SKYLIGHTS IN CLASSROOMS

Optimal design for a cold climate through dynamic daylighting and energy simulations

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Master thesis in Energy-efficient and Environmental
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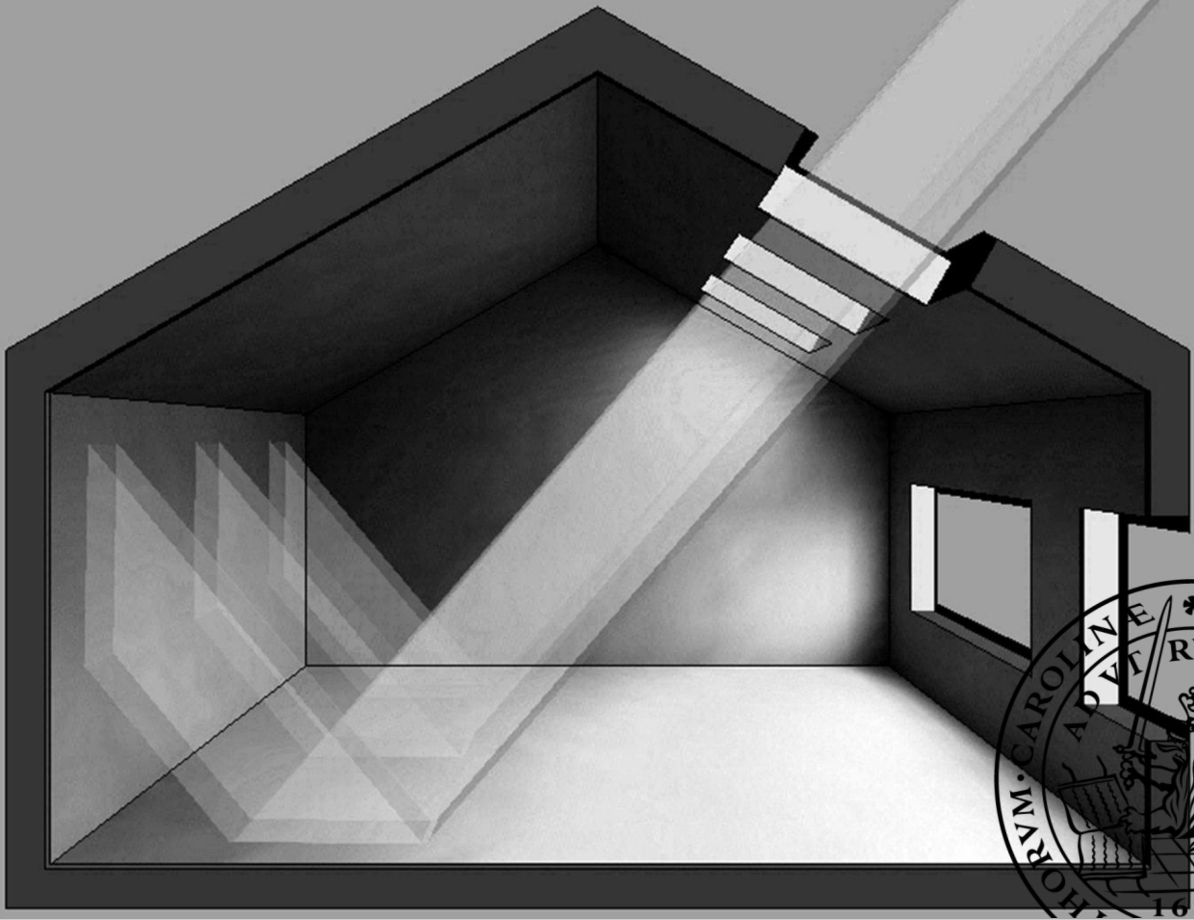

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

Previous studies indicated that skylights can improve the daylight conditions in house or office buildings, decrease the electricity demand for lighting, provide natural ventilation and reduce the heating demand through passive solar heat gain exploitation. This thesis analyses the effect of skylights on the energy use, daylight conditions and thermal comfort in a classroom. The study is performed by dynamic energy and daylight simulations with Grasshopper, DIVA for Rhino and Archsim (EnergyPlus). The simulations were carried out for a single classroom located in Copenhagen, for a Passive construction and a typical Danish construction. The independent variables are: roof tilt, window-to-floor ratio, skylight-to-floor ratio, skylight distribution, amount and position of skylights, and orientation. The dependent variables are: daylight factor, daylight factor uniformity ratio, daylight autonomy, daylight availability and daylight glare probability, heating demand, electricity demand for lighting and overheating time. The results show that skylights can significantly improve the daylight conditions in a classroom in terms of daylight levels and uniformity as well as daylight autonomy while visual discomfort problems can be easily avoided through the use of proper shading devices. The study also shows that the electricity demand for lighting can be significantly reduced while the heating demand is generally increased with the integration of skylights. The results further show that the primary energy can actually be reduced if skylights are placed properly, due to the fact that the electricity use reduction weighs more in the total energy balance when calculating primary energy factors.

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Contribution

This project was completed with the equal contribution and excellent collaboration of Panayiota Paraskeva and Vaia Vakouli. Initially, the methodology part was planned and decided by both team members. The grasshopper script was developed and all encountered problems were solved with the collaboration of both members. Panayiota focused on the passive construction simulations while Vaia focused on the typical construction. The way the results were going to be presented was agreed after discussion and testing between the two members and then graphs of each metric were shared equally and were created by each member. The individual parts of the report were written by either member, then reviewed by the other member and finally corrected and finalized by both members simultaneously. More specifically, after thorough discussion for each part, Vaia focused on the methodology and Panayiota on the result section. The discussion sections were discussed and agreed by both members and then shared and written. The discussion was reviewed and corrected by both team members several times and finally the conclusions were written by both members.

Table of contents

Definitions – Abbreviations

BBR 2012, Boverkets Byggregler: the Swedish Building Code (National Board of housing, Building and Planning building regulations) that came into force on January 2012.

BR10, Bygningsreglementet: the Danish Building Code introduced in December 2010.

BREEAM, Building Research Establishment Environmental Assessment Methodology: the world's longest established and most widely used method of assessing, rating, and certifying the sustainability of buildings

Buoyancy: an upward force that occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The greater the thermal difference and the height of the structure, the greater the buoyancy force, and thus the stack effect that helps drive natural ventilation

CBDM, Climate-Based Daylight Modelling: the prediction of various radiant or luminous quantities using sun and sky conditions that are derived from standard meteorological datasets. CBDM delivers predictions of absolute quantities that are dependent both on the locale and the building orientation, in addition to the building's composition and configuration.

CHP, Combined Heat and Power plants: also known as "cogeneration" is the use of a heat engine or power station to generate electricity and useful heat at the same time. In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration this thermal energy is put to use.

CIE, Commission Internationale de l'Eclairage: the International Commission of Illumination is the international authority on light, illumination, colour, and colour spaces. It is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology.

CIE sky model: a standard published by CIE to generate luminance sky distributions depending on weather and climate that change during the course of a day with the position of the sun. This standard lists a set of luminance distributions which model the sky under a wide range of conditions, from the heavily overcast sky to cloudless weather.

Cooling systems, active/passive: an active cooling system involves the use of energy and it refers to cooling systems that use coolants or a refrigeration cycle. Passive systems do not use energy.

DA, Daylight Autonomy: the percentage of annual daytime hours, usually operational hours, that a given point in a space is above a specified illumination level.

Daylight Availability: a metric that measures DA and whether the time, when illuminance is higher than 10 times the DA threshold, exceeds 5% of the total time.

DF, Daylight Factor: the ratio of the illuminance due to daylight at a point on the indoors working plane, to the simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

DGP, Daylight Glare Probability: the probability in percentage, that the visual comfort of a person under the simulated conditions at the camera viewpoint, is disturbed considering the overall brightness of the view, position of 'glare' sources and visual contrast.

End-use energy: the final transformed energy consumed by a system or building. It may refer to electricity, heating energy etc.

FEBY, Forum för energieffektiva byggnader: the Forum for Energy Efficient Buildings contains the Swedish criteria for “zero-energy”, “passive” and “mini energy” (minienergihus) buildings.

g-value: a coefficient that measures the fraction of incident solar radiation transmitted by a material, expressed as a number between 1 and 0, where 1 indicates the maximum possible solar heat gain, and zero, no solar heat gain.

Heat recovery: the process of utilizing, thought a heat exchanger, the heating energy contained in the extracted air, through mechanical ventilation, from a building, and use it to heat the incoming fresh air. It can also be used in water systems.

IEA countries: an autonomous organization that works to ensure reliable, affordable and clean energy for its 29 member countries and beyond, founded in response to the 1973/4 oil crisis.

Illuminance: the total luminous flux incident on a surface, per unit area. It is a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception. It is measured in lux (lumen/m^2).

Infiltration: the unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope, doors or windows.

Light transmittance or Visual transmittance: the fraction of incident light (electromagnetic radiation) at the spectrum of visible light radiation that passes through a material.

Luminous efficacy: a measure of how well a light source produces visible light. It is the ratio of luminous flux to power and it is measured in lumens per Watt (lm/W).

Natural ventilation: the process of supplying and removing air through an indoor space without using mechanical systems. It refers to the flow of external air to an indoor space as a result of pressure or temperature differences due to wind or buoyancy.

Overcast sky: it is the meteorological condition of clouds obscuring all of the sky. A CIE overcast sky, usually used in daylight simulations and DF calculations, has completely uniform luminance.

Passivhaus (in German), Passive House: a voluntary standard for energy efficiency in a building that reduces its ecological footprint. It results in ultra-low energy buildings that require little energy for space heating.

PEF, Primary Energy Factor: a factor used to convert the end-use energy into primary energy. There are different PEFs for every form of energy (electricity, heating) and for every region or country.

Perez sky model: a mathematical model used in CBDM that describes the relative luminance distribution of the sky dome according to real data gathered from weather stations.

Primary energy: the energy form found in nature that has not been subjected to any conversion or transformation process. It is the energy contained in raw fuels, and other energy resources.

Ray tracing: a technique for generating an image by tracing the path of light through pixels in an image plane and simulating the effects of its encounters with virtual objects.

Solar heat gain or Passive solar gain: the heat gains resulting from solar radiation. The amount of solar gain increases with the strength of the sunlight, and with the ability of any intervening material to transmit or resist solar radiation.

Solar Irradiation or irradiance: the amount of electromagnetic radiation produced by the sun that a surface receives at a given amount of time. It is measured in W/m^2.

Thermal bridge: an area of an object (frequently a building) which has a significantly higher heat transfer than the surrounding materials resulting in an overall reduction in thermal insulation of the object or building.

Thermal comfort: the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

Transmissivity (Radiance): a value calculated through a formula based on the transmittance of a material and it is used (instead of the transmittance) in Radiance based simulations.

U value, thermal transmittance: the rate of transfer of heat (in watts) due to thermal radiation, thermal convection and thermal conduction, through one square meter of a structure, divided by the difference in temperature across the structure. It is expressed in W/m^2K. Well-insulated parts of a building have a low thermal transmittance whereas poorly insulated parts of a building have a high thermal transmittance.

UR, Uniformity Ratio: a DF ratio calculated as the minimum DF value simulated in a plane, divided by the average DF calculated in the plane.

VELUX®: a worldwide operating company that offers roof windows, modular skylights, shading devices, remote controls and installation solutions that focus on energy efficiency and healthy indoor environment through daylight utilization and fresh air.

Visual comfort: the condition of mind that expresses satisfaction with the visual environment. It can be connected to adequate light levels, glare, flicker absence, etc.

λ value, thermal conductivity: the property of a material to conduct heat. It is evaluated primarily in terms of Fourier's Law for heat conduction. Heat transfer occurs at a lower rate across materials of low thermal conductivity than across materials of high thermal conductivity.

Specific for this report

ADGP Annual Daylight Glare Probability: an abbreviation and term used in this study to describe the percentage of annual operational time where DGP is above 40%.

GFR, Glazing to Floor Ratio: the total area of the openings (skylights and windows), including the frame, divided by the floor area. The additional term “Real GFR” used in this study refers to the glazed area of the openings alone, divided by the floor area.

ODA, Optimally Day-lit Area: an abbreviation and term used in this study to determine the percentage of an area that it is not “over-lit” or “under-lit” but satisfactory “day-lit”.

Overheating time: a term used in this study to describe the percentage of operational time where the operative temperature inside the room is above 25°C. The *total overheating time* refers to the percentage of annual time where the operative temperature inside the room is above a certain temperature threshold.

Over-lit area: a term used in this report to describe the area that receives more than ten times the selected target illuminance, for more than 5% of the operational time.

SFR, Skylight to Floor Ratio: the total area of skylights, including the frame, divided by the floor area.

Under-lit area: a term used in this report to describe an area that has DA less than 50%.

WFR, Window to Floor Ratio: the total area of windows, including the frame, divided by the floor area.

1 Introduction

This thesis is focused on the use of skylights in classrooms. In general, skylights can improve the quality and increase the amount of daylight that a space receives. Many researches show that daylight is necessary for a psychological and physical health and can have great positive effect on students' performance. These effects could be enhanced with the integration of skylights and the utilization of daylight in schools.

Skylights also affect the energy performance of a building in various ways. The use of skylights increases the heat losses but also increases the solar heat gains. The heat gains can reduce the heating demand of a space, due to passive solar heating, but they can also create thermal comfort problems like overheating. However the openings can be used to enhance the effect of natural ventilation and possibly prevent overheating issues. The glazing area at the roof can also improve the overall daylight conditions and increase the daylight autonomy, thus decreasing the need for electrical lighting.

This study analyses the impacts of integrating specific skylight models developed by VELUX® on energy consumption, thermal comfort and daylight conditions of a typical school classroom, located in Denmark.

The analysis is performed by parametric studies based on energy and daylight simulations. The studied parameters include roof slope, vertical window area, skylight area, skylight distribution and orientation of the glazing areas. Simulations for two distinctive constructions, one according to the Passivhaus standards and one according to the Danish Building Regulations (BR10), are performed. BREEAM schemes regarding visual comfort are also used to evaluate the daylight conditions. The results are analysed in order to identify energy efficient skylight solutions while providing adequate daylight conditions.

1.1 Aim

The integration of skylights can provide benefits to a building and its users. However, skylights may also create many problems if they are oversized or not adequately protected to prevent glare and overheating. A successful integration depends on many factors like the location of a building, the construction, its use, the design and placement of the skylights.

The aim of this thesis is first to evaluate whether the use of skylights in school buildings located in Denmark, can be beneficial in terms of daylight conditions, thermal comfort, energy performance and environmental impact in terms of primary energy supply. Moreover it strives to identify main factors that enhance the positive effects of skylights and prevent the negative outcomes such as glare and overheating. The goal of this study is to develop guidelines that could assist designers with skylight positioning in the case of new school buildings or renovations.

1.2 Background

Skylights and roof windows are in general a distinctive element of Scandinavian architecture. Many buildings of the past centuries use roof windows to light their attics and many modern buildings use them as well either to light up spaces that have no access to windows, or to enhance the lighting conditions for aesthetic or architectural purposes. Recent reports suggest that skylights can provide many benefits to a building and its users. These benefits could be utilized in school buildings to provide a good indoor environment for the students, adequate lighting conditions and more energy efficient school building designs. The integration of skylights however should be conducted carefully in order to avoid possible negative effects.

1.2.1 Skylights and daylight

The primary purpose of using windows and skylights is natural lighting and view. People like being in a day-lit space and have views of the exterior environment and the sky. In addition, a study suggests that intuitively children generally prefer sitting next to windows and high day lit spaces [1].

Daylight is considered to be the best source of light. It provides high quality and levels of light, without flicker and the optimum spectrum and colour to which our eyes are best adapted [2] [3]. It is also known to regulate and affect many physical functions of our bodies like vitamin D production, endocrine system, hormone levels and cycles, circadian rhythm and others [4]. Some of these functions have a direct impact on human behaviour and psychology [4] [5]. Therefore, the use of daylight can help various buildings improve the wellbeing of their user's and also meet health regulations regarding natural light [6] [5].

Daylight stimulates the brain and keeps the human body in alert thus a well day-lit space can generally improve an employee's, a teacher's or a student's performance [4] [7]. More specifically many researches show that students at day-lit schools perform overall better than other students and have higher educational progress [8]. Another study suggests that students attending day-lit schools are healthier, have better physical development, show better behaviour and have a more positive attitude towards the school [9].

Skylights can improve the daylight conditions of a space since they are more effective at lighting spaces than vertical openings [10] and they generally result in higher illuminance levels [10] [11]. Unlike windows, skylights can also light the inner parts of deep spaces. It is possible that this could result in more uniform light conditions, leading to less need for electric lighting and higher visual comfort, the deficiency of which is closely connected to health issues [12].

Skylights however may also create problems that can disturb a user's comfort directly. These problems should be considered in the design process, and solutions must be proposed and integrated. One of the most common problems of skylights is the appearance of moving sun patches inside the room that can lead to thermal and visual discomfort [10] [13]. This can be solved by placing skylights towards the proper orientation or by using skylight wells, glare control systems or shading devices [14]. Furthermore, skylights in general need more shading hours than windows to avoid overheating, especially during summer [10], while the absence of a shading system and the inability to control the light levels can even compromise the benefits of skylights due to high visual discomfort [8].

1.2.2 Skylights and energy performance

The integration of skylights in buildings may reduce the energy consumption if conducted in a proper way. The utilization of daylight through roof windows, can greatly reduce the energy demand for electric lighting [13] and indirect cooling demand generated by the heat from lamps, as long as the skylight's overheating effect is controlled [6]. The savings can be increased even more if photo-sensor controlled lighting systems are used [15] [6] [16].

A study conducted by Group 14 engineering in the US concluded that the use of skylights in houses to achieve same daylight conditions as vertical openings, results in a reduction of heating and cooling demand in most cases, especially in colder climates. The reduction in heating demand comes primarily from the passive solar heat gains entering the envelope through the skylights. The positive impacts of skylights are more significant in cold rather than hot and tropic climates, suggesting that the benefits from their use are highly depended on climate [11].

The decrease in cooling demand can be a result either of the electric lighting use reduction, that may produce excess heat [3] or through natural ventilation. Natural ventilation can provide very cost and energy efficient free cooling, reducing the cooling demand or hours with overheating [6]. Moreover, the high air exchange rates through natural ventilation can improve indoor air quality significantly without the need for mechanical ventilation and thus reduce operational cost [17].

These energy savings can be essential in many aspects for school buildings. In addition, for marketing and public relation matters, the use of skylights can be a noticeable installation that through energy saving potential can promote a green profile for the building and environmental awareness to the users [13]. For a school building this can also have apparent educational purpose. In financial terms, the potential energy savings at a building can lead to operational cost savings, while the installation of skylights itself usually pays off rather quickly [16].

The sizing and position of the skylights must however be carefully studied since large areas of glazing may lead to excessive heat losses during the heating season and increased solar heat gains during the cooling season, without necessary providing better daylight conditions than if less skylights were used [18], since human visual performance stabilizes in around 500 lux [19].

1.2.3 Importance to decrease energy supply in buildings

The climate change has raised environmental awareness and has led many countries, including Denmark to take actions and sign agreements for the reduction of greenhouse gas emissions (GHG). As part of the European Union in relation to the Kyoto Protocol, Denmark is committed to the goal of reducing GHG emissions by 20% in the period 2013-2020 according the EU15 Burden Sharing Agreement [20].

In 2009, the combustion of fuel in Denmark accounted for the 78% of all GHG emissions and the 98% of the CO_2 emissions while approximately 50% of these emissions were used for electrical and heating energy production [20]. According to the statistics of the Danish International Energy Agency, in 2012, approximately 30% of the electrical production and 50% of the heating energy production was used in the residential sector [21] while around 40% of the total primary energy in IEA countries, member of which is Denmark, is in general consumed by buildings [22]. It is clear that there is a great potential for reducing the energy consumption in buildings that can also lead to a significant emission reduction. For this reason the Danish Energy Agreement of 2008 aims to 4% reduction in gross energy and 75% reduction of the energy used in buildings by 2020 [20].

The need to reduce energy consumption in buildings created new trends and standards. One of the most recognized building standards around the world is Passivhaus (Passive House). The Passivhaus is a building standard focused on energy conservation through highly insulated and airtight building envelope, and mechanical ventilation with heat recovery. The energy demand of a Passive house can be 75% lower compared to typical standard constructions while offering very good indoor comfort [23]. Although this standard started as a model for houses it is now used for all types of buildings including schools, offices, kindergartens etc.

In Denmark this continuous improvement of building envelopes has led to the reduction of heating energy demand while at the same time, electrical energy demand has steadily increased [24]. The use of electric lighting, need for technology integration and electronic equipment, has resulted in electricity being the dominant type of energy consumed in all types of buildings, and that can lead to high primary energy supply and possible overheating problems due to high internal gains [24]. A solution to these problems could be the use of energy efficient equipment, photovoltaics installation or reduction of electric lighting by daylight utilization [24]. Daylight and especially sky-light has a higher luminous efficacy than most electric light sources. The luminous efficacy of diffuse clear skylight is around 130 lm/W (direct sun-light 70-105 lm/W, diffuse overcast sky around 110 lm/W) [25], while LED has a luminous efficacy around 100 lm/W, and Fluorescent T5 around 104 lm/W [26]. As a result, daylight provides more light with less generated heat. Moreover, for lighting, the use of direct daylight is many times more efficient than photovoltaics [3].

1.3 Limitations

This study is based solely on simulations while physical measurements of any kind could not be performed. The study is also limited to one single classroom of a school building located in Copenhagen. The classroom is assumed to have three adiabatic walls, floor adjacent to the ground and no obstructions. In addition the classroom is considered to be empty, no furniture or other obstructions are taken into account in the daylight simulations, except for the glare simulations. Furthermore, the glare simulations are performed for a single position at the centre of the classroom. The construction of the classroom is a lightweight construction with thermal mass only on the ground slab. Finally, the study is limited by the fact that it only considers energy demand for space heating and electricity for lighting. The energy demand for domestic hot water, equipment and fans for mechanical ventilation, is not taken into consideration.

2 Methodology

2.1 Tools – Method

This study analyses the energy performance and daylight conditions of a single classroom and it was performed with the use of dynamic simulation programs, since steady state methods have many limitations. Moreover, for this study, it was important that the tools have the following options: natural ventilation, the possibility to import custom schedules, like lighting schedule deriving from daylight simulations, easy and fast modelling.

This study includes many models with various skylight and window solutions. For this reason there was a need for a flexible tool in terms of modelling. Most of the available dynamic energy simulation tools do not offer any flexibility in modelling. Furthermore they cannot be used for daylighting simulations in detail, thus a second program would have to be used and models would have to be rebuilt.

For the above reasons, Grasshopper that is described below, was used as the main tool for modelling in this study. Grasshopper gives the possibility to quickly modify the models through parametric design and also pre-program the simulations and perform them in batch. There are also plug-ins for Grasshopper that can perform energy and daylight simulations on the same model, share inputs and results.

2.1.1 Grasshopper

All classroom models were built using Grasshopper and all simulations were performed using different plug-ins described below. Grasshopper is a graphical algorithm editor tightly integrated with Rhino's 3D modelling tools [27]. Rhinoceros is a 3D modelling application used widely for computer aided design. The model is generated by adding and connecting different components (commands) into a canvas and an illustration of the model is previewed in Rhinoceros. Moreover, the inputs of the model can be easily change, transforming it from a static to a parametric designed model.

2.1.1.1 DIVA for Rhino

All simulations regarding daylight were performed using DIVA-for-Rhino. DIVA is a highly optimized daylighting and energy modelling plug-in for Rhino. It allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes including radiation maps, photorealistic renderings, climate-based daylighting metrics, annual and individual time step glare analysis, LEED and CHPS daylighting compliance, and single thermal zone energy and load calculations [28]. DIVA uses Radiance as an engine to perform the daylight simulations. Radiance is a suite of programs for the analysis and visualization of lighting in design, based on ray tracing techniques [29] and it is widely used and validated. DIVA can be considered a further development of the program Daysim, which is based on Radiance algorithms and it calculates annual illuminance using a climate-based daylight modelling (CBDM). The

CBMD uses an annual climate file and Perez sky models to calculate the sky luminous distribution for direct and diffuse irradiation of a given sky condition [30].

A DIVA plug-in for Grasshopper also exists, thus the parametric model can be directly connected to the DIVA-for-Grasshopper components. Due to limitations of DIVA's energy component (no heat recovery and no natural ventilation) a different plugin was used for energy simulations.

2.1.1.2 Archsim Energy Modelling

The energy simulations were performed with Archsim. Archsim is a plug-in for Grasshopper developed by Timur Dogan, based on EnergyPlus. EnergyPlus is a widely used, extensively tested, building energy simulation program used to model energy and water use in buildings [31]. Archsim supports advanced daylighting and shading controls, ventilation modules such as wind and stack natural ventilation, airflow-networks, simple HVAC, photovoltaics and phase changing materials [32].

2.1.2 Simulation process

Figure 2-1 shows diagrammatically the order of the computational process which was performed in Grasshopper. Firstly the model (shape, opening position and size) is defined by analysing and executing the model input data. The geometry of the model is then connected to DIVA components for the daylight simulations. Taking into consideration the simulation settings and the model, a daylight analysis is obtained. Using Grasshopper's mathematical operations the results used in this study are calculated. The electrical lighting schedule, based on hourly daylight autonomy (DA), is also exported from the daylight analysis. The schedule is converted and used as an input, along with other settings and the model geometry, to the energy simulation components of Archsim. After the simulation of Archsim is complete, various outputs can be obtained that include energy demand, indoor, outdoor temperatures, ventilation flows, etc. Through Grasshopper's mathematical operations specific results are obtained that will be later analysed.

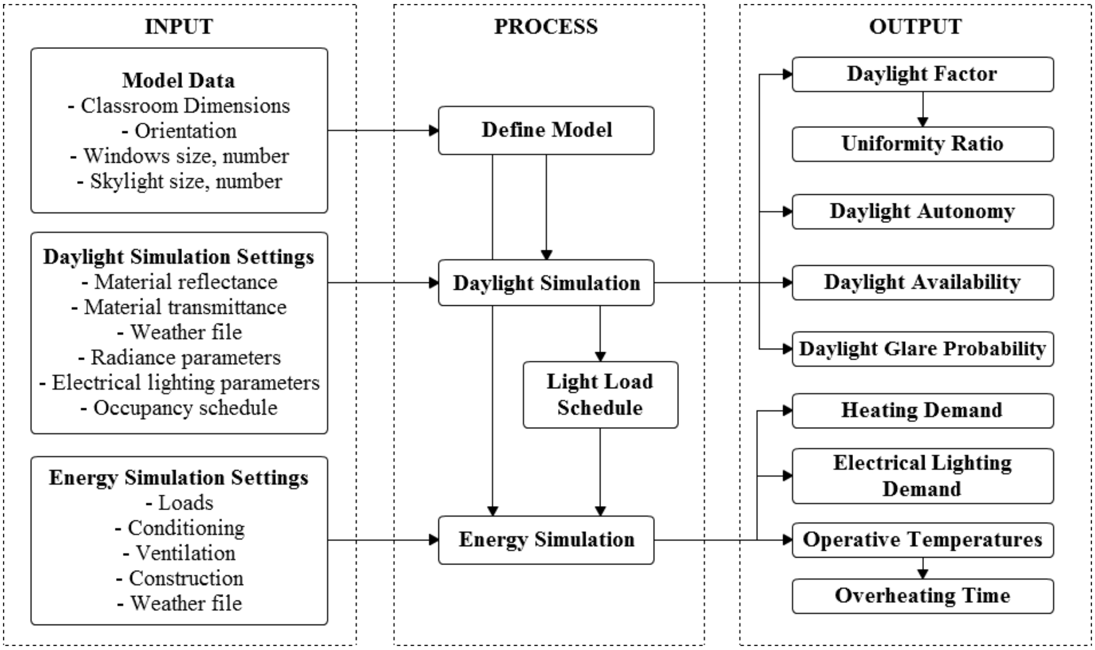


Figure 2-1: The computational process performed in Grasshopper.

2.1.3 Specific simulation settings

Archsim simulations were carried out for a year in 12 step hourly simulations and the algorithm used was “conduction transfer function”. Archsim provides three different ways to simulate natural ventilation: 1) with buoyancy driven flow, 2) wind driven flow and 3) air flow network when multiple spaces are simulated [33]. Only natural ventilation due to buoyancy was simulated since wind driven flow was considered to be highly depended on the surrounding area and microclimate.

DIVA simulations were performed at desk height (0.7m) on a 1m grid (63 points, first point is 0.5m from the walls) while specifically daylight availability and visualizations were performed on a 0.25m gradient grid. The daylight glare probability was simulated for a specific view (180° fisheye view) in the classroom, that represents a student sitting and looking at the white board (eye height is considered to be 1.20m). The position is shown in Figure 2-2. Daylight simulations did not include any shading devices unless specified. High accuracy Radiance settings were used shown in Table 2-1 [34].

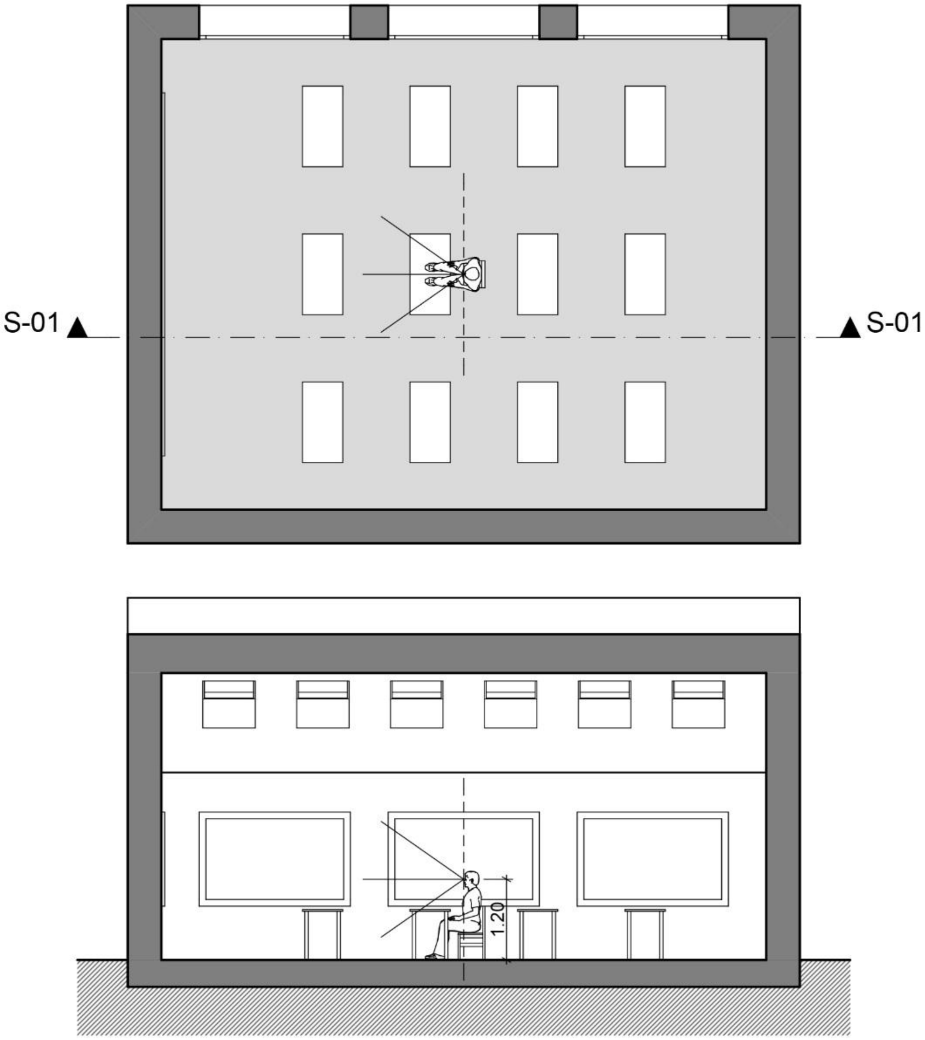


Figure 2-2: Annual Daylight Probability Glare camera position.

Table 2-1: Radiance settings that were used for daylight simulations.

Radiance parameter	**Abbreviation**	**Value**
Ambient bounces	ab	8
Ambient divisions	ad	2048
Ambient super sample	as	512
Ambient resolution	ar	512
Ambient accuracy	aa	0.08

2.2 Building regulations

The studied cases were modelled according specific building regulations. According to the Danish Building Code (BR10) requirements [35], all new and renovated buildings in 2015 must be in accordance with "Low Energy Building Class 2015". There are no specific Danish regulations for Passive Houses so the general requirements according the German Passivhaus Institute are used in Denmark [36]. Basic requirements for school buildings are presented in Table 2-2.

Table 2-2: Requirements for Low Energy Class 2015 and Passivhaus standard.

	Low Energy Class 2015	**Passivhaus**
Annual Primary Energy supply (kWh/m^2)	57 (for 63 m^2) (heating, cooling, DHW, electricity for lighting and ventilation)	120 (heating, DHW, domestic electricity/ no active cooling allowed)
Annual space Heating (kWh/m^2)	-	15
Overheating time	-	10% of operational time
U-values for light weight construction ($W/(m^2K)$)		
Wall	0.19	0.15
Roof	0.13	0.15
Slab	0.09	0.15
Door/ windows	1.40	0.8
Skylight	1.70	0.8
Ventilation		
Per person (l/s)	5	-
Per m^2 (l/s)	0.35	-
Infiltration ($l/(s/m^2)$ at 50 Pa)	1	0.6

2.2.1 Primary energy

The primary energy is the amount of raw energy resources needed for every energy unit consumed in a building [22] [37]. It is used as an indicator of the energy performance of a building in many countries (including Denmark) and standards (Passivhaus) and it is also a good indicator of possible environmental impacts (due to fuel combustion, extraction etc.). However, the total primary energy supply can vary and it depends on the way that the respective energy is produced.

The total primary energy supply is calculated according the corresponding primary energy factors (PEF) for every energy source. In Denmark the average PEF is 2.48 for electricity and only 0,89 for heating due to the very high efficiency of producing district heating at combined heat and power plants (CHP). These factors are probably going to be reduced to

0.6 and 1.8 respectively in 2020, due to the increased wind generated electricity [38]. Additionally in Denmark CO_2 emissions per ton of primary energy supply are very high due to the energy production from fossil fuels and especially coal [20] so primary energy can also be used as an indicator of CO_2 emissions. The CO_2 emissions in kilograms per MWh primary energy are 141 for district heating and 531 for electricity [38]. Besides the end-use energy, the impact of skylight integration on the total primary energy supply (heating and electricity for lighting) was also calculated according the current Danish PEF and according the predictions for 2020.

2.3 BREEAM certification and daylight classification

BREEAM criteria for “Health and Well-being” regarding visual comfort were used to assess the daylight conditions of all cases in this study. BREEAM is a recognized international assessment rating system for evaluating buildings [39]. Since Denmark does not have a customized scheme, the international scheme [40] and part of the Swedish BREEAM scheme [41] were used.

In addition, according to Peter Tregenza, spaces with daylight factor (DF) higher than 10% are considered not suitable for office tasks and may create visual discomfort. Based on the above, three classes were created in order to evaluate the daylight conditions of each case that they are presented in Table 2-3.

Table 2-3: Minimum daylight requirements and classification

Class	First Credit (BREEAM International)	Exemplary Level (BREEAM Sweden)	Exemplary Level - Possibly over-lit
Average DF (%)	2.1	4.2	10
DF Uniformity Ratio	0.3	0.4	0.4
Minimum DF Point (%)	0.6	1.6	1.6

2.4 Classroom model

The study was focused on one single classroom in order to better assess the effects of different skylight solutions. The classroom was assumed to be located in Copenhagen, so the respective weather file, retrieved from the U.S. Department of Energy site [42], was used. The school was assumed to operate from 8:00 to 15:00 weekdays, while it remains closed for around two months during summer (from Saturday, June 16th to Sunday, August 19th, since the weather file starts on Monday). The occupational time is assumed to be the same as the operational time.

2.4.1 Geometry

The classroom was designed to fit 24 students in an area of 63m^2. The average class size in Denmark is 20 students [43] while according to Neufert, a classroom of 65 to 70m^2 is sufficient for 30 to 36 people [44]. The room is rectangular with 9 m length and 7 m depth, it has a double pitch roof and the exterior walls are 3 m height. This geometry was based on examples of renovated one storey schools where skylights were integrated. The room has openings towards one side and skylights on the roof. The sill height of the windows is 0.8m and the window head height is 2.2m. In the energy simulations all elements were considered to be 2D (see Figure 2-3) while at the daylight simulations a lining perpendicular to the openings and same as the thickness of the wall/roof, was taken into account.

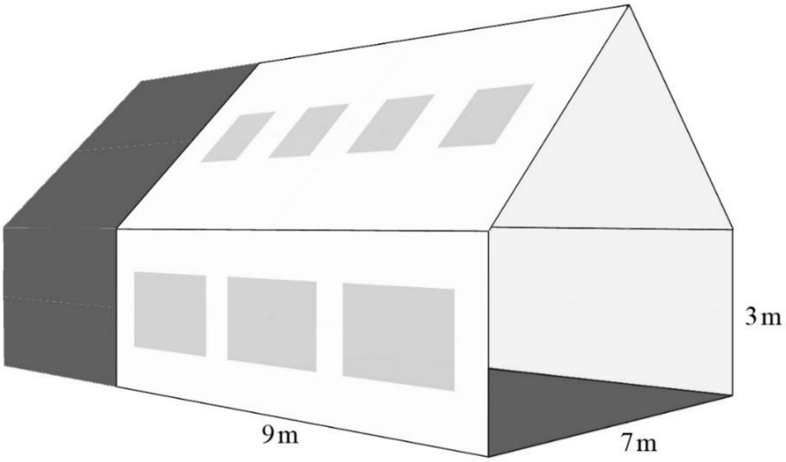


Figure 2-3: 3D illustration and basic dimensions of the studied classroom

2.4.2 Construction

The classroom was simulated for two different construction types. Both constructions are lightweight, wood frame on concrete slab. One construction was designed to comply with suggested requirements for the “Low Energy Class 2015”, as described in the Danish building code (BR10) [35] and the Swedish building regulations (BBR) [45]. This construction is referred to as “typical construction”. The other construction was designed to comply with both Passivhaus standards as designated from the German Passive House Institute [36] and Swedish Passive House requirements as described in FEBY [46] and it is referred to as “passive construction”. Characteristics of the two construction types, are described in Table 2-4. The classroom was assumed to be on the ground and adjacent to other classrooms and spaces, thus the only exterior surfaces were the roof and the wall with the windows.

Table 2-4: Characteristics of the typical and passive construction type.

	Typical construction		**Passive construction**	
	U value (W/m^2K)	Thickness (m)	U value (W/m^2K)	Thickness (m)
Wall	0.18	0.26	0.08	0.55
Roof	0.13	0.35	0.08	0.55
Ground slab	0.09	0.55	0.07	0.60
Infiltration rate	0.04 ach		0.02 ach	

Two glazing types were used for the skylights of each construction type (according the respective requirements) but the same frame, all taken from VELUX® catalogues [47]. Their properties are described in Table 2-5. The properties of windows were assumed to be the same as the skylights used in each case.

Information regarding the frame's thermal transmittance could not be found. VELUX® provides only the total thermal transmittance for each window size (U_{window}) and the linear thermal bridge of the standard "window to wall" connection that it is 0.09W/mK [48]. The total thermal transmittance is calculated using the hot box method [49] in accordance with EN ISO 12 567-2 and it includes all thermal bridge effects, glazing and frame losses. According the above, the thermal transmittance of the frame (U_{frame}) can be estimated by using equation (1):

$$U_o = \sum_{i=1}^{n} \frac{U_i A_i + \Psi L}{A_o} \quad [W/(m^2 \cdot K)] \tag{1}$$

Where:
U_o: the maximum total thermal transmittance (W/m^2K)
A_o: the total area, including all separate elements (m^2)
U_i: the thermal transmittance of the respective element (W/m^2K)
A_i: the area of the respective element (m^2)
Ψ: the thermal bridge of the window connection to the wall (W/mK)
L: the window's perimeter (m)
Thus, for the window:

$$U_{window} = \frac{U_{glazing} A_{\mathrm{glazing}} + U_{\mathrm{frame}} A_{frame} + \Psi L_{frame}}{A_{window}} \quad [W/(m^2 \cdot K)]$$

Different values of U_{frame}, were tested, until the calculated U_{window} values for all window sizes used in this study, were approximately the ones provided from the company's site [48]. The linear thermal bridge between frame and glazing was not taken separately and it was assumed to be incorporated in the frame's thermal transmittance. By using this method the thermal transmittance for the frame was estimated to be $0.72W/m^2K$.

Additionally the passive construction should be, according the regulations, thermal bridge free. For this reason the linear thermal bridge of the “window to wall” connection was considered to be 0.03W/mK. This way also, the total thermal transmittance, for all window sizes, does not exceed 0.9W/m^{2}K, (based on the previous formula) as it should be according the regulations.

Table 2-5: Properties of windows that were used in the study.

	Typical Construction	**Passive Construction**
Glazing type	Function --70	Super Low Energy --66
Pane	double (1 x coated)	triple (3 x coated)
U value (W/m^{2}K)	1.1	0.7
g value (%)	64 %	50 %
Light transmittance (%)	79 %	69 %
Gas type	Argon (15 mm)	Argon (12mm x 2)
Frame U value (W/m^{2}K)	0.72	0.72
Window – wall thermal bridge (W/mK)	0.09	0.03

2.4.2.1 Construction in Archsim

The thermal zone of the classroom in Archsim was defined by a closed single shape where every building element is automatically defined according to its position and it can only be ground slab, interior slab, roof, exterior wall or partition. The openings are inserted as separate surfaces on the envelope, they are automatically recognized and they can only be defined as glazed materials. This means that frames cannot be included.

Archsim also does not have the option to set a total thermal transmittance for a building component. There is a library, and the option to create custom materials that are combined to create custom constructions. Archsim automatically calculates the thermal transmittance and other characteristics of the construction based on the materials’ properties and thicknesses. This method offers many possibilities to the program if the characteristics of each building element are known.

The openings that were described as totally glazed surfaces, were constructed to have the same specifications as the glazings selected from VELUX® catalogues (see Table 2-5). Their sizes were also adjusted to exclude the frame that it was considered to be 0.10m for all window types, according to CAD drawings from VELUX® [50]. The inability to designate the area and material of the frame was considered an important limitation since the total U-value of different size windows and skylights is affected significantly by the frame length. Also, different solutions of skylights and windows may increase the frame length considerably, thus increasing the thermal bridge losses.

EnergyPlus and consequently Archsim do not take into account the effect of thermal bridges that are included in the overall window U-value. In order to include the frames and thermal bridges from windows and skylights into the simulations, their thermal loss contribution was incorporated into the wall's and roof's thermal transmittance respectively. This way these two constructions were transformed, with the help of various mathematical operators of Grasshopper, into parametric constructions with variable thermal transmittance, depending on the frame length and frame area of each case. First the adjusted thermal transmittance of the wall or roof (U_o), including the frames and thermal bridges (of the corresponding case) is calculated according to formula (1) that is reformulated as:

$$U_o = \frac{U_{wall}A_{wall} + U_{frame}A_{frame} + \Psi L_{frame}}{A_o} \quad [W/(m^2 \cdot K)]$$

The outer and inner finishes of the constructions (metal sheet, wood board, gypsum board) is assumed to be fixed while the insulation layer has a standard thermal conductivity and changeable thickness. This layer contains the load bearing construction that it was assumed to cover 10% of the construction area (for both constructions). Since the thickness of the load bearing wood studs was considered to be equal to the insulation, a total thermal conductivity (λ) of insulation layer can be calculated by using the following equation.

$$\lambda = \frac{10}{100}\lambda_w + \frac{90}{100}\lambda_i \quad [W/(m \cdot K)] \tag{2}$$

Where:
λ: the maximum thermal conductivity of the layer (W/mK)
λ_w: the thermal conductivity of the wood, assumed to be 0.13W/mK
λ_i: the thermal conductivity of the insulation, assumed to be 0.038W/mK
Thus, λ is equal to 0.047W/mK

The thermal conductivity of the layer (λ) is considered constant while the thickness (d) is calculated for every case by the following equation, so the overall construction results in the previously calculated U_o.

$$d = \lambda \left(\frac{1}{U_o} + \sum_{i=1}^{n} R_i \right) \quad [m] \tag{3}$$

Where:
d: the thickness of the layer (m)
λ: the maximum thermal conductivity of the layer, that is 0.047W/mK
U_o: the maximum thermal transmittance of the wall (resulted from formula 1) (W/m^2K)
R_i: the resistances of the rest of the layers including air resistances (m^2K/W)

The calculated thickness (d) is then connected to the corresponding Archsim components that are generating the different constructions. This process is executed separately for roof and exterior wall. Figure 2-4 shows a part of Grasshopper's script that is used to generate the parametric wall construction.

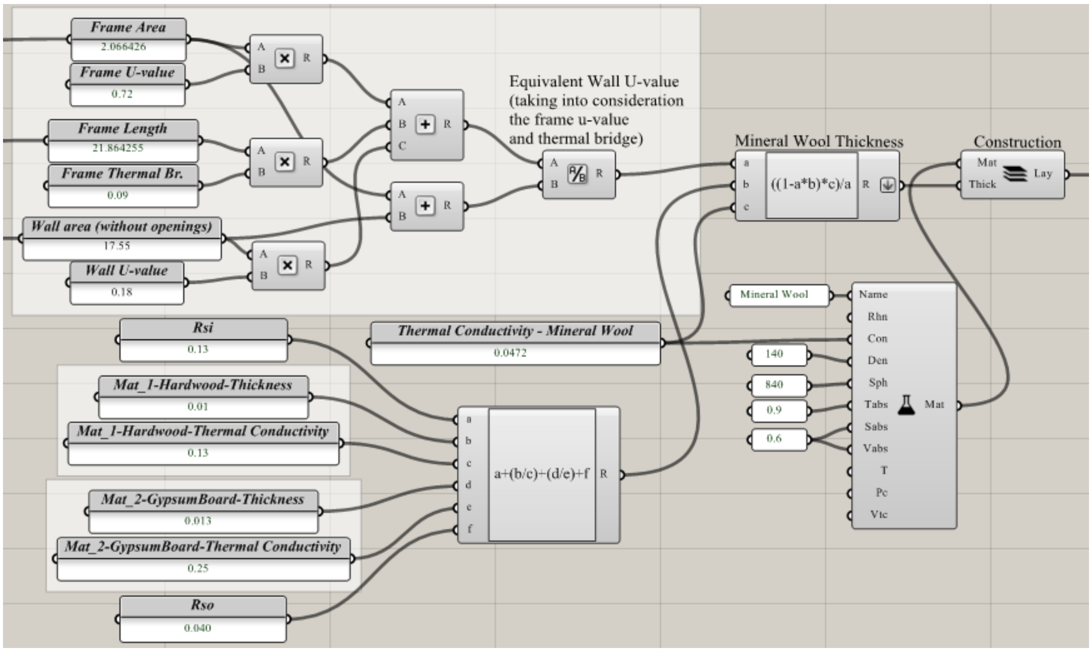


Figure 2-4: Image of Grasshopper's script used for the parametric wall construction.

2.4.3 Shading devices

Windows and skylights were assumed to have interior shading devices while skylights also have exterior. Windows do not have exterior shading in order to better assess the contribution of skylights on overheating and their need for shading. Also an exterior automated shading device is not considered reasonable for vertical windows in a school building. The exterior shading is a dark screen with low solar transmittance, used to reduce solar heat gains, and it is automatically controlled based on the incident solar irradiation on the skylights. A threshold of $300W/m^2$ was assumed in line with results from a study about the impact of control rules on the efficiency of shading devices and cooling [51], and studies about occupants' behaviour regarding shading devices in relation to irradiation on the windows [52].

The interior shading is a translucent screen with diffused properties and high solar transmittance, used to avoid direct sun patches and control glare problems during sunny days. This is assumed to be controlled manually and it was not taken into account in the energy simulations, since it has a minor effect on energy use and the simultaneously use of exterior and interior screen in Archsim is not possible. All screens and their properties were taken from VELUX® catalogues and their specifications are presented in Table 2-6 [47]. Combinations of the screens were simulated in order to confirm that the Daylight Autonomy is not affected by their use.

Table 2-6: Properties of the exterior and interior screen.

	Exterior screen	**Interior screen**
Shading type	Awning (Markiser)	Roller blind (Rullergardin)
Colour	dark grey (5060)	very light grey (0710)
g value (%)	26	76
Light transmittance (%)	18	46
Control set point- irradiation (W/m^2)	300	-

2.4.4 Surface properties

The opaque surfaces of the classroom were simulated as “grey” and purely “diffuse” Radiance *plastic* materials. The glazed surfaces were described as *glass* materials while the shading devices as completely diffuse *trans* materials, all based on the given characteristics from VELUX®. The light transmittance of these materials was converted to Radiance transmissivity using the relevant equation provided by Radiance [53].

The reflectances of the classrooms’ inside surfaces (walls, floor etc.) is suggested for educational spaces by EN 12464 1 [54]. In Scandinavia usually bright colours are used for the walls and the typical reflectance of a white wall is 0.8. However a lower value was used for the simulations since walls in classrooms usually have 50 to 70% obstructed wall area (from collated photos, drawings, pictures, etc.) [55]. Assuming an obstructed wall proportion of 0.5 and 0.5 reflectance, the average wall reflectance is reduced to 0.65. The median value of the suggested range was selected for the other surfaces’ reflectance. The properties of the surfaces that were used in the (daylight) simulations are shown in Table 2-7.

Table 2-7: Properties of the surfaces and materials.

	Material	**RGB colour**	**Specularity**	**Roughness**	**Transmissivity**
Wall (and lining)	Plastic	0.65	0	0	-
Floor	Plastic	0.30	0	0	-
Ceiling (and lining)	Plastic	0.80	0	0	-
Frame	Plastic	0.80	0	0	-
Desk	Plastic	0.65	0	0	-
White board	Plastic	0.80	0.05	0	-
Glazing (triple)	Glass	-	-	-	0.75
Glazing (double)	Glass	-	-	-	0.86
Exterior screen	Trans	1	0	0	0.2
Interior screen	trans	1	0	0	0.5

2.4.5 HVAC

The classroom was assumed to have variable air volume (VAV) mechanical ventilation system (supply and exhaust) with heat recovery, controlled in the simulations by the number of people inside the classroom. The ventilation system is also connected to the district heating and it is used for space heating. One limitation of the simulation program is that there is no setback temperature for heating. This means that heating is turned on immediately when temperature is below the set point and it is turned off when temperature is above the set point.

There is no active cooling system but the skylights and windows open automatically based on indoor and outdoor temperature to allow natural ventilation for cooling. The indoor temperature set point is set to 23°C, which is suggested to be a reasonable value to prevent temperatures above 25°C and at the same time to not trigger the heating system [51]. The openable area of windows an skylights, is assumed to be 30%. There is no upper temperature limit for natural ventilation since outdoor air temperature is rarely above 25°C and never above 27°C according the weather file. In addition, there is no way to control whether outdoor temperature is lower than the indoor, so in case of an upper control limit at e.g. 25°C, there would be no way to enable natural ventilation if indoor temperature was to rise above 28°C. Night ventilation was not simulated in the main study since it is not considered to be a realistic approach for practical safety reasons in single storey school buildings. The effect was however analysed separately for specific cases. No rain sensor was considered. HVAC settings of the model are presented in Table 2-8.

Table 2-8: HVAC settings of the model.

Setting		
Heating		
Set Point	20	°C
Schedule	Always on	
Cooling	No	
Mechanical Ventilation		
Fresh Air per person	7	l/(s · person)
Fresh Air per floor area (minimum)	0.35	l/(s · m^2)
Heat Recovery	75	%
Schedule	Always on	
Natural Ventilation		
Indoor temperature set point	23	°C
Outdoor Air Temperature (min)	10	°C
Schedule	Operational/occupancy time	
Opening Area of windows/skylights	30	%

2.4.6 Internal loads

An illuminance of 500 lux is suggested by IESNA for the performance of visual tasks, of high contrast and small size or low contrast and large size [19]. Based on this, the classroom was assumed to be electrically lit by sixteen suspended T5 fluorescent lamps of 35Watts each that can approximately provide an average illuminance of 500lux [56]. The lights are controlled by a photo sensor dimming system based on the illuminance levels in the classroom. One laptop per two students and one for the teacher is also assumed. Internal loads settings are shown in Table 2-9.

Table 2-9: Internal load settings of the model.

Setting		
Schedule	Operational time	
People	25	
Equipment Load	9.2	W/m^2
Lighting Load	8.9	W/m^2
Target Illuminance	500	lux
Lighting Control	Photo sensor dimming	
Standby Power	1	W
Ballast Loss Factor	20	%

2.5 Studied parameters

The studied parameters and their variables are presented in Figure 2-5 along with the dependent variables that are calculated by the simulations. There are five main parameters that were simulated at all possible combinations, for both types of construction (typical and passive). Additionally, there are two secondary parameters that were simulated only in selected cases and combinations of the five main parameters, because it was considered that their effect would be proportional for all the cases. These cases were simulated in order to investigate furthermore the effect of some additional skylight characteristics that are not taken into consideration in the main parametric study.

The classroom was simulated for three roof tilts of 15°, 30° and 45° that are very common and reasonable for a classroom. The tilt changes the height of the skylights regarding the operational zone, the properties of the skylights (U-value) and the volume of the room (thus the energy demand of the classroom is expected to be higher as the tilt is increasing, since the air volume to heat is more).

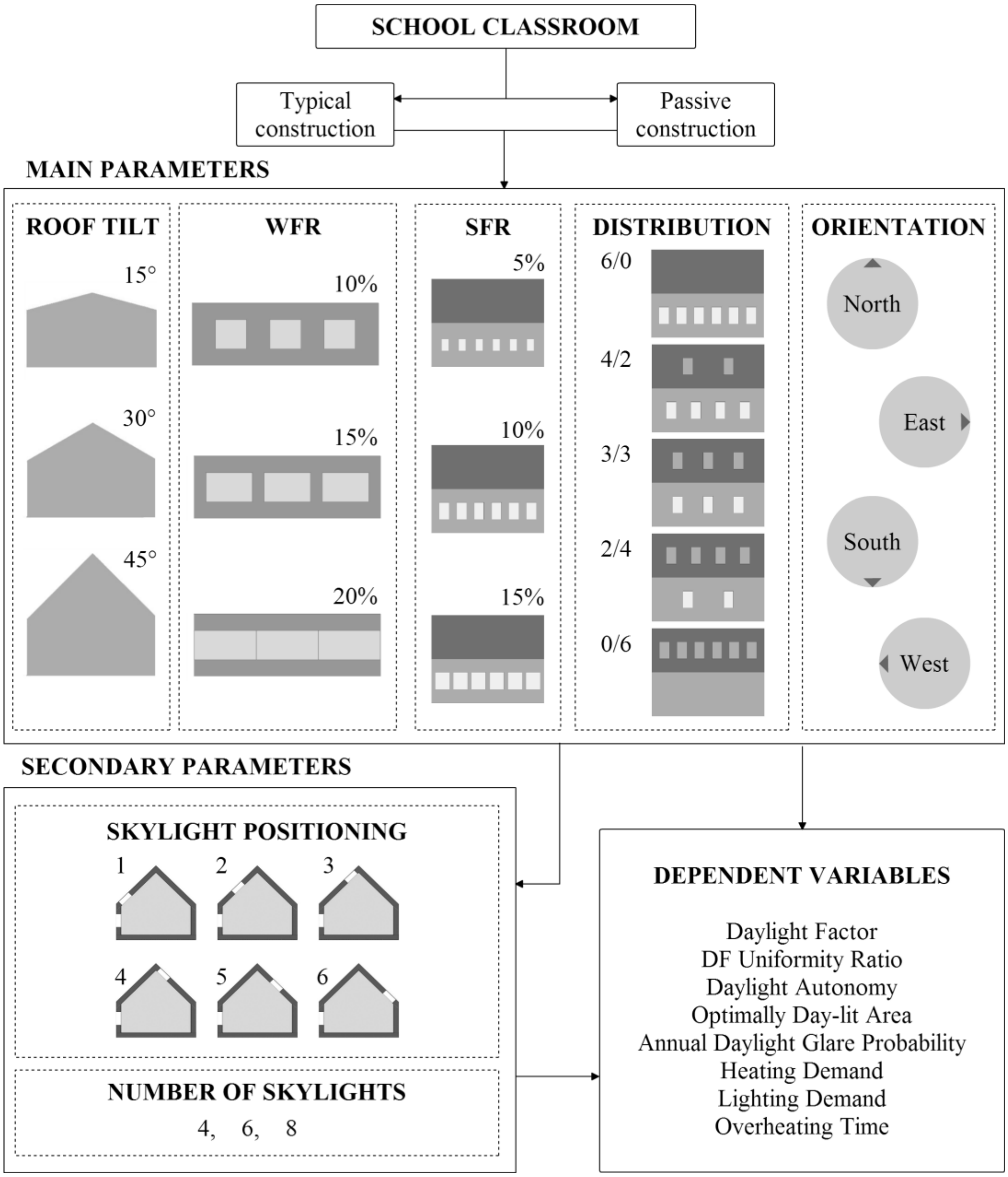


Figure 2-5: Studied parameters and dependent variables.

Three cases of window-to-floor ratio (WFR) were studied of 10%, 15% and 20% that represent 23%, 35% and 46% window-to-façade ratio respectively. Three windows were used. The WFRs combined with four cases of skylight-to-floor ratio (SFR) that are 0%, 5%, 10% and 15% give in total four cases of 15%, 20%, 25% and 30% total glazing-to-floor ratio (GFR) that are able to be compared for different combinations of WFR and SFR. The SFR as well as the WFR expresses the total opening area (frame and glazing) to floor area ratio, and this has as a result that the actual glazed area varies for different combination of SFR and WFR even if the total GFR is equal. In fact the total actual glazing area is decreasing when the equivalent area of openings is placed as skylights rather than as windows. For a frame width of 0,10m, the total actual glazing-to-floor ratio is presented in Table 2-10.

Table 2-10: Actual glazed area for different SFR and WFR combinations.

GFR	SFR	WFR	Actual GFR
10%	0%	10%	7.4%
15%	0%	15%	11.7%
	5%	10%	10%
20%	0%	20%	16%
	5%	15%	14.3%
	10%	10%	14.1%
25%	5%	20%	18.6%
	10%	15%	18.3%
	15%	10%	18.2%
30%	10%	20%	22.6%
	15%	15%	22.5%
35%	15%	20%	26.8%

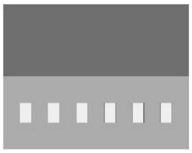
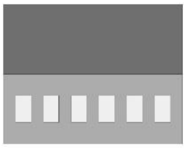
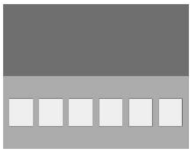
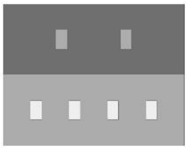
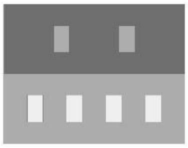
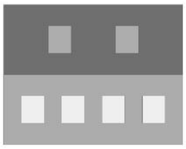
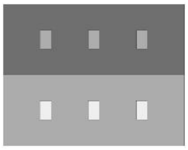
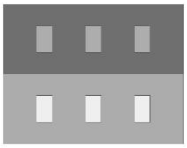
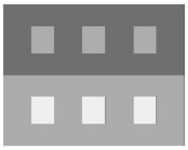
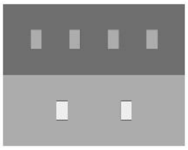
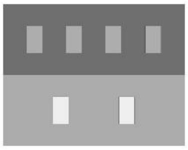
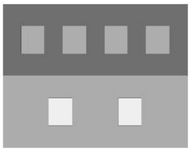
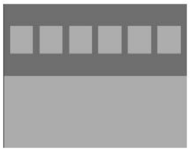
Six skylights of three different sizes are used for each SFR case. The skylights are centrally placed along the roof’s width and evenly spread along the length. The size and dimension of the skylights is standardized and derives from the VELUX® catalogues [47]. For this reason the SFRs cannot be exact. The labels used to define the cases, represent an approximation in order to identify the cases. The skylights that were used for each SFR are presented in Table 2-11.

Table 2-11: Size and number of skylights that were used for different SFR and distributions.

SFR Case	5%	10%	15%
Skylight size/ m	0.55 x 0.98	0.78 x 1.40	1.14 x 1.40
Actual SFR	5.1%	10.4%	15.2%

Five cases of skylight distribution were studied for each SFR that are presented in Table 2-12. The cases are designated by a combination of variables x/y that indicate the amount of skylights that are placed in each side of the roof. The first variable (x) indicates the number of skylights that are placed on the roof side that is facing towards the same orientation as the windows. Respectively, the second variable (y) indicates the number of skylights that are placed on the other side of the roof (usually mentioned as the opposite side). For example, at case 6/0 all six skylights are located on the same side as the windows while at 0/6 they are located on the opposite side of the roof. At the 3/3 case the skylights are equally shared between the two sides of the roof. For cases 4/2 and 2/4, the skylights are unevenly distributed with four skylights on one side and two on the other.

Table 2-12: Illustrations of the roof with different SFR and distributions.

CASE	5% SFR	10% SFR	15% SFR
6/0			
4/2			
3/3			
2/4			
0/6			

All cases that derive from the above parameters, were tested for the four main orientations (north, east, south, west,). The orientation is referred to where the windows of the room are pointing (e.g. for the south orientation the room has the wall with the windows towards south).

Besides these seven parameters that mainly influence the windows' and skylights' characteristics, a small study about additional passive cooling strategies was conducted. These additional strategies include additional ventilation during specific hours after school time and they are available throughout the year (including summer), and permanent exterior shading on windows during summer. This study was conducted in order to assess whether the overheating problems during non-operational hours and especially summer time can be controlled. A case with serious overheating problems was selected for the study.

2.6 Dependent variables

The dependent variables that derived from the simulations and were analysed are presented briefly in Figure 2-3 and they are described below.

The *Daylight Factor* (DF) of every case is the average DF simulated on the grid. DF is the ratio between the average illuminance on a surface and the global horizontal illuminance at a specific time under an unobstructed CIE overcast isotropic sky. It is thus not affected by orientation. It is used as an indicator to assess the light conditions of a room. A space with an average DF of 5% is generally considered to be well day-lit [57].

The *DF Uniformity Ratio* (UR) is the ratio between the minimum DF measured on the grid and the average DF. It is a good indicator to evaluate the daylight uniformity. A low uniformity indicates a space with unevenly lit areas.

The *Daylight Autonomy* (DA) of every case is the average DA on the grid. DA is the percentage of operational hours where a specified illuminance threshold is met by daylight alone [58]. The selected threshold for this study was set to 500 lux. This is the highest value suggested for demanding visual tasks [19].

The *Optimally Day-lit Area* (ODA) is the percentage of floor area (grid) that has a DA above 50% and it is not “over-lit”. This area is considered to be effectively day-lit and it is measured with the help of Daylight Availability metric. Daylight Availability measures the DA of a specific point and simultaneously the time when illuminance is above ten times the target illuminance (5000lux). If this time exceeds 5% of the operational time then this percentage is given as a negative value, instead of the DA. The points with a negative value are considered to be *over-lit* and may encounter glare problems [58]. On the contrary points with DA less than 50% are considered to be *under-lit* (not adequately day-lit). This threshold, above which a point is considered day-lit, is suggested by IESNA and it is strongly connected to subjective human perception, according to an assessment about the correlation of daylight metrics and students’ assessments [59]. ODA helps identify the area where no significant visual discomfort occurs due to direct sunlight or low light levels.

The *Daylight Glare Probability* (DGP) is the probability that a user looking at a specific view will be disturbed because of the vertical illuminance at his/her eyes, overall brightness of the view, position of 'glare' sources and visual contrast. DGP combines the discomfort glare algorithm with an empirical approach and it is proved to be well correlated to a user’s response to discomfort glare [60]. The simulated glare can be divided into four categories: imperceptible (less than 35%), perceptible (equal and more than 35%), disturbing (equal and more than 40%) and intolerable glare when DGP is equal or more than 45%.

The DGP was simulated hourly for a year, for a selected set of cases with 25% GFR. The *Annual Daylight Glare Probability* (ADGP), as referred to in this study, is the percentage of operational time when DGP is more than 40% (intolerable and disturbing). Visualizations of the classroom from above were also rendered in order to identify glare sources for different orientations, distributions, GFR/SFR combinations and selected points in time. Shading devices were only considered for a selected case and specific point in time DGP simulations.

The *Heating Demand* is the annual end-use energy required for space heating only, while *Lighting Demand* corresponds to the end-use electricity used for electrical lighting. Both are measured in kWh/m^2.

The *Overheating Time* is the percentage of operational hours where the operative temperature is above 25°C. This threshold was established based on the cooling set point defined by the Danish regulations and the Passivhaus requirements. The *Total Overheating Time* was also assessed for a specific case and it is the percentage of the operational and non-operational hours where the operative temperature is above 25°C.

3 Results

The following chapters present selected results of this study that sufficiently show the impact of skylights on the daylight conditions and energy performance of the studied classroom. The complete results of this study can be found in Appendix A.

The first chapter shows a preliminary study that was conducted to ensure that the use of shading devices in the energy simulations, was not affecting the simulated daylight autonomy (where shading devices were not used). The results of the main study regarding daylight and energy, for the five main parameters (roof tilt, WFR, SFR, skylight distribution, orientation) are presented separately in two chapters, followed by a chapter about the secondary parameters (skylight position, amount of skylights). Results regarding the end-use and primary energy of both heating and electrical energy for lighting are presented next, while at the end a holistic combination of the daylight and energy results is presented, for all cases.

3.1 Preliminary study - shading devices and daylight autonomy

The impact of the shading device use on the simulated DA was assessed in this study. The results are presented in Table 3-1 and they show that the selected set-point for this study ($300W/m^2$ irradiation on the skylight) does not affect the DA. This table further shows how lower set points and other shading solutions would have affected the daylight autonomy. The calculation was performed for a passive construction case, with a medium GFR ratio (WFR 15%, SFR 10%), 30° roof tilt and all openings oriented towards the south. The hourly average illuminance was calculated for different shading solutions and set points. Then the percentage of time when the DA threshold (500 lux) was not met due to the shading was calculated by the following formula:

$T = 1 – (t / t_{DA})$

Where:

T: relative time without daylight autonomy due to shading (illuminance is below 500lux)

t: the daylight autonomy with shading (hours)

t_{DA}: the daylight autonomy without shading (hours)

Table 3-1: Relative time without daylight autonomy, with shading devices (%).

Shading device set point (W/m²)	Exterior on skylight	Exterior on windows and skylights	Interior on windows and skylights
100	-8.8	-26.5	-1.4
150	-0.2	-13.3	0.0
200	0.0	-3.3	0.0
250	0.0	-0.2	0.0
300	0.0	0.0	0.0

3.2 Daylight analysis

3.2.1 Daylight factor

Figure 3-1 presents the frequency distribution of DF results for all the cases, with and without skylights, for the typical and passive construction types. Figure 3-1 shows that the percentage of cases with DF above 5% is considerably increased for both construction types when skylights are added. Additionally the percentage of cases with DF above 6% is higher for the typical construction than for the passive construction cases. More specifically, for the typical construction most of the cases have a DF between 4 and 8%, while 7% of the cases have a DF higher than 10%. Most of the passive construction cases have a DF between 3 and 6%. Without skylights most of the cases have a DF between 2 and 4% for both constructions.

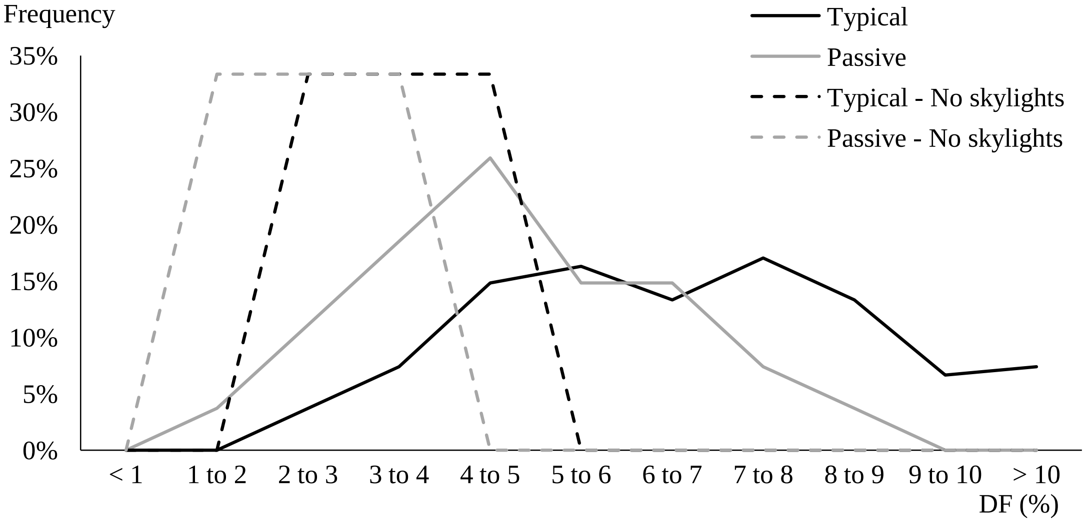


Figure 3-1: Frequency distribution of DF for both construction types, with and without skylights.

Figure 3-2 and Figure 3-3 present the average DF of three selected cases of GFR for all skylight distributions and roof tilts, for typical and passive construction type respectively. The minimum GFR case has 5% SFR and 10% WFR; the medium GRF case has 10% SFR and 15% WFR; the maximum GFR case has 15% SFR and 20% WFR. The skylight distribution is described as two numbers separated by a slash (/) indicating the amount of skylights at the same side as the windows and the amount of skylights at the opposite side of the roof (see Figure 2-5).

Figure 3-2 and Figure 3-3 show that in general, the DF is increased as the total GFR is increased. The DF is always higher for the 15° roof tilt while it is not affected by the skylight distribution, as indicated by the more or less horizontal line. Furthermore, the DF of the passive construction cases is always slightly lower than for the typical construction cases.

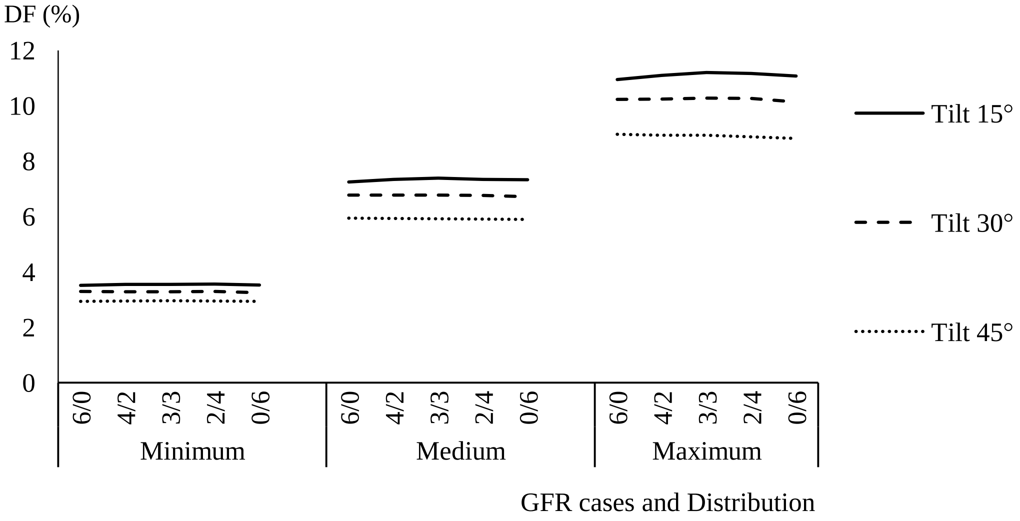


Figure 3-2: Average DF for selected GFR cases, all skylight distributions and different roof tilts for typical construction.

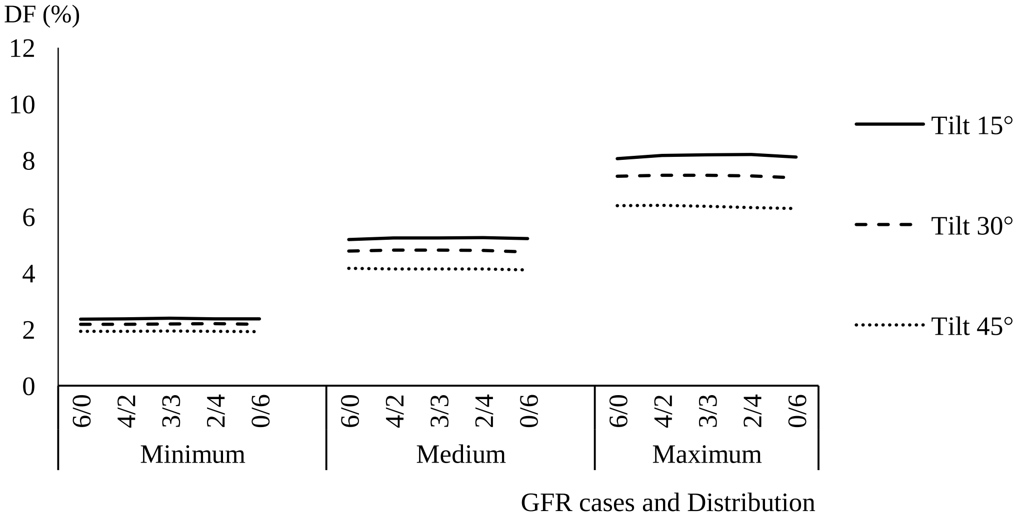


Figure 3-3: Average DF for specific GFR cases, all skylight distributions and different roof tilts for passive construction.

Figure 3-4 and Figure 3-5 present the average DF for different GFRs, combinations of WFR and SFR and roof tilts, for typical and passive construction type respectively. These figures show that for each GFR, the DF is higher when SFR is increased, in most of the cases. Both construction types follow the same trend but the passive construction cases generally result in lower values.

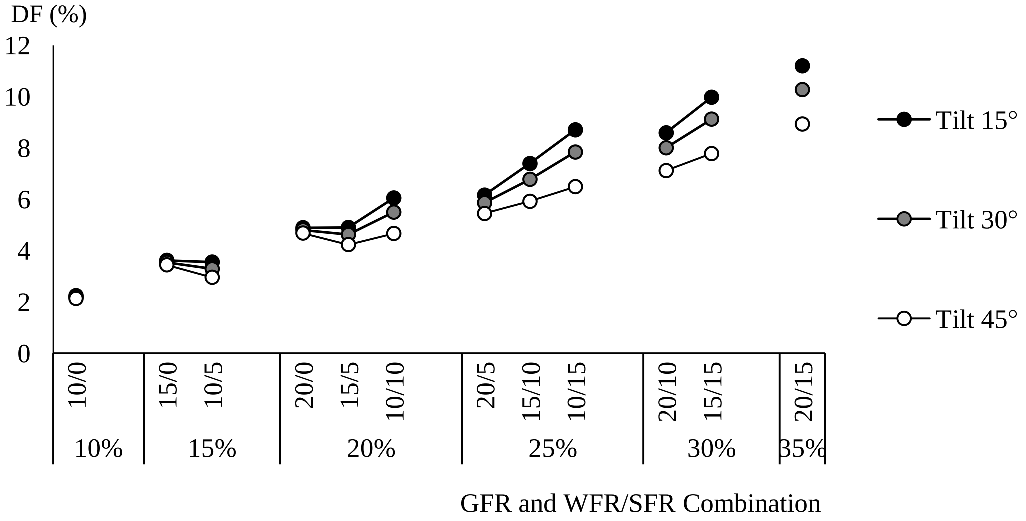


Figure 3-4: Average DF (%) for different GFR, WFR/SFR combinations and roof tilts, for distribution 3/3 and the typical construction.

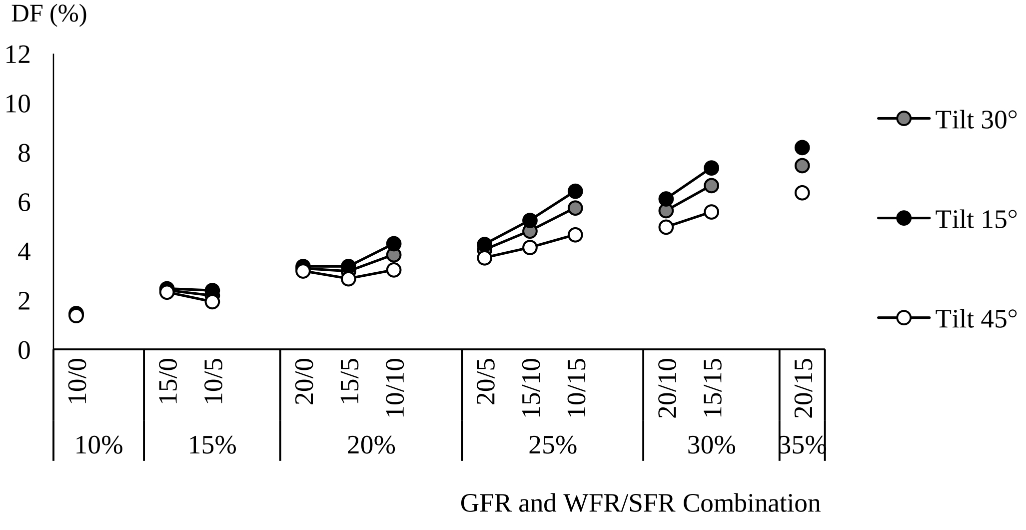


Figure 3-5: Average DF (%) for different GFR, WFR/SFR combinations and roof tilts, for distribution 3/3 and the passive construction.

3.2.2 Daylight factor uniformity ratio

Figure 3-6 presents the frequency distribution of all cases, with and without skylights, for both construction types, in relation to the DF uniformity ratio. Figure 3-6 shows that without skylights, all passive construction cases have UR between 0.3 and 0.4 while almost 90% of the typical construction cases have UR less than 0.3. In addition, the UR is not affected by the construction type when skylights are added and most of the cases have UR more than 0.3 while approximately 40% of the cases have UR more than 0.4.

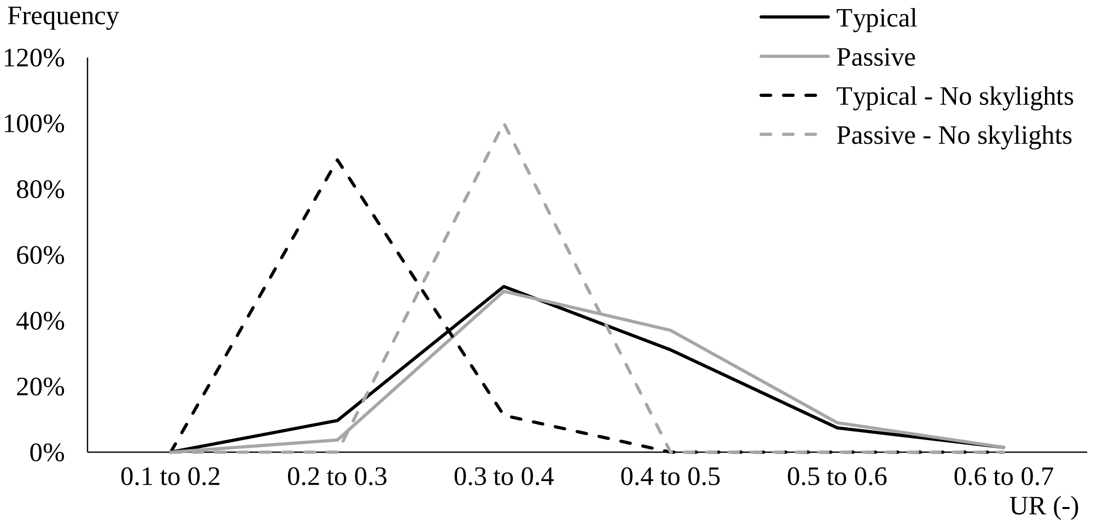


Figure 3-6: Frequency distribution of UR for both construction types, with and without skylights.

Figure 3-7 presents renderings of the DF for a typical construction case with WFR 15%, SFR 10% and every skylight distribution, for 15°, 30° and 45° roof tilts. This figure shows how the skylight distribution affects the DF uniformity differently for every roof tilt.

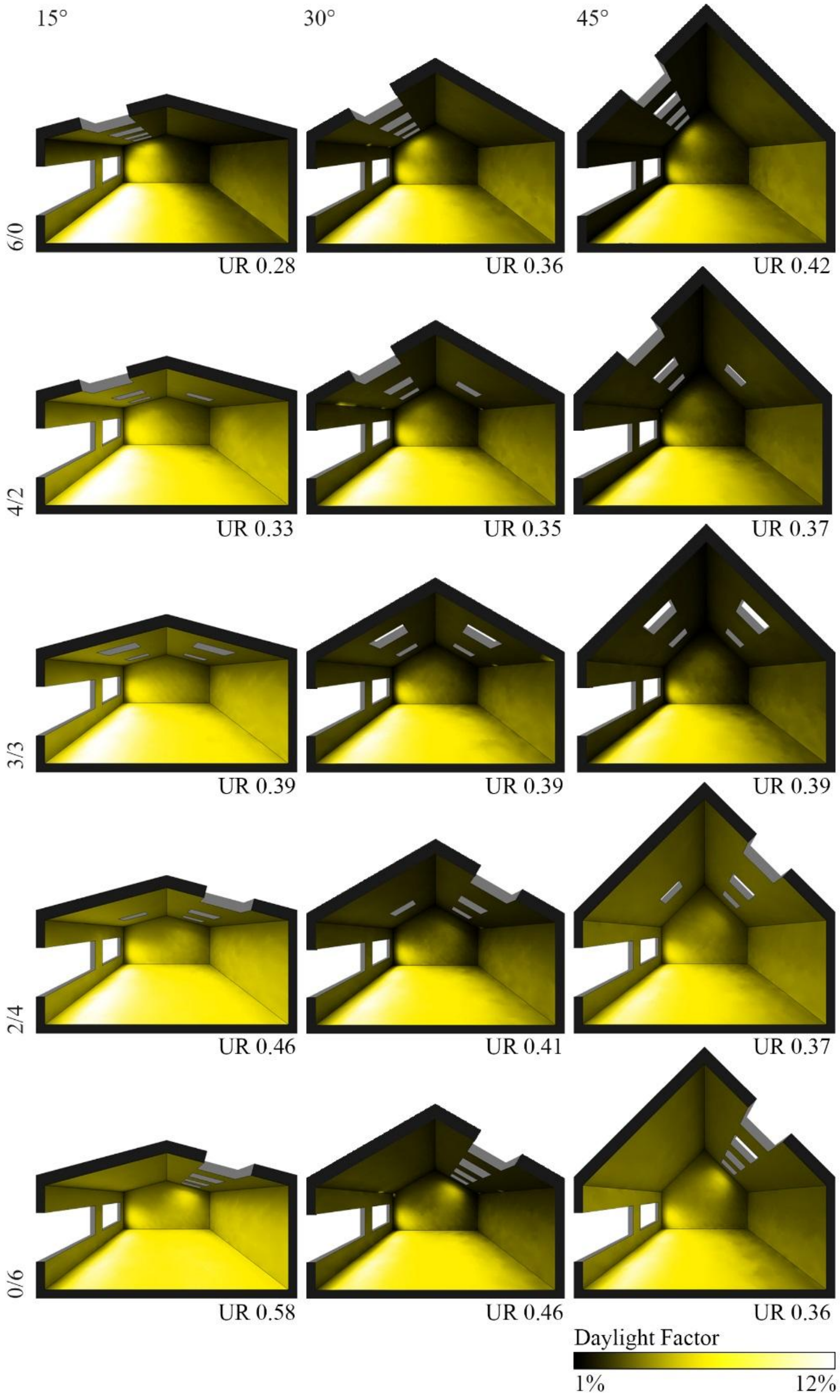


Figure 3-7: DF renderings for a case with 15% WFR, 10% SFR.

Figure 3-8 and Figure 3-9 presents the UR of three selected GFR cases (minimum, medium, maximum) for all skylight distributions and different roof tilts, for typical and passive construction type respectively. These figures show that the UR is slightly increased when GFR is increased. For 15° and 30° tilt, the UR is increased as more skylights are placed on the opposite side of the roof and the UR is highest for the 0/6 distribution case, where all skylights are opposite of the windows. In contrast, for 45° tilt the UR is higher when more skylights are placed towards the window side. The results for the passive construction cases follow the same trend as the typical ones but with slightly higher values.

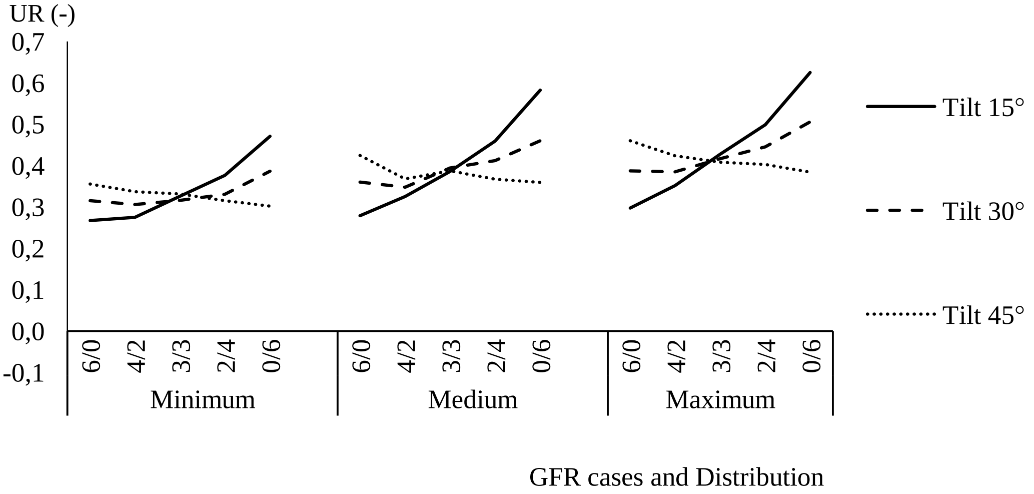


Figure 3-8: UR for selected GFR cases, all skylight distributions and roof tilts for the typical construction.

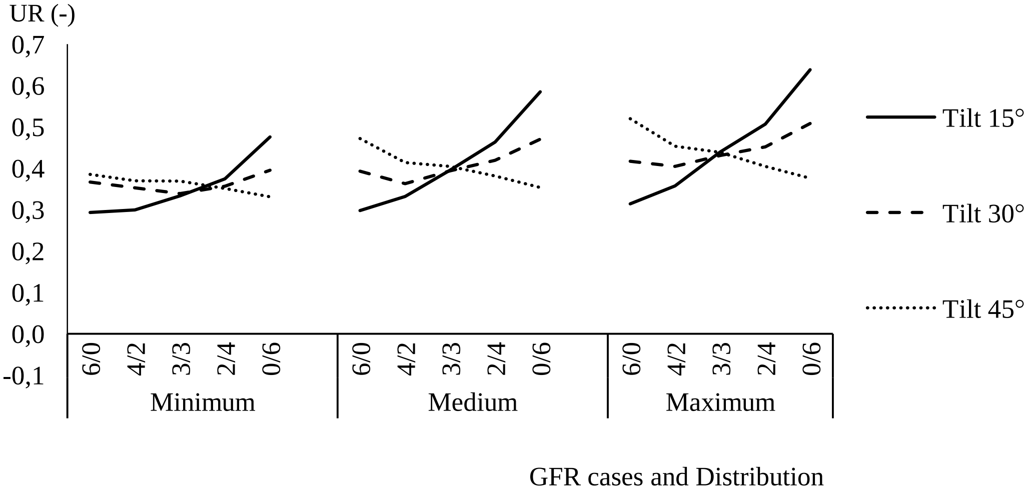


Figure 3-9: UR for selected GFR cases, all skylight distributions and roof tilts for the passive construction.

Figure 3-10 to Figure 3-12 present the UR for different GFRs and combinations of WFR and SFR, for three skylight distribution cases, for the 15°, 30° and 45° roof tilts respectively and for the typical construction. These figures show that the UR generally increases as the SFR increases, except for one case.

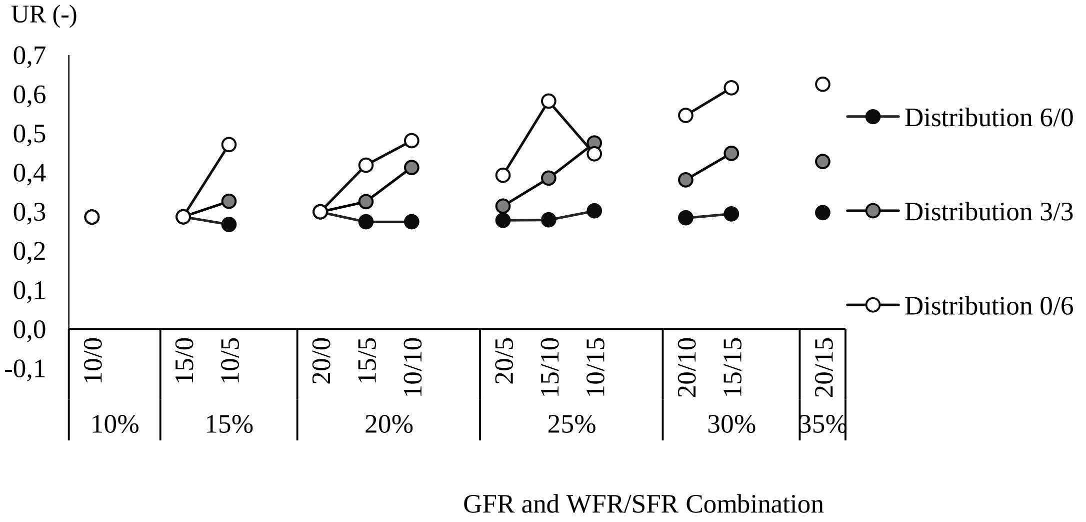


Figure 3-10: UR for different GFRs, WFR/SFR combinations and all skylight distributions, for 15° roof tilt and typical construction.

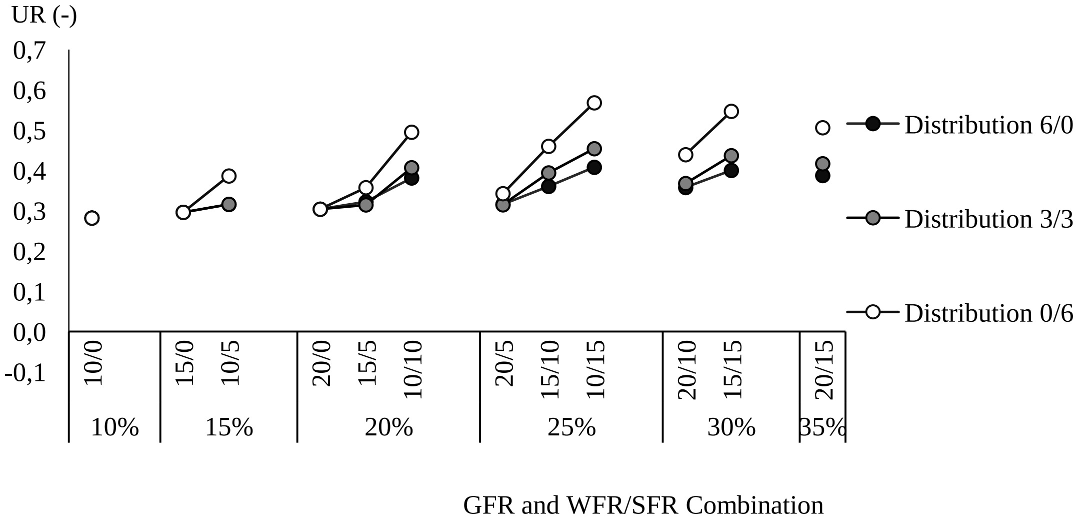


Figure 3-11: UR for different GFRs, WFR/SFR combinations and all skylight distributions, for 30° roof tilt and typical construction.

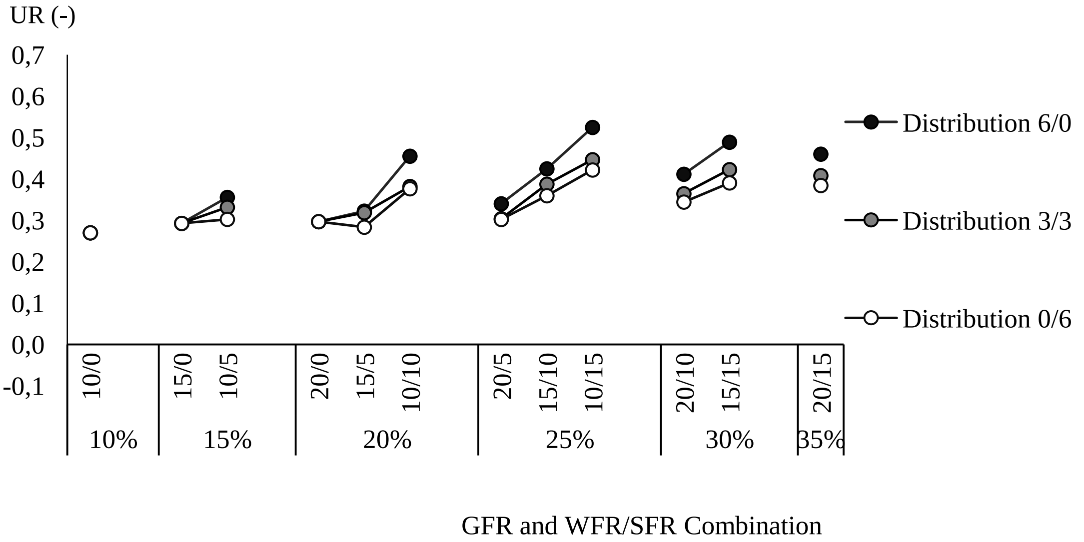


Figure 3-12: UR for different GFRs, WFR/SFR combinations and all skylight distributions, for 45° roof tilt and typical construction.

The UR combined with the DF define the "classes" presented in Chapter 2.3 "BREEAM certification and Daylight classification". Figure 3-13 presents the frequency distribution of every "class", for both construction types, with and without skylights. Figure 3-13 shows that the cases without skylights never reach the BREEAM Exemplary Level while more than 40% of the cases with skylights do.

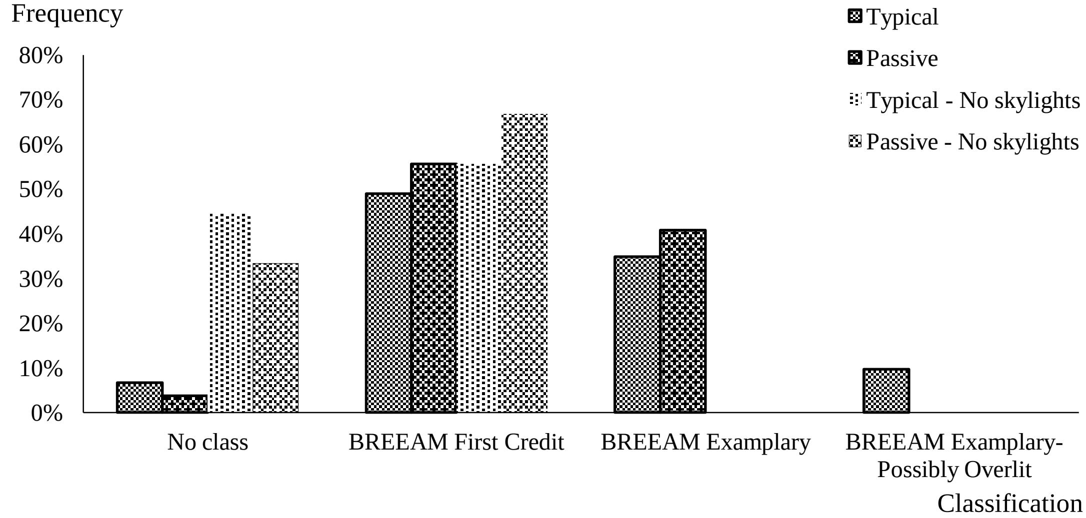


Figure 3-13: Frequency distribution of daylight "classes" for both construction types, with and without skylights.

3.2.3 Daylight autonomy

Figure 3-14 presents the frequency distribution of DA values for all cases of both construction types, with and without skylights. Figure 3-14 shows that most of the cases without skylights have a DA below 50% for the passive construction and below 60% for the typical construction. With skylights, the majority of the typical construction cases have a DA above 70%, the passive cases above 60%, while most of the cases have DA between 70 to 80%, for both constructions.

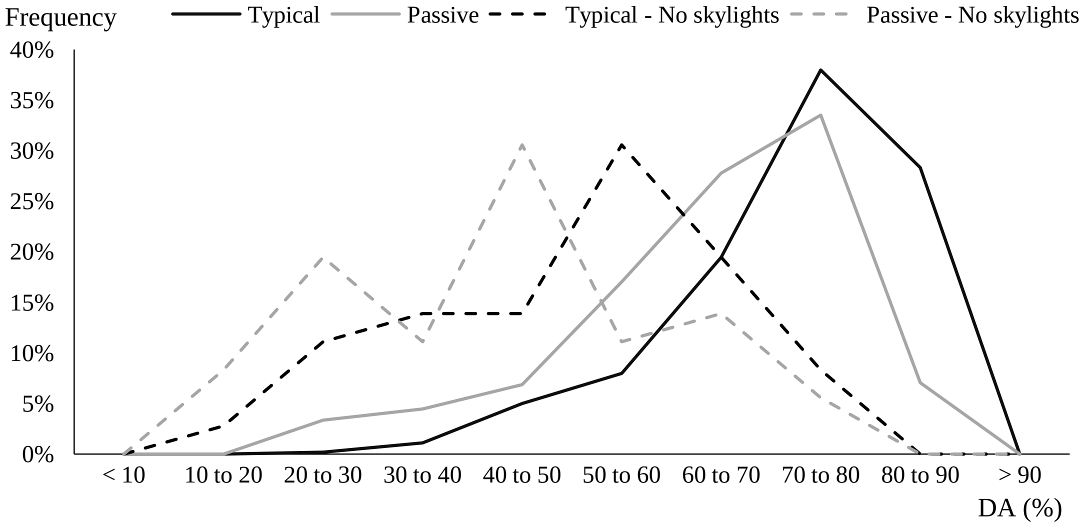


Figure 3-14: Frequency distribution of DA for both construction types, with and without skylights.

Figure 3-15 presents the DA for three selected cases of GFR (minimum, medium, maximum) for all orientations, skylight distributions and construction types, for a 30° roof tilt. This figure shows that the DA increases as GFR increases as expected. The DA for the passive construction type follows a similar trend as the typical one but with generally lower values.

Figure 3-16 presents the DA of a medium GFR case (WFR:15%, SFR:10%), for different roof tilts. This figure shows that the cases with 15° roof tilt result in a higher DA than the cases with higher roof tilts for almost all orientations and skylight distributions. In addition, this figure shows that skylight distribution has a larger effect on DA on the north orientation, for all tilts. Figure 3-17 presents the DA for different GFRs, combinations of WFR/SFR and orientations, for the typical construction, at 3/3 distribution and 30° roof tilt. This figure shows that for all cases, the DA increases when SFR increases at equivalent GFR cases, independent of orientation, but it slightly decreases when skylights are introduced to cases without skylights (0% SFR).

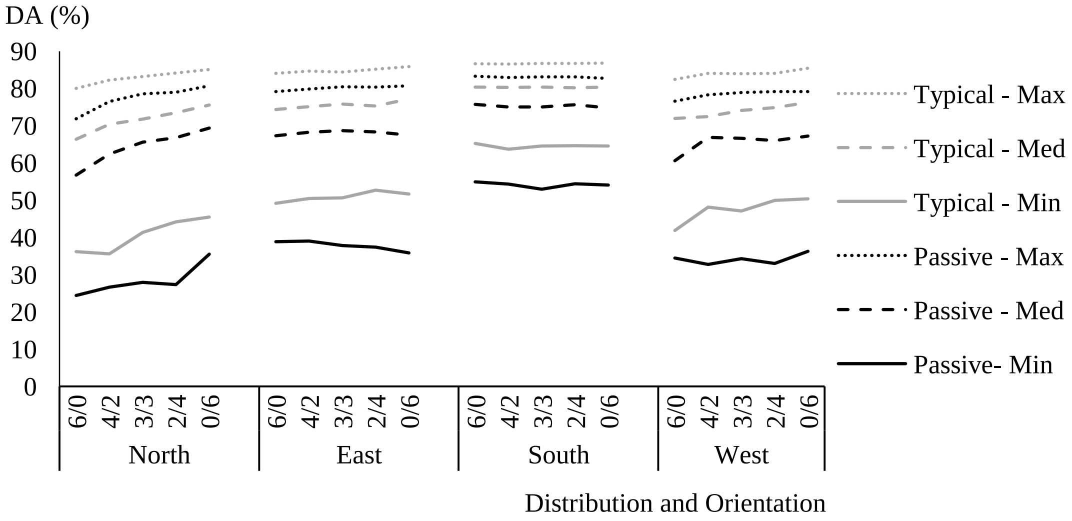


Figure 3-15: Average DA for three selected GFR cases, for all skylight distributions and construction types, for 30° roof tilt.

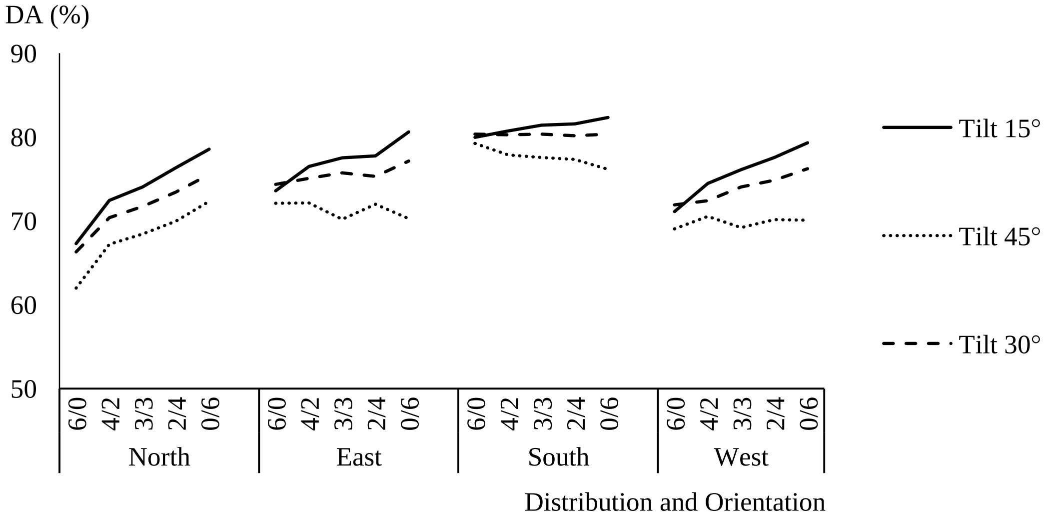


Figure 3-16: Average DA for all skylight distributions, orientations and roof tilts, for a medium GFR case (WFR:15%, SFR:10%) and typical construction.

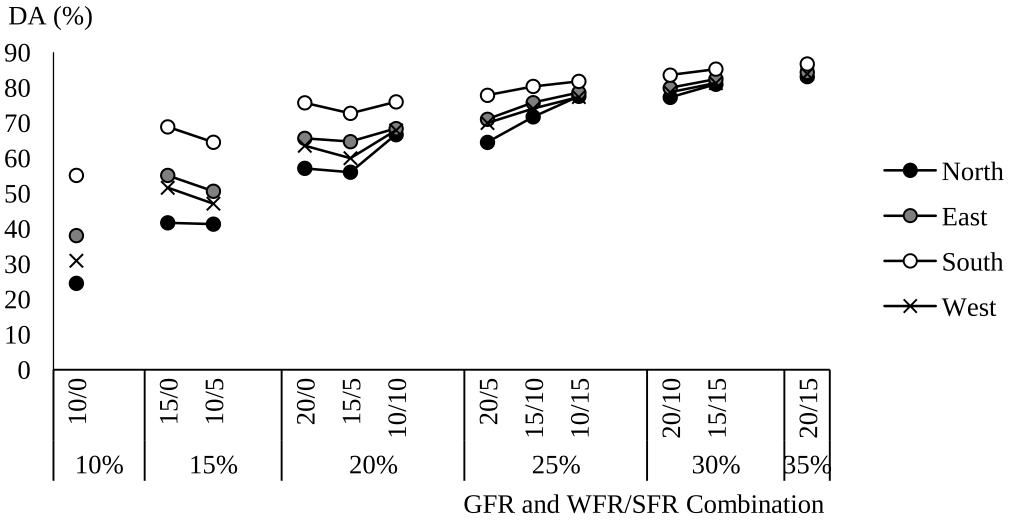


Figure 3-17: Average DA for different GFR, WFR/SFR combinations and orientations, for 30° roof tilt, 3/3 skylight distribution and typical construction.

3.2.4 Optimally day-lit area

Figure 3-18 presents the frequency distribution of the calculated optimally day-lit area (ODA) for all cases, with and without skylights, for the typical and passive construction type. The ODA is defined as the percentage of area that is not “over-lit” or “under-lit” but satisfactory “day-lit”. Figure 3-18 shows that most of the cases without skylights have an ODA of 10 to 40% while with skylights, the ODA is above 60% for most of the cases. The majority of the typical construction type cases result in 60 to 70% ODA, while the passive ones result in slightly higher values of 70 to 80% ODA.

Figure 3-19, Figure 3-20 and Figure 3-21 present the daylight availability in percentages of “over-lit” area (Illuminance above 5000 lux for more than 5% of operational time), “under-lit” area (DA lower than 50%) and ODA (noted as “day-lit” in the diagram), for three selected cases of GFR, for typical construction with 30° roof tilt and all skylight distributions and orientations. Figure 3-22 shows the results for the south orientation and various GFRs and WFR/SFR combinations. These three diagrams show how the “under-lit” and “over-lit” areas fluctuate and are highly dependent on orientation, distribution and WFR/SFR.

Figure 3-23, Figure 3-24 and Figure 3-25, present visualizations of the daylight availability for the three selected cases of GFR presented in Figure 3-19, Figure 3-20 and Figure 3-21 respectively. The ODA areas, “under-lit” areas and “over-lit” areas are represented as grey scaled, black and yellow squares respectively. Its square represents an area of $0.0625m^2$. These figures show how the ODA changes according to orientation, GFR and skylight distribution. The white lines show the skylights’ projection on the grid’s plane.

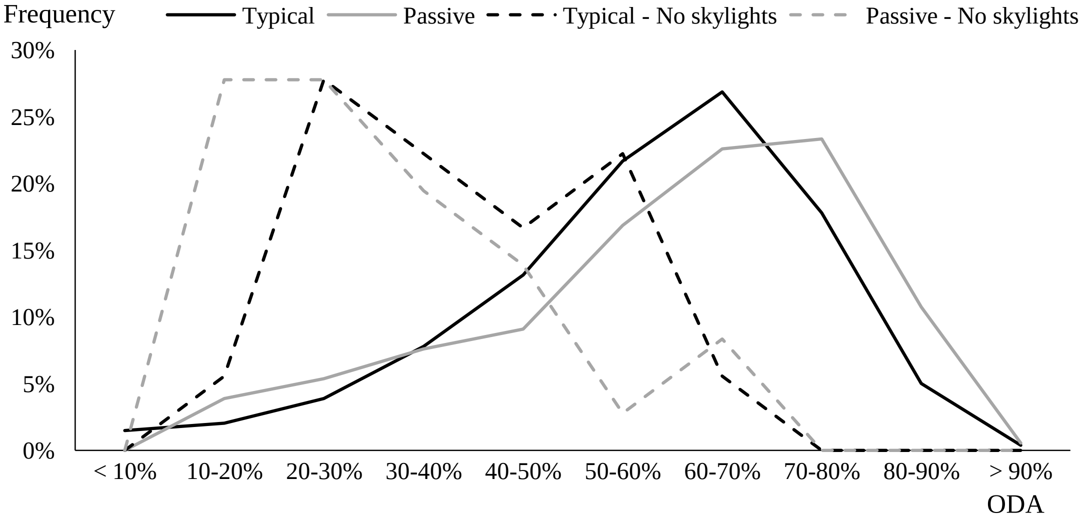


Figure 3-18: Frequency distribution of optimally day-lit area, for both construction types, with and without skylights.

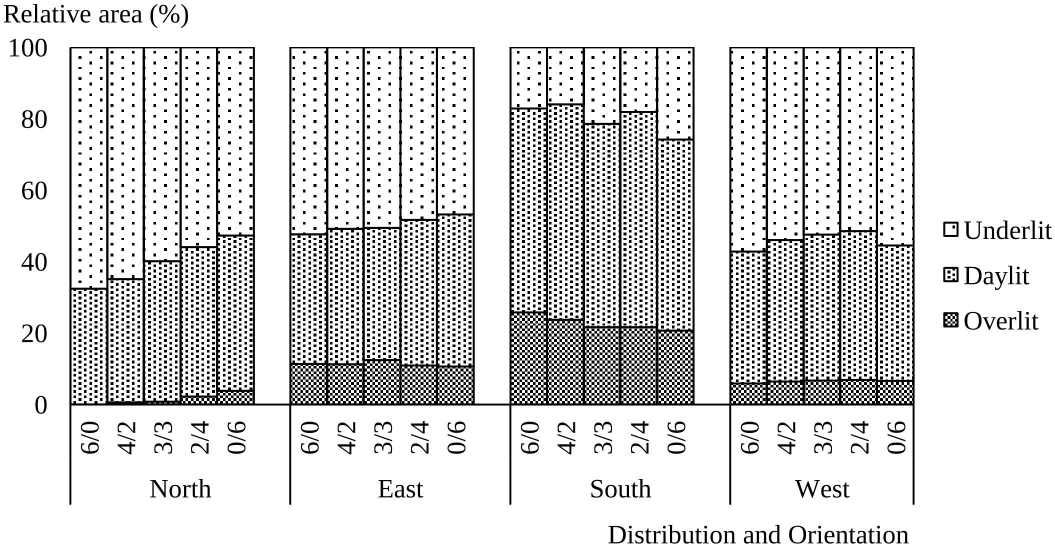


Figure 3-19: Daylight availability for different skylight distributions and orientations, for 10% WFR, 5% SFR, 30° roof tilt and typical construction.

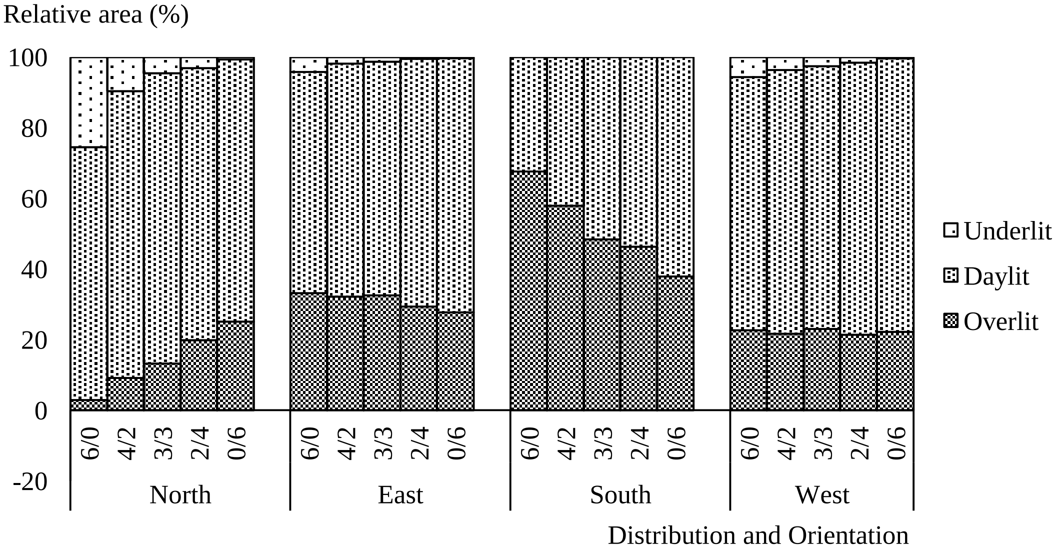


Figure 3-20: Daylight availability for different skylight distributions and orientations, for 15% WFR 10% SFR, 30° roof tilt and typical construction.

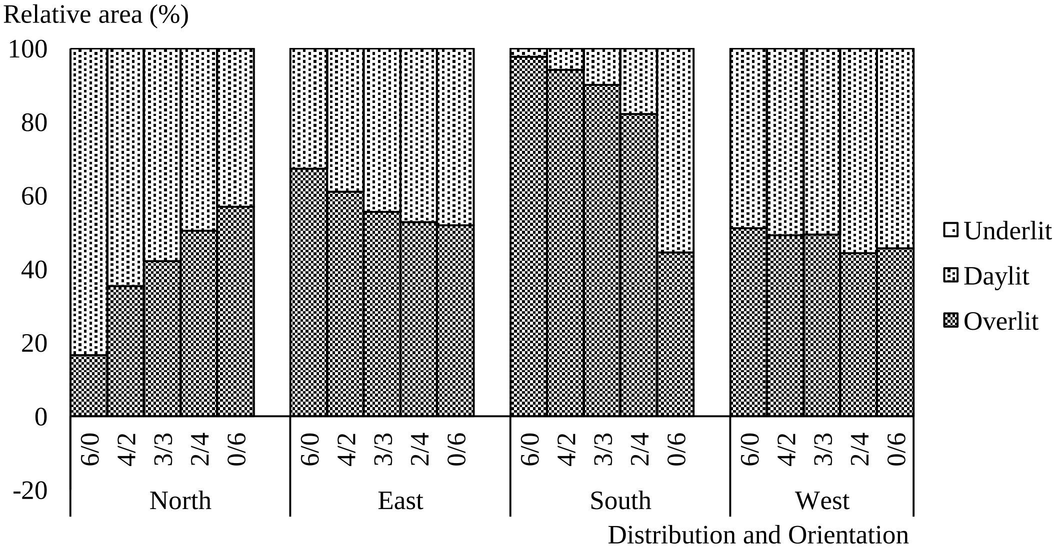


Figure 3-21: Daylight availability for different skylight distributions and orientations, for 20% WFR 15% SFR, 30° roof tilt and typical construction.

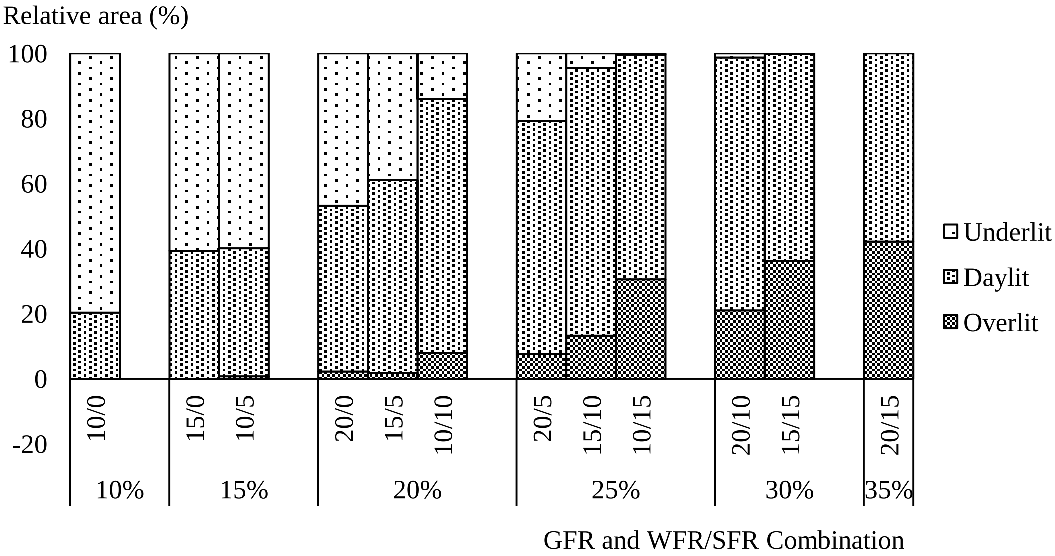


Figure 3-22: Daylight availability for different GFRs, WFR/SFR combinations, for 30° roof tilt, 3/3 skylight distribution, north orientation and typical construction.

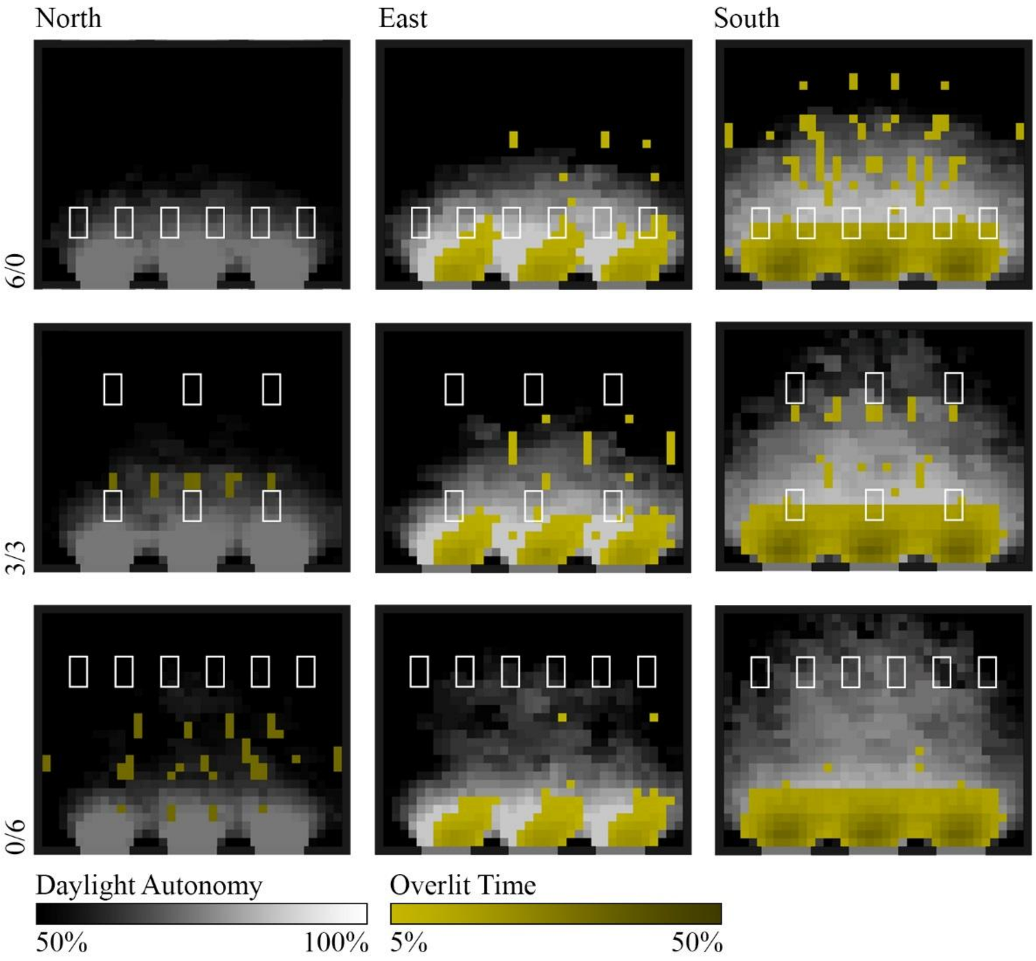


Figure 3-23: Daylight availability for a typical construction case with 10% WFR, 5% SFR, and 30° roof tilt, for three skylight distributions and three orientations.

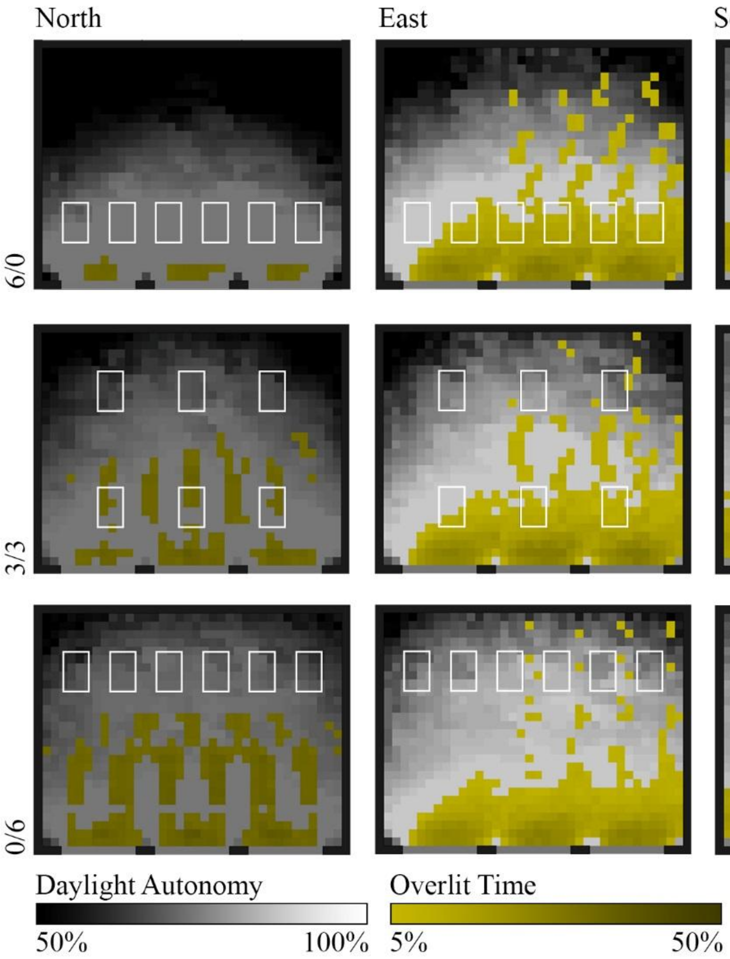


Figure 3-24: Daylight availability for a typical construction case with 15% WFR, 10% SFR and 30° roof tilt, for three skylight distributions and three orientations.

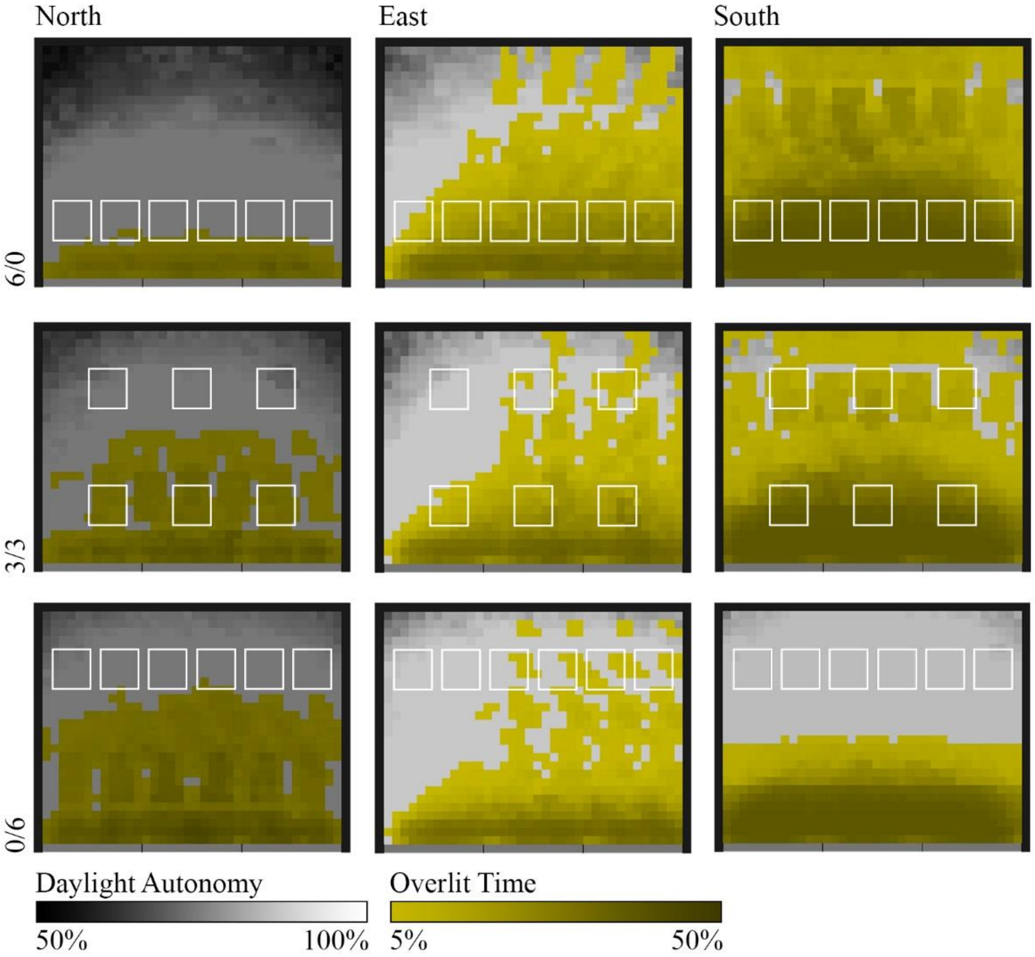


Figure 3-25: Daylight availability for a typical construction case with 20% WFR, 15% SFR and 30° roof tilt, for three skylight distributions and three orientations.

Figure 3-26 and Figure 3-27 present the correlation of ODA to DF and skylight distribution, for typical and passive construction type respectively. These figures show that ODA increases as DF increases, until approximately 6 to 7% DF. ODA decreases as DF increases above 7%. Additionally these figures show that the relation of ODA to DF is stronger for 0/6 and 2/4 distributions, where skylights are oriented towards the opposite direction of the windows, as the R^2 value (the coefficient of determination that indicates how well data fit a statistical model) is closer to 1. Figure 3-28 presents the correlation of ODA to DA for both construction types. This figure shows that most of the cases with ODA above 50%, have a high DA of 60 to 80%, while many cases with DA above 80% have significantly low ODA.

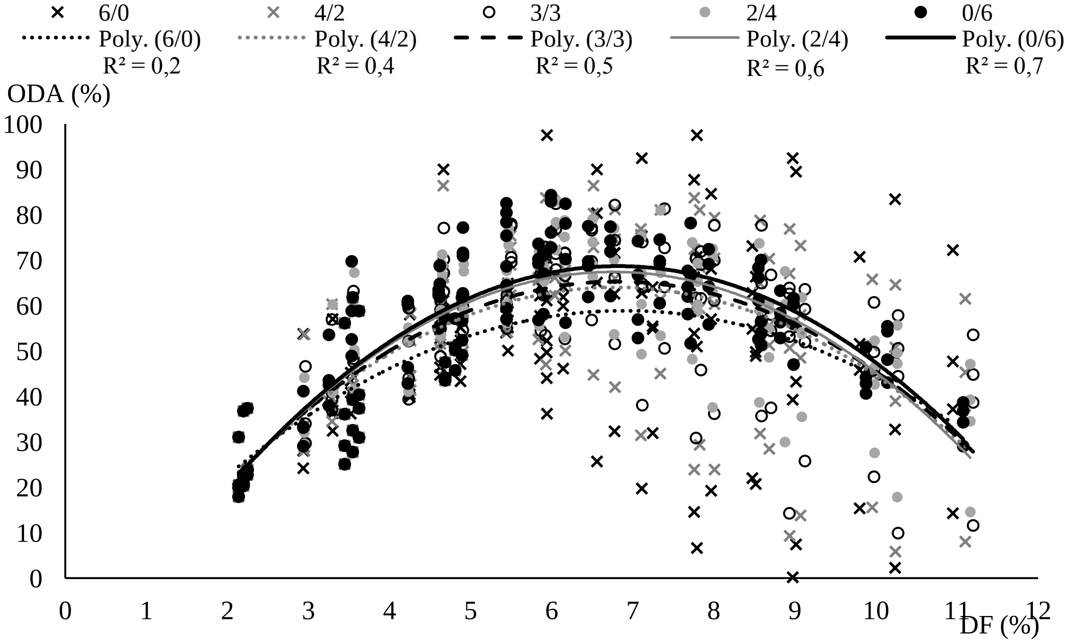


Figure 3-26: Correlation of ODA to DF and skylight distribution, for the typical construction.

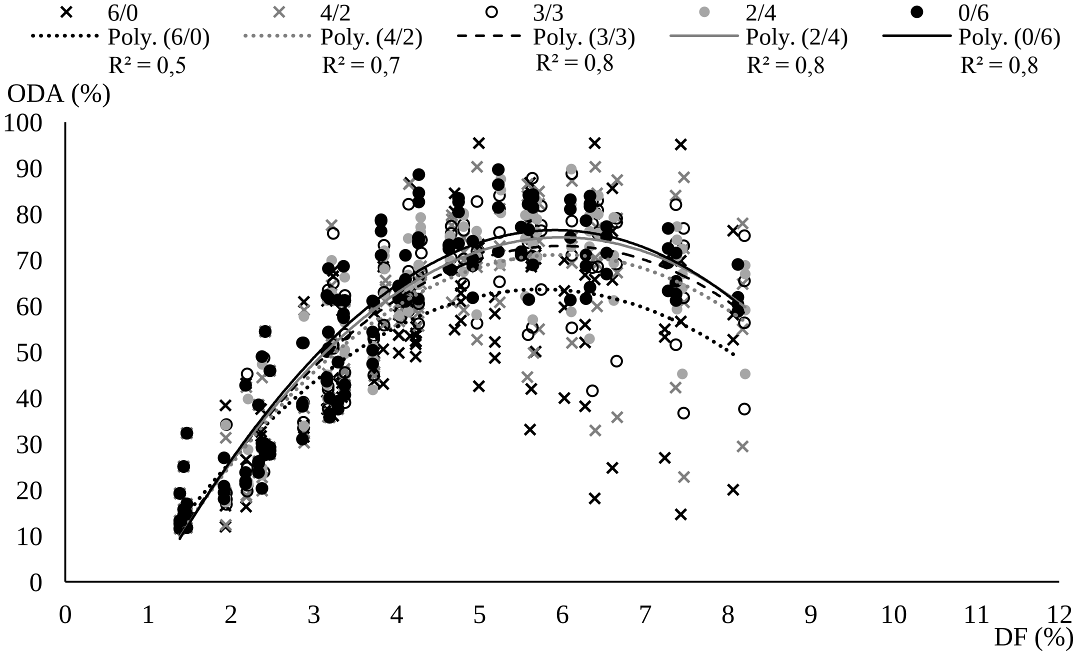


Figure 3-27: Correlation of ODA to DF and skylight distribution, for the passive construction.

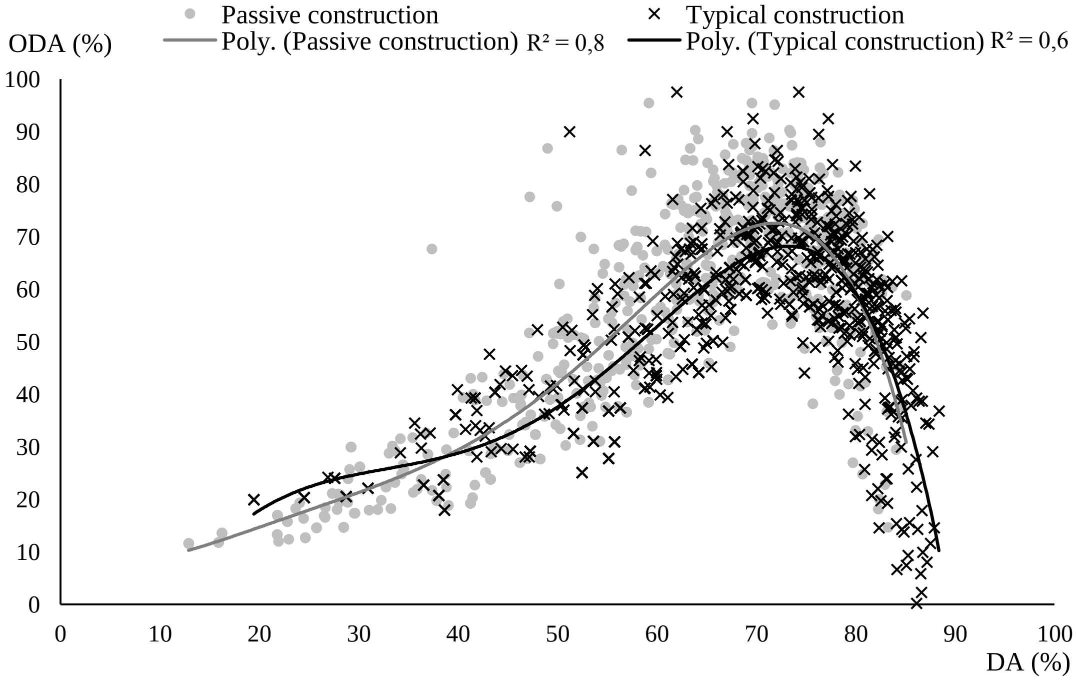


Figure 3-28: Correlation of ODA to DA, for the passive and typical construction type.

Table 3-2 and Table 3-3 present the ODA for all cases of typical and passive construction type respectively, in combination with the daylight classification presented at Chapter 2.3. The ODA values are presented with a grayscale gradient where lighter cells show higher values and darker ones show lower values. The lighter cells with bold font are considered to be optimal regarding daylight conditions. The cases with relatively high percentage of ODA are obtained with GFR of 20 to 25% but it is however highly dependent on orientation, distribution and WFR/SFR combination. The cases that do not meet any BREEAM Daylight criterion most of the times have an ODA of less than 40%. On the other hand, many cases that meet the BREEAM Exemplary Level have an ODA above 60%, while some cases have quite low values of 20 to 40%. Most of the cases with DF above 10% also obtain an ODA value inferior to 50%

Table 3-2: Percentage of Optimally Day-lit Area (ODA) for all typical construction cases.

Values	ODA (%)	*Italic*	BREEAM First Credit
▇▒□	0 to 100% ODA	**Bold**	BREEAM Exemplary - DF>10%
~~Striked~~	No BREEAM Certification	**Bold**	BREEAM Exemplary Level

WFR		10	15	10	20	15	10	20	15	10	20	15	20	10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15	0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35	10	15	15	20	20	20	25	25	25	30	30	35
		North												East											
Tilt 45	6/0	~~*20*~~	*36*	*24*	*48*	*45*	**90**	*59*	**98**	**90**	**92**	**98**	**92**	~~*18*~~	*25*	*28*	*44*	*40*	**59**	*65*	**67**	**65**	**63**	**51**	**39**
	4/2	~~*20*~~	*36*	*29*	*48*	*52*	**86**	*63*	*84*	**86**	*77*	**84**	**77**	~~*18*~~	*25*	*28*	*44*	*41*	**68**	*64*	*69*	**73**	*66*	**60**	**51**
	3/3	~~*20*~~	*36*	*30*	*48*	*52*	*77*	*64*	*70*	**77**	*64*	**70**	**64**	~~*18*~~	*25*	*30*	*44*	*39*	*63*	*60*	*67*	**70**	*65*	**62**	**53**
	2/4	~~*20*~~	*36*	*33*	*48*	*55*	**69**	*68*	*65*	**69**	*60*	**65**	**60**	~~*18*~~	*25*	*30*	*44*	*41*	**67**	*65*	*69*	**74**	*67*	**66**	**57**
	0/6	~~*20*~~	*36*	*33*	*48*	~~*61*~~	*62*	*69*	*58*	**62**	*53*	*58*	*53*	~~*18*~~	*25*	*29*	*44*	~~*43*~~	*65*	*64*	*67*	**69**	*67*	*64*	*58*
Tilt 30	6/0	~~*20*~~	*39*	*32*	*51*	*53*	*60*	*62*	*72*	**88**	*85*	**89**	*83*	~~*21*~~	*28*	*36*	*50*	*45*	*60*	*64*	*63*	**54**	*57*	**43**	*33*
	4/2	~~*20*~~	*39*	*35*	*51*	*57*	*75*	*68*	*81*	**81**	*79*	**73**	*65*	~~*21*~~	*28*	*38*	*50*	*50*	*69*	*66*	*66*	**59**	*60*	**49**	*39*
	3/3	~~*20*~~	*39*	*39*	*51*	*59*	**78**	*72*	*82*	**69**	*78*	**64**	**58**	~~*21*~~	*28*	*37*	*50*	*49*	**71**	*67*	*66*	**62**	*61*	**52**	**44**
	2/4	~~*20*~~	*39*	*42*	*51*	*62*	**76**	*72*	**77**	**60**	**71**	**54**	**50**	~~*21*~~	*28*	*41*	*50*	*53*	**76**	*69*	**70**	**65**	**63**	**54**	**47**
	0/6	~~*20*~~	*39*	*44*	*51*	*63*	**75**	*70*	**74**	**52**	**69**	**47**	**43**	~~*21*~~	*28*	*43*	*50*	*55*	**80**	*69*	**72**	**67**	**64**	**56**	**48**
Tilt 15	6/0	~~*24*~~	~~*40*~~	~~*41*~~	*52*	~~*52*~~	~~*61*~~	~~*62*~~	~~*64*~~	*66*	~~*73*~~	*71*	*72*	~~*24*~~	~~*31*~~	~~*36*~~	*62*	~~*43*~~	~~*50*~~	~~*60*~~	~~*55*~~	*49*	~~*55*~~	*46*	*37*
	4/2	~~*24*~~	~~*40*~~	~~*44*~~	*52*	~~*59*~~	*76*	*70*	*81*	*70*	*79*	*66*	*62*	~~*24*~~	~~*31*~~	~~*43*~~	*62*	~~*50*~~	*66*	*65*	*61*	*51*	*54*	*45*	*38*
	3/3	~~*24*~~	~~*40*~~	*48*	*52*	*63*	**82**	*72*	*81*	**67**	*78*	**61**	**54**	~~*24*~~	~~*31*~~	*40*	*62*	*55*	**71**	*67*	*64*	**54**	*57*	**46**	**39**
	2/4	~~*24*~~	~~*40*~~	*42*	*52*	*69*	**83**	*79*	**81**	**60**	**74**	**52**	**47**	~~*24*~~	~~*31*~~	*50*	*62*	*59*	**78**	*67*	**67**	**55**	**59**	**43**	**35**
	0/6	~~*24*~~	~~*40*~~	*49*	*52*	**72**	**73**	*82*	**69**	**51**	**66**	**44**	**39**	~~*24*~~	~~*31*~~	*53*	*62*	**71**	**83**	*70*	**70**	**54**	**61**	**41**	**29**
		South												West											
Tilt 45	6/0	~~*31*~~	*56*	*54*	*57*	*58*	**57**	*50*	**36**	**26**	**20**	**7**	**0**	~~*21*~~	*29*	*28*	*44*	*40*	**61**	*55*	**70**	**80**	**75**	**71**	**61**
	4/2	~~*31*~~	*56*	*54*	*57*	*58*	**65**	*54*	*47*	**45**	*31*	**24**	**9**	~~*21*~~	*29*	*34*	*44*	*45*	**66**	*58*	*73*	**80**	*76*	**72**	**67**
	3/3	~~*31*~~	*56*	*47*	*57*	*59*	*70*	*55*	*53*	**57**	*38*	**31**	**14**	~~*21*~~	*29*	*34*	*44*	*44*	*67*	*62*	*73*	**77**	*74*	**70**	**63**
	2/4	~~*31*~~	*56*	*44*	*57*	*60*	**71**	*56*	*58*	**66**	*49*	**48**	**30**	~~*21*~~	*29*	*32*	*44*	*52*	**69**	*61*	*73*	**79**	*75*	**74**	**68**
	0/6	~~*31*~~	*56*	*41*	*57*	~~*60*~~	*69*	*57*	*62*	**77**	*57*	*62*	*56*	~~*21*~~	*29*	*33*	*44*	~~*46*~~	*69*	*59*	*72*	**70**	*74*	*68*	*63*
Tilt 30	6/0	~~*37*~~	*62*	*57*	*57*	*57*	*54*	*48*	*32*	**15**	*19*	**7**	*2*	~~*22*~~	*33*	*37*	*46*	*46*	*63*	*58*	*72*	**66**	*68*	**54**	*49*
	4/2	~~*37*~~	*62*	*60*	*57*	*59*	*62*	*53*	*42*	**29**	*24*	**14**	*6*	~~*22*~~	*33*	*40*	*46*	*52*	*73*	*66*	*75*	**68**	*70*	**58**	*51*
	3/3	~~*37*~~	*62*	*57*	*57*	*61*	**70**	*54*	*52*	**46**	*36*	**26**	**10**	~~*22*~~	*33*	*41*	*46*	*55*	**78**	*69*	*74*	**72**	*70*	**59**	**51**
	2/4	~~*37*~~	*62*	*60*	*57*	*62*	**73**	*56*	**54**	**59**	**38**	**36**	**18**	~~*22*~~	*33*	*42*	*46*	*59*	**77**	*72*	**77**	**69**	**73**	**62**	**56**
	0/6	~~*37*~~	*62*	*54*	*57*	*62*	**78**	*57*	**62**	**78**	**56**	**62**	**55**	~~*22*~~	*33*	*38*	*46*	*63*	**83**	*74*	**77**	**67**	**72**	**60**	**54**
Tilt 15	6/0	~~*37*~~	~~*59*~~	~~*45*~~	*57*	~~*55*~~	~~*44*~~	~~*46*~~	~~*32*~~	*21*	~~*22*~~	*15*	*14*	~~*23*~~	~~*37*~~	~~*43*~~	*49*	~~*47*~~	~~*52*~~	~~*64*~~	~~*55*~~	*50*	~~*63*~~	*52*	*48*
	4/2	~~*37*~~	~~*59*~~	~~*60*~~	*57*	~~*59*~~	*62*	*50*	*45*	*28*	*32*	*16*	*8*	~~*23*~~	~~*37*~~	~~*41*~~	*49*	~~*58*~~	*72*	*68*	*69*	*56*	*65*	*51*	*45*
	3/3	~~*37*~~	~~*59*~~	*63*	*57*	*60*	**68**	*53*	*51*	**38**	*36*	**22**	**12**	~~*23*~~	~~*37*~~	*48*	*49*	*63*	**77**	*72*	*73*	**58**	*65*	**50**	**45**
	2/4	~~*37*~~	~~*59*~~	*67*	*57*	*61*	**72**	*53*	**53**	**49**	**39**	**28**	**15**	~~*23*~~	~~*37*~~	*49*	*49*	*68*	**83**	*75*	**75**	**59**	**68**	**46**	**39**
	0/6	~~*37*~~	~~*59*~~	*70*	*57*	**62**	**76**	*56*	**61**	**70**	**53**	**51**	**37**	~~*23*~~	~~*37*~~	*59*	*49*	**77**	**84**	*78*	**75**	**56**	**68**	**43**	**34**

Table 3-3: Percentage of Optimally Day-lit Area (ODA) for all passive construction cases.

Values	ODA (%)	*Italic*	BREEAM First Credit
▨	0 to 100% ODA	**Bold**	BREEAM Exemplary - DF>10%
~~Striked~~	No BREEAM Certification	**Bold**	BREEAM Exemplary Level

	WFR	10	15	10	20	15	10	20	15	10	20	15	20	10	15	10	20	15	10	20	15	10	20	15	20
	SFR	0	0	5	0	5	10	5	10	15	10	15	15	0	0	5	0	5	10	5	10	15	10	15	15
	GFR	10	15	15	20	20	20	25	25	25	30	30	35	10	15	15	20	20	20	25	25	25	30	30	35
		North												East											
Tilt 45	6/0	~~*12*~~	*26*	~~*12*~~	*40*	*32*	*68*	*44*	**87**	**68**	**95**	**87**	**95**	~~*13*~~	*24*	~~*18*~~	*37*	*34*	*44*	*50*	**63**	**81**	**73**	**76**	**66**
	4/2	~~*12*~~	*26*	~~*12*~~	*40*	*33*	*78*	*47*	**87**	**78**	**90**	**87**	**90**	~~*13*~~	*24*	~~*18*~~	*37*	*30*	*52*	*48*	**58**	**80**	**72**	**78**	**71**
	3/3	~~*12*~~	*26*	~~*17*~~	*40*	*39*	*76*	*54*	**82**	**76**	**83**	**82**	**83**	~~*13*~~	*24*	~~*18*~~	*37*	*33*	*51*	*53*	**62**	**70**	**72**	**74**	**68**
	2/4	~~*12*~~	*26*	~~*18*~~	*40*	*39*	*70*	*51*	*75*	**70**	*76*	**75**	**76**	~~*13*~~	*24*	~~*17*~~	*37*	*34*	*52*	*49*	*59*	**75**	*75*	**76**	**73**
	0/6	~~*12*~~	*26*	~~*18*~~	*40*	*39*	*68*	*54*	*71*	**68**	*69*	*71*	*69*	~~*13*~~	*24*	~~*19*~~	*37*	*31*	*51*	*50*	*61*	**72**	*70*	*71*	*71*
Tilt 30	6/0	~~*14*~~	*30*	*16*	*39*	*39*	*43*	*54*	*61*	**71**	*75*	**86**	**95**	~~*15*~~	*28*	*22*	*48*	*38*	*56*	*54*	*63*	**70**	*69*	**66**	**57**
	4/2	~~*14*~~	*30*	*18*	*39*	*39*	*61*	*58*	*72*	**85**	*82*	**87**	**88**	~~*15*~~	*28*	*19*	*48*	*45*	*56*	*59*	*70*	**74**	*71*	**67**	**61**
	3/3	~~*14*~~	*30*	*21*	*39*	*42*	*63*	*59*	*76*	**76**	*88*	**78**	**77**	~~*15*~~	*28*	*20*	*48*	*38*	*56*	*58*	*70*	**78**	*71*	**69**	**62**
	2/4	~~*14*~~	*30*	*21*	*39*	*40*	*68*	*63*	**80**	**71**	**83**	**69**	**67**	~~*15*~~	*28*	*22*	*48*	*45*	*63*	*62*	**77**	**79**	**73**	**71**	**64**
	0/6	~~*14*~~	*30*	*21*	*39*	*44*	*76*	*64*	**83**	**69**	**84**	**67**	**63**	~~*15*~~	*28*	*22*	*48*	*44*	*71*	*64*	**80**	**84**	**77**	**75**	**65**
Tilt 15	6/0	~~*12*~~	*29*	*26*	*43*	*43*	*52*	*55*	*62*	*67*	*70*	*70*	*76*	~~*15*~~	*28*	*33*	*43*	*40*	*52*	*54*	*52*	*52*	*63*	*55*	*53*
	4/2	~~*12*~~	*29*	*20*	*43*	*44*	*65*	*62*	*81*	*85*	*87*	*84*	*78*	~~*15*~~	*28*	*23*	*43*	*46*	*67*	*59*	*69*	*69*	*69*	*63*	*55*
	3/3	~~*12*~~	*29*	*24*	*43*	*39*	**67**	*66*	**84**	**83**	*89*	**82**	**75**	~~*15*~~	*28*	*30*	*43*	*46*	**72**	*67*	**76**	**76**	*71*	**65**	**56**
	2/4	~~*12*~~	*29*	*23*	*43*	*50*	**76**	*68*	**88**	**76**	**90**	**74**	**69**	~~*15*~~	*28*	*29*	*43*	*50*	**77**	*69*	**80**	**80**	**73**	**71**	**59**
	0/6	~~*12*~~	*29*	*20*	*43*	*57*	**75**	**75**	**81**	*64*	**81**	**63**	**62**	~~*15*~~	*28*	*29*	*43*	*58*	**85**	**74**	**86**	*82*	**75**	**73**	**60**
		South												West											
Tilt 45	6/0	~~*19*~~	*38*	~~*38*~~	*62*	*61*	*66*	*59*	**53**	**55**	**43**	**33**	**18**	~~*13*~~	*26*	~~*17*~~	*36*	*32*	*36*	*46*	**61**	**85**	**73**	**85**	**80**
	4/2	~~*19*~~	*38*	~~*31*~~	*62*	*59*	*64*	*60*	**62**	**61**	**53**	**45**	**33**	~~*13*~~	*26*	~~*19*~~	*36*	*38*	*52*	*45*	**63**	**79**	**68**	**84**	**81**
	3/3	~~*19*~~	*38*	~~*34*~~	*62*	*52*	*65*	*61*	**66**	**68**	**56**	**54**	**42**	~~*13*~~	*26*	~~*19*~~	*36*	*35*	*51*	*45*	**68**	**77**	**71**	**80**	**78**
	2/4	~~*19*~~	*38*	~~*34*~~	*62*	*58*	*63*	*61*	*67*	**74**	*58*	**62**	**53**	~~*13*~~	*26*	~~*17*~~	*36*	*39*	*51*	*42*	*64*	**75**	*71*	**80**	**80**
	0/6	~~*19*~~	*38*	~~*27*~~	*62*	*52*	*54*	*61*	*66*	**73**	*62*	*72*	*62*	~~*13*~~	*26*	~~*21*~~	*36*	*38*	*54*	*47*	*66*	**73**	*74*	*77*	*79*
Tilt 30	6/0	~~*25*~~	*54*	*43*	*61*	*61*	*69*	*58*	*57*	**50**	*42*	**25**	**15**	~~*16*~~	*29*	*27*	*38*	*39*	*51*	*50*	*64*	**74**	*69*	**76**	**70**
	4/2	~~*25*~~	*54*	*42*	*61*	*62*	*66*	*61*	*59*	**55**	*50*	**36**	**23**	~~*16*~~	*29*	*22*	*38*	*36*	*64*	*57*	*75*	**82**	*76*	**79**	**73**
	3/3	~~*25*~~	*54*	*45*	*61*	*63*	*73*	*61*	*65*	**64**	*55*	**48**	**37**	~~*16*~~	*29*	*25*	*38*	*43*	*68*	*59*	*78*	**82**	*77*	**79**	**73**
	2/4	~~*25*~~	*54*	*40*	*61*	*61*	*72*	*61*	**67**	**76**	**57**	**61**	**45**	~~*16*~~	*29*	*29*	*38*	*43*	*71*	*58*	**80**	**83**	**80**	**79**	**72**
	0/6	~~*25*~~	*54*	*43*	*61*	*62*	*78*	*62*	**74**	**84**	**61**	**72**	**61**	~~*16*~~	*29*	*24*	*38*	*50*	*79*	*64*	**83**	**81**	**82**	**77**	**72**
Tilt 15	6/0	~~*32*~~	*46*	*38*	*61*	*59*	*49*	*59*	*49*	*38*	*40*	*27*	*20*	~~*17*~~	*29*	*32*	*41*	*44*	*54*	*52*	*58*	*56*	*60*	*53*	*58*
	4/2	~~*32*~~	*46*	*44*	*61*	*61*	*67*	*60*	*61*	*60*	*52*	*42*	*29*	~~*17*~~	*29*	*29*	*41*	*46*	*69*	*56*	*73*	*77*	*75*	*71*	*65*
	3/3	~~*32*~~	*46*	*49*	*61*	*62*	**74**	*61*	**65**	**69**	*55*	**52**	**38**	~~*17*~~	*29*	*30*	*41*	*54*	**74**	*56*	**81**	**81**	*78*	**74**	**65**
	2/4	~~*32*~~	*46*	*47*	*61*	*66*	**79**	*61*	**69**	**76**	**59**	**59**	**45**	~~*17*~~	*29*	*25*	*41*	*56*	**76**	*65*	**85**	**84**	**82**	**77**	**67**
	0/6	~~*32*~~	*46*	*49*	*61*	*69*	**83**	**62**	**72**	*82*	**61**	**69**	**59**	~~*17*~~	*29*	*30*	*41*	*58*	**89**	**74**	**90**	*84*	**83**	**77**	**69**

3.2.5 Daylight glare probability

The annual daylight glare probability (ADGP) was simulated for only one set of cases with 30° roof tilt, 25% GFR and typical construction, for all orientations and skylight distributions. The ADGP is the percentage of operational (occupancy) time with DGP more than 40% and an ADGP of 10% corresponds to 151.2 hours. The results are presented in Figure 3-29. This figure shows that the ADGP is higher for cases oriented towards south and east, and lower for cases oriented towards north and west. For the north orientation, the highest ADGP results in the 0/6 distribution. In contrast, for the south, the highest ADGP results in the 6/0 distribution, while for the east in 3/3 distribution. Additionally, ADGP increases as SFR increases for most of the cases. The correlation of ADGP to ODA is presented in Figure 3-30. The figure shows that cases with higher ADGP tend to have lower ODA.

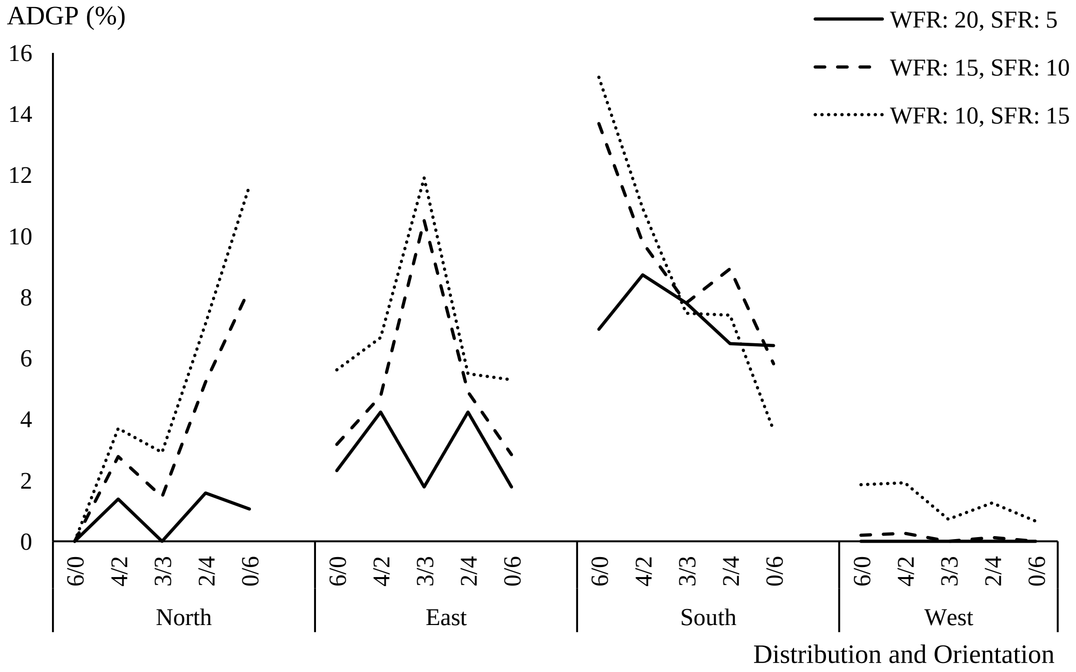


Figure 3-29: ADGP for 30° roof tilt, 25% GFR, all skylight distributions, all orientations and typical construction.

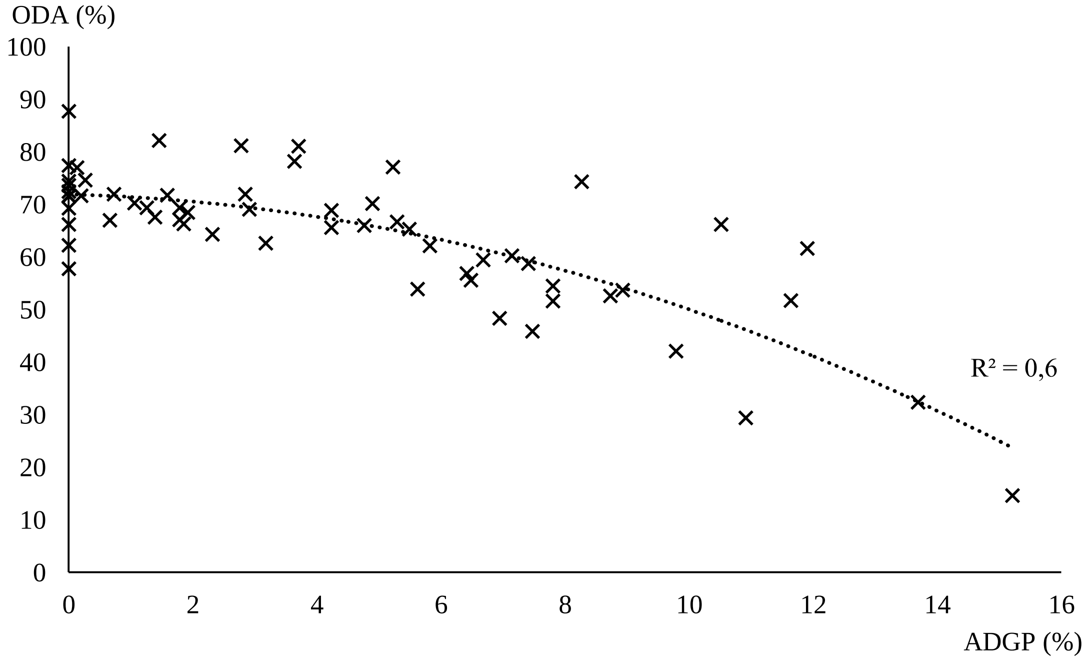


Figure 3-30: Correlation of ADGP to ODA, for all cases with 30° roof tilt, 25% GFR and typical construction.

Figure 3-31 to Figure 3-34 present hourly DGP simulations for a year, as resulted from DIVA, for a selected case with 15% WFR, 10% SFR, 30° roof tilt, 3/3 skylight distribution and typical construction. The x-axis of these diagrams show the months divided in days, from January to December, while y-axis shows the hours during a day. These figures show that for the north orientation, glare appears during summer time only at cases with southern skylights and it increases as more skylights are placed towards south (0/6 distribution case). On the same way, for the south orientation, glare increases during summer, due to the southern skylights, but glare due to the southern windows is also present during winter time. For the east orientation, glare from both rows of skylights (oriented west and south) is present at different hours, and therefore the hours with glare are maximum for the 3/3 distribution. On the other hand, there are very few hours with glare for the west orientation.

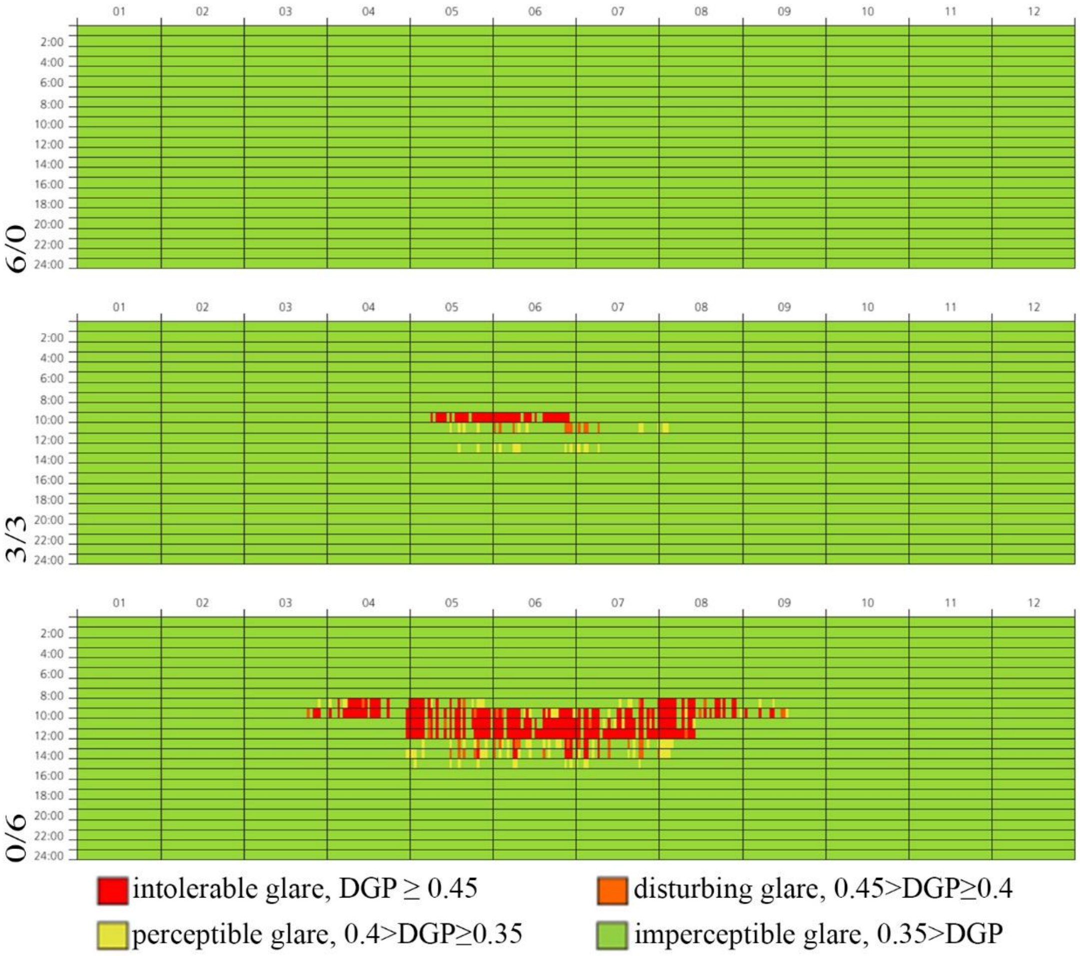


Figure 3-31: Hourly DGP simulation for a case with 15% WFR, 10% SFR and 30° roof tilt, for three distributions and north orientation.

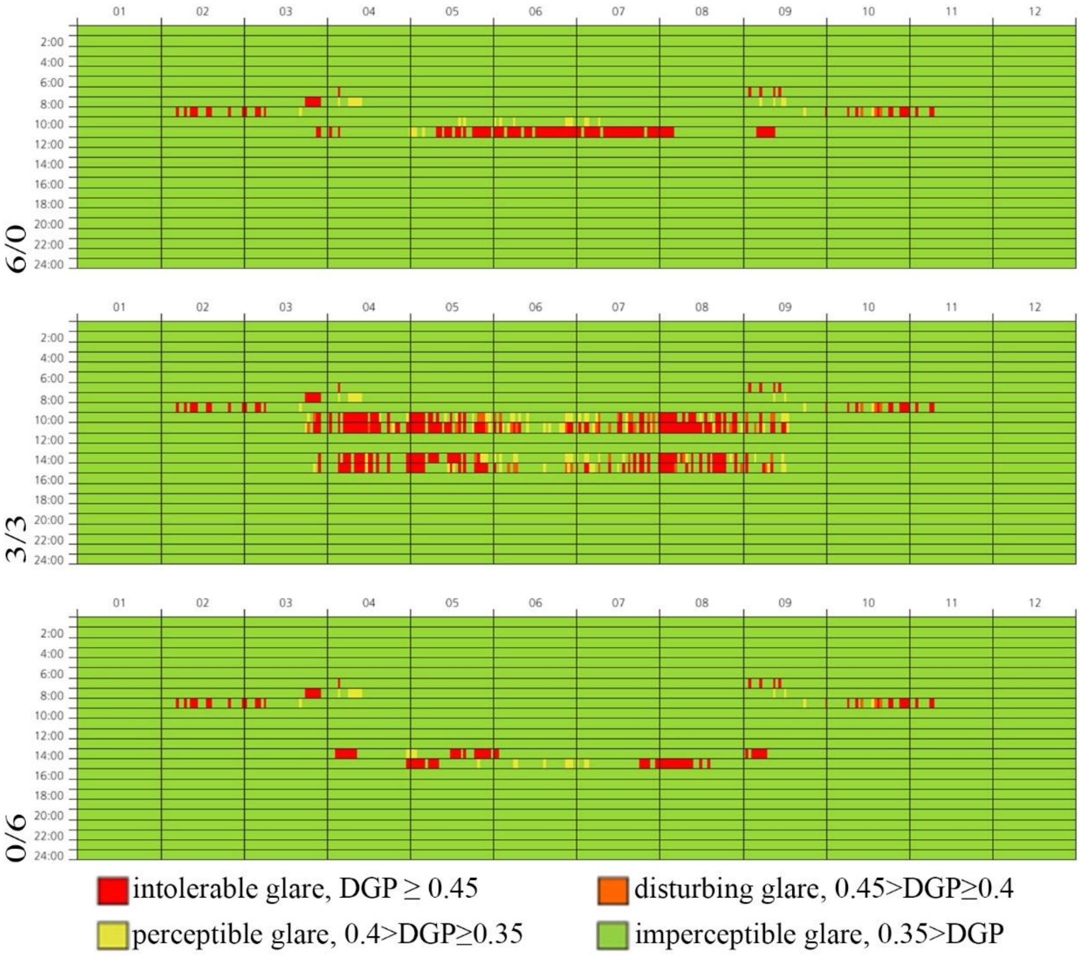


Figure 3-32: Hourly DGP simulation for a case with 15% WFR, 10% SFR and 30° roof tilt, for three distributions and east orientation.

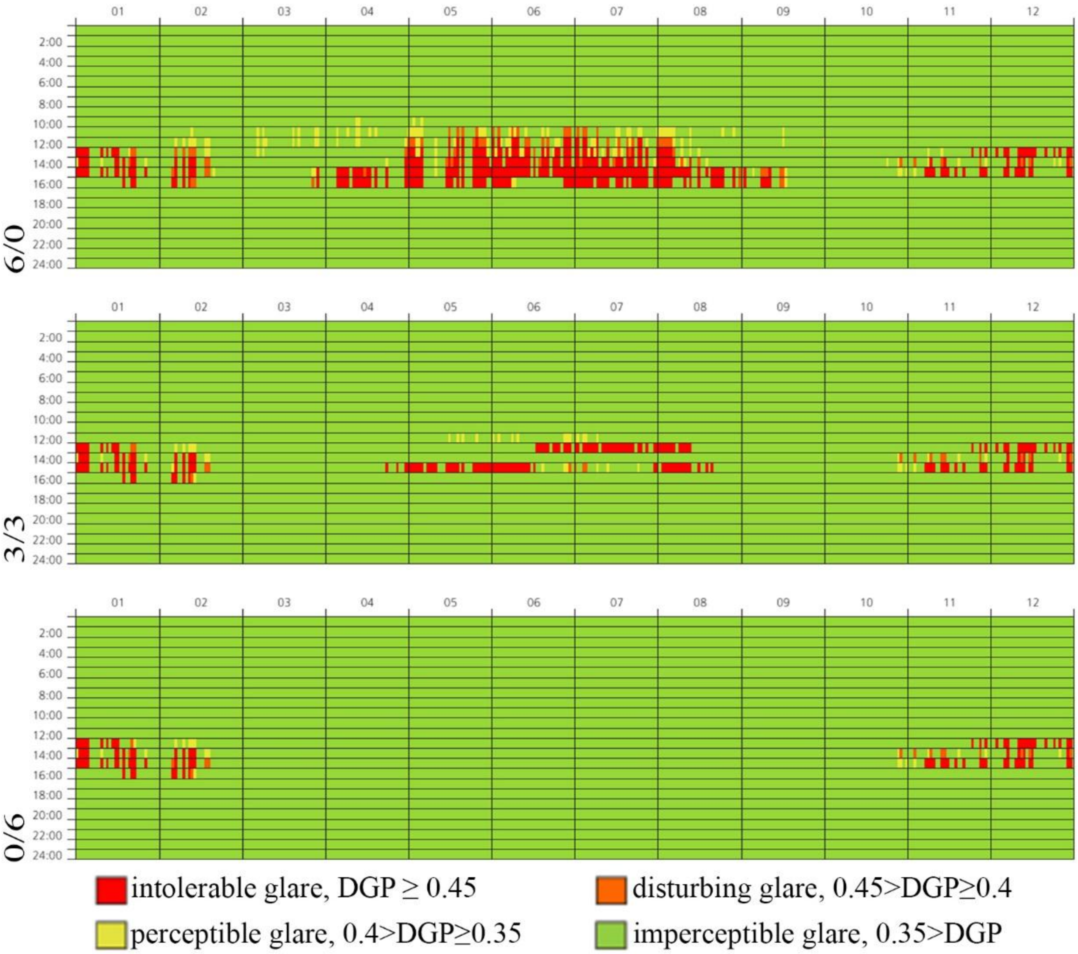


Figure 3-33: Hourly DGP simulation for a case with 15% WFR, 10% SFR and 30° roof tilt, for three distributions and south orientation.

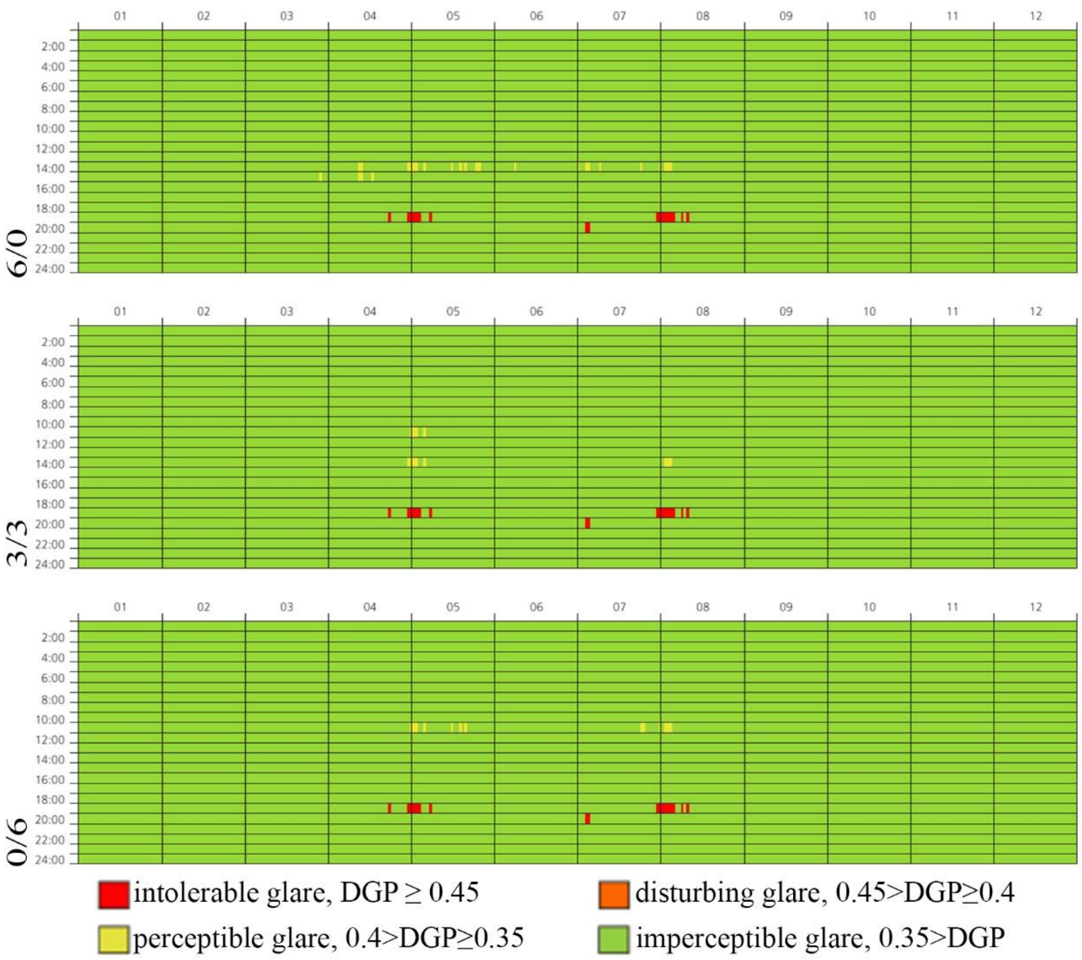


Figure 3-34: Hourly DGP simulation for a case with 15% WFR, 10% SFR and 30° roof tilt, for three distributions and west orientation.

Figure 3-35 to Figure 3-38 are fisheye renderings of a same case with 15% WFR, 10% SFR, 30° roof tilt, 3/3 skylight distribution and typical construction (same case that hourly DGP was simulated), for three selected times (9:00, 12:00, 15:00), three selected dates (solstices and equinox), all orientations and for clear sky conditions. These figures show how different sun-patches from skylights and/or windows appear during different seasons and hours because of the different solar altitudes. These sun-patches are the main source for the glare presented in Figure 3-31 to Figure 3-34. More specifically, Figure 3-35 shows that for the north orientation sun-patches are created only by the southern skylights during summer time. Figure 3-36 shows that for the east, sun-patches are created during morning time only from windows, while patches from all skylights are present almost all day during summer. Figure 3-37 shows that for the south orientation, sun patches are created from either windows or skylights constantly as expected, while Figure 3-38 shows that for the west orientation, sun-patches from skylights are present only during summer and rarely from windows.

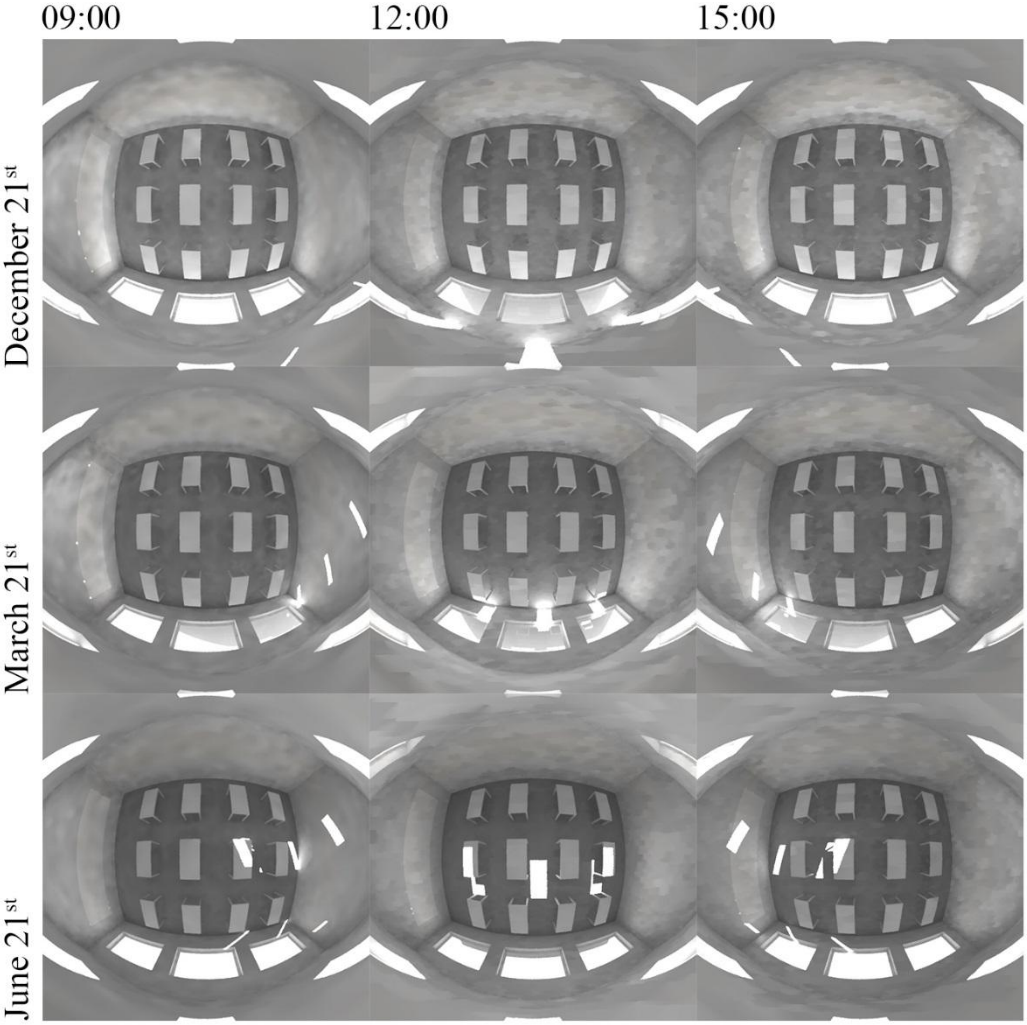


Figure 3-35: Renderings of a case with 15% WFR, 10% SFR and 30° roof tilt, for three times, three dates and north orientation.

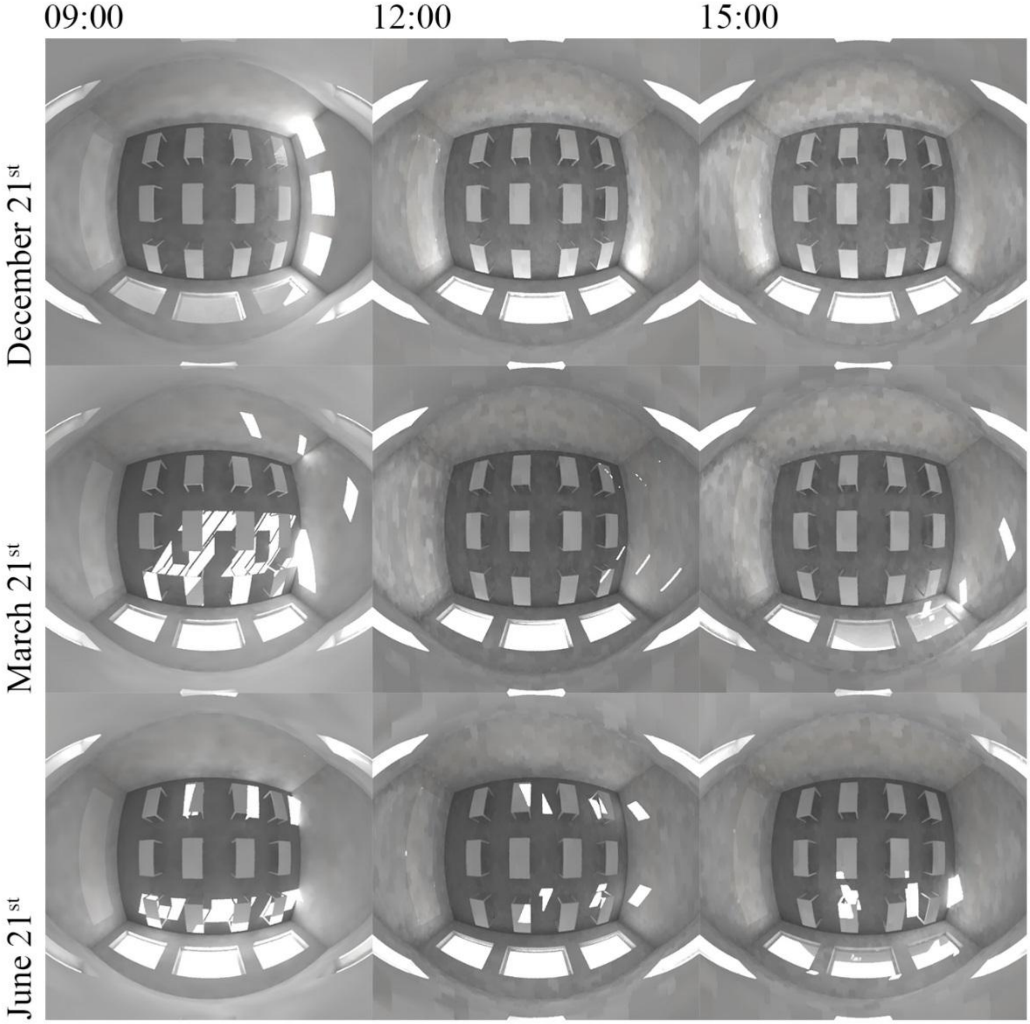


Figure 3-36: Renderings of a case with 15% WFR, 10% SFR and 30° roof tilt, for three times, three dates and east orientation.

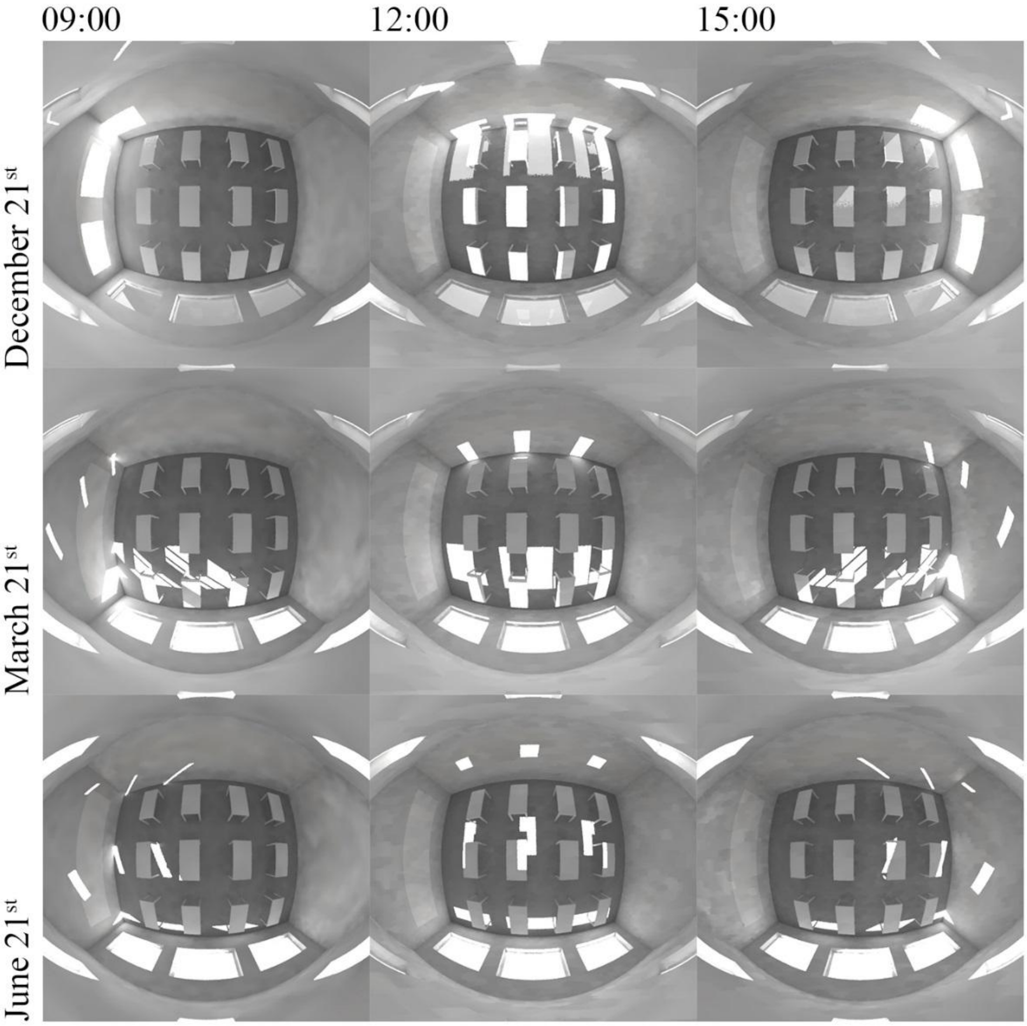


Figure 3-37: Renderings of a case with 15% WFR, 10% SFR and 30° roof tilt, for three times, three dates and south orientation.

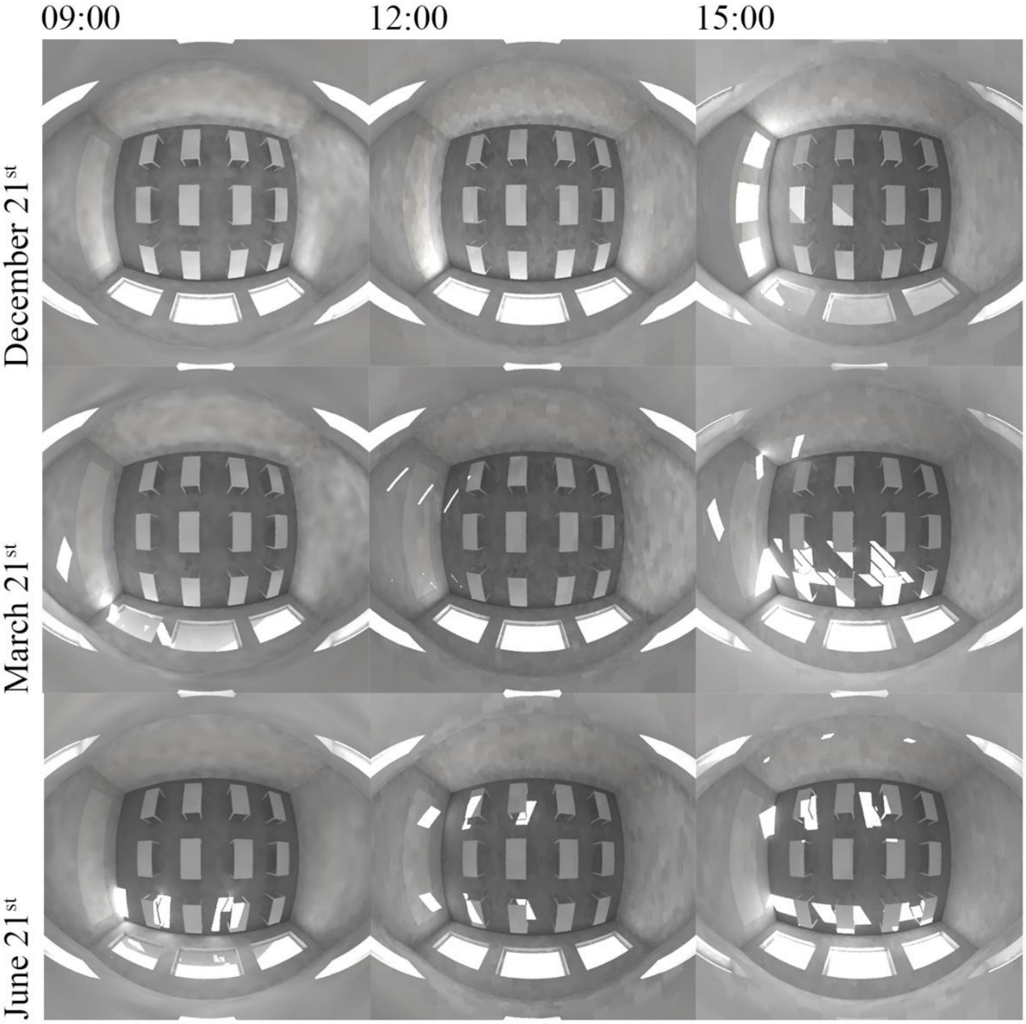


Figure 3-38: Renderings of a case with 15% WFR, 10% SFR and 30° roof tilt, for three times, three dates and west orientation.

Figure 3-39 presents point in time renderings with DGP simulation for four scenarios of the case presented in the previous figures, on June 21st, 11:00 a.m. and south orientation where glare problems are mostly present. The first two instances of this figure present the selected case without and with skylights, and show the effect of skylights on the DGP that increases noticeably from 23 to 59%, with their addition. The next two instances, present the effect of the shading device use on the DGP, and they show that the DGP can be controlled and noticeably decrease to under 30%, with the use of interior or exterior shading on the skylights.

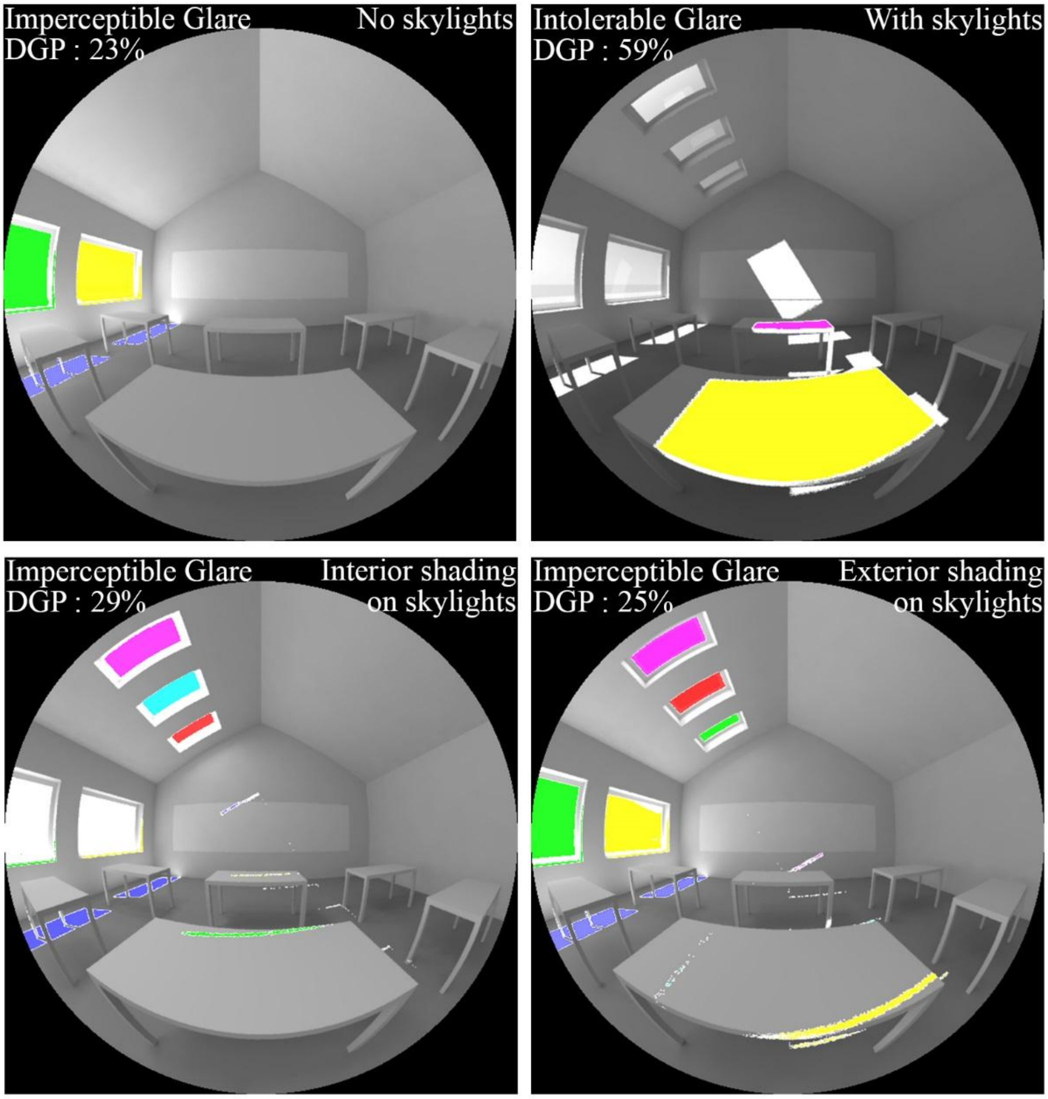


Figure 3-39: DGP simulations for a case with 15% WFR, 10% SFR and 30° roof tilt and south orientation, on June 21st, 11:00 a.m. for four different scenarios.

3.3 Energy analysis

3.3.1 Heating demand

Figure 3-40 presents the frequency distribution of the simulated heating demand, for all cases, with and without skylights. This figure shows that the typical construction cases result in considerably higher heating demand compared to the passive construction cases as expected. Additionally, most of the typical construction cases without skylights, result in a heating demand of 15 to 21kWh/m^2, while with skylights result in 21 to 27kWh/m^2. Similarly, the majority of the passive construction cases without skylights, result in a heating demand of 9 to 12kWh/m^2 while with skylights result in 12 to 15kWh/m^2.

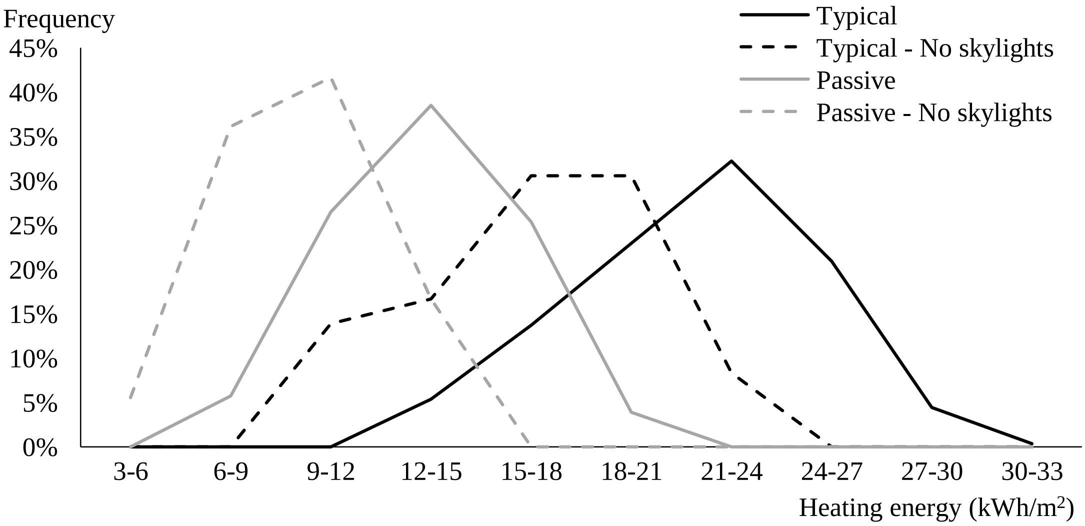


Figure 3-40: Frequency distribution of the simulated heating demand, for both construction types, with and without skylights.

Figure 3-41 presents the frequency distribution of the calculated increase in heating demand when skylights are added. The figure shows more clearly that for all cases the heating demand increases when skylights are added. The passive construction cases have slightly less heating demand increase compared to the typical construction cases.

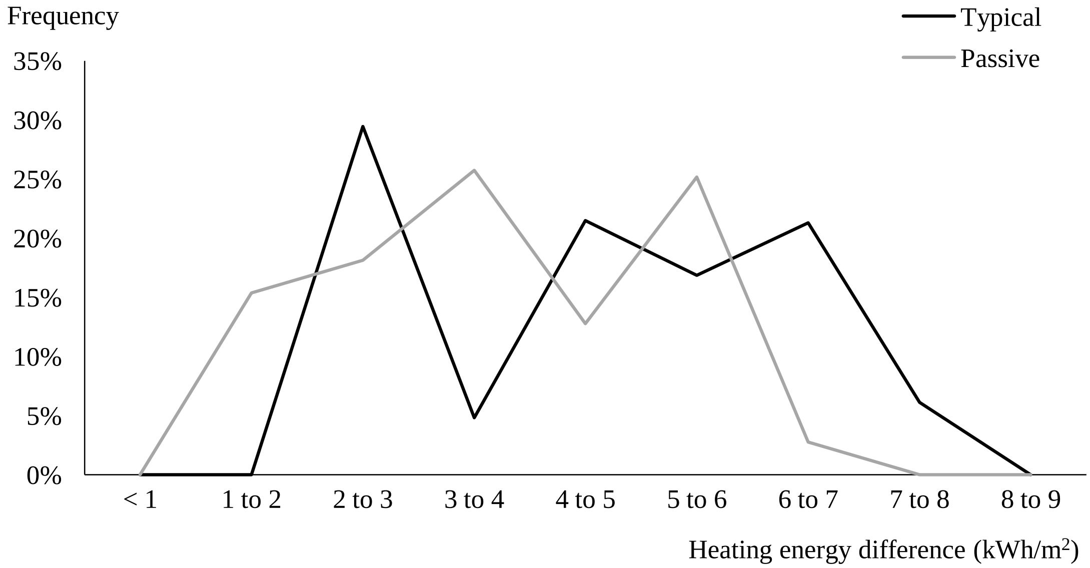


Figure 3-41: Frequency distribution (cases with skylights), according to the heating demand increase, compared to the respective cases without skylights, for both construction types.

Figure 3-42 presents the heating demand for three selected cases of GFRs (minimum, medium and maximum) for all orientations, skylight distributions and both constructions types for a 30° roof tilt. This figure shows that the heating demand is higher for cases with higher GFR while passive construction cases have significantly lower heating demand than the typical ones. Figure 3-43 presents the heating demand of a selected medium GFR case (WFR:15%, SFR:10%), for different roof tilts. This figure shows that the cases with 15° roof tilt have a lower heating demand than the cases with higher roof tilts. In addition, this figure shows that the skylight distribution has a negligible effect on the heating demand, except for the north orientation, where heating slightly diminishes as more skylights are placed towards the south.

Figure 3-44 presents the heating demand obtained for different GFRs, WFR/SFR combinations and orientations, for 3/3 distribution, 30° roof tilt and typical construction. This figure shows that for all cases, the heating demand increases when SFR increases for equivalent GFR, independently of orientation. Moreover, for some cases with skylights, the heating demand is even higher compared to cases with higher GFR and less or no skylight area.

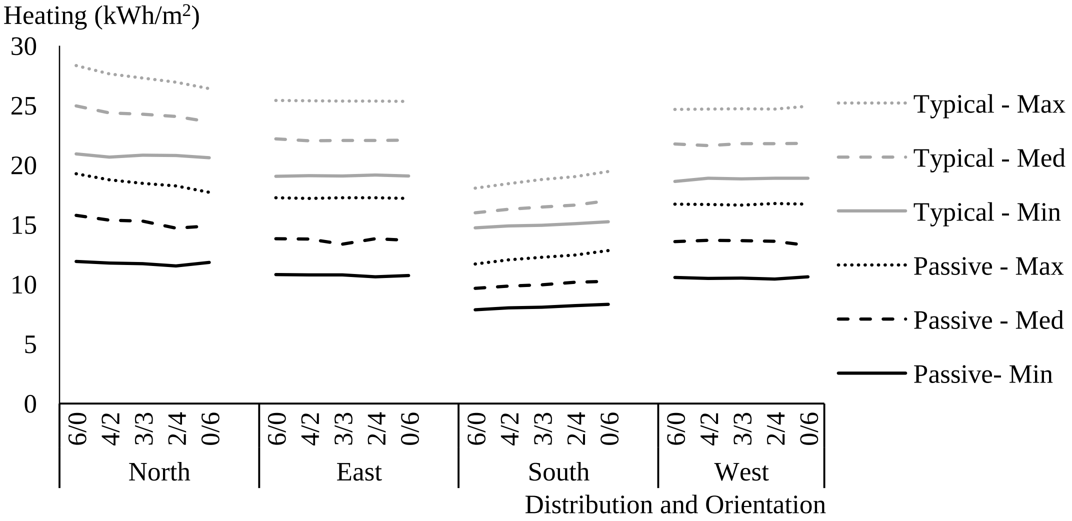


Figure 3-42: Heating demand for three selected GFR cases for 30° roof tilt, all skylight distributions, orientations and construction types.

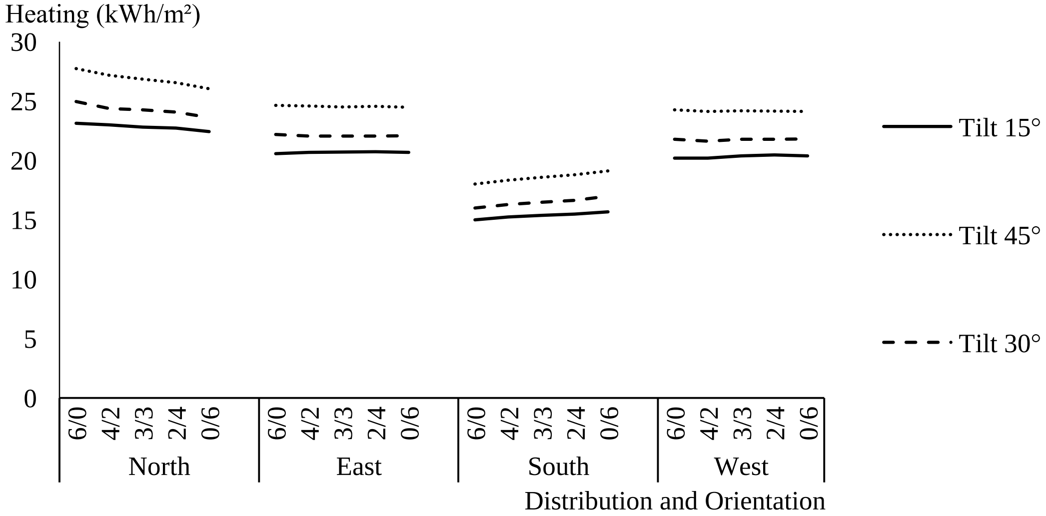


Figure 3-43: Heating demand for all skylight distributions, orientations and roof tilts, for a medium GFR case (WFR:15%, SFR:10%) and typical construction.

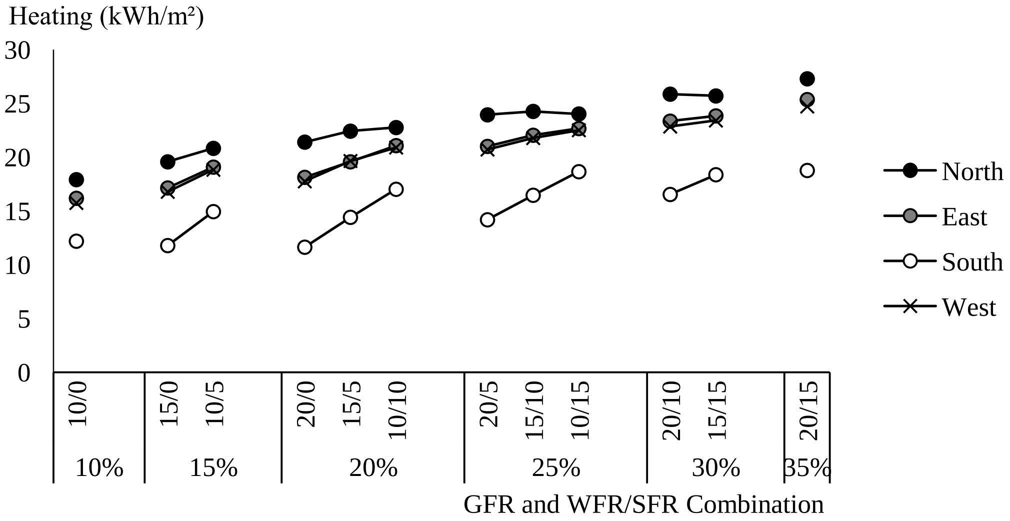


Figure 3-44: Heating demand for different GFRs, WFR/SFR combinations and orientations, for 30° roof tilt, 3/3 skylight distribution and typical construction.

3.3.2 Electricity demand for lighting

Figure 3-45 presents the frequency distribution of the simulated electricity demand for lighting, for all cases, with and without skylights. This figure shows that many of the typical construction cases result in lower lighting demand compared to the passive construction cases, as expected. In addition, the lighting demand is lower for higher percentage of cases with skylights, compared to the cases without skylights, for both construction types. More specifically, the lighting demand is between 4 to 6 kWh/m^2 for most of the cases without skylights, while it is decreased to 2 to 4 kWh/m^2 for most cases with skylights, for both construction types.

Figure 3-46 presents the frequency distribution of the calculated difference in lighting demand when skylights are added. This figure shows more clearly that for almost all cases, the electric lighting demand decreases when skylights are added. The reduction of the lighting demand is almost the same for both construction types. Most of the cases have a reduction in the lighting demand of 0 to 2 kWh/m².

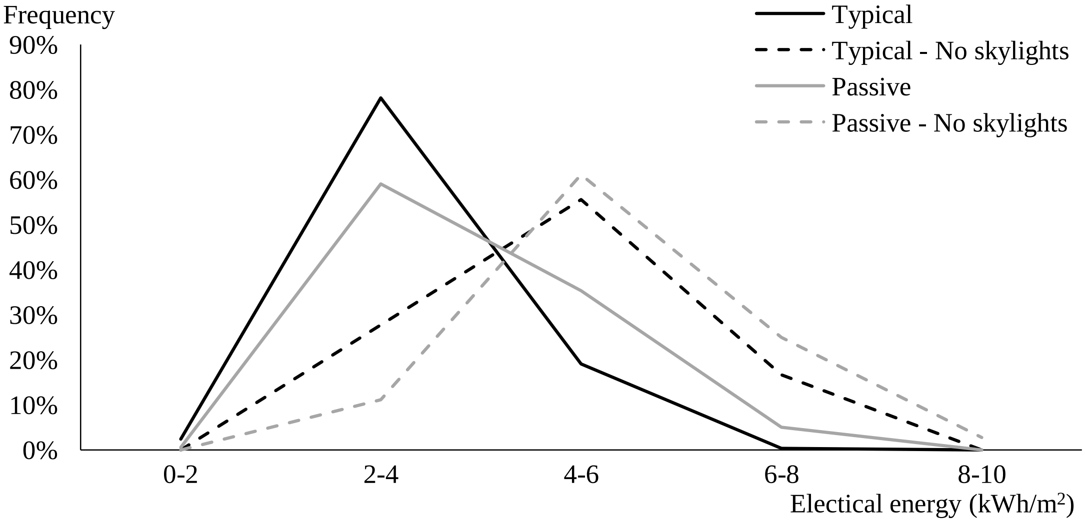


Figure 3-45: Frequency distribution of the simulated lighting demand, for both construction types, with and without skylights.

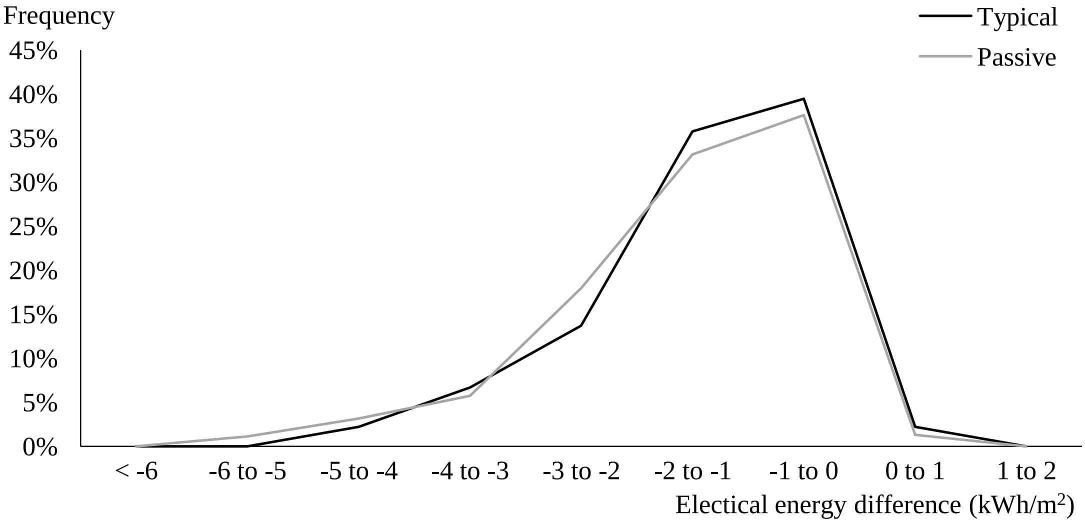


Figure 3-46: Frequency distribution (cases with skylights), according to the lighting demand difference, compared to the respective cases without skylights, for both construction types.

Figure 3-47 shows the lighting demand for three selected cases of GFR (minimum, medium and maximum) for all orientations, skylight distributions and construction types, for a 30° roof tilt. This figure shows that the lighting demand is lower for cases with higher GFR, while passive construction cases result in higher lighting demand compared to the typical construction type cases. Figure 3-48 presents the lighting demand of a selected medium GFR case (WFR:15%, SFR:10%), for different roof tilts. For low roof tilts (15°, 30°)

lighting demand decreases for 0/6 distribution, for many cases. Moreover, the distribution negligibly affects the electric lighting demand on the south orientation.

Figure 3-49 to Figure 3-52 present the lighting demand for different GFRs, combinations of WFR/SFR and orientations, for 3/3 distribution, 30° roof tilt and typical construction. These figures show that for many cases, the lighting demand decreases when SFR increases at equivalent GFR cases. However, this is affected by various parameters (orientation, GFR, WFR/SFR combination, distribution) making it hard to reach a general conclusion.

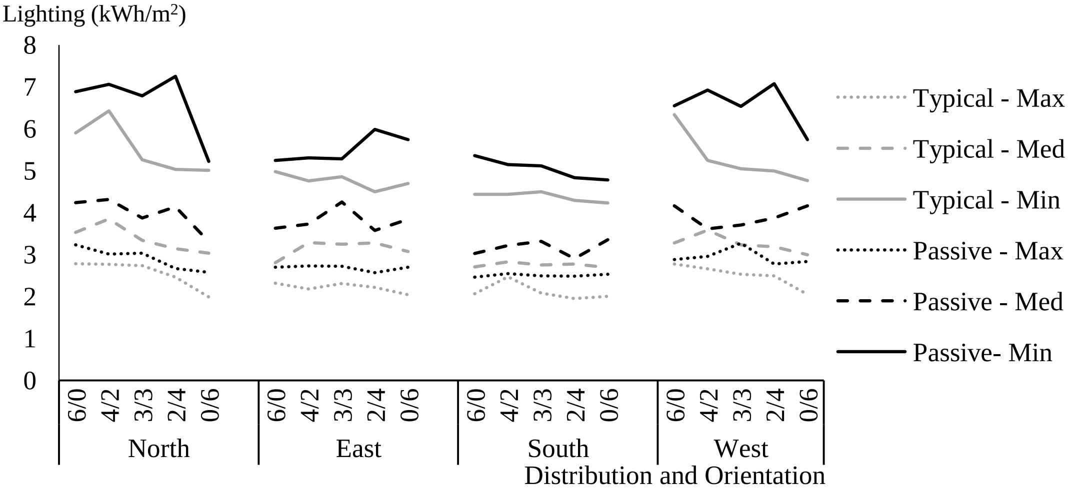


Figure 3-47: Lighting demand for three selected GFR cases, for 30° roof tilt, all skylight distributions, orientations and construction types.

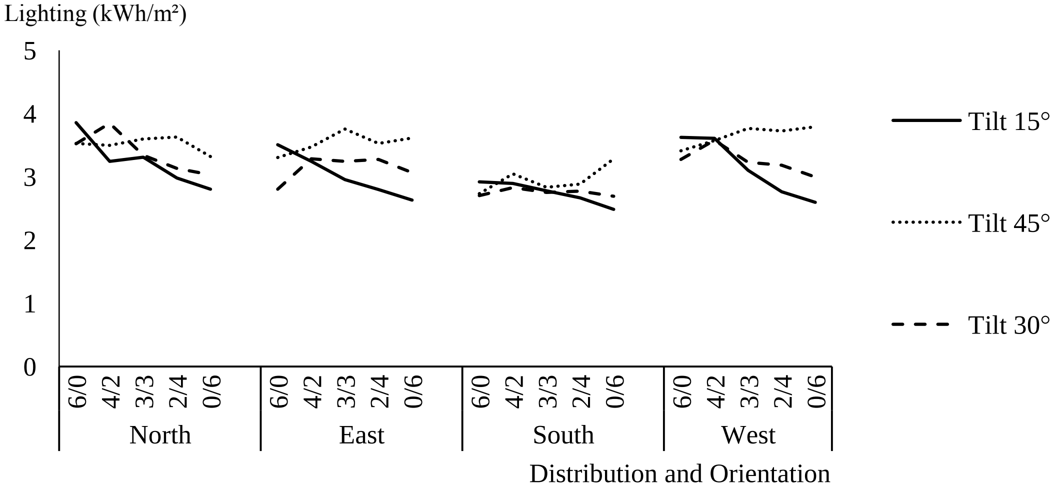


Figure 3-48: Lighting demand for all skylight distributions, orientations and roof tilts, for a medium GFR case (WFR:15%, SFR:10%) and typical construction.

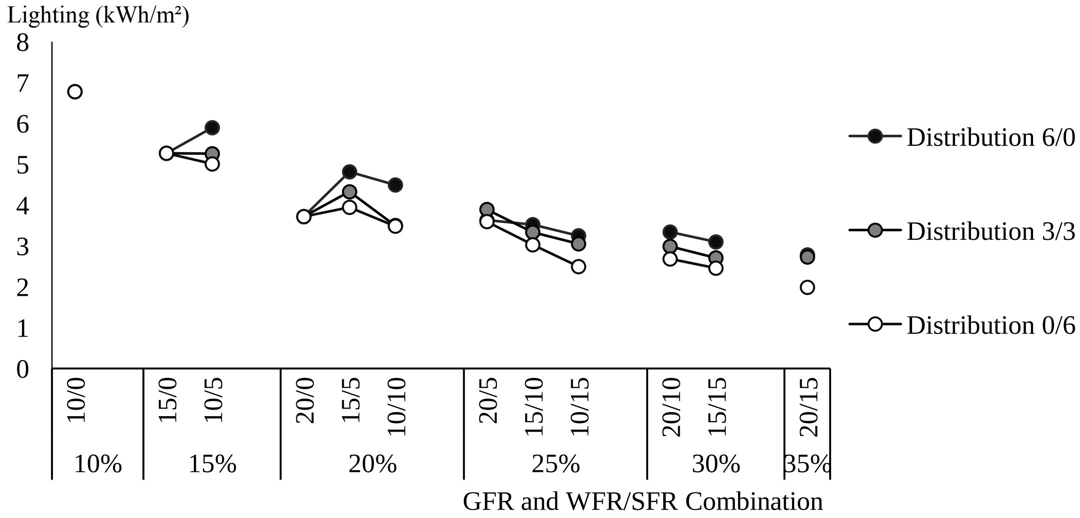


Figure 3-49: Lighting demand for different GFRs, WFR/SFR combinations and three distributions, for 30° roof tilt, north orientation and typical construction.

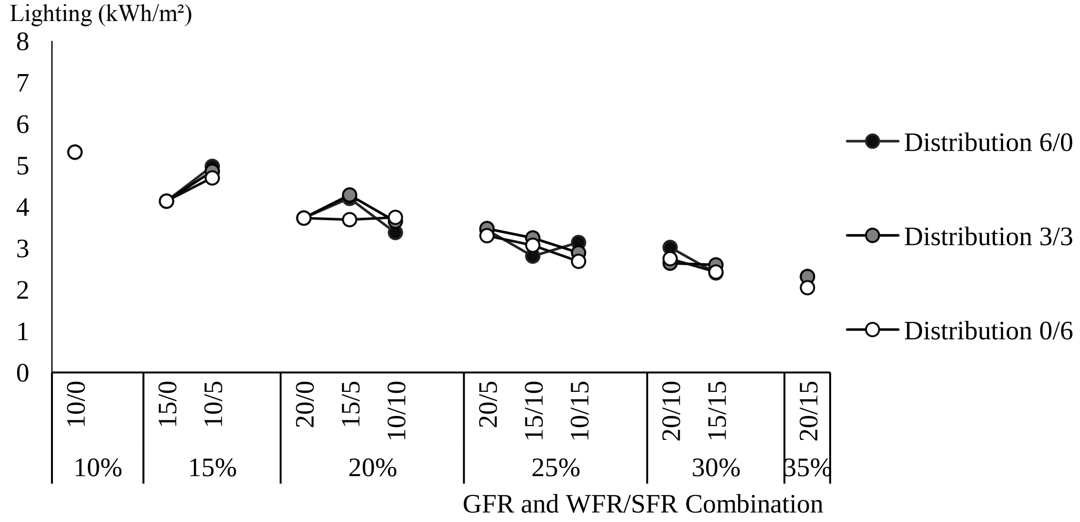


Figure 3-50: Lighting demand for different GFRs, WFR/SFR combinations and three distributions, for 30° roof tilt, east orientation and typical construction.

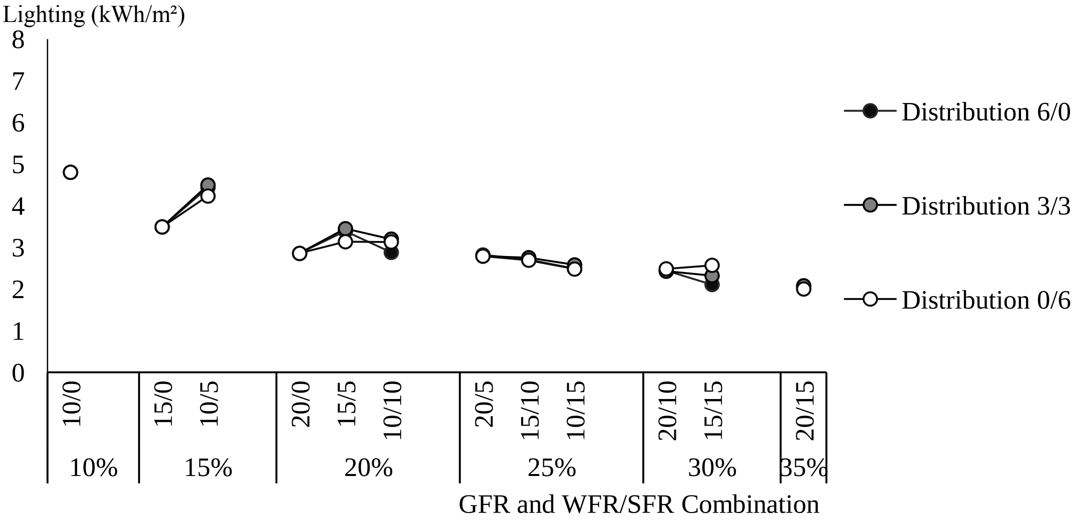


Figure 3-51: Lighting demand for different GFRs, WFR/SFR combinations and three distributions, for 30° roof tilt, south orientation and typical construction.

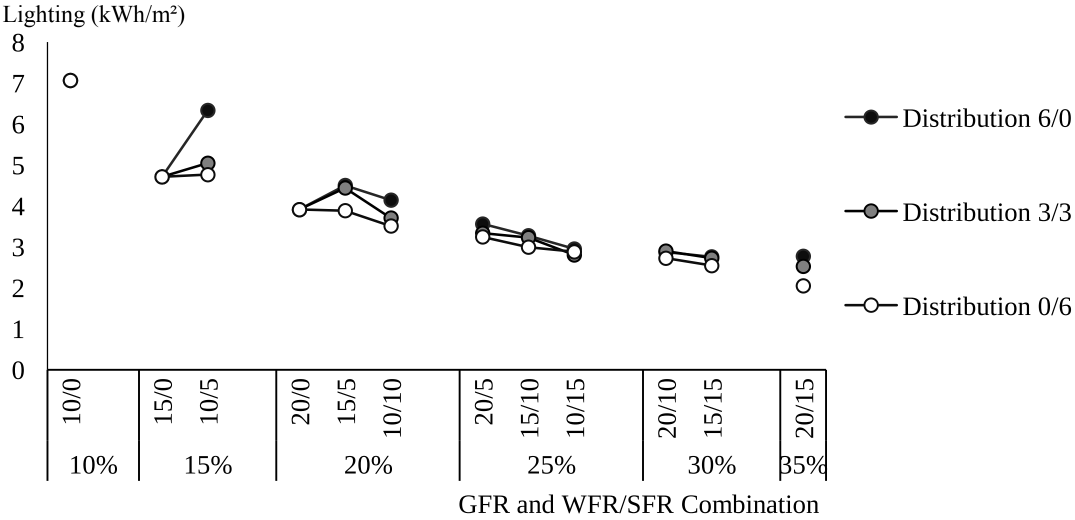


Figure 3-52: Lighting demand for different GFRs, WFR/SFR combinations and three distributions, for 30° roof tilt, west orientation and typical construction.

3.3.3 Overheating time

Figure 3-53 presents the frequency distribution of the calculated overheating time for all cases with skylights. The overheating time is defined as the percentage of operational time where the operative temperature inside the room is above 25°C. The relative time was used in order to assess whether the cases are close or exceed the 10% limit defined by the regulations. An overheating time of 10% corresponds to 151.2 hours annually. This figure shows that almost 50% of the cases, result in less than 2% overheating time (approximately 30 hours) and only 6% of the cases have 8 to 10% (120 to 151 hours), with just 1% above the 10% threshold.

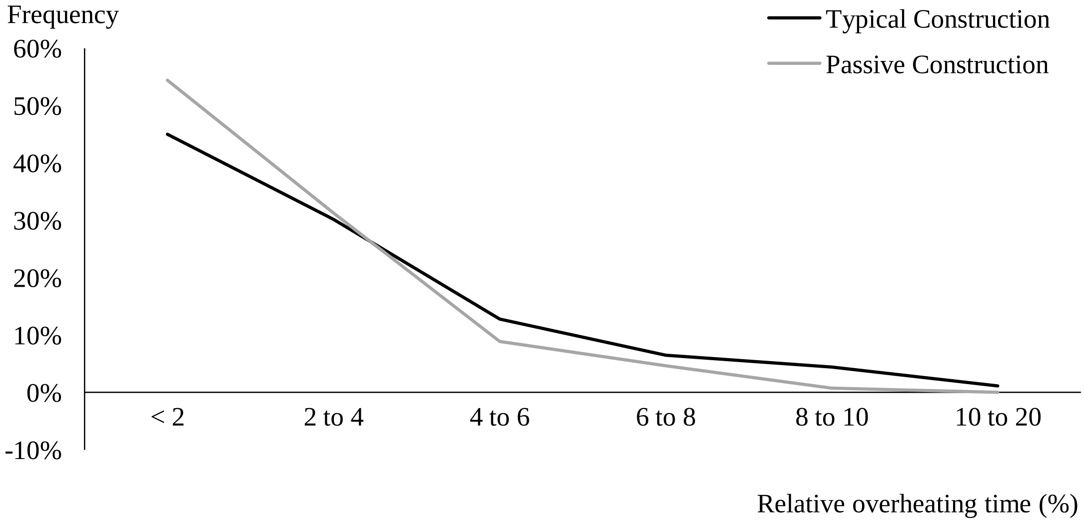


Figure 3-53: Frequency distribution of overheating time for both construction types.

Figure 3-54 presents the overheating time for three selected cases of GFR (minimum, medium, maximum) for all orientations, skylight distributions and construction types, for a 30° roof tilt. This figure shows that the overheating time is higher for the south orientation and for cases with higher GFR, and lower for the north orientation. Also the overheating time for the passive construction cases is almost always lower than for the typical ones.

Figure 3-55 presents the overheating time of a selected medium GFR case (WFR:15%, SFR:10%), for different roof tilts. This figure shows that the effect of skylight distribution on overheating is negligible. Figure 3-56 presents the overheating time for different GFRs, combinations of WFR/SFR and orientations, for 3/3 distribution, 30° roof tilt and typical construction. This figure shows that the overheating time diminishes when SFR increases at equivalent GFR cases, for all orientations except the north where it seems to not be affected or even to slightly increase when the skylight area towards the south increases.

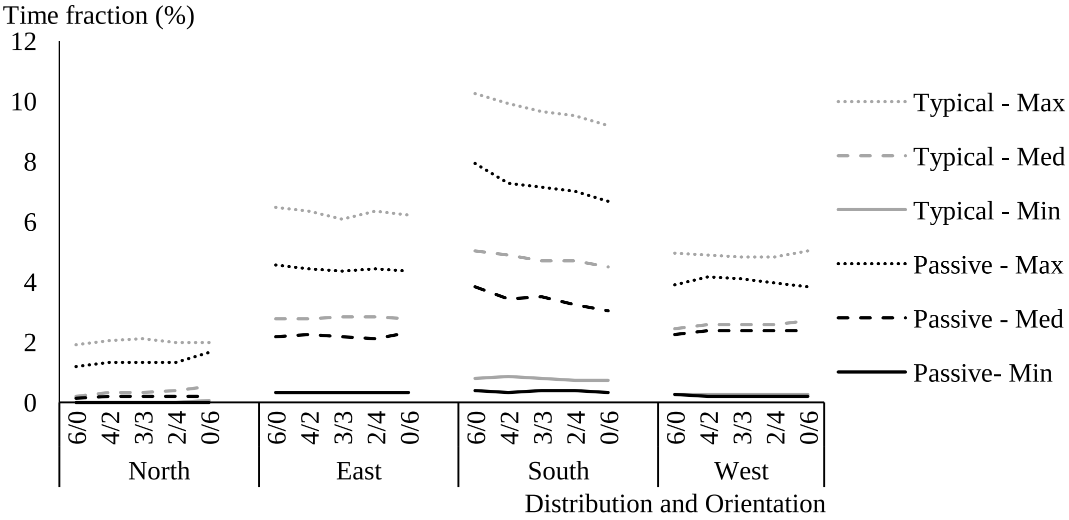


Figure 3-54: Overheating time for three selected GFR cases, for 30° roof tilt, all skylight distributions and construction types.

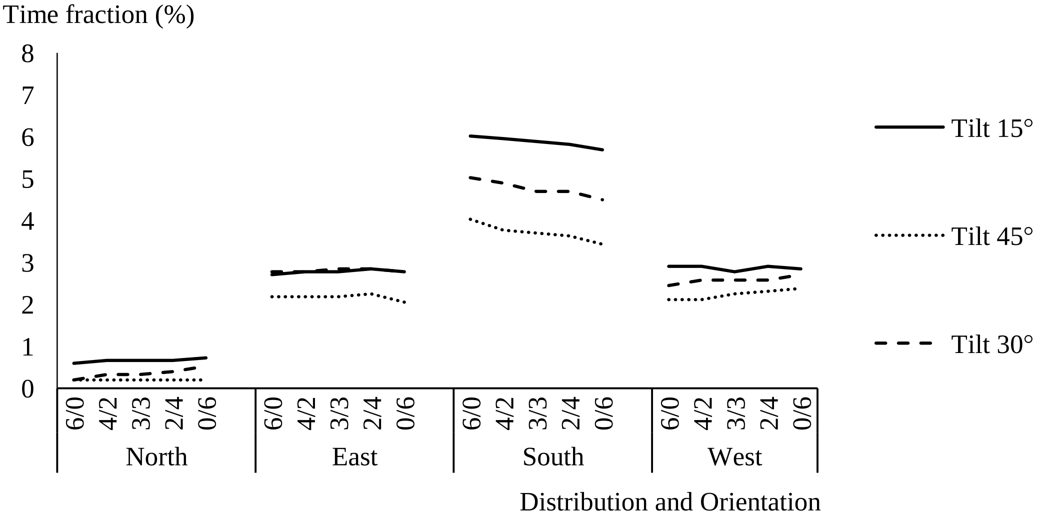


Figure 3-55: Overheating time for all skylight distributions, orientations and roof tilts, for a medium GFR case (WFR:15%, SFR:10%) and typical construction.

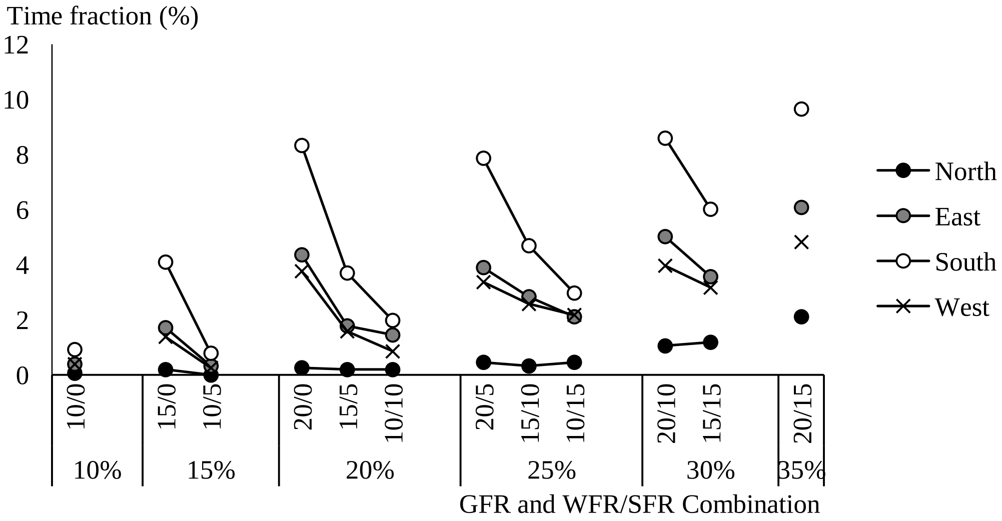


Figure 3-56: Overheating time for different GFRs, WFR/SFR combinations and different orientations, for 30° roof tilt, 3/3 skylight distribution and typical construction

Table 3-4 shows the impact of different passive cooling strategies, regarding shading and natural ventilation, on the overheating time (the percentage of operational time) and on the total overheating time (the percentage of annual time). Cases with more than 10% fraction are highlighted. This study was conducted for one case, in order to show that overheating issues occurring after school time or during summer time, can be dealt with. This study shows that the building can be used throughout the year, if specific measures are applied. Even if it is not used, high temperatures during summer that could damage the building or equipment can be resolved. The selected case has the maximum GFR possible (20% WFR, 15% SFR), with all openings oriented south, 30° roof tilt and typical construction. This case had one of the highest overheating time compared to the other simulated cases, with the default shading and natural ventilation option (bold values in Table 3-4). The operational overheating time and total overheating time decreases significantly when the selected passive cooling strategies are applied and even further with permanent shading on the windows during summer.

Table 3-4: Overheating time and total overheating time for a typical construction case, for different combinations of passive cooling strategies.

Shading option	No shading	Skylight exterior shading (all year)				Additionalw indow ext. shading (summer)
Natural Ventilation option	No natural ventilation		Natural Ventilation (operational time)	Additional night ventilation (00:00-3:00)	Additional ventilation (19:00-21:00) (instead of night ventilation)	
Operative Temperature	Total Overheating time (Fraction of hours annually) (%)					
> 25°C	43.7%	36.4%	**27.5%**	22.1%	19.7%	9.6%
> 26°C	41.5%	32.0%	**23.3%**	16.9%	14.4%	4.6%
> 27°C	38.9%	28.9%	**19.4%**	12.6%	9.5%	2.0%
> 28°C	35.5%	25.1%	**17.0%**	9.2%	6.7%	0.9%
> 29°C	32.1%	21.0%	**15.2%**	6.0%	4.4%	0.2%
> 30°C	29.3%	17.5%	**13.8%**	3.8%	2.6%	0.0%
> 31°C	26.9%	13.0%	**10.9%**	2.1%	1.5%	0.0%
> 32°C	24.1%	9.3%	**8.2%**	1.0%	0.7%	0.0%
> 33°C	21.2%	6.2%	**5.6%**	0.5%	0.3%	0.0%
> 34°C	18.8%	3.9%	**3.5%**	0.2%	0.2%	0.0%
> 35°C	16.7%	2.2%	**2.1%**	0.0%	0.0%	0.0%
	Overheating time (Fraction of operational hours) (%)					
> 25°C	34.5%	25.7%	**10.3%**	8.5%	7.8%	7.4%

3.4 Secondary parameters

The following chapters present the results for the secondary parameters analysed for only specific cases, regarding both daylight and energy. These studies were conducted in order to assess the effect of specific parameters not included in the main study that were however, considered interesting to be investigated.

3.4.1 Skylight position

Table 3-5 shows how the positioning of skylights along the roofs length, affects the energy demand and daylight conditions for a south oriented case with 15% WFR, 10% SFR, 30° roof tilt and all skylights placed on the one roof side. Numbers ‘1’ to ‘6’ correspond to different skylight positioning as illustrated in Figure 2-5 and Figure 3-58 below. ‘1-3’ are different cases of 6/0 distribution and ‘4-6’ are different cases of 0/6 distribution. For ‘1’ and ‘6’ cases, the skylights are placed on the lower part of the roof. For ‘2’ and ‘5’ on the middle (default position) while for ‘3’ and ‘4’ cases on the upper part of the roof. The only significant difference is for the UR which is also presented in Figure 3-57. Figure 3-58 presents visualizations of the DF in a section along the skylights, for every case simulated, that better shows the effect of skylight position on the UR.

Table 3-5: Results of different skylight position for a typical construction case, oriented south, with 15% WFR and 10% SFR.

	Skylight distribution	Position	**Case Number**	DF (%)	UR (-)	Opt. Day-lit area (%)	DA (%)	Heating demand (kWh/m^2)	Lighting demand (kWh/m^2)
Tilt 15°	6/0	Lower Part	**1**	7.1	0.3	38.7	77.9	15.1	2.9
		Middle Part	**2**	7.3	0.3	31.9	80.0	15.0	2.9
		Upper Part	**3**	7.3	0.4	39.5	81.8	15.3	2.7
	0/6	Upper Part	**4**	7.3	0.4	58.4	81.4	16.0	2.7
		Middle Part	**5**	7.3	0.6	60.5	82.3	15.7	2.5
		Lower Part	**6**	7.2	0.5	62.6	82.5	16.0	2.1
Tilt 30°	6/0	Lower Part	**1**	6.7	0.3	34.4	78.0	16.0	2.9
		Middle Part	**2**	6.8	0.4	32.3	80.4	16.0	2.7
		Upper Part	**3**	6.6	0.5	44.0	81.0	16.3	2.6
	0/6	Upper Part	**4**	6.5	0.3	61.8	78.3	17.2	2.9
		Middle Part	**5**	6.7	0.5	62.1	80.3	17.0	2.7
		Lower Part	**6**	6.8	0.6	62.5	81.4	17.0	2.6
Tilt 45°	6/0	Lower Part	**1**	6.2	0.3	36.1	78.6	18.0	2.7
		Middle Part	**2**	5.9	0.4	36.2	79.3	18.0	2.7
		Upper Part	**3**	5.7	0.5	52.0	79.1	18.3	2.7
	0/6	Upper Part	**4**	5.6	0.3	62.3	75.3	19.4	2.1
		Middle Part	**5**	5.9	0.4	62.3	76.1	19.1	3.3
		Lower Part	**6**	6.2	0.6	62.7	79.6	19.3	2.6

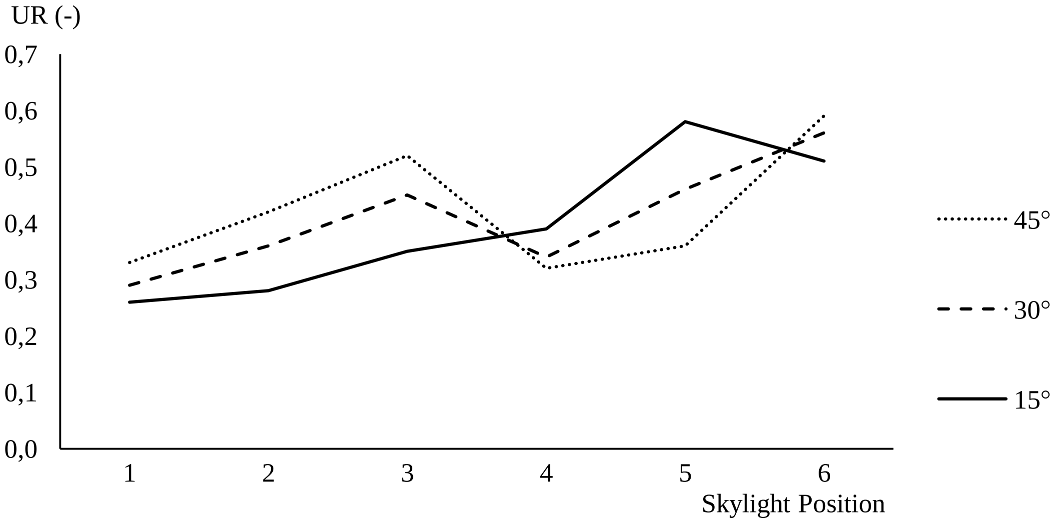


Figure 3-57: DF uniformity ratio for a selected south oriented case with 15% WFR, 10% SFR, for all roof tilts, skylight position and typical construction.

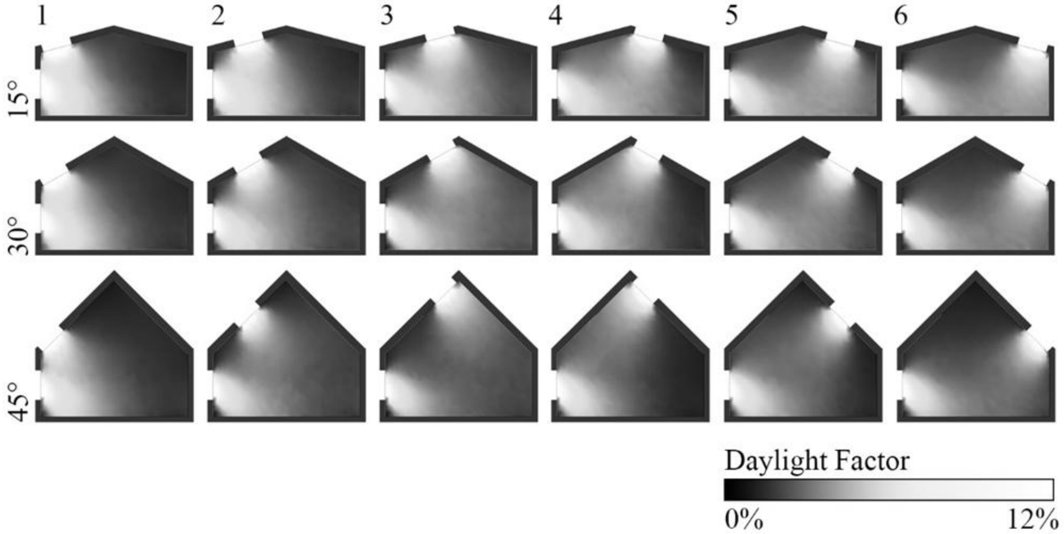


Figure 3-58: Sections of DF for a selected south oriented case with 15% WFR, 10% SFR, for all roof tilts, skylight position and typical construction.

3.4.2 Amount of skylights

Table 3-6 shows how the selection of different skylight size and thus amount of skylights (in order to result in the same SFR), affects the energy and daylight conditions. The results refer to a typical construction case with medium GFR (15% WFR, 10% SFR), 30° roof tilt, 3/3 distribution, oriented south. The results in the table show that heating demand increases when more skylights are used while overheating time decreases. Moreover, DF and DA decrease while ODA increases.

Table 3-6: Results for different skylight amount and size, for a typical construction case with 15% WFR, 10% SFR, 30° roof tilt, 3/3 distribution, oriented south .

Amount of skylights (width x height)	4 (1,14 x 1,40)	6 (0,78 x 1,40)	8 (0,66 x 1,18)
Heating demand (kWh/m^2)	16.0	16.5	16.6
Lighting demand (kWh/m^2)	2.7	2.8	2.8
Overheating time (%)	5.0	4.7	4.6
Daylight factor (%)	7.4	6.8	6.1
Uniformity ratio (-)	0.38	0.38	0.39
Daylight autonomy (%)	81.9	80.4	78.1
Optimally day-lit area (%)	42.2	51.6	53.7

3.5 Heating and lighting, end-use and primary energy

Figure 3-59 and Figure 3-60 present the frequency distribution for all cases with skylights, regarding the difference in annual heating and lighting energy demand, compared to their respective cases without skylights, for typical and passive construction respectively. The energy demand considering the end-use energy (where PEF is 1) and the primary energy demand according to two scenarios of PEF (2015 and 2020 prediction) are presented and can be compared (HPF stand for heating energy primary factor while EPF for electricity).

The figures show that the end-use energy is generally increasing when skylights are added for almost all cases. There are no cases for which the end-use demand is decreased with the integration of skylights for the typical construction, while for the passive construction, the percentage of cases where the end-use demand is decreased is only 3%. On the other hand, the primary energy demand is reduced for approximately 50% of the passive construction cases and 30% of the typical construction cases. The rest of the cases have a primary energy increase of 0 to 3 kWh/m^2, in contrast to the end-use energy increase that is 2 to 6 kWh/m^2 for the majority of the cases for both constructions.

Figure 3-61 presents the end-use and primary energy, with and without skylights, for a selected case with 30° roof tilt, 10% WFR, 15% SFR, 3/3 skylight distribution, oriented north, for typical and passive construction type. This figure shows that with the addition of skylights the end-use energy increases while the primary energy decreases due to the higher primary energy factor for electricity.

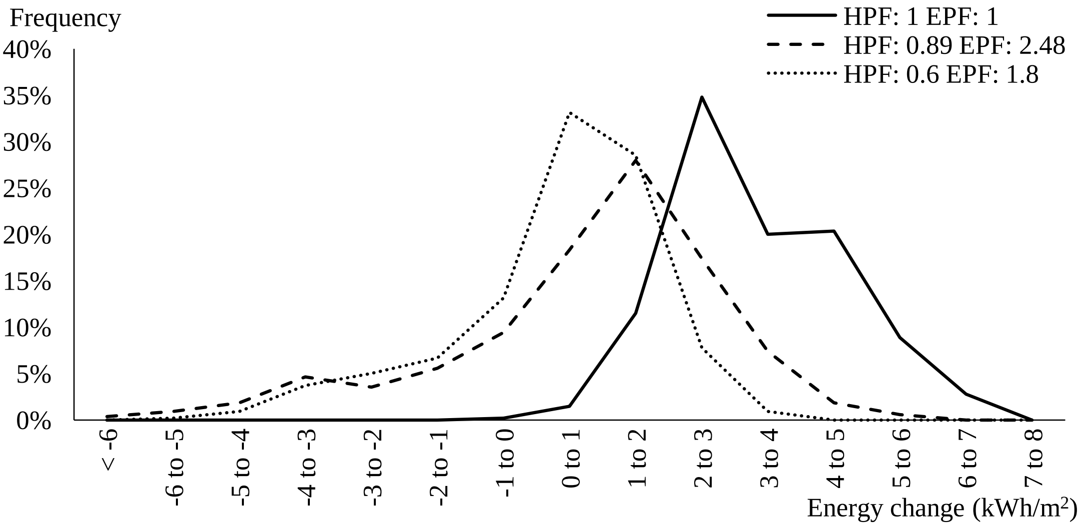


Figure 3-59: Frequency distribution (cases with skylights), regarding difference in energy demand, compared to the respective cases without skylights, for typical construction.

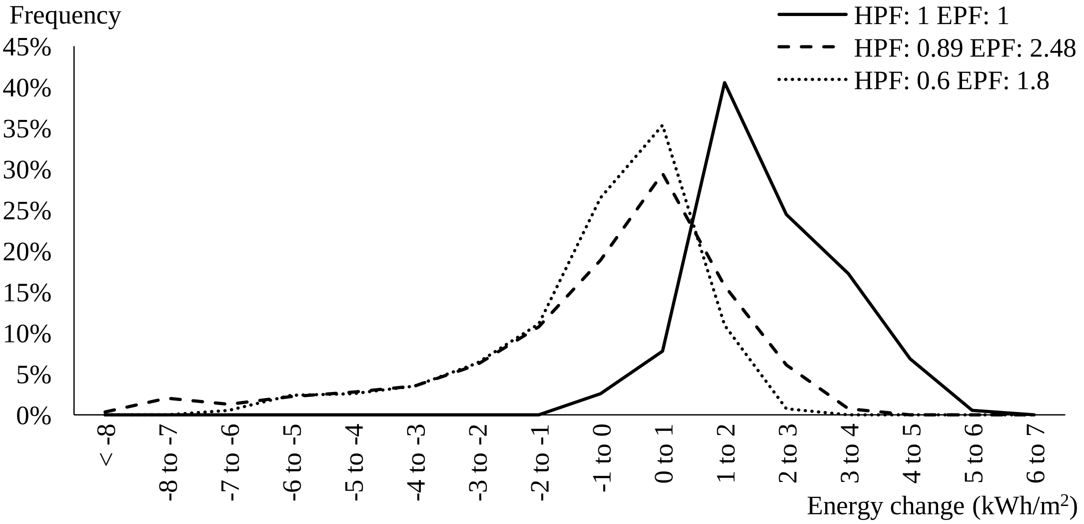


Figure 3-60: Frequency distribution (cases with skylights), regarding difference in energy demand, compared to the respective cases without skylights, for passive construction.

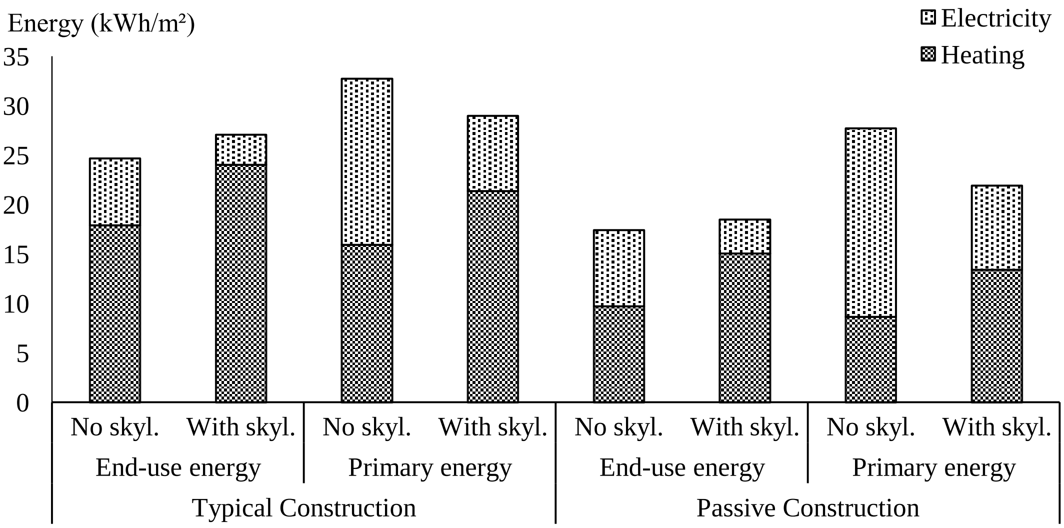


Figure 3-61: End-use and primary energy, with and without skylights, for a selected case, for typical and passive construction type.

Table 3-7 to Table 3-10 present the absolute difference for the end-use and primary energy demand (for the 2015 PEF) for all cases with skylights compared to the same configurations without skylights, for the typical and passive construction type respectively. The values are presented in a grey scale gradient where lighter values correspond to higher reduction in energy demand and darker ones to smaller reduction or increase in energy demand. These tables can be used as guides for the selection of optimal skylight placement regarding end-use or primary energy, especially for renovation cases.

Table 3-7: End-use energy demand difference (kWh/m²) for heating and lighting, compared to the respective cases without skylights, for typical construction.

WFR		10	10	10	15	15	15	20	20	20	10	10	10	15	15	15	20	20	20
SFR		5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
GFR		15	20	25	20	25	30	25	30	35	15	20	25	20	25	30	25	30	35
		North									East								
Tilt 45°	6/0	2	2	3	3	4	5	3	4	6	2	3	4	2	4	4	3	4	5
	4/2	1	2	2	2	3	4	2	4	5	3	3	4	2	4	4	3	4	6
	3/3	1	1	2	2	3	3	2	3	4	3	3	4	2	4	5	3	4	6
	2/4	1	1	1	2	3	3	2	3	4	3	3	4	2	4	5	3	4	6
	0/6	0	0	0	2	2	2	2	2	3	3	3	4	2	4	5	3	4	6
Tilt 30°	6/0	2	3	4	3	4	5	3	5	6	3	3	4	3	4	5	3	4	6
	4/2	2	2	3	2	3	4	3	4	5	2	3	4	3	4	5	3	4	6
	3/3	1	2	2	2	3	4	3	4	5	2	3	4	3	4	5	3	4	6
	2/4	1	1	2	2	2	3	2	3	4	2	3	4	3	4	5	2	4	6
	0/6	1	1	1	1	2	2	2	3	3	2	3	4	3	4	5	2	4	6
Tilt 15°	6/0	2	3	4	2	4	5	2	4	6	3	4	5	3	4	5	3	5	6
	4/2	2	3	3	2	3	4	2	4	5	2	3	4	3	4	5	3	5	6
	3/3	2	2	2	2	3	4	2	3	4	2	3	4	3	4	5	3	4	6
	2/4	1	1	2	2	2	3	2	3	4	2	3	4	2	4	5	3	4	6
	0/6	1	1	1	1	2	2	2	2	3	2	3	4	2	3	4	2	4	5
		South									West								
Tilt 45°	6/0	2	2	3	2	3	4	2	4	5	1	2	2	2	3	4	3	4	5
	4/2	2	3	4	2	3	4	2	4	6	1	2	3	2	3	4	3	4	6
	3/3	2	3	4	2	3	5	2	4	6	2	2	3	2	4	4	3	4	6
	2/4	2	3	4	3	4	5	3	4	6	2	2	3	2	4	4	3	4	6
	0/6	3	4	6	3	4	6	3	5	7	2	2	3	3	4	4	3	5	6
Tilt 30°	6/0	2	2	3	2	3	4	2	4	6	2	2	3	3	4	5	3	4	6
	4/2	2	3	4	2	4	5	2	4	6	1	2	3	2	4	5	2	4	6
	3/3	2	3	4	3	4	5	2	4	6	1	2	2	3	4	5	2	4	6
	2/4	2	3	5	3	4	6	3	5	6	1	2	3	2	3	5	2	4	6
	0/6	2	4	5	3	4	6	3	5	7	1	2	2	2	3	5	2	4	5
Tilt 15°	6/0	2	3	4	2	3	5	2	4	6	2	3	4	2	4	5	3	4	6
	4/2	3	3	5	2	4	5	2	4	6	2	3	3	2	4	5	3	4	6
	3/3	3	4	5	2	4	5	2	4	6	2	3	3	2	3	4	2	4	5
	2/4	3	3	5	2	4	5	2	5	6	1	2	3	2	3	4	2	4	5
	0/6	2	3	5	2	4	5	2	4	6	1	2	3	2	3	4	2	4	5

Table 3-8: Primary energy demand difference (kWh/m²) for heating and lighting (HPF: 0.89, EPF: 2.48), compared to the respective cases without skylights, for typical construction.

WFR		10	10	10	15	15	15	20	20	20	10	10	10	15	15	15	20	20	20
SFR		5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
GFR		15	20	25	20	25	30	25	30	35	15	20	25	20	25	30	25	30	35
		North									East								
Tilt 45°	6/0	-1	-4	-4	2	1	1	2	2	3	1	0	-1	2	1	0	2	2	2
	4/2	-1	-4	-5	1	0	0	1	1	2	2	0	1	1	1	1	2	3	3
	3/3	-1	-4	-5	1	0	-1	1	1	1	2	1	0	1	2	1	2	2	3
	2/4	-2	-5	-6	0	0	-1	1	1	0	2	0	1	1	2	1	2	3	3
	0/6	-3	-6	-7	0	-2	-2	1	0	0	2	1	1	1	2	2	2	3	4
Tilt 30°	6/0	0	-1	-2	2	0	1	2	4	4	2	0	0	3	1	2	2	3	3
	4/2	2	-3	-4	1	1	0	3	3	3	1	0	0	2	2	2	2	3	3
	3/3	-1	-4	-4	0	-1	-1	3	2	3	1	0	0	3	2	2	2	2	3
	2/4	-2	-4	-5	0	-1	-2	2	2	2	1	0	0	3	2	2	1	2	3
	0/6	-2	-5	-6	-1	-2	-3	2	1	0	1	0	-1	2	2	2	2	2	2
Tilt 15°	6/0	1	0	-1	2	1	1	2	3	3	2	1	1	2	3	3	2	3	4
	4/2	0	-1	-3	1	0	0	2	2	2	1	1	0	2	2	3	2	3	3
	3/3	1	-2	-4	1	0	-1	1	1	1	1	0	0	2	1	1	2	2	3
	2/4	-2	-4	-4	1	-1	-2	1	1	0	0	-1	-1	1	1	1	2	2	3
	0/6	-2	-5	-5	-1	-2	-4	0	0	-2	0	-2	-1	1	1	0	1	1	1
		South									West								
Tilt 45°	6/0	1	-1	-2	1	0	1	1	2	2	-1	-3	-5	1	1	0	3	2	3
	4/2	1	0	0	2	1	1	2	3	4	-2	-3	-4	1	1	1	3	4	4
	3/3	2	1	0	1	1	2	2	3	5	0	-3	-4	1	1	1	3	3	4
	2/4	2	1	0	2	1	2	2	3	5	-1	-3	-4	1	1	1	2	3	4
	0/6	2	1	3	3	3	3	2	4	5	-1	-3	-3	2	1	1	3	4	3
Tilt 30°	6/0	1	-1	-1	2	2	2	2	3	4	1	-3	-4	2	1	1	2	2	3
	4/2	1	0	0	2	2	3	2	4	5	-2	-3	-4	1	1	1	2	2	3
	3/3	2	0	0	2	2	3	2	3	4	-2	-4	-5	2	1	1	1	2	3
	2/4	1	0	1	2	3	3	2	4	4	-2	-4	-5	1	1	1	2	2	3
	0/6	1	1	1	2	3	4	2	4	5	-3	-4	-4	1	0	1	1	2	2
Tilt 15°	6/0	2	1	1	1	1	2	2	3	5	0	-1	-1	1	1	1	2	3	3
	4/2	2	1	1	1	1	2	2	3	5	0	-1	-2	1	1	1	2	2	3
	3/3	2	2	1	1	1	2	2	3	4	0	-2	-3	0	0	0	1	1	1
	2/4	2	0	1	1	1	1	2	3	4	-2	-2	-4	1	0	-1	1	1	1
	0/6	0	0	1	0	1	0	2	2	3	-1	-4	-3	1	-1	-2	0	1	0

Table 3-9: End-use energy demand difference (kWh/m²) for heating and lighting, compared to the respective cases without skylights, for passive construction.

	WFR	10	10	10	15	15	15	20	20	20	10	10	10	15	15	15	20	20	20
	SFR	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
	GFR	15	20	25	20	25	30	25	30	35	15	20	25	20	25	30	25	30	35
		North									East								
Tilt 45°	6/0	0	1	2	2	3	4	2	3	4	1	2	3	2	3	3	2	3	4
	4/2	1	0	1	1	2	3	2	2	3	2	2	3	2	3	4	2	3	4
	3/3	0	0	0	1	2	2	2	2	3	2	2	3	2	3	4	2	3	4
	2/4	0	0	0	1	1	2	1	2	3	2	2	3	2	3	4	2	3	5
	0/6	0	-1	-1	1	1	1	1	2	2	2	2	3	1	3	4	2	3	5
Tilt 30°	6/0	1	2	2	2	3	4	2	3	4	1	2	3	2	3	4	2	3	5
	4/2	1	1	1	1	2	3	2	3	4	1	2	3	2	3	4	2	4	5
	3/3	1	1	1	1	2	2	2	2	3	1	2	3	2	3	4	2	4	5
	2/4	1	0	1	1	1	2	1	2	3	2	2	3	1	3	4	2	3	5
	0/6	0	-1	0	0	1	1	1	2	2	2	2	3	1	3	3	2	3	5
Tilt 15°	6/0	1	2	2	2	3	4	2	3	4	2	3	4	2	3	4	2	4	5
	4/2	1	1	1	2	2	3	1	3	4	2	2	3	2	3	4	2	3	5
	3/3	1	0	1	1	3	3	1	2	3	1	2	3	2	3	4	2	3	5
	2/4	0	0	1	1	2	3	1	2	3	1	2	3	1	3	4	2	3	4
	0/6	-1	-1	0	1	1	2	1	2	2	1	2	3	1	2	3	2	3	4
		South									West								
Tilt 45°	6/0	1	1	1	1	1	2	1	2	3	1	1	1	1	2	2	2	2	4
	4/2	1	2	2	1	2	3	1	2	4	1	1	1	1	2	3	2	3	4
	3/3	2	2	2	1	2	3	1	3	4	2	1	2	1	2	3	2	3	4
	2/4	2	2	3	1	2	3	1	3	4	1	1	2	1	2	3	1	3	4
	0/6	2	3	3	1	3	4	1	3	5	1	1	2	1	2	3	2	3	4
Tilt 30°	6/0	1	1	1	1	2	3	1	3	4	1	1	2	2	3	3	2	3	4
	4/2	1	2	2	2	2	3	1	3	4	2	1	2	2	2	4	2	3	4
	3/3	1	1	2	2	3	4	2	3	5	1	1	2	2	3	4	1	3	4
	2/4	1	1	2	2	2	4	2	3	5	2	1	2	2	3	4	2	3	4
	0/6	1	2	3	2	3	4	2	3	5	1	1	2	2	3	3	1	3	4
Tilt 15°	6/0	2	3	3	2	2	4	2	3	5	1	1	2	2	3	4	2	3	5
	4/2	1	3	3	2	3	4	2	3	5	1	1	2	1	3	4	2	3	4
	3/3	1	2	3	2	3	4	2	3	5	1	1	1	1	2	3	2	3	4
	2/4	1	2	3	2	3	4	2	3	5	0	0	1	1	2	3	1	3	4
	0/6	1	2	3	1	3	4	2	3	5	0	0	1	1	2	2	1	3	4

Table 3-10: Primary energy demand difference (kWh/m²) for heating and lighting (HPF: 0.89, EPF: 2.48), compared to the respective cases without skylights, for passive construction.

	WFR	10	10	10	15	15	15	20	20	20	10	10	10	15	15	15	20	20	20
	SFR	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15	5	10	15
	GFR	15	20	25	20	25	30	25	30	35	15	20	25	20	25	30	25	30	35
		North									East								
Tilt 45°	6/0	-3	-5	-6	0	0	-1	1	1	1	0	-1	-2	1	0	-1	1	1	2
	4/2	-2	-6	-8	-1	0	-2	1	0	0	1	0	0	1	1	1	1	2	2
	3/3	-3	-6	-8	0	-2	-2	1	0	0	2	-1	-2	1	0	1	1	2	2
	2/4	-2	-6	-9	-1	-2	-2	0	-1	-1	1	0	0	0	0	1	1	2	2
	0/6	-4	-7	-9	-1	-2	-3	-1	0	-2	2	0	-1	0	1	2	2	2	3
Tilt 30°	6/0	0	-2	-4	0	0	0	1	1	2	0	-1	-1	2	0	1	2	2	3
	4/2	0	-3	-5	-1	-1	-2	1	0	1	0	0	-2	1	0	1	2	3	3
	3/3	0	-4	-6	-1	-2	-2	1	0	0	0	-1	-1	1	1	0	2	3	3
	2/4	1	-5	-6	-1	-2	-3	1	0	-1	2	-1	-2	0	0	0	3	2	2
	0/6	-4	-7	-8	-2	-3	-4	1	-1	-1	1	-1	-2	0	1	0	2	2	3
Tilt 15°	6/0	0	-2	-4	2	2	1	1	2	2	1	1	1	1	1	2	0	2	3
	4/2	-1	-4	-6	1	0	0	1	1	1	0	-1	-1	1	2	1	1	1	3
	3/3	-1	-5	-7	0	1	-1	1	0	0	0	-1	-2	1	0	0	1	1	2
	2/4	-3	-7	-8	0	-1	-2	0	0	0	0	-1	-2	0	0	0	0	1	1
	0/6	-6	-8	-7	0	-2	-3	0	-2	-3	-1	-2	-2	0	-1	-2	0	0	0
		South									West								
Tilt 45°	6/0	-1	-3	-4	0	-2	-2	0	0	0	0	-3	-6	-1	-1	-2	1	0	1
	4/2	0	-1	-2	0	-1	-1	0	0	1	0	-3	-5	0	-1	-1	1	1	1
	3/3	1	-1	-2	0	-1	-1	0	1	2	1	-4	-4	-1	-1	-1	1	1	1
	2/4	1	-1	-2	0	-1	0	0	1	2	0	-3	-4	0	-2	-1	0	1	1
	0/6	1	0	-1	0	0	1	0	1	3	0	-3	-4	0	-1	-1	1	1	1
Tilt 30°	6/0	0	-3	-4	1	0	0	1	1	2	0	-3	-4	1	1	0	1	1	1
	4/2	-1	-1	-3	1	0	1	1	2	3	1	-3	-4	1	0	0	1	1	1
	3/3	-1	-3	-3	1	1	1	1	2	3	0	-3	-4	1	0	1	0	1	2
	2/4	-1	-3	-3	1	0	1	1	2	3	1	-3	-4	1	1	0	1	0	0
	0/6	-1	-2	-2	2	1	1	1	2	3	-2	-3	-5	1	1	0	0	0	1
Tilt 15°	6/0	2	1	-1	2	1	2	1	2	3	0	-3	-3	0	0	1	1	2	3
	4/2	0	1	-1	2	1	1	1	2	3	-2	-4	-5	0	0	0	1	1	1
	3/3	0	-1	-1	2	1	1	1	2	3	-1	-5	-7	0	-1	-1	1	1	1
	2/4	0	-1	-2	1	0	0	1	2	3	-4	-7	-7	0	-1	-2	0	0	0
	0/6	0	-1	-1	0	0	1	1	2	2	-5	-7	-7	-1	-2	-3	0	-1	-1

3.6 Daylight conditions and energy use combined

Table 3-11 and Table 3-12 present the annual end-use energy demand for heating and lighting in kWh/m^2, for typical and passive construction respectively, in combination with various other factors regarding daylight, thermal and visual comfort. These factors are relative overheating hours, daylight/BREEAM classification and percentage of optimally day-lit area (ODA). In the table, cases with overheating time above 10% of the operational time, are marked with a strikethrough, cases with white gradient meet BREEAM's exemplary level and "black-coloured font" cases have ODA above 50%. The ODA threshold derived from the correlation found between ODA, DF and DA, which shows that cases with ODA above 50% have generally high DF and DA. In Table 3-12, the cases where heating demand is above 15kWh/m^2 are also marked with red borderline, since these cases do not meet the Passivhaus criteria. The white cells with black letters, and lower values, are considered to be optimal. These tables can help identify a range of optimal skylight solutions for every orientation, GFR ratio and roof tilt, and they can probably be used as guidelines for the early design phase of a classroom/school.

Table 3-11: Typical construction - end-use energy demand for heating and lighting per square meter.

Values	Annual Energy Demand (kWh/m^2)	■	No Daylight Certified
~~Striked~~	Overheating Time > 10%	▨	BREEAM First Credit
Red	Optimally Day-lit Area < 50%	No fill	BREEAM Exemplary Level

	WFR	10	15	10	20	15	10	20	15	10	20	15	20	10	15	10	20	15	10	20	15	10	20	15	20
	SFR	0	0	5	0	5	10	5	10	15	10	15	15	0	0	5	0	5	10	5	10	15	10	15	15
	GFR	10	15	15	20	20	20	25	25	25	30	30	35	10	15	15	20	20	20	25	25	25	30	30	35
		North												East											
Tilt 45°	6/0	28	28	30	28	30	30	31	31	31	32	32	34	24	24	26	25	27	27	27	28	28	29	29	30
	4/2	28	28	29	28	30	30	31	31	30	32	31	33	24	24	27	25	27	27	27	28	28	29	29	30
	3/3	28	28	29	28	30	29	31	30	30	32	31	32	24	24	27	25	27	28	27	28	28	29	29	30
	2/4	28	28	29	28	29	29	31	30	29	31	31	32	24	24	27	25	27	27	27	28	28	29	29	30
	0/6	28	28	28	28	29	28	30	29	28	31	29	31	24	24	27	25	27	28	27	28	28	29	29	30
Tilt 30°	6/0	25	25	27	25	27	28	28	28	28	30	30	31	22	21	24	22	24	25	24	25	26	26	26	28
	4/2	25	25	27	25	27	27	28	28	27	29	29	30	22	21	24	22	24	25	25	25	26	26	26	28
	3/3	25	25	26	25	27	26	28	28	27	29	28	30	22	21	24	22	24	25	24	25	26	26	26	28
	2/4	25	25	26	25	27	26	27	27	27	29	28	29	22	21	24	22	24	24	24	25	26	26	26	28
	0/6	25	25	26	25	26	25	27	27	26	28	27	28	22	21	24	22	24	25	24	25	25	26	26	27
Tilt 15°	6/0	23	23	25	24	26	26	26	27	27	28	28	30	20	20	23	20	23	24	23	24	25	25	25	26
	4/2	23	23	25	24	26	25	26	26	26	28	27	29	20	20	22	20	22	23	23	24	24	25	25	26
	3/3	23	23	25	24	25	25	26	26	25	27	27	28	20	20	22	20	22	23	23	24	24	25	25	26
	2/4	23	23	24	24	25	24	26	26	25	27	26	28	20	20	22	20	22	23	23	24	24	25	25	26
	0/6	23	23	24	24	24	24	26	25	24	26	25	27	20	20	22	20	22	23	23	23	24	24	24	25
		South												West											
Tilt 45°	6/0	20	18	21	17	20	22	19	21	22	20	22	22	25	24	27	24	27	28	27	28	28	28	28	29
	4/2	20	18	22	17	21	22	19	21	23	21	22	23	25	24	27	24	27	27	27	28	28	29	29	30
	3/3	20	18	22	17	20	23	19	21	24	21	23	23	25	24	27	24	27	27	27	28	28	28	29	30
	2/4	20	18	22	17	21	23	19	22	24	21	23	23	25	24	27	24	27	27	27	28	28	28	29	30
	0/6	20	18	22	17	21	23	19	22	25	22	24	24	25	24	27	24	27	27	27	28	28	29	29	30
Tilt 30°	6/0	17	15	19	14	18	19	17	19	20	19	20	~~20~~	23	22	25	22	24	25	24	25	25	26	26	27
	4/2	17	15	19	14	18	20	17	19	21	19	21	21	23	22	24	22	24	25	24	25	26	26	26	27
	3/3	17	15	19	14	18	20	17	19	21	19	21	21	23	22	24	22	24	25	24	25	25	26	26	27
	2/4	17	15	19	14	18	20	17	19	22	19	21	21	23	22	24	22	24	24	24	25	25	26	26	27
	0/6	17	15	19	14	18	21	17	20	22	19	22	21	23	22	24	22	24	24	24	25	25	26	26	27
Tilt 15°	6/0	16	15	18	13	17	19	16	18	20	18	19	~~20~~	21	20	23	20	23	24	23	24	24	25	25	26
	4/2	16	15	18	13	17	19	16	18	20	18	20	~~20~~	21	20	22	20	23	23	23	24	24	25	25	26
	3/3	16	15	18	13	17	19	16	18	20	18	20	~~20~~	21	20	23	20	22	23	23	23	24	24	25	26
	2/4	16	15	18	13	17	19	16	18	20	18	20	~~20~~	21	20	22	20	22	23	23	23	23	24	24	26
	0/6	16	15	18	13	16	19	16	18	20	18	19	~~20~~	21	20	22	20	22	23	22	23	23	24	24	25

Table 3-12: Passive construction - end-use energy demand for heating and lighting per square meter.

Values	Annual Energy Demand (kWh/m²)	▇	No Daylight Certified
☐	Heating Demand > 15 kWh/m²	▒	BREEAM First Credit
Red	Optimally Day-lit Area < 50%	No fill	BREEAM Exemplary Level

	WFR	10	15	10	20	15	10	20	15	10	20	15	20	10	15	10	20	15	10	20	15	10	20	15	20
	SFR	0	0	5	0	5	10	5	10	15	10	15	15	0	0	5	0	5	10	5	10	15	10	15	15
	GFR	10	15	15	20	20	20	25	25	25	30	30	35	10	15	15	20	20	20	25	25	25	30	30	35
		North												East											
Tilt 45°	6/0	20	19	20	20	20	21	22	22	21	23	22	24	16	16	18	17	18	18	18	19	19	20	20	21
	4/2	20	19	20	20	20	20	22	21	20	22	22	23	16	16	18	17	18	19	18	19	19	20	20	21
	3/3	20	19	20	20	20	20	21	21	20	22	21	23	16	16	18	17	18	18	19	19	19	20	20	21
	2/4	20	19	20	20	20	20	21	20	19	22	21	23	16	16	18	17	18	19	19	19	19	20	20	21
	0/6	20	19	20	20	20	19	21	20	19	22	20	22	16	16	18	17	18	19	19	19	19	20	20	21
Tilt 30°	6/0	17	17	19	18	19	19	20	20	20	21	21	23	15	15	16	15	17	17	17	17	18	19	19	20
	4/2	17	17	19	18	18	19	20	20	19	21	20	22	15	15	16	15	16	17	17	18	18	19	19	20
	3/3	17	17	19	18	19	18	20	19	19	20	20	22	15	15	16	15	16	17	17	18	18	19	19	20
	2/4	17	17	19	18	18	18	20	19	18	20	19	21	15	15	17	15	16	17	17	17	18	18	19	20
	0/6	17	17	17	18	18	17	19	18	17	20	19	20	15	15	16	15	16	17	17	18	17	18	18	20
Tilt 15°	6/0	17	16	18	17	18	19	19	20	19	21	20	22	14	14	16	15	16	17	16	17	18	18	18	20
	4/2	17	16	18	17	18	18	19	19	18	20	20	21	14	14	16	15	16	16	16	17	17	18	18	20
	3/3	17	16	18	17	18	17	19	19	18	20	19	21	14	14	15	15	16	16	16	17	17	18	18	19
	2/4	17	16	17	17	18	17	19	18	17	19	19	20	14	14	15	15	15	16	16	17	17	18	18	19
	0/6	17	16	16	17	17	16	18	18	17	19	18	20	14	14	15	15	15	16	16	16	17	17	17	19
		South												West											
Tilt 45°	6/0	13	13	14	12	13	14	13	14	15	14	14	15	17	17	19	17	18	19	19	19	19	20	19	21
	4/2	13	13	15	12	14	15	13	14	15	14	15	16	17	17	19	17	18	19	19	19	19	20	20	21
	3/3	13	13	15	12	14	15	13	14	16	14	15	16	17	17	19	17	18	19	19	19	19	20	20	21
	2/4	13	13	15	12	14	16	13	15	16	15	16	16	17	17	19	17	18	19	18	19	19	20	20	21
	0/6	13	13	15	12	14	16	13	15	17	15	16	17	17	17	19	17	18	19	19	19	19	20	20	21
Tilt 30°	6/0	12	11	13	10	12	13	11	13	14	13	14	14	16	15	17	16	17	17	17	18	18	18	18	20
	4/2	12	11	13	10	12	14	12	13	14	13	14	15	16	15	17	16	17	17	17	17	18	19	18	20
	3/3	12	11	13	10	12	14	12	13	14	13	14	15	16	15	17	16	17	17	17	17	18	19	19	20
	2/4	12	11	13	10	12	14	12	13	15	13	15	15	16	15	18	16	17	17	17	17	18	18	18	20
	0/6	12	11	13	10	13	14	12	14	15	14	15	15	16	15	16	16	16	17	17	17	17	18	18	20
Tilt 15°	6/0	11	10	13	9	12	13	11	13	14	13	14	14	16	15	17	15	16	17	16	17	18	18	18	20
	4/2	11	10	12	9	12	14	11	13	14	13	14	14	16	15	16	15	16	16	17	17	17	18	18	19
	3/3	11	10	12	9	12	13	11	13	14	13	14	14	16	15	16	15	16	16	16	17	17	18	18	19
	2/4	11	10	12	9	12	13	11	13	14	13	14	14	16	15	15	15	16	16	16	17	17	18	18	19
	0/6	11	10	12	9	11	13	11	13	14	13	14	14	16	15	15	15	16	15	16	16	17	17	17	18

4 Discussion

In the following chapters, the impact of the studied parameters on the energy performance and daylight conditions of the classroom is analysed and discussed. Firstly, the impact of every studied parameter is discussed separately. Secondly, a discussion regarding overheating problems that may occur with the use of skylights is presented, followed by a discussion about the impact of skylights on the primary and end-use energy demand. The next chapter identifies the main parameters that positively affect the studied classroom in terms of daylight, energy use, visual and thermal comfort, and pursues which parameters can be generally applied. The relation of the optimally day-lit area (ODA) to other metrics used in this study, is analysed in the final chapter.

4.1 Impact of studied parameters on daylight and energy

4.1.1 Construction type

The two analysed construction types (typical and passive) have different glazing g-value and different visual transmittance (Tvis). Since the visual transmittance affects the daylight factor (DF) and daylight autonomy (DA) proportionally, the simulated DF and DA for the passive construction cases follow the same trend as the typical construction but with lower values.

Since the DF is proportionally changing for different window transmittances, the ratio between the average DF and minimum DF remains stable. Consequently the uniformity ratio (UR) is not affected by the glazing transmittance. The slight variations in UR are due to different roof and wall thicknesses of the two construction types. One significant result is that the lining thickness positively affects the UR due to the increased reflective area surrounding the glass that diffuses more light in the space.

Passive construction cases generally have higher optimally day-lit area (ODA) compared to the typical ones. This occurs because the lower transmittance results in smaller over-lit areas and thus larger day-lit areas. Another reason is that the deeper lining of the passive construction, blocks more sunlight and diffuses the light so that light patches yielding over-lit areas, are eliminated.

The two types of construction also have different thermal transmittances (U-values) and airtightness levels, resulting in less heating demand for the passive construction cases. However the passive solar heat gains for the passive construction, are less compared to the typical construction, due to the lower glazing g-value, resulting in less overheating time. The relative increase in heating demand for the passive construction cases with skylights, compared to their respective cases without skylights, is more compared to the relative increase for the typical construction. This shows that the addition of skylights has more relative effect for high insulated buildings than for standard building constructions. However the absolute increase in heating demand is more or less similar for both constructions and it depends mainly on the window and skylight orientation. On the other hand, the lower glazing transmittance of the passive construction type, blocks more daylight and thus results in more electrical energy use for lighting.

4.1.2 Roof tilt

The results indicate that lower roof tilts result in higher DF and DA which is explained by the fact that low roof tilts yield larger visible sky angle (light source) and less visible ground area compared to high roof tilts (see Figure 4-1). Illuminance is also highly dependent on the light source’s distance from the measuring plane as light rays are propagated in a more or less radial way from the glazing surface. At lower roof tilts, the skylights are located at lower height and thus closer to the analysis grid. Additionally the impact of the roof tilt on the DF is relatively greater for higher skylight-to-floor rations (SFRs), since more glazing area results in more daylight affected by the tilt.

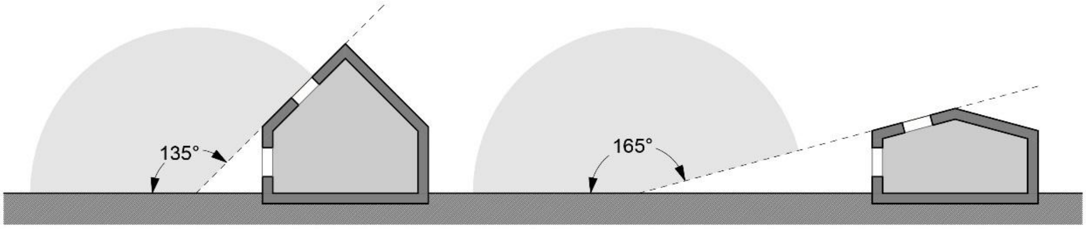


Figure 4-1: Difference in visible sky angle for 45° (left) and 15° (right) roof tilt.

The results also indicate that the roof tilt does not have the same effect on the uniformity ratio (UR) for same skylight distributions. Low roof tilts generally result in more daylight uniformity (higher UR values), when the skylights are placed on the opposite side of the windows. On the other hand, high roof tilts positively affect daylight uniformity when skylights are placed on the same side as the windows, since the back wall area is better day-lit in this case.

Cases with lower tilts also tend to have less under-lit areas but significantly more over-lit areas compared to cases with higher tilts, due to the fact that at low tilts the direct sunlight from the roof mainly reaches the floor and the task area, in contrast to high tilts where a large amount of direct light is reflected and diffused by the vertical walls. In general, higher roof tilts result in higher optimally day-lit area (ODA), for most of the cases, due to the less over-lit areas. However, a general conclusion cannot be drawn, since the ODA is highly dependent on orientation, skylight distribution and glazing-to-floor ratio.

Note that the volume of the classroom changes for every roof tilt. The cases with low roof tilts have less volume and as a consequence less amount of air needs to be heated. The heating demand is thus lower compared to high roof tilt cases. On the other hand, the overheating time is more for low roof tilt cases due to the smaller volume that is easily overheated. Although the ventilation rate is the same for all cases the solar gains and internal gains have a higher effect when the air volume is smaller. Moreover the electricity demand for lighting is smaller because of the daylight autonomy is higher for lower roof tilts.

4.1.3 Glazing-to-floor ratio

Generally, the daylight factor (DF) and the daylight autonomy (DA) increase when the total glazing-to-floor ratio (GFR) increases as expected, since more daylight is provided into the classroom. For equivalent GFR cases, the average DF and DA is usually increasing when more skylights are used rather than more windows. This is because skylights can provide more light at the back of the space and they also provide a larger visible sky angle compared to windows. In some cases with low skylight-to-floor ratio (5%), the average DF and DA slightly drops compared to the cases with only windows. This is a result of the reduced daylight that enters the room, due to the reduction of the actual glazing area and the increase of frame area (see Table 2-10). In reality there are almost always obstructions which may reduce even more the visible sky angle for windows and thus daylight access. In contrast, skylights’ visible angle is less affected by the surroundings. Therefore, the use of skylights can generally be considered a better solution than windows in terms of light access, average DF and DA.

The increase in GFR does not necessarily lead to an improvement in daylight uniformity. The results indicate that the uniformity metric is mostly affected by the skylight-to-floor ratio (SFR) since uniformity is more when the skylight area is increased, even if the total glazing area (windows and skylights) remains the same. Another general observation, is that more skylights result in more over-lit area and less under-lit area.

The results further indicate that the annual daylight glare probability (ADGP) increases when the SFR is increased for equivalent cases of GFR. This is probably because during spring and summer time, where most days are sunny, the solar altitude is high and sun patches are mostly created from the skylights rather than the windows. The only cases where the ADGP is reduced with the increase of skylight area is for the south orientation when more than half of the skylights are placed towards the north.

Higher GFR also leads to higher heating demand since the heat losses through the glazing areas are increased. For equivalent GFR cases, the heating demand also increases as more skylights are used. This is partly because the thermal transmittance (U-value) of the skylights is higher compared to the windows due to the roof tilt. In addition, when windows and skylights are used together, the frame area and length is increased and thus the heat losses through thermal bridges at the connections between wall/roof and openings, are also increased, while the solar gains are reduced (because the glazing area is decreased). On the other hand the electrical demand for lighting is decreasing for higher GFR and SFR.

The overheating time is increasing with higher GFRs due to the increased solar heat gains. However, for equivalent GFR, the overheating time decreases as the SFR increases. This is because natural ventilation through convection is enhanced when skylights are added, and the hot air at the top of the room can be released. Another reason is that skylights are automatically externally shaded when solar irradiation is high and thus unnecessary solar heat gains can be blocked. In this study, windows are not shaded since it is assumed that the vertical shading that can block the view out should be controlled by the pupils. Also the use of internal shades for glare control does not affect overheating significantly.

4.1.4 Distribution and orientation

The results indicate that the average DF is independent of skylight distribution. This is due to the fact that all skylights have the same area and visible sky angle, and the light source is the CIE overcast sky. Consequently, the total amount of daylight entering the room is the same, despite the possible differences in light distribution. The light uniformity is affected by the distribution as it was explained before in the section about tilt angle. However, the highest uniformity is obtained when skylights are placed on the opposite side of the windows, and for the 15° roof tilt. This is because the DF near the windows is always higher than the rest of the room. In this case (15° roof tilt and opposite side skylight distribution), the skylights provide the higher amount of light in the back of the room thereby improving uniformity.

Daylight autonomy (DA) is higher when the windows are oriented towards the south, as expected. West and east orientations result in similar values of DA. North orientated cases result in the lowest DA, except for the 0/6 skylight distribution case (all skylights oriented south). In almost all cases, the DA is higher when skylights are placed on the opposite side of the windows (0/6 distribution), because more light enters the back space. For low roof tilts (15°), this applies even if the skylights are oriented towards the north, because the low roof tilt allows the southern sunlight to enter the room at high solar altitudes. The only exception is for the south orientation and 45° roof tilts, where the skylights are better to be placed on the window side. The lighting demand depends on the DA and thus follows the same principles.

When windows are oriented towards the south, the over-lit area is higher and the under-lit area is lower. In contrast, with north oriented windows, the over-lit area is reduced and the under-lit area is increased. In most of the cases, the percentage of the over-lit area is higher with the 6/0 distribution (skylights next to windows) because a large amount of light is concentrated in the front half area of the room, while it is lower for the 0/6 distribution because the light is better distributed to the back part of the room and the over-lit areas are minimized. The only exception is for the north orientated window cases, where the over-lit area is increasing for 0/6 skylight distribution because the skylights are placed towards the south so more direct light enters the room. In general it is impossible to eliminate the over-lit areas completely, unless all openings are oriented towards the north. In general, the highest percentage (above 90%) of optimally daylight area (ODA) is observed for cases where all openings (windows and skylights) are oriented towards the north and for 45° roof tilt cases. Cases with the windows oriented towards other orientations rarely exceed 80% of ODA.

Generally, windows are an important source of glare at low solar altitudes and skylights at high solar altitudes. Thus, the highest annual daylight glare probability (ADGP) is observed for cases where all openings are oriented towards the south. East oriented cases have also high ADGP, since windows create extended patches during morning hours. North oriented cases have higher ADGP when all or part of the skylights are oriented towards the south since sun patches through the skylights are penetrating the space. However, the time where glare is present is significantly shorter than for south oriented cases since problems occur only at very high solar altitudes during summer time. West oriented cases result in the lowest values of ADGP due to the occupancy times.

Skylight distribution also has a significant impact on ADGP. For south orientated cases, glare probability is reduced when skylights are placed towards the north since sunlight is avoided during summer time. Similarly, for north oriented cases, ADGP is minimized when all openings face towards the north and it is maximized when skylights face south. East oriented cases result in the maximum ADGP when skylights are equally distributed on both roof slopes, because sun patches are present during the whole day.

The south oriented cases result in the lowest heating demand due to the higher passive solar heat gains. In addition, south oriented skylights exploit solar heat gains optimally and can thus reduce the heating demand especially for cases with north oriented windows. On the other hand, for south oriented windows, south facing skylights may lead to thermal or visual discomfort, especially if the glazing-to-floor ratio is high. For east and west oriented windows, the position of the skylights does not significantly affect the heating demand.

4.1.5 Skylight position

The results indicate that the skylight position has a negligible effect on the average daylight factor. On the other hand, the light uniformity is highly dependent on the skylight position and roof tilt. For low roof tilts the uniformity is increasing as the skylights are placed closer to the back wall (on the opposite side of the windows). For high roof tilts the uniformity is increasing as skylights are placed further away from the windows but it is maximum when skylights are placed on the roof side towards the windows. The uniformity is lower when the skylights are placed on the opposite side of the windows and at the upper part, because at this position they provide daylight towards the window side and the back wall area is darker. The uniformity continues to increase as the skylights are placed closer to the back wall, because more of the back area can be day-lit and the distance between the skylight and the analysis grid is smaller.

To sum up, the daylight autonomy (DA) and the optimally day-lit area (ODA), the heating and lighting demands, are affected by many parameters, thus no straightforward conclusion can be drawn regarding the skylight position. However, a general rule is that the average DA is slightly higher for skylight positions that result in high uniformity. Consequently, the lighting demand is also reduced for the respective skylight positions that result in high uniformity. Finally, it should be added that higher uniformity is also more likely to result in higher visual comfort, less discomfort glare and less electric lighting to compensate for the large contrasts in space. The heating demand is not affected by the skylight position since the solar heat gains and thermal losses are only dependent on the tilt and orientation of the skylights.

4.1.6 Amount of skylights

The results show that the amount of skylights and the skylight size, affects the energy performance, thermal comfort and daylight conditions of a space. The heating demand is significantly increased if more small skylights are used compared to fewer, large skylights, which is an effect of the relative increase in frame length and thermal bridges. The increased framing also has an effect on the solar heat gains through the glazing that are reduced thereby increasing the heating demand but shortening the overheating time. The energy demand for lighting is not significantly affected although the glazing reduction might lead to a small increase.

The reduction of the absolute glazed area also reduces the daylight factor and daylight autonomy while light uniformity is not significantly affected. The optimally day-lit area increases because smaller openings allow less sunlight and most of the light is reflected and diffused at the lining around the opening.

4.2 Overheating issues

The majority of the simulated cases (over 90%), do not result in significant overheating problems during occupancy time, except specific cases where the glazing-to-floor ratio (GFR) is above 30% and all openings are oriented south. This is probably because schools do not operate during summer where overheating issues are mostly likely to occur. The use of exterior shading on the skylights and natural ventilation through the skylights, are very effective measures to reduce excessive solar heat gains, release internal gains and avoid overheating.

The study conducted for a selected case with more than 10% overheating time (151.2 hours) during occupancy time, showed that this case has significant overheating problems annually and especially during summer. In this case, the operative temperature is above 28°C for more than 15% of the total annual time (1314 hours). Cases that do not have overheating problems during occupancy time might also present overheating problems during the summer. Even though the school does not operate, high temperatures might cause damage to the building and equipment. Also the classrooms should be able to operate if needed for alternative purposes during summer time such as summer camp activities and the like.

The high temperatures simulated are partly caused by the natural ventilation that it is scheduled to open automatically only during occupancy time. The overheating problems that are caused due to skylight integration, can however be solved easily with additional measures. Night ventilation is a common measure used in office buildings and it could provide additional cooling when needed. However, schools are operating only until afternoon. An overheated classroom after school time, should rather be cooled soon after school is closed than to wait until night time. Additional ventilation in the evening could be more effective for a school building, although outdoor temperature might not be as low as during night time. Additionally, in Denmark outdoor temperature is rarely above 25°C according the weather file used for this study. This may however change in the following years due to climate change.

Additional exterior shading on the windows during summer, can also significantly reduce the overheating time. A shading device would also be a realistic approach for safety reasons after school is closing for summer time. The same measure can also be applied on the skylights. These measures could reduce the solar gains significantly and thus the temperatures inside the building during the summer.

4.3 End-use and primary energy demand

The integration of skylights in classrooms is, in general, increasing the total end-use energy (considering heating and lighting). This is because the solar heat gains through the skylights do not compensate for the heat loses though the glazing, frame and thermal bridges, resulting in an increase in heating demand for all cases. The lighting demand significantly decreases for almost all cases when skylights are integrated. However, lighting corresponds to approximately one fifth of the heating demand and thus the end-use energy in total, rarely seems to decrease with the addition of skylights. For the passive construction cases, where lighting corresponds to a larger share of the total energy use, there are cases where the total end-use energy is reduced by adding skylights. This happens for cases with north oriented windows and south oriented skylights. In these cases, the passive solar heat gains and daylight from the skylights, compensate for the heat losses and reduce the lighting demand significantly. On the other hand, south oriented cases have already quite high daylight autonomy and solar heat gains because of the south oriented windows. Therefore skylights mostly contribute to additional heat losses due to the increased opening area.

In general, the lowest relative increase in heating and lighting end-use energy, after skylight addition, is observed for cases with 10% window-to-floor ratio (WFR) and 5 to 10% skylight-to-floor ratio (SFR). For every WFR, the lowest increase in the total end-use energy is observed for 5% SFR. This is probably because heat losses are increased considerably more than solar heat gains when more skylights are used.

However, heating energy and electrical energy are produced in very different ways and they consume different amount of resources. This difference is depicted by the different primary energy factors (PEF) used to calculate the primary energy supply for each energy source. Although the end-use energy increases, the primary energy supply for this single classroom located in Denmark, can be significantly reduced with the addition of skylights. This is because the PEF for electricity is three times higher than the PEF for heating energy. Significant relative reductions in primary energy are mostly observed for cases with 10% WFR and 5 to 15% SFR. However, for every WFR, the highest reduction (or lowest increase) in the total primary energy (regarding lighting and heating) is observed for 15% SFR. The reduction in primary energy, after the addition of skylights, is relatively higher for the passive construction cases because lighting corresponds to a larger share of the total energy demand.

The reduction in primary energy supply can also be interpreted as reduction in CO_2 emissions and possibly less environmental impacts. In addition, the reduction in primary energy is very significant since many requirements of building codes (including Denmark's) and building standards (like Passivhaus) use primary energy as a factor to assess and classify a building.

However, this reduction in primary energy may be different in the future due to the increased production of electricity by renewable sources that may reduce the PEF and environmental impacts. In addition, the electricity demand may be reduced in the near future due to the constant development in technology that leads to more energy efficient equipment and lighting.

4.4 Optimal skylight integration regarding daylight and energy

The optimal way to integrate skylights into an existing building or a new design is determined by many parameters. The optimum solution for the Danish climate is strongly conditioned by the need to minimize the heating demand, and maximize passive solar gains and daylight utilization while controlling thermal comfort through appropriate shading and natural ventilation.

For typical construction, the cases with the lowest energy demand, with no overheating problems, "exemplary daylight levels" according BREEAM and optimally day-lit area (ODA) above 50% of the total classroom area, can be mostly found for a glazing-to-floor ratio (GFR) of 20 to 25% and a skylight-to-floor ratio (SFR) of 10 to 15%. Skylights should generally be placed opposite the windows. Generally, south orientated windows with 15° roof tilt, result in the lowest energy demand but many cases have ODA less than 50% due to large over-lit areas. The same guidelines also apply for passive constructions. However the integration of skylights should be conducted more carefully. High GFR and SFR can lead to excessive heat losses, especially for other orientations than south, and may result in heating demand above the threshold requirement for passive constructions.

4.5 Optimally day-lit area and relation to other metrics

The optimally day-lit area (ODA), in general, increases when skylights are added. The cases with high ODA are the ones that balance the amount of light entering from windows and skylights. The skylights should be placed in such way to illuminate the back space of the classroom while windows should have a reasonable size to avoid over-illumination of the space near the windows. These conditions should occur for as many hours as possible, throughout the year.

Although this balanced distribution of windows and skylights is described quite accurately by the daylight factor uniformity ratio (UR) metric, weak correlation between ODA and UR values can generally be observed. On the contrary, the analysis shows that the ODA is strongly correlated with the daylight factor metric (DF). In the majority of the cases with DF between 5 to 8%, the ODA is higher than 60%. Passive construction cases result in lower DF values and higher ODA compared to typical construction cases as it is explained in chapter 4.1.1. Thus the optimal DF range for passive constructions is slightly lower than for typical. The ODA is higher for cases with higher DF, approximately until 7% DF for typical construction cases, and until 6% DF for passive construction cases. Beyond these points, the ODA decreases, which shows that most of the space is over lit. This reduction is strongly connected to the skylight distribution. Cases with skylights opposite of the windows' yield a lower reduction in ODA as DF is increased above 6%, with a sharp drop beyond 9% DF. This shows once more that this skylight distribution (0/6) is the optimum from daylight perspective, as it was noticed already.

The correlation between DF and ODA further shows that spaces with DF higher than 10% might create over lighting and probably visual discomfort, confirming general recommendations found in daylight design books about optimum DF values. This relation between ODA and DF may seem strange since these two metrics take into account very different aspects of lighting. ODA focuses on visual comfort and takes into account all sky types, while DF focuses in the way light is distributed through specific opening settings and it is orientation and climate independent.

A strong correlation was also noted between ODA and average daylight autonomy (DA). This is expected as ODA measures the area with DA above 50% and both metrics are climate based. Cases with higher ODA have higher average DA compared to cases with lower ODA, as expected. On the other hand, cases with very high DA (above 80%) may not always have very high ODA. This is because ODA excludes areas that are over-lit and certainly have very high DA.

BREEAM certification is based on DF and UR values. No strong connection is observed between ODA and BREEAM classification, probably because there is a weak correlation between ODA and UR values. Many of the cases that do not meet any of the BREEAM criteria have very low ODA (20-37%) but there are also some cases with ODA over 50%. Cases that meet the criteria for BREEAM's "first credit" have a variable ODA of 25 to 75%. Moreover, cases that reach BREEAM's exemplary level have in most cases ODA values higher than 60% but this is not a rule since there are few cases with ODA less than 10%, due to large over-lit areas. Cases with DF higher than 10% have in many cases ODA less than 50% possibly due to the large percentage of over-lit area, however in north oriented cases the ODA exceeds 50%. This study generally shows that the DF and UR cannot be used alone in order to evaluate the daylight conditions of a classroom. It is more likely that a space with BREEAM's exemplary level and DF between 5 to 8% will have higher ODA compared to a space with no certification, but this is not always the case, as shown in this study.

On the other hand, the relative time where daylight glare, as shown by the annual daylight glare probability (ADGP) calculation, might be observed in a classroom with skylights, seems to be connected to the percentage of over-lit area and thus ODA. This relation, further shows that ODA can be connected to visual discomfort problems. The results show that a case with high ODA is more likely to have low ADGP. The opposite rule however, does not apply. Low ADGP does not mean that a space has high ODA since the ADGP does not give any indications whether this space is under-lit.

One of the general conclusions from this study is that ODA appears to be a good indicator of an adequately day-lit space with minimum visual discomfort occurrences. However, it is good to take into account as many metrics as possible to be sure that a space is adequately day-lit.

5 Conclusions

This thesis studies the effect of skylights on the daylight conditions, energy use and thermal comfort of a single classroom located in Copenhagen and it is based on simulations using Grasshopper, DIVA for Rhino and Archsim. The general conclusions, drawn from the analysis of the results are stated below:

- The integration of skylights improves daylight conditions of deep spaces and it is recommended for spaces where visual performance is important, such as in classrooms.
- The daylight conditions of a space can be improved more easily with the addition of skylights rather than by the increase of window area.
- Skylight integration in combination with daylight-linked photo-electric lighting control can reduce electricity demand for lighting by up to 5 kWh/m^2 annually.
- Regarding daylight conditions, the skylights are better to be placed in the same side as the windows for high pitched roofs (more than 45°), while for low pitched roofs they should be placed on the opposite side.
- In general, the skylights should be placed further away from the windows (on the suggested roof side) as this increases light uniformity and daylight depth penetration.
- Skylights usually increase the probability of glare but this problem can be solved by adding interior or exterior shading devices.
- Regarding both daylight and energy use, the use of fewer and larger skylights is preferable to more and smaller ones, as long as they are well distributed throughout the space.
- The heating demand of passive constructions is relatively more affected by the addition of skylights than typical constructions.

More specific conclusions regarding classrooms located in cold climates are summarized below:

- The integration of skylights generally increases the heating demand and thus the total end-use energy since heating is the dominant energy.
- The primary energy supply of a classroom located in Denmark, could be reduced with the integration of skylights, especially in cases with low window-to-floor ratio (10%), due to the fact that electricity weighs more in the total energy balance of primary energy factors. The reduction is relatively more for passive constructions.
- Regarding daylight and energy use, a skylight-to-floor ratio between 10 to 15% is suggested while the glazing-to-floor ratio should not exceed 25%.
- Overheating problems due to skylight integration are not significant and they are easily solved with the use of natural ventilation and external shading devices.

Besides the conclusions about optimal skylight integration, this study also provided many methodological conclusions that are valuable for future studies about daylight in architectural spaces. The following conclusions refer to cases with skylights located in Denmark or similar latitude and climate:

- A daylight factor of 6 to 8% indicates satisfactory daylight conditions for typical constructions, while 5 to 7% is suggested for passive constructions.
- The daylight autonomy is recommended to not exceed 80% since above this value a lot of space is over-lit, creating visual discomfort.

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APPENDIX A – Simulation results

Typical Construction - Annual Heating Demand (kWh/m²)													
Tilt	Distrib.	North											
45°	6/0	20.63	22.38	23.88	23.92	25.40	26.20	27.03	27.74	27.90	29.25	29.50	30.95
	4/2	20.63	22.38	23.62	23.92	25.22	25.52	26.79	27.16	26.98	28.69	28.57	30.20
	3/3	20.63	22.38	23.42	23.92	25.10	25.19	26.69	26.84	26.54	28.43	28.15	29.82
	2/4	20.63	22.38	23.47	23.92	25.14	25.11	26.59	26.54	26.05	27.97	27.60	29.34
	0/6	20.63	22.38	23.36	23.92	24.83	24.60	26.35	26.03	25.18	27.64	26.77	28.49
	4/2	17.92	19.58	20.68	21.41	22.49	22.91	24.07	24.38	24.45	26.02	26.06	27.63
	3/3	17.92	19.58	20.83	21.41	22.43	22.77	23.95	24.27	24.03	25.87	25.71	27.30
	2/4	17.92	19.58	20.80	21.41	22.34	22.47	23.96	24.07	23.76	25.66	25.31	26.96
	0/6	17.92	19.58	20.60	21.41	22.20	21.94	23.67	23.62	23.00	25.25	24.59	26.41
15°	6/0	16.61	18.21	19.43	19.98	21.00	21.50	22.63	23.14	23.25	24.73	24.88	26.52
	4/2	16.61	18.21	19.39	19.98	20.87	21.36	22.51	23.01	22.89	24.51	24.47	26.07
	3/3	16.61	18.21	19.21	19.98	20.87	21.27	22.56	22.81	22.75	24.39	24.33	25.92
	2/4	16.61	18.21	19.35	19.98	20.83	21.28	22.40	22.73	22.43	24.24	24.21	25.92
	0/6	16.61	18.21	19.27	19.98	20.92	21.02	22.42	22.44	21.99	23.98	23.79	25.53
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Heating Demand (kWh/m²)													
Tilt	Distrib.	East											
45°	6/0	18.97	19.78	21.83	20.77	22.25	23.73	23.62	24.64	25.22	25.90	26.33	27.76
	4/2	18.97	19.78	21.79	20.77	22.73	23.72	23.59	24.58	25.00	25.81	26.21	27.71
	3/3	18.97	19.78	21.70	20.77	22.62	23.59	23.66	24.51	25.06	25.92	26.07	27.63
	2/4	18.97	19.78	21.75	20.77	22.68	23.61	23.66	24.56	24.98	25.79	26.09	27.61
	0/6	18.97	19.78	21.71	20.77	22.73	23.59	23.65	24.48	24.93	25.75	26.01	27.48
30°	6/0	16.19	17.15	19.07	18.14	20.00	21.18	21.04	22.20	22.58	23.28	23.92	25.42
	4/2	16.19	17.15	19.10	18.14	20.06	21.02	20.96	22.04	22.67	23.26	23.86	25.40
	3/3	16.19	17.15	19.09	18.14	19.58	21.09	21.01	22.05	22.67	23.36	23.85	25.37
	2/4	16.19	17.15	19.15	18.14	19.58	21.16	21.08	22.05	22.69	23.32	23.92	25.37
	0/6	16.19	17.15	19.08	18.14	20.11	21.08	21.05	22.09	22.60	23.30	23.79	25.33
15°	6/0	14.67	15.68	17.47	16.64	18.57	19.55	19.56	20.58	21.10	21.77	22.36	23.80
	4/2	14.67	15.68	17.59	16.64	18.13	19.63	19.56	20.68	21.20	21.82	22.39	23.85
	3/3	14.67	15.68	17.55	16.64	18.17	19.71	19.57	20.71	21.20	21.94	22.52	24.01
	2/4	14.67	15.68	17.72	16.64	18.69	19.75	19.59	20.74	21.20	21.82	22.56	23.57
	0/6	14.67	15.68	17.77	16.64	18.70	19.85	19.63	20.68	21.20	21.98	22.65	24.13
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Heating Demand (kWh/m²)													
Tilt	Distrib.	South											
45°	6/0	14.63	13.95	17.12	13.72	16.41	18.71	16.11	18.02	19.81	17.97	19.25	19.68
	4/2	14.63	13.95	17.28	13.72	16.45	19.12	16.19	18.35	20.47	18.31	19.89	20.06
	3/3	14.63	13.95	17.34	13.72	16.69	19.31	16.30	18.59	20.75	18.44	20.23	20.34
	2/4	14.63	13.95	17.43	13.72	16.63	19.57	16.36	18.79	21.15	18.66	20.54	20.57
	0/6	14.63	13.95	17.62	13.72	16.79	20.04	16.53	19.12	21.72	18.99	21.15	21.28
30°	6/0	12.20	11.79	14.74	11.64	14.24	16.52	14.01	15.99	17.77	16.08	17.59	18.06
	4/2	12.20	11.79	14.90	11.64	14.39	16.79	14.15	16.30	18.32	16.33	17.99	18.43
	3/3	12.20	11.79	14.95	11.64	14.42	17.03	14.19	16.47	18.66	16.55	18.38	18.77
	2/4	12.20	11.79	15.08	11.64	14.51	17.23	14.26	16.64	18.96	16.69	18.53	19.03
	0/6	12.20	11.79	15.23	11.64	14.67	17.64	14.38	17.00	19.63	17.01	19.09	19.46
15°	6/0	10.94	10.51	13.54	10.48	13.10	15.45	12.95	15.00	16.87	15.14	16.70	17.15
	4/2	10.94	10.51	13.63	10.48	13.24	15.68	13.06	15.24	17.23	15.33	17.05	17.44
	3/3	10.94	10.51	13.68	10.48	13.30	15.35	13.11	15.37	17.48	15.53	17.17	17.73
	2/4	10.94	10.51	13.76	10.48	13.33	15.96	13.14	15.49	17.63	15.61	17.49	17.59
	0/6	10.94	10.51	14.05	10.48	13.48	16.30	13.23	15.67	18.05	15.88	17.94	18.34
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Heating Demand (kWh/m²)													
Tilt	Distrib.	West											
45°	6/0	18.52	19.46	21.51	20.44	22.32	23.39	23.17	24.27	24.94	25.29	25.82	26.96
	4/2	18.52	19.46	21.59	20.44	22.31	23.45	23.16	24.14	24.86	25.15	25.69	26.87
	3/3	18.52	19.46	21.48	20.44	22.30	23.43	23.15	24.17	24.86	25.17	25.69	26.93
	2/4	18.52	19.46	21.50	20.44	22.33	23.41	23.29	24.17	24.83	25.15	25.69	26.86
	0/6	18.52	19.46	21.50	20.44	22.27	23.49	23.13	24.14	24.74	25.14	25.69	26.99
30°	6/0	15.76	16.79	18.63	17.76	19.67	20.80	20.64	21.77	22.45	22.85	23.37	24.66
	4/2	15.76	16.79	18.89	17.76	19.73	20.86	20.58	21.63	22.40	22.81	23.41	24.70
	3/3	15.76	16.79	18.84	17.76	19.66	20.91	20.72	21.79	22.52	22.86	23.42	24.72
	2/4	15.76	16.79	18.88	17.76	19.82	20.86	20.60	21.78	22.50	22.89	23.40	24.70
	0/6	15.76	16.79	18.90	17.76	19.81	20.95	20.74	21.81	22.43	22.89	23.47	24.93
15°	6/0	14.41	15.38	17.35	16.26	18.26	19.39	19.18	20.20	20.81	21.25	22.00	23.34
	4/2	14.41	15.38	17.39	16.26	18.27	19.48	19.18	20.19	21.08	21.36	22.02	23.31
	3/3	14.41	15.38	17.38	16.26	18.37	19.52	19.24	20.39	21.05	21.46	22.09	23.51
	2/4	14.41	15.38	17.51	16.26	18.28	19.44	19.17	20.46	21.19	21.50	22.19	23.52
	0/6	14.41	15.38	17.55	16.26	17.96	19.67	19.30	20.40	21.04	21.52	22.28	23.68
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Heating Demand (kWh/m²)

Tilt	Distrib.	North											
45°	6/0	11.06	13.03	13.51	14.84	15.36	15.70	17.04	17.31	17.34	18.96	19.02	20.75
	4/2	11.06	13.03	13.31	14.84	15.27	15.22	16.87	16.90	16.70	18.53	18.34	20.08
	3/3	11.06	13.03	13.25	14.84	15.13	14.99	16.78	16.81	16.34	18.37	17.86	19.70
	2/4	11.06	13.03	13.16	14.84	15.05	14.79	16.79	16.61	16.04	18.25	17.62	19.37
	0/6	11.06	13.03	13.03	14.84	14.92	14.38	16.68	16.15	15.32	17.75	16.93	18.75
30°	6/0	9.74	11.59	11.92	13.37	13.76	13.98	15.49	15.79	15.83	17.56	17.39	19.27
	4/2	9.74	11.59	11.78	13.37	13.72	13.65	15.35	15.36	15.25	17.20	16.96	18.76
	3/3	9.74	11.59	11.73	13.37	13.58	13.53	15.30	15.31	15.07	16.97	16.72	18.48
	2/4	9.74	11.59	11.55	13.37	13.48	13.48	15.20	14.71	14.81	16.84	16.48	18.26
	0/6	9.74	11.59	11.84	13.37	13.42	13.25	15.07	14.88	14.36	16.49	15.93	17.70
15°	6/0	8.88	10.92	11.01	12.67	12.84	13.01	14.61	14.75	14.92	16.41	16.63	18.31
	4/2	8.88	10.92	10.99	12.67	12.80	12.88	14.54	14.68	14.76	16.29	16.28	17.96
	3/3	8.88	10.92	10.95	12.67	12.82	12.91	14.50	14.52	14.64	16.28	16.22	17.94
	2/4	8.88	10.92	11.00	12.67	12.77	13.03	14.49	14.63	14.53	16.20	16.11	17.73
	0/6	8.88	10.92	11.16	12.67	12.76	12.83	14.43	14.45	14.09	16.15	15.88	17.62
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Heating Demand (kWh/m²)

Tilt	Distrib.	East											
45°	6/0	10.24	11.42	12.26	12.71	13.48	14.09	14.76	15.26	15.49	16.65	16.88	18.57
	4/2	10.24	11.42	12.23	12.71	13.49	13.95	14.76	14.78	14.91	16.58	16.68	18.32
	3/3	10.24	11.42	12.10	12.71	13.46	14.03	14.71	15.20	15.38	16.57	16.67	18.32
	2/4	10.24	11.42	12.22	12.71	13.50	13.92	14.72	15.21	15.26	16.61	16.57	18.31
	0/6	10.24	11.42	12.14	12.71	13.56	13.88	14.30	15.20	15.26	16.57	16.51	18.23
30°	6/0	8.74	9.94	10.80	11.28	11.98	12.61	13.29	13.83	14.14	15.25	15.51	17.25
	4/2	8.74	9.94	10.80	11.28	12.04	12.55	13.27	13.80	14.12	15.08	15.41	17.21
	3/3	8.74	9.94	10.79	11.28	12.00	12.59	13.27	13.37	14.07	15.18	15.49	17.25
	2/4	8.74	9.94	10.62	11.28	12.09	12.56	12.88	13.83	14.20	15.28	15.46	17.25
	0/6	8.74	9.94	10.73	11.28	12.11	12.53	13.27	13.68	14.18	15.28	15.48	17.20
15°	6/0	7.93	9.10	9.99	10.13	11.18	11.71	12.54	13.05	12.90	14.58	14.77	16.42
	4/2	7.93	9.10	10.05	10.13	11.21	11.86	12.52	12.69	13.52	14.62	14.81	16.37
	3/3	7.93	9.10	10.01	10.13	11.24	11.96	12.53	13.15	13.62	14.62	14.92	16.50
	2/4	7.93	9.10	10.11	10.13	11.34	11.93	12.55	13.21	13.65	14.66	15.00	16.63
	0/6	7.93	9.10	10.12	10.13	11.35	12.04	12.56	13.33	13.62	14.78	15.12	16.79
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Heating Demand (kWh/m^2)													
Tilt	Distrib.	South											
45°	6/0	7.46	7.54	9.26	7.87	9.29	10.69	9.49	10.71	11.80	11.14	11.93	12.63
	4/2	7.46	7.54	9.26	7.87	9.38	10.89	9.60	10.93	12.18	11.33	12.31	12.99
	3/3	7.46	7.54	9.34	7.87	9.41	11.06	9.65	11.09	12.43	11.47	12.56	13.20
	2/4	7.46	7.54	9.35	7.87	9.47	11.22	9.73	11.22	12.69	11.59	12.77	13.46
	0/6	7.46	7.54	9.52	7.87	9.59	11.50	9.81	11.51	13.21	11.90	13.18	13.86
30°	6/0	6.15	6.40	7.87	6.75	8.08	9.55	8.43	9.66	10.82	10.13	11.05	11.71
	4/2	6.15	6.40	8.02	6.75	8.15	9.62	8.51	9.85	11.21	10.33	11.37	12.04
	3/3	6.15	6.40	8.08	6.75	8.22	9.94	8.53	9.96	11.43	10.43	11.64	12.27
	2/4	6.15	6.40	8.21	6.75	8.26	10.13	8.60	10.17	11.64	10.58	11.78	12.46
	0/6	6.15	6.40	8.32	6.75	8.34	10.39	8.70	10.24	12.08	10.80	12.25	12.82
15°	6/0	5.56	5.75	7.29	6.14	7.48	8.96	7.89	9.19	10.46	9.71	10.73	11.48
	4/2	5.56	5.75	7.51	6.14	7.56	9.16	7.93	9.37	10.81	9.86	11.08	11.75
	3/3	5.56	5.75	7.50	6.14	7.62	9.43	8.03	9.38	11.04	9.95	11.24	11.88
	2/4	5.56	5.75	7.58	6.14	7.66	9.48	8.05	9.60	11.21	10.03	11.43	11.94
	0/6	5.56	5.75	7.66	6.14	7.81	9.73	8.10	9.82	11.48	10.22	11.63	12.36
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Heating Demand (kWh/m^2)													
Tilt	Distrib.	West											
45°	6/0	9.94	11.19	12.04	12.40	13.26	13.86	14.35	14.97	15.37	16.29	16.52	17.85
	4/2	9.94	11.19	11.97	12.40	13.28	13.82	14.38	15.01	15.31	16.23	16.28	17.83
	3/3	9.94	11.19	11.90	12.40	13.27	13.85	14.44	15.03	15.21	16.14	16.33	17.79
	2/4	9.94	11.19	11.98	12.40	13.22	13.82	14.50	14.93	15.19	16.18	16.31	17.82
	0/6	9.94	11.19	11.94	12.40	13.22	13.78	14.40	14.98	15.08	16.18	16.31	17.87
30°	6/0	8.52	9.82	10.58	10.91	11.82	12.42	13.01	13.57	14.04	14.78	15.29	16.71
	4/2	8.52	9.82	10.49	10.91	11.85	12.38	12.95	13.69	13.99	14.78	15.19	16.70
	3/3	8.52	9.82	10.53	10.91	11.81	12.36	13.07	13.65	14.01	14.82	15.14	16.65
	2/4	8.52	9.82	10.43	10.91	11.79	12.43	12.99	13.60	13.99	14.89	15.20	16.77
	0/6	8.52	9.82	10.63	10.91	11.82	12.39	13.07	13.26	14.05	14.86	15.27	16.72
15°	6/0	7.63	8.89	9.72	10.12	11.04	11.60	12.28	12.86	13.26	14.13	14.13	15.97
	4/2	7.63	8.89	9.79	10.12	11.09	11.69	12.23	12.91	13.34	14.18	14.52	16.11
	3/3	7.63	8.89	9.78	10.12	11.00	11.73	12.27	12.96	13.56	14.19	14.68	16.22
	2/4	7.63	8.89	9.88	10.12	11.01	11.92	12.36	12.94	13.61	14.33	14.77	16.14
	0/6	7.63	8.89	10.01	10.12	11.10	12.04	12.34	13.11	13.49	14.41	14.91	16.35
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Electrical Lighting Demand (kWh/m²)													
Tilt	Distribution	North											
45°	6/0	7.43	5.25	5.89	4.37	4.85	3.95	3.87	3.53	3.23	3.22	2.96	2.93
	4/2	7.43	5.25	5.81	4.37	4.68	4.22	3.87	3.50	3.13	3.18	2.83	2.81
	3/3	7.43	5.25	5.92	4.37	4.69	4.26	3.89	3.60	3.13	3.22	2.67	2.59
	2/4	7.43	5.25	5.68	4.37	4.12	3.69	3.93	3.63	3.16	3.50	3.12	2.61
	0/6	7.43	5.25	5.09	4.37	4.38	3.45	3.75	3.32	2.89	2.88	2.69	2.57
30°	6/0	6.78	5.27	5.90	3.72	4.82	4.50	3.63	3.53	3.25	3.34	3.10	2.78
	4/2	6.78	5.27	6.42	3.72	4.47	3.86	3.82	3.85	3.00	3.34	2.75	2.77
	3/3	6.78	5.27	5.26	3.72	4.33	3.50	3.90	3.34	3.06	2.99	2.71	2.73
	2/4	6.78	5.27	5.03	3.72	4.31	3.67	3.53	3.14	2.75	2.93	2.56	2.46
	0/6	6.78	5.27	5.01	3.72	3.95	3.49	3.60	3.03	2.50	2.69	2.46	1.99
15°	6/0	6.36	5.10	5.81	4.07	4.73	4.76	3.84	3.86	3.63	3.47	3.18	3.07
	4/2	6.36	5.10	5.19	4.07	4.74	4.12	3.83	3.25	3.09	3.17	2.87	2.67
	3/3	6.36	5.10	5.86	4.07	4.53	3.83	3.46	3.31	2.72	3.01	2.61	2.39
	2/4	6.36	5.10	4.77	4.07	4.42	3.12	3.59	2.98	2.63	2.81	2.09	1.74
	0/6	6.36	5.10	4.72	4.07	3.58	2.84	3.35	2.81	2.41	2.47	1.68	1.34
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Electrical Lighting Demand (kWh/m²)													
Tilt	Distribution	East											
45°	6/0	5.25	4.60	4.66	3.73	4.36	3.65	3.49	3.31	2.74	2.78	2.34	2.20
	4/2	5.25	4.60	4.94	3.73	3.97	3.64	3.69	3.47	3.48	3.13	2.62	2.34
	3/3	5.25	4.60	5.18	3.73	4.06	3.95	3.46	3.76	3.11	2.68	2.86	2.49
	2/4	5.25	4.60	5.01	3.73	4.16	3.76	3.46	3.53	3.46	3.00	2.86	2.59
	0/6	5.25	4.60	5.20	3.73	3.98	3.92	3.46	3.61	3.49	3.06	3.02	2.74
30°	6/0	5.32	4.13	4.97	3.72	4.20	3.38	3.44	2.81	3.13	3.02	2.40	2.31
	4/2	5.32	4.13	4.75	3.72	3.95	3.78	3.71	3.29	2.87	2.94	2.63	2.18
	3/3	5.32	4.13	4.86	3.72	4.28	3.65	3.47	3.25	2.89	2.64	2.59	2.31
	2/4	5.32	4.13	4.50	3.72	4.31	3.33	3.25	3.27	2.82	2.70	2.36	2.21
	0/6	5.32	4.13	4.69	3.72	3.69	3.74	3.30	3.07	2.68	2.75	2.42	2.04
15°	6/0	5.37	4.16	5.26	3.69	3.94	4.13	3.47	3.51	3.46	3.08	2.78	2.63
	4/2	5.37	4.16	4.70	3.69	4.27	3.81	3.45	3.24	3.00	3.01	2.79	2.51
	3/3	5.37	4.16	4.87	3.69	4.25	3.58	3.44	2.95	2.84	2.58	2.22	2.09
	2/4	5.37	4.16	4.23	3.69	3.55	3.31	3.27	2.80	2.61	2.78	2.11	2.31
	0/6	5.37	4.16	4.07	3.69	3.56	2.86	3.01	2.63	2.61	2.32	1.62	1.33
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Electrical Lighting Demand (kWh/m²)													
Tilt	Distribution	South											
45°	6/0	4.95	4.06	4.36	3.07	3.38	3.07	2.75	2.74	2.37	2.44	2.45	1.93
	4/2	4.95	4.06	4.49	3.07	4.05	3.30	3.04	3.05	2.69	2.64	2.51	2.48
	3/3	4.95	4.06	4.61	3.07	3.34	3.49	2.88	2.84	2.88	2.73	2.50	2.52
	2/4	4.95	4.06	4.64	3.07	4.02	3.45	2.95	2.89	2.79	2.63	2.66	2.54
	0/6	4.95	4.06	4.63	3.07	4.06	3.46	2.89	3.28	3.50	2.68	2.82	2.50
30°	6/0	4.80	3.49	4.44	2.86	3.39	2.88	2.82	2.70	2.49	2.44	2.11	2.06
	4/2	4.80	3.49	4.43	2.86	3.31	3.30	2.76	2.83	2.76	2.61	2.55	2.47
	3/3	4.80	3.49	4.50	2.86	3.45	3.20	2.79	2.75	2.58	2.43	2.32	2.08
	2/4	4.80	3.49	4.29	2.86	3.34	3.17	2.75	2.78	2.60	2.50	2.42	1.95
	0/6	4.80	3.49	4.23	2.86	3.14	3.13	2.79	2.69	2.48	2.49	2.57	2.00
15°	6/0	4.60	4.03	4.50	2.99	3.66	3.33	2.91	2.92	2.74	2.70	2.62	2.42
	4/2	4.60	4.03	4.42	2.99	3.35	3.31	2.76	2.90	2.87	2.60	2.55	2.52
	3/3	4.60	4.03	4.47	2.99	3.32	3.83	2.75	2.78	2.65	2.39	2.37	2.00
	2/4	4.60	4.03	4.43	2.99	3.33	2.97	2.77	2.67	2.42	2.39	2.07	2.17
	0/6	4.60	4.03	3.46	2.99	2.92	2.62	2.73	2.49	2.42	2.03	1.43	1.40
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Annual Electrical Lighting Demand (kWh/m²)													
Tilt	Distribution	West											
45°	6/0	6.97	4.90	5.40	3.62	4.27	4.16	3.74	3.41	2.81	2.86	2.62	2.40
	4/2	6.97	4.90	5.00	3.62	4.36	3.90	3.75	3.57	3.14	3.37	3.05	2.83
	3/3	6.97	4.90	5.72	3.62	4.35	3.99	3.90	3.77	3.13	3.26	3.06	2.79
	2/4	6.97	4.90	5.50	3.62	4.25	4.03	3.35	3.73	3.29	3.30	3.09	2.77
	0/6	6.97	4.90	5.55	3.62	4.60	3.80	3.69	3.79	3.55	3.44	3.07	2.60
30°	6/0	7.07	4.71	6.34	3.91	4.50	4.14	3.56	3.28	2.95	2.87	2.76	2.77
	4/2	7.07	4.71	5.24	3.91	4.16	3.90	3.58	3.58	3.11	3.03	2.78	2.66
	3/3	7.07	4.71	5.05	3.91	4.44	3.71	3.34	3.23	2.80	2.90	2.73	2.53
	2/4	7.07	4.71	4.99	3.91	3.89	3.64	3.51	3.19	2.82	2.77	2.76	2.49
	0/6	7.07	4.71	4.77	3.91	3.89	3.51	3.25	3.00	2.88	2.72	2.54	2.05
15°	6/0	6.21	4.78	5.25	4.11	4.35	4.20	3.75	3.62	3.64	3.46	2.91	2.87
	4/2	6.21	4.78	5.01	4.11	4.26	3.80	3.72	3.61	2.89	3.21	2.79	2.76
	3/3	6.21	4.78	5.14	4.11	3.88	3.68	3.56	3.10	2.79	2.82	2.55	1.99
	2/4	6.21	4.78	4.49	4.11	4.20	3.60	3.55	2.77	2.24	2.62	2.02	2.02
	0/6	6.21	4.78	4.51	4.11	4.17	2.84	3.14	2.59	2.43	2.53	1.64	1.32
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Electrical Lighting Demand (kWh/m²)													
Tilt	Distribution	North											
45°	6/0	8.64	5.92	6.67	5.02	5.14	4.85	4.74	4.53	3.90	4.13	3.48	3.23
	4/2	8.64	5.92	7.02	5.02	4.85	4.86	4.70	4.34	3.56	3.82	3.29	3.12
	3/3	8.64	5.92	6.64	5.02	4.97	4.86	4.67	3.87	3.52	3.86	3.51	3.19
	2/4	8.64	5.92	7.01	5.02	4.93	4.77	4.29	3.76	3.42	3.50	3.40	3.19
	0/6	8.64	5.92	6.51	5.02	4.86	4.69	4.01	3.85	3.47	3.86	3.39	2.89
30°	6/0	7.69	5.89	6.88	4.72	5.25	5.29	4.38	4.24	3.97	3.52	3.73	3.24
	4/2	7.69	5.89	7.06	4.72	4.60	4.98	4.37	4.31	3.62	3.45	3.32	3.01
	3/3	7.69	5.89	6.79	4.72	4.96	4.67	4.38	3.87	3.44	3.52	3.14	3.03
	2/4	7.69	5.89	7.25	4.72	4.98	4.19	4.35	4.14	3.31	3.28	2.96	2.67
	0/6	7.69	5.89	5.22	4.72	4.55	3.59	4.36	3.31	2.96	3.24	2.87	2.58
15°	6/0	7.97	5.32	7.21	4.74	5.31	5.59	4.32	4.76	4.14	4.16	3.56	3.35
	4/2	7.97	5.32	6.73	4.74	5.02	5.09	4.31	4.03	3.47	3.80	3.38	3.21
	3/3	7.97	5.32	6.79	4.74	4.84	4.40	4.31	4.25	3.05	3.38	2.96	2.70
	2/4	7.97	5.32	6.10	4.74	4.85	3.56	4.15	3.39	2.84	3.29	2.72	2.73
	0/6	7.97	5.32	4.91	4.74	4.47	3.45	3.95	3.17	3.08	2.76	2.18	1.90
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Electrical Lighting Demand (kWh/m²)													
Tilt	Distribution	East											
45°	6/0	6.08	4.97	5.40	4.14	4.59	4.19	3.63	3.66	3.35	3.31	2.78	2.65
	4/2	6.08	4.97	5.85	4.14	4.43	4.68	3.74	4.33	4.28	3.51	3.35	3.02
	3/3	6.08	4.97	6.08	4.14	4.71	4.37	3.91	3.78	3.60	3.55	3.37	2.88
	2/4	6.08	4.97	5.86	4.14	4.42	4.70	3.93	3.78	4.10	3.47	3.65	3.09
	0/6	6.08	4.97	6.18	4.14	4.29	4.92	4.45	3.89	3.92	3.63	3.81	3.17
30°	6/0	6.02	4.93	5.25	3.78	4.85	4.22	3.77	3.63	3.51	3.29	3.16	2.70
	4/2	6.02	4.93	5.31	3.78	4.41	4.53	3.78	3.73	3.48	3.70	3.22	2.73
	3/3	6.02	4.93	5.28	3.78	4.45	4.28	3.76	4.25	3.69	3.48	3.04	2.72
	2/4	6.02	4.93	5.98	3.78	4.21	4.35	4.28	3.57	3.34	3.17	3.04	2.57
	0/6	6.02	4.93	5.74	3.78	4.12	4.40	3.74	3.84	3.29	3.17	2.88	2.70
15°	6/0	6.04	4.96	5.85	4.38	4.76	4.97	3.65	4.15	4.83	3.43	3.62	3.22
	4/2	6.04	4.96	5.45	4.38	4.67	4.36	3.76	4.42	3.56	3.28	3.48	3.21
	3/3	6.04	4.96	5.45	4.38	4.51	4.01	3.72	3.57	3.29	3.25	3.03	2.75
	2/4	6.04	4.96	5.10	4.38	4.07	4.12	3.60	3.39	3.18	2.96	2.78	2.28
	0/6	6.04	4.96	4.88	4.38	4.11	3.58	3.55	3.07	3.21	2.61	2.18	1.90
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Electrical Lighting Demand (kWh/m²)

Tilt	Distribution	South											
45°	6/0	5.94	4.97	4.80	3.94	4.21	3.53	3.38	3.09	2.71	2.73	2.49	2.40
	4/2	5.94	4.97	5.37	3.94	4.21	4.27	3.38	3.39	3.28	2.88	2.83	2.63
	3/3	5.94	4.97	5.62	3.94	4.38	4.29	3.41	3.29	3.34	2.95	2.85	2.74
	2/4	5.94	4.97	5.85	3.94	4.37	4.33	3.34	3.39	3.31	2.95	2.90	2.65
	0/6	5.94	4.97	5.48	3.94	4.41	4.55	3.44	3.60	3.55	2.98	3.31	2.83
30°	6/0	6.04	4.35	5.36	3.42	4.15	3.64	3.05	3.03	2.73	2.68	2.69	2.46
	4/2	6.04	4.35	5.14	3.42	4.33	4.52	3.07	3.21	2.96	2.84	2.86	2.55
	3/3	6.04	4.35	5.11	3.42	4.18	3.63	3.30	3.31	3.01	2.84	2.77	2.49
	2/4	6.04	4.35	4.83	3.42	4.06	3.44	3.09	2.91	3.03	2.75	2.82	2.48
	0/6	6.04	4.35	4.78	3.42	4.28	3.56	3.03	3.36	3.13	2.84	2.63	2.53
15°	6/0	5.38	4.26	5.45	3.34	4.31	4.51	3.13	3.32	3.34	2.93	3.14	2.73
	4/2	5.38	4.26	4.74	3.34	4.37	4.41	3.28	3.29	3.19	2.83	2.86	2.53
	3/3	5.38	4.26	4.83	3.34	4.24	3.42	2.98	3.30	2.86	2.80	2.61	2.57
	2/4	5.38	4.26	4.64	3.34	4.11	3.53	2.93	2.95	2.71	2.75	2.42	2.36
	0/6	5.38	4.26	4.52	3.34	3.54	3.31	2.98	2.74	2.75	2.51	2.37	1.97
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Annual Electrical Lighting Demand (kWh/m²)

Tilt	Distribution	West											
45°	6/0	7.51	5.86	6.59	4.75	4.91	4.78	4.60	4.07	3.23	3.31	2.96	3.11
	4/2	7.51	5.86	6.69	4.75	4.97	4.87	4.43	3.96	3.51	3.62	3.63	3.14
	3/3	7.51	5.86	7.23	4.75	4.90	4.67	4.26	3.89	3.95	3.96	3.73	3.38
	2/4	7.51	5.86	6.75	4.75	5.05	4.84	3.98	3.90	3.94	3.70	3.75	3.21
	0/6	7.51	5.86	6.72	4.75	5.16	5.02	4.40	4.07	3.98	3.77	3.65	3.17
30°	6/0	7.20	5.02	6.54	4.68	4.83	4.78	4.14	4.16	3.47	3.52	2.91	2.88
	4/2	7.20	5.02	6.92	4.68	4.68	4.75	4.37	3.62	3.69	3.78	3.19	2.95
	3/3	7.20	5.02	6.53	4.68	4.81	4.80	3.89	3.70	3.53	3.71	3.40	3.27
	2/4	7.20	5.02	7.08	4.68	4.86	4.58	4.22	3.87	3.57	3.40	3.15	2.78
	0/6	7.20	5.02	5.74	4.68	4.68	4.62	3.95	4.16	3.33	3.42	2.95	2.83
15°	6/0	7.90	5.65	7.22	4.62	5.05	5.34	4.10	4.33	4.58	4.10	4.17	3.56
	4/2	7.90	5.65	6.48	4.62	4.68	4.80	4.29	4.15	3.76	3.58	3.55	3.06
	3/3	7.90	5.65	6.58	4.62	5.03	4.47	4.13	3.80	3.13	3.49	3.14	2.76
	2/4	7.90	5.65	5.62	4.62	4.86	3.73	3.80	3.60	2.89	3.17	2.78	2.61
	0/6	7.90	5.65	5.10	4.62	4.41	3.30	3.75	3.16	3.15	2.86	2.10	2.13
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction – Relative Overheating Time (%)													
Tilt	Distribution	North											
45°	6/0	0.07	0.20	0.00	0.26	0.07	0.07	0.20	0.20	0.20	0.66	0.86	1.59
	4/2	0.07	0.20	0.00	0.26	0.07	0.13	0.20	0.20	0.20	0.66	0.93	1.59
	3/3	0.07	0.20	0.00	0.26	0.13	0.13	0.20	0.20	0.20	0.66	0.93	1.59
	2/4	0.07	0.20	0.00	0.26	0.13	0.13	0.20	0.20	0.20	0.79	0.93	1.52
	0/6	0.07	0.20	0.00	0.26	0.13	0.20	0.20	0.20	0.40	0.79	0.86	1.52
30°	6/0	0.07	0.20	0.00	0.26	0.20	0.13	0.46	0.20	0.20	0.99	1.06	1.92
	4/2	0.07	0.20	0.00	0.26	0.20	0.20	0.46	0.33	0.40	1.06	1.19	2.05
	3/3	0.07	0.20	0.00	0.26	0.20	0.20	0.46	0.33	0.46	1.06	1.19	2.12
	2/4	0.07	0.20	0.00	0.26	0.20	0.20	0.46	0.40	0.60	1.06	1.12	1.98
	0/6	0.07	0.20	0.07	0.26	0.20	0.20	0.60	0.53	0.53	1.06	1.39	1.98
15°	6/0	0.07	0.20	0.20	0.26	0.20	0.20	0.60	0.60	0.73	1.12	1.32	2.18
	4/2	0.07	0.20	0.20	0.26	0.20	0.20	0.60	0.66	0.79	1.26	1.46	2.25
	3/3	0.07	0.20	0.07	0.26	0.20	0.20	0.60	0.66	0.79	1.26	1.52	2.31
	2/4	0.07	0.20	0.07	0.26	0.20	0.20	0.60	0.66	0.86	1.39	1.65	2.38
	0/6	0.07	0.20	0.07	0.26	0.20	0.26	0.60	0.73	0.93	1.39	1.65	2.58
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Relative Overheating Time (%)													
Tilt	Distribution	East											
45°	6/0	0.40	1.59	0.33	2.91	1.59	1.06	2.98	2.18	1.92	3.64	2.98	5.16
	4/2	0.40	1.59	0.33	2.91	1.59	0.93	3.04	2.18	1.85	3.70	2.98	5.29
	3/3	0.40	1.59	0.33	2.91	1.59	0.86	3.04	2.18	1.79	3.70	2.98	5.16
	2/4	0.40	1.59	0.33	2.91	1.59	0.73	2.98	2.25	1.79	3.70	3.04	4.89
	0/6	0.40	1.59	0.33	2.91	1.59	0.73	3.04	2.05	1.72	3.70	2.98	4.89
30°	6/0	0.40	1.72	0.33	4.37	1.79	1.46	3.90	2.78	2.31	4.83	3.57	6.48
	4/2	0.40	1.72	0.33	4.37	1.85	1.46	3.90	2.78	2.38	4.96	3.51	6.35
	3/3	0.40	1.72	0.33	4.37	1.79	1.46	3.90	2.84	2.12	5.03	3.57	6.08
	2/4	0.40	1.72	0.33	4.37	1.79	1.32	3.84	2.84	2.25	4.89	3.44	6.35
	0/6	0.40	1.72	0.33	4.37	1.79	1.39	3.84	2.78	2.31	4.63	3.44	6.22
15°	6/0	0.40	1.79	0.40	5.16	2.45	1.59	4.50	2.71	2.65	5.89	4.17	7.28
	4/2	0.40	1.79	0.40	5.16	2.38	1.52	4.50	2.78	2.65	5.89	4.17	7.34
	3/3	0.40	1.79	0.40	5.16	2.38	1.59	4.50	2.78	2.58	5.75	4.03	7.41
	2/4	0.40	1.79	0.40	5.16	2.38	1.59	4.43	2.84	2.58	5.82	4.10	7.34
	0/6	0.40	1.79	0.40	5.16	2.31	1.59	4.50	2.78	2.58	5.82	4.03	7.47
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Relative Overheating Time (%)

Tilt	Distribution	South											
45°	6/0	0.46	3.11	0.53	6.88	2.71	1.46	6.08	4.03	2.51	7.01	5.03	8.86
	4/2	0.46	3.11	0.53	6.88	2.58	1.32	6.02	3.77	2.45	7.01	5.03	8.20
	3/3	0.46	3.11	0.46	6.88	2.51	1.32	6.02	3.70	2.45	6.94	5.03	8.07
	2/4	0.46	3.11	0.46	6.88	2.58	1.32	6.02	3.64	2.38	6.61	4.89	8.07
	0/6	0.46	3.11	0.40	6.88	2.58	1.32	5.95	3.44	2.38	6.42	4.89	7.87
30°	6/0	0.93	4.10	0.79	8.33	3.70	1.98	8.07	5.03	3.17	8.80	6.48	10.25
	4/2	0.93	4.10	0.86	8.33	3.70	1.98	7.94	4.89	3.04	8.33	5.95	9.92
	3/3	0.93	4.10	0.79	8.33	3.70	1.98	7.87	4.70	2.98	8.60	6.02	9.66
	2/4	0.93	4.10	0.73	8.33	3.70	1.85	7.94	4.70	2.71	8.53	6.08	9.52
	0/6	0.93	4.10	0.73	8.33	3.44	1.79	7.80	4.50	2.78	8.33	5.89	9.19
15°	6/0	1.12	4.50	1.19	9.33	4.56	2.25	9.13	6.02	3.84	9.59	7.67	11.44
	4/2	1.12	4.50	1.19	9.33	4.50	2.12	8.99	5.95	3.44	9.39	7.21	11.44
	3/3	1.12	4.50	1.19	9.33	4.50	2.18	8.99	5.89	3.37	9.46	7.41	11.38
	2/4	1.12	4.50	1.19	9.33	4.50	2.18	8.93	5.82	3.37	9.26	7.21	11.11
	0/6	1.12	4.50	1.06	9.33	4.37	2.12	8.86	5.69	3.11	9.06	6.94	10.65
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Relative Overheating Time (%)

Tilt	Distribution	West											
45°	6/0	0.33	1.12	0.20	2.98	1.26	0.53	2.78	2.12	1.59	3.57	3.11	4.03
	4/2	0.33	1.12	0.20	2.98	1.26	0.53	2.71	2.12	1.59	3.44	2.78	4.10
	3/3	0.33	1.12	0.20	2.98	1.26	0.53	2.91	2.25	1.65	3.51	2.91	4.17
	2/4	0.33	1.12	0.26	2.98	1.26	0.53	2.91	2.31	1.59	3.37	2.84	3.97
	0/6	0.33	1.12	0.26	2.98	1.26	0.46	2.78	2.38	1.46	3.31	2.78	4.03
30°	6/0	0.40	1.39	0.26	3.77	1.65	0.73	3.37	2.45	2.12	4.17	3.57	4.96
	4/2	0.40	1.39	0.26	3.77	1.59	0.73	3.37	2.58	2.12	4.03	3.31	4.89
	3/3	0.40	1.39	0.26	3.77	1.59	0.86	3.37	2.58	2.18	3.97	3.17	4.83
	2/4	0.40	1.39	0.26	3.77	1.59	0.73	3.37	2.58	2.25	4.10	3.31	4.83
	0/6	0.40	1.39	0.26	3.77	1.65	0.86	3.37	2.71	2.38	4.17	3.24	5.03
15°	6/0	0.40	1.72	0.46	4.10	2.05	1.26	3.90	2.91	2.25	4.70	3.90	5.89
	4/2	0.40	1.72	0.53	4.10	2.05	1.19	3.90	2.91	2.25	4.76	3.70	6.08
	3/3	0.40	1.72	0.46	4.10	2.05	1.26	3.84	2.78	2.31	4.70	3.57	6.02
	2/4	0.40	1.72	0.46	4.10	2.05	1.19	3.84	2.91	2.38	4.70	3.70	5.95
	0/6	0.40	1.72	0.53	4.10	2.05	1.12	3.77	2.84	2.45	4.76	3.84	5.95
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Relative Overheating Time (%)													
Tilt	Distribution	North											
45°	6/0	0.00	0.07	0.00	0.20	0.00	0.00	0.13	0.07	0.07	0.13	0.20	0.99
	4/2	0.00	0.07	0.00	0.20	0.00	0.00	0.13	0.13	0.13	0.20	0.33	0.93
	3/3	0.00	0.07	0.00	0.20	0.00	0.00	0.13	0.13	0.13	0.33	0.40	1.12
	2/4	0.00	0.07	0.00	0.20	0.00	0.00	0.13	0.13	0.20	0.33	0.40	0.99
	0/6	0.00	0.07	0.00	0.20	0.00	0.00	0.13	0.13	0.20	0.33	0.46	1.12
30°	6/0	0.07	0.13	0.00	0.20	0.00	0.00	0.20	0.13	0.20	0.46	0.40	1.19
	4/2	0.07	0.13	0.00	0.20	0.07	0.13	0.20	0.20	0.20	0.46	0.60	1.32
	3/3	0.07	0.13	0.00	0.20	0.07	0.13	0.20	0.20	0.20	0.53	0.66	1.32
	2/4	0.07	0.13	0.00	0.20	0.13	0.13	0.20	0.20	0.20	0.46	0.66	1.32
	0/6	0.07	0.13	0.00	0.20	0.13	0.20	0.20	0.20	0.40	0.60	0.73	1.65
15°	6/0	0.07	0.13	0.00	0.20	0.20	0.20	0.20	0.20	0.26	0.73	0.79	1.52
	4/2	0.07	0.13	0.07	0.20	0.20	0.20	0.20	0.20	0.40	0.79	0.93	1.52
	3/3	0.07	0.13	0.00	0.20	0.20	0.20	0.26	0.20	0.40	0.86	0.93	1.72
	2/4	0.07	0.13	0.00	0.20	0.20	0.20	0.26	0.20	0.46	0.86	0.99	1.79
	0/6	0.07	0.13	0.00	0.20	0.20	0.20	0.26	0.40	0.53	0.99	1.19	1.85
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Relative Overheating Time (%)													
Tilt	Distribution	East											
45°	6/0	0.40	1.12	0.26	2.45	1.19	0.33	2.31	2.05	1.72	2.98	2.51	3.77
	4/2	0.40	1.12	0.33	2.45	1.12	0.33	2.31	1.98	1.59	2.91	2.45	3.84
	3/3	0.40	1.12	0.26	2.45	1.12	0.26	2.31	1.85	1.59	2.84	2.65	3.77
	2/4	0.40	1.12	0.26	2.45	1.12	0.26	2.31	1.98	1.59	2.91	2.58	3.77
	0/6	0.40	1.12	0.26	2.45	1.12	0.26	2.25	1.92	1.52	2.84	2.71	3.70
30°	6/0	0.40	1.39	0.33	2.51	1.46	0.66	2.91	2.18	1.92	3.51	2.84	4.56
	4/2	0.40	1.39	0.33	2.51	1.46	0.66	2.91	2.25	1.85	3.51	2.91	4.43
	3/3	0.40	1.39	0.33	2.51	1.46	0.66	2.91	2.18	1.85	3.44	2.91	4.37
	2/4	0.40	1.39	0.33	2.51	1.46	0.66	2.91	2.12	1.85	3.57	2.98	4.43
	0/6	0.40	1.39	0.33	2.51	1.46	0.66	2.91	2.31	1.85	3.44	3.11	4.37
15°	6/0	0.40	1.65	0.33	2.91	1.52	0.99	3.44	2.45	2.25	3.97	3.64	5.09
	4/2	0.40	1.65	0.33	2.91	1.59	0.99	3.37	2.45	2.18	3.90	3.57	5.16
	3/3	0.40	1.65	0.33	2.91	1.72	0.93	3.44	2.45	2.12	3.90	3.44	5.22
	2/4	0.40	1.65	0.33	2.91	1.65	0.86	3.37	2.45	2.12	3.90	3.51	5.22
	0/6	0.40	1.65	0.33	2.91	1.59	0.73	3.44	2.51	2.05	3.97	3.51	5.22
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Relative Overheating Time (%)													
Tilt	Distribution	South											
45°	6/0	0.46	2.18	0.33	5.36	1.98	0.93	4.83	2.78	1.98	5.42	4.17	6.35
	4/2	0.46	2.18	0.33	5.36	1.85	0.93	4.76	2.58	1.92	5.22	3.64	6.35
	3/3	0.46	2.18	0.33	5.36	1.92	0.93	4.76	2.58	1.98	4.89	3.64	6.15
	2/4	0.46	2.18	0.33	5.36	1.92	0.93	4.63	2.58	1.92	4.83	3.51	6.22
	0/6	0.46	2.18	0.26	5.36	1.92	0.86	4.63	2.65	1.98	4.89	3.44	5.95
30°	6/0	0.53	2.65	0.40	5.95	2.51	1.26	5.95	3.84	2.51	6.28	5.03	7.94
	4/2	0.53	2.65	0.33	5.95	2.45	1.26	5.89	3.44	2.45	6.48	4.76	7.28
	3/3	0.53	2.65	0.40	5.95	2.51	1.26	5.89	3.51	2.31	6.22	4.50	7.14
	2/4	0.53	2.65	0.40	5.95	2.51	1.26	5.69	3.24	2.45	6.15	4.50	7.01
	0/6	0.53	2.65	0.33	5.95	2.45	1.06	5.82	3.04	2.38	6.08	4.17	6.68
15°	6/0	0.66	3.11	0.66	6.94	3.11	1.79	6.68	4.50	2.78	7.14	5.49	8.66
	4/2	0.66	3.11	0.46	6.94	3.04	1.59	6.61	4.17	2.65	6.81	5.29	8.27
	3/3	0.66	3.11	0.53	6.94	3.11	1.65	6.55	4.10	2.58	6.61	5.09	8.13
	2/4	0.66	3.11	0.53	6.94	3.04	1.52	6.55	4.10	2.51	6.81	5.22	8.00
	0/6	0.66	3.11	0.53	6.94	2.91	1.39	6.48	3.97	2.45	6.61	4.96	7.74
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Relative Overheating Time (%)													
Tilt	Distribution	West											
45°	6/0	0.26	0.66	0.20	2.31	0.60	0.26	2.38	1.65	1.12	2.84	2.65	3.37
	4/2	0.26	0.66	0.20	2.31	0.73	0.26	2.45	1.72	1.12	2.98	2.58	3.57
	3/3	0.26	0.66	0.20	2.31	0.60	0.26	2.45	1.65	1.12	2.71	2.51	3.44
	2/4	0.26	0.66	0.20	2.31	0.60	0.26	2.45	1.59	1.06	2.71	2.58	3.37
	0/6	0.26	0.66	0.20	2.31	0.60	0.26	2.45	1.79	1.06	2.78	2.65	3.31
30°	6/0	0.33	0.93	0.26	2.65	1.19	0.46	2.71	2.25	1.59	3.17	2.84	3.90
	4/2	0.33	0.93	0.20	2.65	1.12	0.46	2.84	2.38	1.59	3.24	2.71	4.17
	3/3	0.33	0.93	0.20	2.65	1.12	0.46	2.91	2.38	1.65	3.17	2.78	4.10
	2/4	0.33	0.93	0.20	2.65	1.06	0.46	2.84	2.38	1.72	3.24	2.78	3.97
	0/6	0.33	0.93	0.20	2.65	1.06	0.46	2.78	2.38	1.85	3.31	2.71	3.84
15°	6/0	0.33	1.19	0.26	2.91	1.39	0.73	2.98	2.38	2.12	3.64	3.04	4.83
	4/2	0.33	1.19	0.26	2.91	1.39	0.66	3.11	2.45	2.18	3.64	3.04	4.89
	3/3	0.33	1.19	0.26	2.91	1.39	0.66	3.04	2.51	2.18	3.64	2.98	5.03
	2/4	0.33	1.19	0.26	2.91	1.46	0.66	3.04	2.51	2.25	3.64	2.98	5.03
	0/6	0.33	1.19	0.26	2.91	1.46	0.66	2.98	2.51	2.25	3.44	2.91	4.76
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	North											
45°	6/0	19.44	39.73	26.89	52.56	46.37	51.21	60.83	61.98	67.05	69.65	74.25	77.22
	4/2	19.44	39.73	34.17	52.56	47.97	58.79	61.56	67.21	72.10	73.52	77.65	79.17
	3/3	19.44	39.73	36.29	52.56	51.43	61.57	61.71	68.43	74.11	73.54	79.14	80.76
	2/4	19.44	39.73	37.17	52.56	53.51	63.68	63.27	69.95	74.75	74.67	78.60	81.62
	0/6	19.44	39.73	40.73	52.56	55.78	67.67	64.51	72.33	77.27	76.44	80.95	82.62
30°	6/0	24.51	41.68	36.21	57.13	50.51	54.00	62.48	66.30	69.84	71.84	76.25	79.95
	4/2	24.51	41.68	35.62	57.13	55.48	64.41	64.37	70.40	75.29	74.56	79.65	82.22
	3/3	24.51	41.68	41.30	57.13	56.03	66.67	64.49	71.73	77.56	77.25	80.97	83.14
	2/4	24.51	41.68	44.21	57.13	57.17	67.06	68.65	73.44	78.63	77.75	82.13	84.14
	0/6	24.51	41.68	45.46	57.13	59.40	71.10	69.33	75.54	80.75	79.76	83.33	85.08
15°	6/0	27.57	43.70	39.92	59.03	55.68	58.75	63.17	67.29	70.35	72.83	75.86	79.16
	4/2	27.57	43.70	44.75	59.03	58.22	65.49	66.37	72.46	77.46	77.13	80.95	83.67
	3/3	27.57	43.70	43.14	59.03	59.76	68.67	68.68	74.05	79.17	79.51	82.43	84.89
	2/4	27.57	43.70	49.27	59.03	59.57	70.14	69.68	76.33	80.22	80.33	83.86	85.83
	0/6	27.57	43.70	52.79	59.03	63.56	72.24	70.92	78.54	82.19	81.86	84.62	86.68
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	East											
45°	6/0	38.62	52.46	47.14	64.19	60.32	62.73	68.40	72.11	75.46	76.97	80.67	82.92
	4/2	38.62	52.46	46.73	64.19	59.27	64.52	67.97	72.14	73.92	76.14	79.46	82.60
	3/3	38.62	52.46	44.32	64.19	61.08	63.73	67.35	70.21	74.24	77.30	78.54	82.63
	2/4	38.62	52.46	45.51	64.19	58.73	63.43	69.87	72.00	74.02	76.17	78.90	82.08
	0/6	38.62	52.46	43.32	64.19	59.97	62.08	68.76	70.27	74.37	77.33	79.10	82.33
30°	6/0	38.05	55.13	49.14	65.63	62.59	67.03	70.60	74.35	77.24	77.92	80.94	84.02
	4/2	38.05	55.13	50.44	65.63	62.75	67.60	70.08	75.10	78.02	79.57	82.05	84.67
	3/3	38.05	55.13	50.63	65.63	64.70	68.40	71.03	75.75	78.59	79.92	82.44	84.37
	2/4	38.05	55.13	52.63	65.63	64.90	69.65	71.21	75.30	78.89	79.76	83.22	85.11
	0/6	38.05	55.13	51.68	65.63	65.43	68.67	71.37	77.16	79.41	80.48	83.54	85.86
15°	6/0	38.51	55.73	48.68	66.90	61.90	64.97	70.59	73.59	75.94	78.24	79.92	83.19
	4/2	38.51	55.73	53.78	66.90	66.60	69.76	72.05	76.48	79.40	80.44	83.24	85.56
	3/3	38.51	55.73	55.68	66.90	66.89	71.70	73.17	77.54	80.17	81.65	84.40	86.37
	2/4	38.51	55.73	55.40	66.90	68.27	71.81	73.57	77.76	81.21	82.06	84.65	87.03
	0/6	38.51	55.73	58.79	66.90	68.49	73.89	75.16	80.63	82.30	82.95	85.75	87.73
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	South											
45°	6/0	53.60	67.40	63.11	73.30	70.51	74.73	77.25	79.25	80.87	82.52	84.13	86.11
	4/2	53.60	67.40	61.56	73.30	70.83	72.62	76.14	77.87	80.16	81.63	83.14	85.25
	3/3	53.60	67.40	59.90	73.30	70.98	72.54	76.57	77.57	78.27	80.92	82.37	84.62
	2/4	53.60	67.40	59.95	73.30	70.11	71.54	76.37	77.32	78.13	81.24	81.87	84.57
	0/6	53.60	67.40	58.79	73.30	70.29	69.75	76.56	76.14	75.56	81.05	81.30	83.98
30°	6/0	55.13	68.89	65.24	75.71	72.44	76.32	78.16	80.37	82.33	83.19	85.08	86.60
	4/2	55.13	68.89	63.68	75.71	73.71	75.02	78.30	80.29	81.59	83.03	84.84	86.52
	3/3	55.13	68.89	64.52	75.71	72.73	75.98	77.84	80.37	81.79	83.56	85.27	86.73
	2/4	55.13	68.89	64.65	75.71	73.41	75.49	78.71	80.17	81.17	83.48	84.65	86.65
	0/6	55.13	68.89	64.52	75.71	73.98	75.38	77.71	80.33	81.38	82.94	84.60	86.75
15°	6/0	56.30	68.97	65.48	75.35	73.56	74.83	78.21	79.95	81.59	82.21	84.08	86.22
	4/2	56.30	68.97	64.75	75.35	74.70	76.65	79.13	80.73	82.63	83.87	85.40	87.16
	3/3	56.30	68.97	65.95	75.35	74.56	76.76	78.60	81.41	83.30	84.27	86.11	87.51
	2/4	56.30	68.97	66.06	75.35	75.35	77.03	79.37	81.57	83.10	84.49	86.05	87.89
	0/6	56.30	68.97	67.94	75.35	75.60	77.97	79.87	82.32	83.21	85.02	86.54	88.38
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	West											
45°	6/0	28.73	47.24	41.87	59.92	53.79	58.92	64.19	69.03	74.38	74.56	78.90	81.71
	4/2	28.73	47.24	43.11	59.92	57.62	61.86	65.94	70.54	73.44	74.52	77.92	80.48
	3/3	28.73	47.24	41.75	59.92	59.21	62.83	65.90	69.21	74.21	74.10	77.95	80.76
	2/4	28.73	47.24	42.71	59.92	57.76	62.05	67.48	70.14	74.05	75.57	78.02	81.70
	0/6	28.73	47.24	42.21	59.92	58.21	63.37	66.54	70.06	73.52	74.59	78.22	81.16
30°	6/0	30.92	51.60	41.87	63.52	59.19	63.86	67.22	71.90	76.30	76.87	80.97	82.43
	4/2	30.92	51.60	48.10	63.52	61.14	66.83	69.02	72.41	76.89	77.84	80.63	84.06
	3/3	30.92	51.60	47.11	63.52	60.02	67.90	69.98	74.05	77.35	78.68	81.30	83.90
	2/4	30.92	51.60	49.89	63.52	61.65	68.24	70.33	74.84	78.22	79.00	82.13	84.03
	0/6	30.92	51.60	50.35	63.52	63.06	68.62	70.59	76.24	79.97	79.67	83.19	85.40
15°	6/0	36.52	52.48	46.94	62.35	58.32	64.02	67.32	71.11	74.67	75.79	78.83	82.00
	4/2	36.52	52.48	49.56	62.35	62.54	70.05	68.97	74.46	79.02	78.78	82.16	83.98
	3/3	36.52	52.48	51.25	62.35	63.83	71.19	69.71	76.13	80.14	79.97	83.10	85.43
	2/4	36.52	52.48	52.65	62.35	62.38	70.63	71.37	77.56	81.08	81.10	84.00	86.11
	0/6	36.52	52.48	53.71	62.35	65.79	72.17	73.56	79.33	82.22	82.11	85.19	87.35
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	North											
45°	6/0	12.89	30.10	21.92	41.49	34.17	37.35	46.52	48.98	53.63	59.17	63.33	69.54
	4/2	12.89	30.10	22.95	41.49	39.54	47.19	48.03	56.44	63.97	63.84	69.30	73.32
	3/3	12.89	30.10	26.51	41.49	41.38	49.92	50.54	59.40	65.92	65.63	71.52	74.76
	2/4	12.89	30.10	23.63	41.49	41.70	52.33	51.65	63.24	68.00	66.81	72.21	75.95
	0/6	12.89	30.10	27.81	41.49	42.86	56.40	55.10	64.60	70.03	69.41	74.86	76.92
30°	6/0	16.24	29.22	24.44	45.89	40.48	41.25	55.46	56.71	57.84	64.30	66.84	71.83
	4/2	16.24	29.22	26.63	45.89	45.56	50.17	53.76	62.37	68.56	68.54	73.57	76.44
	3/3	16.24	29.22	27.92	45.89	45.17	54.54	56.70	65.60	71.03	68.95	74.97	78.57
	2/4	16.24	29.22	27.32	45.89	46.37	58.02	59.49	66.79	71.22	70.84	76.51	78.95
	0/6	16.24	29.22	35.48	45.89	50.06	61.43	58.75	69.30	74.68	74.10	77.90	80.67
15°	6/0	15.89	33.63	29.06	48.87	42.41	47.14	55.40	56.89	62.16	63.17	69.51	72.37
	4/2	15.89	33.63	32.25	48.87	44.57	54.73	57.94	65.78	68.98	69.62	74.49	78.37
	3/3	15.89	33.63	28.92	48.87	49.24	57.84	58.57	65.08	72.62	71.29	76.75	79.87
	2/4	15.89	33.63	33.63	48.87	49.54	61.67	60.78	67.67	74.57	73.46	78.70	80.49
	0/6	15.89	33.63	41.44	48.87	55.81	63.10	62.73	70.48	75.97	76.21	79.63	82.62
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	East											
45°	6/0	24.62	43.25	33.22	56.94	49.81	50.40	61.70	63.02	65.65	69.14	73.81	77.59
	4/2	24.62	43.25	31.90	56.94	50.81	49.94	61.29	63.25	64.03	69.63	72.33	75.90
	3/3	24.62	43.25	31.03	56.94	50.25	50.27	61.57	63.76	66.54	68.98	72.16	76.79
	2/4	24.62	43.25	29.54	56.94	53.49	49.56	59.16	64.00	63.05	70.78	71.57	75.52
	0/6	24.62	43.25	28.03	56.94	54.25	52.37	59.46	61.94	64.40	69.62	71.38	75.19
30°	6/0	25.75	48.24	38.81	61.10	53.32	57.03	63.08	67.24	69.71	72.11	74.24	79.14
	4/2	25.75	48.24	39.02	61.10	55.60	60.29	64.17	68.24	70.90	72.59	76.13	79.79
	3/3	25.75	48.24	37.83	61.10	56.06	59.87	65.63	68.68	70.87	73.24	76.52	80.44
	2/4	25.75	48.24	37.37	61.10	55.65	58.17	64.90	68.35	71.92	74.19	77.08	80.37
	0/6	25.75	48.24	35.87	61.10	57.75	58.35	65.38	67.46	70.73	74.71	78.00	80.67
15°	6/0	28.48	46.97	36.78	61.13	51.92	57.02	66.27	64.83	67.75	71.43	73.81	77.54
	4/2	28.48	46.97	41.67	61.13	56.89	59.97	65.90	67.94	72.06	73.84	76.02	79.95
	3/3	28.48	46.97	43.87	61.13	58.29	63.21	65.13	69.16	73.32	75.03	79.14	81.84
	2/4	28.48	46.97	43.27	61.13	59.94	62.13	66.14	70.21	73.81	76.51	78.79	82.62
	0/6	28.48	46.97	45.00	61.13	58.37	62.86	67.16	71.75	74.16	77.84	80.67	83.65
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	South											
45°	6/0	41.24	59.14	53.14	68.13	65.57	68.76	72.52	73.44	76.00	77.90	79.97	82.25
	4/2	41.24	59.14	52.25	68.13	65.63	65.08	71.21	71.97	73.92	76.33	78.11	81.21
	3/3	41.24	59.14	46.46	68.13	64.03	62.95	70.43	72.33	73.02	75.78	77.51	80.46
	2/4	41.24	59.14	46.75	68.13	64.25	61.33	71.78	70.63	72.06	76.21	76.70	80.48
	0/6	41.24	59.14	46.19	68.13	63.98	58.44	70.40	69.97	69.52	76.10	75.30	79.11
30°	6/0	42.75	61.14	54.92	70.62	67.38	69.62	73.29	75.67	77.02	79.25	80.67	83.24
	4/2	42.75	61.14	54.32	70.62	66.30	67.57	74.05	75.00	76.97	78.59	80.17	82.92
	3/3	42.75	61.14	52.95	70.62	67.67	68.14	73.41	74.97	76.06	78.25	80.46	83.11
	2/4	42.75	61.14	54.41	70.62	67.29	67.05	74.44	75.65	76.57	79.03	80.17	83.05
	0/6	42.75	61.14	54.02	70.62	65.59	66.06	73.33	74.75	74.51	79.35	80.08	82.63
15°	6/0	47.76	65.21	54.81	70.90	67.10	67.37	73.84	74.84	75.67	78.35	79.70	82.33
	4/2	47.76	65.21	55.41	70.90	67.48	69.49	74.17	76.52	77.62	79.54	80.95	84.05
	3/3	47.76	65.21	58.10	70.90	68.41	70.95	74.63	76.56	78.19	79.68	81.95	84.59
	2/4	47.76	65.21	57.51	70.90	68.48	70.13	74.65	77.11	77.90	80.95	82.57	84.35
	0/6	47.76	65.21	56.84	70.90	69.51	70.84	74.81	77.75	78.21	81.29	82.29	85.08
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Average Daylight Autonomy (%)													
Tilt	Distrib.	West											
45°	6/0	21.79	34.52	26.62	48.68	45.13	47.30	50.65	57.60	63.62	67.13	70.63	74.71
	4/2	21.79	34.52	28.89	48.68	46.27	49.95	56.25	60.14	62.71	66.62	69.86	74.06
	3/3	21.79	34.52	24.05	48.68	46.79	51.05	54.13	61.08	63.75	67.21	69.32	74.25
	2/4	21.79	34.52	29.62	48.68	44.43	51.08	57.90	61.05	63.75	66.48	70.59	73.92
	0/6	21.79	34.52	28.14	48.68	46.29	50.97	55.13	61.94	65.02	67.05	69.68	75.08
30°	6/0	22.81	41.10	34.46	52.65	50.05	52.63	57.52	60.60	66.81	69.52	72.79	76.52
	4/2	22.81	41.10	32.73	52.65	52.29	56.17	60.35	66.89	67.59	69.63	75.24	78.29
	3/3	22.81	41.10	34.30	52.65	53.08	56.16	61.94	66.62	69.33	69.30	75.05	78.87
	2/4	22.81	41.10	33.03	52.65	51.56	58.89	61.95	65.98	69.30	72.19	75.21	79.17
	0/6	22.81	41.10	36.27	52.65	54.16	57.44	63.02	67.19	71.13	73.44	77.10	79.17
15°	6/0	21.81	36.94	35.41	54.57	50.25	53.78	61.52	62.60	65.13	68.19	71.60	75.17
	4/2	21.81	36.94	38.81	54.57	56.87	56.63	60.81	67.54	72.03	71.90	75.76	79.51
	3/3	21.81	36.94	33.38	54.57	50.57	60.81	62.00	68.29	72.11	72.54	77.21	81.29
	2/4	21.81	36.94	38.73	54.57	53.63	62.41	64.92	70.11	74.35	74.13	77.62	81.78
	0/6	21.81	36.94	43.57	54.57	57.29	64.14	64.84	69.56	73.73	76.38	79.70	82.19
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Optimally Day-lit Area (%)													
Tilt	Distrib.	North											
45°	6/0	19.94	36.11	24.21	47.52	44.54	89.98	58.63	97.52	89.98	92.46	97.52	92.46
	4/2	19.94	36.11	28.87	47.52	52.28	86.41	63.39	83.73	86.41	76.88	83.73	76.88
	3/3	19.94	36.11	29.76	47.52	52.18	77.08	64.19	70.34	77.08	63.89	70.34	63.89
	2/4	19.94	36.11	32.64	47.52	55.16	69.05	67.66	65.38	69.05	60.32	65.38	60.32
	0/6	19.94	36.11	33.33	47.52	61.01	61.90	68.65	58.13	61.90	52.88	58.13	52.88
30°	6/0	20.34	39.29	32.44	50.89	52.78	60.12	62.20	71.53	87.70	84.62	89.48	83.43
	4/2	20.34	39.29	34.52	50.89	56.65	75.40	67.56	81.15	81.05	79.37	73.21	64.58
	3/3	20.34	39.29	39.29	50.89	59.13	77.98	71.63	82.14	69.05	77.68	63.59	57.84
	2/4	20.34	39.29	41.87	50.89	62.20	76.39	71.73	77.08	60.22	70.73	53.77	49.60
	0/6	20.34	39.29	43.55	50.89	63.49	75.40	70.24	74.31	51.69	69.15	47.02	43.06
15°	6/0	24.01	40.38	40.87	52.38	52.38	61.11	61.90	64.09	66.37	73.12	70.73	72.22
	4/2	24.01	40.38	44.44	52.38	58.53	76.29	70.34	81.05	70.34	78.77	65.77	61.51
	3/3	24.01	40.38	47.62	52.38	62.70	82.44	71.63	81.35	66.77	77.68	60.71	53.57
	2/4	24.01	40.38	41.57	52.38	69.15	83.33	78.77	80.95	60.42	73.71	52.28	47.12
	0/6	24.01	40.38	48.91	52.38	71.63	72.82	82.44	69.35	51.29	66.17	44.25	38.69
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Optimally Day-lit Area (%)													
Tilt	Distrib.	East											
45°	6/0	17.96	25.10	28.08	44.15	39.88	59.23	64.88	67.16	65.08	62.80	50.99	39.29
	4/2	17.96	25.10	28.08	44.15	41.37	67.66	63.79	68.95	72.82	65.67	59.92	50.69
	3/3	17.96	25.10	29.66	44.15	39.38	63.10	60.12	66.77	69.74	64.78	61.71	53.17
	2/4	17.96	25.10	29.56	44.15	41.07	66.67	65.08	68.55	74.01	67.16	65.58	56.75
	0/6	17.96	25.10	29.07	44.15	42.86	64.78	64.48	67.06	68.75	66.77	64.09	58.33
30°	6/0	20.73	27.78	36.31	50.20	44.74	59.72	64.29	62.60	53.87	57.04	43.25	32.74
	4/2	20.73	27.78	38.00	50.20	50.40	68.95	65.58	65.97	59.42	60.32	48.51	38.99
	3/3	20.73	27.78	37.00	50.20	48.81	70.63	67.06	66.17	61.61	61.11	51.98	44.44
	2/4	20.73	27.78	40.77	50.20	53.37	75.60	68.85	70.14	65.28	62.90	54.17	47.22
	0/6	20.73	27.78	42.56	50.20	54.96	80.46	69.35	71.92	66.67	64.19	55.95	48.12
15°	6/0	23.71	30.95	36.21	61.81	43.35	49.70	59.92	54.86	48.91	54.86	45.83	37.20
	4/2	23.71	30.95	42.56	61.81	49.90	66.17	65.18	61.31	51.29	53.87	44.84	37.90
	3/3	23.71	30.95	40.48	61.81	54.56	71.43	66.57	64.09	54.46	56.75	45.83	38.69
	2/4	23.71	30.95	50.30	61.81	59.13	78.37	67.26	67.26	54.96	58.93	42.66	34.52
	0/6	23.71	30.95	52.58	61.81	70.93	82.94	70.24	69.84	53.87	61.11	40.67	29.07
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Optimally Day-lit Area (%)													
Tilt	Distrib.	South											
45°	6/0	31.05	56.15	53.77	57.14	58.04	57.24	50.10	36.21	25.69	19.74	6.65	0.20
	4/2	31.05	56.15	53.67	57.14	58.33	64.68	54.17	47.02	44.74	31.45	23.91	9.33
	3/3	31.05	56.15	46.63	57.14	59.42	70.14	54.96	53.47	56.85	38.10	30.85	14.29
	2/4	31.05	56.15	44.15	57.14	60.12	71.23	56.15	57.74	66.37	49.31	48.21	29.96
	0/6	31.05	56.15	41.17	57.14	60.32	68.85	57.04	62.30	77.48	56.94	62.00	56.35
30°	6/0	36.81	61.81	57.04	57.14	57.14	54.07	48.31	32.34	14.58	19.25	7.44	2.28
	4/2	36.81	61.81	60.32	57.14	59.42	62.30	52.58	42.06	29.37	23.91	13.79	5.85
	3/3	36.81	61.81	56.94	57.14	61.11	69.54	54.46	51.59	45.83	36.21	25.79	9.92
	2/4	36.81	61.81	60.22	57.14	61.61	73.31	55.56	53.67	58.73	37.60	35.52	17.86
	0/6	36.81	61.81	53.57	57.14	62.30	78.37	56.85	62.10	78.17	55.85	61.61	55.46
15°	6/0	37.40	58.83	45.24	56.65	55.16	44.05	46.13	31.94	20.73	22.02	15.38	14.29
	4/2	37.40	58.83	59.82	56.65	58.83	62.20	50.10	45.04	28.47	31.85	15.58	8.04
	3/3	37.40	58.83	63.19	56.65	59.92	67.96	52.68	50.60	37.50	35.71	22.32	11.61
	2/4	37.40	58.83	67.26	56.65	61.31	72.22	53.08	53.37	48.61	38.69	27.58	14.58
	0/6	37.40	58.83	69.74	56.65	62.40	76.09	56.25	60.52	70.04	52.58	50.79	36.81
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Optimally Day-lit Area (%)													
Tilt	Distrib.	West											
45°	6/0	20.54	29.17	28.08	43.55	40.48	61.11	55.16	70.44	80.36	75.30	70.73	61.01
	4/2	20.54	29.17	33.63	43.55	44.54	66.17	57.94	73.12	80.26	75.60	72.42	67.06
	3/3	20.54	29.17	34.03	43.55	44.05	67.16	62.30	72.92	76.59	74.01	70.44	62.60
	2/4	20.54	29.17	32.04	43.55	52.08	68.75	60.52	72.72	79.07	75.20	73.91	67.56
	0/6	20.54	29.17	33.13	43.55	46.43	68.75	59.42	71.83	69.74	74.21	67.66	63.29
30°	6/0	22.12	32.54	36.90	45.73	46.43	62.50	57.74	71.63	66.27	68.06	54.46	48.91
	4/2	22.12	32.54	39.58	45.73	51.59	72.82	66.17	74.60	68.45	70.44	57.94	50.79
	3/3	22.12	32.54	40.87	45.73	54.96	77.58	69.25	74.40	71.92	69.94	59.23	50.60
	2/4	22.12	32.54	41.67	45.73	59.03	76.98	72.42	76.98	69.35	72.52	61.81	55.65
	0/6	22.12	32.54	38.00	45.73	62.70	82.54	73.61	77.38	66.96	72.42	60.32	54.37
15°	6/0	22.72	37.40	43.45	49.11	47.12	52.28	64.19	55.46	49.80	62.80	51.59	47.72
	4/2	22.72	37.40	40.97	49.11	58.13	72.12	67.86	69.05	55.65	64.88	51.19	45.34
	3/3	22.72	37.40	48.31	49.11	62.50	76.88	71.53	72.72	58.04	64.98	49.80	44.84
	2/4	22.72	37.40	49.40	49.11	67.56	82.94	75.10	74.90	59.23	67.66	46.43	39.29
	0/6	22.72	37.40	58.83	49.11	77.18	84.33	78.08	74.50	56.45	68.35	42.86	34.33
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Optimally Day-lit Area (%)

Tilt	Distrib.	North											
45°	6/0	11.61	26.19	12.00	39.98	31.55	67.66	43.65	86.81	67.66	95.44	86.81	95.44
	4/2	11.61	26.19	12.40	39.98	32.64	77.58	47.22	86.51	77.58	90.28	86.51	90.28
	3/3	11.61	26.19	16.87	39.98	39.09	75.79	53.57	82.14	75.79	82.74	82.14	82.74
	2/4	11.61	26.19	18.25	39.98	38.89	69.94	51.29	74.70	69.94	76.29	74.70	76.29
	0/6	11.61	26.19	18.06	39.98	38.79	68.15	54.37	71.03	68.15	68.75	71.03	68.75
30°	6/0	13.59	29.96	16.37	39.29	39.38	43.06	53.67	60.91	71.13	74.60	85.62	95.14
	4/2	13.59	29.96	18.45	39.29	39.29	61.01	58.33	71.73	84.92	81.94	87.40	88.00
	3/3	13.59	29.96	21.03	39.29	41.87	63.00	58.73	76.49	76.39	87.80	78.17	76.88
	2/4	13.59	29.96	21.13	39.29	39.88	68.06	62.90	80.16	70.63	83.04	69.35	66.96
	0/6	13.59	29.96	21.33	39.29	44.44	76.29	64.09	83.43	68.95	84.13	66.96	62.60
15°	6/0	11.81	29.27	25.69	42.86	43.25	51.69	55.46	61.90	66.77	70.04	70.04	76.39
	4/2	11.81	29.27	19.84	42.86	43.85	64.78	62.20	81.15	84.52	87.20	84.03	77.98
	3/3	11.81	29.27	23.91	42.86	38.99	67.46	66.47	84.03	82.94	88.79	82.04	75.30
	2/4	11.81	29.27	23.21	42.86	49.60	76.09	68.45	87.60	75.89	89.78	74.40	68.85
	0/6	11.81	29.27	20.34	42.86	57.44	74.50	74.90	81.45	64.09	81.05	63.29	61.90
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Optimally Day-lit Area (%)

Tilt	Distrib.	East											
45°	6/0	12.70	23.81	18.25	36.61	34.23	44.35	49.80	62.60	80.56	72.72	75.69	65.77
	4/2	12.70	23.81	18.06	36.61	30.26	51.98	47.62	58.04	79.76	71.73	78.47	70.54
	3/3	12.70	23.81	17.96	36.61	33.43	51.49	52.88	62.00	70.44	71.92	73.81	68.35
	2/4	12.70	23.81	17.36	36.61	33.93	51.59	48.61	58.83	75.30	74.50	76.39	72.92
	0/6	12.70	23.81	19.44	36.61	31.05	50.79	50.40	61.01	72.42	70.24	71.43	71.13
30°	6/0	14.58	27.68	22.32	47.82	37.60	55.85	53.77	62.80	70.24	69.25	65.67	56.65
	4/2	14.58	27.68	18.85	47.82	45.34	56.25	58.83	69.94	74.11	70.63	67.26	60.81
	3/3	14.58	27.68	19.74	47.82	37.70	55.85	57.54	70.24	77.58	70.83	69.15	61.81
	2/4	14.58	27.68	21.73	47.82	45.04	62.60	62.10	77.28	78.87	73.41	71.03	63.89
	0/6	14.58	27.68	21.92	47.82	43.65	71.03	64.38	80.46	84.23	76.59	75.10	65.38
15°	6/0	14.68	27.78	32.64	42.76	40.18	52.38	54.07	52.18	52.08	63.29	54.96	52.68
	4/2	14.68	27.78	22.72	42.76	46.33	67.26	58.53	68.85	69.15	69.35	63.39	54.96
	3/3	14.68	27.78	29.66	42.76	45.54	71.53	66.57	75.99	75.79	71.03	64.88	56.35
	2/4	14.68	27.78	28.67	42.76	50.50	77.18	68.95	80.26	79.96	72.92	70.83	59.13
	0/6	14.68	27.78	29.27	42.76	58.33	84.62	73.71	86.41	81.65	74.90	72.52	60.42
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Optimally Day-lit Area (%)													
Tilt	Distrib.	South											
45°	6/0	19.25	38.49	38.39	61.61	60.91	66.47	58.53	53.47	54.86	42.56	33.13	18.15
	4/2	19.25	38.49	31.35	61.61	59.13	64.48	59.92	62.00	60.81	52.68	44.54	32.94
	3/3	19.25	38.49	34.23	61.61	51.98	64.98	60.91	65.87	67.86	56.25	53.77	41.57
	2/4	19.25	38.49	34.13	61.61	57.74	62.90	60.81	66.77	74.40	58.13	62.10	52.88
	0/6	19.25	38.49	26.98	61.61	51.98	54.27	61.11	65.77	73.12	61.81	71.83	61.61
30°	6/0	25.10	54.46	43.15	61.31	61.11	68.55	58.13	56.85	50.10	41.96	24.80	14.68
	4/2	25.10	54.46	42.36	61.31	62.20	65.58	60.71	59.13	54.96	49.80	35.81	22.82
	3/3	25.10	54.46	45.24	61.31	63.49	73.21	61.21	64.88	63.59	55.36	48.02	36.71
	2/4	25.10	54.46	39.78	61.31	61.21	72.02	61.01	67.46	76.09	57.04	61.21	45.24
	0/6	25.10	54.46	42.76	61.31	62.30	78.47	61.61	73.61	83.53	61.41	71.53	61.21
15°	6/0	32.34	45.93	37.60	61.21	59.03	49.01	59.03	48.71	38.19	39.98	26.98	20.04
	4/2	32.34	45.93	44.44	61.21	60.91	67.06	59.62	60.81	59.92	51.98	42.26	29.46
	3/3	32.34	45.93	48.71	61.21	62.30	74.40	60.52	65.28	68.55	55.26	51.59	37.60
	2/4	32.34	45.93	47.32	61.21	66.27	79.27	61.41	69.15	75.69	58.73	59.33	45.24
	0/6	32.34	45.93	49.01	61.21	68.65	82.64	61.51	71.83	82.24	61.31	69.44	58.83
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Optimally Day-lit Area (%)													
Tilt	Distrib.	West											
45°	6/0	13.29	25.79	16.57	35.81	32.34	36.11	45.63	60.62	84.52	73.41	84.92	80.06
	4/2	13.29	25.79	19.44	35.81	37.80	51.59	44.74	63.10	78.87	68.45	83.93	81.15
	3/3	13.29	25.79	19.35	35.81	34.72	50.79	44.94	67.56	77.38	70.63	79.66	77.98
	2/4	13.29	25.79	17.36	35.81	38.59	51.29	41.77	64.09	75.00	70.83	79.76	79.66
	0/6	13.29	25.79	20.83	35.81	38.19	54.37	47.42	65.77	73.31	74.11	77.18	78.57
30°	6/0	15.77	29.27	26.59	37.60	39.38	50.60	49.80	64.38	73.51	68.55	76.29	69.84
	4/2	15.77	29.27	22.32	37.60	35.91	64.19	56.65	74.80	82.24	76.39	79.07	72.52
	3/3	15.77	29.27	24.80	37.60	42.56	68.35	59.03	77.78	81.75	77.28	79.07	73.12
	2/4	15.77	29.27	28.77	37.60	42.86	70.93	57.94	79.76	82.94	80.06	79.27	72.42
	0/6	15.77	29.27	23.81	37.60	50.10	78.77	64.19	82.64	81.45	82.14	77.28	71.53
15°	6/0	16.96	28.57	31.75	40.67	44.05	53.57	52.28	58.33	55.95	59.72	53.27	58.13
	4/2	16.96	28.57	29.46	40.67	45.63	68.65	55.65	73.02	76.98	74.90	71.23	64.78
	3/3	16.96	28.57	30.16	40.67	53.87	74.31	56.15	81.15	80.85	78.47	73.71	65.48
	2/4	16.96	28.57	24.80	40.67	56.45	75.99	64.68	85.22	84.03	82.04	77.28	66.96
	0/6	16.96	28.57	30.16	40.67	57.64	88.59	74.11	89.68	83.93	83.13	76.88	69.05
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Over-lit Area (%)													
Tilt	Distrib.	North											
45°	6/0	0.00	0.00	0.00	0.89	0.00	0.00	2.38	1.69	0.00	7.54	1.69	7.54
	4/2	0.00	0.00	0.79	0.89	0.79	12.10	3.77	15.97	12.10	23.12	15.97	23.12
	3/3	0.00	0.00	0.40	0.89	1.19	21.33	4.56	29.56	21.33	36.11	29.56	36.11
	2/4	0.00	0.00	1.39	0.89	1.88	30.65	5.85	34.62	30.65	39.68	34.62	39.68
	0/6	0.00	0.00	3.37	0.89	3.47	38.10	9.03	41.87	38.10	47.12	41.87	47.12
30°	6/0	0.00	0.00	0.00	2.28	0.20	0.30	4.37	2.98	2.88	10.12	8.33	16.57
	4/2	0.00	0.00	0.60	2.28	1.98	5.36	5.85	9.23	17.26	16.96	26.49	35.42
	3/3	0.00	0.00	0.79	2.28	1.88	7.94	7.54	13.29	30.56	21.03	36.31	42.16
	2/4	0.00	0.00	2.18	2.28	3.67	15.67	8.13	19.84	39.78	29.17	46.23	50.40
	0/6	0.00	0.00	3.77	2.28	6.45	21.83	12.60	25.10	48.31	30.85	52.98	56.94
15°	6/0	0.00	0.00	0.00	2.88	2.08	4.86	8.73	10.42	16.57	15.97	22.32	27.78
	4/2	0.00	0.00	0.50	2.88	1.49	5.95	8.33	12.60	27.68	17.96	33.53	38.49
	3/3	0.00	0.00	1.49	2.88	2.78	10.22	9.13	16.27	33.23	22.02	39.29	46.43
	2/4	0.00	0.00	0.99	2.88	2.68	13.49	9.42	17.86	39.58	26.29	47.72	52.88
	0/6	0.00	0.00	4.17	2.88	5.65	26.59	12.60	30.65	48.71	33.83	55.75	61.31
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Over-lit Area (%)													
Tilt	Distrib.	East											
45°	6/0	10.12	19.44	10.62	27.48	20.83	15.97	28.77	29.66	34.62	37.20	49.01	60.71
	4/2	10.12	19.44	10.71	27.48	21.13	15.08	28.67	26.79	26.09	34.23	40.08	49.31
	3/3	10.12	19.44	10.91	27.48	21.03	17.76	28.47	27.98	29.27	35.02	38.29	46.83
	2/4	10.12	19.44	10.71	27.48	20.93	15.18	28.17	25.89	23.81	32.54	34.42	43.25
	0/6	10.12	19.44	11.31	27.48	21.43	15.77	28.17	26.09	27.28	32.84	35.71	41.67
30°	6/0	10.02	19.94	11.31	27.98	23.02	22.52	30.36	33.23	46.03	42.96	56.75	67.26
	4/2	10.02	19.94	11.21	27.98	23.02	20.24	30.26	32.24	39.98	39.68	51.49	61.01
	3/3	10.02	19.94	12.40	27.98	23.12	19.84	30.36	32.54	38.29	38.89	48.02	55.56
	2/4	10.02	19.94	10.91	27.98	21.83	18.15	29.86	29.37	34.72	37.10	45.83	52.78
	0/6	10.02	19.94	10.62	27.98	21.23	16.07	28.77	27.78	33.33	35.81	44.05	51.88
15°	6/0	10.42	20.54	12.40	28.37	24.01	26.19	31.15	36.51	47.82	44.84	53.97	62.80
	4/2	10.42	20.54	12.20	28.37	24.50	25.99	31.25	36.61	48.31	46.13	55.16	62.10
	3/3	10.42	20.54	13.19	28.37	24.40	24.31	31.25	35.42	45.54	43.25	54.17	61.31
	2/4	10.42	20.54	12.40	28.37	23.61	20.14	30.85	32.74	45.04	41.07	57.34	65.48
	0/6	10.42	20.54	10.91	28.37	22.52	15.97	29.46	30.16	46.03	38.89	59.33	70.93
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Over-lit Area (%)													
Tilt	Distrib.	South											
45°	6/0	20.54	36.71	24.70	42.86	41.37	42.76	49.90	63.79	74.31	80.26	93.35	99.80
	4/2	20.54	36.71	22.82	42.86	39.29	34.72	45.83	52.98	55.26	68.55	76.09	90.67
	3/3	20.54	36.71	21.33	42.86	39.19	28.77	45.04	46.53	43.15	61.90	69.15	85.71
	2/4	20.54	36.71	21.33	42.86	38.00	25.50	43.85	42.26	33.63	50.69	51.79	70.04
	0/6	20.54	36.71	20.54	42.86	36.71	21.23	42.96	37.70	21.73	43.06	38.00	43.65
30°	6/0	20.54	36.90	25.79	42.86	42.56	45.83	51.69	67.66	85.42	80.75	92.56	97.72
	4/2	20.54	36.90	23.71	42.86	40.28	37.30	47.42	57.94	70.63	76.09	86.21	94.15
	3/3	20.54	36.90	21.63	42.86	38.69	30.26	45.54	48.41	54.17	63.79	74.21	90.08
	2/4	20.54	36.90	21.63	42.86	38.10	26.49	44.44	46.33	41.27	62.40	64.48	82.14
	0/6	20.54	36.90	20.63	42.86	37.00	21.13	43.15	37.90	21.83	44.15	38.39	44.54
15°	6/0	20.63	37.50	27.28	43.35	44.05	54.46	53.87	68.06	79.27	77.98	84.62	85.71
	4/2	20.63	37.50	23.41	43.35	40.38	37.20	49.90	54.96	71.53	68.15	84.42	91.96
	3/3	20.63	37.50	23.21	43.35	39.88	32.04	47.32	49.40	62.50	64.29	77.68	88.39
	2/4	20.63	37.50	21.63	43.35	38.49	27.78	46.92	46.63	51.39	61.31	72.42	85.42
	0/6	20.63	37.50	20.83	43.35	37.60	23.51	43.75	39.48	29.96	47.42	49.21	63.19
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Over-lit Area (%)													
Tilt	Distrib.	West											
45°	6/0	5.56	12.60	5.56	18.85	13.00	7.74	19.25	16.87	18.65	23.61	29.27	38.99
	4/2	5.56	12.60	5.75	18.85	13.39	9.52	19.15	18.45	18.75	23.81	27.48	32.94
	3/3	5.56	12.60	5.95	18.85	13.39	11.61	19.15	20.34	21.33	25.30	29.37	37.40
	2/4	5.56	12.60	5.75	18.85	13.59	10.52	19.74	17.56	19.64	23.12	25.89	32.44
	0/6	5.56	12.60	5.95	18.85	13.39	10.71	19.35	17.96	25.60	24.01	32.14	36.71
30°	6/0	5.56	12.50	5.85	18.65	15.48	12.10	20.34	22.72	33.33	31.25	45.54	51.09
	4/2	5.56	12.50	6.45	18.65	14.68	12.10	20.14	21.73	30.36	29.07	42.06	49.21
	3/3	5.56	12.50	6.65	18.65	15.18	13.49	21.73	23.02	27.88	29.96	40.77	49.40
	2/4	5.56	12.50	6.85	18.65	15.28	13.19	20.73	21.43	30.46	27.48	38.19	44.35
	0/6	5.56	12.50	6.55	18.65	13.99	12.90	19.74	22.22	32.94	27.58	39.68	45.63
15°	6/0	5.46	13.79	7.14	19.35	16.57	17.16	23.02	28.87	42.66	34.13	47.82	52.28
	4/2	5.46	13.79	6.75	19.35	16.87	17.16	22.42	27.08	43.45	35.02	48.81	54.66
	3/3	5.46	13.79	7.04	19.35	16.87	18.35	23.21	26.79	41.96	35.02	50.20	55.16
	2/4	5.46	13.79	7.04	19.35	16.27	14.88	21.53	25.10	40.77	32.34	53.57	60.71
	0/6	5.46	13.79	6.65	19.35	15.87	15.08	21.53	25.50	43.35	31.65	57.14	65.67
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Over-lit Area (%)													
Tilt	Distrib.	North											
45°	6/0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4/2	0.00	0.00	0.60	0.00	0.60	7.04	0.60	7.54	7.04	8.43	7.54	8.43
	3/3	0.00	0.00	0.20	0.00	0.20	13.79	0.20	14.48	13.79	16.37	14.48	16.37
	2/4	0.00	0.00	0.99	0.00	1.09	22.12	1.39	22.52	22.12	23.41	22.52	23.41
	0/6	0.00	0.00	1.49	0.00	2.58	27.28	2.98	27.98	27.28	31.25	27.98	31.25
30°	6/0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4/2	0.00	0.00	0.00	0.00	0.00	1.69	0.00	3.37	7.84	4.27	8.83	10.32
	3/3	0.00	0.00	0.00	0.00	0.00	3.47	0.00	4.07	18.55	5.06	19.84	22.82
	2/4	0.00	0.00	0.10	0.00	0.20	8.04	0.50	9.82	27.88	11.41	30.16	33.04
	0/6	0.00	0.00	2.38	0.00	2.48	11.41	3.08	11.90	30.95	14.68	33.04	37.40
15°	6/0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	2.28	2.78	7.14	13.99
	4/2	0.00	0.00	0.00	0.00	0.00	1.19	0.10	1.49	7.44	3.17	11.71	20.54
	3/3	0.00	0.00	0.99	0.00	0.99	4.17	0.99	4.56	14.58	5.95	17.36	24.70
	2/4	0.00	0.00	0.00	0.00	0.00	6.35	0.20	6.65	22.32	8.23	25.60	31.15
	0/6	0.00	0.00	0.69	0.00	0.69	15.77	1.09	17.66	34.92	18.95	36.71	38.10
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Over-lit Area (%)													
Tilt	Distrib.	East											
45°	6/0	6.05	11.51	6.25	18.75	11.61	7.24	19.54	14.38	13.99	24.01	23.41	34.23
	4/2	6.05	11.51	6.05	18.75	11.61	7.24	19.25	13.29	12.40	22.12	20.14	29.46
	3/3	6.05	11.51	6.15	18.75	11.90	7.44	19.64	14.88	14.58	23.51	23.02	31.55
	2/4	6.05	11.51	6.05	18.75	11.81	7.04	20.04	13.19	11.51	22.62	19.25	27.08
	0/6	6.05	11.51	6.25	18.75	12.00	6.85	19.94	14.88	10.62	22.92	20.73	28.37
30°	6/0	6.05	11.71	6.05	19.94	12.20	8.04	21.03	17.26	23.21	27.88	33.04	43.35
	4/2	6.05	11.71	6.25	19.94	11.81	8.63	20.93	17.76	20.34	26.98	30.85	39.19
	3/3	6.05	11.71	6.05	19.94	12.10	8.93	20.83	16.57	17.96	26.98	30.36	38.19
	2/4	6.05	11.71	6.45	19.94	12.30	8.04	20.63	15.77	17.76	25.50	28.67	36.11
	0/6	6.05	11.71	6.15	19.94	12.00	6.55	20.83	14.68	13.79	23.21	24.80	34.62
15°	6/0	6.05	11.71	6.55	20.54	13.39	11.21	22.72	21.13	26.79	29.66	38.00	47.22
	4/2	6.05	11.71	6.35	20.54	12.90	9.62	21.92	18.85	24.90	28.27	35.52	45.04
	3/3	6.05	11.71	6.55	20.54	13.10	9.72	22.82	19.64	22.12	28.17	34.92	43.65
	2/4	6.05	11.71	6.15	20.54	12.40	9.23	21.63	16.07	19.25	26.88	29.17	40.87
	0/6	6.05	11.71	6.25	20.54	11.81	7.14	21.23	13.29	16.47	25.10	27.48	39.58
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Over-lit Area (%)													
Tilt	Distrib.	South											
45°	6/0	15.48	24.01	17.26	38.10	28.67	31.45	41.47	46.53	44.94	57.44	66.87	81.85
	4/2	15.48	24.01	16.07	38.10	26.39	21.73	39.88	38.00	39.09	47.32	55.46	67.06
	3/3	15.48	24.01	15.77	38.10	24.90	17.36	39.09	33.23	31.25	43.75	46.23	58.43
	2/4	15.48	24.01	16.17	38.10	25.89	18.65	38.89	31.05	23.71	41.87	37.90	47.12
	0/6	15.48	24.01	15.48	38.10	24.70	15.77	37.90	25.60	15.67	38.10	27.58	38.39
30°	6/0	15.77	24.80	18.15	38.39	29.76	27.98	41.87	43.15	49.90	58.04	75.20	85.32
	4/2	15.77	24.80	15.67	38.39	26.69	25.89	39.29	40.87	45.04	50.20	64.19	77.18
	3/3	15.77	24.80	15.67	38.39	26.09	21.23	38.79	34.82	36.01	44.64	51.98	63.29
	2/4	15.77	24.80	15.67	38.39	26.69	19.15	38.79	32.54	23.81	42.96	38.79	54.76
	0/6	15.77	24.80	15.67	38.39	25.69	15.87	38.29	25.99	16.17	38.59	28.47	38.79
15°	6/0	15.67	25.69	16.47	38.49	30.16	32.44	40.97	50.00	60.81	60.02	73.02	79.96
	4/2	15.67	25.69	15.97	38.49	28.87	23.51	40.18	37.80	39.58	48.02	57.74	70.54
	3/3	15.67	25.69	17.06	38.49	28.17	21.23	39.48	34.72	31.45	44.74	48.41	62.40
	2/4	15.67	25.69	15.67	38.49	27.58	17.76	38.59	30.85	23.81	41.27	40.67	54.76
	0/6	15.67	25.69	15.77	38.49	25.99	15.58	38.49	28.17	16.67	38.69	30.56	41.17
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Over-lit Area (%)													
Tilt	Distrib.	West											
45°	6/0	1.79	5.16	1.88	11.01	5.65	2.08	11.41	6.85	5.06	13.19	11.31	19.94
	4/2	1.79	5.16	1.88	11.01	6.05	2.28	11.11	7.64	5.46	12.80	12.80	18.45
	3/3	1.79	5.16	2.08	11.01	5.95	2.98	11.21	7.54	10.12	13.69	15.77	21.33
	2/4	1.79	5.16	1.98	11.01	5.95	3.17	11.21	8.53	8.43	13.59	14.29	19.25
	0/6	1.79	5.16	2.08	11.01	5.85	4.27	11.51	8.83	9.42	14.68	14.68	20.14
30°	6/0	1.98	5.65	1.98	11.61	6.55	2.88	12.30	7.64	11.11	14.88	19.94	30.16
	4/2	1.98	5.65	2.18	11.61	5.85	3.27	12.40	8.73	11.31	15.18	19.15	27.38
	3/3	1.98	5.65	2.48	11.61	6.45	3.27	12.50	9.52	12.90	17.16	20.34	26.88
	2/4	1.98	5.65	2.08	11.61	6.45	5.06	12.00	10.71	13.79	16.37	20.34	27.58
	0/6	1.98	5.65	2.08	11.61	6.94	3.57	13.19	8.83	16.67	14.88	22.52	28.47
15°	6/0	1.98	5.75	2.18	12.20	6.75	4.17	13.69	13.19	20.54	20.44	30.85	38.19
	4/2	1.98	5.75	2.08	12.20	6.65	4.56	12.60	10.42	16.96	19.74	26.59	34.72
	3/3	1.98	5.75	2.08	12.20	6.94	4.27	12.80	10.91	16.27	18.25	25.99	34.52
	2/4	1.98	5.75	2.08	12.20	6.45	4.17	12.60	10.12	14.58	17.16	22.72	33.04
	0/6	1.98	5.75	2.08	12.20	6.94	3.27	13.39	9.42	15.58	16.87	23.12	30.95
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Average Daylight Factor (%)

Tilt	Distribution												
45°	6/0	2.14	3.45	2.94	4.69	4.25	4.67	5.46	5.94	6.56	7.11	7.79	8.97
	4/2	2.14	3.45	2.95	4.69	4.26	4.66	5.45	5.93	6.52	7.10	7.76	8.94
	3/3	2.14	3.45	2.96	4.69	4.24	4.67	5.45	5.92	6.49	7.12	7.78	8.93
	2/4	2.14	3.45	2.95	4.69	4.23	4.65	5.45	5.91	6.51	7.11	7.73	8.88
	0/6	2.14	3.45	2.94	4.69	4.23	4.62	5.44	5.90	6.45	7.06	7.68	8.82
30°	6/0	2.20	3.54	3.30	4.81	4.62	5.44	5.86	6.78	7.76	7.97	9.02	10.24
	4/2	2.20	3.54	3.29	4.81	4.63	5.50	5.84	6.78	7.83	8.01	9.07	10.24
	3/3	2.20	3.54	3.29	4.81	4.63	5.50	5.87	6.78	7.84	8.01	9.13	10.27
	2/4	2.20	3.54	3.30	4.81	4.63	5.47	5.85	6.77	7.80	7.99	9.09	10.26
	0/6	2.20	3.54	3.25	4.81	4.61	5.44	5.84	6.73	7.72	7.94	8.98	10.14
15°	6/0	2.25	3.62	3.52	4.89	4.88	5.94	6.14	7.25	8.52	8.48	9.80	10.95
	4/2	2.25	3.62	3.55	4.89	4.91	6.04	6.17	7.34	8.69	8.57	9.96	11.10
	3/3	2.25	3.62	3.55	4.89	4.90	6.05	6.16	7.39	8.71	8.59	9.98	11.20
	2/4	2.25	3.62	3.57	4.89	4.92	6.05	6.16	7.34	8.68	8.56	9.98	11.17
	0/6	2.25	3.62	3.53	4.89	4.91	5.99	6.17	7.33	8.58	8.55	9.88	11.08
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Average Daylight Factor (%)

Tilt	Distribution												
45°	6/0	1.38	2.33	1.93	3.19	2.88	3.23	3.73	4.16	4.70	4.99	5.61	6.39
	4/2	1.38	2.33	1.94	3.19	2.88	3.21	3.73	4.15	4.67	4.97	5.58	6.40
	3/3	1.38	2.33	1.94	3.19	2.87	3.23	3.72	4.14	4.66	4.97	5.59	6.36
	2/4	1.38	2.33	1.94	3.19	2.88	3.22	3.71	4.14	4.64	4.97	5.55	6.33
	0/6	1.38	2.33	1.92	3.19	2.86	3.18	3.71	4.11	4.63	4.92	5.50	6.29
30°	6/0	1.43	2.41	2.18	3.29	3.16	3.84	4.03	4.77	5.68	5.62	6.60	7.43
	4/2	1.43	2.41	2.18	3.29	3.17	3.87	4.03	4.81	5.72	5.65	6.66	7.47
	3/3	1.43	2.41	2.20	3.29	3.17	3.85	4.05	4.81	5.75	5.64	6.66	7.46
	2/4	1.43	2.41	2.21	3.29	3.16	3.85	4.03	4.81	5.69	5.64	6.62	7.45
	0/6	1.43	2.41	2.18	3.29	3.16	3.81	4.02	4.75	5.65	5.60	6.53	7.37
15°	6/0	1.47	2.47	2.36	3.37	3.34	4.23	4.23	5.19	6.27	6.02	7.24	8.06
	4/2	1.47	2.47	2.38	3.37	3.37	4.29	4.27	5.24	6.42	6.12	7.37	8.18
	3/3	1.47	2.47	2.40	3.37	3.37	4.30	4.27	5.24	6.43	6.11	7.37	8.20
	2/4	1.47	2.47	2.38	3.37	3.37	4.29	4.26	5.26	6.43	6.11	7.38	8.21
	0/6	1.47	2.47	2.37	3.37	3.36	4.27	4.26	5.23	6.33	6.10	7.28	8.12
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Typical Construction - Daylight Factor Uniformity Ratio (-)

Tilt	Distribution												
45°	6/0	0.27	0.29	0.36	0.30	0.32	0.45	0.34	0.42	0.52	0.41	0.49	0.46
	4/2	0.27	0.29	0.34	0.30	0.32	0.41	0.31	0.37	0.47	0.37	0.44	0.42
	3/3	0.27	0.29	0.33	0.30	0.32	0.38	0.30	0.39	0.45	0.36	0.42	0.41
	2/4	0.27	0.29	0.32	0.30	0.32	0.40	0.29	0.37	0.44	0.37	0.42	0.40
	0/6	0.27	0.29	0.30	0.30	0.28	0.38	0.30	0.36	0.42	0.34	0.39	0.38
30°	6/0	0.28	0.30	0.32	0.30	0.32	0.38	0.32	0.36	0.41	0.36	0.40	0.39
	4/2	0.28	0.30	0.31	0.30	0.30	0.37	0.32	0.35	0.42	0.34	0.41	0.39
	3/3	0.28	0.30	0.32	0.30	0.31	0.41	0.31	0.39	0.45	0.37	0.44	0.42
	2/4	0.28	0.30	0.33	0.30	0.33	0.44	0.33	0.41	0.51	0.40	0.47	0.45
	0/6	0.28	0.30	0.39	0.30	0.36	0.49	0.34	0.46	0.57	0.44	0.55	0.51
15°	6/0	0.29	0.29	0.27	0.30	0.27	0.27	0.28	0.28	0.30	0.28	0.29	0.30
	4/2	0.29	0.29	0.28	0.30	0.28	0.33	0.29	0.33	0.37	0.32	0.35	0.35
	3/3	0.29	0.29	0.33	0.30	0.33	0.41	0.31	0.39	0.48	0.38	0.45	0.43
	2/4	0.29	0.29	0.38	0.30	0.36	0.50	0.34	0.46	0.50	0.44	0.53	0.50
	0/6	0.29	0.29	0.47	0.30	0.42	0.48	0.39	0.58	0.45	0.55	0.62	0.63
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

Passive Construction - Daylight Factor Uniformity Ratio (-)

Tilt	Distribution												
45°	6/0	0.33	0.33	0.39	0.34	0.41	0.51	0.38	0.47	0.50	0.45	0.54	0.52
	4/2	0.33	0.33	0.37	0.34	0.36	0.43	0.37	0.41	0.50	0.41	0.46	0.45
	3/3	0.33	0.33	0.37	0.34	0.35	0.42	0.36	0.40	0.47	0.40	0.45	0.44
	2/4	0.33	0.33	0.35	0.34	0.34	0.41	0.34	0.38	0.44	0.37	0.42	0.40
	0/6	0.33	0.33	0.33	0.34	0.33	0.38	0.34	0.35	0.41	0.36	0.38	0.38
30°	6/0	0.34	0.33	0.37	0.34	0.35	0.40	0.35	0.39	0.42	0.39	0.43	0.42
	4/2	0.34	0.33	0.35	0.34	0.33	0.38	0.35	0.36	0.42	0.37	0.41	0.40
	3/3	0.34	0.33	0.34	0.34	0.34	0.41	0.34	0.39	0.45	0.39	0.44	0.43
	2/4	0.34	0.33	0.36	0.34	0.35	0.44	0.35	0.42	0.48	0.41	0.46	0.45
	0/6	0.34	0.33	0.40	0.34	0.38	0.50	0.37	0.47	0.52	0.45	0.52	0.51
15°	6/0	0.33	0.33	0.29	0.34	0.30	0.30	0.31	0.30	0.30	0.31	0.31	0.31
	4/2	0.33	0.33	0.30	0.34	0.31	0.33	0.32	0.33	0.36	0.33	0.36	0.36
	3/3	0.33	0.33	0.33	0.34	0.34	0.40	0.34	0.40	0.46	0.39	0.45	0.44
	2/4	0.33	0.33	0.37	0.34	0.37	0.44	0.37	0.46	0.44	0.44	0.53	0.51
	0/6	0.33	0.33	0.48	0.34	0.44	0.42	0.41	0.59	0.38	0.57	0.63	0.64
WFR		10	15	10	20	15	10	20	15	10	20	15	20
SFR		0	0	5	0	5	10	5	10	15	10	15	15
GFR		10	15	15	20	20	20	25	25	25	30	30	35

APPENDIX B - Construction details

The construction of the classroom was set as presented in the table below.

		Typical Construction			Passive Construction		
		d (m)	λ (W/mK)	R (m^2K/W)	d (m)	λ (W/mK)	R (m^2K/W)
Wall	Rso (energyplus default)	-	-	0.040	-	-	0.040
	Hardwood (exterior)	0.01	0.13	0.077	0.01	0.13	0.077
	Air gap	0.03	-	-	0.03	-	-
	Mineral wool (90%)	0.21	0.038	4.974	0.5	0.038	11.842
	Wood studs (10%)	0.21	0.13	0.162	0.5	0.13	0.385
	Gypsum Plasterboard	0.013	0.25	0.052	0.013	0.25	0.052
	Rsi (energyplus default)			0.130			0.130
	Total	0.26		5.434	0.55		12.526
	Total U value (W/m^2K)			0.184			0.080
Roof	Rso (energyplus default)	-	-	0.040	-	-	0.040
	Metal cladding	0.005	0.29	0.017	0.005	0.29	0.017
	Air gap	0.03	-	-	0.03	-	-
	Mineral wool (75%)	0.3	0.038	7.105	0.5	0.038	11.842
	Wood studs (15%)	0.3	0.13	0.231	0.5	0.13	0.385
	Gypsum Plasterboard	0.013	0.25	0.052	0.013	0.25	0.052
	Rsi (energyplus default)			0.100			0.100
	Total	0.35		7.545	0.55		12.436
	Total U value (W/m^2K)			0.133			0.080
Ground Slab	Rso (energyplus default)	-	-	0.040	-	-	0.040
	XPS	0.35	0.034	10.294	0.4	0.034	11.765
	Concrete slab	0.2	1.13	0.177	0.2	1.13	0.177
	Floor screed	0.03	0.41	0.073	0.03	0.41	0.073
	Linoleum	0.001	0.17	0.006	0.001	0.17	0.006
	Rsi (energyplus default)			0.170			0.170
	Total	0.55		10.760	0.60		12.231
	Total U value (W/m^2K)			0.093			0.082

APPENDIX C – Frame U-value estimation

The frame's U-value was set so the calculated window's U-value, according the formula below, is equal to the U-value provided by VELUX®. The calculated values are presented in the tables below.

$$U_{window} = \frac{U_{glazing}A_{\text{glazing}}+U_{\text{frame}}A_{frame}+\Psi L_{frame}}{A_{window}}$$

Where:
U_{window}: the total thermal transmittance of the window
A_{window}: the total area of the window
U_i: the thermal transmittance of the respective element
A_i: the area of the respective element
Ψ: the thermal bridge of the window connection to the wall (depends on construction type)
L: the window's perimeter

Typical construction

Glazing U-value (W/m^2K)	Frame U-value (W/m^2K)	Linear thermal bridge Ψ (W/mK)
1.1	**0.72**	**0.09**

Window code	Width (m)	Length (m)	Total window U-value (according Velux) (W/m^2K)	U-value (calculated by Formula A) (W/m^2K)
CK02	0.55	0.78	**1.5**	**1.5**
CK04	0.55	0.98	**1.4**	**1.4**
CK06	0.55	1.18	**1.4**	**1.4**
FK06	0.66	1.18	**1.4**	**1.4**
MK08	0.78	1.4	**1.4**	**1.3**
PK06	0.94	1.18	**1.3**	**1.3**
SK08	1.14	1.4	**1.3**	**1.3**

Passive construction (default thermal bridge)				
Glazing U-value (W/m^2K)		Frame U-value (W/m^2K)		Linear thermal bridge Ψ (W/mK)
0.7		**0.72**		**0.09**
Window code	Width (m)	Length (m)	Total window U-value (according Velux) (W/m^2K)	U-value (calculated by Formula A) (W/m^2K)
CK02	0.55	0.78	**1.2**	**1.3**
CK04	0.55	0.98	**1.2**	**1.2**
CK06	0.55	1.18	**1.2**	**1.2**
FK06	0.66	1.18	**1.1**	**1.1**
MK08	0.78	1.4	**1.1**	**1.1**
PK06	0.94	1.18	**1.1**	**1.1**
SK08	1.14	1.4	**1.0**	**1.0**

Passive construction (reduced thermal bridge)				
Glazing U-value (W/m2K)		Frame U-value (W/m^2K)		Linear thermal bridge Ψ (W/mK)
0.7		**0.72**		**0.03**
Window code	Width (m)	Length (m)	Total window U-value (according Velux) (W/m^2K)	U-value (calculated by Formula A) (W/m^2K)
CK02	0.55	0.78	**1.2**	**0.9**
CK04	0.55	0.98	**1.2**	**0.9**
CK06	0.55	1.18	**1.2**	**0.9**
FK06	0.66	1.18	**1.1**	**0.9**
MK08	0.78	1.4	**1.1**	**0.8**
PK06	0.94	1.18	**1.1**	**0.8**
SK08	1.14	1.4	**1**	**0.8**

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