AALBORG UNIVERSITET
STUDENTERRAPPORT

DAYLIGHT

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Master's Thesis - Building Physics
Delivery date: 17.09.2019
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Studenterrapport

Uddannelse:
Master i bygningsfysik

Semester:
04

Titel på masterprojekt:
Dagslys

Projektperiode:
1. februar 2019 – 17. september 2019

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Antal normalsider: 61

Vedlagt kvittering fra Digital Eksamen

Afleveringsdato: 17 september 2019

Resume:
The purpose of this report is to research the daylight conditions for a room in a new office building with a window glass orientation towards west. This thesis study starts with 2 different window size that are examined in terms of daylight reaching into the room. Methods described in Danish Building Regulation 2018 of calculating daylight are used and compared to Danish Standard 17037 methods.
Indoor climate dynamic simulations are further analyzed for the window type that fulfil the daylight requirements for BR18, to establish the energy demands. Different ventilation systems are analyzed to see which one represents the optimal solution, while still considering the daylight requirements.
Further dynamic simulations for a future climate change scenario, A1B from The Intergovernmental Panel on Climate Change (IPCC) which is the United Nations method used to assess climate change predictions, will be analyzed in order to determine the predicted changes for daylight and thermal indoor climate towards 2100.
This thesis can be of interest for both architects and engineer professions that have a curiosity for understanding the requirements set by BR18 for daylight while still considering the importance of it in a thermal indoor climate context and a future perspective towards climate changes predictions.
The conclusion is that both methods described in BR18 reach similar results, while DS 17037 can validate some of the results. The thermal indoor climate can be balanced by a mechanical ventilation with cooling or a mechanical ventilation with venting.
The climate change future predictions have an influence on daylight, and thermal indoor climate. It is inconclusive how much daylight illuminance will reach the room, but according to the daylight transmitted through the window glass, less daylight is estimated to reach the room. Thermal indoor climate can still be balanced with a mechanical ventilation with venting, while the mechanical ventilation with cooling raises questions of overheating temperatures in the future.

Preface

This master thesis is the result of the 4th semester project of a part-time of Master program in Building Physics. The master program is offered by the School of Engineering and Science (SES) department at Aalborg University Copenhagen.
The master program has a duration of 2 years and its meant to be taken next to a full-time job. The purpose of this master thesis was to analysis the new daylight demands set by the Danish Building Regulation 2018, which raised a lot of questions within the architecture industry. The thesis is presenting the methods daylight can be calculated for new buildings, as a part of a thermal indoor climate context with future perspective questions regarding climate changes. This subject became an interest because of the many questions that had been raised regarding daylight and the new regulations from different Engineering and Architectural firms.
The project was prepared in parallel with my job, at an architectural firm. I would like to thank my employer for the support and flexibility they offered.
Finally, I would like to thank my two supervisors, Senior researcher Kim B. Wittchen and Researcher Nanet Mathiasen, who with great commitment have supported and guided throughout these months.

Summary

The purpose of this report is to research the daylight conditions for a room in a new office building with a window glass orientation towards west. This thesis study starts with 2 different window size that are examined in terms of daylight reaching into the room. Methods described in Danish Building Regulation 2018 of calculating daylight are used and compared to Danish Standard 17037 methods.
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Resume (på dansk)

Formålet med denne rapport er at undersøge dagslysforholdene for et rum i en ny kontorbygning med vinduesglas orientering mod vest. Denne tese starter med 2 forskellige vinduesstørrelser, der undersøges med henblik på dagslys, der når ud i rummet. Metoder beskrevet i Dansk Bygningsreglementet 2018 til beregning af dagslys bruges og sammenlignes med Dansk Standard 17037 metoder.

Indeklima dynamiske simuleringer analyseres yderligere for vinduestypen, der opfylder dagslyskravene til BR18, for at opnå energikravene. Forskellige ventilationssystemer undersøges for at se, hvilken der repræsenterer den optimale løsning, mens man stadig tager hensyn til dagslysbehovene.

Yderligere dynamiske simuleringer for et fremtidigt klimaændringsscenarie, A1B fra Det Mellemstatslige Panel for Klimaændringer (IPCC), som er De Forenede Nationers metode, der bruges til at forudsige klimaændringer, vil blive analyseret for at bestemme de forudsagte ændringer for dagslys og termisk indeklima mod 2100.

Denne afhandling kan være af interesse for både arkitekter og ingeniørprofessionelle, som er nysgerrig efter at forstå de krav, der stilles af BR18 til dagslys, samt betydningen af det i en termisk indeklimasammenhæng og et fremtidsperspektiv med henblik på klimaændringer.

Konklusionen er, at begge metoder beskrevet i BR18 når lignende resultater, hvorimod DS 17037 kan validere nogle af resultaterne. Det termiske indeklima kan justeres ved en mekanisk ventilation med køling eller en mekanisk ventilation med udluftning.

De fremtidige forudsigelser af klimaændringerne har indflydelse på dagslys og det termiske indeklima. Det er uklart, hvor meget dagslysbelysning der når rummet, men ifølge dagslyset der sendes gennem vinduesglasset, estimeres det, at mindre dagslys når rummet. Termisk indeklima kan stadig justeres vha. en mekanisk ventilation med udluftning, mens den mekaniske ventilation med afkøling rejser spørgsmål om overophedningstemperaturer i fremtiden.

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1. Introduction

1.1. Background

The focus of the report is to analyze the daylight condition in a new office building located in Copenhagen, Denmark. The office building is based on is a fictive project where the surroundings are unknown. The analysis is based on one room located in the office building, where two different window sizes, facing west, are considered as an option for the building façade design. The scope is to follow the Danish Building Regulation 2018 and conclude which one of the windows provides the better option for daylight into the room, and how that affect the thermal indoor climate. It should be taken into consideration that BR18 is representing the lowest value for quality of buildings in Denmark, in order to ensure an acceptable standard quality level for all new buildings.[1]

Maximizing the daylight intake in a room is challenging because it involves the risk of overheating from solar energy radiations and that will have an impact on the thermal indoor climate.[2] The west orientated window has been chosen because of the complexity that it raises regarding daylight and the solar energy radiations transmitted through the window glass opening. The daylight intake is harder to control than on the south orientated window, because of the sun's height. [3]

Further dynamic simulations are to be done on the window glass size that presents the best conditions for daylight and analyze the thermal indoor climate. Challenges such as overheating, CO_2 level etc should be given a viable solution. These solutions of how to balance the loads applied to the thermal indoor climate are to be further analyzed.

Moreover, since the buildings that we build today, are meant to last for the next 100 years what challenges will they face? Climate change is an issue that should be considered now, that's why, based on the UN's climate change prediction scenarios, all the simulations regarding daylight and thermal indoor climate are to be given a glance to what this office room "might" be facing in the future.

[1] (Trafik-, Bygge- og Boligstyrelsen, 2018)
[2] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)
[3] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)

1.2. Scope

The focus of this report is to provide answers to the following questions:

- Are the 2 methods described in Danish Building Regulation 2018, of calculating daylight in a room reaching similar results? What about in comparison with DS 17037?

- How does a model that achieves daylight condition influence the indoor climate conditions and how a better energy balance can be achieved in the room?

- How does the future climate change scenarios influence the building built now in terms of daylight and indoor climate?

1.3. Limitations

All parameters for thermal indoor climate are not analyzed, only the ones relevant to this situation that have an influence on daylight in a room.

Daylight demands and requirements are described only for office buildings, therefore living spaces and residential buildings are not included.

SimLight, the program to calculate the target illuminance (lux), does not consider the correction factor for surroundings, therefore, in the end results one very important parameter is missing. Solar shades are also not taken into the simulations when calculating the target illuminance (lux).

The 0,5 meters around the walls from the calculation grid in the simulation programs, are not subtracted from the target illuminance results for daylight, as indicated in both BR18 and DS/EN 17037.

2. Theory

2.1. Daylight

The daylight element is distinguished from electrical lighting, by elements such as light color, intensity and direction.
In order to benefit of utilizing daylight as a light source in a building there are some elements that need to be designed and calculated to assure that enough daylight reaches the building through the openings.
Therefore, parameters such as geographical location of the building, its orientation towards the true north, rooms depth, building shade, shadow from surroundings and factors that can create shadows and disrupt light should be design carefully.
The conditions of solar radiations, and daylight before it reaches a buildings surface are required to understand the light input and solar radiations. [4]

The solar radiations, also known as electromagnetic radiations from the sun, that reaches the earth surface, are divided into 2 types.
One of them is the direct solar radiation and is defined as the as being a part of the suns solar radiations that reaches the earth surface after selective attenuation from the atmosphere.[5]
The other type of solar radiations is the diffuse sky radiation. The diffuse sky radiations are also a part of the solar radiations that reach the earth's surface after being scattered by air molecules, cloud particles and so on.[6]
The sum of direct solar radiations and the diffuse sky radiation is called global solar radiation. The higher the amount of solar radiation that reaches the atmosphere, the higher the radiation the diffuse sky spreads, and the lower the direct solar radiations reaches the earth's surface. [7]

Daylight is described as part of the global solar radiations that can get the chance to impact the overall visual experience.[8]

From Figure 1, with the continuous black line, is represented by the sun's surface temperature at 6000K. The light grey line represents the solar radiations outside the atmosphere, and the dash grey line represents the solar radiations on the Earth's surface.

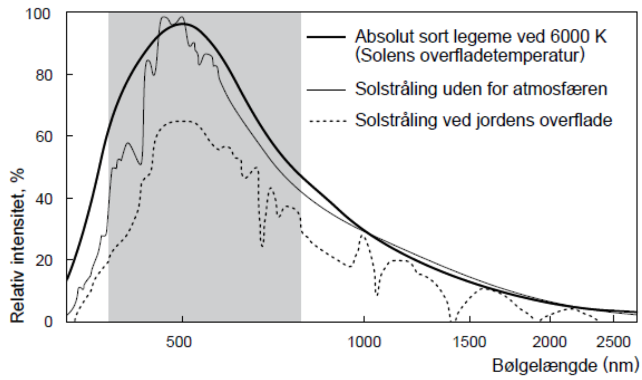

Figure 1 – The grey part represents as the solar radiation, that humans perceived as light. The visible radiations in the electromagnetic spectrum is located between approx. 380-740 nm. Figure from SBI 219.

As seen in Figure 1, the solar radiations are between 30-3000 nm on the wave range. Daylight is the part of the solar

[4] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 16)
[5] (Dansk standard, 2018, s. 33)
[6] (Dansk standard, 2018, s. 33)
[7] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 16)
[8] (Dansk standard, 2018, s. 34)

radiations that humans describe as light that can be perceived by the human eyes, and it finds itself between 380-740 nm.

Outside the grey marked zone, there are the infrared and ultraviolet wave ranges. (Figure 2)

The ultraviolet (UV) can be found on the wave range diagram between 280-380nm, and that contains 4% of the solar radiation energy. The infrared (IR) region, found between 740-3000 nm, supplies with 44% solar radiation energy.

The part that is perceived as daylight, and the one that people “see”, is approx. 52% of the solar radiations that reaches the earth. [9]

Farve	Bølgelængdeinterval (målt i vakuum)
IR	740-3000 nm
rød	625-740 nm
orange	590-625 nm
gul	565-590 nm
grøn	520-565 nm
cyan	500-520 nm
blå	450-500 nm
indigo	430-450 nm
violet	380-430 nm
UV	280-380 nm

Figure 2 – Solar radiations when reaching earth surface. Figure from SBi 219.

The solar radiations that get in contact with a surface, or a façade is composed of these 3 elements:

- Direct solar radiations
- Diffuse sky radiations
- Reflected radiations from earth’s surface [10]

To understand how much reflectance a surface gives, one must first understand the output of light and the radiation from different sky types.

The output from the light is measured in lumen per watt lm/W and it represents the light intensity on a surface (lux =lm/m^2) and the corresponding radiation effect that reaches the surface. (W/m^2)

In Denmark, the following values are used:

- Direct daylight 103 lm/W
- Overcast sky 121 lm/W
- Clear sky without sun 146 lm/W

Light intensity (lux) = Light output (lm/W) * Radiation effect (W/m^2)

Direct solar radiations can create a very high luminance of the surfaces that it reaches. The light emitted from a surface to the eye is called a luminance, and the unit for this is candela per m^2. (Cd/m^2)

High intensity reaching a work plane, can create visual discomfort and unwanted glare. Therefore, solar shades can be recommended to prevent direct daylight discomfort.

The direct radiations have a higher intensity on a perpendicular angle, and these values decrease rapidly if the angle changes. (for example, a façade)

For example, for a south facing window, the solar radiations are higher in the spring and autumn, while of the west and east façade is higher in the summer. [11]

Diffuse sky radiations create the diffuse light. This means that the façade is exposed from all directions, from the light that reflects from the free and surroundings. A clear sky luminance distribution is uneven, and the highest luminance in this case can be found around the sun.

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[9] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 17)
[10] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 18)
[11] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 19)

As a characteristic for the clear sky, the horizontal luminance is higher than the zenith luminance. On the other side an overcast sky determines exactly the opposite. The intensity of the light is higher on the zenith and decreases towards the horizon. [12]

Daylight can vary a lot throughout a day. In the summer season the light intensity with direct solar radiations comes up to 100.000 lux on a horizontal surface, where 12.000 lux comes from the clear sky radiations and the rest comes from the direct solar radiations.
To define the light intensity on an overcast day, it is crucial to determine the height of the sun and the abundance of clouds.

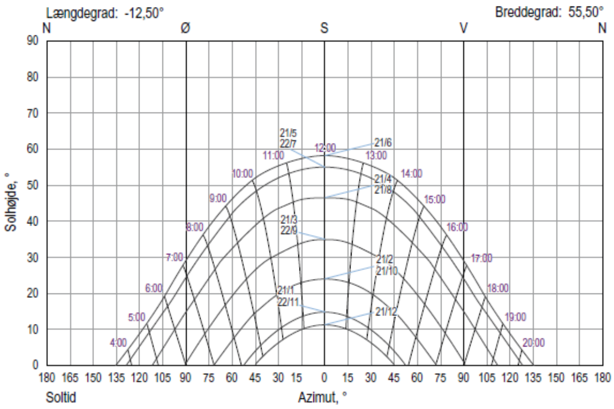

Figure 3 - Solar diagram. Figure from SBi 219.

Figure 3, Solar diagram, can be used to assess the position of the sun in the sky from sunrise until sunset.
The position of the sun shows the azimuth on the horizontal axis and the sun's height on the vertical axis.

Orientation, of the window placements contributes to how much illuminance the room is getting. Figure 4, illustrates the illuminance on a horizontal plane and all the 4 orientations.
South facing windows received the most daylight, and solar energy radiations. Adjustable solar shades can help in achieving a good daylight factor and control the heat from solar energy radiations.
East and West windows received the same amount of daylight and solar radiations, therefore are exposed to overheating and solar shades are not as effective as on the south façade because of the sun's height.
The north windows received less daylight, but that also means they rarely might need solar shades. [13]

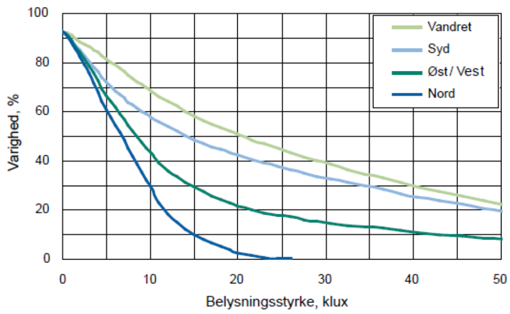

Figure 4 - Variation of global illuminance, the entire year from 8-18 on a vandret (horizontal plane), as well as South façade (Light blue), East/West (green) and North (dark blue). Figure from SBi 219.

When calculating the daylight factors, there are some standard sky types predefined in Denmark. It is considered that the illumination reaching inside a room will vary as much as the daylight outside. Therefore, when assessing how much daylight factor might get in a room, an overcast sky will be used for this. It is because of the need to assess the most critical situation for a light performance in a specific work activity.
An overcast sky can mean 2 different situations, and both are standard sky situations.

[12] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 19)
[13] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)

One of them is an even overcast sky, and the other one is a CIE-overcast sky (CIE, 2003). The even overcast sky it's defined by a "mixed of skies", partly cloudy, partly, semi-cloudy and a clear sky (without sun), achieving some simple calculations.
CIE overcast sky, is a completely overcast sky, and is the most realistic when calculating daylight factor. CIE stands for the International Lighting Committee, from French translation. [14]

CIE overcast sky is expressed by the following formula.

$L_\theta = L_Z *(1 + 2\sin\theta / 3)$

L_θ is the skies illuminance at the height angle θ, cd/m^2.

The luminance depends on the height angle measured from a horizontal angle, but still dependent of the sun's position on the sky and orientation. The luminance in Zenith L_Z, is 3 times bigger than on the horizon. [15]

Using the Zenith luminance, can the light intensity be calculated for a vertical plane and a horizontal plane, following these formulas:
Horizontal plane:

$E_H= (7\pi / 9) * L_Z$[16]

Vertical plane:

$E_V= (\pi/6 + 4/9) * L_Z$[17]

E_H is the light intensity on a horizontal plane, lux
E_V is the light intensity on a vertical plane, lux
L_Z is the zenith illuminance, cd/m^2

The results for the light intensity for both a horizontal plane (E_H), and a vertical plane (E_V) for a CIE overcast sky, are 0,396. [18]

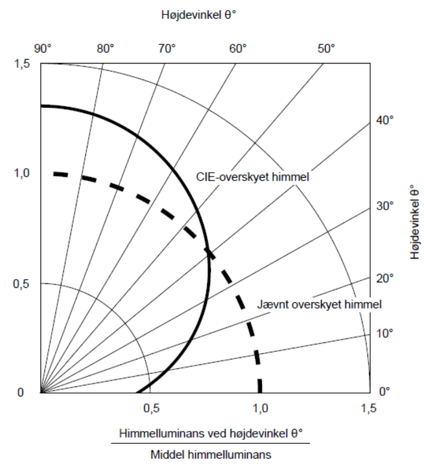

Figure 5 - CIE overcast sky in comparison with an even overcast sky. Figure from SBi 219.

Figure 5, represents the variations between a CIE overcast sky and an even overcast sky according to their height angle at the same average luminance.
The figure illustrates how the Zenith, placed in the middles, spreads out towards the horizontal plane.

[14] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)
[15] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 26)
[16] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)
[17] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)
[18] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)

As a quick method to calculate the light intensity of an overcast sky on a horizontal plane, according to the suns height the following formula can be used:

$E_H = 500 * \theta$[19]

Where θ represents the suns heights in degrees.

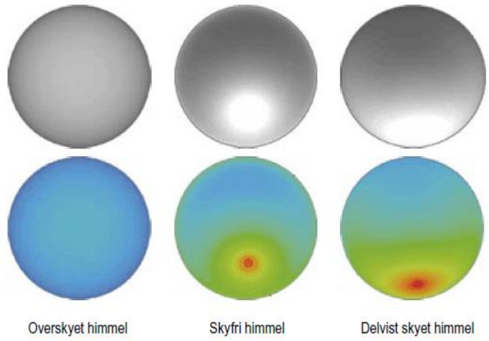

Figure 6 - 3 CIE skies: first picture of an overcast sky, second of a clear sky and third of a partially clear sky (CIE, 2003). Figure from SBi 219.

CIE clear sky is defined by a totally cloudless sky, but it doesn't received luminance from the sun. The clear sky has a complex luminance distribution that is uneven. Clear sky represents the light that got through diffusion and scattering of the atmosphere and changes with the sun's position.
For this situation, the higher luminance can be found around the sun, and the clear sky is known for having a higher luminance for the horizontal luminance than the zenith luminance. [20]

For a horizontal surface can be calculate as such:

$E_H = 1100 + 15500 * \sqrt{\sin\theta}$ [21]

This formula is only for a clear sky without direct solar radiation.
CIE partially clear sky, is calculated as such:

$E_H = 1200 * \theta - 2800$ [22]

θ is the solar height, in degrees ($8 < \theta < 50$)

2.1.1. Daylight on a window

The requirements for daylight in a building are becoming increasingly restricted because of the emphasis that is has. Windows have become more than an esthetical element, they can also be used as a source of light and compensate for the purpose of achieving the light requirements. Using the daylight is such matter can have benefits for the indoor climate and as a result the electricity provided to the electric lighting can be optimized.
It is proven that the electric lighting is up to 30% of the sum of electrical consumption in the public sector and private offices. [23]

Before placing a window, an important aspect is the façade. Its purpose is to assure a good energy frame, protect from the outside climate, and at the same time allow enough daylight

[19] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 26)
[20] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 27)
[21] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 27)
[22] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 28)
[23] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 7)

access through the window openings, view to the surrounding, also protect from overheating and glare.
The openings in some cases should be designed to include natural ventilation or hybrid ventilation solutions. No matter what functions are prioritized first for the façade, the design of it has an influence on both indoor climate and the energy balance of the building. [24]

The daylight intake described in Figure 4, would often be reduced by the shadows created by surroundings and neighbour buildings. [25]

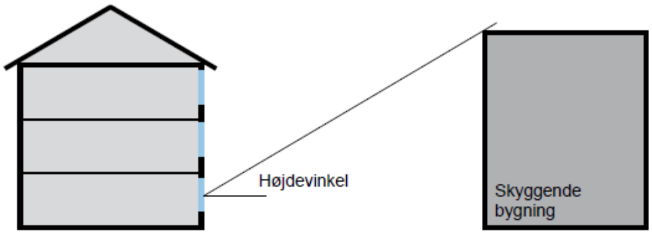

Figure 7 - Shadowing created by a neighbor building. Figure from SBi 219.

Figure 7, illustrates the shadowing created by a nearby building in front of the one that needs to be calculated. The angle of calculating the shadowing factors is measured in the middle of the glass. As a guideline, according to SBi 219, if an angle from an adjacent building is larger than 20° then the daylight is quite critical. [26]
Other factors such as surrounding (trees) and solar shadings will also limit the daylight access that reaches the glass area.

Figure 8, represents how much the daylight factor is reduced behind the glass according to the angle that the CIE overcast sky hits a vertical or horizontal plane opening. On a horizontal opening, approx. 2/3 of daylight comes in between 90-45° angle.
On a vertical plane opening, approx. 2/3 of daylight illuminance come in between 0-45°.

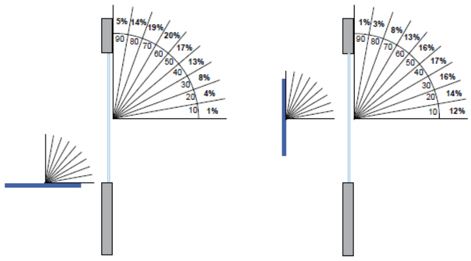

Figure 8 - Daylight reduction in a percentage according to the angle shadowing, for a CIE overcast sky, for a horizontal plane, and a vertical plane opening. Figure from Bygningsreglementets vejledning.

Buildings shape, orientation and depth also represents a parameter that can influence the daylight factor. A rooms depth should therefore not be too big, and work placements should not be placed further than 5-6 meters from the façade. The deepness of the room is decided by the windows size, but the rooms shape, and furniture also can have an impact on the daylight.

There is an effective method to check the rooms depth by calculating it. Figure 9Figure 9 represents the general rule developed by experts.
This calculation would determine the greatest distance from the window that the room can have. [27]

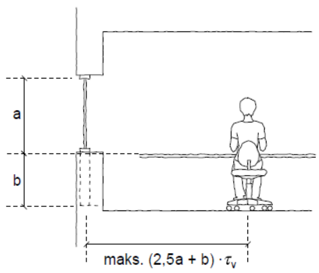

Figure 9 - Depth of room calculation principle. Figure from SBi 219.

[24] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 35)
[25] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 29)
[26] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 30)
[27] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 33)

2,5 * (Top of window – table height) + 1 * (the thickness of the frame under the table) * 0,79 = how deep the room can be in meters

This rule of thumb is applied to small offices, where the rooms width is larger than the length. In deeper rooms it can be challenging to get enough daylight in the back of the room, without creating discomfort from glare caused by the large illuminance next to the window, while creating a drastic contrast from higher to lower intensity daylight. The back of the room will therefore need to be supplemented with electrical lighting. [28]

From the early stages an understanding of the room, help architects determine how much daylight it might achieve. Decisions such as buildings shape, location and orientation are important. Moreover, when considering the interior parameters such as depth of the room from the window opening. The window glass size of an opening contributes to the amount of daylight reaching the room. [29]
More about the **orientation** of the window opening and how does daylight and solar radiation impact the window's glass, can be found under 2.1. Daylight.

Window size, as shown in Figure 9, a rule for smaller offices with a horizontal window opening can be applied. Though that rule doesn't take into consideration trees, or surrounding buildings that could create shadows. When specifying the window size, there are 2 distinctive parameters that need to be considered. Those are the window area and glass area. That is because the frame around the glass also takes a certain percentage out of the area of the glass. When calculating the rules described in the Danish Building Regulation the glass area is proportioned to the floor area. The height of the window especially for deeper spaces is very important. [30]

Window shape and placement is defined by the height of the window on the façade. The higher the placement of the window on the external wall, the deeper the daylight spreads across the room, while evenly spreading daylight. A higher window placement can also create glare and discomfort because of the direct solar radiations, while a lower place window will create a comfortable daylight for the workplaces close to the window.
The shape of the window opening influences the distribution of daylight in a room.
By using lighter colors on the window frame, the glare inside can be reduced. While darker colors on the window frame can cause a contrast between the window and surrounding, therefore more discomfort from glare can be caused.

Horizontal window placed on a façade, the daylight level will decrease from the intensity it has closer to the window as it goes into the room. That is because daylight direction is an oblique downward component. With the help of the reflectance of the surfaces in the room, can daylight provide an appropriate spreading of the light.
In a room after passing the window opening, daylight would reflect into the floor, as well as other horizontal and vertical surfaces close to the window. The ceiling would receive a reflectance from the ground and surrounding, while the back of the room would get daylight from the reflectance of the surfaces inside the room. [31]

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[28] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 34)
[29] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 35)
[30] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 36)
[31] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 38)

A **skylight** is an opening placed on a horizontal plane for example in a roof construction where daylight reaches the room from the top. The placement of a skylight should be carefully considered, in such a way that reflected daylight on the horizontal planes could be reflected further without creating a visible contrast in the room. A skylight should be used to supply daylight from a window place in a façade so that the daylight could get a better distribution in the room. [32]

View to the surrounding is also an element that is required from the Danish Building Regulations for a person to experience the feeling of outdoor environment. Elements such as knowing the changes in the weather and time of day are significant when considering the view to the surroundings. Window distributions on a façade, and their size and shape can have an impact on this parameter. [33]

Window type and solar shadings. Danish climate because of its variety requires on some of the orientation solar shades, to control the daylight and solar radiations that get into the room.
Larger windows require efficient solar shades, where daylight intake can be controlled, while avoiding unwanted glare and resulting in a decreasing amount of solar energy radiations. Solar shades should not exclude daylight from coming into the room and then overcompensating its lack by using electrical lighting. Solar shades represent a crucial element in controlling the thermal indoor climate and energy usage. When dealing with solar energy radiations loads, there are 2 ways the issue can be handled. One is by reducing the windows glass size, but that will reduce the amount of daylight that penetrates the room and the second option would be applying solar shades. [34]
According to SBi 219, larger windows that predominate from the facades area, are recommended the use or solar shadings.
The adjustable solar shades can protect more effectively against solar energy radiations, while allowing as much daylight to pass through the room. When placing the solar shades, the ones placed on the external side, are more effective than the ones placed inside. [35]
The solar shades with higher light transmittance area, are reflecting more daylight that will go through the window's glass. [36]
Openings towards east, south and west usually require an effective solar shade. Window openings do not only let daylight to transmit into the building but also allow solar energy radiations to overheat the room. Therefore, it is important to consider all parameters when designing a window opening. [37]
A solid solar shade reduces the daylight access into the room permanently.

Direct solar radiations can also create the glare effect and be perceived as disturbing. That can happen when the higher illuminance from the direct solar radiations gets in contact with a surface. For example, in working places, a computer. In this example, a solar shade should be considered. [38]

[32] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 40)
[33] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 41)
[34] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 43)
[35] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 43)
[36] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 43)
[37] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 44)
[38] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 47)

2.1.1.1. Window element

U-values of a window

The unit for a U-value is W/m^{2}K. A U-value, also known as thermal transmittance, is the rate of transfer of heat though a building part, divided by the difference temperature from inside and out. It is known that a lower u-value means that it's a better insulated element. [39]
A method of how to calculate u-values for window is:

$$U = \frac{\mathrm{Ag} * \mathrm{Ug} + \mathrm{lg} * \psi\mathrm{g} + \mathrm{Ap} * \mathrm{Up} + \mathrm{Af} * \mathrm{Uf} + \mathrm{lk} * \psi\mathrm{k}}{Ag + Ap + Af}$$

Ag is the glass area in m^2
lg is the perimeter around the glass in m
Ap is the panel area in m^2
Af is the frame area in m^2
lk is the length of line losses for cold bridges in m
Ug is the thermal transmittance in the middles of the glass in W/m^{2}K
Ψg is the line loss cold bridge for glass distance profile in W/mK
Up is the thermal transmittance for the filling in W/m^{2}K
Uf is the thermal transmittance for the frame in W/m^{2}K
Ψk is the line loss of other cold bridges in W/mK [40]

Elements that need to be considered before calculating a U-value:
- Window type (glass, plastic, how many layers of glass, what's the filling between glass)
- Frame material (wood, metal etc.)
- Opaque panels in the windows [41]

Glass fraction (F_F)

Glass area is the representative of how much the glass out of the entire window area, is the actual glass area. It is calculated by subtracting the window frame are from the total area of the window. Each window needs to have its own calculation of how much glass area they have. Usually it is expressed in a percentage. [42]

[39] (Lymath, 2015)
[40] (Dansk Standard, 2011, s. 32)
[41] (Dansk Standard, 2011, s. 33)
[42] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 63)

Daylight transmittance (LT)

The light transmittance of the window is measured in the middle of the window. When designing a window, the Danish Building regulations should be overhold regarding the energy frame calculations. It is recommended to choose a window with a higher light transmittance.[43]
As illustrated in Figure 10, with blue color that is the daylight on a glass. Daylight when in contact with the glass, splits in 3 parts. One part will be transmitted through the glass, another part will be absorbed along the way by the materials, and the last part, shown as LR_{ud} is the light that gets reflected into the surroundings.
Represented with the yellow color, in Figure 10, is the solar energy, where the same principle as the daylight applies.

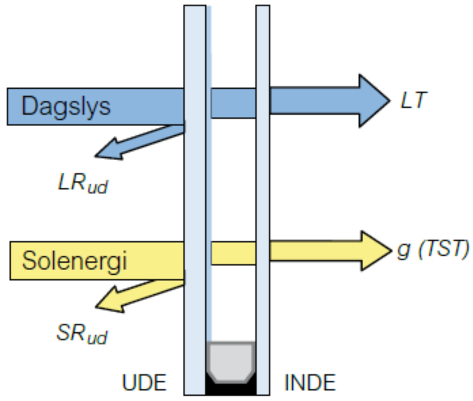

Figure 10 - Transmittance and reflections on a 2 layers window. Figure from SBi 219.

Windows solar energy transmittance (g-value)
The g-value is by the solar heat load that is transmitted through a windows glass area.[44]
As seen in the figure Figure 11, in an office building, it is expected that the solar heat load transmitted into the room in the summer season should be low and that can be achieved by a lower g-value. The figure illustrates the situation for both summer and winter.

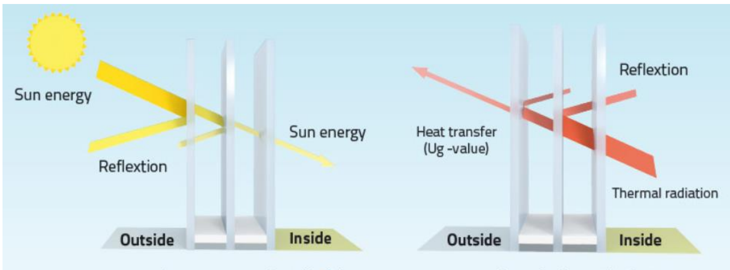

Figure 11 - Visualization of a windows property. Picture from https://www.pana.hr/en/proizvodi/dodatna-oprema/staklo/.

2.1.1.2. Solar shades

The demands are getting tighter for solar shades, because of the necessity of controlling daylight and the solar energy that comes through the windows. The larger windows require an effective shading solution because of the solar radiations and glare disturbance.
The solar shades should only reduce the solar radiations when needed and protect from glare, but in the same time, daylight should not be totally closed from reaching the room.
The window size has an impact on both the indoor climate as well as the energy consumption. When working with larger windows, or façade that are out of glass, it's important to reduce the solar radiations and to have the opportunity to control the daylight coming into the office in the cloudy days.
Controlling these factors can be made with a solar shading. Solar shadings are more effective when placed outside the building, because in that way they reach the solar radiations before the window. This way it won't get to warm inside the room.

[43] (Dansk Standard, 2018, s. 45)
[44] (Søren Aggerholm, 2016, s. 45)

Solar shades should also be designed in such a way that they won't obstruct the view to the surroundings.
Solar shades can influence the thermal indoor climate by reducing the solar radiations and maintaining a balanced indoor climate temperature; by changing the solar radiations temperature when reaching an indoor building part; also, by assuring that people or surfaces don't get in contact with direct solar radiations. [45]
As a rule of thumb, it is described in SBI 264, that if the inside measurement of the window represents more than 30-35% of the facades area, then outside solar shadings are recommended.

When choosing or designing the solar shades the following criteria should be considered:

- Opacity control
- Glare control
- Night privacy
- Visual to the surroundings and outside
- Daylight utilization
- Seeing the colors [46]

Solar shades can be found in different shapes and they all have specific properties.

Shadings from the external sides of the windows
As illustrated in Figure 12. Mostly recommended for east and west orientate window openings to reduce the solar radiations from south on the middle of the day. They can be integrated into the design by a column, or a horizontal element. This solution also reduces the daylight with a factor of 0,8-0,9. They only protect against glare a part of the day, and not the entire day. The heat reduction that comes from the solar energy radiations is greater in the winter period. [47]

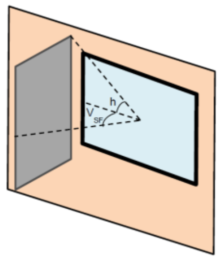

Figure 12 - Shadings from the side of the window. Figure from Bygningsreglementets vejledning om korrektioner til 10 pct.-reglen for dagslys.

Shadings from the top of the window
This solution is recommended for avoiding the direct solar radiations especially when the sun is highest. The orientation that is best suited for this solar shading is south-east, south-west and south, if the shadings from the top are made with a solid material, that could reduce the daylight. Solar shades affect the solar energy transmitted into the room, creating a better thermal indoor climate by reducing overheating from solar energy radiations. The disadvantage is that they obstruct the view to the surroundings. [48]

Light shelves on the window
A horizontal light shelve is designed to shadow the area closer to the window and reflect the daylight deeper in the room by reflecting it to the ceiling and then further into the space. Usually is mounted on the window, at a minimum height of 2 meters, in such a way that it divides the opening in 2 zones. One zone that will create shadow and another that will reflect daylight into the room. [49]

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[45] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 21)
[46] (Dansk Standard, 2005, s. 12)
[47] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 44)
[48] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 52)
[49] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 53)

Recommended for south-east and south-west orientate window openings.
It might reduce the daylight, but it creates a good spread into the room of daylight. The reflection factor isn’t optimal in the winter period, but it reduces daylight.
As for the thermal indoor climate can benefit in the winter from the lower solar height and get more solar energy radiations. [50]

Awning

An awning solar shade can be used towards all 4 orientations. The challenge that most awnings have is that the solar radiations can pass through the sides of it, but that can be avoided if the awning has a side coverage.
If the sides are being close, then a warm air will gather under it. [51]
Most of the daylight reaching inside the room, will be reflected from the ground. A translucent awning will create a diffuse light inside the room, while a colored awning will reflect the color inside the room.[52]

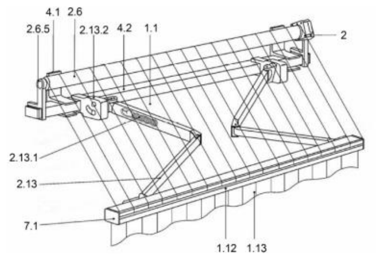

Figure 13 - Awnings illustration. Figure from DS/EN 12216.

Most daylight can be achieved when the awning is folded in. When is folded out, it disturbs the view to the surrounding, that being the sky element.
They don’t fully function on windy days and require maintenance once a year. [53]

Lamella solar shades

Lamella solar shades can be used in all 4 orientations to reduce solar radiations. They can be found in vertical or horizontal model, also can be place outside, inside or even between 2 layers of the glass in the window. Their role is not only to reduce solar radiations, but also to control the daylight, minimize the glare and other disturbances.
The placement of the lamella and their angle can describe how effective they are to reduce solar radiations. [54]
The most recommended solutions are the external blinds that can be controlled according to the angle and be pulled up completely when necessary.[55]
Because lamella solar shades can reduce the intake of daylight on a window, it is therefore important to choose lighter types then darker ones, so that solar shades are not excessively suppressed. If lighter lamella is chosen, a lower reflectance should be chosen, so they don’t create glare. [56]
The solar energy radiation can be reduced to 0,2 kW for a solar shade with an angle of 0° for external lamella with a light transmittance of 0,5. [57]
Regarding daylight, if a solid lamella solar shade is chosen the daylight will be permanently reduced. Otherwise a system that can be controlled or fully removed are mostly recommended because they can get most daylight and reduction of solar energy radiations. [58]

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[50] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 59)
[51] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 61)
[52] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 62)
[53] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 65)
[54] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 65)
[55] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 71)
[56] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 71)
[57] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 66)
[58] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 68)

Regarding the view to the surrounding, this depends a lot of the type of lamella if they are solid or not, their angle, and the distance between them. The highest factor can be achieved by the lamella that can be controlled by its users. [59]
They also require maintenance for once a year.

Screens
Screens can be used towards all 4 orientations, and they can be used on the outside, inside, or in between the layers of glass in the window. They are usually designed to have the possibility to get fully folded up or partly.
As any solar shades, the external types are always more effective than the ones placed inside.
A light curtain, with a solar reflected material can come as down as 0,1 kW. A darker curtain will need a ventilation system, because of the temperature difference.
Interior screens should always be lighter on the external side, so that solar radiations will reflect outside. Solar shading factor usually is between 0,4 - 0,7. [60]
Regarding daylight intake, it all depends on the light transmittance of the screen, the opening between, color and structure. The light transmittance is higher for a lighter screen than the darker ones. They don't require much space and can be a part of the façade or window. [61]

2.1.1.3. Window Corrections factors

The corrections factors are in correlation with the Danish Building Regulation 2018, guidelines for correcting for the 10 percent calculation methods. The 10 percent rule is described to be a minimum demand that needs to be achieved.
The documentations are usually applied on the most critical rooms in a building, where further analysis needs to be taken. The floor area decides what the minimum size of the window's glass should be.
Correction factors that apply to the glass area, are the parameters that reduce the daylight into the room, by shadowing. The glass area should be corrected for all the parameters that create shadows or disturb the daylight access into the room. The glass area after the corrections should be minimum equally with the minimum glass area for the room. [62]
Glass area is calculated as the total window area, minus the frame, panels areas; This area should be 10%.

The minimum glass area is calculated as:

$$A_{G,min} = 0,1 * A_{floor}$$

$A_{G,min}$ is the minimum glass area that needs to be achieved for a room, including the correction factors. So, when calculation the 10 percent rules, the parameters that have an impact or create a shadow on the window, need to be multiply with the actual glass area ($A_{Gvin,I}$), and the result represents the actual glass area for the window, that is corrected for all the shadow giving parameters.

Reduction factors are decided for an overcast CIE sky which is representative for the most critical daylight situation.

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[59] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 69)
[60] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 77)
[61] (Johnsen, SBI-anvisning 264 Solafskærminger, 2006, s. 82)
[62] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 5)

The glass area needs to be multiplied with all the shadowing giving parameters relevant for the window in order to be corrected for the daylight. This can be done as such:

$A_{Gkor,i} = F_{LT} * F_{VÆG} * F_{OMG} * F_{OH} * F_{SF} * F_{AFS} * F_{ATR} * F_{RUM} * F_{FL} * F_{OVLYS} * A_{Gvin,i}$
$= F_{G,kor,i} * A_{Gvin,I}\ m^2$

$A_{Gkor,i}$ = is the actual glass area for the window that is corrected for all the shadow giver parameters.
$A_{Gvin,I}$ = is the actual glass area of the window
$F_{G,kor,i}$ = is the result of all the relevant correction factors for the window
F_{LT} = Factor for glasses light transmittance
$F_{VÆG}$ = Factor for wall thickness
F_{OMG} = Factor for the surroundings
F_{OH} = Factor for an overhang over window
F_{SF} = Factor for side shadowing of the window
F_{AFS} = Factor for solar shades
F_{ATR} = Factor for glass in the windows facing an atrium
F_{RUM} = Factor for deepness of rooms
F_{FL} = Factor for windows placed on more surfaces
F_{OVLYS} = Factor for glass in a skylight

2.1.1.3.1. Correction for the glass light transmittance

A windows light transmittance is provided by manufacturers. This is the daylight radiation that is measured in the middle of the window perpendicularly. The reference light transmittance is set to 0,75. If the window chosen, has a lower or higher value, that should be corrected. [63]

$F_{LT} = LT_{akt} / LT_{ref}$

LT_{ref} = is 0,75, that is used a reference
LT_{akt} = is the actual light transmittance

2.1.1.3.2. Correction for the thickness of the external wall

Because of the energy frame demands have increased considerably the last years, the wall thickness became thicker and thicker as the insulation layer increased. Depending on the window size, and thickness of the wall this factor can have an impact on the daylight reduction factor.
It can be problematic to have a small or narrow window in a thicker wall construction.

Wall thickness, m	0,3	0,4	0,5	0,6	0,7	0,8
Glass area ≤ 0,5 m^2	1,00	1,00	0,81	0,65	0,51	0,50
Glass area 1,0 m^2	1,00	1,00	0,91	0,80	0,67	0,56
Glass area 1,5 m^2	1,00	1,00	0,96	0,88	0,76	0,65
Glass area 2,0 m^2	1,00	1,00	1,00	0,95	0,83	0,71
Glass area ≥ 3,0 m^2	1,00	1,00	1,00	1,00	1,00	0,91

Table 1 - Correction factor for wall thickness[64]

[63] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 8)
[64] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 9)

For example, if there is a room that is 10 m^2 and has a glass area, A_{Gvin}, of 1,5 m^2 on a wall thickness of 0,5m, the $F_{væg}$ will therefore be 0,96 according to Table 1.
Explained in BR18, the minim glass area will result to 1,0 m^2. ($A_{G,min} = 0,1 * A_{floor}$)
$A_{G,kor} = F_{VÆG} * A_{Gvin} = 0,96 * 1,5\ m^2 = 1,44\ m^2$
1,44 m^2 is bigger than the minim glass area of 0,5 m^2. Therefore, after the correction this example is still achieving the demands.

2.1.1.3.3. Correction for shadows from the surroundings

The shadows from surroundings can be from neighbor buildings that created an angle shadow on the window on an elevation as illustrated in Figure 7. That is measured on a horizontal plane from the center of the windows glass to the upper edge of the neighbor building. The daylight reduction factor will therefore be higher on the lower floors.
As illustrated in Figure 14, the shadow from parallel buildings are calculated as an average of the profile angle from the other buildings. Angles should be calculated ± 45° from a vertical plane from the middle of the window glass until the corner. Higher angles than 45° should not be taken into consideration, because everything higher than that will get a reduction factor of 0,5. [65]

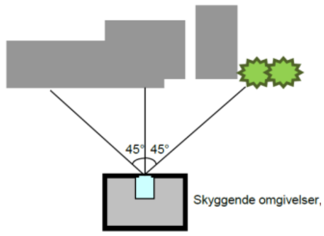

Figure 14 - Shadow from surroundings, location plan. Figure from Bygningsreglementets vejledning om korrektioner til 10 pct.-reglen for dagslys.

The angles are calculated as an average of all angles, and that value is corrected.
The following table has been provided from BR18 guidelines to define the correction factor from the surroundings:

Reduction factor for shadow from the surroundings												
Profile Angle, V_h	0 °	10 °	15 °	20 °	25 °	30 °	35 °	40 °	45 °	50 °	55 °	60 °
Correction factor	1,00	1,00	0,95	0,91	0,84	0,77	0,66	0,55	0,50	0,50	0,50	0,50

Table 2 - Correction factor table for shadows from the surroundings[66]

2.1.1.3.4. Correction for an overhang over window

The overhang over the window glass reduces the daylight mostly at the top of the window, by blocking a part of the daylight that comes into the room. The overhang can smoothen the light transmitted into the room by achieving a more even daylight distribution.
The angle from Figure 15, is used when the overhang is very long, and the edges on the sides are unknown.
According to the V_{OH} angle by the using Table 3, the correction factor can be chosen for the specific angle projection.

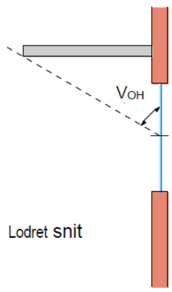

Figure 15 - Section of an overhang over windows glass. The angle is measure from the center of the glass until the edge of the overhang and it's noted as V_{OH}. Figure from Bygningsreglementets vejledning.

[65] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 10)
[66] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 11)

Angle V_{OH} projection	0 °	15 °	20 °	25 °	30 °	35 °	40 °	45 °	50 °	55 °	60 °	65 °
Correction factor	1,00	1,00	1,00	1,00	0,95	0,89	0,80	0,70	0,60	0,55	0,50	0,50

Table 3 - Correction factor for an undefine length over the window.[67]

The overhang can be considered too long and Table 3 can be used for correction, if the angle created from both sides is a 60° angle or larger, as seen in Figure 16.

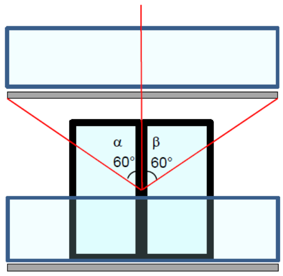

Figure 16 - Overhang over window glass for an angle larger than 60°. Figure from Bygningsreglementets vejledning

If the angle is uneven and under 60° angle from the center of the glass as illustrated in Figure 17, then the angle α and β, will be measured and corrected after those angles. If the overhang is passing the center of the glass, then the result can also be negative. Table 4, should be used to determine the correction factor.

V_{OH} 30 °		α								
		-20°	-10°	0°	10°	20°	30°	40°	50°	60°
β	-20°									1,00
	-10°								1,00	1,00
	0°							1,00	1,00	1,00
	10°						1,00	0,99	0,99	0,98
	20°					1,00	0,99	0,98	0,98	0,97
	30°				1,00	0,99	0,98	0,97	0,97	0,96
	40°			1,00	0,99	0,98	0,97	0,97	0,97	0,96
	50°		1,00	1,00	0,99	0,98	0,97	0,97	0,96	0,95
	60°	1,00	1,00	1,00	0,98	0,97	0,96	0,96	0,95	0,95
V_{OH} 40 °		α								
		-20°	-10°	0°	10°	20°	30°	40°	50°	60°
β	-20°							1,00	1,00	1,00
	-10°						1,00	1,00	1,00	1,00
	0°					1,00	0,99	0,98	0,96	0,95
	10°				1,00	0,98	0,95	0,95	0,92	0,90
	20°			1,00	0,98	0,95	0,92	0,90	0,88	0,87
	30°		1,00	0,99	0,95	0,92	0,88	0,86	0,85	0,85
	40°	1,00	1,00	0,98	0,95	0,90	0,86	0,84	0,83	0,81
	50°	1,00	1,00	0,96	0,92	0,88	0,85	0,83	0,80	0,80
	60°	1,00	0,99	0,95	0,90	0,87	0,85	0,81	0,80	0,80
V_{OH} 50 °		α								
		-20°	-10°	0°	10°	20°	30°	40°	50°	60°
β	-20°						1,00	1,00	0,99	0,97
	-10°					1,00	0,98	0,95	0,93	0,92
	0°				1,00	0,96	0,92	0,89	0,86	0,83
	10°			1,00	0,95	0,91	0,86	0,83	0,80	0,77
	20°		1,00	0,96	0,91	0,86	0,81	0,77	0,75	0,72
	30°	1,00	0,98	0,92	0,86	0,81	0,76	0,73	0,70	0,67

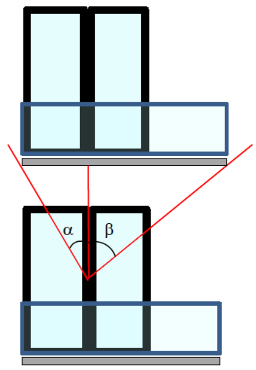

Figure 17 - Uneven overhang over window glass. Figure from Bygningsreglementets vejledning

[67] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 12)

	40°	1,00	0,95	0,89	0,83	0,77	0,73	0,69	0,66	0,65
	50°	0,99	0,93	0,86	0,80	0,75	0,70	0,66	0,63	0,62
	60°	0,97	0,92	0,83	0,77	0,72	0,67	0,65	0,62	0,60

Table 4 – Correction factor for an uneven overhang defined by the angle V_{OH}, α and β. A negative value means that the angle passes the center of the glass. [68]

2.1.1.3.5. Correction for side shadowing of the window

This type is significant for building in an L-shape or a building with more angles that reduces daylight from the buildings shape. That could be 50% daylight reduction or more. The ground floor level are the levels where the daylight reduction is the most critical. [69]

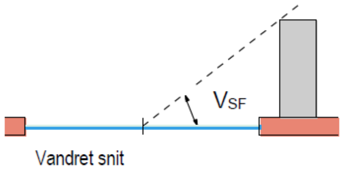

Figure 18 - Illustrates the angle V_{SF} that is measured on a plan, from the center of the window until the corner of the shadowing element. Figure from Bygningsreglementets vejledning

Same principles as in the correction for an overhang applies. The angle V_{SF} measured on a horizontal plan from the center of the window to the corner that creates the shadowing on the side, is calculated with a reflectance of 0,2 and if height is unknown, then the following table can be used to define V_{SF} correction factor.

Correction from shadowing from the side of the window										
Angle V_{SF}	0 °	10 °	20 °	30 °	40 °	50 °	60 °	70 °	80 °	90 °
Correction factor	1,00	0,97	0,93	0,88	0,83	0,78	0,72	0,66	0,59	0,53

Table 5 - Correction angle V_{SF} [70]

As illustrated in Figure 12, if the height of the element is known, then another table needs to be used for the correction factor where the height is expressed on the façade on a vertical plane in an angle from the center of the window to the top of the overhang.

Correction from shadowing from the side of the window when the height is known											
Height of projection		V_{SF} angle									
	h	0 °	10 °	20 °	30 °	40 °	50 °	60 °	70 °	80 °	90 °
	40 °	1,00	0,97	0,94	0,91	0,88	0,85	0,82	0,79	0,76	0,74
	60 °	1,00	0,97	0,94	0,90	0,85	0,80	0,75	0,70	0,64	0,59
	80 °	1,00	0,97	0,93	0,88	0,83	0,78	0,72	0,66	0,59	0,53

Table 6 - Correction factor when the height angle is known and the V_{SF}. [71]

An overlapping shadow correction can also be made for windows that are smaller placed in a thicker façade construction with a shadowing from the side and the window placement in the wall.

2.1.1.3.6. Correction for solar shades

Solar shades have an impact on the design of the building, but also on the thermal indoor climate. Solar shades can reduce the daylight from direct solar radiations, while reducing the glare effect and considerably influencing the amount of daylight reflected into the room.

[68] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 14)
[69] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 16)
[70] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 16)
[71] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 17)

Fixed solar shades placed externally from the window glass opening can reduce daylight with up to 40% reaching the room. This is the case for horizontal thin lamella placed in front on the window. In the following table it is observed the correction factors for lighter and darker lamella, and their light reflectance according to the angle they have. [72]

Correction factor for fixed lamella solar shades				
Lamella angle	0°	15°	30°	45°
Light lamella, RL= 0,8	0,60	0,52	0,42	0,30
Darker lamella, RL=0,2	0,50	0,38	0,26	0,12

Table 7 - Correction factor for fixed lamella solar shades[73]

If the lamella solar shades can be turned and change their angle, then the reduction factor should be calculated for the most open situation of them.

Figure 19, shows how the angle of fixed solar shades for lamella are calculated in the correction factor table.

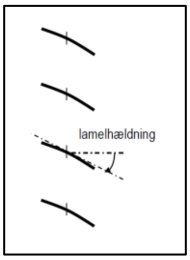

Figure 19 - Lamella angle. Figure from Bygningsreglementets vejledning

2.1.1.3.7. Correction for glass in the windows facing an atrium

Atriums are made sometimes to create more working places that have daylight access. The daylight reaching through an atrium is lower than the daylight from a window places in vertical façade.
The lower levels in an atrium usually only gets daylight reflected from surfaces in the atrium. [74]

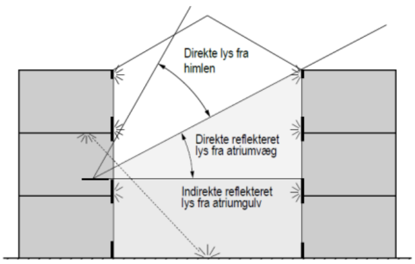

Figure 20 - An atrium daylight distribution. One part comes from the direct light from the sky, another part from the reflected wall surfaces in the atrium, and the last from the reflected floor in the atrium. Figure from Bygningsreglementets vejledning

The glass in the window facing an atrium can be calculate as such:

$F_{ART} = F_{G,kor} * F_{LT\text{-}tag} * F_{TAG}$ [75]

$F_{G,kor}$ is the correction factor for shading from surroundings and other parameters such as overhang or side shadowing on the window. When calculating this, the atrium is not considered as a covered part.
$F_{LT\text{-}tag}$ is the correction factor for the light transmittance of the transparent roof surface. This is given by manufacturer.
F_{TAG} Correction factor for the opening for the frame construction and loadbearing part of the roof.
If the roof height is not thicker than 0,6 meters, the following table can be used as a guideline:

[72] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 20)
[73] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 20)
[74] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 21)
[75] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 21)

Type of roof construction	Correction factor for roof construction F_{TAG}
Light roof construction	0,80
Medium roof construction	0,60
Heavy roof construction	0,40

Table 8 - Correction factor for roof construction when calculation the factor for a window towards an atrium.[76]

2.1.1.3.8. Correction for rooms with bigger depth from the window

In the situations that rooms are deeper that 5-6 meters from the window, then a larger contrast is created between the area closer to the window compared to the area furthers from the window.
In offices, if the room is deeper than 5 meters, a correction factor needs to be applied. If desks are placed furthest into the room, this needs to be corrected, as the daylight level decreases quite fast from the window opening and into the room. Also, when employees are working more than 6-8 meters from the window, they tend to be unsatisfied by the indoor climate environment. [77]
As an indication factor the following Table 9 is been given from BR18 as a guidance.

Correction factor for deeper rooms, F_{RUM}				
Working place depth, meters	5,0	6,0	7,0	8,0
Correction factor	1	0,9	0,77	0,64
Minimum glass area per m façade, m^2	0,5	0,6	0,7	0,8
Necessary glass area % out of the net floor area	10	11,1	13,0	15,6
Necessary glass area per m façade, m^2	0,50	0,67	0,91	1,25

Table 9 - Correction factor for deeper rooms[78]

2.1.1.3.9. Correction for skylights and windows placed on more surfaces

Skylights receive more daylight then the windows placed on the facades, therefore the glass area for a skylight has a correction factor of F_{OVLYS} = 1,4 if the skylight is placed on an angle of 60° from a horizontal angle or lower than that. [79]

When placing window openings on more external walls or roofs, the contrast in the room gets reduced, in which case the correction factor multiple surfaces can be applied.
This rule applies only if the areas of the glass corrected between the smallest and largest corrected glass area in 2 surfaces is at minimum 0,3. The correction factor multiple windows places on external walls and roof is F_{FL} = 1,2. [80]

2.1.1.3.10. Documentation of correction factor

The method described should be applied for all the rooms that are critical in a building and all the windows in those rooms. Table 10, should be used as a documentation for all the correction factors that are necessary on the windows. [81]

[76] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 21)
[77] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 22)
[78] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 22)
[79] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 23)
[80] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 23)
[81] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 24)

Type 1	Parameter	Information	Units	Symbols
Room and area identification	Building	Id.		
	Floor	Number		
	Room	Id.		
	Net floor area		m^2	A_{floor}
	Windows area		m^2	$A_{vin\ i}$
	Glass area		m^2	$A_{G,vin\ i}$
Correction factor for	Window type			F_{LT}
	Wall thickness			$F_{\text{VÆG}}$
	Surroundings			F_{OMG}
	Overhang over window			F_{OH}
	Shadowing from the side			F_{SF}
	Shades from solar shades			F_{AFS}
	Window glass orietanted towards atrium			F_{ATR}
	Deepness of the room			F_{RUM}
	Windows on more surfaces			F_{FL}
	Skylight			F_{OVLYS}
Results of the correction factor				$F_{G,kor,i}$
Glass area correction			m^2	$F_{G,kor,i} * A_{G,vin\ i}$

Table 10 - Documentation for glass area correction.[82]

2.1.2. Daylight in a room

The daylight is described as brighter near the window and then rapidly decreases while furthering away from the window, into the room. When calculating the daylight, the reference plane is set to 0,85 above the floor. The daylight access comes from the free, into the room through a window glass, and some of it will have contact with the rooms surfaces before it reaches the task area. [83]

The contribution of daylight inside a room comes from the followings:

- Direct daylight from the sky
- Reflected daylight from the surfaces outside the room (surrounding buildings)
- Reflected daylight from the surfaces inside the room (walls, floors, ceiling, furniture, equipment etc.) [84]

The daylight that comes into a room should be adjusted to the task that needs to be proceed in the room. Daylight has an impact on how people perceive space, their wellbeing and their senses, therefore the right window placement, size, and correction factors are important. [85]

[82] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 25)
[83] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 50)
[84] (Jens Christoffersen, 2002, s. 8)
[85] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 50)

Daylight factor

This factor defines how much daylight it will reach into the room and its described by the daylight factor.
The daylight factors (DF) unit is a percent, and it represent the relation between the daylight intensity of a horizontal plane outside and the actual intensity on a reference plane inside the room.
For example, the daylight intensity outside is 10.000 lux, and if the daylight inside is 200 lux, that will represent a 2 percent.

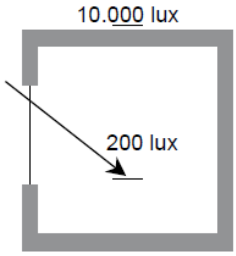

Figure 21 - Daylight factor definition – Figure from Sbi 219.

$DF= E_{indoors}/E_{outdoors} *100\%$ [86]

$E_{indoors}$ = the illuminance at a target point inside the room (lux)
$E_{outdoor}$= the daylights illuminance measured on a horizontal plane outside, in the free (lux)

When calculating daylight in a room, the worst-case scenarios must be considered, as for when a sky is overcast. A CIE overcast it's the most accurate to simulate with when determining the daylight factors. [87]

To calculate the daylight factor, the 3 elements that add to this, need to be summed. The daylight that comes directly from the sky, the externally reflected components from surroundings, and the internally reflected components.

DF= SC + ERC + IRC

SC = Sky component
ERC = Externally Reflected Component
IRC = Internally Reflected Component

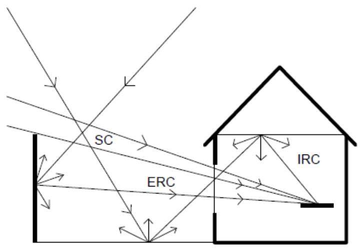

Figure 22 - Illustrations of the factors that create the daylight factor. Figure from Sbi 219.

The daylight inside a room can be affected by many factors, such as:

- Placement of the window, for example on the wall or on the ceiling
- The rooms geometry
- The daylight that comes from the window
- The reflectance of surfaces
- The furniture in the room [88]

[86] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 51)
[87] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 25)
[88] (Jens Christoffersen, 2002, s. 9)

2.1.2.1. Surface reflectance in a room

When the daylight reached the internal surfaces, the light is divided into 3 parts. One part of the light goes into the material, also known as transmitted, another part goes into the material, also known as absorbed, and the last part is called reflected. The reflected light is representing a third part of the light that goes back into the room. [89]
If the material is not transparent, then only the first 2 parts happen with the element. [90]
The internally reflectance, is one factors that contributes to the daylight factor. When the daylight goes through a horizontal window the first elements it will reflect into will be the floor because they are vertical places; and afterwards the elements closest to the window (for example walls). The ceilings though get their reflected light from the earth surface. [91]

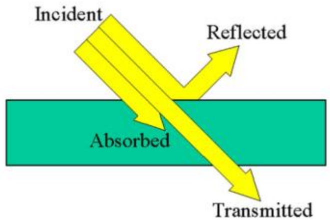

Figure 23 - Absorptivity, Reflectivity and Transmissivity principle (picture from:https://kaiserscience.wordpress.com)

The higher values, of reflectance are lighter colors, while the lower values represent darker colors.
For example, a white wall has a reflectance of 0,80-0,90; while a black wall has a reflectance on 0,05. More examples of colors of paint or different material finishes such as wood, tiles, linoleum can be found in SBi 219.

According to the Danish standards regarding Lighting of work places some recommended values have been given:

Celling	0,7 - 0,9
Walls	0,5 - 0,8
Floors	0,2 - 0,4
Furniture, machinery, objects	0,2 - 0,7[92]

2.1.2.2. Placement of window

The window plays the most important role in defining the daylight factor in a room. For example, if placing a window higher, it will spread light throughout the room, if it's placed lower, it will give very good light only for the nearby place closed to the window but might rarely deliver enough daylight through the room.

2.1.2.3. Furniture

The placement of furniture can have a significant change for the internally reflectance from the building parts. If the daylight reaches the furniture, and then reflects into the walls, it might reduce its values. [93]

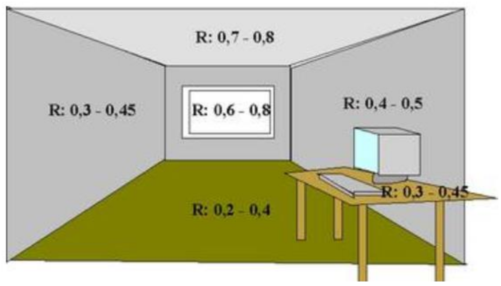

Figure 24 Reflectance of surfaces. From https://www.bfa-i.dk

[89] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 120)
[90] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 120)
[91] (Johnsen & Christoffersen, SBI-anvisning 219, Dagslys i rum og bygninger, 2008, s. 77)
[92] (Dansk Standard, 2011, s. 9)
[93] (Dansk Standard, 2018, s. 83)

A bookcase for example has a light reflectance of 0,3-0,4.

2.1.3. Demands and recommendations

In Denmark, daylight regulation requirements and view to surroundings can be found in the Danish Building Regulations, the Danish Working Environment Authority as well as the Danish Standards. The Danish Building Regulation is a demand and a minimum indication of what needs to be achieved, while the Danish Working Environment Authorities and Danish Standards are recommendations.
These regulations and recommendations are meant to help architects and engineers, design a building according to the standards that are available when the building is made. It is the architects and engineers' responsibility to assure that they are following the standards that are current at that time.

2.1.3.1. Danish Building Regulation 2018

The Danish Building Regulations covers requirements for daylight and view to the surroundings. According to the requirements the buildings must be designed in such a way that enough daylight and view to the surrounding must be ensured in order to achieve optimal comfort for the people residing in the room.
The following points have a significance when designing:

> *"1) Daylight must be utilized as a source of light to the extent it is possible.*
>
> *2) Unnecessary energy use should be avoided.*
>
> *3) Unnecessary transfer of heat to the rooms should be avoided.*
>
> *4) Nuisance from direct sunlight can be avoided.*
>
> *5) Blinding nuisance must be avoided. "*

(Trafik-, Bygge- og Boligstyrelsen, 2018)

2.1.3.1.1. View of the surroundings

When designing spaces that are meant for working, living rooms, or teaching rooms it must be designed with windows that can provide view to surroundings for people. Windows must be calculated and designed with solar shades to ensure a pleasant usage time.
When designing windows, the seasonal variations must be taken into consideration. In the summer months, the focus is to limit the high temperature, overheating from solar energy radiations and in autumn minimizing the risk of glare, due to low sun height. Solar shades are known to reduce visibility to the surroundings; therefore, a lot of consideration needs to be made when working with them. [94]

2.1.3.1.2. Daylight

The spaces designed for working, living room, kitchens, institutions or teaching rooms must have access to daylight to ensure enough daylight in the room. There are therefore different

[94] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §378)

factors that need to be considered such as location, orientation, the building or rooms shape, depth, as well as the surrounding buildings or environment.[95]
There are 2 methods to calculate daylight conditions in a room. The results need to be documentated to provide proof of minimum daylight conditions. These methods are:

1. The 10 percent rule requirement is applied on a room which should be documented and where the actual floor area and glass area for all the windows in the room are considered. The glass area in all the windows need to be corrected/adjusted by all shadowing factors. [96]
   In offices, the floor area is defined by the area where you can place workstations, also known as the place where you can work or have a desk. This area starts continuously from the windows and creates a net area into the room. The workplace area in offices is defined to be at 0,85 meters above floor level. [97]

   According to BR18 the glass area from the windows should cover a minimum of 10% of the floor area, while using the method described in paragraph 2.1.1.3. Window correction factors.

   Daylight calculations are determined on an overcast sky (CIE sky), for a more accurate daylight condition. This way some of the light will come from the sky and the rest will come from surrounding buildings, materials and terrain. [98]

2. The second requirement is to achieve a minimum of 300 lux illuminance target for at least 50% of the work plane.
   When calculating illuminance, the horizontal plane is placed at 0,85 meters above the floor and a grid is made to indicate the points where the illuminance is calculated. Therefore, it needs to demonstrate that the illuminance intensity from daylight in the grid connection points is obtaining 300 lux on half of the relevant floor area, for half of daylight hours in a year. [99]
   Simulations need to be made by using a climate date with The Design Reference Year DRY 2001-2010.
   Standard values of reflectance on surfaces are also described in the guidelines and these can be seen in the following table:

Surface	Reflectance
Ceiling	0,70
Walls	0,50
Floors	0,20
Glass surface	0,15
Window frame	0,70
Outdoor elements, terrain, trees etc	0,10
Surrounding buildings	0,20

Table 11 - Standard values for surface reflectance, guidelines [100]

[95] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §379)
[96] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §379)
[97] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §379 - §381)
[98] (Trafik-, Bygge- og Boligstyrelsen, 2019, s. 7)
[99] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §379 - §381)
[100] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §379 - §381)

2.1.3.2. Danish Working Environment Authority

2.1.3.2.1. View of the surroundings

From the working room, it must be possible to look at the surrounding through a window glass opening or a glass door opening. A view to the surrounding is described in the guidelines as being a view to the outside environment. In this situation a skylight cannot count as giving a view to the surroundings.
It is required that a working room has visibility to the outside environment through a window glass opening. Although, it is not a requirement for each individual work place to get that.
In some cases, it can be accepted that the employees from the room get a sense of the weather and the surrounding that can be achieved by glass partition wall for example. [101]

2.1.3.2.2. Daylight

According to the daylight recommendations from the Danish Working Environment Authority, guidelines are given for a working room, where there should be enough daylight access; therefore, it is recommended for the window area on a vertical plane, to correspond with a minimum of 10 percent of the floor area. For a skylight a minimum of 7 percent of the floor area is required.
Because of different circumstances, design or the shape of the room, the recommendations can't always be fulfilled, and there might not be enough daylight access. In those situations, the daylight factor of 2 percent on the working space or task area can be accepted.
There are situations where, because of the special working conditions with for example, photosensitive products, daylight access should not be allowed. In those situations, there are no requirements for daylight. Though, there are many situations where daylight access can be a disadvantage because of the tasks that need to take place in the working room. For example, bakery, production halls etc. When building a new construction with these special conditions, a municipality exemption needs to be granted for the corresponding cases of the building regulation.
Another recommendation is that the windows should be designed in such a way that they don't represent a risk of glare, overheating or discomfort for the employees. When designing a window, the security risk needs to be considered too.
If the windows are placed on south, east, or west, and are representing a large amount of the external wall, then external solar shades are recommended to protect from direct solar radiations. [102]

2.1.3.3. Danish Standards

The Danish Standards that are going to be described are DS/EN 17037:2018 regarding daylight conditions and recommendations as well as view of the surroundings.

2.1.3.3.1. View of the surroundings

> *"A view of nature may have a positive influence on a person's wellbeing, and job satisfaction, and people generally prefer to sit near a daylight opening and to look outside."*

(Dansk Standard, 2018)

[101] (Arbejdstilsynet, 2007)
[102] (Arbejdstilsynet, 2007)

View of the surrounding is defined as the visual connection to the outside, understanding the local environment, when the weather and the time of the day changes. The view to the surroundings purpose is for employee to get the opportunity to relax, by changing the scene and focus. This is very important for situations where occupants spend long periods indoors.[103]

A view to the surrounding is composed by the following elements:

- A layer of sky
- A layer of landscape (can include other buildings, nature of horizons line)
- A layer of ground

More criteria about quality of view out, width of view out, rating of width of view openings as a function of the utilized area, and how to verify that these criteria are being fulfilled can also be found in the guidelines and are explained in detailed.

2.1.3.3.2. Daylight

It is mentioned that the target illuminance level is considered achieved if a part of the reference plane, in a room get enough daylight for at least half of the daylight hours. The reference plane is located at 0,85 meters from the floor, if not mentioned otherwise. Also, that a small part of the reference plane, can be disregarded to account of singularities. [104]
When calculating daylight there must be taken into consideration the sky luminance distribution, external surroundings, openings towards the daylight, and internal reflections. That can be done by calculating a daylight factor, or by calculating the indoor daylight illuminances for a specific reference plane, over the year for a number of hours. [105]

Recommended surface reflections:

Ceiling	0,7 - 0,9
Walls	0,5 – 0,8
Floors	0,2 – 0,4
External walls	0,2 – 0,4

The smaller values are recommended to be used when calculating the target illuminance, but any of the amounts in the intervals are accepted.

There are described 2 methods:

Calculation method using daylight factor

The calculation method describes that any reliable method that is using an overcast sky shall be accepted.
A grid point system is created, where the first 0,5 meters from the walls should be excluded from the results. The reference plane should also be set 0,85 meters from the finish floor level. [106]

The following target method is used:

D_T = illuminance level / $E_{v,d,med}$ = 300lux/$E_{v,d,med}$ *100 (%)[107]

[103] (Dansk Standard, 2018, s. 10)
[104] (Dansk Standard, 2018, s. 9)
[105] (Dansk Standard, 2018, s. 19)
[106] (Dansk Standard, 2018, s. 19)
[107] (Dansk Standard, 2018, s. 19)

D_T = 2%

D_T = target daylight factor in order to get enough illuminance for more than half of the daylight hours, over 50% on the reference plane for 300 lux.
$E_{v,d,med}$ = median diffuse horizontal illuminance from the sky (the illumination produce by a skylight on a horizontan surface of the Earth for half of the daily hours in the year) For Copenhagen, Denmark is 14200 this value.

D_{TM} = illuminance level / $E_{v,d,med}$ = 100lux/$E_{v,d,med}$ *100 (%)[108]
D_{TM} = 0,7%

D_{TM}= minimum daylight factor that needs to be achieved for more than half of the daylight hours, over 95% of the reference plane for 100 lux.

The following table was recommended for daylight provision for a vertical opening:

Recommended level for vertical daylight opening	Target illuminance	Fraction of the space for target level	Minimum target illuminance	Fraction of the space for min. target level	Fraction of the daylight hours
Minimum	300	50%	100	95%	50%
Medium	500	50%	300	95%	50%
High	750	50%	500	95%	50%

Table 12 - Daylight factors [109]

Calculation method using illuminance level
This method is based on a computer dynamic calculation, or a specialized, validated software to calculate in detail from the illuminance target, based on climate data.
The reference plane should be set up in the programs, and if there are any solar shadings, those should be included in the dynamic models.
For a vertical placed window, the target illuminance that needs to be achieved is 300 lux on the reference plane for 50% of the plane, for 2.190 h (half of the daylight hours in a year). Also, a minimum of 100 lux on a reference plane for 95% of the plane for 2.190 h also needs to be achieved.

[108] (Dansk Standard, 2018, s. 19)
[109] (Dansk Standard, 2018, s. 13)

2.2. Thermal indoor climate

According to the Danish Standards DS 3033, that is a voluntarily guideline of how to classify the thermal indoor climate the following parameters are described as being the ones that define the building category:

- Ventilation rate
- CO_2
- Thermal conditions
- Radon
- Formaldehyde
- Particles
- Damp/mould
- Daylight and artificial lighting
- Acoustics conditions.[110]

2.2.1. Air change rate

The air change is a term for the air volume flow, which is measured in m^3/h per hour.
Meaning that when the air changes is 1 time an hour, it indicates that the room is getting the same amount of air, corresponding to the room's net volume within an hour.
Although that doesn't mean that the entire air from the room is changed or replaced over an hour. This doesn't indicate how efficient the air change is, but how much quantity of air volume changes. [111]
Building Regulation indicates that the requirements for ventilation that are not covered by paragraph 443 to 447, should be dimensioned according to the size and use of the room and its load. [112]
The following formula should be used to determine the total ventilation rate air change for the room:

$q_{tot} = n * q_p + A * q_B$[113]

q_{tot} is the total ventilation rate of the room, l/s
n is the design value for number of the persons in the room, -
q_p is the ventilation rate for occupancy per person, l/s, pers
A is the rooms floor area, m^2
q_B is the ventilation rate for emissions from building, l/s, m^2

The ventilation rate for non-residential buildings can be also found in table B.3 in (Dansk Standard, 2007), where the rates for a category 2, is an airflow per person (l/s/per) of 7. The airflow for building emission from pollutions ($l/s/m^2$) is 0,7.

[110] (Dansk Standard, 2011, s. 10)
[111] (Bergsøe, 2016)
[112] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §443 - §447)
[113] (Dansk Standard, 2007, s. 33)

2.2.2. Carbon Dioxide

Carbon Dioxide (CO_2) is found in the earth's atmosphere and humans' exhalations. CO_2 is measured inside a building and it serves as an indicator that shows if the ventilation system is adequate in relation to the people using the space.
In the free, outdoors, the CO_2 concentration is approx. 400 ppm, and the inside CO_2 level according to Danish Building Regulation 2018, should not exceed the maximum of 1000 ppm. If it exceeds the 1000ppm, it means that the air quality needs improvement inside that room. This can be improved by ventilation, by opening a window and venting, which would create a better air quality. [114] CO_2 inside a room can be determined by the following formula:

$CO_{2,equilibrium}$ = total CO_2 emission / air change * volume + CO_2outdoors[115]

2.2.3. Thermal conditions

The thermal comfort depends on air temperature, clothes, activity and personal preferences for each person. [116]
An unbalanced air temperature can cause a person to feel headaches, lack of concentration and a reduced work efficiency. This could happen if the air quality is not good enough. A rooms temperature is determined by the supply of heating to the room, and the heat loss from the building frame. Ventilation can also supply or remove heat from a room. [117]

It is best for people to find themselves in a more neutral thermal condition. That can be defined by not being either too warm to cold. Temperature difference from cold to warm in a horizontal plane can be perceived as a discomfort. [118]

2.2.4. Ventilation

Ventilation in a room can be done with 3 methods. Those are:
-Natural ventilation
-Mechanical ventilation
-Hybrid ventilation[119]

Natural ventilation is the ventilation achieved by the use of natural forces.
Entrance of air from the outside environment, through random holes through the energy frame is called infiltration.
The addition of air from the outdoors, into the thermal indoor climate through openings is called ventilation. This air addition to the room is based on a pressure difference without assistance from mechanical ventilation, but instead driven by forces like the wind effect.
Natural ventilation can be performed as single sided ventilation, cross ventilation, or combined between levels ventilation, or combined between cross and combined ventilation.[120]
Cross ventilation is primarily driven by pressure differences caused by the wind influence.
The combined ventilation between levels, is the ventilation that utilizes the driven forces primarily from using density differences in cold and warm air, creating a pressure difference.[121]

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[114] (Lyng, u.d.)
[115] (Dansk Standard, 2011, s. 11)
[116] (VELUX, u.d.)
[117] (Witterseh, u.d.)
[118] (Valbjørn, 1993, s. 17)
[119] (Dansk Standard, 2013)
[120] (Karl Terpager Andersen, 2002, s. 11)
[121] (Karl Terpager Andersen, 2002, s. 12)

The three types of ventilations can be combined and integrated from the building design phase, and that is most common in office building.

Mechanical ventilation works by blowing in air supplied from the outdoors (supply air) and removing a corresponding amount of air (extract air).
The mechanical balanced ventilation can be found in 2 systems. One is based on Constant Air Volume (CAV) and the other one is based on Variable Air Volume (VAV).

Hybrid ventilation is composed by both natural ventilation and mechanical balanced ventilation in the same part of the building.

Ventilation supplied in a room principles:

- Mixing ventilation principle is based on the air distribution system that consist from blowing from one or more diffusers that are placed outside the room. The air velocity is dimensioned after how far it's located from the air diffuser. The system should be dimensioned in such a way that the air in the room has a low air velocity and a constant temperature spread throughout the room.
- Concentration distribution is the basic idea behind the mixing ventilation system. The purpose is to create an air flow that recirculates and removes the polluted air from their source in such a way that the local concentrations are distributed in a larger volume in the room. [122]
- Displacement ventilation system is usually used in rooms that are demanded by more loads from people and equipment. When choosing the displacement ventilation system, the supply air fitting is placed lower, for example closer to the floor or as low as possible on the wall, where the air can be supplied directly into the working zone at a lower speed. Convection currents over any heat sources, such as equipment or people, that is produced is moving upwards into the room because of the air movement. Therefore, the hot rising air, is removed by the extraction fitting that removed this air from the room just below the ceiling. The air that is polluted is in this way spread all over the room, but the task area where people are meant to work is designed in such a way that clean air is supplied by the system. People generate heat, that's why when using this system, it needs to be considered that the air moves from the lower side of the room towards a head height. The supply air speed and temperature must be lower, so people don't experience draught. Therefore, the temperature difference should be lower than 3 degrees between 0,1 meters and 1,1 meters above the floor. [123]

2.2.5. Thermal indoor climate loads

Sun exposure through the window glass opening, and higher outdoor temperatures will add a heat load to the building. Electrical lighting, equipment, computers, and people are also adding a heat load to an indoor climate. That overheating should be removed using ventilation. [124]

The thermal indoor climate in buildings is designed in such a way that people can occupy the space. People are the loads that apply for a room.
A person's activity refers to as a metabolic rate (met), while the clothes that a person is wearing is known as clothes index (clo).

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[122] (Nielsen, s. 217)
[123] (Nielsen, s. 224)
[124] (Witterseh, u.d.)

People's level of activity is decisive for the head production for a person. For example, 1 met is the same as 100W and it's the heat production a person gives for a relaxed sitting activity. The clothes are representing a heating insulation for people and allow them to change their comfort accordingly. [125]
For example, if an adult is sitting in an office, at an activity of 1,2 met.

CO_2: 17 l/h $C(O_2)$
Moisture = 0,07 kg/h (H_2O)
Heat = 100 W (Watt)

The outside climate can be cold in the winters and warm in the summers and it will affect the thermal indoor climate through transmission losses from building parts. These standards values can be found in DS418, where the dimensioning outside temperature it set to 12 ˚C and the indoor temperature to 20 ˚C. [126]

2.2.6. Demands and recommendations

Demands for a balanced thermal indoor climate has been set by the Danish Building Regulation (2018), and recommendations and guidelines by the Danish Working Environment Authority. There are specific requirements for temperature, carbon dioxide, daylight, ventilation etc.

2.2.6.1. Danish Building Regulations 2018

2.2.6.1.1. Temperature

> *"In rooms where people stay for longer periods of time, it must be ensured that a satisfactory thermal indoor climate in terms of health and comfort can be maintained during the intended use and activities of the room."*

(Trafik-, Bygge- og Boligstyrelsen, 2018)

The demands regarding temperature can be found in paragraph 386. The BR18 also sets a demand that the simulations and documentation regarding the thermal indoor climate, must be made using Design Reference Year, DRY 2018 for the calendar year of 2010. [127]

Offices have a defined maximum number of hours per year that are counted in the working hours, where the temperature should not exceed 26 °C for a maximum of 100 hours and 27°C for a maximum of 25 hours.

The thermal indoor climate is thus the experienced temperature, considering the activity in the room. In order to avoid draught feeling is it recommended to consider the importance of ventilation system, that can be found in paragraph 420-452 in BR18. [128]
The temperature can also cause discomfort for some people, this is a subjective experience that depend on each's individual comfort space, and activity level. The risk of experiencing discomfort depends on the air temperature as well as the turbulence intensity of the air. [129]

[125] (Karl Terpager Andersen, 2002, s. 21)
[126] (Dansk Standard, 2011, s. 12)
[127] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §385 - §392)
[128] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §385 - §392)
[129] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §420 - §452)

2.2.6.1.2. Carbon Dioxide

The demands regarding CO_2 level indoors, can be found in the Danish Building Regulation, in paragraph 420-452, in the guideline descriptions.
The air change rate in a room needs to be designed in such a way that the level of carbon dioxide is hold under 1000 ppm. That is in buildings where the main suppliers of CO_2 are the people. It is recommended further DS 447. [130]

2.2.6.2. Danish Working Environment Authority

2.2.6.2.1. Temperature

According to the Danish Working Environment Authority, the temperature for an office working environment, in a sedentary working task is not allowed to exceed 25 ° C.[131]
The reason why a temperature can get too high in a room is because it is supplied with more heat that it can give out. Heat could come from inside or outside.
An example of outside heat can be from the sun that goes through larger windows; and as an example of heat supplied from the inside could be people, equipment, electric lighting etc.
A temperature that varies more than 4 °C on a working day can feel uncomfortable; also, from the floor level to the head level the temperature difference shouldn't exceed more than 4 °C. [132]

2.2.6.2.2. Carbon Dioxide

In a room where people are the main source of carbon dioxide (CO_2), the content of CO_2 in the room air should not be greater than 0,1 percent. If the air content exceeds 0,2 percent CO_2, even for a shorter period of a working day, the air change is insufficient. [133]

2.3. Climate change

Climate change is an issue the entire world is facing now and it's a result of the emissions from man-made greenhouse gases for the past hundred years. The emissions are also continuing in the form of energy consumptions, agriculture, industry, transport and many more factors. [134]

The major expected changes that follow the climate change, that is increasing towards 2100 are higher temperatures, more wind, more extreme weather conditions and rising of sea level. [135]

The Danish Commission on Climate Change policy had made a strategy of how to ameliorate the future predictions by focusing on 3 main issues up to 2050 and those points are:

1. Energy supply independency of fossil fuels.
2. Lowering the emissions of greenhouses gases.

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[130] (Trafik-, Bygge- og Boligstyrelsen, 2018, s. §420 - §452)
[131] (Arbejdstilsynet, 2005)
[132] (Arbejdstilsynet , 2008)
[133] (Arbejdstilsynet , 2008)
[134] (Koordineringsenhed for forskning i klimatilpasning (KFT), 2010, s. 13)
[135] (Klima-, Energi- og Bygningsministeriet, 2014, s. 5)

3. Adapting the building industry to the future climate challenges. [136]

The future predictions of climate change are based on the scenarios used by the Intergovernmental Panel on Climate Change (IPCC) where the climate changes are expected to increase towards 2100. [137]

In the UN Climate Panel IPCC, the SRES-scenarios have been documented in 2007. These scenarios focus on future predictions of greenhouse gas emissions, while also considering the evolutions of economy, technology and population growth. [138]

The UN has predicted fours main scenarios: A1, A2, B1, and B2 that are predicting different climate future changes according to the different conditions.

Moreover, DMI has set up a scenario based on EU's vision where the temperature should not increase for more than 2 degree to pre-industrial level (EU2C)

In Denmark the focus regarding climate adaptation strategies is based on A2, B2 and EU2C scenarios. But A1B is also taken into consideration. [139]

A1B Scenario
According to this scenario, the greenhouse emissions will continue until 2050, which will represent the peak, and then decrease after that. It also presumes that a rapid economic growth will happen and a growth in the population too. A rapid growth of efficient new technologies will accrue, and a mixture of fossil and non-fossil energy solutions will be implemented. DMI has gathered the data and predictions for this scenario on Denmark for 2021-2050. A1B can represent all the different scenarios until 2050. [140]

A2 Scenario
This scenario predicts a continuous steady increase in the emission of greenhouse gases, a growth of population and a slower fragmentated growth of global economy and technology. DMI had calculated A2 scenario for Denmark for 2071-2100. [141]

B2 Scenario
This scenario is very similar to A2 Scenario, where the emission of greenhouse gases is slightly reduced. The population growth is also more moderate. [142]

EU2C - EU's 2-degree scenario
This scenario assumes that the global temperature does not rise more than 2 degrees to 2100. EU2C is the same as A1B until 2020, and afterwards the emission from greenhouse gasses peaks and gets stabilized.EU2C represents a lower emission prediction for the future compared to A2 and B2. DMI has calculated EU2C for Denmark for 2071-2100. [143]

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[136] (Torben V. Rasmussen)
[137] (Klima-, Energi- og Bygningsministeriet, 2014, s. 4)
[138] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)
[139] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)
[140] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)
[141] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)
[142] (Torben V. Rasmussen, s. 5)
[143] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)

Other similar scenarios before IPCC had been done, called RCP scenarios. (Representative Concentration Pathway) A comparison between those previous scenarios and current ones can be seen on Figure 21.

Until 2050, according to A1B scenario the following predictions are made:

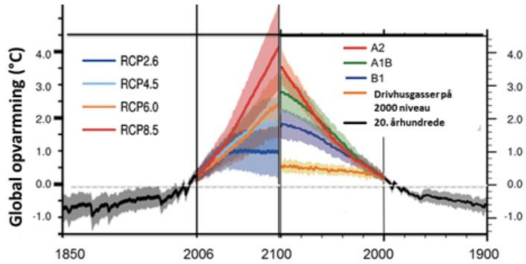


Figure 25 - Comparison of RCP scenarios and IPCC scenarios of future climate change. Picture from www.klimatilpasning.dk.

Scenario	A1B Until 2050	A1B Until 2100
Annual average temperature	+ 1.2° C (± 0.2°C)	+ 2,9 (± 0,3ºC)
Average winter temperature	+ 1.5° C (± 0.2ºC)	+ 3,5 (± 0,3ºC)
Average summer temperature	+ 0.9° C (± 0,1ºC)	+ 2,2 (± 0,2ºC)
Annual rainfall	+ 7% (± 3%)	+ 14 % (± 6 %)
Winter rainfall	+ 11% (± 3%)	+ 25 % (± 6 %)
Summer rainfall	+ 4% (± 4%)	+ 5 % (± 8 %)
Sea		
Average wind speed	+ 1%	
Sea + Land		
Average wind speed	+ 3%	

Figure 26 - Climate change predictions for A1B.[144]

Extreme weather condition predictions for A1B can be seen in Table 13. Year 1990 represents the values we considered representative nowadays.

Factors	1990	2050	2100
Number of days with frost (days/year)	85 (± 8)	61 (± 7)	29 (± 5,3)
Growth season's length (days/year)	230 (± 11)	270 (± 12)	300 (± 11)
Hot summer nights (days/year)	8 (± 4)	13 (± 4)	44 (± 13)
Number of days with ≥ 10 mm rainfall (days/year)	19 (± 2)	22 (± 2)	26 (± 3)
Number of days with ≥ 20 mm rainfall (days/year)	2 (± 0,3)	3 (± 0,5)	5 (± 0,7)
Largest volume of rainfall (mm)	70 (± 8)	75 (± 8)	81 (± 7)
Largest volume of 5-day rainfall (mm)	94 (± 6)	100 (± 5)	108 (± 7)
Average intensity of rainfall (mm/day)	5,0 (± 0,2)	5,2 (± 0,2)	5,6 (± 0,2)
Heat wave days (days/year)	1,5 (± 1)	2,8 (± 1)	5,0 (± 2,6)
Longest heat wave (days)	3,2 (± 0,9)	4,2 (± 0,9)	5,6 (± 1,9)

Table 13 -Extreme weather conditions for A1B. [145]

Scenario A2, B2 and EU2C can be seen in Table 14.

[144] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)
[145] (Miljø- og Fødevareministeriet / Miljøstyrelsen, 2015)

Scenario	A2			B2			EU2C		
Years	2006-2035	2036-2065	2071-2100	2006-2035	2036-2065	2071-2100	2006-2035	2036-2065	2071-2100
On land									
Annual average temperature	+0,6°C	+1,4°C	+3,1°C	+0,7°C	+1,4°C	+2,2°C	+0,7°C	+1,2°C	+1,4°C
Average winter temperature	+0,6°C	+1,4°C	+3,1°C	+0,7°C	+1,3°C	+2,1°C	+1,0°C	+1,7°C	+2,0°C
Average summer temperature	+0,5°C	+1,3°C	+2,8°C	+0,6°C	+1,3°C	+2,0°C	+0,7°C	+1,1°C	+1,3°C
Annual rainfall	+2%	+4%	+9%	+2%	+5%	+8%	0%	0%	0%
Winter rainfall	+8%	+19%	+43%	+6%	+11%	+18%	0%	0%	+1%
Summer rainfall	-3%	-7%	-15%	-2%	-4%	-7%	-2%	-3%	-3%
Maximum daily rainfall	+4%	+10%	+21%	+5%	+12%	+20%	+11%	+18%	+22%
At sea									
Average wind speed	+1%	+2%	+4%	+1%	+1%	+2%	+1%	+1%	+1%
Maximum wind speed	+2%	+5%	+10%	0%	+1%	+1%	+1%	+1%	+1%
Maximum sea level			+0,45-1,05 m						

Table 14 - Expected Scenarios for A2, B2 an EU2C.[146]

Table 15 illustrates the extreme weather conditions for A2, B2 and EU2C, where the Present is the average value of number of events measured from 1961 until 1990.

Factors	A2	B2	EU2C	Present
Number of days with frost (days/year)	-44	-31	-26	73
Growth season's length (days)	55	39	22	224
Longest heat wave/year (days)	9	4	4	5
Hot summer nights (days)	20	13	10	10
Number of days with ≥ 10 mm rainfall (days/year)	3	3	-1	13
Largest volume of 5-day rainfall/year (mm)	4	4	1	47
Average intensity of rainfall for days with more than 1 mm rainfall (mm/day)	0,3	0,3	0	4,7
Extreme rainfall (% rainfall over 95 percentile)	5	6	0	32

Table 15 - Extreme weather conditions for A2, B2 and EU2C predictions.[147]

[146] (Torben V. Rasmussen, s. 5)
[147] (Torben V. Rasmussen, s. 5)

After seeing the impact that the prediction for future climate change involve, it needs to be considered that buildings, drainage systems, infrastructure and everything that is getting built nowadays, is expected to last for at least 100 years. [148]

Buildings that are built now are vulnerable to the predicted climate changes. That's why these parameters should be incorporated in the new building regulations. The Danish building regulation is based on a measured climate data and applied by performance-based building requirements, and therefore what is built today does not integrate the future predictions. [149] Until the quality data on climate change predictions has not been improved, it is challenging to get them integrated on the demands. [150]However, they should still be taken into consideration for new buildings.

[148] (Olesen, 2018, s. Bygninger og anden infrastruktur)
[149] (Torben V. Rasmussen)
[150] (Torben V. Rasmussen, s. 8)

3. Case study

As mentioning in the introduction this case study is based on a fictive project. The focus is to analyze two window sizes in an office building. The latest demands and recommendations are to be followed.
The location of the building it set to be in city area, more exactly in Copenhagen, with unknown surroundings.
The rooms shape represents a critical role in the simulations because of its depth, and it's also one of the parameters that can influence the daylight conditions the room. Even though it's a fictive project, as most projects in real life the design is fixed, and few parameters can be change. In this case the room size is fixed, and the only options are two different window sizes that should be analyzed.

Within the simulations the shape of the room is a rectangular room, where the smallest side includes direct access to daylight.
The office room has been pre-set with the information from Table 16.

Length	6 meters
Width	4 meters
Height	3 meters

Table 16 - Room dimensions

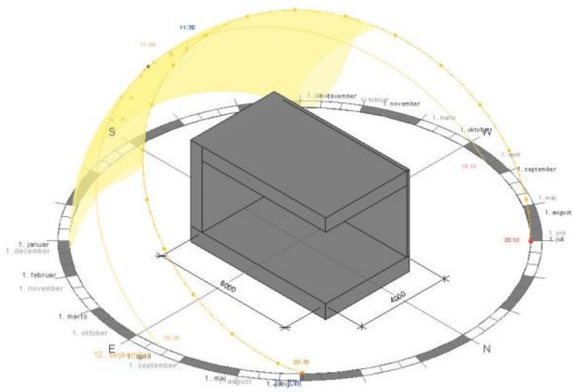


Figure 27 - 3D visualization of the room (Revit)

The facade is located on the 4 meters side that represent the external wall, where daylight access can be provided through a window glass opening. All the other walls are interior walls towards other office rooms with the same conditions as the one being simulated.
Details about the construction of the building can be found in the building part notes in appendix A.

3.1. Daylight

In order to achieve the energy frame demands, a 3 layer window has been chosen for the project with a 0,05 meters frame width. The placement of both windows has been set central to the room, as illustrated in Table 18 and Table 20, in order to achieve most daylight target illuminance throughout the room.

Window type 1

This window is 3 meters width and 1,5 meters height placed central on the wall's width. The offset of the window is set 0,8 meters from floor level, with the following characteristics:

Type	Area	U_W	Ff	G_g	U_g	LT_g
1	4,5	0,86	0,88	0,51	0,52	0,72

Table 17 - Window type 1 properties

U_W = U-value, thermal transmittance.
Ff = The elements percent of glass area. For example, if you have 70% of glass area, then the Ff should be 0,7.
G_g = The glasses G-value, solar energy transmittance. The amount of solar energy that goes into the building.
U_g = Glasses U-value, thermal transmittance.
LT_g = Glasses light transmittance. The amount of sun light that goes into the building.

Glass filling	4-20-4-20-4 Energy/clear/energy with Argon (1)
Profile and frame	Frame tree/aluminum
Color	White, inside
	Black, outside

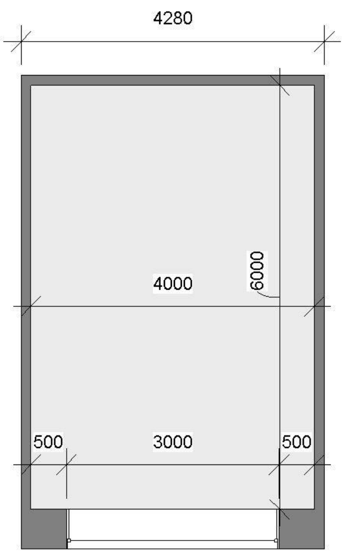
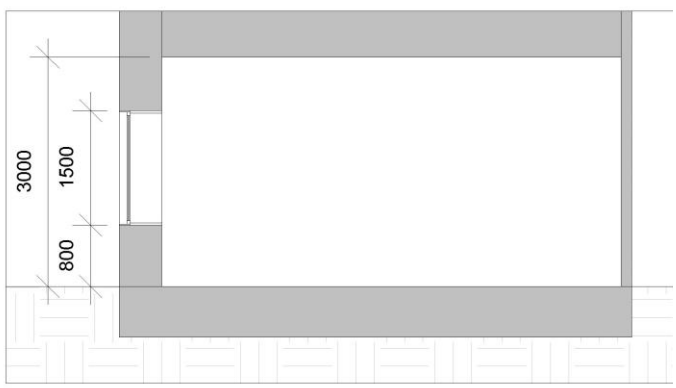
Plan	Section
	

Table 18 - Revit visualization of window type 1 and placement in the room

Window type 2

This window is 2,5 meters width and 2,8 meters height placed central on the wall's width. The offset of the window is set to be 0 from floor level. With the following characteristics:

Type	Area	U_W	Ff	G_g	U_g	LT_g
2	7	1,1	0,92	0,51	0,52	0,72

Table 19 - Window type 2 properties.

Glass filling	4-20-4-20-4 Energy/clear/energy with Argon (1)
Profile and frame	Frame tree/aluminum
Color	White, inside
	Black, outside

Plan	Section

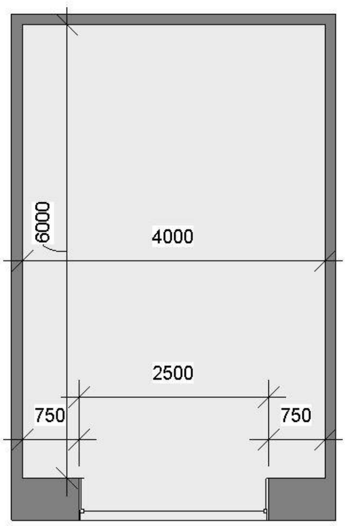
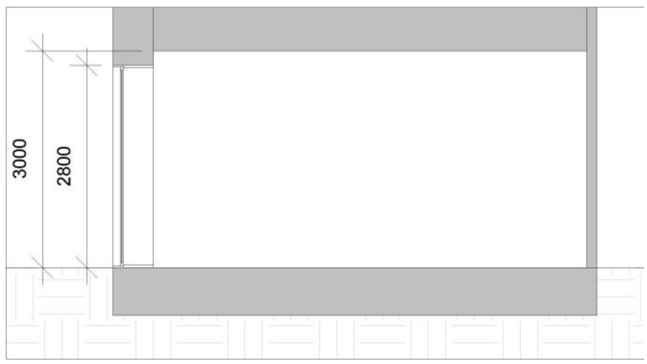

	

Table 20 - Revit visualization of window type 2 and placement in the room	

Internally reflectance of surfaces
The reflectance's of the internal surfaces are following the recommended values, but do not represent the minimum values.

Ceiling: 0,7 – white ceiling
Walls: 0,6 – Grey walls
Floor: 0,4 – Wooden floors

The reference plane in the simulations is placed 0,85 from the floor. That is the height where the task area is located in a room designated to be an office.

In SimLight simulation program a grid of 0,5 * 0,5 meters is placed to locate all the points where the daylight target illuminance should be measured, as illustrated in Figure 28.

The climate set used is the Danish Reference Year, DRY 2013, for the calendar year of 2010. The sky used for daylight simulations is CIE overcast sky, because it offers the most critical results. A CIE sky is recommended from both BR18 and DS/EN 17037.
The orientation in this case it's not mentioned since all will end to the same results when simulating with a CIE sky.

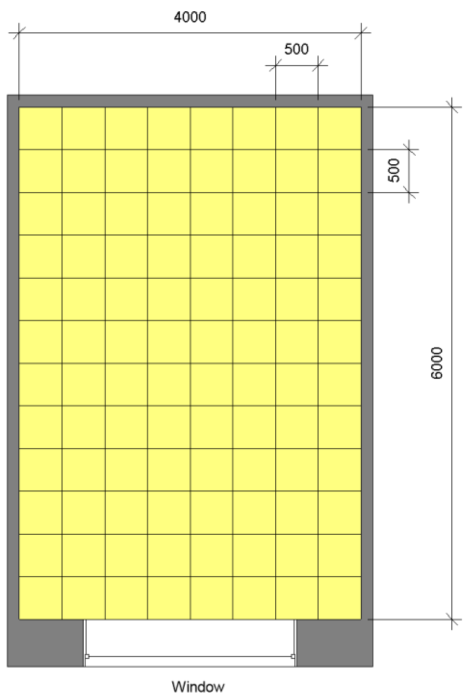


Figure 28 - Grid design into the room for calculating the target illuminance.

Solar shades

For this project lamella solar shades have been chosen with a light reflectance on the lamella factor is 0,8 expected to be placed at a 0-degree angle.

3.2. Thermal indoor climate condition

Thermal indoor climate dynamic simulations are performed for window type 2 described in the study case on a facade window glass opening orientated towards west. The following conditions are defined in BSim, to simulate the thermal indoor climate conditions:

Systems	Unit measure
Equipment	0,4 kW
Heating	3 kW
Infiltration	0,03 h^{-1}
Lighting	0,55 kW
People	0,4 kW
Ventilation	0,0462 m^3/s
Night Fan	-

Table 21 - Loads of thermal indoor climate

In the simulations the room is calculated with 4 workplaces. Therefore, equipment is 0,4 kW, where it is calculated as 4 workstation times 100W per each. Four people are also meant to work in the room.
The ventilation is dimensioned after the formula described in 2.2.1 Air change rate.

3.3. Climate change

The emission scenario chosen for this project is A1B from IPCC for the years 2020-2050 and 2070-2100.
Mechanical ventilation is simulated in the results chapter while further analyze for mechanical ventilation with cooling and hybrid ventilation system are simulated further on in the analysis chapter for climate change scenarios and thermal indoor climate for future climate changes.

4. Methods

The research is based on the Danish Building Regulation 2018, the Danish standards and the relevant SBi-instruction materials. SBi and Danish standards are representative by offering guidelines and recommendation in order to achieve the Danish Building Regulations minimum demands.

4.1. Programs

A variety of programs are used to simulate daylight and thermal indoor climate, as well as future climate change predictions from IPCC.

4.1.1. BSim

BSim is a program designed to analyzing buildings and their conditions, while considering thermal indoor climate, energy consumption, daylight, moisture and natural ventilation. [151]

4.1.1.1. SimLight – Daylight calculation

SimLight calculates daylight condition for a reference point or a grid of points in a reference plane in a space at a specific height. The daylight calculated from SimLight comes from 3 directions: Direct sky radiations, the externally reflected daylight (from the earth surface) and internally reflected daylight for simulations done for an even overcast sky and a CIE overcast sky. It is to be noted that other buildings reflectance cannot be calculated in the current version of the program. In the calculation, at a horizontal level the external illuminance is set at 10.000 lux. [152]
The daylight factor in a room calculated with an overcast sky will achieve the same results regardless the windows glass orientation. Therefore, this method is used to define the minimum daylight in a room. [153]
Solar shades daylight reduction coefficient does not affect the daylight factor reaching the room.

4.1.1.2. tsbi5 – Indoor climate, thermal and moisture conditions

tsbi5 is the also the core of the BSim program. The thermal indoor conditions are established by performing dynamic simulations to determine the indoor climate, energy and moisture situation in a building. It can be used in the design phase of a project to determine heating, cooling and ventilation systems and in testing different options until the most optimal solution is discovered regarding solar shades, venting, ventilation, cooling etc. [154]
The dynamic simulations done are based on climate data files for Denmark using a DRY (Design Reference Year) supplied by the Aalborg University for both current conditions and future climate change scenarios for A1B, for 2020-2050 and 2070-2100.

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[151] (Statens Byggeforskningsinstitut , u.d.)
[152] (Jens Christoffersen, 2002, s. 55)
[153] (Jens Christoffersen, 2002, s. 56)
[154] (Statens Byggeforskningsinstitut , u.d.)

4.1.2. VELUX Daylight Visualizer 3

VELUX Daylight Visualizer is a program meant to simulate the daylight conditions in a building. The same as SimLight, it considers the daylight in a room from 3 directions, and it can be calculated at a reference plane in the room. [155]

Some factors such as windows glass light transmittance, solar energy transmittance, and window frame width cannot be adjusted when using this program.

[155] (VELUX, u.d.)

5. Results

5.1. Daylight

The following results are for Window Type 1 and Window type 2 described in the 3. Case study chapter for the 10 percent rule, daylight factor and the 300 lux illuminance.

The 10 percent rule is a demand set by the Danish Building regulation 2018. A similar calculation method is described in the Danish standards DS/EN 17037 for a daylight factor calculation, using a daylight factor to which a correction factor is added. The Danish standards are representing a recommendation and a guideline towards other methods.
Both the Danish Building regulation 2018 and the Danish standards DS/EN 17037 refer to the illuminance target calculations in a similar way and set the same minimum demands.

On both window sizes Type 1 and Type 2, the 10 percent rules are applied, and a documentation as described in BR18 guidelines are made in order to document the results. These documentations are based on a handmade calculation based on the correction factors applied on specific window glass area. The calculation as an excel file can be seen in Appendix B.

5.1.1. The 10 percent rule

Before starting to add the correction factors for the 10 percent rule, a check calculation can be done to examine if the minimum glass area is achieved in the room before adding the correction factors.

$A_{G,min} = 0,1 * A_{floor}$

$A_{G,min} = 0,1 *24 \text{ m}^2 = 2,4 \text{ m}^2$

In this case only the relevant correction factors for Window type 1 and 2 are being used to correct the glass area. Therefore, the results are based on these factors:

$A_{Gkor,i} = F_{LT} * F_{VÆG} * F_{OMG} *F_{RUM}* F_{AFS} * A_{Gvin,i}$
$= F_{G,kor,i} * A_{Gvin,I} \text{ m}^2$

Factor for window frame type (F_{LT})
Light transmittance in our case has been provided by a manufacturer to be 0,72.
$F_{LT} = LT_{act} / LT_{ref}$
$F_{LT} = 0,72 / 0,75$
$F_{LT} = 0,96$

Factor for wall thickness ($F_{VÆG}$)

Using the Table 1 described in the theory chapter and considering that the external wall thickness in this project is 0,558 meters and both window type 1 and 2 the glass area is larger than 3 meters, the factor for wall thickness can be chosen from the table.

The external wall thickness described in this project, that can be seen in Appendix A, and is located between 0,5 m and 0,6 m in the table, for a glass area larger than 3 m^2. For both 0,5 and 0,6 wall thickness in meters, the correction factor in the table is 1,00.

For both Window type 1 and 2 the Correction factor for the wall thickness, $F_{VÆG}$ = 1,00.

Factor for the surroundings (F_{OMG})

This project is based on a fictive project as described in the case study, where the surroundings are unknown, and the worst-case scenario is being taken into the documentation using Table 2 described in the theory.
The correction factor remains constant after 45° profile angle from surrounding buildings. That is to be considered the worst-case scenario, F_{OMG} =0,50.

Factor for a room with bigger depth from the window (F_{RUM})
As illustrated in Figure 9, a formula was described of how to check if the depth of the room is too deep from the daylight source, the window glass opening.
Results for window type 1:
(2,5 * (2,30 – 0,75) + 0,70) * 0,79 = 3,6 meters

The results indicate for window type one enough daylight will only be for the first 3,6 meters from the window, while the depth of the room is of 6 meters.

The results for window type 2:
(2,5 * (2,75 – 0,75) + 0,70) * 0,79 = 5,3 meters

The 5,3 meters from the windows glass opening will get enough daylight into the room with window type 2. That still not enough to ensure daylight for all the 6 meters depth of room.

According to Table 9, for a room that is deeper than 5 meters from the windows glass opening should have a correction factor added.
From the table, the correction factor for a room with a 6 meters depth, is F_{RUM} = 0,9.

A minimum glass area per façade is set to be 0,6 m^2. For window type 1, the glass is 3,97 m^2 which is bigger than 0,6 m^2. For window type 2 is 6,47 m^2, which also complies with the minimum glass area per façade in m^2.

Necessary glass area % out of the floor area.
For window type 1:
3,97/24*100 = 16%
Window type 2:
6,47/24*100=26%
From these results, both window type 1 and window type 2 have more than the minimum of 11,1% that is the necessary glass area % from the floor area.

Necessary glass area per façade, from the table is set to 0,67 m^2. Window type 1, has a glass are of 3,97, which is higher than 0,67, therefore it complies with the necessary demands. Window type 2, has a glass area of 6,47, which also complies with the necessary demands, of 0,67 m^2.

Factor for Solar shades (F_{AFS})

Lamella Solar shades, with lighter color has been chosen, with a daylight reflectance of RL = 0,8, and a 0-degree angle. Therefore, F_{ARS} = 0,6.

5.1.1.1. Window Type 1

The window area is 4,5 m^2, from which only 3,97 m^2 is the glass area, reported to a 24 m^2 office room.

Type 1	Parameter	Information	Units	Symbols
Room and area identification	Building	Office Building		
	Floor	Ground floor		
	Room	Office room		
	Net floor area	24	m^2	A_{floor}
	Windows area	4,5	m^2	$A_{vin\ i}$
	Glass area	3,97	m^2	$A_{G,vin\ i}$
Correction factor for	Window type	0,96		F_{LT}
	Wall thickness	1		$F_{VÆG}$
	Surroundings	0,5		F_{OMG}
	Deepness of the room	0,9		F_{RUM}
	Shades from solar shades	0,6		F_{AFS}
Results of the correction factor		0,26		$F_{G,kor,i}$
Glass area correction		1,03	m^2	$F_{G,kor,i} * A_{G,vin\ i}$
Percentage		4%		

Table 22 - Daylight 10 percent rule results for Window type 1.

Table 22 illustrates that the results indicate the glass area with the correction factors is lower than the minimum set demands from BR18, of 10% of the floor area. The results indicate that final corrected area represents 4% from the floor area, which does not comply with the minimum BR18 demand.
Further analysis to improve this value are done in the next chapter Analysis.

5.1.1.2. Window Type 2

The window area is 7 m^2, from which 6,47 m^2 represents the glass area reported to a 24 m^2 office room.

Type 2	Parameter	Information	Units	Symbols
Room and area identification	Building	Office Building		
	Floor	Ground floor		
	Room	Office room		
	Net floor area	24	m^2	A_{floor}
	Windows area	7	m^2	$A_{vin\ i}$
	Glass area	6,47	m^2	$A_{G,vin\ i}$
Correction factor for	Window type	0,96		F_{LT}
	Wall thickness	1		$F_{VÆG}$
	Surroundings	0,5		F_{OMG}
	Deepness of the room	0,9		F_{RUM}
	Shades from solar shades	0,6		F_{AFS}
Results of the correction factor		0,26		$F_{G,kor,i}$
Glass area correction		1,68	m^2	$F_{G,kor,i}$ * $A_{G,vin\ i}$
		Percentage	7%	

Table 23 - Daylight 10 percent rule results for Window type 2.

Window type 2, after the correction factors are applied on the glass area, results with a 7% corrected glass area of the floor area. Window type 2, does not fulfil the minimum demands from BR18, of 10 percent rule.
Next chapter, Analysis, will present different options of how this percentage can be improved.

5.1.2. Daylight factor

As mentioned in the Danish Standard, there is a minimum daylight factor that needs to be achieved on the reference plane in the room. The method described here is just a recommendation.

A 2% daylight factor needs to be achieved for 50% of the reference plane, for the half of the daylight hours. (2.190h)

A 0,7% daylight factor needs to be achieved for 95% of the reference plane for the half of the daylight hours. (2.190h)

A method of how to apply the correction factors or how to correct the daylight factor was not described. Therefore, the same correction factor used on the 10 percent rule would be used in these calculations. The results might vary or be different.

5.1.2.1. Window Type 1

VELUX Daylight Visualizer

VELUX Daylight Visualizer simulation results illustrated in Figure 29, are showing a higher intensity daylight factor closer to the window that fades away as it spreads into the room.
The daylight factor closer to the window is over 16 DF.
The darker green line in the picture represents the border where the 2 DF ends, and it can be observed that it doesn't cover the 50% of the rooms area.
The dark blue line represents the 1 DF, that is passing a bit over the middle of the room, therefore, 0,7 DF is also not overholding for 95% of the area.

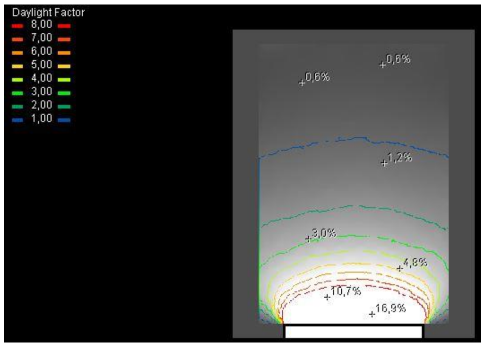


Figure 29 - Velux daylight visualizer - daylight factor for window type 1

SimLight

The result from SimLight for daylight factor, have been corrected with the same correction factors used in the 10 percent rule. (See appendix C)

$F_{LT} * F_{VÆG} * F_{OMG} * F_{RUM} * F_{AFS} = F_{G,kor,i}$ (correction factor applied for each grid point result is SimLight)

0,96 * 1,00 * 0,5 * 0,9 * 0,6 = 0,26

The correction factor of 0,26 has been multiplied with each point in the grid system where it resulted with 10% of the reference plane is achieving DF of 2.
As a minimum recommendation, 0,7 daylight factor should cover 95% of the reference plane for half of the daylight hours. 0,7 DF is achieved for 39% of the reference plane.
Window type 1, is therefore not fulfilling the minimum recommended values from DS/EN 17037.

5.1.2.2. Window Type 2

VELUX Daylight Visualizer

Figure 30 illustrates the results for window type 2. There can be seen that the area close to the window, has a higher DF, over 21%, and it continues with a higher level. From the darker green line, that represents the 2 DF can be noticed that it covered more than 50% of the reference plane.
Also, the darker blue line, represents the border line for 1 DF. It can be noticed that it covered throughout the room. Therefore, it can be confirmed that the 95% reference plane has more than 0,7 DF.

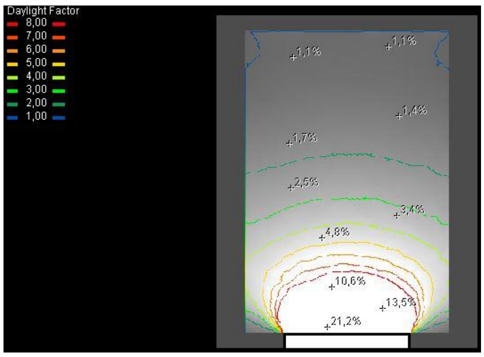


Figure 30 - Velux daylight visualiser - daylight factor for window type 2

SimLight

The same correction factor as described for window type 1, of 0,26 is used for the simulations from SimLight for daylight factor.
The results from multiplying the correction factor with each point in the grid system, result with a 0,7DF for 55% of the reference plane and a 2% DF result of a 13% of the reference plane.
The recommended method described in DS/EN 17037 is not fulfilling the described guideline demands for window type 2.

5.1.3. The illuminance target – 300 lux

As described in the theory chapter, the minimum recommended target illuminance is 300 lux for a 50% of the reference plane on 50% of the daylight hours. A minimum target illuminance of 100 lux for 95% of the room, in 50% of the daylight hours is a recommendation from DS.

5.1.3.1. Results for Window type 1 from SimLight

Table 24 illustrates how the daylight spreads into the room as a total illumination and from internally reflected surfaces.

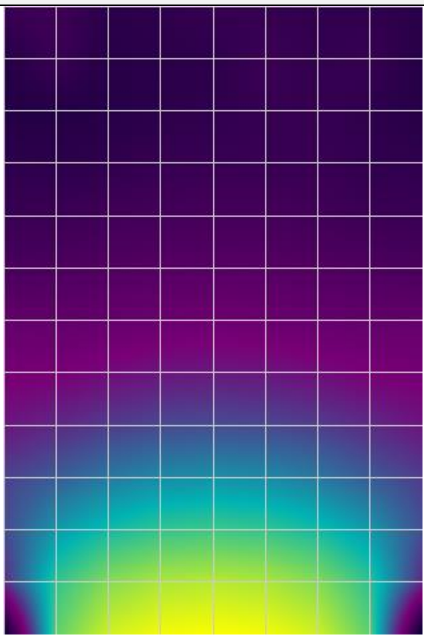
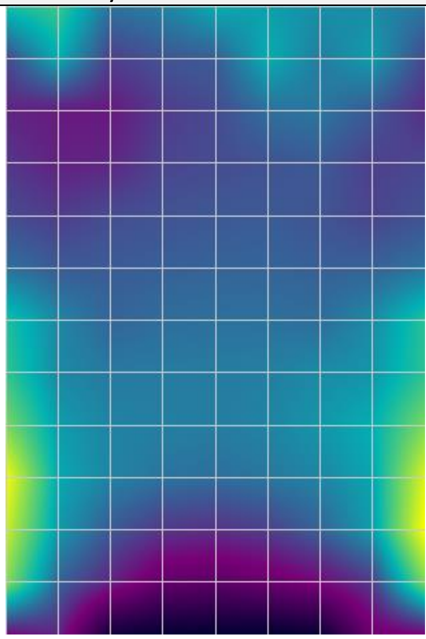
Type 1	Total illumination	Internally reflected
Visualisation of the illumination		
300 lux	35%	
100 lux	100%	

Table 24 - 300 lux results for Window type 1

The results illustrate that 35% of the reference plane achieves an illumination of a minimum 300 lux. The minimum of 100 lux, is fulfilled for 100% of the floor area. The minimum of 100 lux is a recommendation from the Danish standards and don't represent a requirement.

More detailed results can be seen on appendix C.

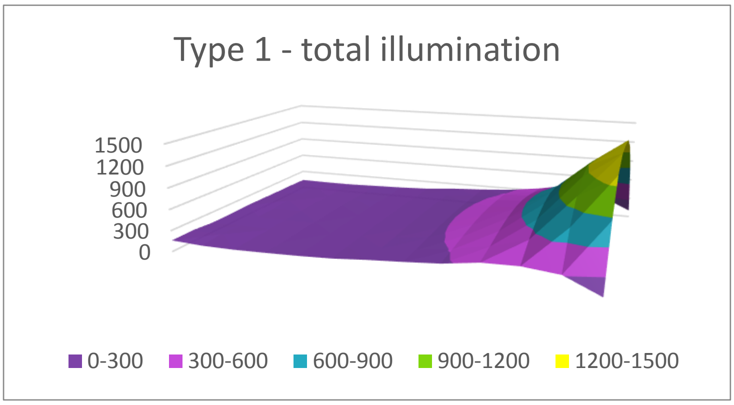


Figure 31 - 3D visualization of window type 1 of total illumination

5.1.3.2. Results for Window type 1 from VELUX Daylight Visualizer

Figure 32 illustrates the results from VELUX Daylight Visualizer for window type 1. The green line is the border line that indicates how much of the reference plane achieves 300 lux, and from a visual assessment the 50% of the reference plane is not covered. The recommendation of 100 lux for 95% of the floor area is also not fulfilled, since 95 lux are recorded in the middle or the room. None of the demands or recommendations are fulfilled.

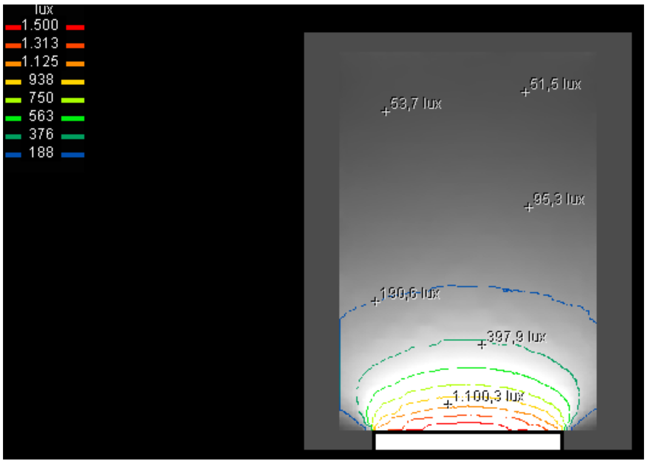


Figure 32 - VELUX Daylight Visualizer simulation on Type 1

5.1.3.3. Results for Window type 2 from SimLight

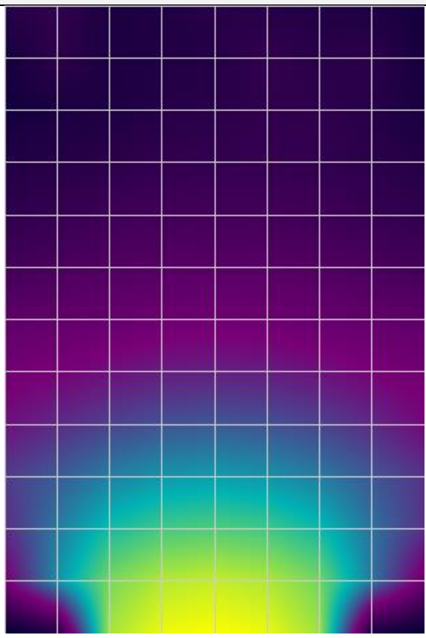
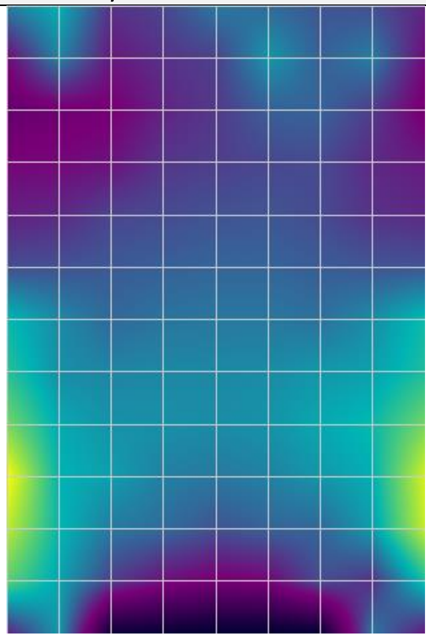
Type 2	Total illumination	Internally reflected
Visualisation of the illumination		
300 lux	50%	
100 lux	100%	

Table 25 - 300 lux results for Window type 2.

Table 25, illustrates that window Type 2, is getting 300 lux illuminance on 50% of the reference plane, and 100 lux in the entire room.

Internally reflected illuminance helps with maintaining the 100 lux spread throughout the room.

A detailed result of the simulation can be seen on Appendix C.

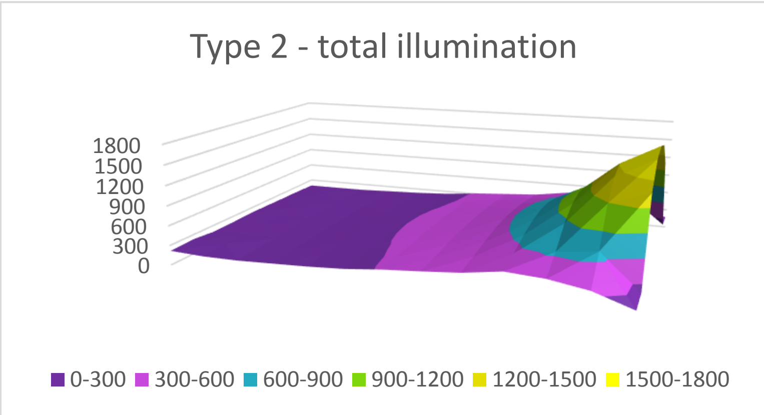


Figure 33 - 3D visualization of window type 2 of total illumination

5.1.3.4. Results for Window type 2 from VELUX Daylight Visualizer

Figure 34 illustrates the results from VELUX Daylight Visualizer, where from a visual assessment, the 300 lux demands are not fulfilled for 50% of the reference plane, while the 100 lux on 95% of the reference plane, recommendations are fulfilled.

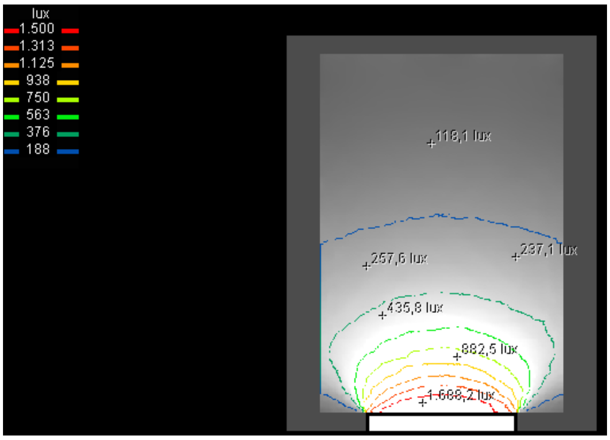


Figure 34 - VELUX Daylight Visualizer simulation on Type 2

5.2. Thermal indoor climate

With the parameters described in chapter 3.2. about the thermal indoor climate conditions for this case study, Window type 2 was chosen for further simulations regarding thermal indoor climate conditions.

Temperature

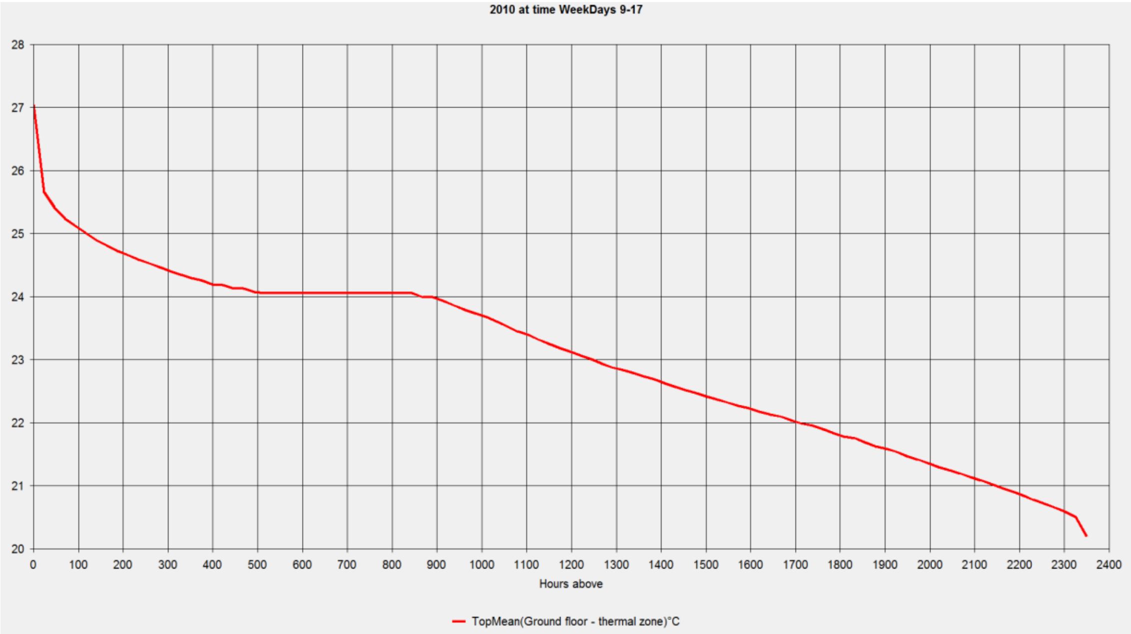


Figure 35 -Result of hours above for the indoor temperature for the working hours

From Figure 35, it can be observed that the number of hours of 27 °C is maintained under 25 hours, and the 26°C is also under 100 hours as required from BR18. These hours are counted only in the working hours. The thermal temperature in the indoor climate fulfils the requirements from BR18.
These demands are fulfilled without mechanical cooling. The solar shades and night fan control helped in achieving the balanced temperature indoors.

Carbon Dioxide

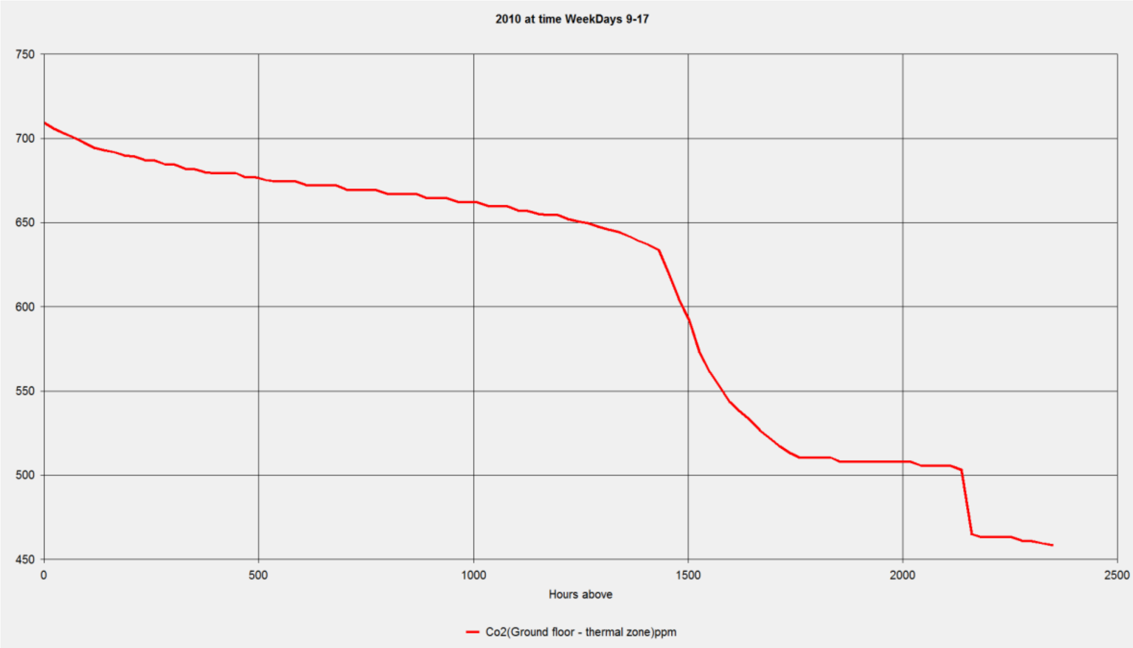


Figure 36 – Results of CO_2 with hours above for the entire year.

The CO_2 level results are between 460 – 700 ppm for the year 2010 in the week days during working hours. That is under the maximum value set by BR18, of 1000ppm.

Solar Shadings

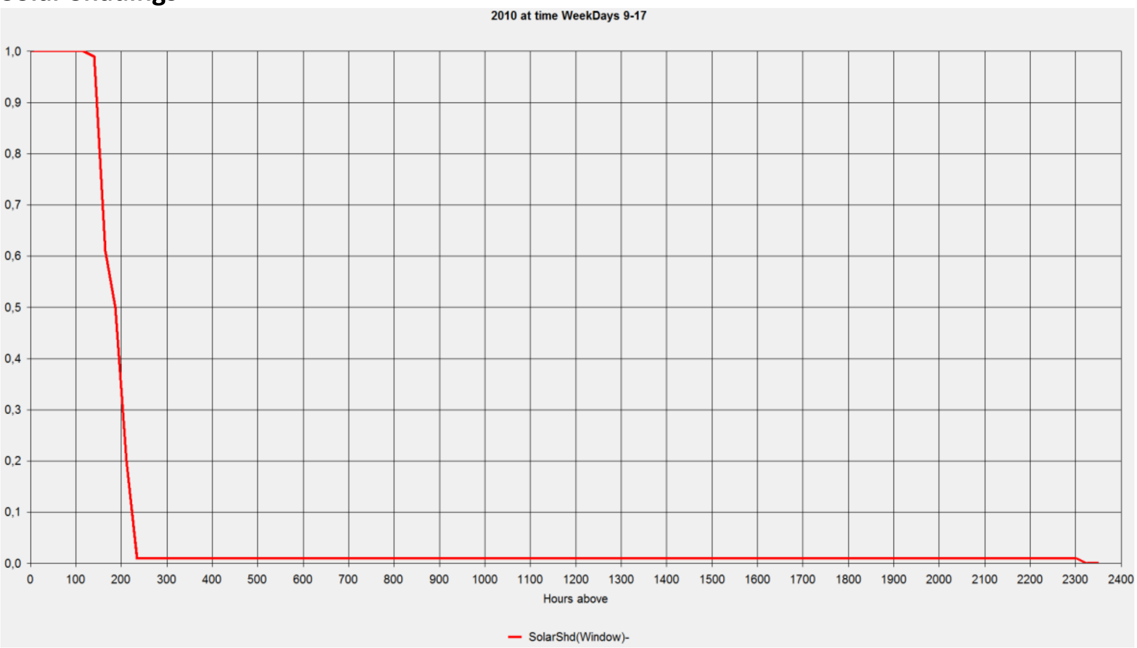


Figure 37 - Solar shades hours above over the entire year.

Almost 150 hours of the year have a factor is 1,0 for the solar shades. That means that they are used at their full capacity, in a 37 hours working week that represents approx. 4 weeks.
A total of approximately 6 weeks of the year, the solar shades will be needed to protect from solar energy radiations, overheating and glare.

Solar energy radiations

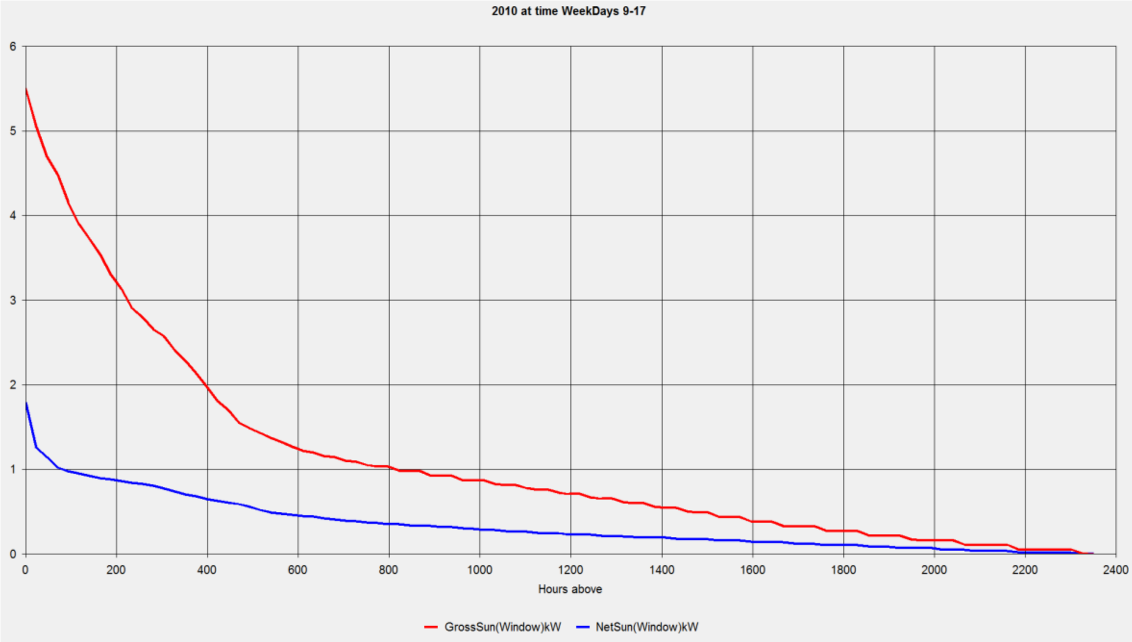


Figure 38 - Solar energy radiations transmitted through the window glass into the thermal indoor climate with blue, and the total solar energy radiations reaching the window glass, represented with red.

From Figure 38, it is represented with the red line the solar energy radiations in kW reaching the window. Blue line represents how much solar energy is transmitted through the window glass chosen into the thermal indoor climate. The difference from the red line to the blue line is the windows g-value effectivity.
A maximum of approximately 2 kW, solar energy radiations will be added to the room.

Daylight transmittance

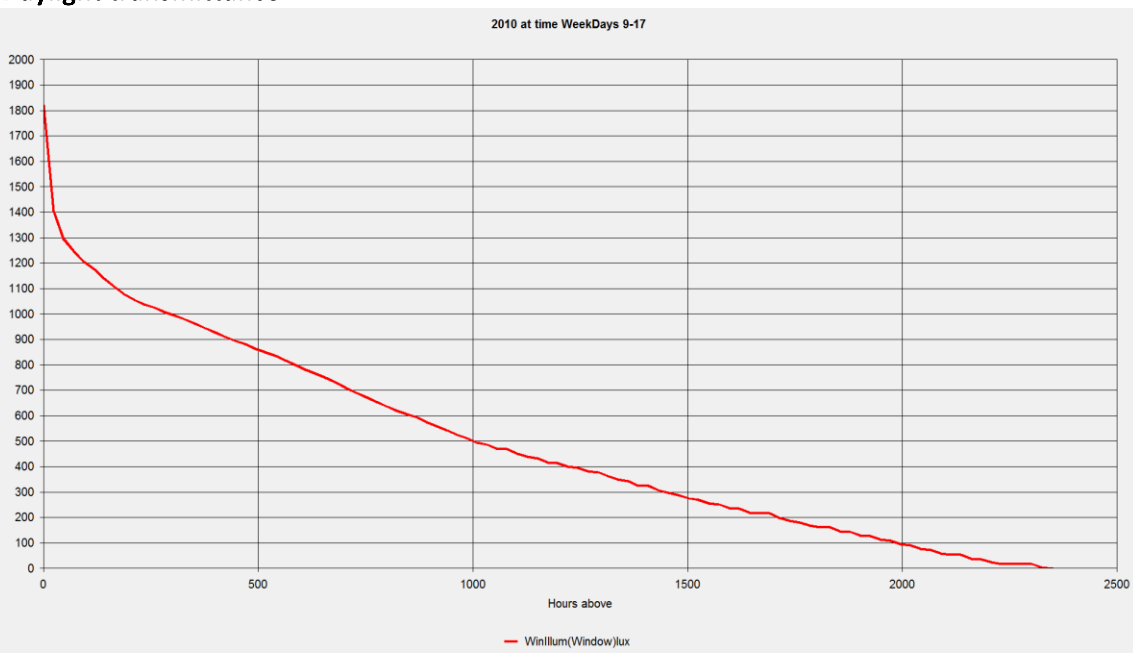


Figure 39 – Results for daylight transmitted through the window glass into the thermal indoor climate.

In Figure 39, the lux intake through the window glass in the working hours. Approx. 1400 hours get 300 lux.

Energy balance

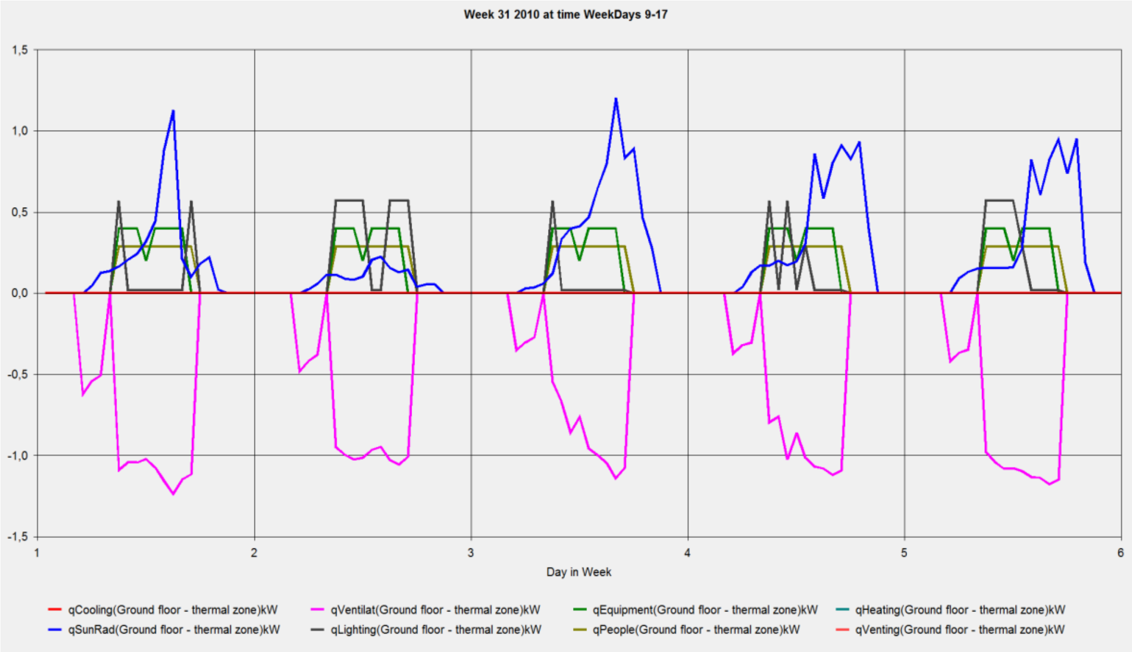


Figure 40 - Energy balance for week 32, the warmest outside temperatures in 2010.

Figure 40 illustrates the energy balance for the thermal indoor climate, where all the loads are illustrated. The ventilation through a ventilation rate air change is balancing the overheating inside the room, getting the indoor temperature and air quality balanced. Note that heating is used only in the winter period, but it is still a parameter that influences the energy balance.

5.3. Climate change

All results are simulated with A1B scenario for climate change predictions.
Results are illustrated as in present (2010 conditions), 2020-2050, and 2070-2100 scenarios for the thermal indoor climate with the current conditions.

5.3.1. Outdoor climate change conditions

External global temperature

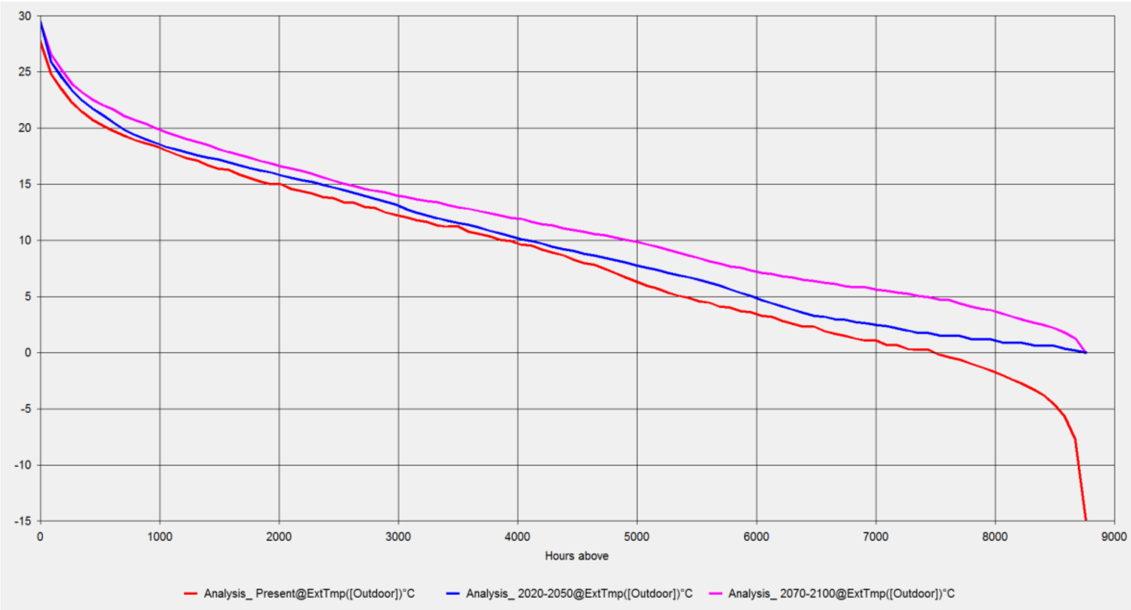


Figure 41 - External global temperature. Simulations done for Present (2010), 2020-2050 and 2070-2100.

Figure 41, as illustrated in the theory, for the years 2050 an annual average increase in global temperature is assumed for +1,2°C with a ± 0.2°C uncertainty; while for the year 2100, an increase in the average global temperature is +2,9°C with an uncertainty of 0,3°C.
In Figure 26, can also be seen that the average in both situations should increase with 0,9 °C for 2050 and respectively with 2,2 °C for 2100, while the lower annual average temperatures are reduced.

Relative humidity

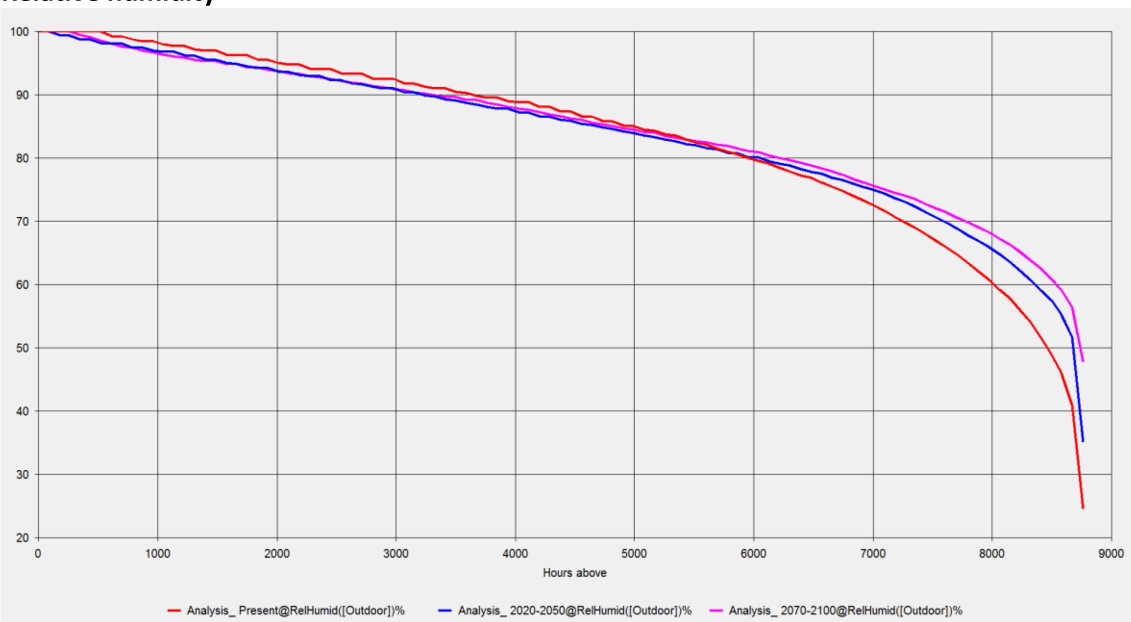


Figure 42 - Relative humidity, RF%, for the present, 2020-2050 and 2070-2100 climate change scenarios.

Figure 42 illustrates that the outdoors relative humidity, will only increase in hours above toward 2100 for an annual average estimation.

Wind speed

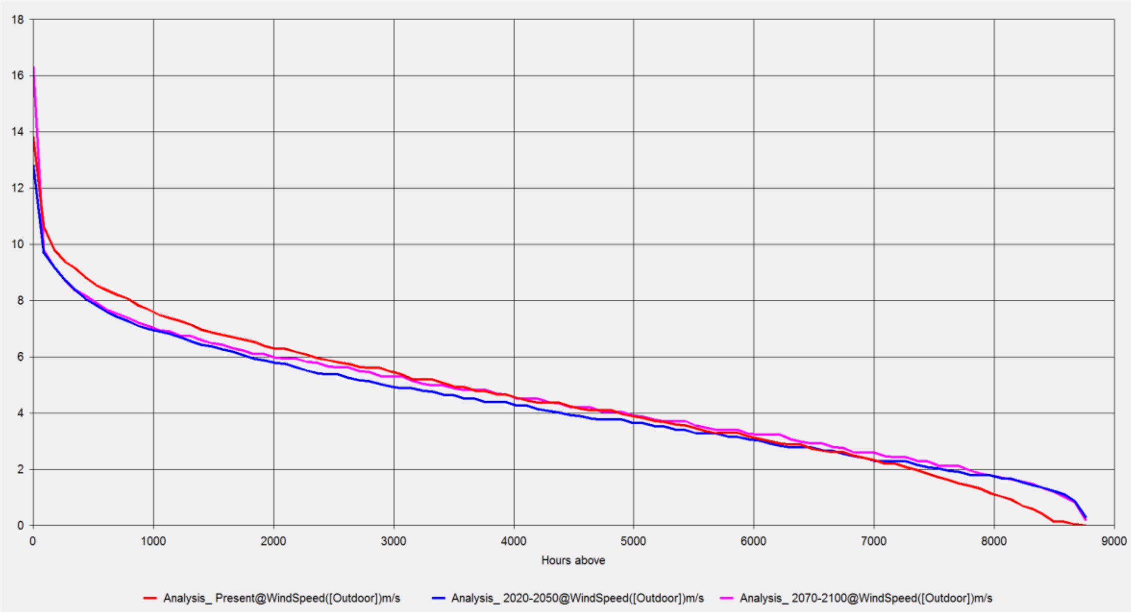


Figure 43 - Wind speed (m/s) for the climate change future scenarios for 2020-2050, 2070-2100 and the present.

Figure 43 illustrates that in 2100, there will be higher values for the wind speed (m/s) than in the present. If now the maximum wind speed is approx. 13 m/s, towards 2100, the maximum wind speed can reach approx. 16 m/s.

Solar radiations reaching the window glass

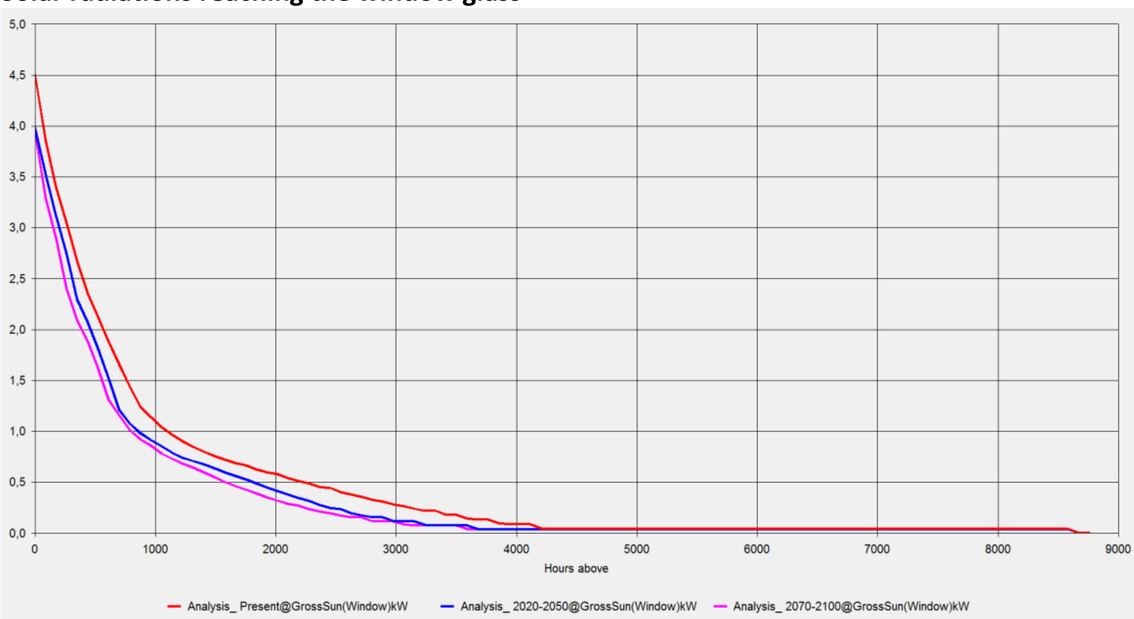


Figure 44 - Solar radiations reaching the windows glass for the present and the future climate change scenarios for 2020-2050 and 2070-2100.

Figure 44 illustrates that the future climate change scenarios will have an impact on the solar energy radiations reaching the window glass. A maximum value of 4,5 kW might reach the window surface now, while in the future only 4 kW solar radiations will reach the window glass surface.

5.3.2. Daylight

Further simulations cannot be investigated in SimLight since the result are inconclusive (same results as previous simulations). In chapter 5.3.3. Thermal indoor climate, the daylight transmittance through a window glass opening is analyzed. That can offer an overall idea of the daylight predictions changes regarding daylight.

5.3.3. Thermal indoor climate

The same model used for 5.2. Thermal indoor climate was used to simulate for the future climate change scenarios.

Indoors temperature

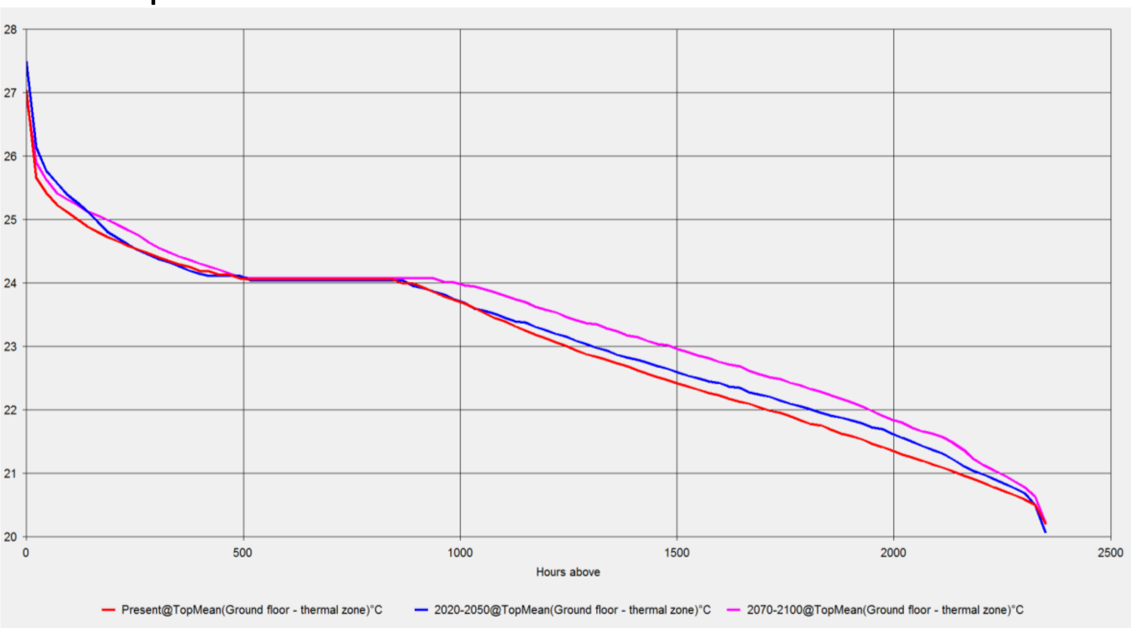


Figure 45 - Results, indoors temperature for climate change scenarios.

Figure 45 illustrates the hours above for the thermal indoor climate. According to figure, the average annual temperatures will increase gradually towards 2100, in comparison to the present.

Solar Shades

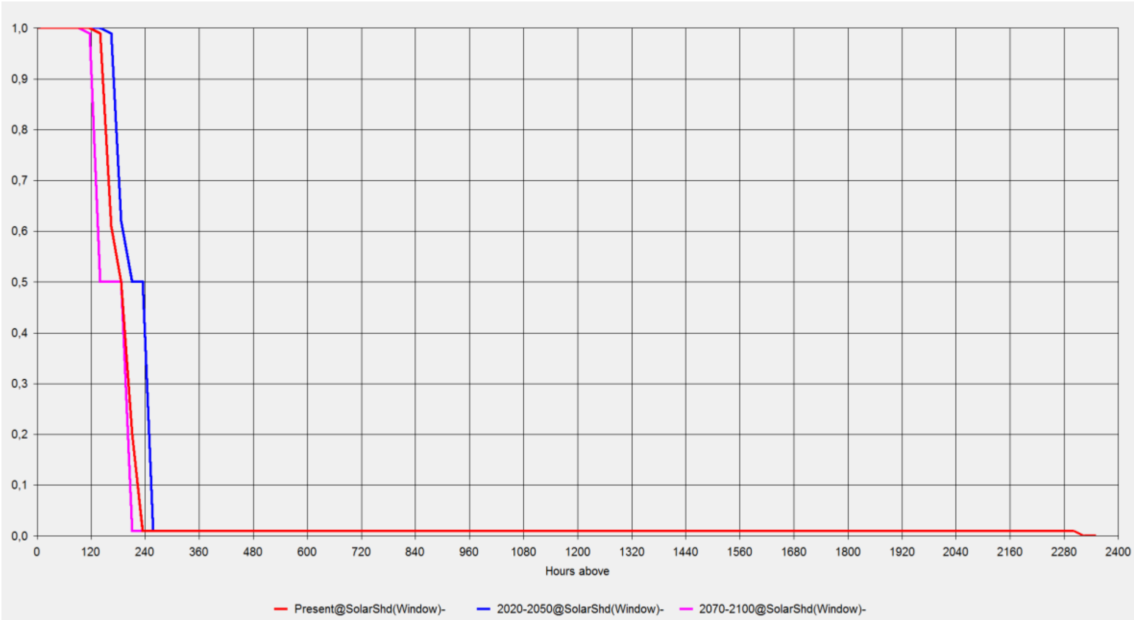


Figure 46 - Results for solar shades coefficient for future climate change scenarios.

Figure 46 illustrates that in the use of solar shades, by 2100 will decrease in average by 20 hours. Less usage of solar shades might be required in the future.

Daylight transmittance

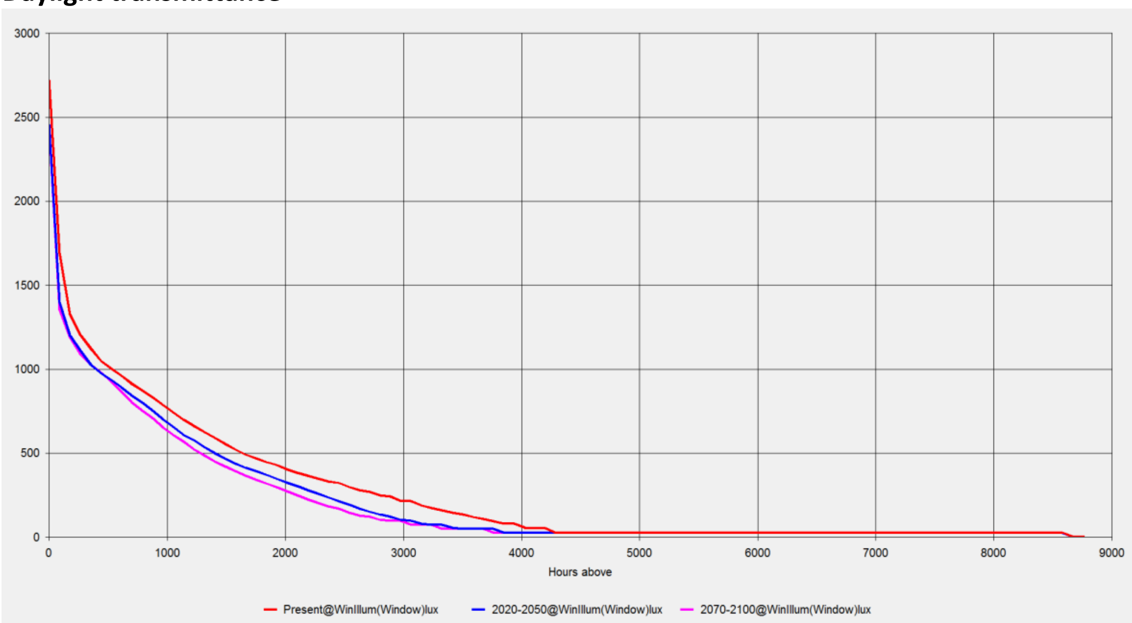


Figure 47 - Daylight transmitted through the window glass.

Figure 47 illustrates that in the present almost 2800 lux are transmitted through the window glass into the room, while by 2100, only 2400 lux might be transmitted through the window glass area. Decrease in all the hours above regarding daylight can be seen for 2020-2050, and even lower values for 2070-2100.
Lower daylight might be an effect of the future climate change.

Energy balance

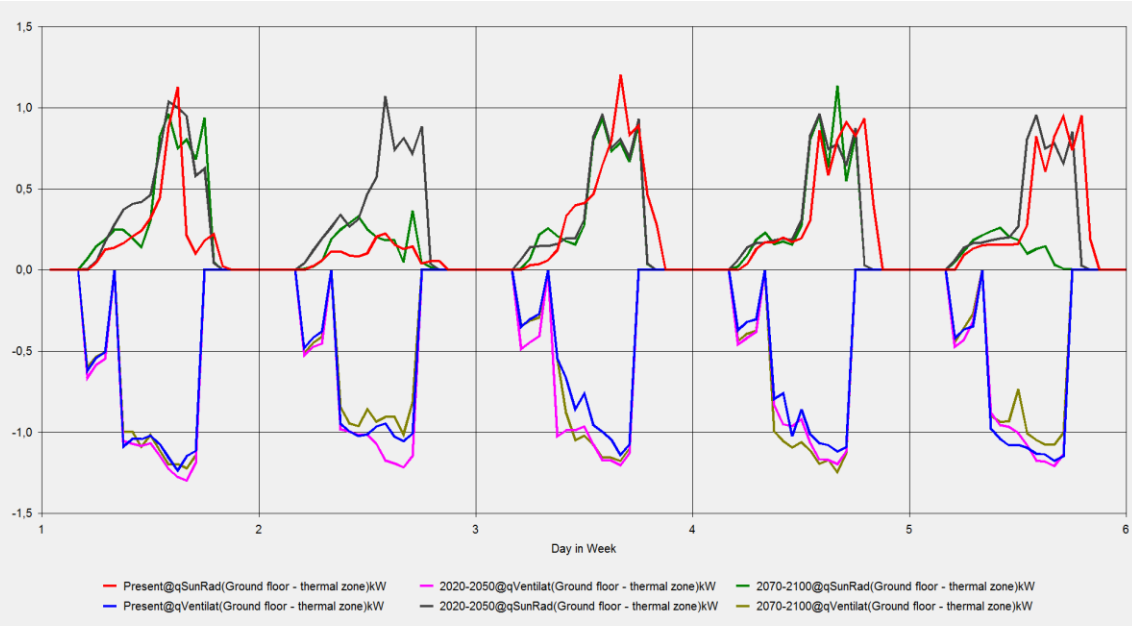


Figure 48 - Results for energy balance for future climate change scenarios for week 32.

Since parameters such as people, equipment and lighting are representing some loads that are unchanged, Figure 48, illustrates the solar radiation and the ventilation for the present, year 2020-2050 and 2070-2100.
It can be seen, that the solar radiations reaching the room, in time are getting reduced, while there is still a need of more ventilation, that is because of the increase global temperature in the outdoors.

Solar energy radiations

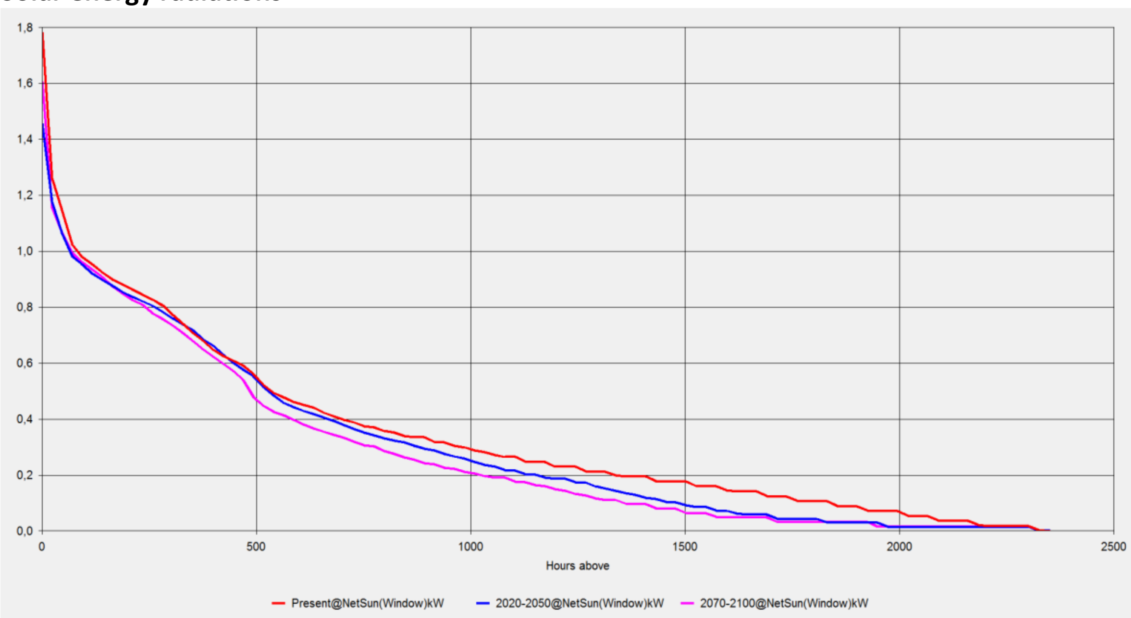


Figure 49 - Solar energy radiation transmitted through the window glass.

From Figure 46 and Figure 49, can be seen that the solar energy radiation transmitted through the window glass will decrease within time.

6. Analysis

Analysis is done based on the results from chapter 5. Results, where different solutions are applied on the room, for reaching better results.

6.1. Daylight

6.1.1. The 10 percent rule

On the 10 percent rule, numerous variations can change the results according to the correction factors applied on the window glass area.

6.1.1.1. Window Type 1

For window type 1, the solar shades are removed from the correction factors.

Type 1	Parameter	Information	Units	Symbols
Room and area identification	Building	Office Building		
	Floor	Ground floor		
	Room	Office room		
	Net floor area	24	m^2	A_{floor}
	Windows area	4,5	m^2	$A_{vin\ i}$
	Glass area	3,97	m^2	$A_{G,vin\ i}$
Correction factor for	Window type	0,96		F_{LT}
	Wall thickness	1		$F_{VÆG}$
	Surroundings	0,5		F_{OMG}
	Deepness of the room	0,9		F_{RUM}
Results of the correction factor		0,43		$F_{G,kor,i}$
Glass area correction		1,72	m^2	$F_{G,kor,i} * A_{G,vin\ i}$
Percentage		7%		

Table 26 - Analysis, window type 1, without solar shades.

Table 26, illustrates the new results from which the solar shades correction factor has been removed from the glass corrected area, the results changed from a 4% to a 7% glass area corrected per floor area.
Even by removing the solar shades, the demands from BR18 cannot be fulfilled, of a minimum of 10%.

6.1.1.2. Window Type 2

On window type 2, as illustrated in Table 27, the solar shades have been removed.

Type 2	Parameter	Information	Units	Symbols
Room and area identification	Building	Office Building		
	Floor	Ground floor		
	Room	Office room		
	Net floor area	24	m^2	A_{floor}
	Windows area	7	m^2	$A_{vin\ i}$
	Glass area	6,47	m^2	$A_{G,vin\ i}$
Correction factor for	Window type	0,96		F_{LT}
	Wall thickness	1		$F_{VÆG}$
	Surroundings	0,5		F_{OMG}
	Deepness of the room	0,9		F_{RUM}
Results of the correction factor		0,43		$F_{G,kor,i}$
Glass area correction		2,80	m^2	$F_{G,kor,i} * A_{G,vin\ i}$
Percentage		<u>12%</u>		

Table 27 – Analysis, window type 2, without solar shades.

By removing the solar shades, the glass corrected area has considerably increased from a 7% to a 12% of the floor area.

By adding an opening to the window to create the possibility of venting, as illustrated in Table 28, and the glass area is minimized from 6,47 to 4,9 m^2, even though the solar shades have been removed the percentage of glass corrected area is 9% from the floor area.

Type 2	Parameter	Information	Units	Symbols
Room and area identification	Building	Office Building		
	Floor	Ground floor		
	Room	Office room		
	Net floor area	24	m^2	A_{floor}
	Windows area	7	m^2	$A_{vin\ i}$
	Glass area	4,9	m^2	$A_{G,vin\ i}$
Correction factor for	Window type	0,96		F_{LT}
	Wall thickness	1		$F_{VÆG}$
	Surroundings	0,5		F_{OMG}
	Deepness of the room	0,9		F_{RUM}
Results of the correction factor		0,43		$F_{G,kor,i}$
Glass area correction		2,12	m^2	$F_{G,kor,i} * A_{G,vin\ i}$
Percentage		<u>9%</u>		

Table 28 - Analysis, window type 2, without solar shades and minimized glass area because of a window opening.

If the glass area reduction is minimum 5,3 m^2, then a 10% glass corrected area can be achieved for window type 2.
Window type 2, as illustrated in Table 27, by removing the solar shades could get enough daylight to fulfil the demands set by BR18.

6.1.2. Daylight factor

The daylight factor can vary the same as the 10 percent rule, accordingly to the correction factor applied on it. As lower as the correction factor is, as less space will be covered by the 2 DF, respectively 0,7 DF.
Therefore, by adding the correction factor from the 10 percent rule, of 0,43 to the results from SimLight, for window type 1, only 21% of the reference plane achieves a 2 DF, while 63% of the reference plane achieves a 0,7 DF.
Window type 2 achieves 2 DF on 27% of the reference plane, while 99% of the reference plane gets a 0,7 DF.
In both cases, the daylight factor is below the minimum recommended requirements from DS/EN 17037.

6.1.3. The illuminance target – 300 lux

According to the Danish Standards, regarding the intervals of reflections that can be on ceiling, walls and floors there have been made 3 different simulations to analyze the difference between the lower, medium and higher reflectance values of the surfaces and the results that might have in the room.[156]
The focus is also to see how much of the 300 lux illuminance target is spreading through the room, as well as the 100 lux.

[156] (Dansk Standard, 2011, s. 9)

6.1.3.1. Results for Window type 1 from SimLight

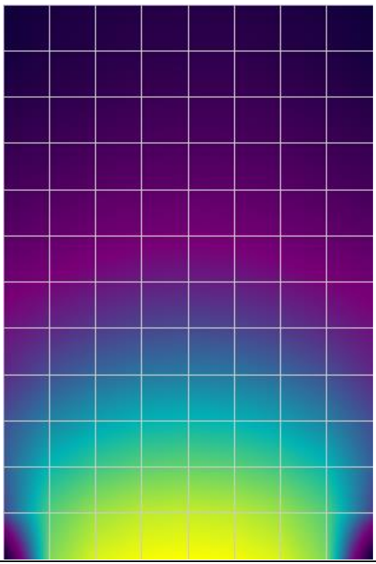
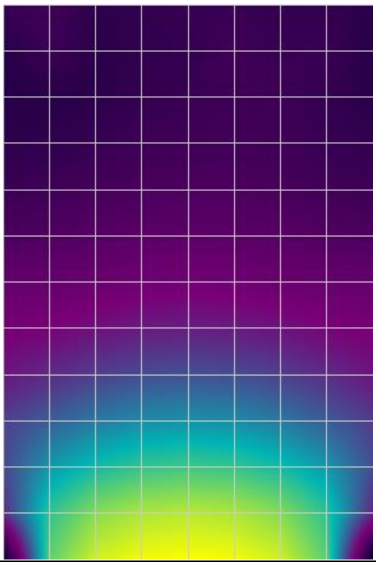
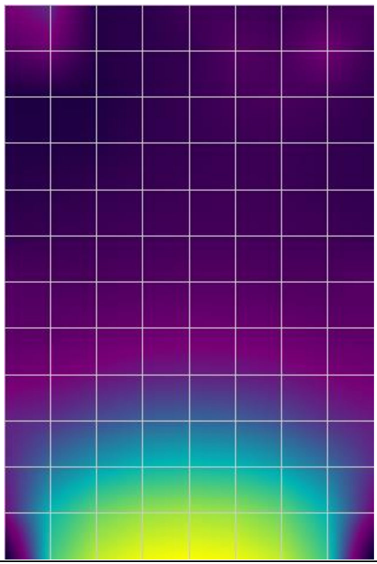
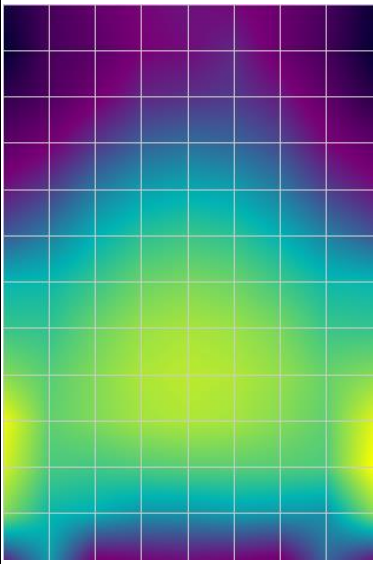
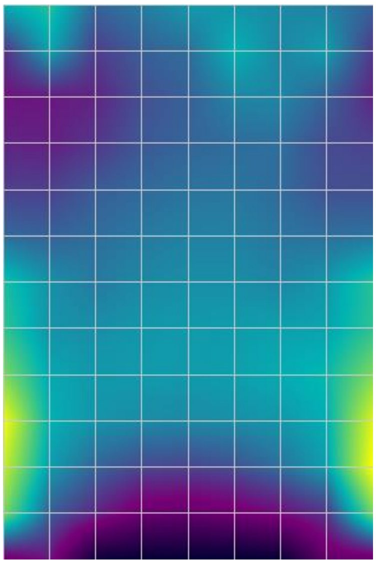
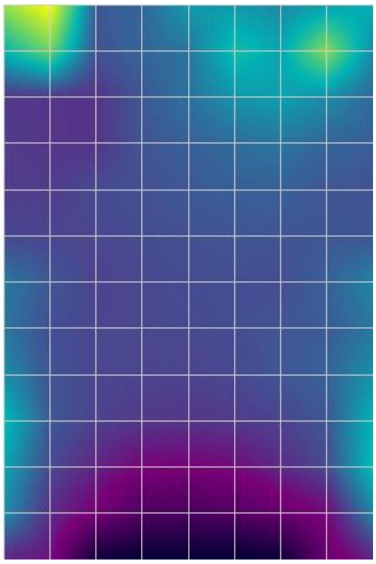
Type 1	Low reflectance of surfaces	Medium reflectance of surfaces	High reflectance of surfaces
R	Ceiling 0,7 Walls 0,5 Floor 0,2	Ceiling 0,8 Walls 0,6 Floor 0,3	Ceiling 0,9 Walls 0,8 Floor 0,4
Total illumination			
300lx	25%	35%	84%
100lx	60%	100%	100%
Internally reflected			

Table 29 - Window type 1 - reflectance of surfaces

Table 29, illustrates that as higher the reflectance value of the building surfaces has, as more covering of the target illumination there can be achieved into the room.

In the first example with the lower reflectance values, most of the daylight is reaching on the adjacent walls from the external wall, and the floor. The elements are not reflecting the daylight that much into the room because they represent the lowest reflectance values.

On the second examples, it can be noticed that the adjacent walls to the external wall are reflecting more of the daylight and spread it throughout the room.
On the last example, where the reflectance of the surfaces is set to the highest values recommended, can be seen that the materials reflect enough daylight to supply 300 lux in 84% of the reference plane. The daylight is reflected by all surfaces and maintained in the room.

6.1.3.2. Results for Window type 2 from SimLight

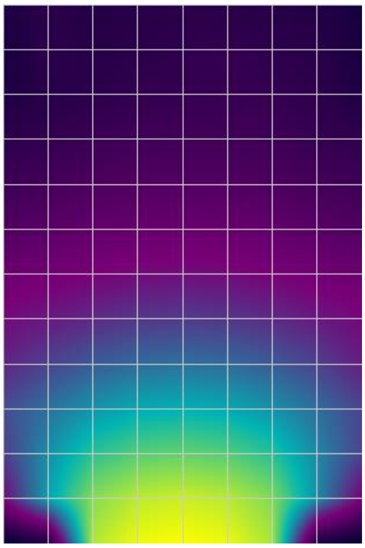
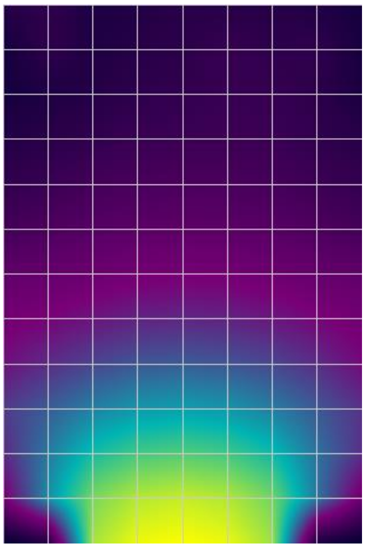
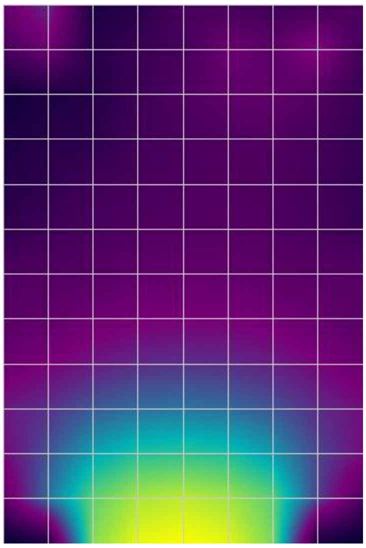
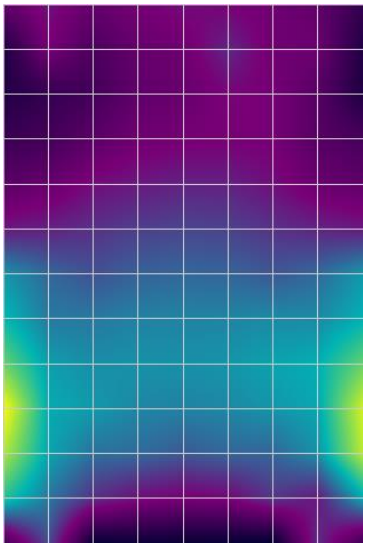
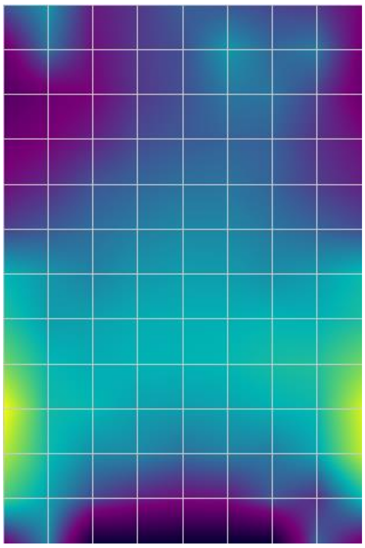
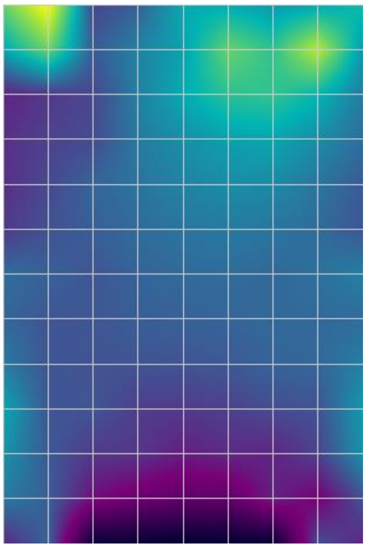
Type 2	**Low reflectance of surfaces**	**Medium reflectance of surfaces**	**High reflectance of surfaces**
R	Ceiling 0,7 Walls 0,5 Floor 0,2	Ceiling 0,8 Walls 0,6 Floor 0,3	Ceiling 0,9 Walls 0,8 Floor 0,4
Total illumination			
300lx	39%	55%	100%
100lx	100%	100%	100%
Internally reflected			

Table 30 - Window type 2 reflectance of surfaces

Table 30 illustrates the same principles as just explained in Table 29. The values achieved for Window type 2 are through higher because of the windows glass area size.

6.2. Thermal indoor climate

From the daylight analysis, it is concluded that an option without solar shades for the Window type 2, could achieved enough daylight inside the room.
Also, an option with a 5,3m^2 glass area reduction could be another option with including natural ventilation done by venting to the room.
Therefore, from the daylight analysis, for the thermal indoor climate, 3 models have been made:

1. Mechanical ventilation without solar shades – This model has the same properties as the one described in the case study, without solar shades. Just mechanical ventilation.
2. Mechanical ventilation with cooling – This model, is the same as the first one and has mechanical cooling added to the ventilation system, for the entire building. (-15 W/m^2) The cooling effect is dimensioned for a large office building, and as mentioned before, the room is based on a fictive project where the total area of the building is unknown. This is a cooling system from the ceiling meant to balance the thermal indoor climate when the indoor temperatures get to high. [157]
3. Mechanical ventilation with venting – This model, based on the first one, has a 5,3 m^2 glass opening for natural ventilation. It has both mechanical ventilation and natural ventilation, and no cooling. (3 h^{-1} venting from the side)

Indoor temperature

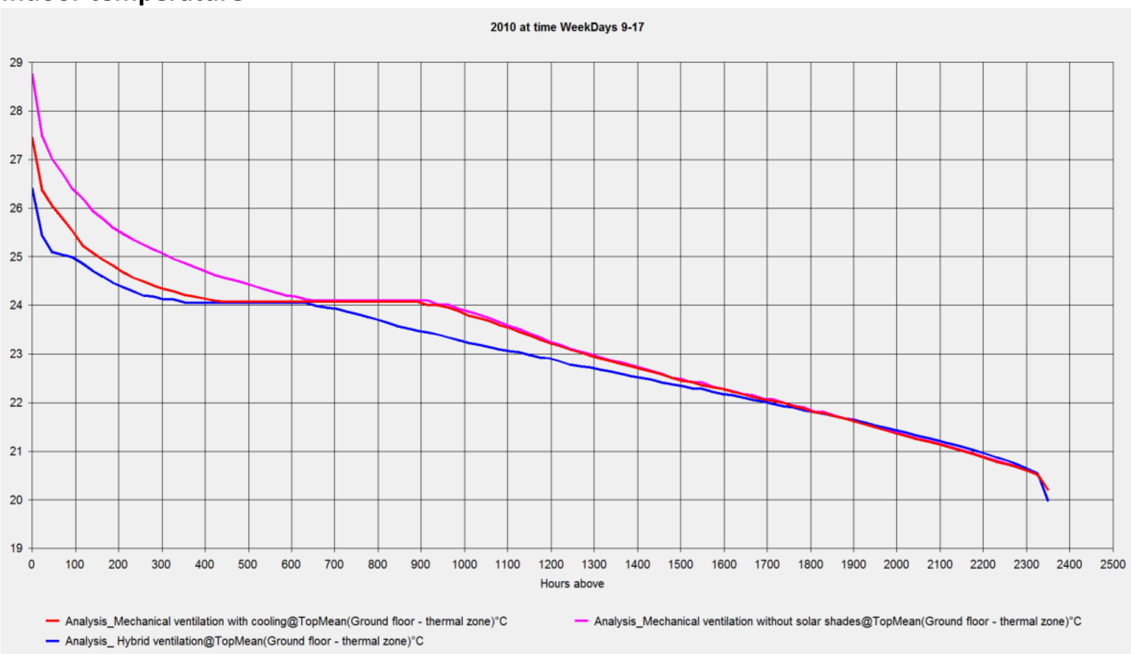


Figure 50 - Analysis of hours above for the indoor temperature for the working hours

From Figure 50, can be seen that the maximum number of hours for 27° C which is 25 hours, and 26°C which is 100 hours required from BR18 for an indoor temperature in an office building is not achieved by a mechanical ventilation system alone.

[157] (Statens Byggeforskningsinstitut, SBi, 2009)

Both options for mechanical ventilation with cooling and mechanical ventilation with venting, fulfil the minimum requirements for BR18, in the working hours.

Carbon Dioxide

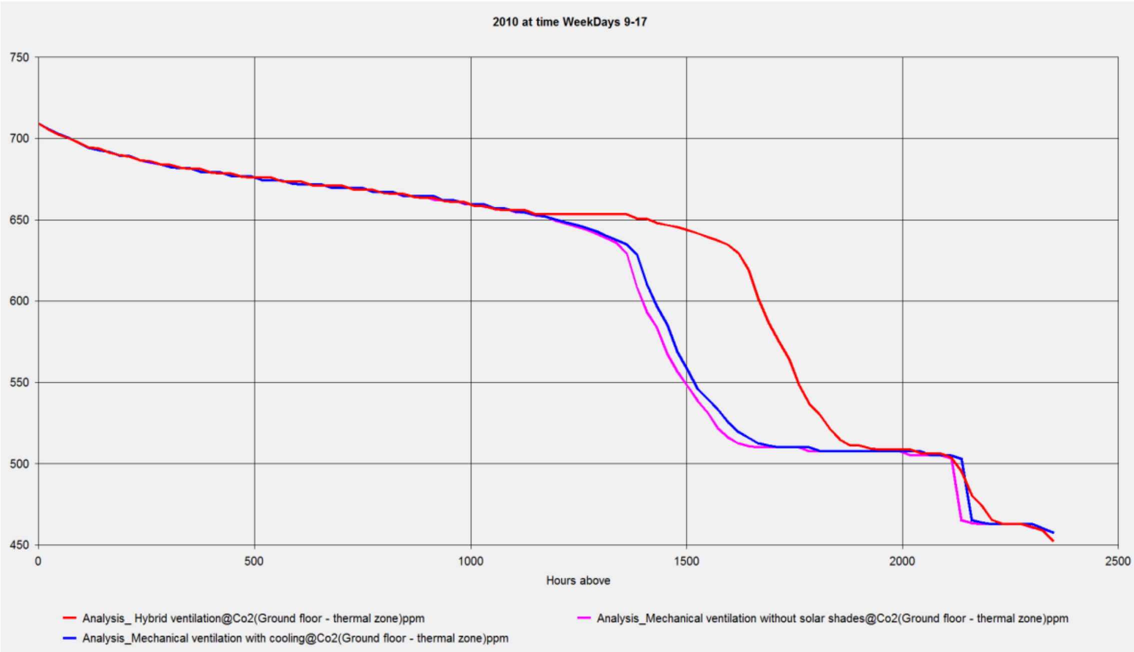


Figure 51 - Analysis of CO_2 with hours above for the entire year.

Figure 51 illustrates that the CO_2 level in all the options is maintained under the 1000 ppm, that is required from BR18.

Solar energy radiations

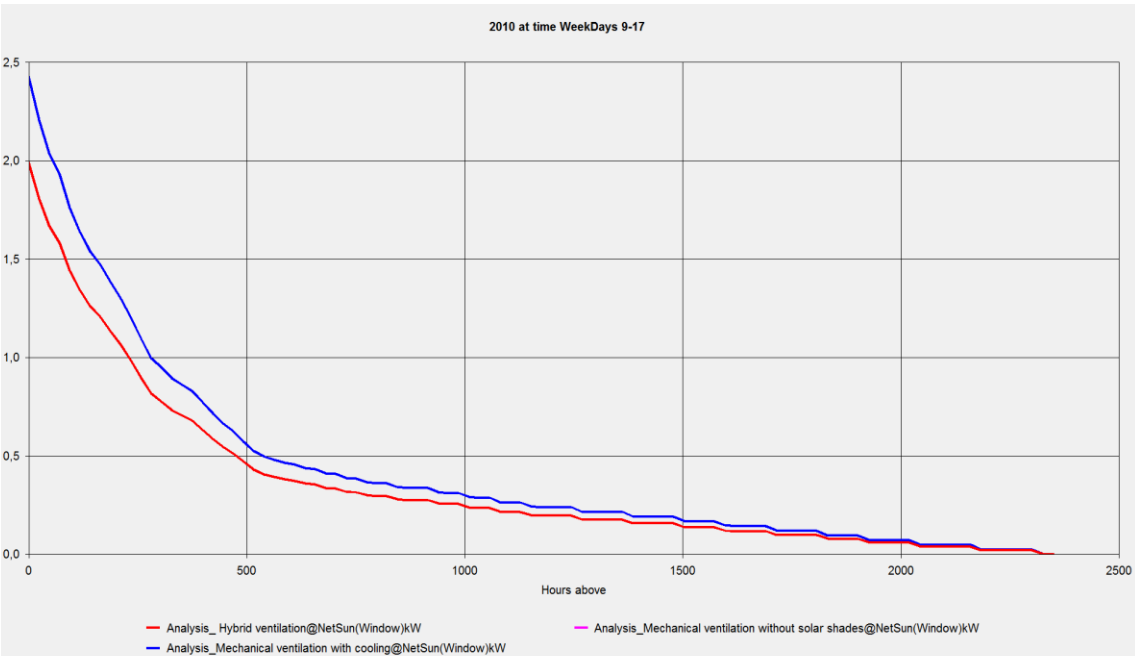


Figure 52 - Solar energy radiations transmitted through the window glass into the thermal indoor climate.

Figure 52, illustrates that the option with natural ventilation, gets less solar energy radiations transmitted insides the thermal zone. That is because the windows glass area is reduced by the opening designed for venting. Mechanical ventilation with and without cooling receives a higher amount of solar energy radiations transmitted through the glass because the glass area is larger in those options.

Daylight transmittance

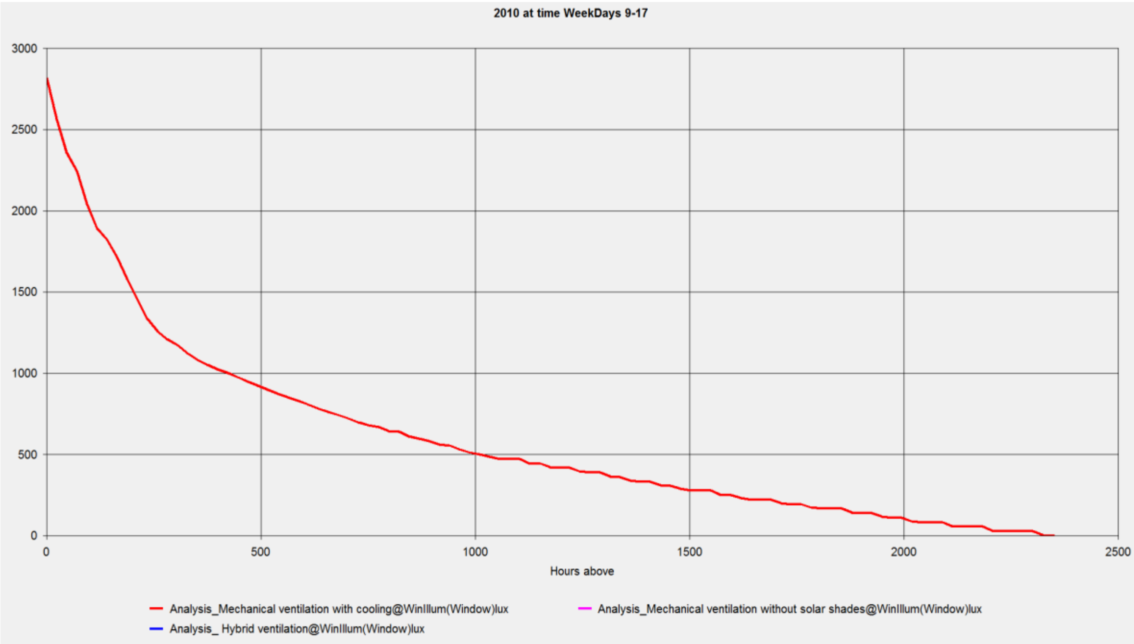


Figure 53 - Analysis for daylight transmitted through the window glass into the thermal indoor climate.

Figure 53 in comparison with Figure 39 from the results with solar shades, has the average values with a higher illuminance represented by the daylight transmitted thought the window glass area.

Air change rate

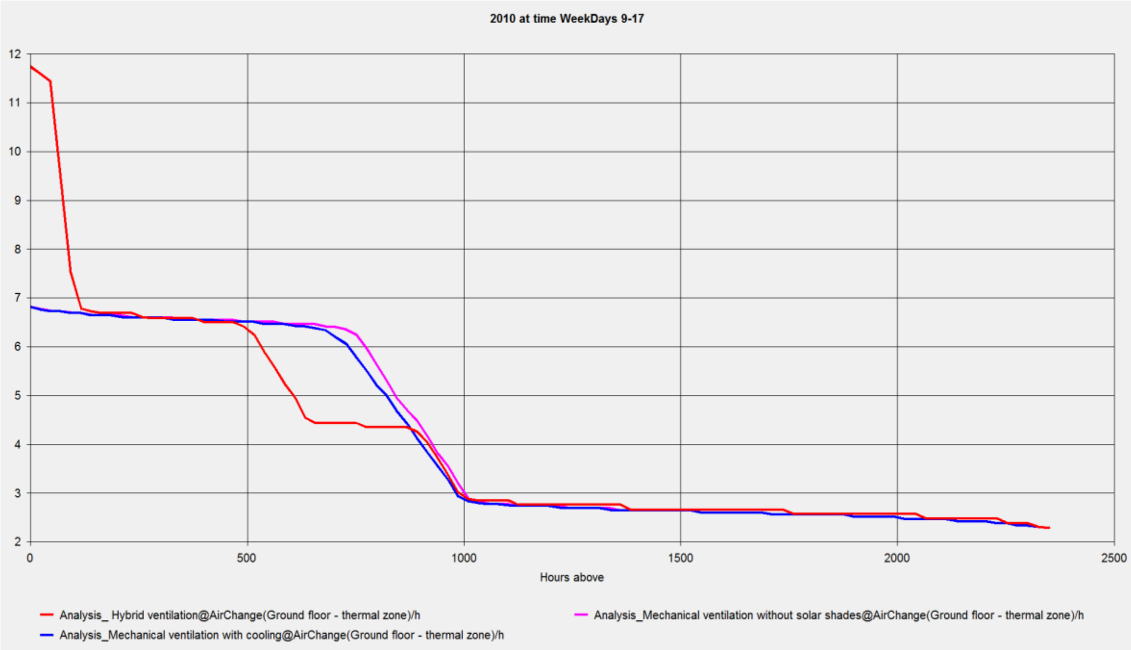


Figure 54 - Air change rate for different ventilation methods

From Figure 54, it can observed that the air change rate for the mechanical ventilation does not exceed the value of 7, as designed, while by using of both natural ventilation and mechanical ventilation, the air change rate could be adjusted for the occupancies needs.

6.3. Climate change

Since the minimum daylight wasn't achieved for a mechanical ventilation system with solar shades, this model is not considered for further simulations. Both solutions with mechanical ventilation with cooling and mechanical ventilation with venting will be analyzed further without solar shades. The analysis on the two options that fulfil both daylight and indoor climate conditions for the present are simulated with the future climate changes scenarios.

Temperature

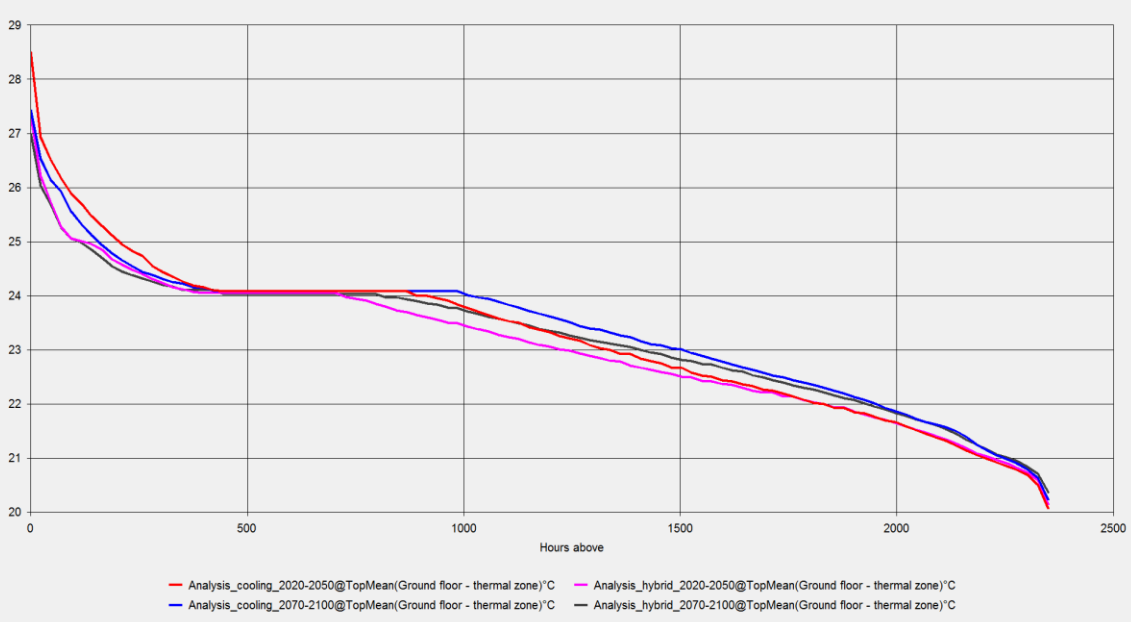


Figure 55 - Analysis, hours above indoor temperature for climate change scenarios for mechanical ventilation with cooling and a hybrid ventilation system.

Figure 55 illustrates the highest indoor temperatures for a mechanical ventilation with cooling, where 27°C for 25 hours and 26°C for 100 hours are not fulfilled. Values of approx. 200 hours are recorded for a 26°C temperature. Moreover, temperatures to almost 29°C can be seen in the figure.
A mechanical ventilation with venting, will still fulfil the current demands in regards to indoor temperatures.

Solar energy radiation

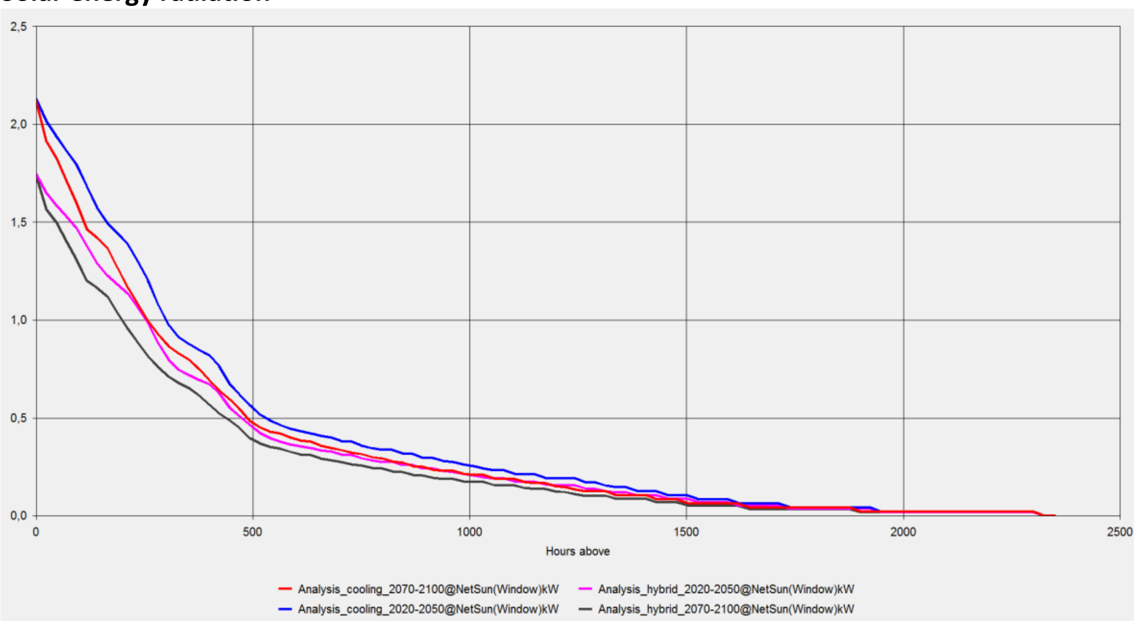


Figure 56 - Solar energy radiations through the window glass for the future climate change scenarios.

Figure 56 illustrates that the future climate change scenarios for the mechanical ventilation with venting system received less solar energy radiations transmitted into the thermal indoor climate. The reason for that is the reduction of glass area when adding an opening to the window. A difference of almost 1,0 kW can be noticed on the maximum values between the 2 different solutions throughout the hours.

Daylight transmittance

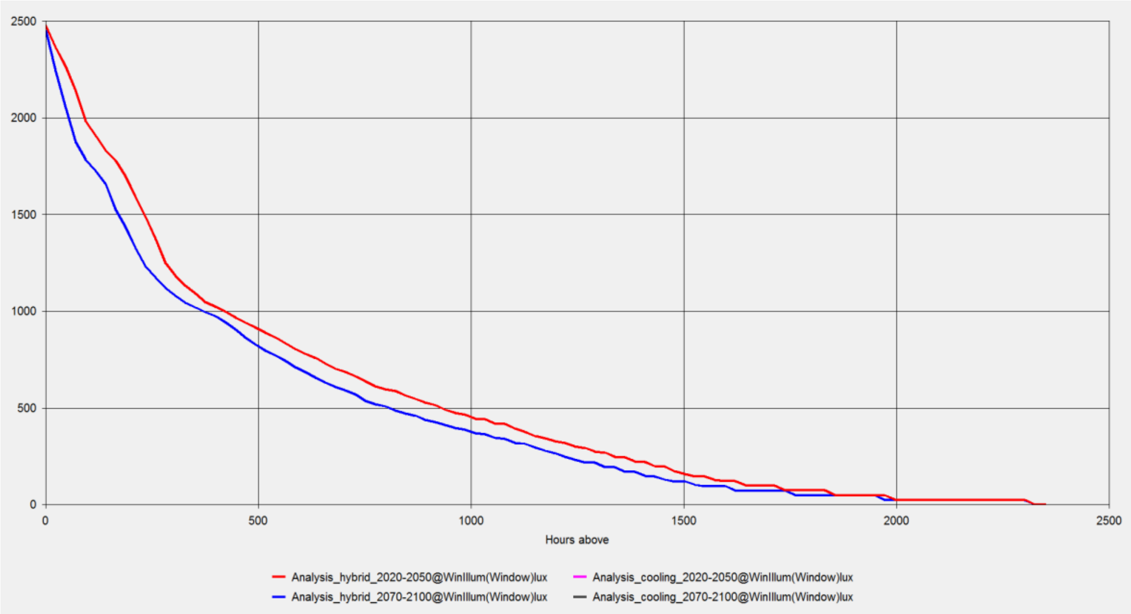


Figure 57 - Analysis, daylight transmittance through the window glass for future climate change scenarios.

As it can be seen in Figure 57 from 2020-2050 scenario until 2070-2100 scenario, a decrease in the daylight transmitted through the window glass opening of approx. 50 lux will occur towards 2100. Therefore, the daylight reaching the room in the future will be lower.

Energy balance for a mechanical ventilation with cooling for future climate change scenarios

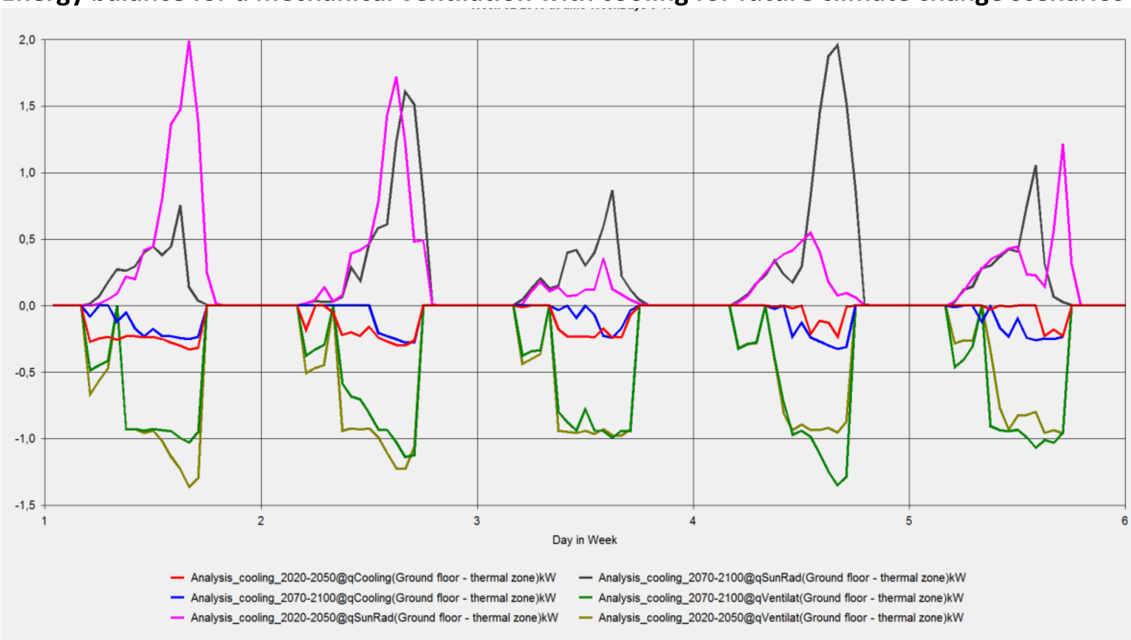


Figure 58 - Energy balance for the mechanical ventilation with cooling for 2020-2050 and 2070-2100 for week 32.

Figure 58 illustrates the warmest week in the year, week 32, and the energy balance between the thermal indoor climate for the two future scenarios. People, equipment and lighting are not added since they are a constant load. It can be noticed from the figure that the cooling is supplying the ventilation system to reduce the over loads from solar radiations, and all the other loads applied to the room.

Energy balance for a mechanical ventilation with venting for future climate change scenarios

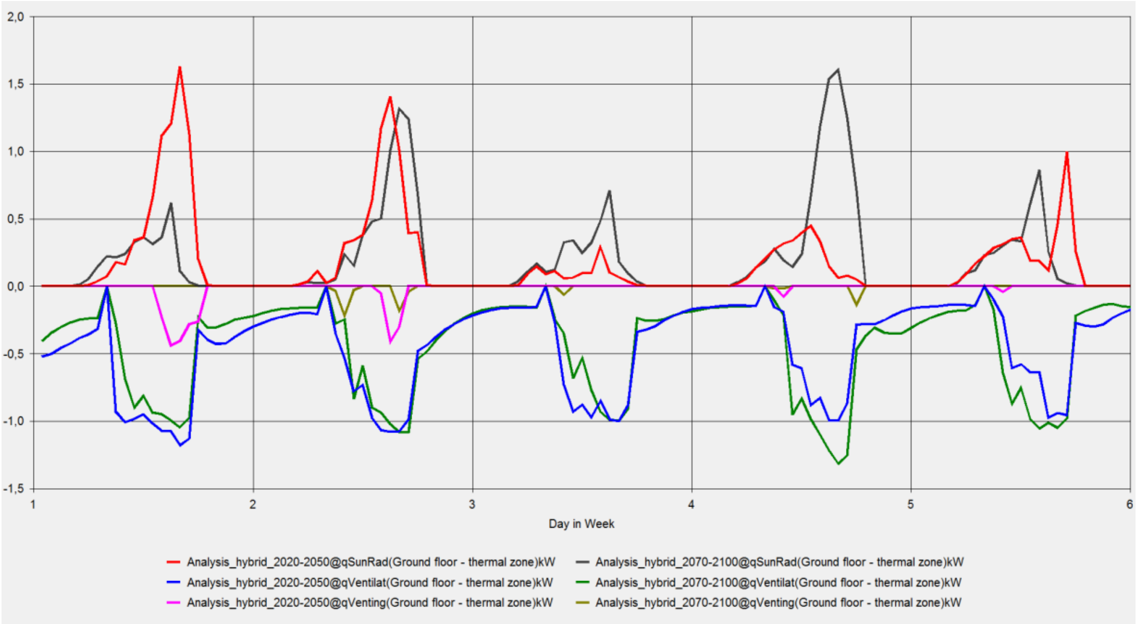


Figure 59 - Energy balance for a mechanical ventilation with venting for 2020-2050 and 2070-2100 for week 32.

Figure 59 illustrates that the ventilation system with venting is using night control fans to balance the thermal indoor climate. Venting is used only when needed to balance the indoor temperatures.

7. Discussion

7.1. Daylight

7.1.1. The 10 percent rule

The 10 percent rule is an efficient solution that can be used in early phase of a project as a validation when designing a room, to check if the space achieved enough daylight. It is important that all the correction factors are strongly considered, since they can make a difference in the calculations.
Window type 1 from the results throughout the analysis didn't achieved a minimum of 10% glass corrected area of the floor area. The reason, as explained in the theory is because the window opening is placed lower in the façade, therefore, most of the daylight reaching the room is on the area closer to the window.
Window type 2, with solar shading cannot achieved the minimum daylight demands. The demands for BR18 can be achieved by removing the solar shades.

7.1.2. Daylight factor

Daylight factor (DF) is as dependent to the correction factors as the 10 percent rule. Any changes on the correction factors coefficient can affect the results as much as the 10 percent rule does.
The results are inconclusive since a method wasn't described on how to apply the correction factors or even how to calculate the factor coefficient according to DS/EN 17037.

7.1.3. The illuminance target – 300 lux

SimLight results don't include the solar shading as a factor that reduces the illuminance target to be achieved in the room. Therefore, most of the analysis had been focused on the elements that could be controlled and their importance. That is the internal reflectance coefficient of ceiling, walls, and floors. As illustrated in Table 29 and Table 30 the lower reflectance materials don't usually achieve the minimum illuminance target of 300 lux for 50% of the reference plane, while the higher reflectance, could for both window type 1 and 2 achieve the minimum values set by BR18.
It is recommended to simulate with the lowest values of internally reflected surface because it illustrates the worst-case scenarios. T
The internally reflected surfaces used in the results, had been chosen with a medium reflectance values as an overall, because of the colors and materials chosen of internal building part finishes.
Same simulations have been done with VELUX Daylight Visualizer, where the results are based on a visual assessment. The results in this program are overall lower than the results achieved in SimLight. Information about window's frame width and light transmittance coefficient as well as solar energy transmittance coefficient of the window cannot be adjusted in this program.

7.1.4. Comparison of 10 percent rule, daylight factor and the illuminance target

Results of illuminance level from SimLight program is compared with VELUX Daylight Visualizer, while the 10 percent rule is compared with the daylight factor.
10 percent rule is compared with the daylight factor results.

Window type 1

Window type 1 - Danish Building Regulation 2018 Demands			
10 percent rule		300 lux illuminance target for 50% of the net floor area	
With solar shadings	Without solar shading	SimLight	VELUX Daylight Visualizer
4%	7%	35%	Not achieved (visual assessment)

Table 31 - Window type 1, daylight demands summary.

Window Type 1 - Recommendation from Danish Standards DS/EN17037				
Programs	Daylight factor		Illuminance target	
	2,0 DF for 50% of the net floor area in half of the daylight hours	0,7 DF for 95% of the net floor area in half of the daylight hours	300 lux for 50% of the net floor area in half of the daylight hours	100 lux for 95% of the net floor area in half of the daylight hours
SimLight	10%	39%	35%	100%
VELUX Daylight Visualizer	Not achieved (visual assessment)	Not achieved (visual assessment)	Not achieved (visual assessment)	Not achieved (visual assessment)

Table 32 - Window type 1, daylight recommendation summary.

Window type 1 results and analysis (Table 31 and Table 32), indicates with all the used methods described by the demands and recommendations, that the window does not provide enough daylight into the room.

Window type 2

Window type 2 - Danish Building Regulation 2018 Demands			
10 percent rule		300 lux illuminance target for 50% of the net floor area	
With solar shadings	Without solar shading	SimLight	VELUX Daylight Visualizer
7%	12%	50%	Not achieved (visual assessment)

Table 33 - Window type 2, daylight demands summary.

Table 33, illustrates that the 10% is achieved only without solar shades, while SimLight results are achieving a minimum of 300 lux on 50% of the reference plane. SimLight also doesn't simulate with solar shades so the results without solar shades are most accurate to compare with. Simulations done with VELUX Daylight Visualizer don't fulfil the demands.

Window Type 2 - Recommendation from Danish Standards DS/EN17037				
Programs	Daylight factor		Illuminance target	
	2,0 DF for 50% of the net floor area in half of the daylight hours	0,7 DF for 95% of the net floor area in half of the daylight hours	300 lux for 50% of the net floor area in half of the daylight hours	100 lux for 95% of the net floor area in half of the daylight hours
SimLight	13%	55%	50%	100%
VELUX Daylight Visualizer	Achieved (visual assessment)	Achieved (visual assessment)	Not achieved (visual assessment)	Achieved (visual assessment)

Table 34 - Window type 2, daylight recommendation summary.

Table 34, illustrates the recommendation set by Danish standard results, where the comments about daylight factor and VELUX simulation results are similar as for window type 1.

7.2. Thermal indoor climate

As resulted from the daylight analysis, only window type 2 without solar shadings could achieve the minimum demands regarding daylight and is considered as an option for further thermal indoor climate analysis.

Regarding the temperature inside the room, a mechanical ventilation couldn't remove all the thermal loads applied to the room. A mechanical ventilation with cooling could fulfil the demands from BR18. Also, a mechanical ventilation with venting could fulfil the demands too.

CO_2 level in all the cases was under the maximum limit set by BR18.

The mechanical ventilation with venting has more advances regarding the heat load from solar radiations that reach into the room.

While on the mechanical ventilation with cooling, the cooling system is working in removing the extra heat loads.

7.3. Climate change

A mechanical ventilation with solar shades, will not benefit the daylight conditions in the future climate change scenarios, and that option is not fulfilling the minimum daylight illuminance for the current demands.

A mechanical ventilation with cooling, it is a good solution regarding daylight illuminance now, but in the future climate changes scenarios the room is facing many hours that will exceed the maximum indoors temperature. That is because of the solar radiations and all the loads applied to the room in relation to the higher outdoor temperatures.

A mechanical ventilation with venting achieved a balanced thermal indoor climate regarding the demands and requirements now and with the future climate change scenarios. Daylight illuminance is lower than the mechanical ventilation with cooling because of the glass area reduction in the window. It is also a favorable factor, since the solar energy radiation transmitted into the room is also lower. Daylight transmitted into the room is getting lower and lower for the climate change predictions, but for now, it fulfils the requirement.

8. Conclusion

8.1. Daylight

Window type 1, cannot achieve the minimum daylight requirements in the room because of the window placement, it is placed lower in the façade and the daylight reaching the room is not spread throughout the room.
Window type 2, can achieve the minimum daylight on a solution that does not include solar shades.

The 2 methods described in the Danish Building Regulation 2018, for the 10 percent rule of corrected glass area of the floor area and the 300 lux illuminance target for minimum 50% of the work plane do reach similar results for the daylight amount reaching the room.
Either one of the methods can be used to calculate the daylight in a room.
Both methods described calculate the worst-case scenario of daylight in a room, with a CIE overcast sky.

The methods described in DS17037, for the daylight in a room, are similar to the methods described in BR18. The daylight factor method is, alike the 10 percent rule from BR18 because it is based on a correction factor applied to the daylight factor inside the room. A specific method of how to apply the correction factors on the DF wasn't described in the Danish standards, that explains the reason why the results are so inconclusive.
The other method of 300 lux illuminance target for a minimum 50% of the room is the same in DS17037 as in BR18. The Danish standards though, require also a minimum illuminance target for the entire room too, of 100 lux for 95% of the work plane, that is not requested from the BR18.

8.2. Thermal indoor climate

To achieve a balanced thermal indoor climate on Window type 2 without solar shades, a mechanical ventilation with cooling or a mechanical ventilation system with venting could fulfil that.
The hybrid ventilation system, because of the reduction of the glass area, gives less daylight in the room but enough to achieve the minimum daylight demands.

The two ventilation principles can create balance between the loads applied to the room from the solar energy radiation, people, equipment, lighting and the air change rate needed for the room to ensure that the maximum number of hours from BR18 for indoor temperature is not exceed in the working hours and CO_2 level.

8.3. Climate change

According to A1B climate change scenario towards 2100, predictions such as higher outdoors temperatures are illustrated. The rainfall and the more extreme weather precipitation also lead to a more humid annual average and higher wind speed.
Daylight transmitted through the window glass area is getting lower than in the present, as well as the solar energy radiations.
With today's standards, thermal indoor climate based on a mechanical ventilation with cooling design is not removing the overheat from the room for the future climate change scenario. The mechanical ventilation with venting, is still fulfilling the demands set in BR18 for a balanced energy in the room.

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Appendix

Appendix A: Building part notes
Appendix B: 10 Percent rules
Appendix C: Daylight Results
Appendix D: Zip file with BSim files used for Daylight simulations
Appendix E: Zip file with BSim files used for Indoor climate simulation
Appendix F: Zip File with BSim log files used for Climate change simulations
Appendix G: Zip files with Velux models