation that daylight performance increases when the width/depth ratio increases. For example, sDA goes from 31.28% to 72.94% by increasing the width/depth ratio from 0,5 to 2. The reason why the daylight perforance outcome correlation is not linear can be explained by the fact that depth is the most important parameter for the performance outcome fordaylight. The sDA of the width/depth ratio of 0.67 is higher than 0.75, but to be lienar it must be lower. This is because the depth of w/d ratio of 0.67 is 5.4 m and of 0.75 it is 7.2 m. The daylight factor and the recommendation level for the European standard will also increase when the width/depth ratio increases. However, a higher width/depth ratio has a negative effect on the ASE and total energy consumption, since more direct sunlight will fall on the total surface in percentage terms. A high width/depth ratio has a negative effect on energy consumption. The area of the façade compared to the floor is larger at a 2 width/depth ratio than at 0,5 and will cause the cooling and heating consumption to increase. With a ratio of 0,5, the heating and cooling consumption is at its lowest, but the total lighting load will increase. However, this is less than the increase in cooling and heating consumption. Therefore, a balance will have to be found in the width/depth ratio to achieve a good result for energy and daylight performance measures.

Width/depth ratio												
Total												
Width	Depth	W/D	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
3,6	7,2	0,50	31,28	1,73	1,39	0,18	11,33	8,54	16,51	75,16	2,97	11,74
3,6	5,4	0,67	46,23	2,75	1,87	0,50	11,66	11,63	14,80	80,62	1,86	12,50
5,4	7,2	0,75	31,79	1,46	1,45	0,18	11,12	8,24	16,38	72,69	3,68	12,14
3,6/5,4/7,2	3,6/5,4/7,2	1,00	48,50	2,18	2,13	0,58	11,44	11,74	14,76	78,94	2,75	12,75
7,2	5,4	1,33	50,41	2,47	2,08	0,60	11,30	11,27	14,66	75,36	3,41	13,34
5,4	3,6	1,50	70,29	3,60	2,94	1,25	12,19	16,64	13,28	87,48	1,33	13,71
7,2	3,6	2,00	72,94	4,18	3,16	1,36	12,22	16,57	13,26	84,80	1,88	14,31
Context 00												
Width	Depth	W/D	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
3,6	7,2	0,50	44,59	2,98	1,98	0,48	13,92	7,58	16,05	77,33	2,48	12,62
3,6	5,4	0,67	64,52	4,54	2,66	0,98	15,27	10,36	14,51	84,14	1,68	13,56
5,4	7,2	0,75	45,26	2,57	2,05	0,52	13,55	7,40	15,93	74,77	3,24	13,03
3,6/5,4/7,2	3,6/5,4/7,2	1,00	65,79	3,70	3,01	1,13	14,82	10,58	14,51	82,33	2,56	13,77
7,2	5,4	1,33	71,39	4,24	2,93	1,19	14,67	9,87	14,52	78,53	3,10	14,57
5,4	3,6	1,50	84,42	6,27	4,16	2,09	17,24	14,70	13,43	92,89	1,34	14,51
7,2	3,6	2,00	85,56	7,06	4,44	2,17	17,30	14,63	13,52	90,36	1,74	15,03
Context 01												
Width	Depth	W/D	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
3,6	7,2	0,50	29,44	2,21	1,46	0,06	11,81	7,79	17,27	76,04	2,63	11,74
3,6	5,4	0,67	43,89	3,72	1,97	0,44	12,22	10,66	15,42	81,41	1,48	12,65
5,4	7,2	0,75	29,62	1,81	1,48	0,01	11,58	7,60	17,16	73,65	3,30	12,04
3,6/5,4/7,2	3,6/5,4/7,2	1,00	46,48	2,82	2,25	0,46	11,96	10,64	15,34	79,48	2,53	13,02
7,2	5,4	1,33	45,53	3,17	2,15	0,46	11,81	10,17	15,33	75,94	3,07	13,42
5,4	3,6	1,50	70,79	4,53	3,13	1,15	12,78	15,19	13,65	87,77	1,41	14,24
7,2	3,6	2,00	72,85	5,49	3,38	1,28	12,80	15,15	13,65	85,15	1,83	14,84
Context 02												
Width	Depth	W/D	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
3,6	7,2	0,50	19,81	0,00	0,73	0,01	8,27	10,24	16,21	72,11	3,80	10,87
3,6	5,4	0,67	30,28	0,00	0,97	0,07	7,49	13,88	14,47	76,31	2,41	11,30
5,4	7,2	0,75	20,48	0,00	0,80	0,00	8,24	9,72	16,04	69,65	4,49	11,35
3,6/5,4/7,2	3,6/5,4/7,2	1,00	33,24	0,02	1,12	0,15	7,53	14,00	14,43	75,01	3,18	11,47
7,2	5,4	1,33	34,32	0,00	1,14	0,15	7,42	13,77	14,15	71,62	4,07	12,03
5,4	3,6	1,50	55,66	0,00	1,53	0,52	6,56	20,04	12,77	81,77	1,25	12,39
7,2	3,6	2,00	60,41	0,00	1,65	0,64	6,56	19,94	12,61	78,89	2,06	13,07



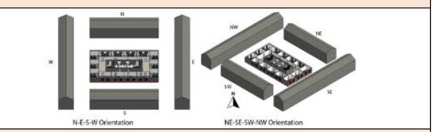
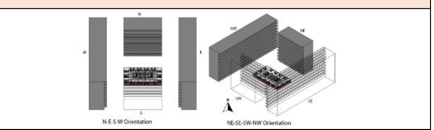



Table 41, Width/depth ratio and the influence on daylight performance measures

Figure 84 shows again that the deeper the room the lower the daylight provision will be, but will have a positive effect on ASE and total energy consumption. The wider the room the higher the daylight provision, but the ASE will also be higher and there is more heat loss and heat gains during the summer and the winter.

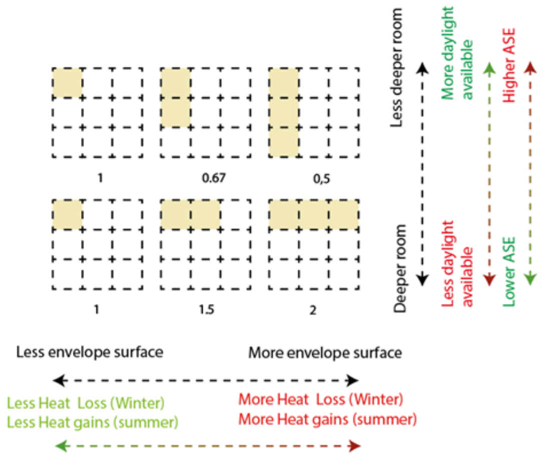
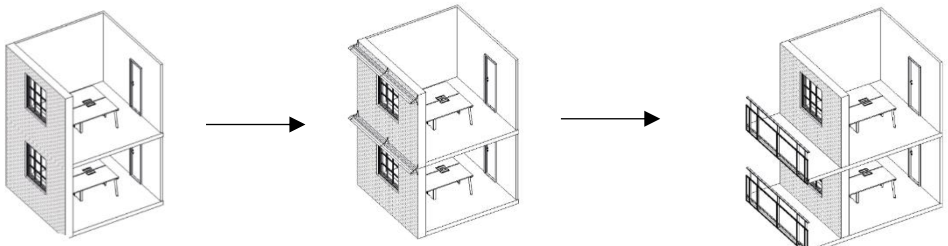


Figure 84, Width/depth ratio

- Fixed shading device

To see if even more energy can be saved, two external fixed shading devices are used. However, this can reduce the availability of daylight, increase the need for artificial lighting and block favourable solar radiation in the winter. In this study, no fixed shading and 2 different fixed shading systems were included to see if this has a positive influence on the total points for BREEAM and LEED.



1. No fixed shading 2. Small fixed shading (0,3 m) 3. Significant fixed shading (1,2 m)

Below are the results for the performance outcome for daylight and energy consumption of the different scenarios. At the top of the table the total average of all scenarios can be seen. Below, it is divided into different contexts. When the small fixed shading is compared to the situation where no fixed shading device is used, the daylight provision in the room will not drop dramatically. For example, the sDA will only decrease by 0.83%. The total energy consumption will also decrease by 1.17 kWh/m2 . If a significant fixed shading is used, the energy consumption will decrease even more, but this will also have a considerable impact on the daylight provision in the room. The biggest impact on the ASE is when a large shading device is used.

Shading										
Total										
	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
1	52,70	3,62	2,55	0,73	12,99	11,00	14,79	80,37	2,55	13,42
2	51,87	3,20	2,30	0,69	12,17	11,18	14,74	79,20	2,65	13,31
3	44,91	0,76	1,57	0,51	9,54	13,86	14,86	78,07	2,60	11,93
Context 00										
	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
1	67,25	5,94	3,59	1,27	17,07	10,31	14,77	85,41	2,12	13,98
2	67,38	5,40	3,25	1,27	16,09	10,06	14,65	83,54	2,29	14,12
3	63,08	1,57	2,24	1,06	12,31	11,72	14,41	79,38	2,68	13,44
Context 01										
	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
1	52,39	4,90	2,81	0,67	13,89	10,14	15,36	81,72	2,21	13,62
2	50,96	4,20	2,48	0,60	12,87	10,19	15,32	80,18	2,36	13,54
3	40,50	0,70	1,48	0,33	9,54	12,49	15,49	77,57	2,53	12,17
Context 02										
	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
1	38,47	0,02	1,24	0,26	8,03	12,54	14,25	73,99	3,31	12,67
2	37,27	0,00	1,16	0,21	7,56	13,30	14,26	73,87	3,30	12,28
3	31,15	0,00	0,99	0,14	6,78	17,36	14,67	77,27	2,58	10,20

Table 42, shading

In figure 85 and 86 the results of the 3 different contexts are separated to see the influence of the parameter on the different scenarios. Figure 85 shows that for each scenario the sDA will decrease when a fixed shading device is used in front of the facade. The energy consumption will not always decrease with the different scenarios. When using a large obstruction for fixed shading in an environment where the sunlight is blocked by buildings the size of an apartment building, the energy consumption will increase a little bit. This has to do with the fact that the favourable solar radiation in the winter is already too much blocked by the environment and with a lot of fixed shading this becomes too much.

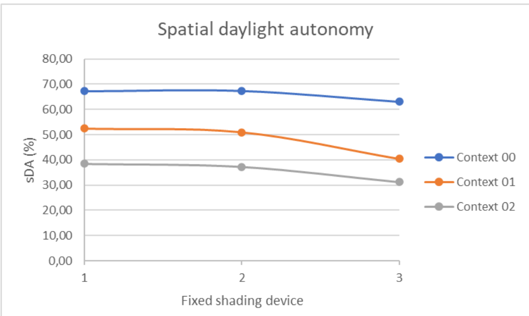


Figure 85, Average sDA

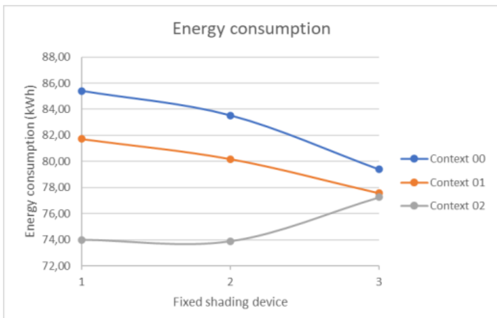


Figure 86, Average energy consumption

- Glass characteristics

Figure 87 compares the WWR with the average result for the energy consumption and average recommendation level. The figure shows that the average for the European standard rises fastest between the WWR of 10% and 60%, while for energy consumption the average only starts to rise at 40%. It can also be seen that method one for the European standard rises less quickly than method 2.

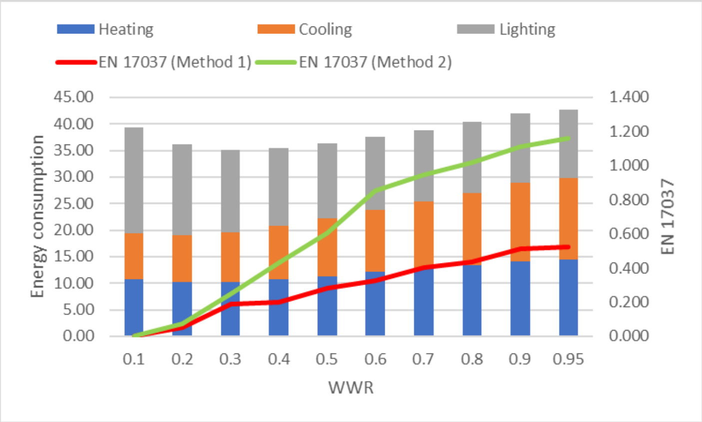


Figure 87, EN 17037 performance and energy consumption compared to the WWR

From Table 35-37 it became clear that a certain window-to-wall ratio is needed to achieve a certain performance level. However, this will not only affect the window-to-wall ratio, but also the total energy consumption. Figures 88 and 89 compare the effect of the window-to-wall ratio with the average consumption of the different HVAC installations and the average total energy consumption of all variants. The total energy consumption will decrease until the WWR of 40% and will only increase thereafter. This is because, as can be seen in figure 88, heating only starts to increase after 30% WWR. The total energy consumption for lighting will only decrease as the window-to-wall ratio increases. However, after 40% the energy consumption will increase, because heating and cooling together consume more energy than the lighting consumption alone. A sustainable building must therefore seek a good balance between daylight and energy consumption.

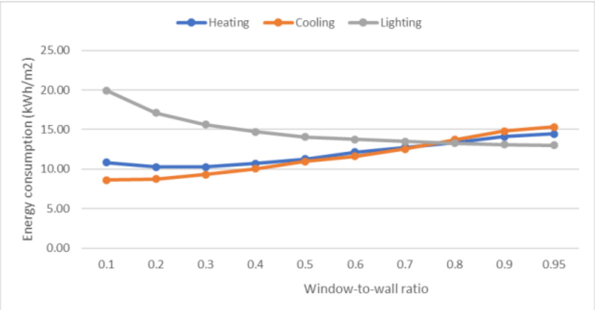


Figure 88, Influence of WWR on the different HVAC-elements

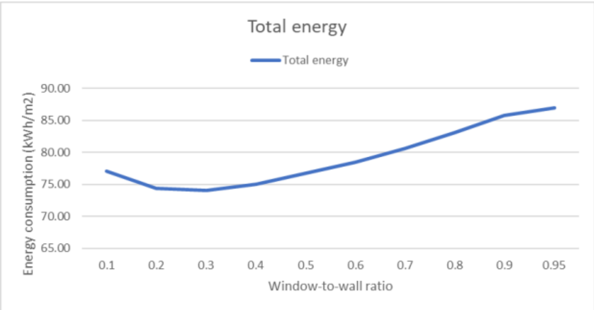


Figure 89, Influence of WWR on the total energy consumption

VLT and SHGC

By changing the properties of the glass, the cooling consumption can also be reduced. The heating load will increase slightly. When using a VLT that is almost the same, the daylight provision will hardly change. When changing the VLT from 0.77 to 0.68, the sDA will decrease by 0.06%. This will have the greatest effect in a situation where the solar radiation is not blocked by buildings in the vicinity. This is also shown in the table below. The reduction in total consumption when using SHGC of 0.6 instead of 0.37, is the most for context with no obstacles (Context 0) and the least for context with big obstructions (Context 2).

VLT and SHGC											
Totaal											
VLT	SHGC	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
0,77	0.6	49,86	2,50	2,14	0,64	13,32	11,17	14,80	80,98	2,41	13,13
0,68	0,37	49,80	2,55	2,14	0,65	9,82	12,85	14,80	77,45	2,78	12,65
Context 00											
VLT	SHGC	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
0.77	0.6	65,83	4,26	3,03	1,20	17,92	9,81	14,61	85,95	2,09	14,05
0.68	0,37	65,97	4,35	3,03	1,20	12,39	11,59	14,61	79,61	2,63	13,64
Context 01											
VLT	SHGC	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
0.77	0.6	48,04	3,24	2,26	0,53	13,96	10,04	15,39	81,83	2,13	13,42
0.68	0,37	47,85	3,29	2,25	0,53	10,23	11,84	15,39	77,82	2,61	12,80
Context 02											
VLT	SHGC	sDA	ASE	DF	EN 17037	Cooling loads	Heating loads	Lighting loads	Total loads	Points BREEAM	Points LEED
0.77	0.6	35,70	0,00	1,13	0,20	8,09	13,66	14,39	75,17	3,02	11,92
0.68	0,37	35,57	0,01	1,13	0,21	6,83	15,14	14,39	74,92	3,11	11,50

Table 43, Effect of different VLT and SHGC

4.5 Total points

The influence of the different parameters and orientation on the points will be visualised below. Sections 4.1 and 4.2 show that for daylight and energy a different orientation is preferable in order to make the best use of visible sunlight and solar gain. The graph below shows the change in points for daylight and energy when the parameters are changed.

Figure 90 shows that the number of points changes with different orientations. As daylight only accounts for 15% of the total points for LEED and 6.67% for BREEAM, energy has the biggest influence on the total points. Looking at the average points for LEED for each orientation, the best orientation to score the highest in LEED is west and east. For BREEAM this orientation is slightly different because the daylight factor is not based on the orientation and also for daylight provision only 1 point can be achieved. The orientation is entirely based on the energy results. For BREEAM the average of the total points is highest for the orientation North, North-East and North-West. Since the orientation of the building cannot usually be changed, at most a few rooms are not oriented in a certain way, the parameters that can be changed in a design are also discussed.

Figure 91 shows the average points for BREEAM and LEED with the different depth/width ratio. It can be seen that there is a difference between the best width/depth ratio for LEED and for BREEAM. As BREEAM is based on a fixed reference value this gives a better picture. The best width/depth ratio is between 0.75 and 1.33. When the width/depth ratio is too large, it will cause too much energy to be lost through too large a loss area. When the widht/depth ratio is too small, there will not be enough daylight.

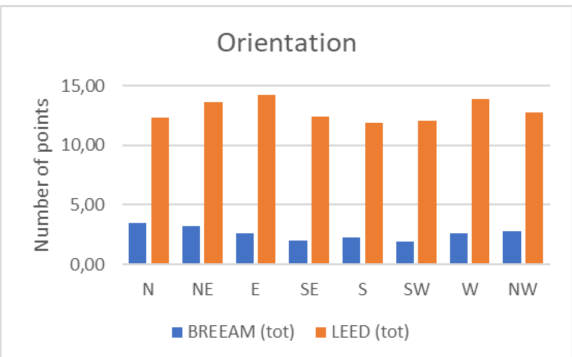


Figure 90, Points in relation to orientation

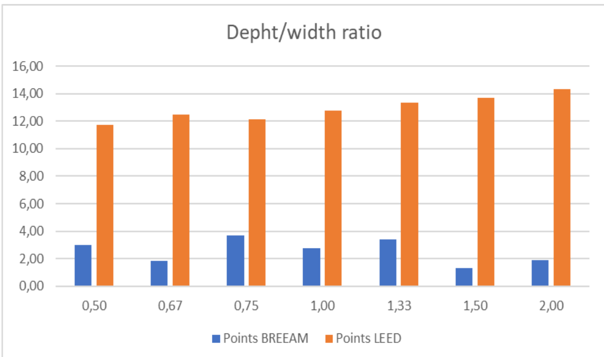


Figure 91, Points in relation to depth/width ratio

The window-to-wall ratio and glass characteristics can also be changed to achieve more points for BREEAM and LEED. The WWR will only have an effect on the recommendation level for the European standard. It can be seen that for BREEAM the WWR of 0.3 will give the highest score and the Solar heat gain coefficient of 0.37 will ensure that the total energy consumption will be even lower.

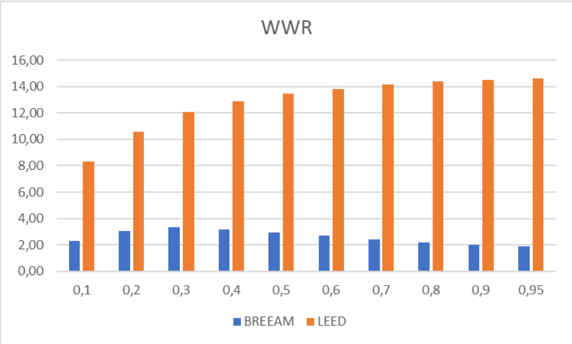


Figure 92, Points in relation to WWR

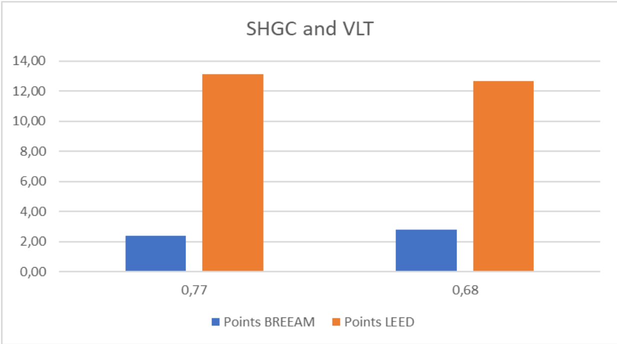


Figure 93, Points in relation to SHGC and VLT

If the annual sunlight exposure or the cooling consumption is too high, one can still choose to use fixed shading devices. If a narrow fixed shading device (300 mm) is chosen, the number of points will raise by 0,10, but the ASE will be slightly lower. A large fixed shading device will cost a number of points, because there will not be enough daylight. For BREEAM the number of points will be reduced by 0,05.

In figure 95 you can see at which parameters the points change the most. The most important parameter is the WWR and then the depth/width ratio. The shading and solar heat gain coefficient has some impact on the number of points, but not very much.

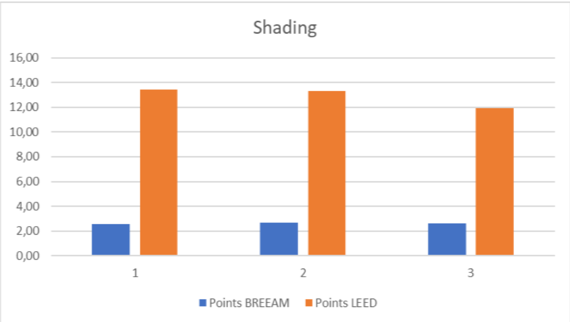


Figure 94, Points in relation to shading

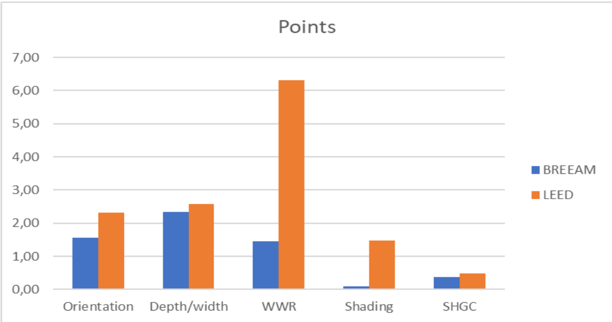
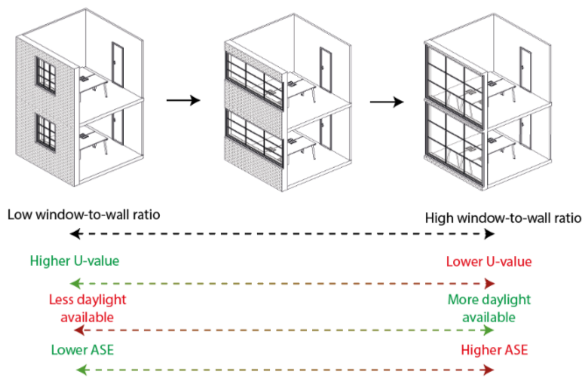


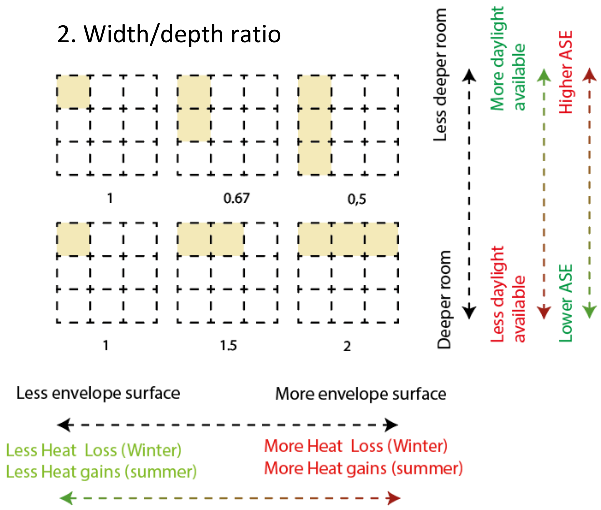
Figure 95, Average points based on different parameters

This paragraph has shown that the European standard has an influence on the performance outcome of BREEAM and LEED. To reduce the effect on ASE and energy consumption, some parameters needs to be changed when the high recommendation level requirements of the European norm is met. Below these parameters are summarized and what they will do on the outcome. The parameters are sorted by how much effect it will have. The window-to-wall ratio will have the most effect and SHGC the least. However, any adjustment will also have a effect on the daylight provision.

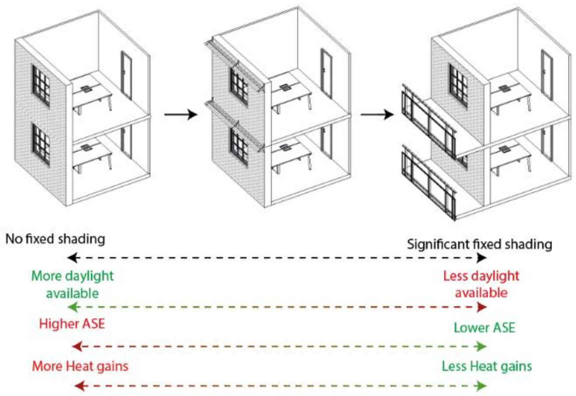
1. Window-to-wall ratio



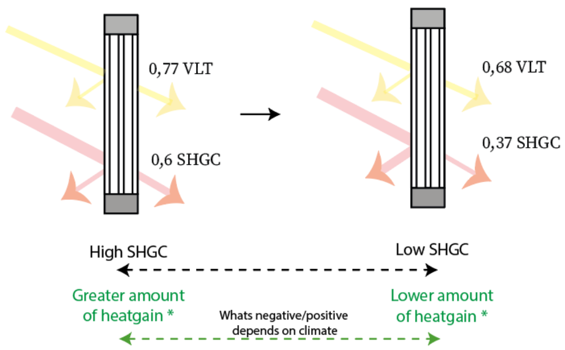
2. Width/depth ratio



3. Fixed shading device



4. SHGC



5. Discussion

In this section, the results from section 4 will be discussed. First the daylight results will be discussed, then the energy results ,the results for the score distribution for BREEAM and LEED will also be discussed and finally, the parameters that can make the influence of the European standard on BREEAM and LEED less severe will be discussed. The aim of this study was to investigate how much influence the recommendation levels for daylight provision for the European standard had on the green certificates. Finally, the limitations and recommendations for future research are given.

5.1 The difference between the European norm and the daylight outcome performance of LEED and BREEAM

In paragraph 4 it becomes clear that the European standard, BREEAM and LEED use different performance measures to assess daylight provision. From analyzing the different data it becomes clear that a minimum performance level for the European standard is still not enough to meet the requirements for the performance outcome for daylight provision for BREEAM and LEED. For BREEAM, this is mainly due to the uniformity ratio, which is insufficient for most of the variants, and for LEED, the sDA percentage is often still not enough for 3 points. For BREEAM and LEED, the variants only meet the requirements if the Medium and High recommendation levels for the European standard are met.

The most favorable orientation for the European standard is towards the South-East and South-West. This does not correspond to the favorable orientation for LEED, as this performance measure uses blinds. The most favorable orientations for EN 17037 will result in too high ASE values for LEED, and the blinds will be down too often. For LEED, the north orientation is the best orientation to have the best chance of scoring the highest for daylight provision. This is because the use of blinds affects the outcome. For BREEAM the orientation will not matter as it has no effect on the daylight factor.

It should also be taken into account that when a certain performance level for daylight provision has been achieved for the European standard using method 2 (based on internal illuminance per hour for a typical year) this same variant will usually score lower with method 1 (based on daylight factors).

5.2 The effect of the European norm on the energy outcome performance of LEED and BREEAM

The results for energy partly correspond to the results from the literature, such as those from Bernard & Flourentzos (2019). The energy consumption goes up when the recommendation level for the European standard is higher than minimum. If the average energy consumption of all variants, when the minimum performance level is achieved, is compared to the high performance level, the total energy consumption will be 8.33 kWh/m^2 more than the energy consumption for minimum. When the points for BREEAM are compared with meeting the minimum performance level and high performance level for the European standard, the average score is 0.6 points less.

5.3 Influential parameters

In order to reduce the impact on energy consumption and ASE by choosing the high recommendation level for EN 17037, various parts of the design can be changed. For each part it is important to find a balance between energy and daylight. The most important component is the window-to-wall ratio. This has the greatest effect on achieving the various Recommendation levels for EN 17037, but also on the ASE and energy consumption. After a WWR of 40% the energy consumption will increase more and more, while after 60% the sdA and daylight factor will not increase as quickly. Another important parameter is the width/depth ratio. When the width/depth ratio is too high, it will result in an excellent daylight performance outcome but the energy consumption will be too high. When the width/depth ratio is too low, the energy consumption will be quite low, but there will be not enough daylight due to the depth of the room. The best width/depth ratio for a balance between daylight and energy is between 0.75 and 1.33.

Fixed shading can be used to ensure that cooling consumption is reduced even further. This does cause the heating loads to go up, but in most cases not higher than the cooling load goes down. This is not the case for scenarios with high buildings as context. The cooling consumption can also be lowered by lowering the SHGC of the glass. Reducing the energy consumption of the building will ensure that it scores better for BREEAM and LEED.

5.4 Limitations and Future research

There are some limitations of this study from which recommendations for future studies also emerge.

- The first limitation of this study is that it only investigates one function, an office, where only a closed floor plan is used. A number of case studies with open floor plans could strengthen the research.
- Another limitation of this study is that only one performance criterion of the European norm was examined. It would have been interesting to analyze the DGP and to compare it with the ASE outcome.
- It would have been interesting to include slightly less efficient installations and Rc-values in this research. This makes the influence of various parameters even more visible.
- Fixed values are used for the occupancy schedule, heating setpoints and cooling setpoints. It can be interesting to see if this has much influence on the results when a different occupancy schedule is used.
- This research takes into account the Dutch building regulations and climate. The results may be different for a warmer or colder climate with different building regulations.
- No costs are taken into account. This is also an important aspect in choosing between the parameters.
- As the Energy credits for LEED are based on a baseline model, and this changes when the area of the proposed design changes, the effect of the European standard on the LEED points is different for each model and harder to predict than for BREEAM

5.5 Use of the flowchart

The flowchart can be used by architects, engineers and climate consultants dealing with the European standard or with BREEAM and LEED. In the appendix the whole flowchart is shown and in section 3 there is a description per topic how the flowchart is structured and how the different performance measures are calculated.

6. Conclusion

This graduation research seeks an answer to: How does the European standard for daylight in buildings influence the energy performance in buildings and what influence does this have on the BREEAM and LEED certificates? For this purpose a quantitative research has been carried out with the help of analyses which mainly consists of descriptive statistics.

The results show that if the daylight provision recommendation for the European standard is met, green building certificates such as BREEAM and LEED can still be fulfilled. However, it does affect the energy consumption of the building. If the high recommendation level for the European standard is met, the energy consumption will increase by 8.33 kWh/m2 compared to the minimum recommendation level. If the optimal orientation for the European standard for daylight is used (South-East and South-West) the energy consumption will be even higher than the consumption mentioned above. The average lighting consumption will decrease with the high recommendation level.

For the daylight performance measures for BREEAM and LEED, the European standard does have a positive influence. If the medium and high performance levels are achieved, the requirements for the green building certificates are also met. The only difference with the European standard is that for most variants oriented between South-West and South-East with a high performance level, the ASE is too high. This can be avoided by using fixed shading in front of the facade by blocking direct sunlight. If a choice can be made as to which method is used to calculate the daylight provision, method two will generally be higher. This method is based on internal illuminance per hour for a typical year instead of method one, that uses the daylightfactor calculation.

To reduce the negative impact of the European standard on BREEAM and LEED, certain parameters can be chosen differently. The most important parameters for meeting the high-performance level and minimizing primary fossil energy consumption is the window-to-wall ratio and width/depth ratio. To find a balance between daylight and energy consumption, the optimal width/depth ratio is between 1.33 and 0.75. The optimum window-to-wall ratio is between 40% and 60%. The daylight performance measure will not increase that much after 60% and the energy consumption increases the most after passing the window-to-wall ratio of 40%. To reduce the cooling consumption and ASE even more, one can choose to apply fixed shading in front of the facade. This will cause the heating consumption to increase, but in most cases the cooling consumption decreases more. Another possibility is to choose a lower SHGC. In most cases, this will reduce the cooling consumption more than it increases the heating consumption.

This study has shown that the European standard does have an influence on green building certificates, but this influence does not have to be too big if the parameters are chosen correctly.

7. Reflection

In this section, I will reflect on the process of graduation and my learning process. My preference for the graduation project was a study in which daylight was combined with computational design. This fascination fitted well with this subject where the new European standard for daylight in buildings was investigated on the influence of green building certificates using parametric analysis. The reflection deals with four topics: the relationship between research and designing, research method, societal relevance and the ethical issues during the research. The planning of the graduation consisted mainly of two parts. The first part was to research the European standard and the effect on green certificates and the second part was to simulate different variants to see if what the effect of the European standard will be on green building certificates. Looking back at the process and the planning, the planning I made for P2 turned out differently than I hoped. While making the parametric study, I found that not all subjects had been investigated yet and I still had to put in a lot of time to research some of the simulation assumptions.

The use of a plug-in (Pollination) for the parallel simulation of variants also took longer than expected, which is why I eventually went back to using the Honeybee plugin that I was more familiar with for simulating the variants. The results of pollination (which was still in beta version at the time) took longer than when the variants were simulated locally one after the other.

Looking back on the P3 presentation, it would have been more convenient to show some results instead of just the methodology. This would make more clearer which way I wanted to go instead of only showing the end results when everything was simulated. By simulating everything at once, and not doing a small study first with a few parameters, I only found out in the end that the sDA was set to daylight hours and not to 8am-6pm and for energy, the light schedules were not tracked. I had to simulate this again.

In the end, I learned a lot from this research and from the feedback I received from the mentors and consultants. The scientific way of writing has become better and better during the period, also because of the teachers comments on the report.

- the relationship between research and design.

The first period up to P2 consisted mainly of research. What are the requirements for the European standard, BREEAM and LEED, and how could they possibly influence each other? After the P2, research and design is often applied alternatively. For certain design parameters, it must first be examined what will be introduced and how this will affect it. After this has been done, all the variants can be simulated and compared with each other. Looking back, I think the research and design with this thesis forms a complete story about the influence of the European standard on green building certificates.

- T**he relationship between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master program (MSc AUBS).**

The relationship with the graduation research (daylight) and the studio (theme) is that for Energy & Climate both contribute to a comfortable and healthy climate in buildings. Sufficient daylight can ensure that people are less likely to suffer from health problems. It also examines whether a building will not consume too much energy if the highest standard of daylight provision is pursued. This research also has a lot to do with computational design, since different variants are simulated with the help of Grasshopper, with different parameters in order to be able to analyze the performance measures in the end.

The relationship with the track building technology is also very visible in this research. The focus of the track building technology is on innovative and sustainable building components and their integration into the built environment. This research mainly focuses on sustainability and comfort in buildings. How can indoor spaces become healthier with the help of daylight, but not at the expense of the sustainability of the building?

- Elaboration on research method and approach chosen by the student in relation to the graduation studio methodical line of inquiry, reflecting thereby upon the scientific relevance of the work.

The various standards and parameters were first examined with a literature search. The research method consisted of analyzing quantitative data. A single-zone approach is used to analyze and simulate the amount of daylight and energy consumption of all the variants. The analyses consist mainly of descriptive statistics. During this process, the data is collected and the characteristics of the dataset are summarized. This helps to understand and describe the characteristics of the dataset. The first analysis consists of describing the characteristics of the daylight dataset, such as the mean of a performance outcome or the relationship between different performance outcomes. The frequency distribution for certain performance outcomes and parameters is also analyzed and summarized in graphs and tables. These analyses are also done for the total points for BREEAM and LEED.

- Elaboration on the relationship between the graduation project and the wider social, professional and scientific framework, touching upon the transferability of the project results.

The results of this research can very well be used for wider social, professional and scientific framework. Since not many studies have been done on the new European standard, this can help in exploring this standard and how much influence it has on a design. It also complements earlier research. This research shows that there are certain methods of the European standard that score less well in daylight provision compared to the 2nd method. This research can also be used as a kind of guideline for designers who have to deal with the European standard and green building certificates.

Discuss the ethical issues and dilemmas you may have encountered in (i) doing the research, (ii, if applicable) elaborating the design and (iii) potential applications of the results in practice.

During my research, I have not really come across ethical issues and dilemmas. The only conflicting goal in this project is that it is for the health of the user go for the highest recommendation values for daylight for the European norm in a design because of the positive health effects for users in a building. However, this has a negative effect on the sustainability of the building because of the higher energy consumption in a building. This will also increase the chance of glare. So when do you opt for less daylight and use less energy as a result?

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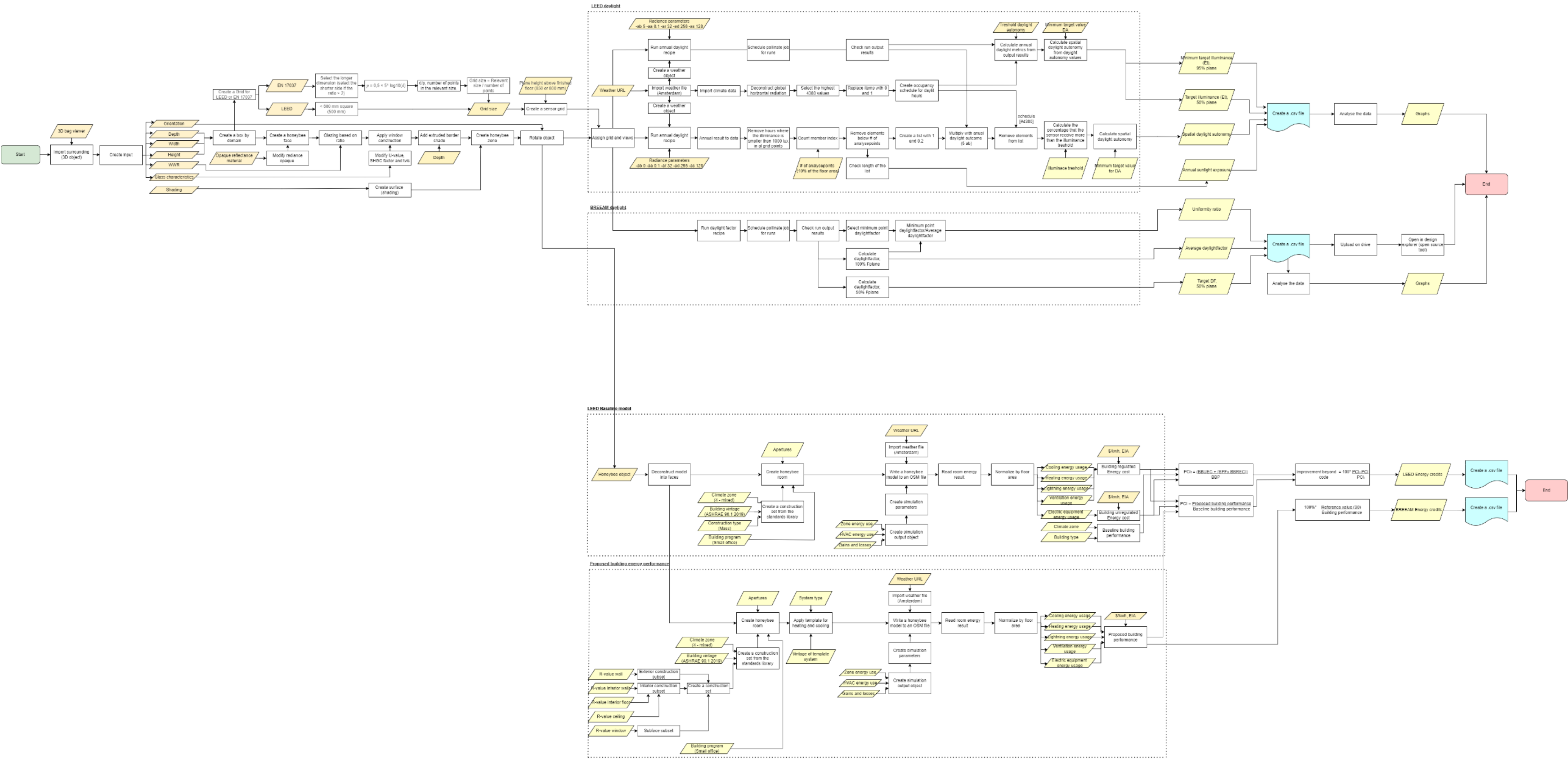
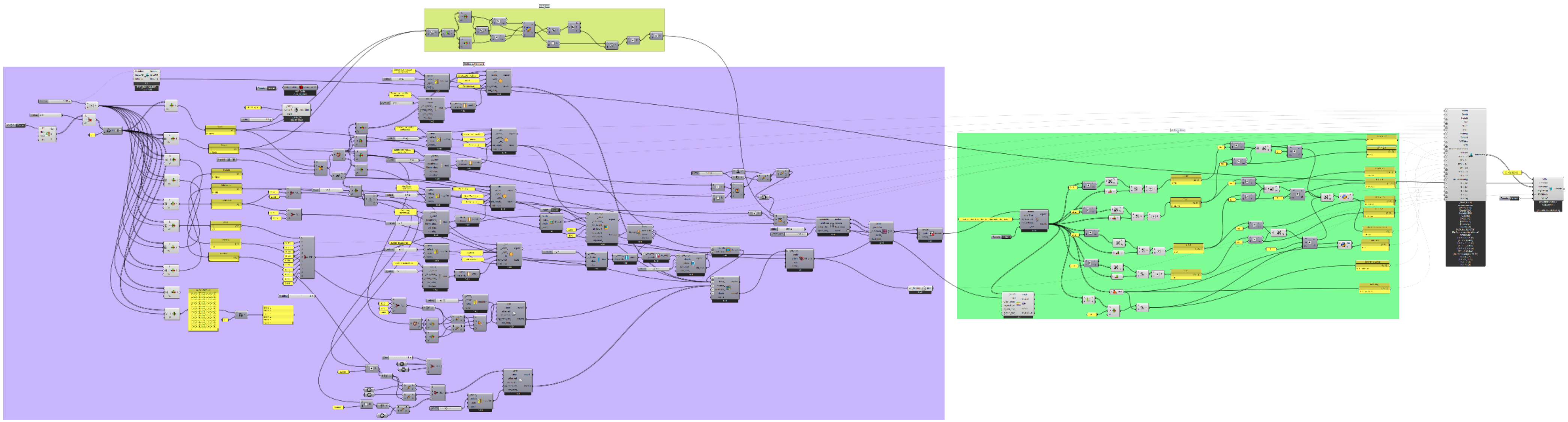
Appendix A, Flowchart

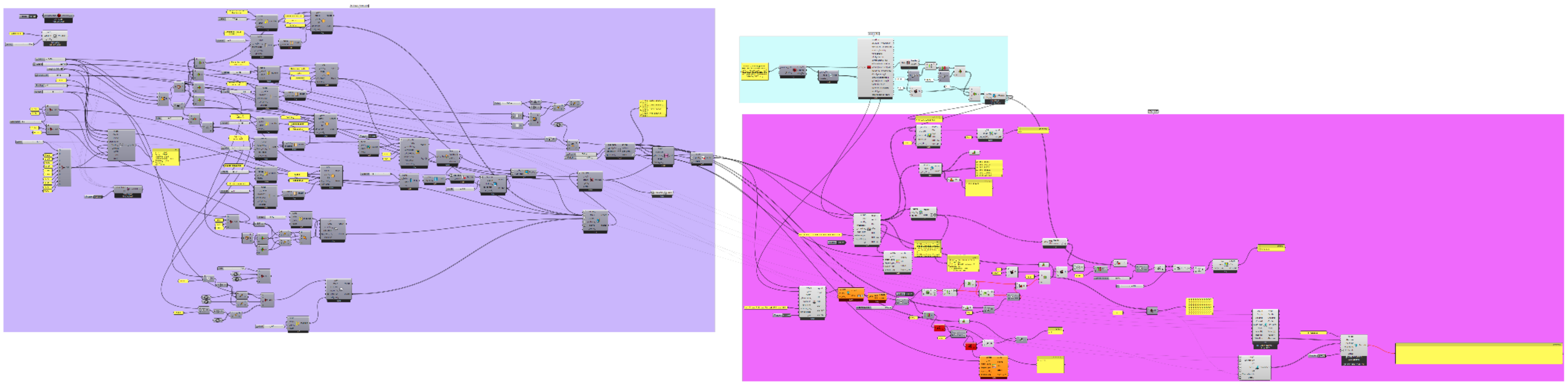


Appendix B, Grasshopper

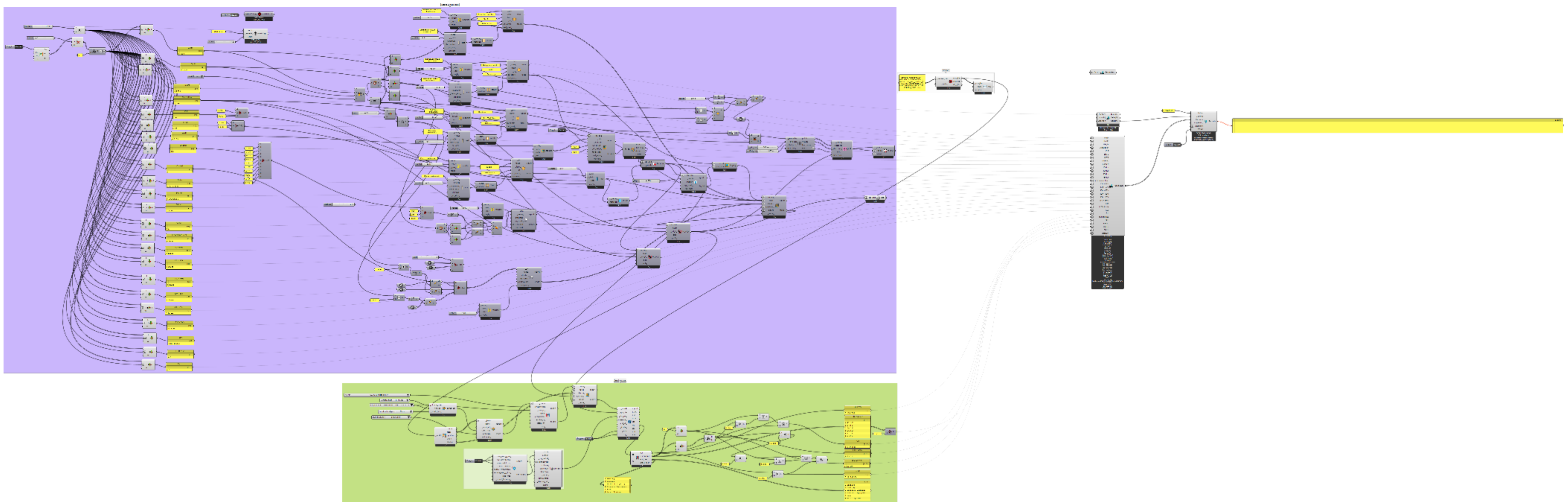
B1, Daylight factor



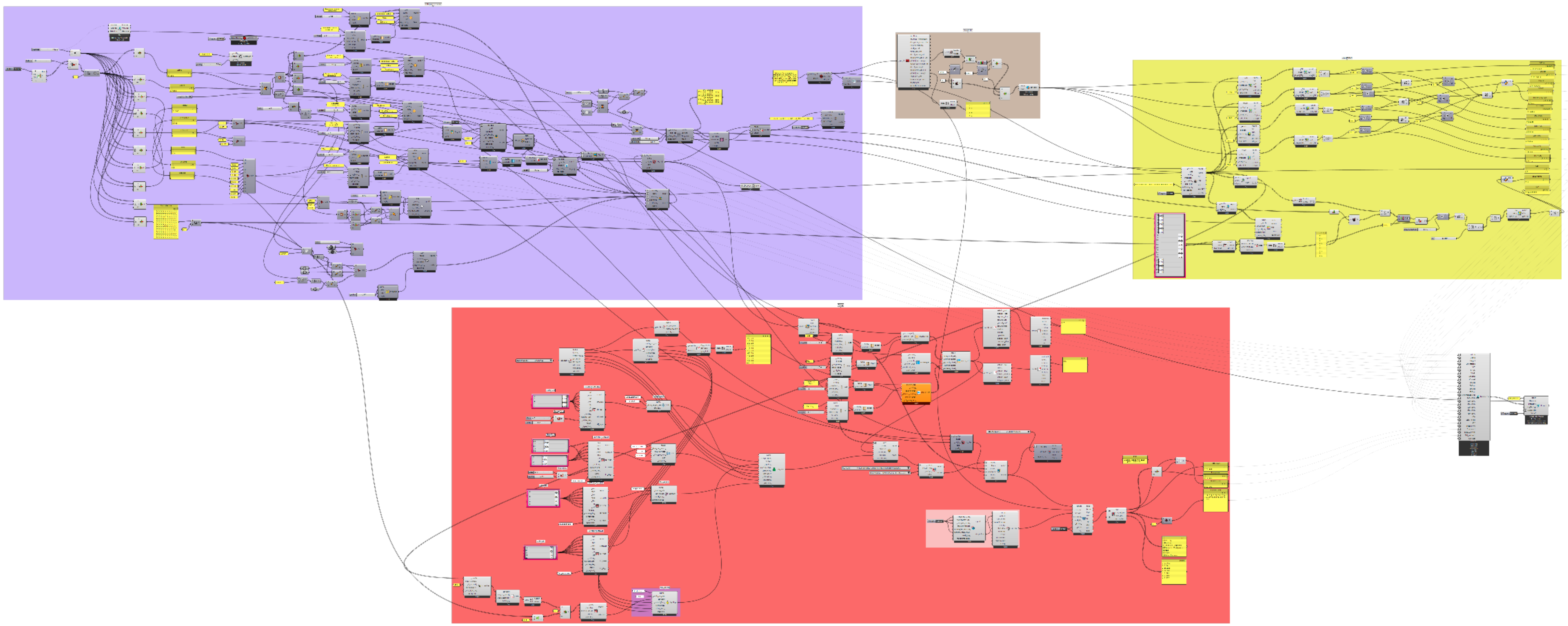
B2, Spatial Daylight Autonomy and Annual sunlight exposure



B3, Baseline model energy consumption (LEED)



B3, Proposed model energy consumption



Appendix C, tables

C1, Daylight

	DF	N	NE	E	SE	S	SW	W	NW
None	None	944	928	916	922	917	929	917	925
	Minimum	5	2	1	0	1	5	1	1
	Medium	0	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0	0
Minimum	None	168	184	196	189	193	182	195	187
	Minimum	260	272	252	244	243	246	258	262
	Medium	0	0	0	0	0	0	1	0
	High	0	0	0	0	0	0	0	0
Medium	None	0	0	0	0	2	1	0	0
	Minimum	98	89	107	108	113	102	102	100
	Medium	63	54	45	41	46	42	41	61
	High	0	0	0	0	0	0	0	0
High	None	0	0	0	1	0	0	0	0
	Minimum	0	0	3	11	6	10	2	0
	Medium	48	57	66	70	65	69	69	50
	High	34	34	34	34	34	34	34	34
	Total	1620	1620	1620	1620	1620	1620	1620	1620

Performance level comparison Method 2 VS Method 1; Figure 55-58 Report

DF	
High	34
Medium	111
Minimum	363
None	1112
	1620

Performance level (Method 1); Figure 53 Report

	N	NE	E	SE	S	SW	W	NW
High	82	91	103	116	105	113	105	84
Medium	161	143	152	149	161	145	143	161
Minimum	428	456	448	433	436	428	454	449
None	949	930	917	922	918	934	918	926
	1620	1620	1620	1620	1620	1620	1620	1620

Performance level (Method 2); Figure 54 Report

	Uniformity ratio	
<0.10	4	
>0.10, <0.20	220	224
>0.20, <0.30	404	628
>0.30, <0.40	335	963
>0.40, <0.50	290	1253
>0.50, <0.60	185	1438
>0.60	182	182
	1620	

Uniformity ratio; Figure 64 Report

BREEAM		
	0	1146
	1	474

BREEAM Results; Figure 63 Report

	N	NE	E	SE	S	SW	W	NW
Unsatisfactory	0	0	1	501	315	419	0	0
>7% <10%	0	0	14	126	153	131	1	0
Nominally aceptable	0	0	154	174	147	156	40	0
Clearly acceptable	1620	1620	1451	818	1004	912	1579	1620
	1620	1620	1620	1619	1619	1618	1620	1620

Annual Sunlight Exposure; Figure 61 Report

Orientation	Blinds down
N	0.00%
NE	0.98%
E	3.40%
SE	4.87%
S	5.10%
SW	4.51%
W	3.26%
NW	0.86%

Blinds down schedule; Figure 60

LEED	N	NE	E	SE	S	SW	W	NW
0	744	799	817	893	871	892	818	795
1	264	254	245	226	234	225	236	243
2	211	207	207	201	207	206	217	209
3	401	360	351	300	308	296	349	373
	1620	1620	1620	1620	1620	1619	1620	1620

Points Spatial Daylight Autonomy; Figure 59 Report

		N				NE				E				SE			
		None	Minimum	Medium	High	None	Minimum	Medium	High	None	Minimum	Medium	High	None	Minimum	Medium	High
sDA	Max	55	95	100	100	52	98	100	100	55	98	100	100	50	97	100	100
	Min	0	50	95	100	0	35	88	100	0	38	77	96	0	30	65	96
	Mean	16	72	99	100	21	65	97	100	21	63	94	100	19	58	87	100
ASE	Max	0	0	0	0	0	0	0	0	5	8	8	53	20	35	46	53
	Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mean	0	0	0	0	0	0	0	0	0	1	2	29	2	10	22	29

		S				SW				W				NW			
		None	Minimum	Medium	High	None	Minimum	Medium	High	None	Minimum	Medium	High	None	Minimum	Medium	High
sDA	Max	48	98	100	100	50	93	100	100	55	98	100	100	53	100	100	100
	Min	0	28	70	98	0	28	65	95	0	35	76	98	0	43	80	100
	Mean	19	58	90	100	19	58	89	100	21	63	95	100	21	66	97	100
ASE	Max	13	21	32	41	18	32	38	43	3	4	5	10	0	0	0	0
	Min	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
	Mean	1	6	14	22	2	8	18	26	0	0	1	1	0	0	0	0

sDA result; Report

C2, Energy

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
Heating	10.81	10.28	10.26	10.68	11.28	12.13	12.76	13.36	14.12	14.43
Cooling	8.61	8.76	9.31	10.05	10.98	11.62	12.55	13.69	14.81	15.33
Lighting	19.94	17.12	15.60	14.70	14.06	13.73	13.49	13.26	13.08	13.00
Total energy	77.11	74.37	74.02	75.01	76.71	78.51	80.62	83.09	85.74	86.97
EN 17037 (Method 1)	0.000	0.049	0.191	0.198	0.284	0.327	0.401	0.438	0.512	0.525
EN 17037 (Method 2)	0.000	0.074	0.250	0.432	0.606	0.853	0.944	1.019	1.113	1.159

Influence of WWR on the different HVAC-elements; Figure 87 and 88 report

	Total	average Heating	average Cooling	Average lighting	MaxHeating	Min heating	Max cooling	Min cooling
None	36.13	11.05	8.98	16.09	31.29	6.00	60.44	6.00
Minimum	38.23	12.64	12.42	13.17	32.58	6.79	43.51	6.79
Medium	43.64	13.68	17.14	12.82	56.44	3.86	36.01	3.86
High	51.96	15.60	23.35	13.01	54.87	3.00	26.58	3.00

HVAC energy consumption compared to EN 17037 ; Figure 73 and 74 report

	Orientation	Average energy consumption	average heating	average cooling	Average lighting
N	0.00	74.39	14.61	8.55	12.65
NE	45.00	75.32	11.47	9.59	13.94
E	90.00	79.40	9.94	12.24	15.20
SE	135.00	83.42	10.57	14.47	16.66
S	180.00	81.89	11.16	14.21	15.89
SW	225.00	83.63	12.66	13.39	16.07
W	270.00	78.83	11.39	11.22	14.56
NW	315.00	76.85	14.30	8.91	13.41

Average HVAC consumption; Figure 65-68 report

	Orientation	BREEAM BREEAM (day)	BREEAM (ene)	BREEAM (tot)	LEED LEED (day)	LEED (ene)	LEED (tot)	EN17037
N	0	0.29	3.16	3.45	1.17	11.14	12.30	0.614815
NE	45	0.29	2.93	3.22	1.08	12.59	13.66	0.626543
E	90	0.29	2.32	2.61	1.06	13.15	14.20	0.654938
SE	135	0.29	1.74	2.03	0.95	11.45	12.39	0.666049
S	180	0.29	1.92	2.21	0.97	10.91	11.89	0.662346
SW	225	0.29	1.60	1.89	1.17	10.90	12.07	0.652469
W	270	0.29	2.28	2.57	1.06	12.80	13.86	0.651235
NW	315	0.29	2.51	2.80	1.10	11.63	12.73	0.631481

Points certificates, Figure 90 report

	None	Minimum	Medium	High
LEED (daylight)	0.13	1.93	2.99	3.00
LEED (energy)	11.03	12.86	13.05	12.72
LEED (Total)	11.16	14.79	16.04	15.72
BREEAM (daylight)	0.00	0.51	0.97	1.00
BREEAM (energy)	3.15	1.64	0.53	0.07
BREEAM (total)	3.16	2.15	1.50	1.07

Average LEED and BREEAM points; Figure 69 report

C3, Influential parameters

Width	Depth	Height	Orientatie	VLT	SHGC	WWR	Shading	Context	out:100 lux		out:300 lux		out:500 lux		out:750 lux		out:Performance lev		Perf	out:100 >	out:300 >5	out:300 >9	out:500 >	out:500 >95%	out:750 >50%	out:sDA	out:LEED F	out:ASE	out:AVG d	out:Perfo	out:BREEA	out:Uni ve
5400	5400	2600	180	0,77	0,60	60%	0	1	98.44		62.50		46.88		32.81		Minimum		1.00	True	True	False	False	False	False	53.13	1.00	12.00	3.38	Minimum	0.00	0.22

									sDA		ASE		EN 17037 (ill)		AVG		UNI		EN 17037 (DF)
5400	5400	2600	180	0,77	0,60	60%	0	1	53,15		12		Minimum		3.38		0,22		Minimum

Width									sDA		ASE		EN 17037		AVG		UNI		EN 17037 (DF)		Lighting	Heating		Cooling		Lighting		BREEAM points		LEED points	
3600	5400	2600	180	0,77	0,60	60%	0	1	47.5	10.63%	12	0.00%	1	0.00%	3.2	5.33%	0.19	13.64%	0	100.00%		4	0.00%	22.434	1.05%			0	100.00%	13	18.75%
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	1	0.00%	3.38	0.00%	0.22	0.00%	1	0.00%		4	0.00%	22.672	0.00%			3	0.00%	16	0.00%
7200	5400	2600	180	0,77	0,60	60%	0	1	50	5.93%	13	-8.33%	1	0.00%	3.38	0.00%	0.26	-18.18%	1	0.00%		4	0.00%	22.791	-0.52%			8	-166.67%	17	-6.25%
									Min	0.00%		-8.33%		0.00%		0.00%		-18.18%		0.00%			0.00%		-0.52%				-166.67%		-6.25%
									Max	10.63%		0.00%		0.00%		5.33%		13.64%		100.00%			0.00%		1.05%				100.00%		18.75%
									Change range	10.63%		8.33%		0.00%		5.33%		31.82%		100.00%			0.00%		-1.57%				-266.67%		-25.00%

Depth									sDA		ASE		EN 17037		AVG		UNI		EN 17037 (DF)			Heating		Cooling				BREEAM points		LEED points	
5400	3600	2600	180	0,77	0,60	60%	0	1	85	-59.92%	17	-41.67%	2	-100.00%	17	-402.96%	0.43	-95.45%	2	-100.00%		7.29	-82.25%	28.578	-26.05%			1	66.67%	15	6.25%
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	1	0.00%	3.38	0.00%	0.22	0.00%	1	0.00%		4	0.00%	22.672	0.00%			3	0.00%	16	0.00%
5400	7200	2600	180	0,77	0,60	60%	0	1	37.5	29.44%	8	33.33%	0	100.00%	2.35	30.47%	0.16	27.27%	0	100.00%		2.429	39.28%	19.862	12.39%			10	-233.33%	16	0.00%
									Min	-59.92%		-41.67%		-100.00%		-402.96%		-95.45%		-100.00%			-82.25%		-26.05%				-233.33%		0.00%
									Max	29.44%		33.33%		100.00%		30.47%		27.27%		100.00%			39.28%		12.39%				66.67%		6.25%
									Change range	89.37%		75.00%		200.00%		433.43%		122.73%		200.00%			-121.53%		-38.44%				-300.00%		-6.25%

VLT and SHGC									sDA		ASE		EN 17037		AVG		UNI		EN 17037 (DF)			Heating		Cooling				BREEAM points		LEED points	
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	Minimum	0.00%	3.38	0.00%	0.22	0%	Minimum	0%		4	0.00%	22.672	0.00%			3	0.00%	16	0.00%
5400	5400	2600	180	0,68	0,37	60%	0	1	50	5.93%	12	0.00%	Minimum	0.00%	3.4	-0.59%	0.22	0%	Minimum	0%		4	0.00%	16	29.43%			5	-66.67%	17	-6.25%
									Min	0.00%		0.00%		0.00%		-0.59%		0.00%		0.00%			0.00%		0.00%				-66.67%		-6.25%
									Max	5.93%		0.00%		0.00%		0.00%		0.00%		0.00%			0.00%		29.43%				0.00%		0.00%
									Change range	5.93%		0.00%		0.00%		0.59%		0.00%		0.00%			0.00%		-29.43%				-66.67%		-6.25%

Orientation									sDA		ASE		EN 17037		AVG		UNI		EN 17037 (DF)			Heating		Cooling				BREEAM points		LEED points	
5400	5400	2600	0	0,77	0,60	60%	0	1	60.93	-14.64%	0	100.00%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		7.14	-78.60%	12.10	46.64%			7.00	-133.33%	17.00	-6.25%
5400	5400	2600	45	0,77	0,60	60%	0	1	51.56	2.99%	0	100.00%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		4.00	-0.03%	13.91	38.66%			7.00	-133.33%	17.00	-6.25%
5400	5400	2600	90	0,77	0,60	60%	0	1	51.56	2.99%	1	91.67%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		4.00	0.00%	18.39	18.91%			4.00	-33.33%	17.00	-6.25%
5400	5400	2600	135	0,77	0,60	60%	0	1	51.56	2.99%	23	-91.67%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		3.91	2.35%	22.77	-0.42%			2.00	33.33%	17.00	-6.25%
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		4.00	0.00%	22.67	0.00%			3.00	0.00%	16.00	0.00%
5400	5400	2600	225	0,77	0,60	60%	0	1	46.88	11.80%	21	-75.00%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		10.29	-157.20%	49.08	-116.49%			0.00	100.00%	16.00	0.00%
5400	5400	2600	270	0,77	0,60	60%	0	1	57.81	-8.77%	0	100.00%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		4.00	-0.03%	17.24	23.95%			4.00	-33.33%	18.00	-12.50%
5400	5400	2600	315	0,77	0,60	60%	0	1	56.25	-5.83%	0	100.00%	Minimum	0%	3.38	0%	0.22	0%	Minimum	0%		4.10	-2.40%	13.24	41.60%			7.00	-133.33%	18.00	-12.50%
									Min	-14.64%		-91.67%		0%		0%		0%		0%			-157.20%		-116.49%				-133.33%		-12.50%
									Max	11.80%		100.00%		0%		0%		0%		0%			2.35%		46.64%				100.00%		0.00%
									Change range	26.43%		191.67%		0%		0%		0%		0%			-159.55%		-163.13%				-233.33%		-12.50%

WWR									sDA	sDA change	ASE	ASE change	EN 17037		AVG		UNI		EN 17037 (DF)			Heating		Cooling				BREEAM points		LEED points	
5400	5400	2600	180	0,77	0,60	10%	0	1	3.13	94.11%	0	100.00%	0	100.00%	0.36	89.35%	0.2	9.09%	0	100.00%		3.14	21.40%	10.10	55.46%			10.00	-233.33%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	20%	0	1	17.19	67.66%	0	100.00%	0	100.00%	0.91	73.08%	0.21	4.55%	0	100.00%		2.86	28.55%	12.29	45.80%			8.00	-166.67%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	30%	0	1	29.69	44.14%	0	100.00%	0	100.00%	1.46	56.80%	0.23	-4.55%	0	100.00%		2.86	28.55%	14.48	36.13%			8.00	-166.67%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	40%	0	1	37.50	29.44%	6	50.00%	0	100.00%	1.91	43.49%	0.23	-4.55%	0	100.00%		3.14	21.40%	16.77	26.05%			7.00	-133.33%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	50%	0	1	43.75	17.69%	9	25.00%	1	0.00%	2.5	26.04%	0.23	-4.55%	0	100.00%		3.53	11.88%	19.62	13.44%			5.00	-66.67%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	1	0.00%	3.38	0.00%	0.22	0.00%	1	0.00%		4.00	0.00%	22.67	0.00%			3.00	0.00%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	70%	0	1	56.25	-5.83%	12	0.00%	1	0.00%	3.69	-9.17%	0.24	-9.09%	1	0.00%		4.48	-11.93%	25.63	-13.02%			1.00	66.67%	17.00	-6.25%
5400	5400	2600	180	0,77	0,60	80%	0	1	57.81	-8.77%	12	0.00%	1	0.00%	3.85	-13.91%	0.26	-18.18%	1	0.00%		4.95	-23.85%	28.48	-25.63%			0.00	100.00%	17.00	-6.25%
5400	5400	2600	180	0,77	0,60	90%	0	1	57.81	-8.77%	12	0.00%	1	0.00%	4	-18.34%	0.28	-27.27%	1	0.00%		5.43	-35.75%	31.25	-37.81%			0.00	100.00%	17.00	-6.25%
5400	5400	2600	180	0,77	0,60	95%	0	1	60.94	-14.66%	12	0.00%	1	0.00%	4.05	-19.82%	0.28	-27.27%	1	0.00%		5.72	-42.90%	32.48	-43.28%			0.00	100.00%	17.00	-6.25%
									Min	-14.66%		0.00%		0.00%		-19.82%		-27.27%		0.00%			-42.90%		-43.28%				-233.33%		-6.25%
									Max	94.11%		100.00%		100.00%		89.35%		9.09%		100.00%			28.55%		55.46%				100.00%		0.00%
									Change range	108.77%		100.00%		100.00%		109.17%		36.36%		100.00%			-71.45%		-98.74%				-333.33%		-6.25%

									sDA		ASE		EN 17037 (ill)		AVG		UNI		EN 17037 (DF)			Heating		Cooling				BREEAM points		LEED points	
5400	5400	2600	180	0,77	0,60	60%	0	1	53.15	0.00%	12	0.00%	1	0.00%	3.38	0.00%	0.22	0.00%	1	0.00%		4.00	0.00%	22.67	0.00%			3.00	0.00%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	60%	1	1	53.13	0.04%	7	41.67%	1	0.00%	2.93	13.31%	0.24	-9.09%	0	100.00%		4.19	-4.78%	19.62	13.44%			4.00	-33.33%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	60%	2	1	31.18	41.34%	0	100.00%	0	100.00%	1.63	51.78%	0.33	-50.00%	0	100.00%		8.00	-100.05%	11.72	48.32%			7.00	-133.33%	15.00	6.25%
									Min	0.00%		0.00%		0.00%		0.00%		-50.00%		0.00%			-100.05%		0.00%				-133.33%		0.00%
									Max	41.34%		100.00%		100.00%		51.78%		0.00%		100.00%			0.00%		48.32%				0.00%		6.25%
									Change range	41.34%		100.00%		100.00%		51.78%		50.00%		100.00%			-100.05%		-48.32%				-133.33%		-6.25%

Width	Depth	Height	Orientation	VLT	SHGC	WWR	shading	Context	sDA		ASE		EN 17037 (ill)		AVG		UNI		EN 17037 (DF)			Heating		Cooling				BREEAM points		LEED points	
5400	5400	2600	180	0,77	0,60	60%	0	0	53.13	0.00%	7	41.67%	1	0.00%	2.93	13.31%	0.24	-9.09%	0	100.00%		3.91	2.35%	29.05	-28.15%			1.00	66.67%	17.00	-6.25%
5400	5400	2600	180	0,77	0,60	60%	0	1	53.13	0.00%	12	0.00%	1	0.00%	3.38	0.00%	0.22	0.00%	1	0.00%		4.00	0.00%	22.67	0.00%			3.00	0.00%	16.00	0.00%
5400	5400	2600	180	0,77	0,60	60%	0	2	29.69	44.12%	0	100.00%	0	100.00%	1.44	57.40%	0.4	-81.82%	0	100.00%		4.19	-4.78%	11.53	49.16%			8.00	-166.67%	16.00	0.00%
									Min	0.00%		0.00%		0.00%		0.00%		-81.82%		0.00%			-4.78%		-28.15%				-166.67%		-6.25%
									Max	44.12%		100.00%		100.00%		57.40%		0.00%		100.00%			2.35%		49.16%				66.67%		0.00%
									Change range	44.12%		100.00%		100.00%		57.40%		81.82%		100.00%			-7.12%		-77.31%				-233.33%		-6.25%