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Report Title: **Comparative Analysis of PV Shading Devices for Energy Performance and Daylight**	Date: 03.06.2012 Number of pages (incl. appendices): 154			
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Abstract:

The comfort and energy demand of a building are influenced significantly by glazed area of the facade. The glazed areas in the building are always challenging. Large glazing allows more daylight to get into the room but at the same time cause more heat gain and heat loss through the building envelop. Shading devices are very suitable elements for installing PV panels. The aim of this study is to evaluate the potential impact of different PV shading devices on energy performance and daylight of office buildings in Nordic climate.

This dissertation is based on literature studies of relevant books and articles on the solar shading systems and the comparative analysis of different cases. The quantitative data for the comparative analysis is achieved by means of computer simulations using *COMFEN*, *ECOTECT* and *PVsyst*.

The focus of this study is on *external solar shading devices*. Five different control strategies were analyzed: No shading devices, Overhang, Movable vertical blinds, Movable horizontal blinds, PV integrated in glass. These shading systems are applied to three facades: south, west and east facades. Comparable assessments have been conducted in terms of window heat gains, energy consumptions, energy production of PV cells, daylight and glare.
The outcome of this effort would be used in practical projects such as *powerhouse one*.

Keywords:

1. Solar shading system
2. PV Shading device
3. Energy Performance
4. Daylight

Comparative Analysis of PV Shading Devices for Energy Performance and Daylight

by

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in

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Finally, I am immensely grateful to my family and friends, and dedicate the thesis to them; for their understanding, support, and endless love.

Introduction

The building and construction sector in Norway consumes 40% of the total primary energy and 40% material use (ZEB Annual report, 2010). As a long term solution, energy efficient buildings are essential to deal with the problem of fossil fuels energy sources (Santos, Laustsen, & Svendsen, 2008). Large amounts of energy are required to provide good indoor environment and thermal comfort. The energy is used for heating, cooling, and lighting.

The comfort and energy demand of a building are influenced significantly by glazed area of the facade. There is an increase use of large window openings and curtain walls in today‘s architecture (Stegou-Sagia, Antonopoulos, Angelopoulou, & Kotsiovelos, 2007). The glazed areas in the building are always challenging. Large glazing allows more daylight to get into the room but at the same time provides more heat gain and heat loss through the building envelop. Therefore, it has potential to cause thermal discomfort. (F.Smith, 2001)

To prevent the building from overheating and provide thermal comfort, shading devices are used frequently. Overheating protection has become important especially in office buildings; where internal heat gains and high occupant density occurs at the same time (Roetzel, Tsangrassoulis, Dietrich, & Busching, 2010).

Additionally, shading devices are very suitable elements for installing PV panels. Building Integrated Photovoltaics (BIPV) has become very popular worldwide. Photovoltaic panels can replace the building materials and produce clean electricity (Montoro, Vanbuggenhout, & Ciesielska). Nowadays, a huge number of shading systems are available on the market and it is not always easy to choose the best solution for a building. Many parameters influence the choice of the system and control strategies.

The aim of this study is to evaluate the potential impact of different shading devices on energy performance and daylight of office buildings in Nordic climate. The goal is to provide a comparative analysis of a variety of solar PV shading devices. This study has analyzed external shading systems in terms of their influence on energy demand, energy production of PV cells, daylight and glare. The outcome this effort would be used in practical projects such as ***powerhouse one.***

Powerhouse one will be the first energy-positive building in Norway, located at Brattorkaia in Trondheim. The project was established by Entra, Skanska, Snøhetta, the environmental organization ZERO and the aluminum company Hydro. Foundation work is already under way, and the building supposed to be ready in summer 2013. This study is conducted to prepare solar shading guidelines for powerhouse project. See Figure 1 and Figure 2 (Powerhouse , 2012)

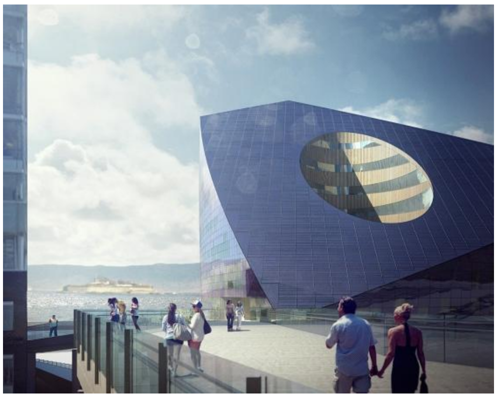


Figure 1. Side view of Powerhouse 1- Trondheim

Figure 2. Exterior view of Powerhouse 1-Trondheim

The focus of this study is on *external solar shading devices*. The typical model of an office room is chosen for simulations. Five different control strategies were analyzed:

1. No shading devices
2. Overhang
3. Movable vertical blinds
4. Movable horizontal blinds
5. PV integrated in glass

These shading systems are applied in three facades: south, west and east facades.

The report is organized in four chapters:

PART I, *Literature review,* provides state of the art overview of shading devices, their influence on energy performance and daylight in similar projects. This part of report investigates typologies of solar shading devices and design considerations to achieve successful daylight and visual comfort.

PART II, *Methodology,* explains the employed methods, inputs, simulation assumptions and calculation procedures for energy consumptions and energy production of PV cells. The last part focuses on daylight and glare measurements which have been practiced in this study.

PART III, *Results,* is dedicated to describing the results from simulations. Comparison studies have been conducted in terms of *heat gain, energy consumption, energy production of PV cells, daylight* (daylight factor, daylight illuminance level), and *glare.*

PART IV, *Discussion and Conclusion*, discusses the result and evaluates the performance of different shading devices. A rating system is established by the author and used for comparing the results. In this part, suggestions for *powerhouse* and future works will be proposed.

CHAPTER I_ Literature Review

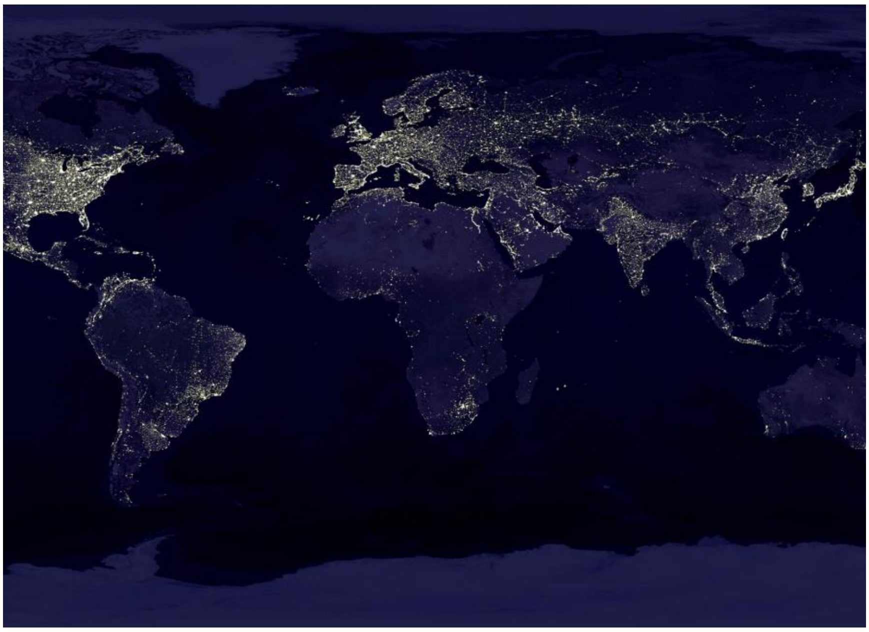


Figure 3. World-wide energy consumption by night

Literature review

To begin each study, state of the art knowledge in the field and orientation of researches in that area is necessary. This chapter gives an overview of researches which have been done so far.

The literature review indicates that many studies have been done in investigating the impact of shading devices, windows in thermal properties in the building. Many numerical studies have been carried out to provide the design criteria for shading systems. (Kim & Kim, 2009). The most important measures for choosing shading devices have been presented by (Yüceer, 2012). The aim of all these criteria is to minimize energy consumption of buildings.

There are a number of studies that deal with the problem of the impact of shading devices on energy loads in the building. The optimum shading system depends on shading type, location and weather consideration. (Datta, 2001) Studies have shown that shading devices reduce the cooling load of the building but have a negative impact on heating loads, because they reduce the useful solar gains during the winter. (Dubois M.-C. , 1997)

Several studies explored visual and thermal comfort of fixed and movable shading devices. Tzempelikos (Tzempelikos & Roy, 2004) applied a study for the facade renovation of an office building in Montreal. The study considered the impact of several shading systems (interior and exterior) on the daylighting and thermal performance of buildings.

Nielsen (Nielsen, Svendsen, & Jensen, 2011) investigated three types of shading facades (without solar shading, with fixed solar shading, and with dynamic solar shading) in an office building and evaluate energy demand for heating, cooling and lighting. David (David, Donn, Garde, & Lenoir, 2011) studied thermal and visual comfort of different types of external fixed shading systems in non-residential buildings. Bessoudo (Bessoudo, Tzempelikos, & Athienitis, 2010) presented an experimental study of indoor thermal environment near a glass facade with different interior shading devices (roller shades and venetian blinds).

There have been some efforts on promoting design of shading systems. Kim (Kim 2009) developed an advanced shading device system based on the venetian blind system to provide a better view and energy performance.

"*User behavior*", the role of occupants in evaluating the shading system, is an issue that some researches have concentrated on it. The *user behavior*, especially in terms of daylighting and glare has become very important (Dubois, Demers, & Potvin, 2007) (Hygge & Lofberg, 1997). One of the subtasks in TASK 31 IEA is dedicated to the user response to the daylight and daylight system. (Murphy, 2007) In some projects users were asked about their favorite rib position or daylight situation such as ZVK Wiesbanden building in Germany. "*Only by involving users the control concepts of solar protection guarantee optimum daylight usage during operation".* (Bauer, Molse, & Schwarz, 2007)

The literature review shows that only a few studies investigate photovoltaic shading systems. Janak (Janak & Kainberger, 2009) for *EU PV-Light Project* focused on an experimental quantification of moveable PV shading devices in office buildings. The aim of the project was evaluating the influence of three PV-shading systems on energy demand in the building. They simulated two office orientations: west and south, for two different climates_ Berlin and Madrid.

According to their results, for a middle European climate like Berlin, an office with a three louver canopy system has the lowest energy demand. The presented reason was that "*this type of shading is very efficient for reduction of the cooling load but it allows some solar gain in the heating season.*" (Janak & Kainberger, 2009) For south European climate the "Synchronous Tracking Louvre" (STL) has the lowest energy demand especially in south facade. (ZSW, 2007) Figure 4 shows different types of shading systems which they have studied: (Klotz, Schroeder, & Mohring , 2007)

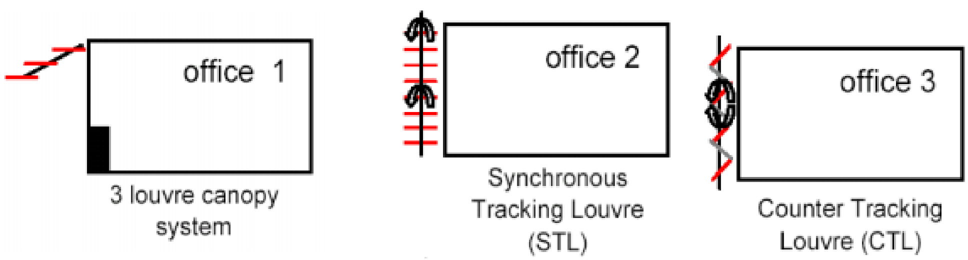


Figure 4. Three PV shading systems used in (Janak & Kainberger, 2009)

Speaking of PV integrated building; the power produced by the PV can be used to fulfill building's energy demands. A manually adjustable shading device, to optimize the PV inclination, would improve the PV electricity production to 50 – 60%. (Bloem, Colli, & Strachan, 2005)

As it discussed before, the main objective of this study is to investigate the influence of different PV shading systems on thermal and visual comfort in office buildings in Norway.
In the following section different types of shading systems and design considerations, in respect to the daylight and glare will be explained.

Shading Systems

Importance of shading

Solar radiation incident on a surface may derive from three sources: direct radiation from the sun, diffuse radiation from the sky vault, and reflected radiation from surrounding surfaces and buildings (Figure 5). External shading devices can block the direct radiations, and reduce the impact of the diffuse and reflected components. (Stack, Goulding, & Lewis)

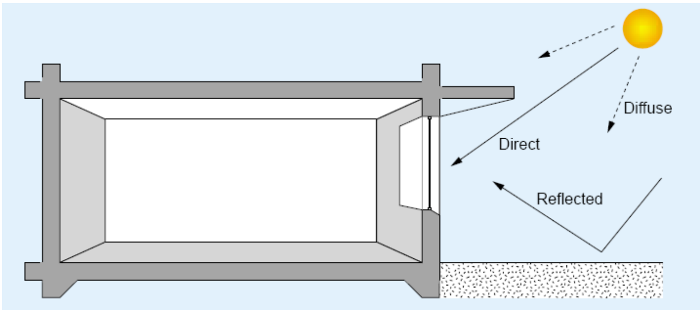


Figure 5. Direct, diffuse and reflected radiation

The main roles of shading systems are to improve thermal comfort by reducing overheating. Also, shading devices provide visual comfort by minimizing glare. (Lechner, 2008) Since solar shading systems reduce the cooling demand in warm seasons, a good level of solar protection is essential in green buildings. (Bauer, Molse, & Schwarz, 2007) Solar shading systems are not only important for energy reduction of a building but also for improvement of indoor thermal comfort. They can also decrease incremental costs of building by their impacts on energy saving. (Yao & Yan, 2011)

An optimal shading device represents a system which provides maximum shading for a specific period throughout the year (summer), while permitting maximum solar radiation for another period (winter). (Bader, 2011) In other words, when the solar radiation is not used for daylight it should be blocked during the overheated period of the year. The ideal shading device allows views and breezes to enter the window. (Lechner, 2008) In this regards, climate is one of the key parameters in designing shading protections. There are a variety of solution approaches for shading systems in different climates and regions. (Bauer, Molse, & Schwarz, 2007) Designing a solar protection in hot climate such as Madrid or Egypt differs from the one in cold Norway or humid climates.

Due to an increase in the use of large windows and curtain walls in today‘s architecture, designing suitable shading solutions get more and more crucial. Nowadays, Building Integrated Photovoltaics (BIPV) has become very popular in Europe. PV that is integrated into the fabric of a building replaces conventional building materials and produces clean electricity. PV modules can be integrated into different parts of the building fabric, such as roofs, facades, skylights and shading systems. Shading systems are very suitable for PV installations. (Montoro, Vanbuggenhout, & Ciesielska) Figure 6 and Figure 7 show PV integrated on the building envelops.

This study focuses on PV integrated in shading systems and glazing facades.

Figure 6. PV integrated in facade at Norwegian university of science and technology (NTNU)

Figure 7. PV shading at Council Building, Edingen, Germany

Shading types

Many parameters are involved in selecting a shading system. The type, size and location of a shading device depend on the amount of direct, diffuse and reflected solar radiation. (Lechner, 2008) Within a variety of shading systems they still can be divided into two main categories: internal shading devices and external shading devices.

Internal shading

Internal shading is almost always adjustable, and is typically in the form of roller or venetian blinds or curtains. (Lechner, 2008) See Figure 8-Figure 13. Internal devices do not obstruct direct sunlight until it has passed through the glazing. The glazing layers absorb the heat and release it into the room. As a result, internal shading devices should not be defined as shading devices since shading structures are intended to keep the heat outside. They should rather be categorized as glare control devices. (Bader, 2011)

Figure 8. Internal shading- venetian blinds

Figure 9. Internal shading- roller blind

Figure 10. Venetian blind between glazing

Figure 11. Internal shading

Figure 12. Internal shading

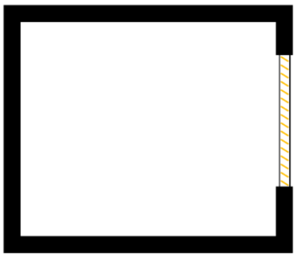


Figure 13. Shading in cavity between glazing

External shading

External shading devices are the most effective sun protectors and have the most effect on the aesthetics of a building. (Lechner, 2008) Direct solar radiation can be effectively controlled by exterior shading devices. They block the sun before it can even heat up the surface or penetrate the window. For additional solar controls, implementation of louvers and fins with different inclination are very useful. There are many different types of external shading devices available on the market. Yet, they can be divided into two major categories: Vertical shading and horizontal shading. Table 1 demonstrates different types of shading systems.

Horizontal shading

The most common shading device is horizontal shading devices. This shading system is divided into many types; such as overhangs, lamella or blinds. Blinds can pose in front of the window or in the cavity between the glazings. Movable horizontal fins can provide almost full shading. Moreover, they can be adjusted manually by the users, or automatically based on the sun position. (Bader, 2011)

Vertical shading

Vertical blinds are one of the most effective solar protections. They properly fulfill energy, daylight, visibility and flexibility requirements. Vertical lamella provides very good daylighting and view to the outside. (Bauer, Molse, & Schwarz, 2007)

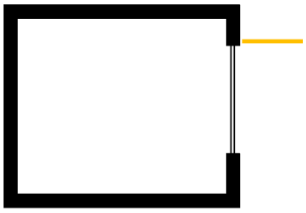
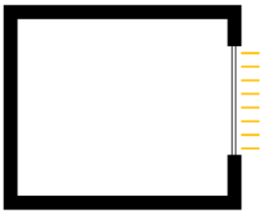
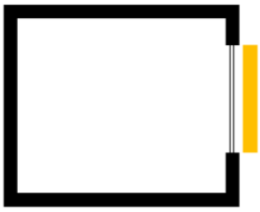
Type	**Name**	**picture**	**Criteria for evaluation**		
			Glare protection	View outside	Light guiding into the room
 **Overhang/ horizontal Canopy**	Horizontal Canopy single		Depends	Yes	Yes
	Horizontal canopy double (light shelf)		Depends	Yes	Yes
 **Horizontal louvers**	Tracking louver		Yes	Depends	Depends
	Horizontal shading		Yes	Depends	Depends
	Horizontal blind		Yes	Depends	Depends
 **Vertical louvers**	Vertical louvers		Yes	Depends	Depends
	Sliding		Depends	Depends	Depends
	Roller blind		Yes	Depends	Depends
PV printed on glass			Yes	Depends	Depends

Table 1. External Shading devices

Photovoltaic shading devices

Shading devices are very good elements in buildings for installing PV panels because PV panels can be designed for the optimum angle. (Lechner, 2008) PV cells can be integrated into the canopy shading system either horizontal or vertical. PV cells vary in size, shape, pattern, and color. Two types of PV glazing systems are: semi-transparent and opaque system. (Lechner, 2008) Not only south but also east and west facade can be covered with PV and still produce large amount of electricity.

PV cells can be integrated into windows, providing a semi-transparent facade. These kinds of BIPV can be also used as shading. Glass PV laminates, replacing conventional cladding material, are basically the same as tinted glass. The PV glazing is especially suitable for skylights or clerestories, since they are not designed for view to the outside. (Lechner, 2008)

Two options exist for achieving transparent glazing:

1. *Mono or multi crystalline cells:* (0-100% transparency)
   In this module PV cells filter partial light to get into the room. Light effects from these panels lead to an ever changing pattern of shades inside the building.(Figure 15)
2. *Semitransparent thin-film modules:* (10% transparency)
   The PV cells can be so thin or laser grooved on the window. This type of PV glass allows 10% light transmit the window, thus it is possible to see through. This provides a filtered vision to the outside.(Figure 14)

Figure 14. Semi-transparent modules

Figure 15. Solar decathlon 2009- Team Spain

Building and daylight

In modern office buildings around 25 % of the energy is required for artificial lighting. Modern daylight technology can greatly reduce energy used for artificial light. Substantial energy saving can be achieved by maximizing natural lighting. (F.Smith, 2001)

Facade envelop is the primary factor for the amount of daylight reaching into the room. (Bauer, Molse, & Schwarz, 2007) Other parameters which influence on daylight level are: (F.Smith, 2001) (Bauer, Molse, & Schwarz, 2007)

- ***Orientation and window size:*** There is no doubt that the amount of glazing area has obvious impact on the amount of daylight. But the point is that "*more window areas in not always better, it may simply increase contrast."* Although large glazing allows more daylight to get into the room but at the same time provides more heat gain and heat loss through building envelop. Therefore, it provides potential for thermal discomfort. (F.Smith, 2001)

  There are some rules for window ratio and the floor area in the building sector. According to TEK10 standards (TEK, 2010), the total U value of windows/doors multiply to proportion of windows/doors of a building heated area should not exceed than 0.24.

  Daylight normally penetrates about 4-6 meters from the window into the room. The practical depth of a daylighted zone is typically limited to 1.5 times the window head height. (F.Smith, 2001)

- ***Obstruction to the light admission*** (i.e. nearby buildings)
  Vegetation and nearby buildings can shade whole facades and roofs, reducing solar gains and daylight. This issue becomes more important in BIPV buildings. Shading can reduce the efficiency of PV productions. Surrounding obstacles influence on human feelings. The amount of sky which occupants can see from the inside is a crucial factor in determining *satisfaction daylighting*. (F.Smith, 2001)

- ***Window glazing material:*** Choosing the right glazing material has a significant impact on successful daylighting. Transparent glazing comes in a verity of types: clear, tinted, heat absorbing, reflective, and spectrally selected. (Lechner, 2008)

- ***Solar shading device:*** As it was mentioned the solar protection has significant influence on the daylight level. (Bauer, Molse, & Schwarz, 2007) The easiest way of obtaining daylight is venetian blinds. In this system, in the cutoff position, diffused sunlight can get into the room. More effective system is a combination of horizontal blinds in the upper part of window and vertical blinds in the lower part. (Figure 16) Upper horizontal blinds allow natural daylight to get deep into the room. In addition, this kind of systems brings a high level of visual comfort. See Figure 17.

Figure 16. Combination of horizontal and vertical blinds

Figure 17. External shading system (SOKA-Bau – Wiesbaden)

- ***Controlling system***
- ***Interior design and Furniture***
- ***Choice of colors and material***

Visual Comfort

Visual comfort is usually the main factor which has a significant role in meeting lighting requirements. It describes the environment's freedom from visual problems, specially glare. (Yener, 1998) The degree of visual comfort is determined by both daylighting and artificial lighting levels. (Bauer, Molse, & Schwarz, 2007)
A good daylight condition is possible when the following is achieved:

• Appropriate illuminance, light direction and distribution of the task

• Glare control

• Appropriate contrast

• Appropriate color

Visual Comfort Probability (VCP) is a rating system to estimate of the percentage of people that would consider a given lighting arrangement visually comfortable. A VCP of 70 percent is considered acceptable by IES Standards. Tables are used to determine

Glare

Glare is an issue that results from improper controlling of lighting systems. *Discomfort glare* causes visual discomfort and impair visual performance, over a period of time. Normally, glare is divided into two major categories: *direct glare* and *reflected glare*.

"*Direct glare*" is caused by light entering the eye directly from a bright light source, even though the person is not looking directly at the source.

"*Reflected glare*" is the result of the reflection of light from a glossy or polished surface.

Glare protection:

In a room with computer workplace, there must be an adequate glare protection in order to limit high luminance. There are some notable solutions for glare protection: (Bauer, Molse, & Schwarz, 2007)

1. External solar shading can be useful for glare protection. However, not all types of shading are suitable for glare protection.
2. Curtains and interior shadings are the most effective ways to reduce the effect of glare.
3. In case of movable shadings (blinds), glare protection can be achieved by inverting the direction of movements from bottom to top.

CHAPTER II_ Methodology

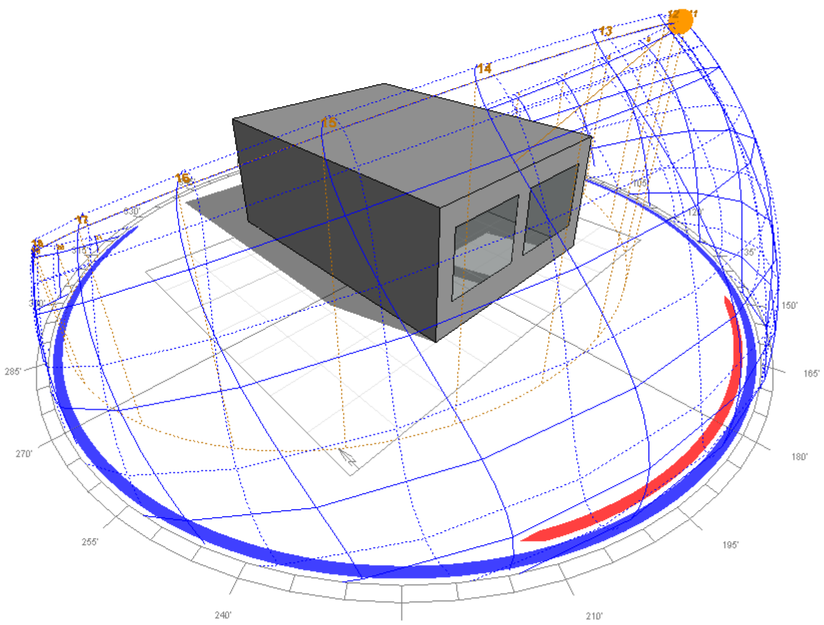


Figure 18. The case model with no shading device

Quantitative simulation research

The main aim of this study is to investigate the influence of different types of shading devices on energy performance and daylight in buildings. This report is based on literature studies of relevant books and articles on shading systems and comparative analysis of PV shading devices in different facades.

The focus of this study is on external solar shading devices. Four shading systems in south, east and west facades are examined and compared. These shading systems are: overhang, vertical louver, horizontal louver and PV integrated on glazing.

The presented method is based on quantitative simulation research. The quantitative data for the comparative analysis has been acquired from computer simulations with COMFEN (LBNL Window & Daylighting Software -- COMFEN), ECOTECT (Ecotect Analysis - Sustainable Building Design Software - Autodesk) and PVsyst (PVsyst: Software for Photovoltaic Systems).

In order to demonstrate the influence of shading systems, the following four steps are performed:

A. Defining shading systems:

The first step was defining scenarios. Different types of shading systems are discussed in chapter 1, literature review. In this step, four shading systems are discussed: Overhang, horizontal blind, vertical blind and solar PV Glass. These scenarios will be explained in detail in the following section.

B. Calculating energy consumptions:

The next step was calculating energy demands for heating, cooling and artificial lighting of each scenario. For this purpose COMFEN 4.0 has been chosen as the simulation software. COMFEN is a facade analysis tool based on ENERGYPLUS (EnergyPlus) and RADIANCE (Radiance). It is developed by Lawrence Berkeley National Laboratory (LBNL). COMFEN is able to account complex interaction of shading devices, blinds and the glazing properties together. In terms of software reliability, the same model is simulated in SIMIEN (SIMIEN, v5.004) and the results are compared against those acquired from COMFEN. The comparison was promising and the results were very close. Results from SIMIEN can be found in the Appendix 4.

C. Calculating electricity production of PV cells:

For PV electricity calculation, PVSYST is used. PVSYST is a tool for sizing and data analysis of PV systems. The advantage of this software is that shading effect can be taken into account. It is possible to model shading tracking and estimated self-shading effect on PV cells. PVSYST contains a comprehensive library of different products available on the market.

PVGIS (Photovoltaic Geographical Information System) is another tool which is used for calculating electricity production of PV glass. PVGIS (Photovoltaic Geographical Information System) is part of SOLAREC (SOLAREC) program and provides rough assumption of PV production. For this scenario, PVGIS is utilized instead of PVSYST; since PV glass values are not available in PVSYST library.

D. Evaluating daylight and glare:

As it was mentioned COMFEN is RADIANCE-based tool. Daylight illuminance level and glare are simulated by COMFEN. For evaluating daylight factor, ECOTECT is used.

Simulation assumption

Model setup:

Simulations are carried out for the typical rectangular office room. The dimensions of the models are:

Office width: 4.8 m

Office depth: 6.5 m

Office height: 2.8 m

Glazing area: 5.4 m

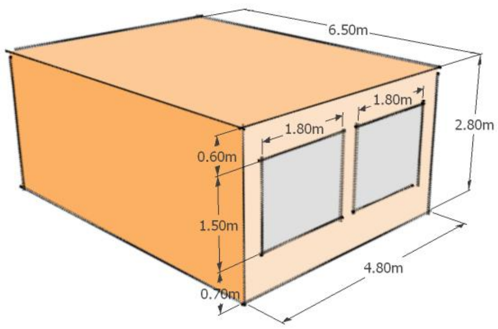


Figure 19. View of the office geometry

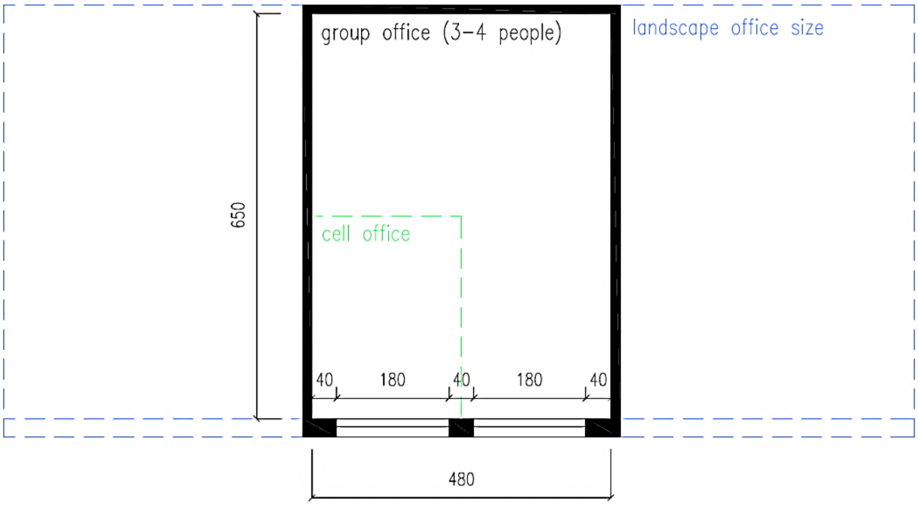


Figure 20. Plan view of office

In principle, the office has three or four workplaces. This module can be part of a bigger landscape office or be divided into smaller rooms and used as cell offices. In Figure 20 green line shows standard cell office (2.4 *3.2 m) and blue line demonstrate landscape office. The room depth has been assumed to be quite large. So daylight conditions can be checked in big rooms, like cell office.

In the model, the ratio of window to the wall surface is 40%. Based on researches, the optimal percentage of glazing area to the facade module in office buildings is between 35% and 45%. (Goia, Haase, & Perino, 2012)

Climate and context

In this study, Oslo weather file is used in all simulations. The weather data in COMFEN have been taken from Energy Plus. In this program, library of weather files is limited to Oslo. As we didn't have Trondheim weather data, the location of simulations is assumed to be Oslo.

Materials

The building is designed to be a very high performance green building which assures energy efficiency with good indoor environment. High performance buildings need to comply with standards and building energy codes. In this study, all the values and set points for simulations have been taken from report 42, passive house standards. (Dokka, Klinski, Haase, & Mysen, 2009) these values include: u-value of components, internal loads, air supplement, etc.

To meet passive house criteria, very well insulated walls and energy-efficient windows and glazing systems have been chosen. The following specifications are used in simulations:

- U-value of the exterior wall: 0.10 W/m^2k
- Interior components (floor, ceiling, and interior walls): adiabatic constructions
- U-value of windows: 0.8 W/m^2k
  _ Window type: AFG Triple glazed, low-e glass
  _ Window frame: wood
  _ Visual Transmittance (TVis): 0.54
  _ Solar Heat Gain Coefficient (SHGC): 0.311

These specifications are common among all scenarios, except the last scenario, PV glass.
PV Glass is a special product with different characteristics. We have chosen ASI- THRU from SCHOTT (ASI® THRU | SCHOTT North America) solar. This specific product which is available in market has the following characteristics:

- U-value of PV glass: 1.1 W/m^{2}k
  _ Visual Transmittance (TVis): 0.16
  _ Solar Heat Gain Coefficient (SHGC): 0.18
  _ Color: gray

Schedule and set points

All criteria and values (such as u-values, internal heat loads, etc.) which are required for simulations have been taken from report 42 (Dokka, Klinski, Haase, & Mysen, 2009). According to the passive house report, internal heat gain for lighting in an office building is 5 W/m^2 and for equipment is 6 W/m^2. It is stated that, the average internal heat gain per day in the year is equal to 5.4 W/m^2.

Inner temperature is assumed to be between the ranges of 17 to 26 °C in a year.

COMFEN has defined different schedules, like occupancy, lighting, heating and cooling, for different types of buildings. These schedules present a fraction to occupancy, lighting and equipment loads based on working hours and working days. For more detailed information see the Appendix 2.

HVAC system

HVAC system which is used for simulation is package single zone system. This system consists of air conditioner. HVAC economizer for temperature and enthalpy is utilized for the system. The electricity consumption for fans and pumps will not be evaluated.

A. Defining shading systems:

The wide ranges of shading typologies are discussed in chapter 1, literature review. Shading systems can be divided into two main categories: internal shadings and external shadings. External shading devices can be fixed or movable.

This study has been focused on external shading systems. Both fixed and movable types were examined and compared. In the following section, shading devices which have been applied in this study will be explained in detail.

Five different scenarios are studied: without shading device, overhang, vertical louvers, horizontal louvers and PV glass. Each of these scenarios is applied to three facades: south, west, and east.

1. *Without shading device*

In the first scenario the office model does not have any shading protection throughout the year. In the text, it has been mentioned as a base case. Shading systems will be compared with this scenario, a situation where there is no shading device.

2. *Overhang:* *fixed external shading*

In this scenario, horizontal fixed solar shading is studied. Figure 21 shows the side view of the canopy system. It has 60 cm depth and 480 cm length. The shading device is completely covered by PV cells which have a 40 degree slope.

3. *Vertical Blinds:* *movable external shading*

Vertical Blinds are movable shading devices which can be mounted in front of the window. The widths of slats are 8 cm and the distance between each blind is 9 cm. These blinds are covered by PV cells. In this scenario slats are rotated according to the sun position and block beam solar. The tilt of slats is in the range of 0 -180 degree from horizontal line. (Figure 22)

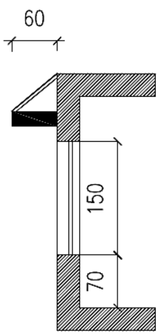


Figure 21. Side view overhang

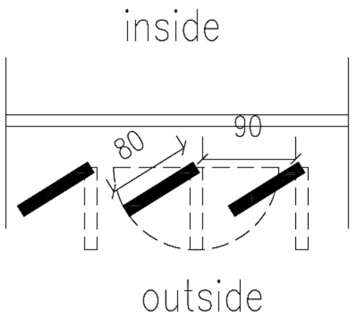


Figure 22. Plan view of vertical blinds

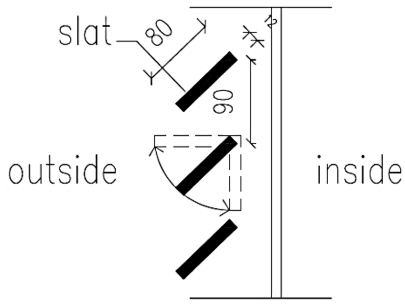


Figure 23. Side view of horiznotal blinds

4. ***Horizontal Blinds***: *movable external shading*

The horizontal louver that is tested in this study consists of blinds that are tracking according to the sun position. Like vertical louvers, they have 80 mm depth and the gap between each blind is 90mm. Horizontal blinds cover the full width of the window. The rotation of slats is from 0- 90 degree from horizontal line. (Figure 23).

5. ***PV Glass:*** *PV integrated in the glazing*

Glass PV laminates can be applied to windows providing a semi-transparent facade. (Montoro, Vanbuggenhout, & Ciesielska) The semi –transparent PV glass allows the light to pass the window and get into the room. (Figure 24) Integrated photovoltaic cells on glazing (BIPV) can provide effective shading and be used for glare protection. For this scenario a product available on the market has been chosen: ASI THRU from SCHOTT solar company. **(**Figure 25**)** The U value of this product is 1.1 W/m^{2}K which is higher than other glazing. (ASI® THRU | SCHOTT North America)

Figure 24 The semi-transparent solar module technology

Figure 25 Semi-transparent PV integrated on roof_ elementary school in Munich- Trudering (Germany)

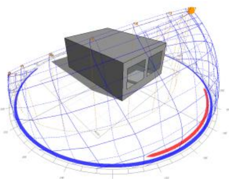
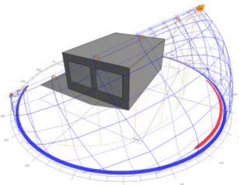
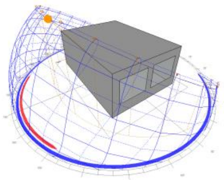
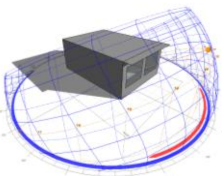
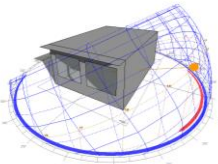
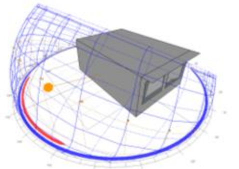
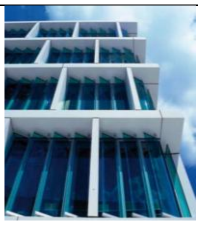
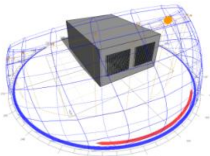
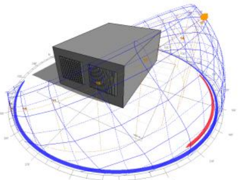
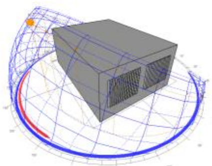
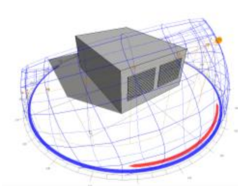
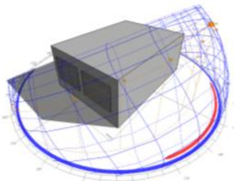
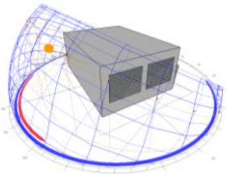
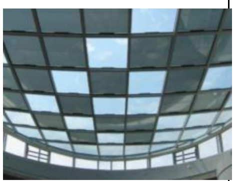
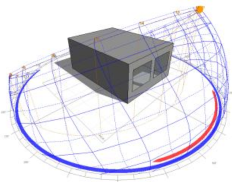
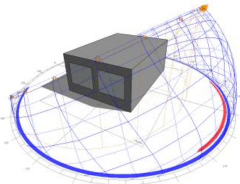
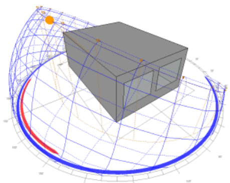
	Scenarios	South	West	East
1. Without shading				
2. Overhang				
3. Vertical Blinds				
4. Horizontal Blinds				
5. PV Glass				

Table 2. Scenario variants

5 scenarios are applied is three facades: south, west and east. Table 2 shows scenario variants

Shading control

In cold climates, heating of the interior space in winter is desirable. *Solar radiation* would heat up the space and reduce the difference between the room temperature and the outside temperature.

Varieties of shading control algorithms are available in COMFEN. For vertical and horizontal blinds two control algorithms is applied: On if "***High outside air temperature***" and "***High solar incident***" on the window.

This means that shading device is deployed/ lowered if the *outside air temperature* exceeds setpoint 1 (°C) and if the *solar radiation incident on the window* exceeds setpoint 2 (W/ m^2).

A detailed study has been conducted to find out the optimal set point values for "*outdoor temperature*" and "*solar radiation incident*". The complete study is shown in the Appendix 1.

The shading device is activated when the outdoor air temperature is higher than 10 (°C) and radiation incident on the window exceeds 200 W/ m2, regardless of the office hours. According to the weather data, the average outdoor air temperature gets higher than 10 from May till September.

In this study it is assumed, that the slats *block beam solar*. The slats angel adjusted at every simulation timestep (15 minutes) in order to block direct solar radiation from coming into the room. For horizontal blinds, the minimum slat tilt is 0 and the maximum tilt 90 degree. For vertical minimum and maximum angel's tilt are 0 and 180.

Simulation variants:

The scenario specifications are summarized in Table 3.

Scenario	**Shading device**	**Size** (cm)	**Space between louvers** (cm)	**Coverage**	**Blind strategy**	**Glass type**
1	Without shading	_	_	_	_	AFG Ti-R Low-E glass (U value: 0.80 w/m^{2}k)
2	Overhang	60*480*20	_	Above window, Full width of facade	Always on	AFG Ti-R Low-E glass (U value: 0.80 w/m^{2}k)
3	Vertical Blinds	8*150*1	9	Full height	On if outside temperature +10 and solar radiation +200 W/ m2	AFG Ti-R Low-E glass (U value: 0.80 w/m^{2}k)
4	Horizontal Blinds	8*180*1	9	Full width	On if outside temperature +10 and solar radiation +200 W/ m2	AFG Ti-R Low-E glass (U value: 0.80 w/m^{2}k)
5	PV Glass	150*180	_	Full window	Always on	Double glazing (U value: 1 w/m^{2}k)

Table 3. Simulation variants

B. Calculating energy consumptions

The energy demand for heating, cooling and artificial lighting is calculated by COMFEN. In order to show the total energy influence of different scenarios (shading controls) two different evaluation approaches are applied:

1. *Net energy demand:* total energy demand for heating, cooling and lighting are calculated. Heating and cooling demand means required energy demand for thermal comfort in the zone. For the lighting, it means electric energy demand for lighting system.

2. *Delivered energy:* Delivered energy includes all system efficiencies, transmission and distribution losses for heating and cooling. In this study heat pump is assumed as a heating source. Performance factor for systems are taken from (NS3031, 2007). For the heat pump system, a performance factor of 2.34 is used. Annual coefficient of performance (COP) of the cooling system is assumed 2.4. The delivered energy is calculated by the following formulas:

   ***$E_{del,el}$* (delivered electricity)** = $E_{del,el}$ for heat pump + $E_{del,el}$ for cooling system+ $E_{del,el}$ for El-specific demand

$$Edel,el\ \ for\ heat\ pump = \frac{\text{Annual net energy demand for heating}}{\text{Average annual efficiency of heat pump}}$$

$$Edel,el\ for\ cooling\ system = \frac{\text{Annual net energy demand for cooling}}{\text{annual coefficient of performance of cooling system}}$$

3. Total net energy balance: total energy balance is an annual energy balance between delivered electricity and electricity production from PV cells. It is calculated by this formula:

   Total net energy balance = delivered electricity - electricity production of PV

Mismatch factor

In Zero Emission Buildings (ZEB), if a building is connected to the power grid, excess electricity can be given to the grid. (Marszal, et al., 2011) In this way the grid is used as a storage unit. Such an interaction with the grid can result in a diurnal and seasonal mismatch between *energy supply from energy sources into the grid* and the *energy demand of the building, taken out of the grid*. (Voss & Heinze, 2009). In other words, mismatch factor is an indicator which measures the on-site generation capacity and annual energy demand. (Sartori, Graabak, & Dokka, 2010)

Mainly three different forms of mismatch are under analysis in the activities of IEA Task40 (IEA-SHC Task 40 /Annex 52 "Zero Energy Building"):

• The temporal mismatch of the energy generation with the building load: building performance mismatch

• The temporal mismatch of the energy transferred to a grid with the needs of a grid: grid interaction mismatch

• The mismatch between the type of energy imported and exported: fuel switching mismatch

The temporal mismatch may occur at a daily level or at seasonal level.

In this study, mismatch factor for *building performance* is estimated. This criterion evaluates the net energy balance between on-site energy production and delivered energy.

C. Calculating electricity production of PV cells

PV production assumption

This study works on PV integrated buildings. PV cells are integrated in all shading scenarios; fixed shading, movable shadings and PV integrated in the glazing. Energy productions of Photovoltaic cells are calculated by PVsyst tool and PVGIS. In this section PV characteristic and assumptions which have been used for each scenario, will be explained in detail.

Overhang: this shading system is completely covered by PV cells. The area is around 2.25 m^2 and the slope of PV panels is 40 degrees. According to the results, the optimum angel of PV panels in Norway, for a fixed mounting, is around 40 degrees from the horizontal plane.

Overhang is fixed shading device and stands always. So, for this scenario, PV production has been calculated for a whole year. PV cell systems are made of polycrystalline. The maximum nominal power of these cells is 240 Wp. PVsyst is used as a simulation tool.

Horizontal and vertical blinds:

Horizontal and vertical blinds are movable. The slats are covered by PV cells and they track the sun position. Having controllable and dynamic blinds, we can reduce substantial amount of energy demand. Also, in tracking systems, efficiency of PV production will be increased significantly. Figure 26 shows the PV area on one of the slats.

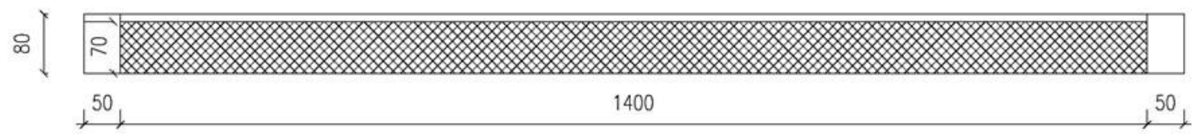


Figure 26. PV integrated on slat

The shading blinds are activated when the outside temperature is higher than 10 °C and if the solar radiation incident on the window exceeds 200 W/ m^2. According to the COMFEN weather file, the average outdoor temperature in Oslo gets above 10 °C from May to September. It means that shading systems are on from May to September, and they are not activated for the rest of the year. In this case we can get the most benefit from solar radiation in cold months.

PV production is calculated specifically for these months. Since there is no shading system from September till May, PV cells will not produce any electricity in this period.

Like overhang, PV cells are made of polycrystalline with a maximum 240 Wp nominal power. PVSYST has been used for modeling and calculating electricity production. Also Self-shading effect of blinds has taken into account.

PV Glass

The PV glass system is semi –transparent PV glass which has been made of silicon thin-film elements. For this scenario a product available on the market has been chosen ASITHRU from SCHOTT. The maximum nominal power of ASITHRU PV is 100 Wp. PV cells cover the whole surface of windows. This surface is equal to 5.4 m^2 for two windows on the facade.

Electricity production of PV cells in this scenario has been calculated by PVGIS tool. Semi-transparent ASITHRU PV has different parameters (PV type, peak power, etc.) which were not available in PVsyst library. Therefore, the author used another tool for this scenario.

D. Evaluating daylight and glare

Dynamic simulation methods are common practice to ensuring optimal daylight illuminance level. This section described the methods and assumption which are used for evaluating daylight and glare analysis.

Daylight assumption

The daylight illuminance setpoint is set at 500 Lux. (Mitchell, Yazdanian, Zellany, Curcija, & Bjornstad, 2011)The lighting control is continues light dimming based on daylight levels. Continuous control provides an ideal lighting system for calculating upper limits of savings using natural daylight. More detail about the mechanism is available in the Appendix 2.

Analysis method

There are wide varieties of dynamic metrics for evaluating daylight conditions in a space. Daylight analysis is the process that estimates the amount of light entering into the building from outside. Advanced computational methods allow designers to examine and simulate spaces for lighting availability and visual comfort. These methods and simulation tools help architects and designers to refine design solutions. (Glare Analysis | Daylighting Pattern Guide)

This section describes two dynamic methods which have used for daylight evaluation; Daylight Factor (DF) and Useful Daylight Illuminances (UDI). Ecotect is used for calculating daylight factor. Useful daylight illuminances is measured by COMFEN.

Daylight factor

Daylight factor is the most common metric used to test and simulate daylighting designs in ‘overcast sky simulators’. Illuminance from the sky varies from moment to moment. So, daylight illuminance in the room will also change. Daylight Factor is a ratio that represents the amount of available indoor illumination relative to the outdoors illumination at the same time under overcast skies. (CIBSE Lighting Guide 10, 1999) Daylight Factor is typically calculated by following formula:

$$\text{Daylight Factor} = \frac{\text{Illuminance indoors}}{\text{Horizontal illuminance from an unobstructed sky}} \times 100\%$$

BREEAM-nor (BREEAM-NOR ver. 1.0, 2012) provides guidelines for average daylight factor in buildings according to the latitude of building location. This table can be seen in Table 4.

Latitude (°)	Average Daylight Factor		
	First credit - all buildings	Exemplary level	
		Single-storey buildings	Multi-storey buildings
≤40	1.5	3	2.25
40-45	1.7	3.4	2.55
45-50	1.8	3.6	2.7
50-55	2.0	4	3
55-60	2.1	4.2	3.15
≥60	2.2	4.4	3.3

Table 4. Average daylight factor measured at a height of 0.8 meters according to the latitude at the building location Ref: (BREEAM-NOR ver. 1.0, 2012)

According to Table 3, the average daylight factor should not be lower than 2.1, for a building in Oslo. Daylight factor is calculated for all scenarios.

The daylight factor is not influenced by the orientation of the building. The reference sky is rotationally invariant and independent of the geographical latitude of the building. (Littlefair, 1990) The daylight factor provides a feeling of how "bright" or "dark" a given building is, but since it is based on a single sky luminance distribution, its credibility to evaluate the annual daylight level in a building is intrinsically limited. (Tregenza, 1980)

Daylight Autonomy (DA) is percentage of occupied time hours in the year when daylight is sufficient to provide illuminance level requirements at the given point in the space. The recommended illuminance level is usually between 300 and 500 lux. However, many office occupants tend to work at lower daylight levels than the commonly referred 300 or 500 lux. (Reinhart & Voss, 2003) Daylight autonomy is commonly referred to as 'dynamic daylight metrics'. It considers real daylight contribution and also the manual control of shading systems. (Reinhart, Mardaljevic, & Rogers, 2006).

Useful Daylight Illuminances (UDI)

Useful Daylight Illuminances (UDI), proposed by Mardaljevic and Nabil in 2005, is a modification of "*Daylight Autonomy*". The aim of this metric is to determine when daylight levels are ‘useful’ for the occupant. The suggested range for occupied times of the year is between 100-2000 lux. Daylight illuminance, lower than 100 lux, is detected as too dark and upper than 2000 lux is meant too bright. The upper threshold (more than 2000 lux) is likely appearance of glare and might lead to visual discomfort. (Reinhart, Mardaljevic, & Rogers, 2006)

Glare assumption

Too much daylight can produce excessive glare, which is particularly undesirable in computer and other work environments. Glare within the range that the eye can handle is called discomfort glare; glare preventing us from doing a task is called disability glare. (Daylighting in Buildings, 1994)

One way to improve the quality of the lighted space is minimizing the glare effect. Shading devices can limit the glare. Digital daylight simulations are used for estimating the glare level in the room. Glare evaluation is simulated by COMFEN which has RADIANCE in back.
The presented approach to glare evaluation is Discomfort Glare Index (DGI), developed by Hopkins (Hopkinson R. G., 1970) and (Hopkinson, 1972). This measure is a function of source and background luminance, source size and location, and direction of view.

The DGI is described by the following equation: (EnergyPlus Engineering References, 2010)

$$G_I = 10\log_{10} \sum_{i=1}^{\substack{\text{number of}\\\text{windows}}} \mathrm{G_i}$$

Where Gi is discomfort glare constant and is calculated by:

$$G = \frac{L_w^{1.6}\Omega^{0.8}}{L_b + 0.07\omega^{0.5} L_w}$$

Where
G = discomfort glare constant
L_w = average luminance of the window as seen from the reference point
Ω = solid angle subtended by window, modified to take direction of occupant view into account

L_b = luminance of the background area surrounding the window

DGI values are shown in Table 5.

16	Just perceptible
20	Just acceptable
22	Borderline between comfort and discomfort
24	Just uncomfortable
28	Just intolerable

Table 5. DGI index

More detail about methods and calculations can be found in Energyplus manual. (EnergyPlus Engineering References, 2010) Maximum DGI for office buildings is 22.

A Clear sky in a summer day may be considered as a worst case for glare appearance. In this study, glare condition is checked for three days: 15th of January, 15th of March, 15th of July.

Evaluation Method

In the next chapter, results from the simulations will be discussed. The shading systems will be evaluated in each faced, in terms of heat gains, energy demand, energy production of PV cells, daylight and glare. An evaluation system established to compare and evaluated the performance of all scenarios. The evaluation system consists of a table which has filled with colors.

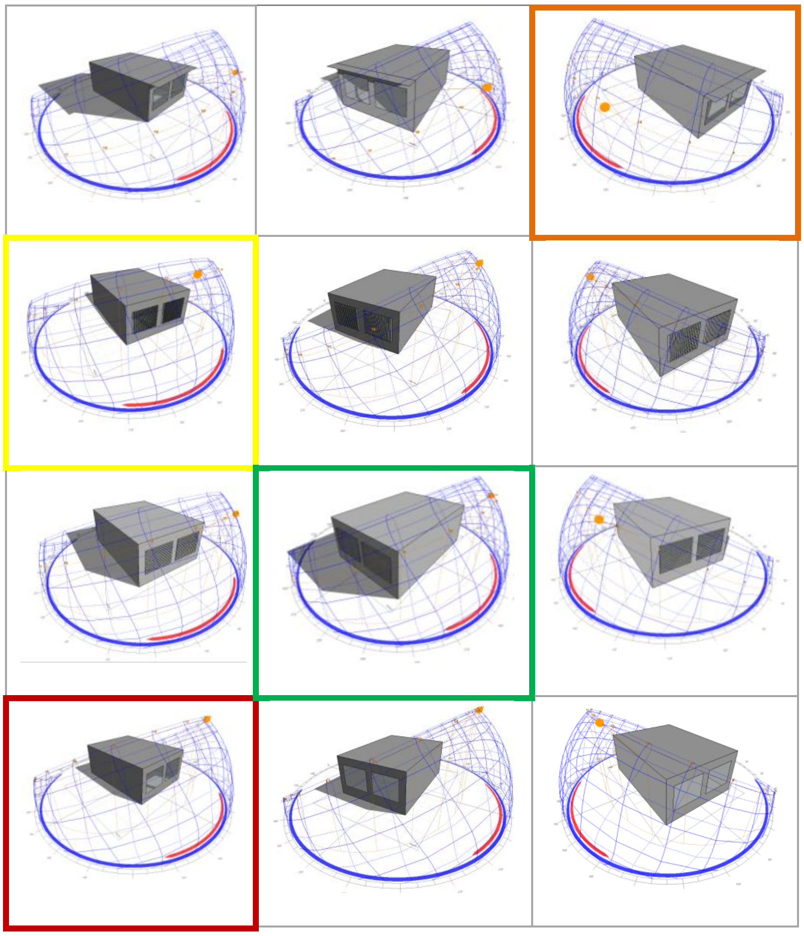
The table presents a rating system which makes the comparison easier. Each color has a different meaning and a specific credit. The rating system is based on the priority of the best performance. Black color represents the options with the best performance which has 4 credits. On the other hand, the worst options are shown using white color. White color does not have any credit. The same logic exists for other colors. Table 6 depicts colors and their corresponding credits.

Color	Description	Credit
	best performance	4
	2nd best performance	3
	3rd best performance	2
	4th choice	1
	5th choice	0

Table 6. Rating system_ colors and credit

The system will be discussed more in detail in chapter 4, discussion and conclusion.

CHAPTER III_ Results



Result

To investigate the influence of shading devices on energy efficiency and daylight in the building, different scenarios are simulated by COMFEN and ECOTECT. The simulation assumptions and evaluation criteria are described in the previous chapter, methodology.

In the following chapter, the results from the simulations will be discussed and different scenarios in the west and east facades will be compared. Comparable assessments have been conducted for *heat gain, energy consumption, energy production of PV cells, daylight and glare.*

HEAT GAIN

The advantage of COMFEN is the possibility to measure solar radiation on a facade and window. The aim of *heat gain* analysis is to study how shading devices can influence on solar radiation strikes a building, and thus heat gain. The results lead us lead us to evaluate the best location for window design and PV implementation.

In this section monthly heat gain and annual heat gain of windows for each scenario will be discussed, respectively to the south, west and east facades.

South facade

Figure 27 demonstrates monthly heat gain of windows in south facade. It can be seen that shading devices have a significant role in the amount of solar gain through windows. The impacts can specifically be seen in summer months from June till September. Solar shadings are used to reduce heat gains in the summer and protect inner space from overheating.

In south facade, the peak day for cooling demand is Aug 21st and for heating demand is January 3rd.

Vertical blind has the lowest amount of heat gain during summer months. As it was mentioned in chapter 2, methodology, it is assumed that vertical and horizontal blinds are not activated during winter time. Thus, they allow more solar radiation to get through into the room when they are needed. With this assumption, it seems that vertical blinds, as well as horizontal blinds, perform very well in different seasons.

Having PV on glass results in less amount of heat gain, compared to other scenarios. PV glass is gray and has less solar transmittance (0.54). It blocks solar radiation, and thus dramatically reduces heat gain over the year.

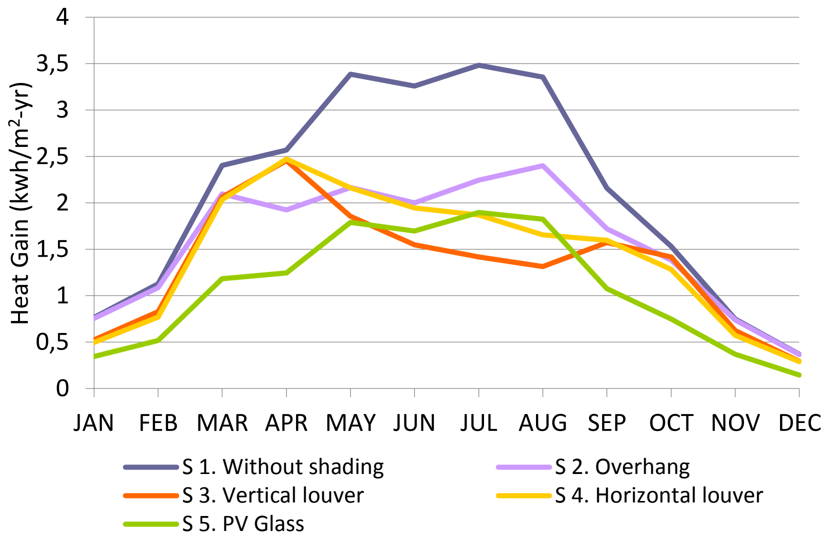


Figure 27. Monthly Heat Gain for All Windows per unit floor area in south facade (kWh/m2-yr)

Figure 28 shows annual heat gains for all windows in south facade. Again, it can be seen that the highest amount of heat gain is available when we do not have shading devices. On the other hand PV glass has the lowest amount of heat gain.

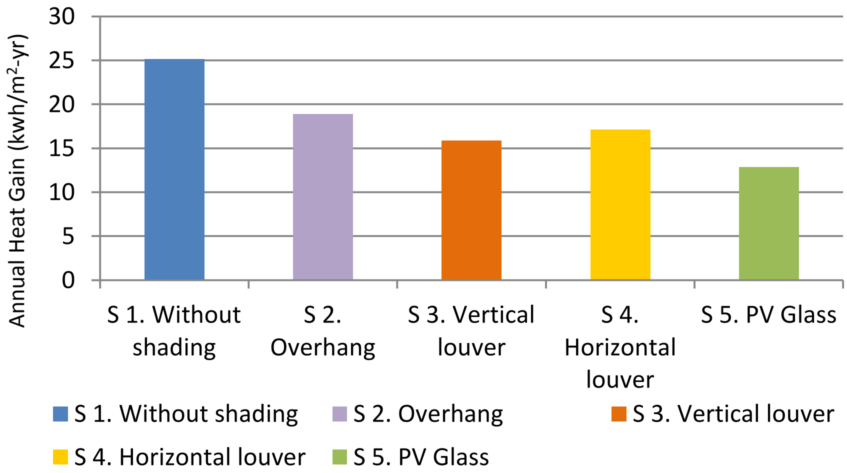


Figure 28. Annual Heat Gain for All Windows per unit floor area in south facade (kWh/m2-yr)

West facade

Figure 29and Figure 30 illustrate the influence of shading devices on heat gain in west facade.

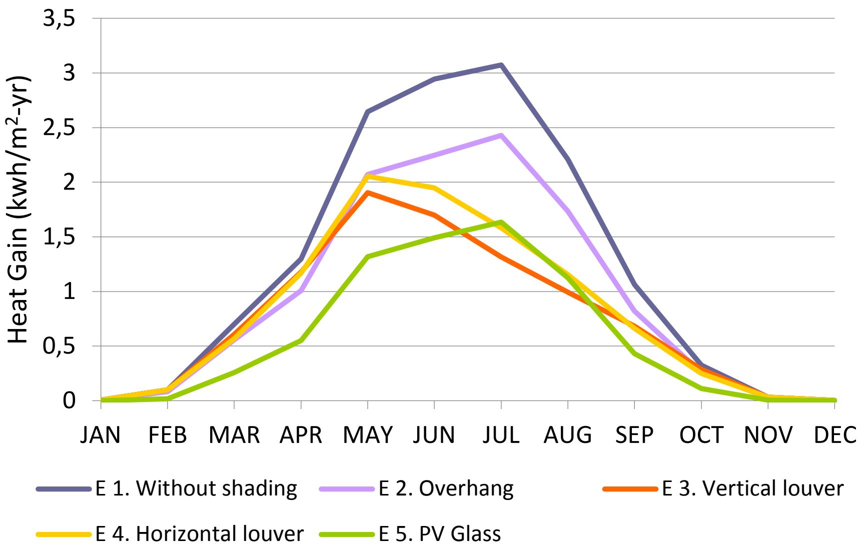


Figure 29. Monthly Heat Gain for All Windows per unit floor area in west facade (kWh/m2-yr)

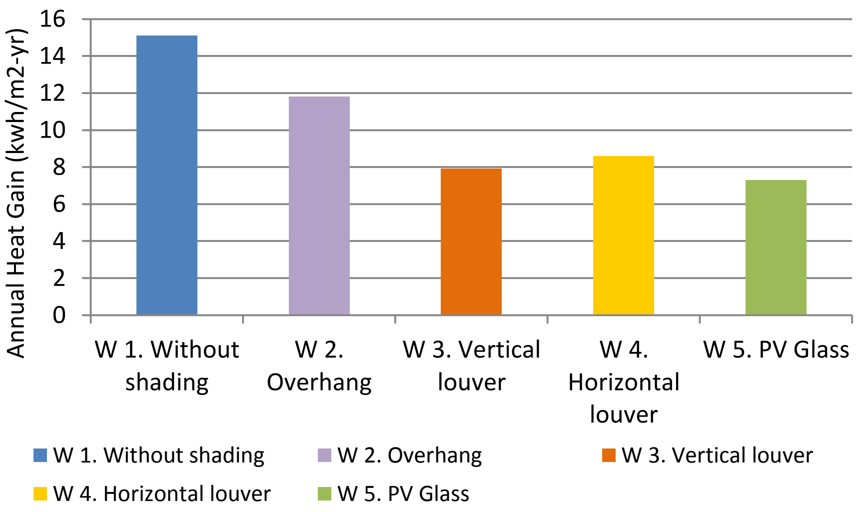


Figure 30. Annual Heat Gain for All Windows per unit floor area in west facade (kWh/m2-yr)

In Norway, due to the high latitude, amounts of solar radiation differ significantly in summer and winter. In the summer, the sun rises very early and sets very late. West facing surface receives solar radiation from noon until sunset. Thus, it gets less heat than south oriented surface.

On the west facade, overhang device allows 33% more heat gain than vertical louvers. While vertical and horizontal louvers have their peak gain in April, overhang and PV glass have the highest gain in July. (Figure 29) It can be seen that, PV glass gets the lowest amount of heat annually. (Figure 30)

East facade

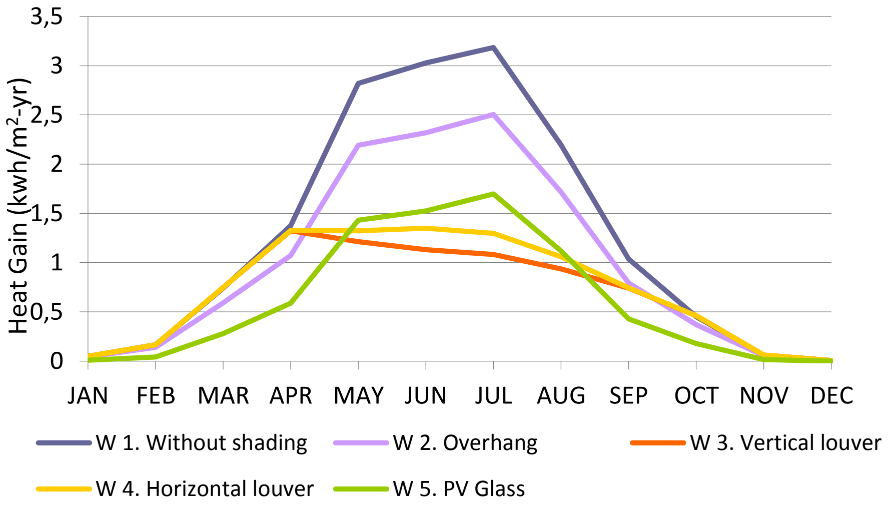


Figure 31. Monthly Heat Gain for All Windows per unit floor area in east facade (kWh/m2-yr)

The situation in the east facade is very similar to the west facade. They get less solar radiation than the south facing surface. The results demonstrate that in east facade, the peak demand days for cooling and heating are July 31st and December 26th. (Figure 31)

The maximum amount of heat from solar radiation can be gained when there is no shading device. In winter, there is not a big difference between the shading systems, in heat gain. But it can be seen that there is a huge dissimilarity in summer. Shading devices block solar radiation in summer and therefore some scenarios have a very low heat gain. Vertical and horizontal blinds gain 55% less heat in the summer, in comparison with the first option, where there is no shading device. Like other facades, the lowest amount of heat gain goes to the glass with PV. (Figure 31)

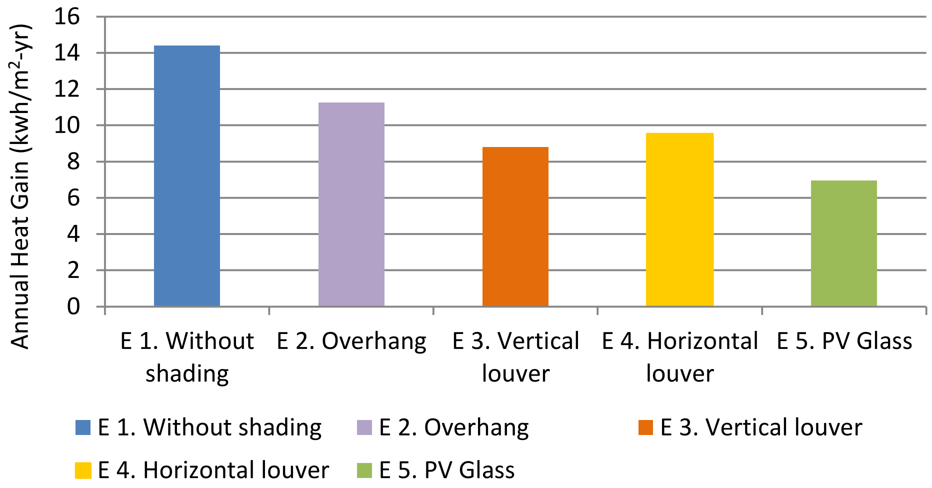


Figure 32. Annual Heat Gain for All Windows per unit floor area in east facade (kWh/m2-yr)

Comparison annual heat gain of shading systems in all facades

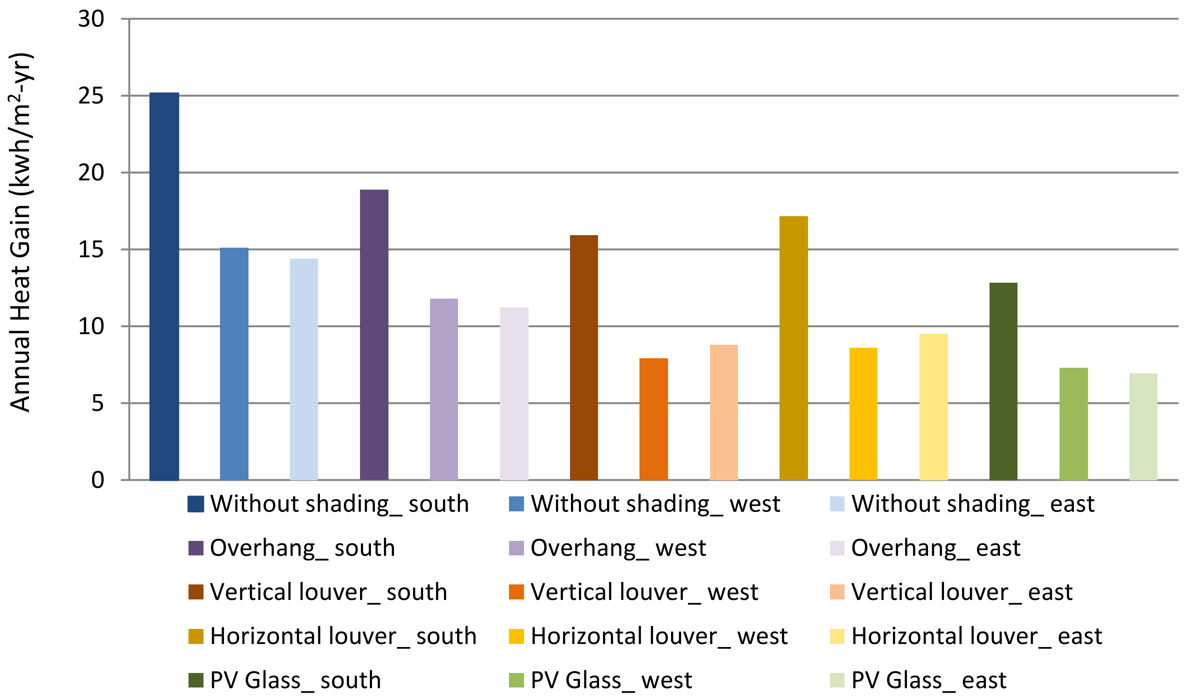


Figure 33. Annual heat gain of shading systems in all facades (kWh/m2-yr)

Based on the results from simulations, there is an uneven distribution of solar radiation for different shading systems and facade orientations.

In all scenarios, the south facade gets the highest amount of heat through the year. The results are reasonable. In north hemisphere, a south oriented surface receives the most solar radiation. Thus it is logical that there is a decreasing amount of heat gain in the west and east facade. Figure 33 shows that, vertical and horizontal blinds on the south facade obtain around 50% more heat than those on the west facade.

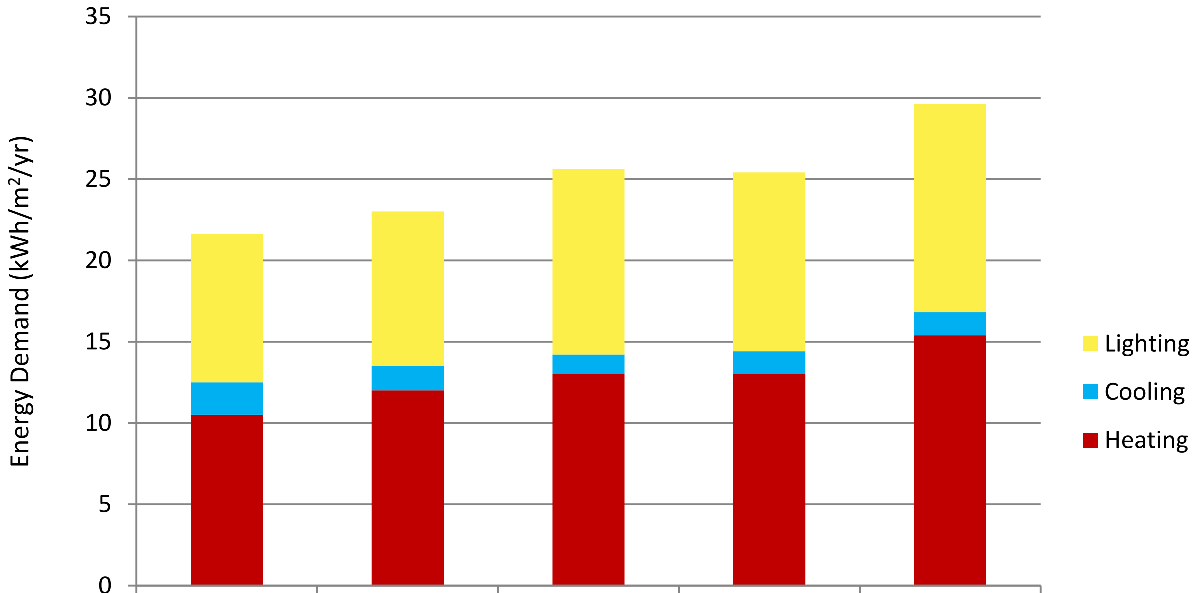
Due to the symmetrical path of the sun, the east and west facing facades of a building have similar requirements. The altitude angle of the sun is very low in the morning and in the afternoon and very high at noon. Vertical and horizontal blinds have their lowest heat gain on west facade. On the other hand, overhang and PV glass receives less heat on the east facade.

The highest amount of heat gain is achieved when no shading protection for windows have been used.

Energy demand

One of the important questions is about the influence of shading systems on energy consumption based on building orientation. This chapter discusses *energy demand* for each shading device and compares different scenarios. *Energy demand* means energy consumption for heating, cooling and artificial lighting.

South facade



	S1. No shading	S2. Overhang	S3.Vertical blinds	S4. Horizontal blinds	S5. PV Glass
Lighting	9,1	9,5	11,4	11	12,8
Cooling	2	1,5	1,2	1,4	1,4
Heating	10,5	12	13	13	15,4

Figure 34. Annual energy demand in south facade (kWh/m2-yr)

Figure 34 shows energy demand including heating, cooling, and lighting for shading systems in south facade.

It can be seen that the first scenario, no shading device, has the lowest total energy consumption. At the same time, it allocates the highest amount of cooling demand among all other scenarios. This result indicates that shading devices decrease cooling demand of the building. In our case, although the cooling demand is rather small (2 kWh/m^2-yr), shading device can reduce more than 25% cooling demand.

Overhang, with small differences, has the second place in terms of total energy demand. Using shading devices, lighting demand will be increased.

The highest amount of heat can be gained where there is no shading device. (Figure 34) According to the results, there is a correlation between the amount of solar radiation and lighting demand. The more solar radiation on windows, the less heating and lighting demand.

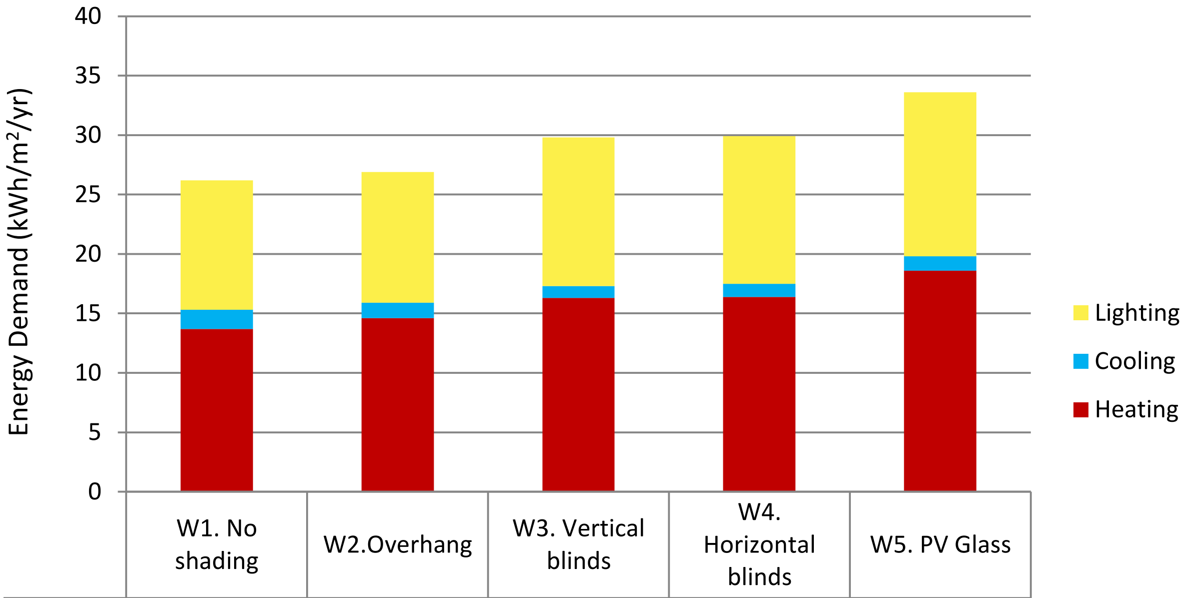
There exist no significant differences in energy consumption, between horizontal and vertical blinds. Yet, lighting demand is a bit lower in horizontal blinds. In both cases the heating demand is increased compared to the base case.

PV glass had the lowest amount of annual heat gain, while it has the highest total energy consumption. PV Glass provides more shade; thus, increases the lighting demand. PV glass blocks more solar radiations and has higher heating demand in winter.

West facade

Figure 35 compares energy requirements for different shading devices in the west facade. Very similar results to south facade have been observed.

Like south facade, the west has the lowest total energy demand when there is no shading device. It can be seen that, shading devices have a notable impact on lighting. They increase the energy requirement for artificial lighting.



	W1. No shading	W2.Overhang	W3. Vertical blinds	W4. Horizontal blinds	W5. PV Glass
Lighting	10,9	11	12,5	12,4	13,8
Cooling	1,6	1,3	1	1,1	1,2
Heating	13,7	14,6	16,3	16,4	18,6

Figure 35. Annual energy demand in west facade (kWh/m2-yr)

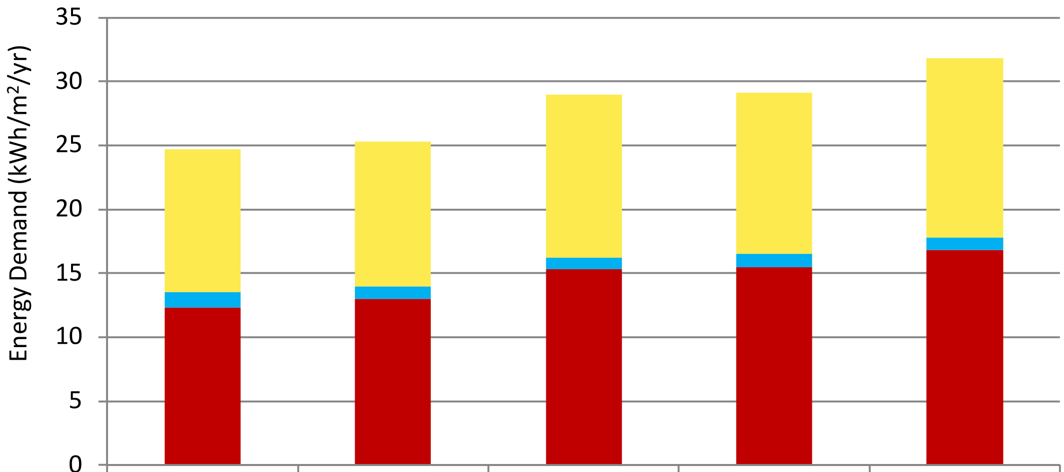
It has to be mentioned that in the west facade, vertical blind has the minimum heat gain during summer. The results restated that, the lowest cooling demand in summer is allocated to the vertical blind.

PV glass would provide much more shading than other types of shading systems. This shading effect not only increases the lighting demand but also raises the heating demand in winter.

In this study, the impact of PV temperature on indoor environment has not taken into account.

East facade

On the east facade, the base model (no shading device) with 13,7 kWh/m^2 heating demand is slightly better than overhang. In terms of heating demand, the overhang has the best performance among all other cases. (Figure 36)



	E1. No shading	E2. Overhang	E3. Vertical blinds	E4. Horizontal blinds	E5. PV Glass
Lighting	11.2	11.3	12.8	12.6	14
Cooling	1.2	1	0.9	1	1
Heating	12.3	13	15.3	15.5	16.8

Figure 36. Annual energy demand in east facade (kWh/m2-yr)

Horizontal and vertical louvers have almost the same performance, in terms of total energy demand. Among all scenarios, vertical louver provides the lowest demand for cooling. This reflects the states that, where high amounts of cooling is required (i.e. in hot climates), vertical louver performs the best in the west and east facades.

Again, due to the more shading that PV glass provides, more energy for lighting and heating is required.

Energy production of PV panels

This study has been conducted to compare electricity production of PV cells in different types of shading systems. Photovoltaic cells are integrated into the solar shading devices. In chapter 2, methodology, PV system sizing in each shading type are explained in detail. PV production is calculated for all orientations; south, west and east facades.

In order to have realistic comparison PV cells which are used in shading systems should have the same values. In this study, simulation variants for overhang, vertical and horizontal louvers assume the same. This means that they have the same type of PV cells, nominal peak power, and system efficiency. See the Appendix 3 for detailed PV systems

PV glass has specific characteristics. Likewise other PV shading systems, in this scenario PV cells are made of thin-film. This product is less efficient than other PV types.

Figure 37 shows the PV area integrated into the different shading structures.

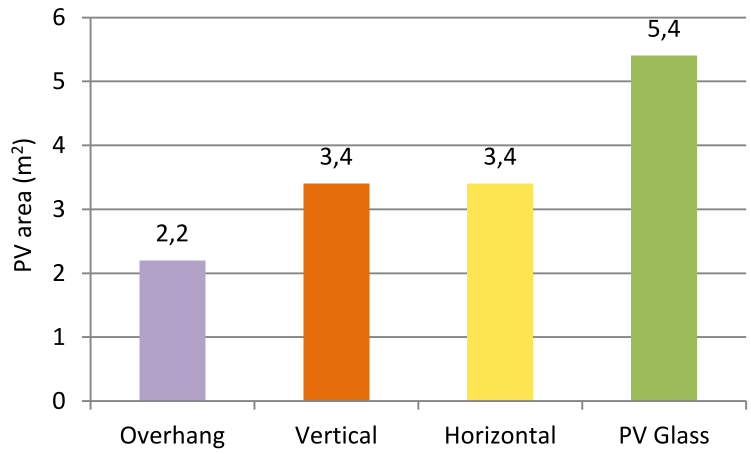


Figure 37. PV area in different scenarios (m^2)

Overhang with 2.2 m^2 has the smallest area and PV glass with 5,4 m^2 has the largest PV area. Vertical and horizontal louvers have the same area.

It assumed that vertical and horizontal blinds are activated when the solar radiation is higher than 200 w/m^2 and outdoor air temperature more than 10 degrees. According to the weather file used in COMFEN, from May till September, the average outdoor air temperature gets higher than 10 degrees. This assumption is also applied for calculating PV production. First the annual PV production estimated for each month in the year. Figure 38 shows the annual electricity production of different systems in south, east and facade facades.

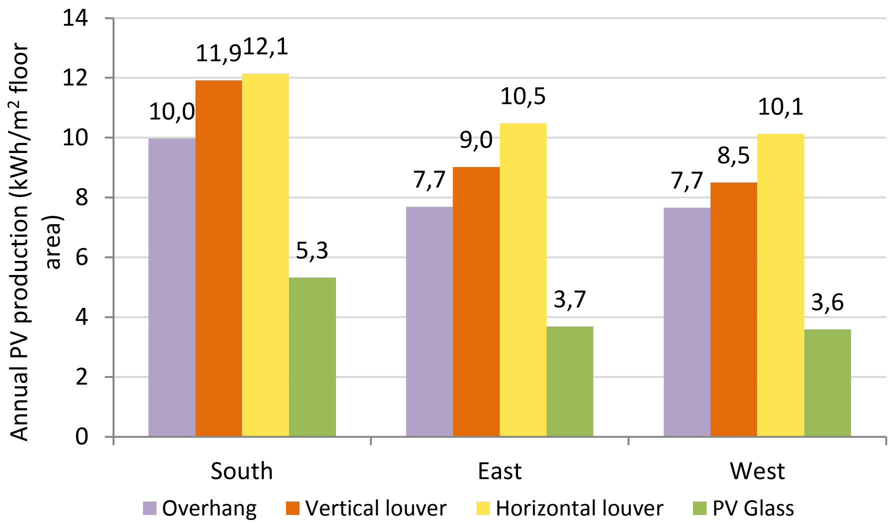


Figure 38. Annual electricity production of PV cells in all scenarios (kWh/m^2 floor area)

It can be seen that, annual electricity production of horizontal blind is the highest in all facades, compared to the other types. South facade produces has more potential to provide energy than east and west facade.

Overhang is an external fix shading system which stands through the year. The same situation exists for PV glass; it is always on. Thus, energy production for these two scenarios is calculated for entire a year. Horizontal and vertical blinds are activated from May till September. Figure 38 compares electricity production of different cases, based on the controlling assumptions for horizontal and vertical blinds.

Figure 39 demonstrates the electricity as we described, regardless of the shading system, the highest annual energy production can be achieved in south facade. The interesting point is that, from May till September, horizontal blind has the highest electricity production in east facade. See Appendix 3 for more detailed.

An explanation for that could be the self-shading effect that horizontal blinds would make. The south facing surface receives more solar radiation than other orientations. Due to the high latitude and day length, the sun is higher in the sky throughout the summer. This fact results in having the most self-shading effect in south facade. Shading effect decreases efficiency of PV cells.

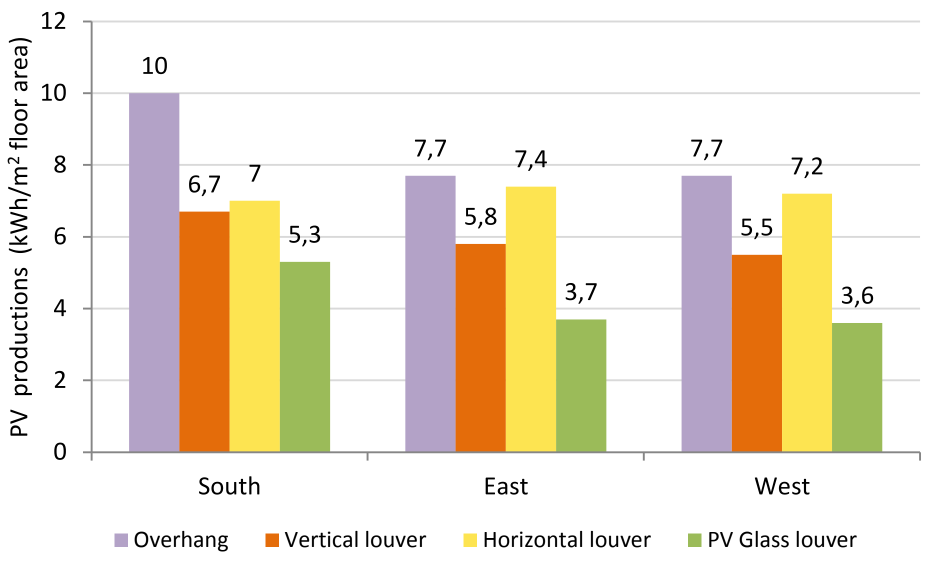


Figure 39. Electricity production of PV cells based on shading control strategies (kWh/m^2 floor area)

Daylight evaluation

This chapter will discuss the influence of shading systems on the lighting level. The study has been conducted to evaluate daylight and the glare situation in a room. Average daylight factor and daylight illuminance level have been studied for all scenarios. For these purposes, COMFEN and ECOTECT are used as simulation tools.

Daylight Factor

In the following, daylight factor in different scenarios, in south, east and west facades are illustrated. ECOTECT is used for estimating daylight factor bacuse COMFEN does not calculate the daylight factor.
The major weakness of the daylight factor is that the orientation of the building does not influence the daylight factor, because the reference sky is rotationally invariant and independent of the geographical latitude of the building.

Figure 40 shows daylight factor for 5 scenarios: without shading device, Overhang, vertical blind, horizontal blind, PV glass. The highest average DF is available where there is no shading device. Shading systems have influence on amount of solar radiation, thus, natural lighting.

The average DF in all scenarios is more than 2%, however, in the backside of the room the DF in not proper. In horizontal blinds scenario, daylight factor near the window is around 7%, while it gets lower than 2 % in the back of the room.

Compared to the vertical blind, horizontal louver allows less sunlight to get into the space. Among all scenarios, PV glass has the lowest average daylight factor. This type of glass has a lower light transmittance than other glazing, thus blocks more solar radiation.

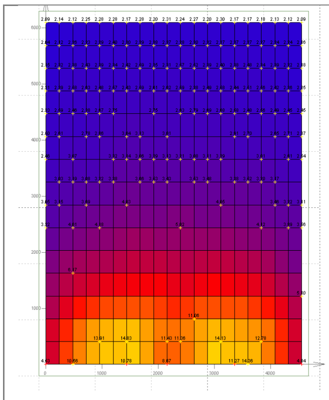
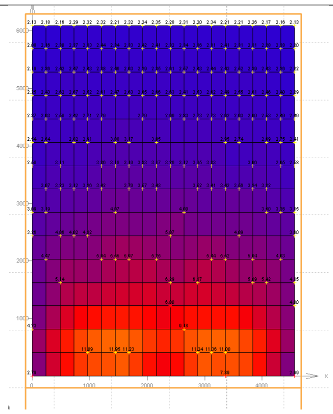
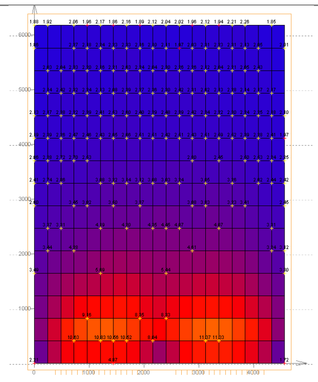
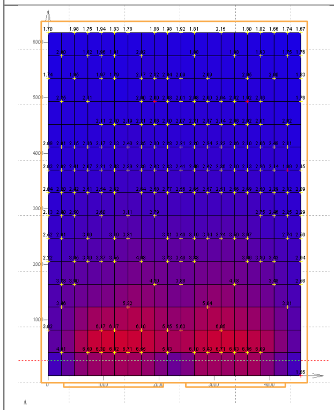
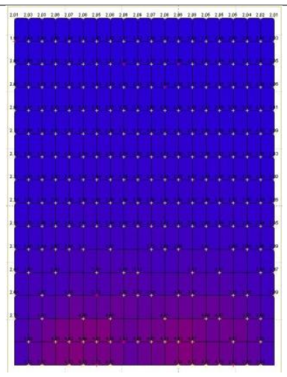
		
S1. Without shading DF: 4,90	S2. Overhang DF:4,33	S3. Vertical louver DF:3,8
		
S4. Horizontal louver DF:2,95	S5. PV glass DF: 2,5	

Figure 40. Average Daylight Factor

The highest amount of daylight can be reached near the window openings.

There is a lack of natural daylight in the backside of the room. In this situation, more artificial lighting will be required.

Useful Daylight Illuminances (UDI)

As it mentioned in chapter 2-methodology, Useful Daylight Illuminances (UDI) is modification of Daylight Autonomy (DA). This measure proposes the situation when daylight levels are 'useful' for the occupant. The suggested useful range is between 100 to 2000 lux. The room is too dark if illuminance be lower than 100 lux. On the other hand, probably glare will be appeared, when the daylight illuminance is higher than 2000 lux.

In the following section UDI of each facade in two seasons (summer and winter) will be compared. Gray color shows the suggested range for proper illuminance which is between 100 to 2000 lux.

South facade

Following figures exhibit useful daylight illuminances in south facade. Figure 41 display UDI in summer.

Summer

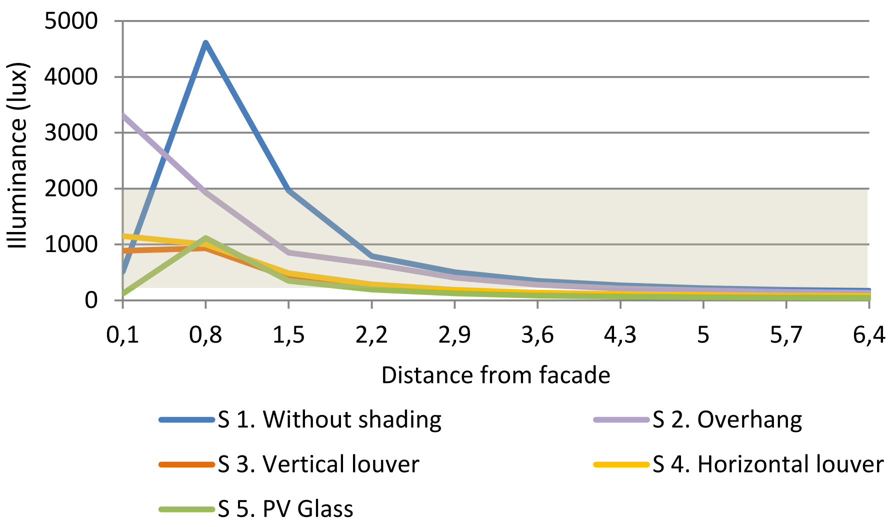


Figure 41. UDI in south facade in summer

During the summer, when there is no shading devices, the amount of illuminances exceed from recommended band. This problem occurs in first 1.5 meters distance from facade. Illuminance level can increase up to double the standard value. This point results in having glare in the first scenario. Other scenarios more or less are located in the band and probably will not suffer from glare. Another point is that in all scenarios after 4 meters distance, illuminance level is very low.

During winter the situation is a bit different. In winter sun is low in the sky. Due to the high latitude and length of the day, the amount of solar radiations which hits a surface is low.

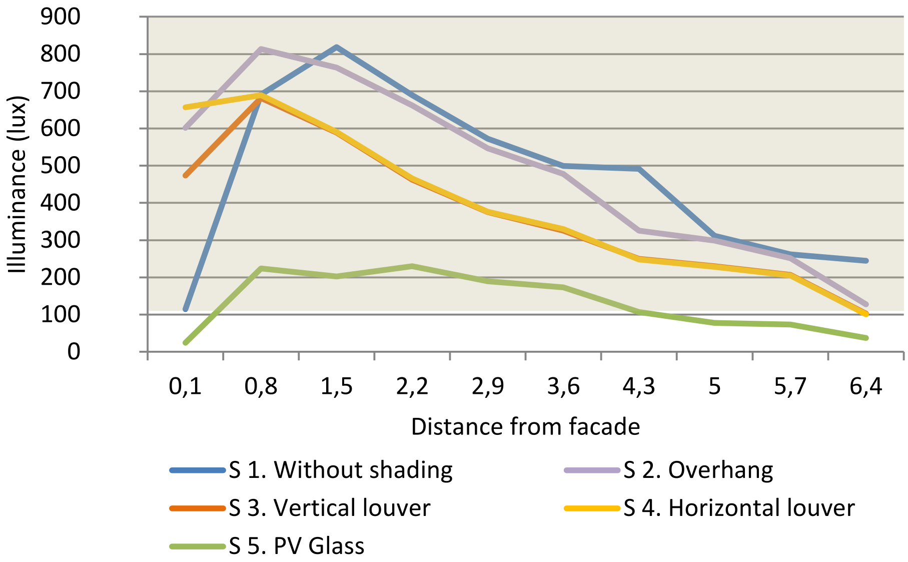


Figure 42. UDI in south facade in winter

Figure 42 shows daylight illuminance level in winter. The base model has the highest illuminance level; this model doesn't have any solar protection. Vertical and horizontal blinds are almost in the same range.

In winter time all scenarios except PV glass are in the range of acceptable illuminance level. The illuminance of PV glass is lower than 100 lux in the backside of room. PV glass provides enough daylight only in 4 meter distance from the opening.

West facade

Summer

Figure 43 and Figure 44 show the influence of different shading systems on illuminance level in west facade. Compared to the south facade, west facade receives less solar radiations. Figure 43 shows that there is a need to glare protections in west facade, during summer. In summer, horizontal and vertical blinds block more solar radiation thus they have less daylight level.

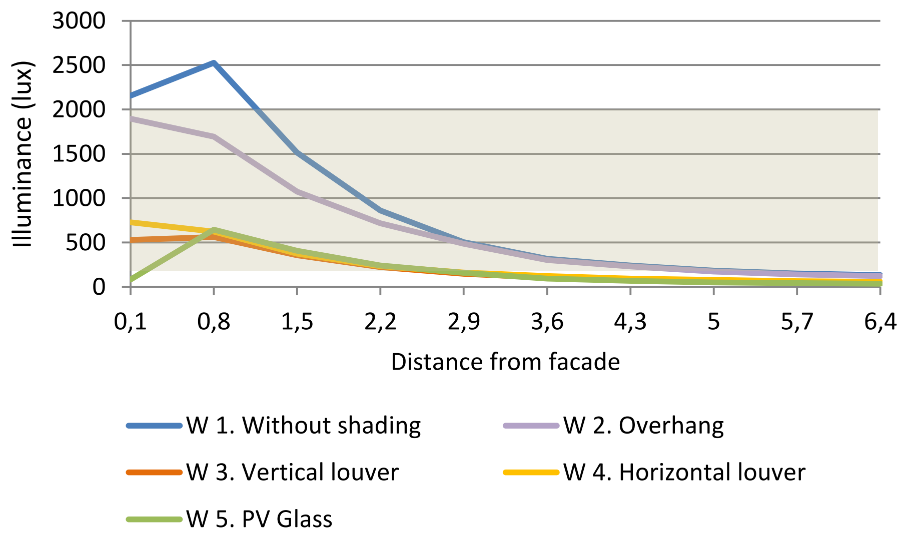


Figure 43. UDI in west facade in summer

Winter

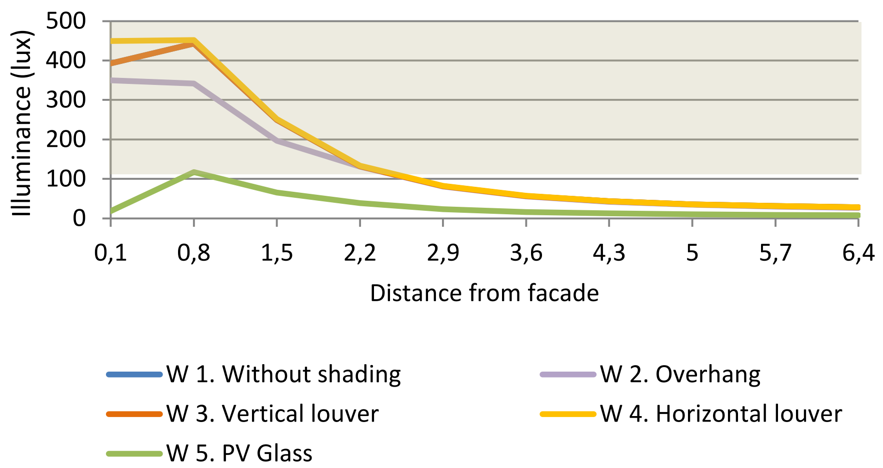


Figure 44. UDI in west facade in winter

In the winter, PV glass has the least daylight illuminance. Daylight illuminance level which can be gained by PV glass is not acceptable. Therefore, more artificial lighting is required for this scenario. Energy consumption calculations also confirm this point. PV glass has the highest amount of lighting demand. (Figure 44)

East facade

Summer

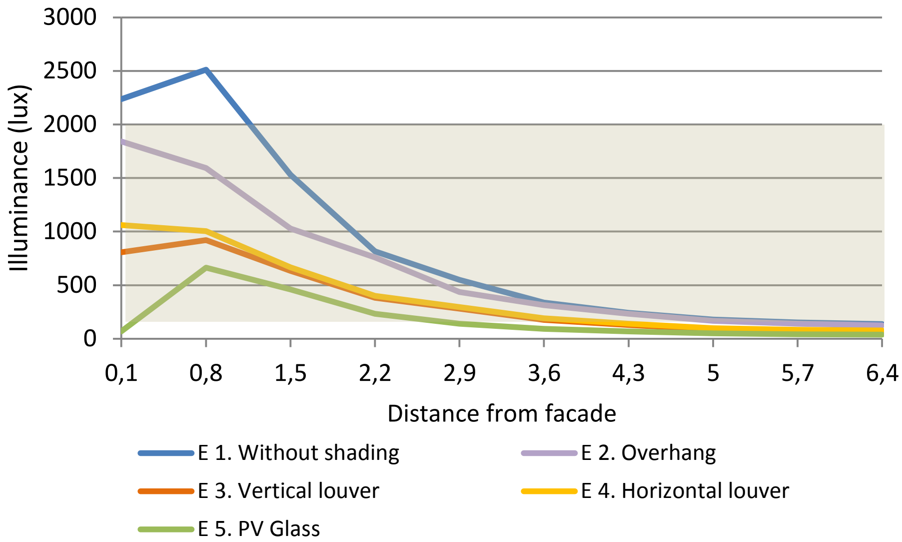


Figure 45. UDI in east facade in summer

To prevent glare effect, shading device seems necessary in summer. According to the simulation results, daylight illuminance can reach to 2500 lux in the areas close to the window. (Figure 45)

Horizontal fixed shading provides better results. Vertical and horizontal blinds perform very similar. Both of them provide proper daylight in a distance of 3 meters from the facade. PV glass provides more shade. Thus, the lower daylight illuminance level can be seen in this case. In all cases, the daylight level is not enough in the back of the room.

Winter

The daylight illuminance level in winter is too low, even without shading devices. This value gets lower than 100 lux after 2.5 meters depth.

PV glass provides more shade than other types of shading systems. This fact keeps daylight level always lower that 100 lux. Which means the illuminance level is not acceptable and the room is too dark. For PV glass scenario, in winter, entire lighting demand must be provided by artificial lighting. (Figure 46)

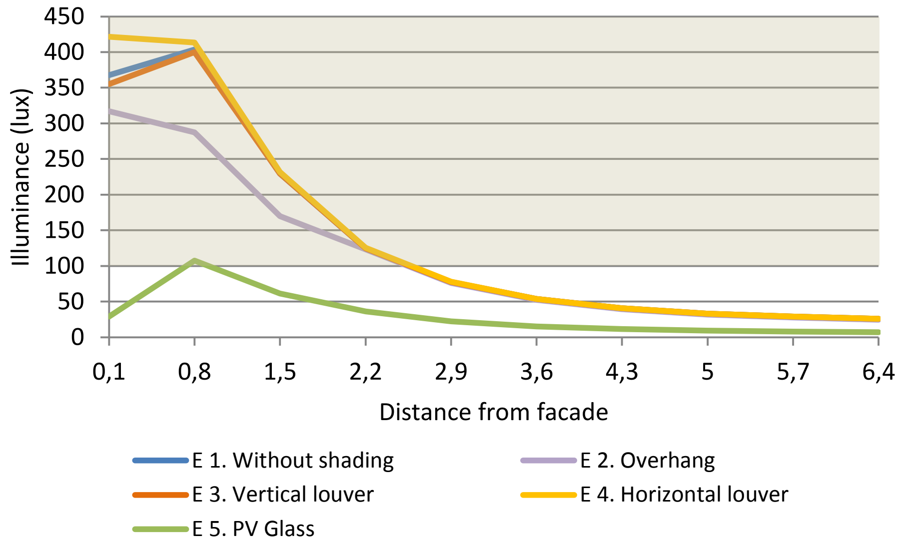


Figure 46. UDI in east facade in summer

Glare

Too much daylight can produce excessive glare, which is not desirable in computer rooms and work environments. Discomfort glare is calculated based on DGI (discomfort glare index) by COMFEN.

Table 7 describes the average and maximum glare index. Average glare index is the annual discomfort glare index at reference 1. The average glare index for all cases is lower than 16, which means it is not perceptible.

	Avg. Glare index	Maximum glare index (GI) at Ref 1	Month of Maximum GI
S 1. Without shading	13.96	17.01	January
S 2. Overhang	13.96	17.01	January
S 3. Vertical louver	10.5	13.6	February
S 4. Horizontal louver	11.03	15.35	January
S 5. PV Glass	8.87	12.0	January
W 1. Without shading	12.02	14.83	June
W 2. Overhang	12.02	14.83	June
W 3. Vertical louver	8.2	11.66	April
W 4. Horizontal louver	8.73	11.56	April
W 5. PV Glass	6.36	9.43	June
E 1. Without shading	12.84	14.84	September
E 2. Overhang	12.84	14.83	September
E 3. Vertical louver	8.61	12.87	April
E 4. Horizontal louver	9.04	13.49	March
E 5. PV Glass	7.36	9.54	September

Table 7. Average and maximum glare index at reference 1

Maximum glare index presents the worst case for glare appearance. A south facing window has the highest DGI in winter. In winter the sun is low in the sky and the solar radiations can get deep into the room. This fact results in glare effect in winter.
The west facing window has its highest glare index at the beginning of the summer in June. In east facade, glare effect would be a problem, particularly in summer and September.

Glare protection seems very necessary in the summer months. It can get very high where there is no proper shading device.

PV glass provides the best glare protection in all facades. It has the lowest solar transmittance and blocks the solar radiation. Vertical blind has the 2nd best performance.

In the evening, west facade suffers the most glare effect. The same situation exists for east facade in the morning.

Figure 47-Figure 49 illustrate the rendering images of glare conditions in south, west and east facades. In the simulation, clear sky (as the worst case) is assumed for the glare comparison. Imaginary dates have also been chosen: 15^{th} of January, 15^{th} of March, 15^{th} of July at 3pm.

SOUTH Facade (Clear Sky, 3PM)

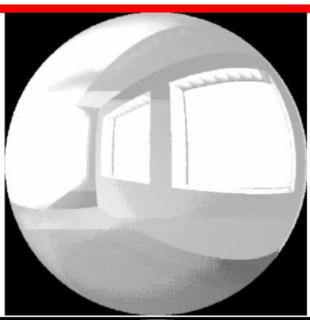
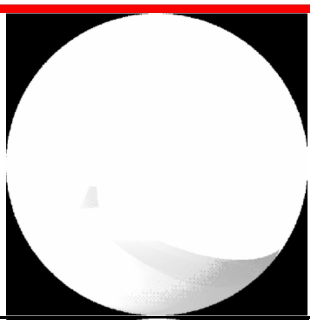
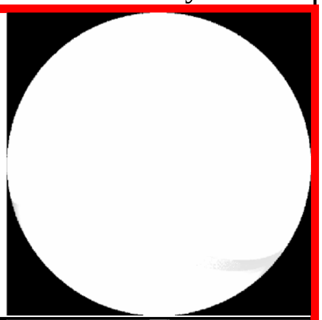
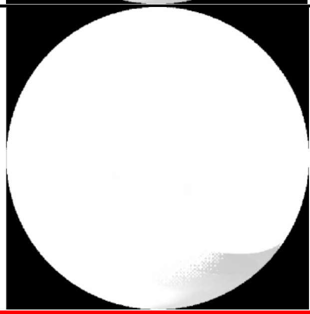
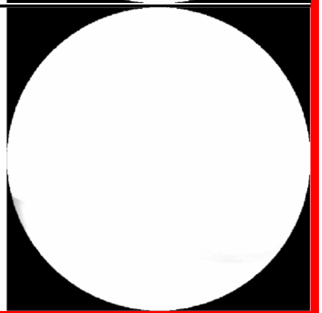
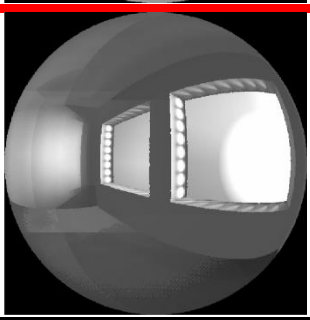
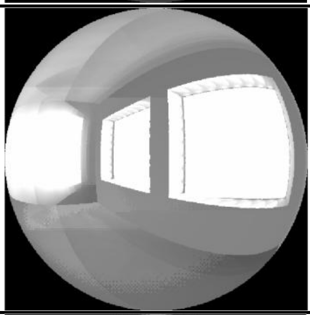
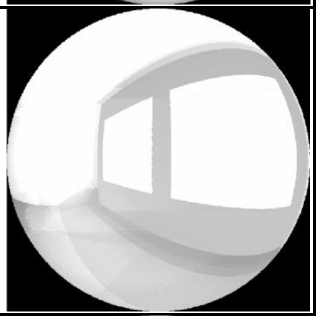
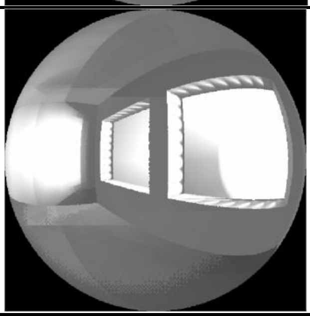
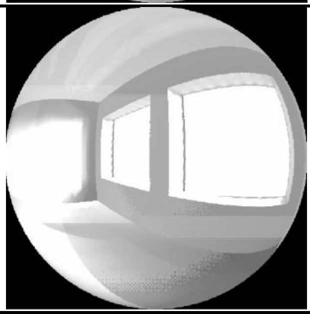
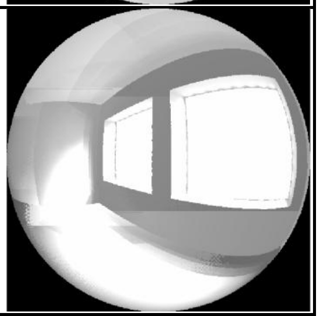
	15 Jan	15 March	15 July
S 1. Without shading			
S 2. Overhang			
S 3. Vertical louver			
S 4. Horizontal louver			
S 5. PV Glass			

Figure 47. Glare comparison in south facade

EAST Facade (Clear Sky, 3PM)

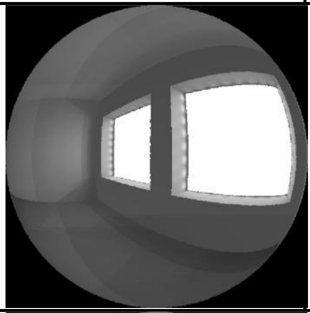
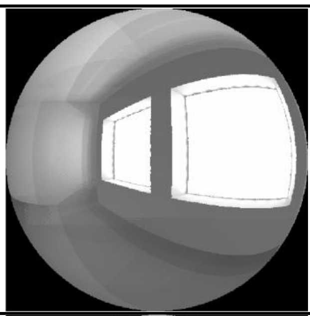
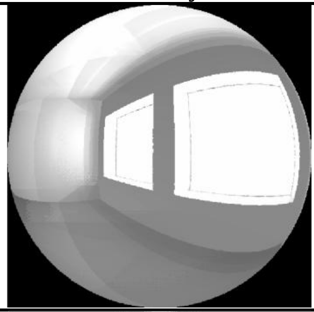
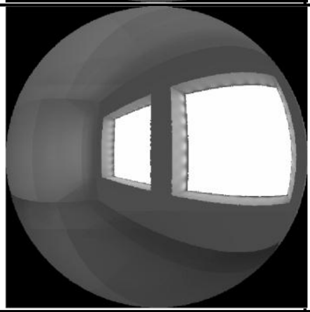
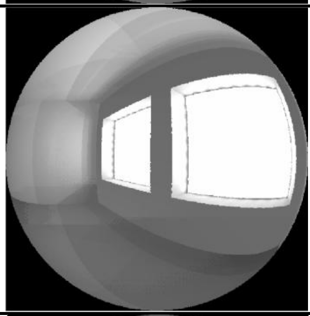
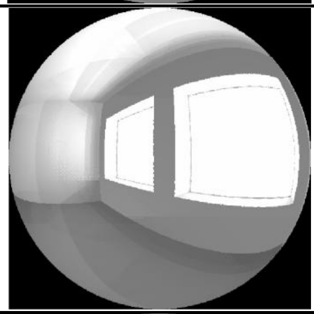
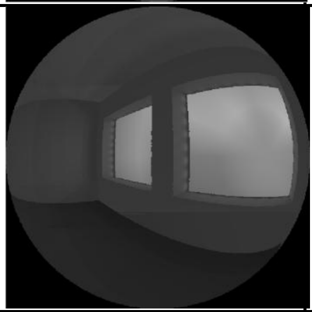
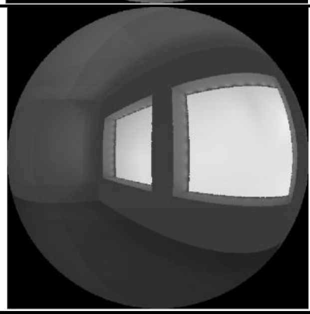
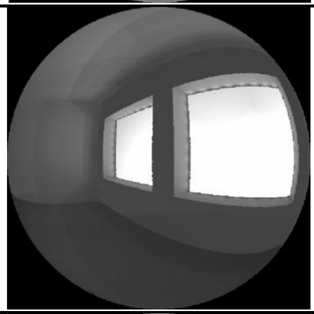
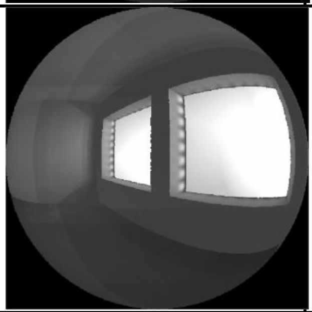
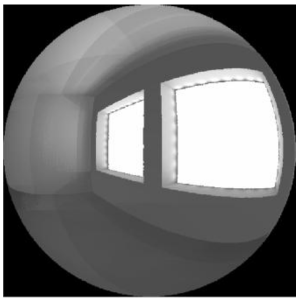
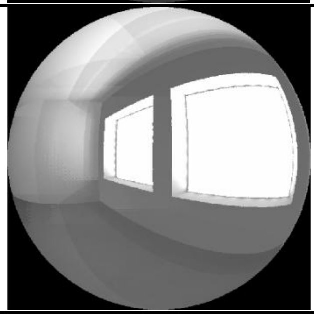
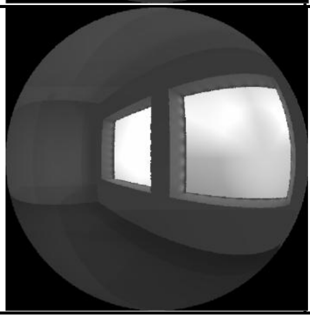
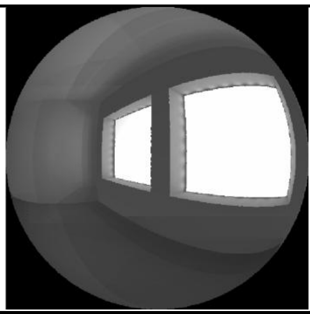
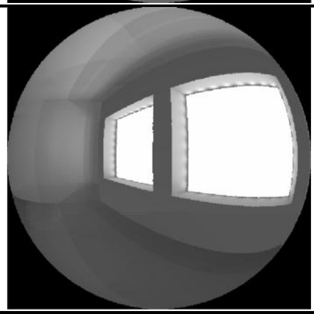
	15 Jan	15 March	15 July
E 1. Without shading			
E 2. Overhang			
E 3. Vertical louver			
E 4. Horizontal louver			
E 5. PV Glass			

Figure 48. Glare comparison in east facade

WEST Facade **(Clear Sky, 3PM)**

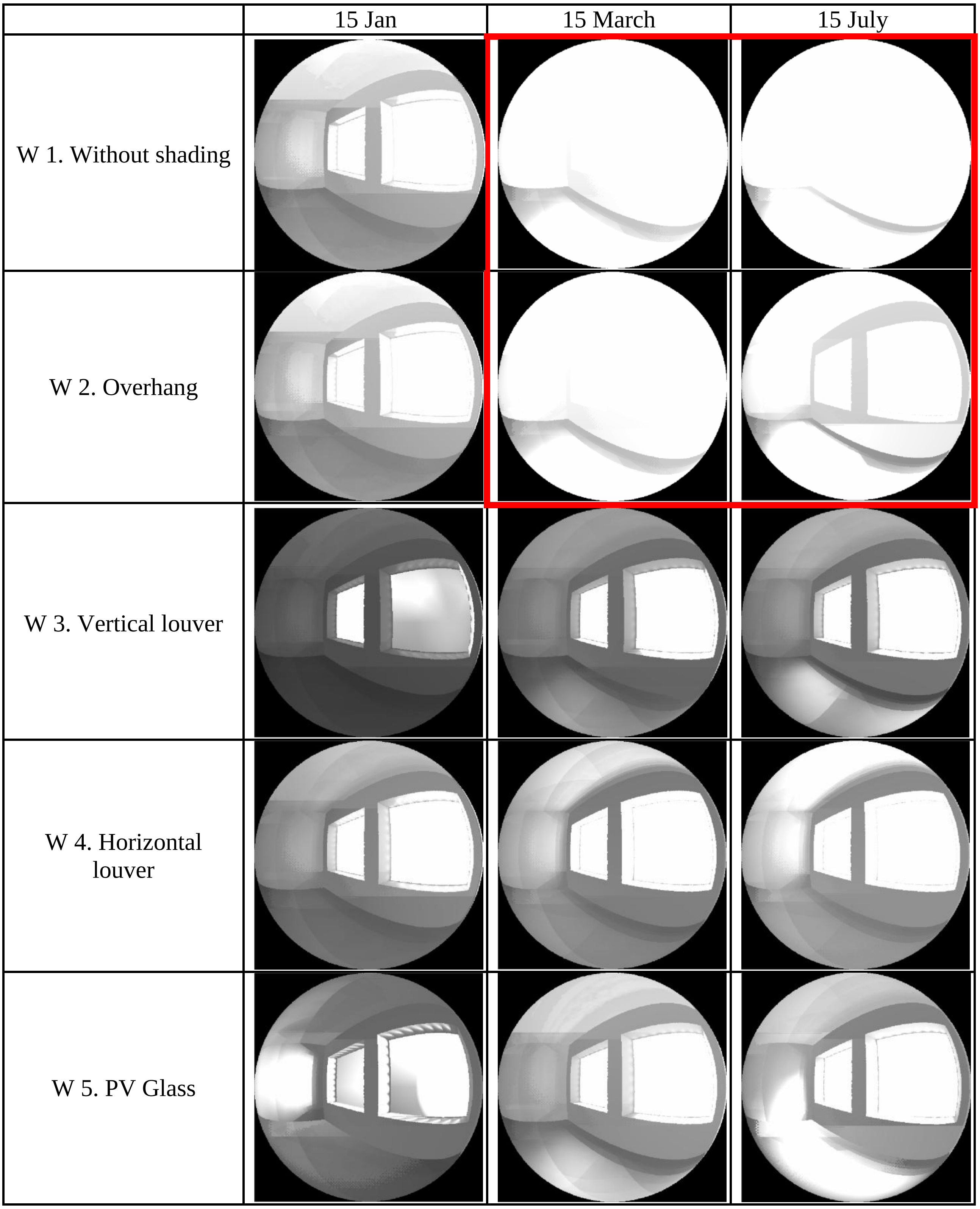


Figure 49. Glare comparison in west facade

CHAPTER IV_ Discussion and Conclusion

Figure 50. Glazed facade

Discussion

Five different control strategies were analyzed: no shading device, overhang, vertical louver, horizontal louver, and PV glass. These scenarios have been applied into three facades: south, east and west. Computer simulation tools, COMFEN, PVSYST and ECOTECT are used for energy performance and daylight analysis.

Results indicated that shading systems have great impact on heat gains as well as energy loads in buildings. Basically, solar shading devices decrease cooling demand. But at the same time, they increase heating and lighting demand. PV cells that are integrated into the shading devices can produce notable amount of electricity. The energy production of PV cells depends on their efficiency, covered area, orientation and angle of the surface. Shading systems have an influence on daylight and glare as well. Moreover, the energy demand for artificial lighting can be decreased by uniform daylight distribution.

The simulation results will be discussed and compared in this chapter. A rating system has been established for comparing and evaluating shading systems. In the following, this method will be explained.

Rating system

All the scenarios are compared and summarized in Table 9. This table is divided into five primary categories: heat gains of windows, energy consumption, PV productions, daylight and glare.

The evaluation system explained briefly in methodology. More detailed specification of the system will be discussed in this chapter. Table 9 presents a rating system which makes the comparison easier. Each color has a different meaning and a specific credit. Colors and their credits are shown in Table 8, again.

Color	Description	Credit
(black)	best performance	4
(dark olive)	2nd best performance	3
(olive)	3rd best performance	2
(light olive)	4th choice	1
(white)	5th choice	0

Table 8. Rating system_ colors and credit

	Heat gain of windows kWh/m² floor area		Energy consumption (kWh/m2/yr)			PV production (kWh/yr)	Daylight factor	Daylight illuminance	Avg. Glare index	result
	summer	Winter	Heating	Cooling	Lighting					
S1	10	2,26	10,5	2	9,1	0	4,90	258,95	13,96	13
S2	6,6	2,2	12	1,5	9,5	10	4,33	185,26	13,96	15
S3	4,2	1,6	13	1,2	11,4	6,7	3,8	132,93	10,5	14
S4	5,4	1,5	13	1,4	11	7	2,95	139,15	11,03	13
S5	5	1	15,4	1,4	12,8	5,3	2,5	59,18	8,87	8
W1	8,4	0,22	13,7	1,6	10,9	0	4,90	145	12,02	13
W2	6,5	0,18	14,6	1,3	11	7,7	4,33	136,22	12,02	15
W3	3,1	0,215	16,3	1	12,5	5,5	3,8	76,93	8,2	14
W4	3,7	0,21	16,4	1,1	12,4	7,2	2,95	79,45	8,73	12
W5	4,3	0,05	18,6	1,2	13,8	3,6	2,5	41,65	6,36	7
E1	8,2	0,16	12,3	1,2	11,2	0	4,90	129,18	12,84	13
E2	6,4	0,08	13	1	11,3	7,7	4,33	125,30	12,84	17
E3	4	0,11	15,3	0,9	12,8	5,8	3,8	83,33	8,61	15
E4	4,6	0,1	15,5	1	12,6	7,4	2,95	86,34	9,04	12
E5	4,2	0,01	16,8	1	14	3,7	2,5	37,07	7,36	8

Table 9. Comparison all scenarios

In some cases two scenarios have the same number. In those cases, both scenarios have been given the same rank. For example in south facade, the heating demand in vertical and horizontal blinds is 13 (kWh/m²/yr.). Both of them are considered to be in the 3rd place.

The first group shows the solar heat gain of all windows in summer and winter.
In summer, we try to minimize solar heat gain and prevent the room from overheating. In the south facade, vertical louver has the lowest heat gain, which is desirable. It is shown by black color means it has the best performance. In the same facade, horizontal louver gains less heat than vertical louver in summer. Therefore, it has the 2nd best performance. A window without

shading device receives the maximum solar radiation during the summer. So, this scenario has the least efficiency. It is marked by white color and has 0 credits.

In winter, we try to get the maximum solar heat gains. The highest amount of heat can be gained where we do not have shading device. Thus, this scenario has the best performance and marked by the black color. On the other hand, PV glass does not perform very well in winter. It is marked with the white color, which means it has the 5th rank.

In the second part of Table 9, ***energy consumption*** for each scenario is reviewed. This section will discuss to heating, cooling and lighting demand. The same rating system is applied here. The scenario which has the lowest energy consumption has the best performance.

There is a correlation between the amount of heat gain and energy demand in the building. This parallel relation can specifically be distinguished under two conditions: summer and cooling demand, winter and heating demand.

In summer, shading devices protect the window from direct sunlight and reduces unwanted solar heat gain. Thus, the cooling demand will be decreased. In winter, more heat gain is desirable. The energy from solar radiation increases indoor temperature. Thus, heating demand will be decreased and better performance can be achieved.

Lighting demand is also connected with solar radiation and daylight. Artificial lighting is required when low luminous is available.

The next column shows ***electricity production of PV panels***. However, an overhang has the smallest PV area; it produces the highest amount of energy in all facades. Three reasons for the high energy production can be discussed here. First, the overhang is fixed and can produce electricity throughout the whole year. Second, it has the optimal angle towards the sun. Finally, it does not suffer from self-shading effect.

PV glass is a semi-transparent PV system. Photovoltaic cells are used in PV glass are made of Thin-film. This scenario has the lowest energy production, although it has the largest area among all other types.

The other part of the table is related to ***daylight evaluations***. Daylight factors and useful daylight illuminance have been discussed in chapter 3. There is a direct trend between daylight availability and artificial lighting demand in a building. Higher daylight level results in less lighting demand. In Table 8, scenarios with daylight factor or illuminance level are marked as the best performance.

The other part of table shows average glare index. PV glass has the lowest glare index. Overhang is not very effective to protect glare. Glare protection is necessary, particularly for the cases with no shading device or overhang.

The last column contains the credits summation. The value in this column is the summation of a given scenarios' credits. These credits are from the following columns:

_ Energy consumption (heating, cooling, lighting)

_ PV productions

_ Daylight factor

_ Average glare index

Table 9 provides an overview of shading device performances. The aim of the coloring system is to compare shading devices and scenarios from different aspects.

The rating system does not propose a proper evaluation system. This system can be criticized in different aspects, some will be discussed here:

Weighting

The weight of each parameter is not considered in this assessment. It is assumed that all parameters have the same impact, which may not be always true. In a real building project, different concerns have different weights and values. Some issues are more crucial than the others and some can be neglected.

As an example, in Norway, heating demand is more critical than cooling demand. Passive cooling strategies can be applied to fulfilling cooling demand; however heating up a cold room in winter requires a lot of energy and efforts.

Another example is about the glare and energy performance of a building. Which one is more important than the other? Answering these types of questions is not easy. Many parameters are involved, such as: priorities, situation, climate, function, etc.

Numerical values

Another negotiable issue is number values. There are some cases that two scenarios have the same values or the difference between them is too small and can be ignored. What has to be done in these cases?

The rating method is applied in all cases, even where the numerical values are very close. For the cases with the same values, the higher credit has been chosen.

This framework does not seem very fair. Small distinctions can add or deduct one credit. And even one credit can change the results.

All in all, this method is not a good way to evaluate and judge the performance of shading systems. The author does not aim to compare all the parameters together.
This table provides an overview of different shading devices and their performance.

In the following, the shading systems will be evaluated from their "*energy loads*" aspect. Table 10 shows energy loads of different scenarios. The total delivered energy is delivered energy for heating, cooling and lighting. The calculation method has been described in chapter 2, methodology.

Scenarios	Energy consumption (kWh/m2/yr)			Total Delivered energy (kWh/m2/yr)	PV production (kWh/m2/yr)	Net energy balance (kWh/m2/yr)	Mismatch factor
	Heating	Cooling	Lighting				
S1. Without Shading	10,5	2	9,1	14,42	0	14,42	–
S2. Overhang	12	1,5	9,5	15,25	10	5,25	1,52
S3. Vertical Blinds	13	1,2	11,4	17,45	6,7	10,75	2,60
S4. Horizontal Blinds	13	1,4	11	17,13	7	10,13	2,44
S5. PV Glass	15,4	1,4	12,8	19,96	5,3	14,66	3,76
W1. Without Shading	13,7	1,6	10,9	17,42	0	17,42	–
W2. Overhang	14,6	1,3	11	17,78	7,7	10,08	2,30
W3. Vertical Blinds	16,3	1	12,5	19,88	5,5	14,38	3,61
W4. Horizontal Blinds	16,4	1,1	12,4	19,86	7,2	12,66	2,75
W5. PV Glass	18,6	1,2	13,8	22,24	3,6	18,64	6,18
E1. Without Shading	12,3	1,2	11,2	16,95	0	16,95	–
E2. Overhang	13	1	11,3	17,27	7,7	9,57	2,24
E3. Vertical Blinds	15,3	0,9	12,8	19,71	5,8	13,91	3,39
E4. Horizontal Blinds	15,5	1	12,6	19,64	7,4	12,24	2,65
E5. PV Glass	16,8	1	14	21,59	3,7	17,89	5,83

Table 10. Comparison of energy performance of all scenarios

The window with no shading device needs the lowest amount of delivered energy. This indicates that, shading devices do not have an influence on the total energy reduction in Norway. Shading devices reduce the cooling demand but at the same time they increase electricity consumption. This impact is considerable in and as a result total delivered energy will be increased.

PV integrated in shading devices change the priorities for choosing the best shading system. In most cases, energy production of PV cells can cover the energy demand for lighting. Electricity production of PV cells depends on PV type, efficiency of system, area, orientation and angle of cells. Without a doubt, an efficient systems result in more energy productions.

Net energy balance is the annual balance between delivered energy and energy productions. There is a direct correlation between net energy balance and PV productions. More efficient systems have the better energy performance.

The overhang shading system has the best performance in terms of energy loads. PV integrated in this system provides a substantial amount of electricity through the whole year. A horizontal blind has better performance than a vertical blind. The total delivered energy in both cases is very close. But the horizontal blind can produce much more energy than the vertical one. This can be explained by the self-shading effect of a vertical blind.

PV glass and no shading device is the last choice. PV glass has the lowest energy production, as well as the highest delivered energy consumption. Therefore, this system is not very energy efficient.

Conclusion

- Shading devices affect the building envelope performance, and particularly solar radiation and heat gains.
- In general the results of this study comply with similar studies elsewhere. Generally, shading devices obstacle solar radiations. Thus, they decrease cooling demand in summer and increase heating demand in winter. Shading devices provide shade inside the room. Thus, lighting demand will be increased as well.
- In this study, the overhang PV shading system has the best performance in terms of energy loads. PV integrated in this system provides a substantial amount of electricity through the whole year. Moreover, it provides a good daylight level, in summer and winter. The weakness of this system is about not being protected from glare.
- In Norway, shading devices do not have influence on reducing total energy demand of the building. They reduce the cooling demand in summer, however increase the electricity consumption. This impact gets more important in office buildings, and as a result total delivered energy will be increased.
- Shading devices are necessary for glare protection. In case of a window with no shading device or overhang, additional sun-screen or similar internal shading devices may help protect the interior from glare.
- Movable shading devices are very suitable for providing shade throughout the day. They are able to provide optimized shading with respect to the sun position.
- Without PV shading devices, vertical and horizontal blinds have almost identical *energy demand*. PV integrated in shading systems has influence of energy performance of the building. Horizontal blinds can produce more electricity than the vertical ones. Thus, they have better performance.
- PV glass provides much more shading than other types of shading devices. The shading effect increase lighting and heating demand. Covering the complete surface using PV glaze will decrease the efficiency significantly.

Suggestion for "powerhouse" or similar projects

- Overhang is a very good solution for PV integrated shading systems. This type of shading device is very common and available on the market. It can provide shading and daylight, without compromising the view to the outside. Glare protection is required for this shading system.
- Movable PV shading devices are costly and difficult to maintain. They can be used as a glare protection. They increase the energy demand for artificial lighting. Therefore, these types of shading systems are not recommended.
- PV glazing system, which covers complete window surface, has negative impact to energy performance of the building. More studies are required to evaluate the idea of *using PV glass in some parts of window*.

Future work

More research and development regarding shading devices are still necessary. There are some suggestions for future research direction:

More scenarios

In this study only a few shading systems are studied and more cases and variables need to be investigated. Some of them are:

- Fixed PV shading devices (e.g. horizontal and vertical blinds)
- Interior shading and glare protection such as such as internal venetian or roller blind
- Different colors and materials for the shading devices
- Different windows
- Integration of PV glazing in lower part of window, or combination of different shading systems
- Different climates

View contact

One of the important issues in evaluating shading systems is the view contact. PV glazing provides view contact to the outside but blinds block that. This criterion has not been conducted in this study and can be one of the future work possibilities.

Passive solar design or active solar design?

In this study, it was assumed that shading devices are not activated during the winter. Thus, the building can benefit from passive solar energy.

Although there is not much solar radiation in winter in Norway, PV cells still can produce a little bit energy. Due to the short day length in winter, use of artificial lighting is inevitable. This fact rise up the question that should PV shading devices be activated during winter as well? Which system is more efficient? Reducing heating consumption by passive solar energy or producing energy by PV cells (active solar energy)?

Cost assumption

More studies can be done in investigating cost assumption of PV shading systems, particularly for movable PV shading devices.

Aesthetic/visual qualities

Shading devices have a great impact on the architectural expression of the facade. Therefore, external shading systems should be selected because of their functionality and their potential to improve aesthetic of a building. As part of future research, beauty and aesthetics of shading devices could be defined.

Analysis method for daylight and glare

Daylight evaluation is conducted based on Daylight Factor (DF) and Useful Daylight Illuminance (UDI). Further studies can be done in terms of other analysis method, specifically *Daylight Autonomy (DA)*. *Daylight Glare Probability* (DGP) can be studied for glare evaluation.

Bibliography

(1994). *Daylighting in Buildings.* Dublin: University College Dublin, Energy Research Group.

Daylighting and window design. (1999). CIBSE.

NS3031. (2007). Calculation of energy performance of buildings – Method and data. Standard Norge.

EnergyPlus Engineering References. (2010). *US Department of Energy*.

(2010). *ZEB Annual report.* Trondheim: ZEB The Research Center on Zero Emission Buildings.

(2012). *BREEAM-NOR ver. 1.0.* BRE Global Ltd.

Powerhouse . (2012, 3). Retrieved from Powerhouse_ Energy-positive buildings: http://powerhouse.no/en/plushouse/

Arnesen, H., Kolås, T., & Matusiak, B. (2011). *A guide to dayligthting and solar shading systems at high latitude.* Trondheim: ZEB Project report 3.

ASI® THRU | SCHOTT North America. (n.d.). Retrieved from SCHOTT Glass Manufacturers | SCHOTT Glass | SCHOTT North America: http://www.us.schott.com/architecture/english/products/photovoltaics/asi-thru.html?highlighted_text=asi%20thru

Bader, S. (2011). *High-performance façades for commercial buildings.* The university of Texas Austin.

Bauer, M., Molse, P., & Schwarz, M. (2007). *Green Building_ Guidebook for Sustainable Architecture.* Springer.

Bessoudo, M., Tzempelikos, A., & Athienitis, A. (2010). Indoor thermal environmental conditions near glazed facades with shading devices; Part I: Experiments and building thermal model. *Building and Environment, 45*(11), 2506–2516.

Bloem, J., Colli, A., & Strachan, P. (2005). Evaluation of PV technology implementation in the building sector. *International Conference "Passive and Low Energy Cooling"* (pp. 677-681). Santorini, Greece: Strathprints.

Christoffersen, J., & Wienold, J. (2008). Assessment of user reaction to glare with three solar shading systems. *Indoor Air 2008.* Copenhagen, Denmark.

Datta, G. (2001). Effect of fixed horizontal louver shading devices on thermal perfomance of building by TRNSYS simulation. *Renewable Energy*.

David, M., Donn, M., Garde, F., & Lenoir, A. (2011). Assessment of the thermal and visualefficiency of solar shades. *Building and Environment, 46*(7), 1489–1496.

Demerd, C., & Potvin, A. (2007). Daykighting and Thermal strategies in the design process: case study of Laval university's new medical faculty building. *Conference Proceeding of American Solar Energy Society (ASEC).* Ohio.

Dokka, T. H., Klinski, M., Haase, M., & Mysen, M. (2009). *Prosjektrapport 42; Kriterier for passivhus- og lavenergi bygg – Yrkesbygg.* SINTEF Byggforsk.

Dubois, C., Demers, C., & Potvin, A. (2007). The Influence of Daylighting on Occupants; Comfort and Diversity of Luminous Ambiences in Architecture. *Proceedings of American Solar Energy Society (ASES).* Cleaveland, Ohio.

Dubois, M.-C. (1997). *Solar Shading and Building Energy Use, A Literature Review, Part 1.* Lund, Sweden: KFS AB.

Ecotect Analysis - Sustainable Building Design Software - Autodesk. (n.d.). Retrieved from http://usa.autodesk.com/ecotect-analysis/

EnergyPlus. (n.d.). Retrieved from Building Technologies Program: Energy Simulation Software: http://apps1.eere.energy.gov/buildings/energyplus/

F.Smith, P. (2001). *Architecture in a Climate of Change_ A guide to sustainable design.* Oxford: Architectural press, Elsevier.

Glare Analysis | Daylighting Pattern Guide. (n.d.). Retrieved from Daylighting Pattern Guide: http://patternguide.advancedbuildings.net/using-this-guide/analysis-methods/glare-analysis

Goia, F., Haase, M., & Perino, M. (2012). Optimal transparent percentage in façade modules for office buildings in a central Europe climate: case study Frankfurt. *Improving Energy Efficiency in Commercial Building Conference (IEECB'12) .* Frankfurt.

Herkel, S., Kuhn, T., & Wienold, J. (n.d.). *Comparison of control strategies for shading devices.* Fraunhofor.

Hien, W. N., & Istiadji, A. D. (2003). Effect of External Shading Devices on Daylight and Natural Ventilation. *Eighth International IBPSA Conference*, (pp. 475-482). Eindhoven, Netherlands.

Hopkinson. (1972). Glare from Daylights in Buildings. *Applied Ergonomics*.

Hopkinson, R. G. (1970). Glare from windows. *Constructions Research and Development Journal, 2*, 98.

Hygge, S., & Lofberg, H. A. (1997). User Evaluation of Visual Comfort in Some Buildings of the Daylight Europe Project. *RIGHT LIGHT, 2*(4).

IEA-SHC Task 40 /Annex 52 "Zero Energy Building". (n.d.). Retrieved from International Energy Agency Solar Heating and Cooling Program | IEA-SHC: http://www.iea-shc.org/task40/

Janak, M., & Kainberger, R. (2009). Integrated Building Energy and Lighting Simulation in the Framework of EU PV–LIGHT Project. *Building Simulation 2009* (pp. 1671- 1677). Glasgow, Scotland: Eleventh International IBPSA Conference.

Kim, J. T., & Kim, G. (2009). Advanced external shading device to maximize visual and view performance. *2nd International Conference on Sustainable Healthy Buildings* (pp. 49-60). Seoul, Korea: SHB2009.

Klotz, F., Schroeder, S., & Mohring , H. (2007). *Multi-functional Lightweight PV Louvres - Results from the European fp5 project “PV-Light”.* Germany: Zentrum für Sonnenenergie- und WasserstoffForschung Baden-Württemberg (ZSW). Retrieved from Eco Building Club.

LBNL Window & Daylighting Software -- COMFEN. (n.d.). Retrieved from http://windows.lbl.gov/software/comfen/comfen.html

Lechner, N. (2008). *Heating, cooling, lighting; design methods for architects.*

Lerum, V. (n.d.). 4D PV- Photovoltaic Shading devices as Architectural Time Pieces.

Littlefair, P. (1990). Predicting annual lighting use in daylit buildings. *Building and Environment*, 43–54.

Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I., & Napolitano, A. (2011). Zero Energy Building – A review of definitions and calculation methodologies. *Energy and Buildings*.

Meek, C., & Breshears, J. (2010). *Dynamic Solar Shading and Glare Control for Human Comfort and Energy Efficiency at UCSD: Integrated Design and Simulation Strategies.* Washington: American Solar Energy Society.

Mitchell, R., Yazdanian, M., Zellany, K., Curcija, C., & Bjornstad, B. (2011). *COMFEN 4 Manual_ for Calculating the Energy Demand and Comfort Impacts of Windows in Commercial Buildings.*

Montoro, D. F., Vanbuggenhout, P., & Ciesielska, J. (n.d.). *Building Integrated Photovoltaics: An overview of the existing products and their fields of application.* EPIA (European Photovoltaic Industry Association).

Murphy, P. (2007). *IEA Solar Heating & Cooling Programme- 2006 Annual Report.* Washington, DC: Morse Associates, Inc. Retrieved from http://www.iea-shc.org/annualreport/shc_annual_report_2006.pdf

Nazzal, A. (2001). A new daylight glare evaluation method: Introduction of the monitoring protocol and calculation method. *Energy and Buildings*, 257–265.

Nielsen, M. V., Svendsen, S., & Jensen, L. B. (2011). Quantifying the potential of automated dynamicsolarshading in office buildings through integrated simulations of energy and daylight. *Solar Energy, 85*(5), 757–768.

Photovoltaic Geographical Information System. (n.d.). Retrieved from JRC's Institute for Energy and Transport: http://re.jrc.ec.europa.eu/pvgis/

PVsyst: Software for Photovoltaic Systems. (n.d.). Retrieved from http://www.pvsyst.com/

Radiance. (n.d.). Retrieved from http://radsite.lbl.gov/radiance/

Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic daylight performance metrics for sustainable building. *LEUKOS, 3*, 1-25.

Reinhart, C., & Voss, K. (2003). Monitoring manual control of electric lighting and. *Lighting Research & Technology, 35*(3), 243-260.

Reinhart, C., Bourgeois, D., Dubrous, F., Laouadi, A., Lopez, P., & Stelescu1, O. (2007). Daylight1-2-3 – A State of the art Daylighting/Eenergy Analysis Software for Initial Design Investigations. *Building Simulation 2007*, (pp. 1669-1676).

Roetzel, A., Tsangrassoulis, A., Dietrich, U., & Busching, S. (2010). On the influence of building design, occupants and heat waves on comfort and greenhouse gas emissions in naturally ventilated offices. A study based on the EN 15251 adaptive thermal comfort model in Athens, Greece. *Building Simulation, 3*(2), 87-103.

Rubino, M., Cruz, A., Garcia, J. A., & Hita, E. (1994). Discomfort glare indices: a comparative study. *Applied Optics*.

Santos, I., Laustsen, J., & Svendsen, S. (2008). Characterization and performance evaluation of solar shading devices. *8th Symposium on Building Physics in the Nordic Countries*, *1*, pp. 103-110.

Sartori, I., Graabak, I., & Dokka, T. H. (2010). Proposal of a Norwegian ZEB definition: Storylines and Criteria. *zero emission buildings - proceedings of Renewable Energy Conference 2010.* Trondheim.

SIMIEN. (v5.004). ProgramByggerne ANS. Oslo, Norway.

SOLAREC. (n.d.). Retrieved from ESTI: http://re.jrc.ec.europa.eu/esti/activities_projects/solarec_en.htm

Stack, A., Goulding, J., & Lewis, J. (n.d.). *Shading Systems; Solar Shading for the European climates.* Dublin: ENERGIE. Retrieved from http://erg.ucd.ie/UCDERG/pdfs/mb_shading_systems.pdf

Stegou-Sagia, A., Antonopoulos, K., Angelopoulou, C., & Kotsiovelos, G. (2007). The impact of glazing on energy consumption and comfort. *Energy Conservation and Management, 48*(11), 2844-2852.

TEK. (2010). *Guidelines on technical requirements for buildings.* Oslo, Norway: Department of Regional and Local Autonomies.

Tregenza, P. (1980). The daylight factor and actual illuminance ratios. *Lighting Research and Technology*, 64-68.

Tzempelikos, A., & Roy, M. (2004). A Simulation Design Study for the Facade Renovation. Montreal: Canadian Solar Buildings Conference.

Voss, K., & Heinze, M. (2009). Goal zero energy building – exemplary experience based on the solar estate Solarsiedlung Freiburg am Schlierberg, Germany. *Green Building, 4*.

Wienold, J. (2009). Dynamic Daylight Glare Evaluation. *Eleventh International IBPSA Conference* (pp. 944-951). Scotland: Building Simulation.

Wienold, J., Frontini, F., Herkel, S., & Mende, S. (2011). Climate based Simulaton of Different Shading Devices Systems for Comfort and Energy Demand. *12th Conference of International Building Performance Simulation Association*, (pp. 2680-2687). Sydney.

Yao, J., & Yan, C. (2011). Evaluation of The Energy Performance of Shading Devices based on Incremental Costs. *World Academy of Science, Engineering and Technology*, 450-452.

Yener, A. K. (1998). A method of obtaining visual comfort using fixed shading devices in rooms. *Building and Environment*, 285-291. Retrieved from http://infohouse.p2ric.org/ref/32/31148.pdf

Yüceer, N. S. (2012). An Approach to Overhang Design, Istanbul Example. In E. B. Babatunde, *Solar Radiation* (pp. 315-322). InTech.

ZSW. (2007). *Lightweight PV Louvers for Multi-Functional Solat Control and Daylight System with Improved Building Integration.* Research funded by the European Community. Retrieved from http://ec.europa.eu/energy/renewables/solar_electricity/doc/pv_light.pdf

Figure References

Figure 1. http://powerhouse.no/nyheter/

Figure 2. http://powerhouse.no/nyheter/

Figure 3. http://nssdc.gsfc.nasa.gov/planetary/image/earth_night.jpg

Figure 4. (Janak & Kainberger, 2009)

Figure 5. (Stack, Goulding, & Lewis)

Figure 6. http://www.forskningsradet.no/servlet/Satellite?blobcol=urldata&blobheader=image%2Fjpeg&blobkey=id&blobtable=MungoBlobs&blobwhere=1274487175539&ssbinary=true

Figure 7. http://www.coltinfo.co.uk/products/photovoltaic-shading-pv-shading-louvre/edingen-council-building.jpg

Figure 8. http://www.oceanviewshades.com/images/photos/sheer-shades/image1_jpg.jpg

Figure 9. http://jennskistudio.blogspot.no/2010/05/roller-blinds.html

Figure 10. http://www.pleatedblinds.net/wp-content/uploads/venetian-blinds-double-glazing.jpg

Figure 11. Created by Author.

Figure 12. Created by Author.

Figure 13. Created by Author.

Figure 14. http://www.archiexpo.com/prod/schott-ag/glass-glass-photovoltaic-modules-58393-200233.html

Figure 15. http://www.solardecathlon.upm.es/imagenes/bw/fac_herencia.jpg

Figure 16. Warema brochure_ Using energy efficiently with modern sun shading systems

Figure 17. http://cms.latz-riehl-partner.de/components/com_joomgallery/img_thumbnails/buero-_und_verwaltungsbauten_11/zvk_wiesbaden_22/zvk_wiesbaden_20090626_1226406804.jpg

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Figure 24. http://www.actec.dk/SolarSchottASI-Glass-Design.htm

Figure 25. http://www.schott.com/architecture/english/products/photovoltaics/asi-thru.html

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Figure 50. http://www.bfrl.nist.gov/buildingtechnology/documents/FederalRDAgendaforNetZeroEnergyHighPerformanceGreenBuildings.pdf

Appendix

Appendix 1. Shading Control

Appendix 2. Simulation assumptions

Appendix 3. PV calculations

Appendix 4. Simien

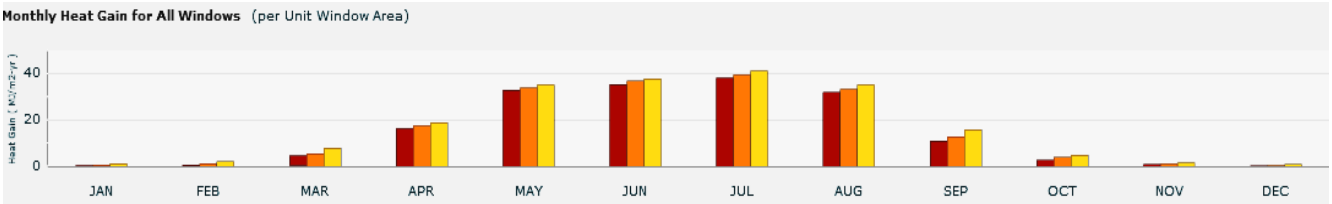
Appendix 1

Shading Control

Shading Control

This study has been conducted to figure out the optimal controlling control strategy.

For vertical and horizontal blinds two control algorithms are applied: On if **high outdoor temperature** and **high solar incident on the window**. So two setpoints are required. One setpoint for solar incident and another for temperature. Three altevrnaitves for solar incident have been studied. These are: 100 (W/m^2) , 150(W/m^2), 200(W/m^2).
Horizontal blind in south façade has been chosen as a case model.



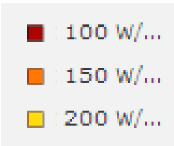


Figure 51. Monthly heat gain for all window, per unit window area (MJ/m2-yr). (Horizontal blinds in south façade)

Optimum Solar incident for shading control

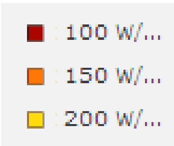


Figure 51 demonstrates the influence of different alternatives on heat gain. The different solar incident has not that much effect on heat gain. Solar shading device which gets activated in the 100 W/m2 solar incident, results in less heat gain. Among these alternatives, there is not a significant difference in the amount of heat gains in summer.

Figure 52 shows annual energy demand of three alternatives: 100 (W/m^2) , 150(W/m^2), 200(W/m^2).

The energy demand for different cases is very close. As a result the shading operation base on solar incident does not have crucial influence on energy consumptions. The main influence of this controlling method would be on glare effect.

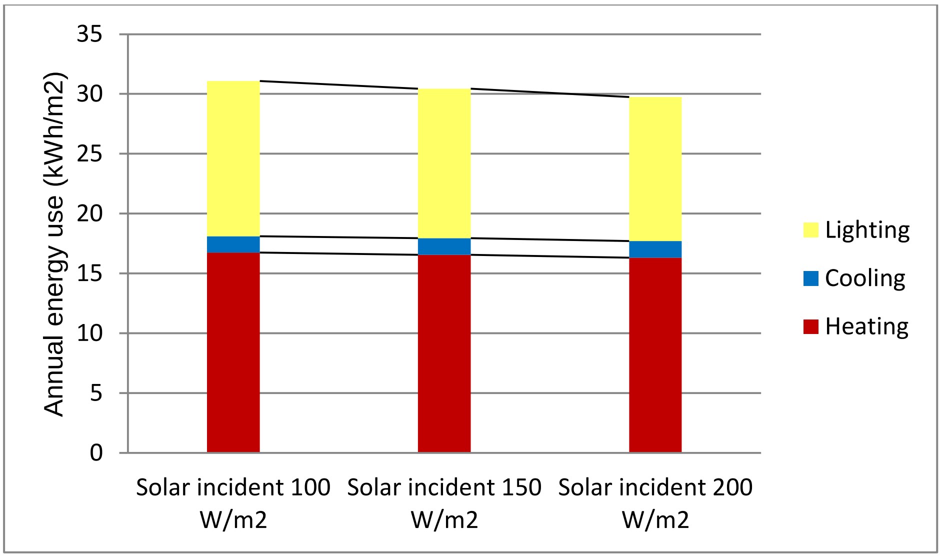


Figure 52. Annual energy demand of three alternatives. 100, 150, 200 W/m2

Glare protection is necessary when a shading device activates in the high solar incident. Since solar incident has significant influence on energy demand. Thus, shading devices will be activated at 200 W/m2.

Optimum Temperature for shading control

Other control algorithms for shading devices is outdoor temperature. If the outdoor air temperature gets higher than a specific setpoint, the shading devices will be activated. Four different setpoints for outdoor temperature have been studied. These include: 0°C, 5°C, 10°C, 15 °C.

Shows that the highest amount of heat gain in spring will be achieved where shading devices activated at 10 °C.

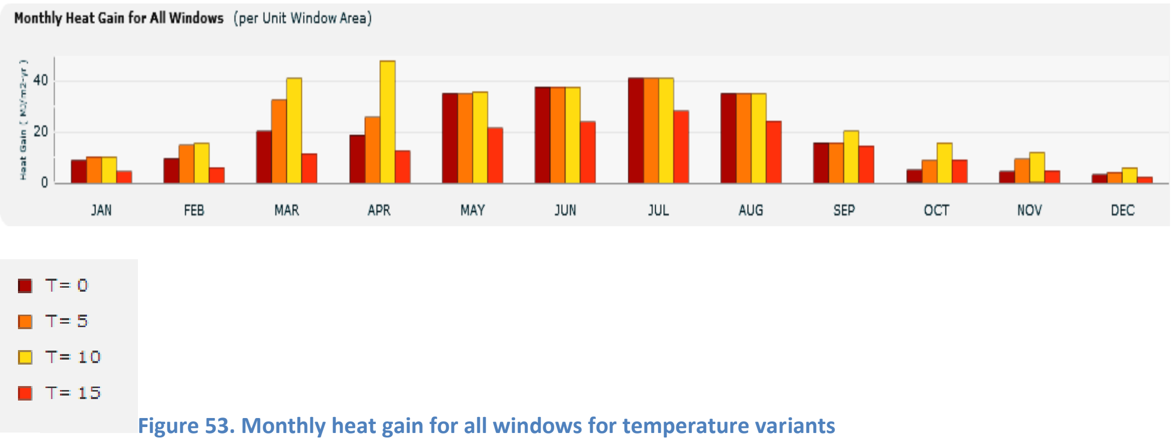


Figure 53. Monthly heat gain for all windows for temperature variants

Appendix 2

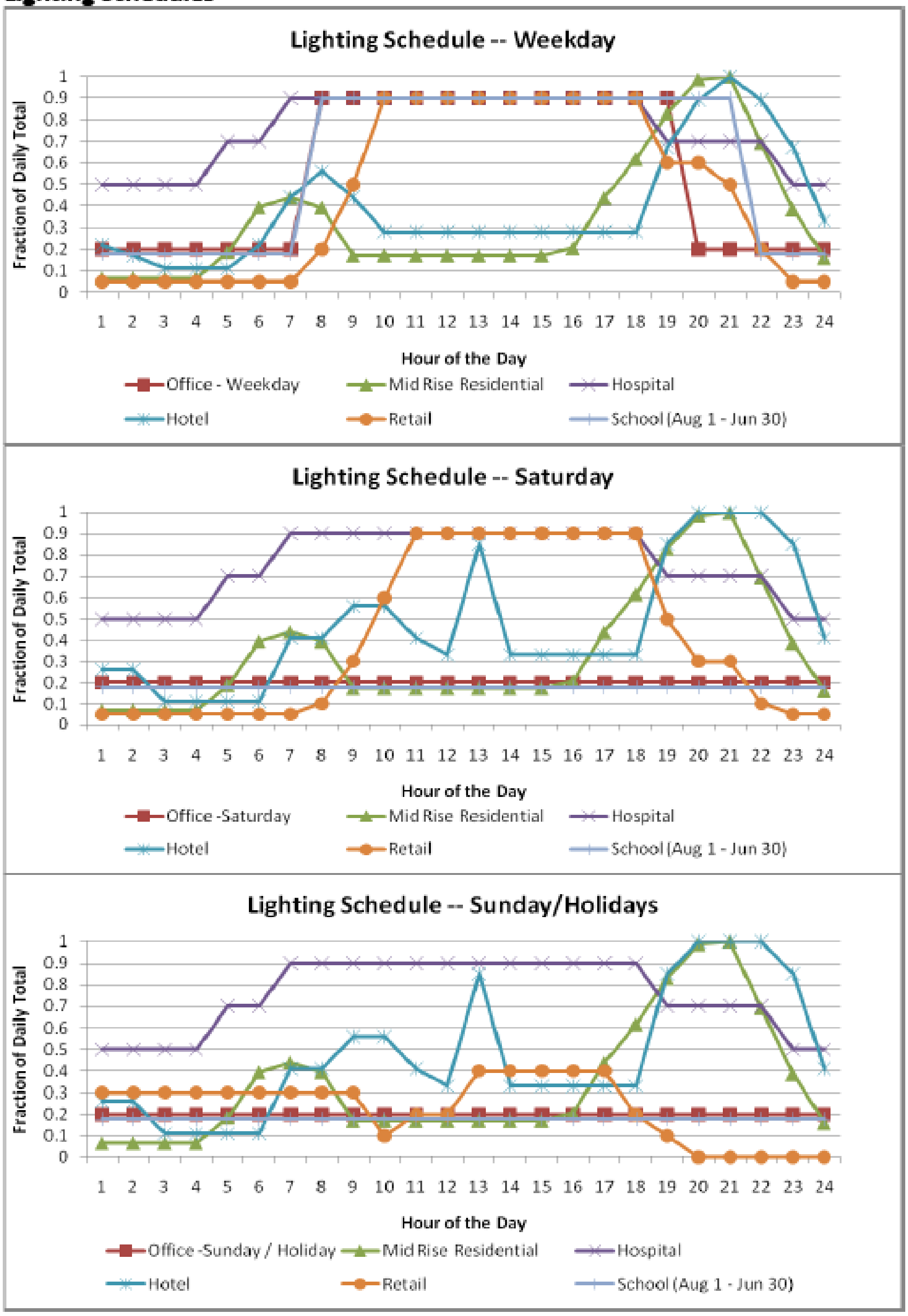
Simulation assumption

In this chapter simulation assumptions for COMFEN will be explained. All the figures and description are taken from COMFEN manual.

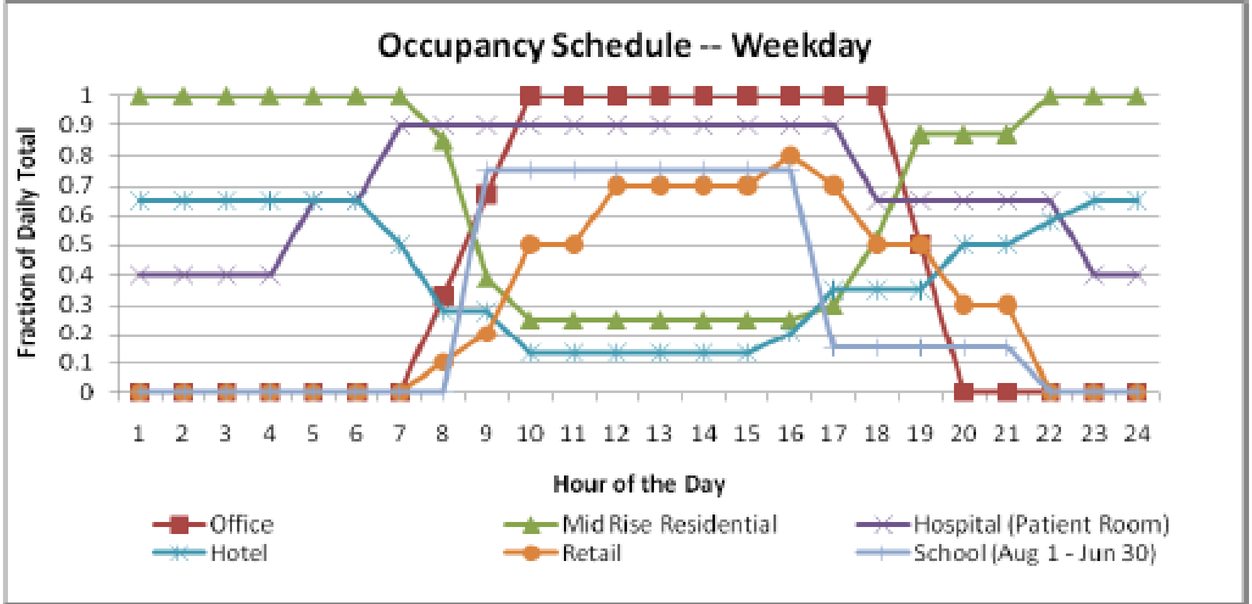
Schedules for Building Types

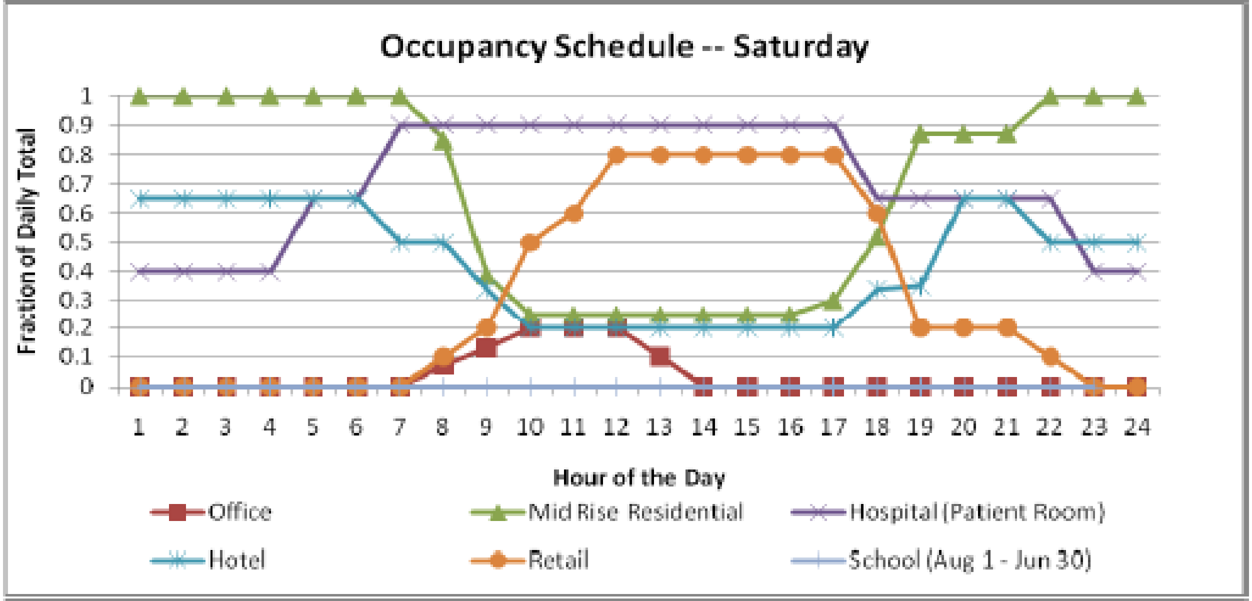
Each Building Type has a different set of operating schedules, which control when the lights are on, when the buildings are occupied, when the equipment is running, as well as the fraction of the total value that is applied to each hour.

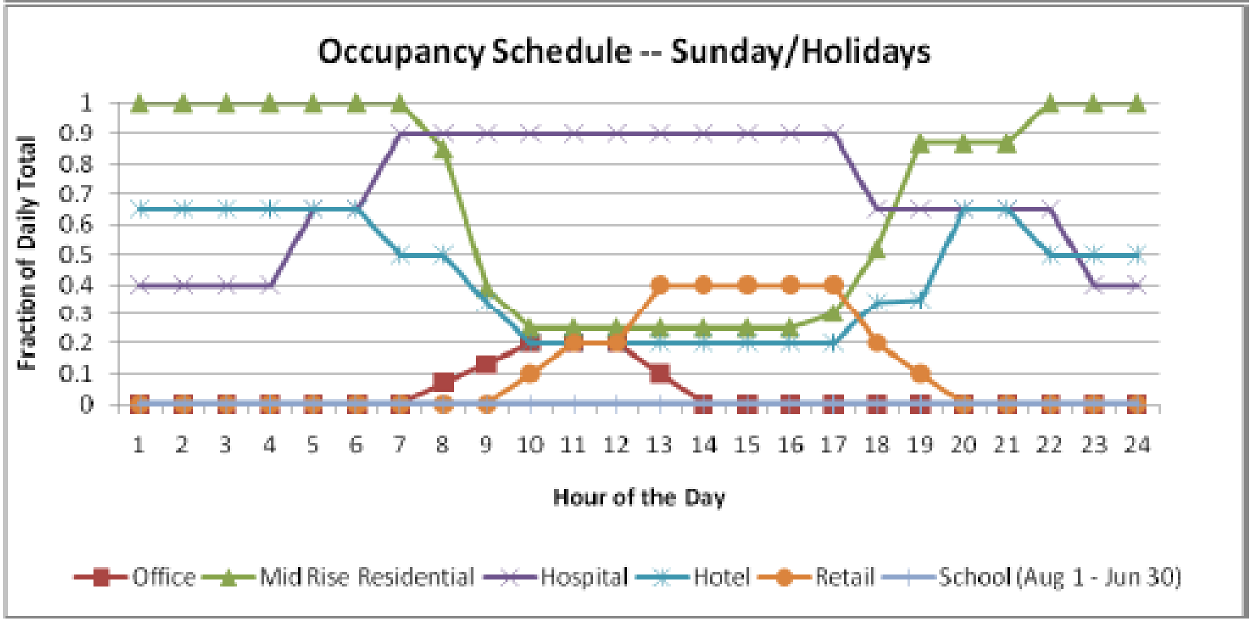
Lighting Schedules



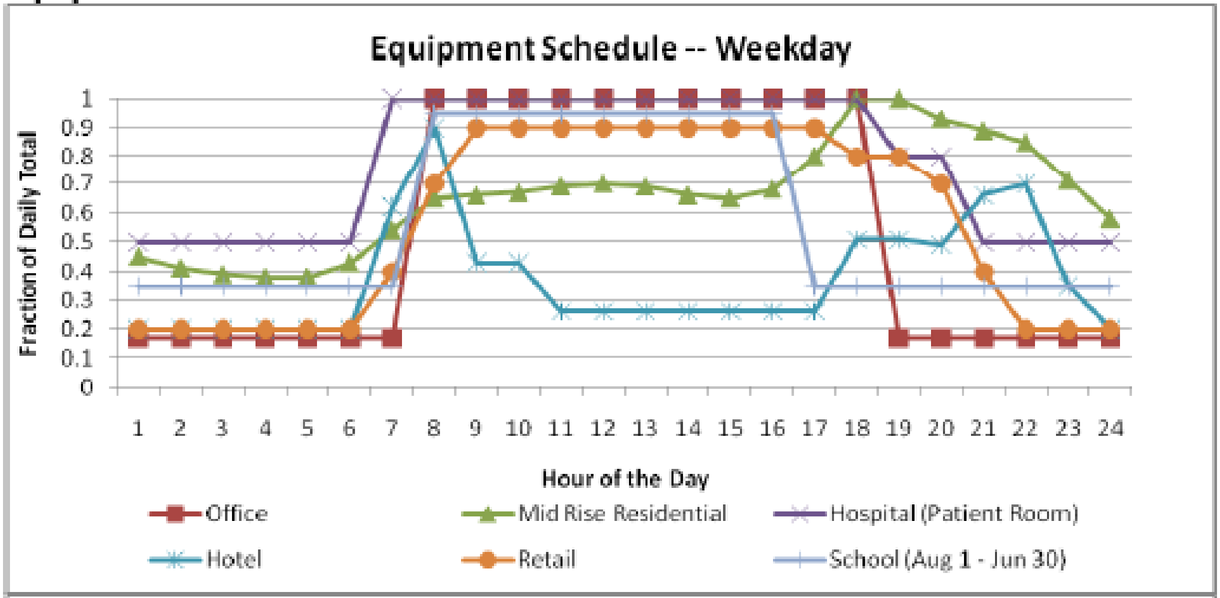
Occupancy Schedules

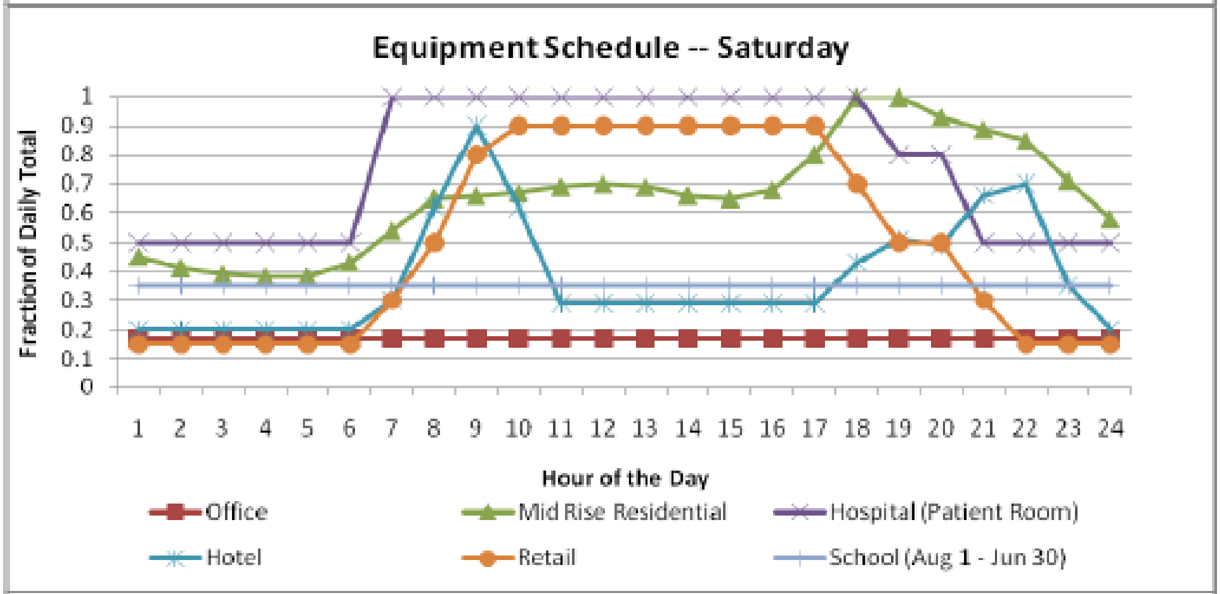


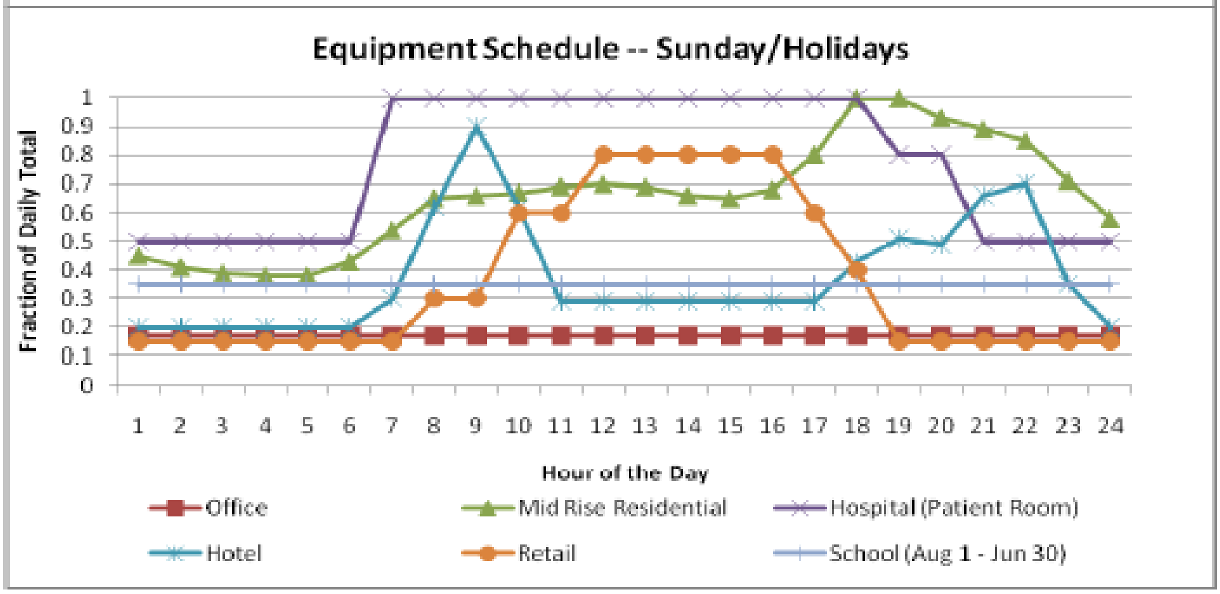




Equipment Schedules







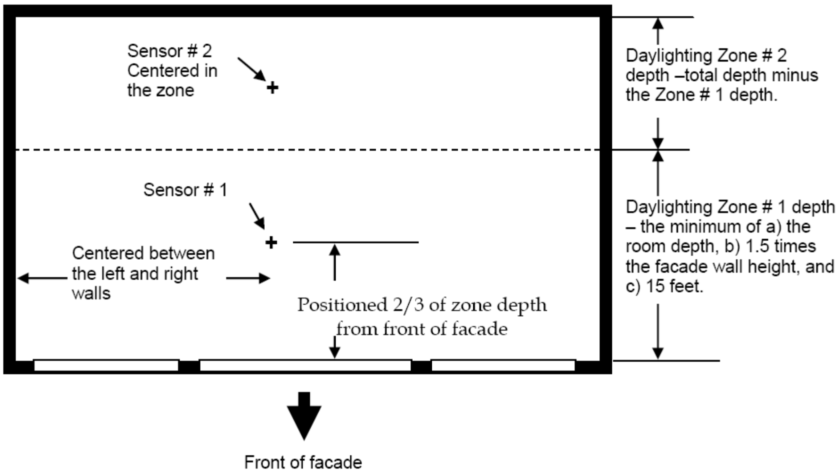
Infiltration

Time	**Infiltr.** (week day)	**Infiltr.** (Sat.)	**Infiltr.** (all other days)
24:00 – 6:00	1	1	1
6:00 – 18:00	0.25	0.25	1
18:00 – 22:00	0.25	1	1
22:00 – 24:00	1	1	1

Occupancy, Lighting and Equipment

Time	**Occ.** (week day)	**Occ.** (Sat.)	**Occ.** (all other days)	**Light.** (week day)	**Light.** (Sat.)	**Light.** (all other days)	**Equip.** (week day)	**Equip.** (Sat.)	**Equip.** (all other days)
24:00 – 5:00	0	0	0	0.05	0.05	0.05	0.4	0.3	0.3
5:00 – 6:00	0	0	0	0.1	0.05	0.05	0.4	0.3	0.3
6:00 – 7:00	0.1	0.1	0	0.1	0.01	0.05	0.4	0.4	0.3
7:00 – 8:00	0.2	0.1	0	0.3	0.01	0.05	0.4	0.4	0.3
8:00 – 12:00	0.95	0.5	0	0.9	0.5	0.05	0.9	0.5	0.3
12:00 – 13:00	0.5	0.5	0	0.9	0.5	0.05	0.8	0.5	0.3
13:00 – 14:00	0.95	0.5	0	0.9	0.5	0.05	0.9	0.5	0.3
14:00 – 17:00	0.95	0.1	0	0.9	0.15	0.05	0.9	0.35	0.3
17:00 – 18:00	0.7	0	0	0.7	0.05	0.05	0.8	0.3	0.3
18:00 – 20:00	0.4	0	0	0.5	0.05	0.05	0.6	0.3	0.3
20:00 – 22:00	0.1	0	0	0.3	0.05	0.05	0.5	0.3	0.3
22:00 – 24:00	0.05	0	0	0.1	0.05	0.05	0.4	0.3	0.3

Setpoints



Zone Depth: A primary daylight zone depth is calculated as the minimum of a) the room depth, b) 1.5 times the facade wall height, and c) 15 feet.

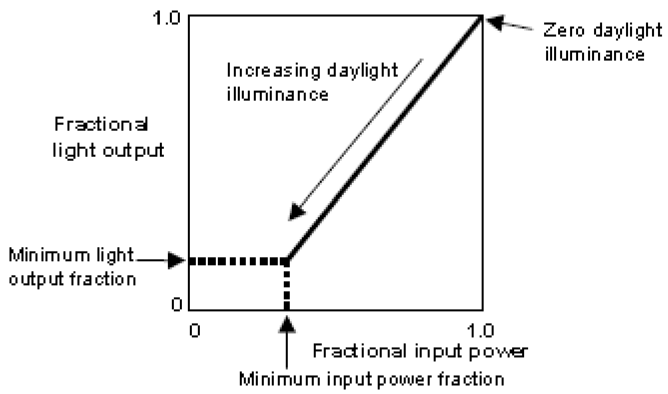
- **Sensor # 1:** Daylight sensor #1 is positioned 2/3 of the primary daylight zone depth from facade wall (centered in the width of the facade zone) and positioned at desk height: 2'-6" (0.76 m) above the floor. Sensor #1 controls a fraction of the facade zone lights equal to the primary daylight zone depth divided by the facade zone depth.

- **Sensor # 2:** Any remaining depth in the facade zone is considered a secondary daylight zone. Sensor #2 is positioned halfway between the primary daylight zone depth and the "back wall." Similar to sensor #1, the sensor is centered in the width of the facade zone and positioned at desk height: 2'-6" (0.76 m) above the floor. Sensor #2, if used, controls the remaining fraction of lights.

Continuous Control

With Continuous control, the overhead lights dim continuously and linearly from maximum electric power, maximum light output to minimum electric power, minimum light output as the daylight illuminance increases. The lights stay at the minimum point with further increase in the daylight illuminance.

The Minimum input power fraction for Continuous control type is the lowest power the lighting system can dim down to, expressed as a fraction of maximum input power. For Continuous/off lighting control, this is the power fraction reached just before the lights switch off completely.



Control action for a continuous dimming system

The Minimum output fraction for Continuous control type, is the lowest lighting output the lighting system can dim down to, expressed as a fraction of maximum light output. This is the fractional light output that the system produces at minimum input power. For Continuous/off lighting control, this is the power fraction reached just before the lights switch off completely.

For a continuously-dimmable control system, it is assumed that f_P is constant and equal to $f_{P,min}$ for $f_L<f_{L,min}$ and that f_P increases linearly from $f_{P,min}$ to 1.0 as f_L increases from fL,min to 1.0 (Figure 60). This gives

$$f_P = \begin{cases} f_{P,\min} & \text{for } f_L < f_{L,\min} \\ \dfrac{f_L + (1-f_L) f_{P,\min} - f_{L,\min}}{1 - f_{L,\min}} & \text{for } f_{L,\min} \le f_L \le 1 \end{cases}$$

Appendix 3

PV Calculations

Overhang_south

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site	**Oslo**		**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			
Simulation variant :	**Overhang_ south**			
	Simulation date	13/05/12 12h30		

Simulation parameters

Collector Plane Orientation	Tilt	39°	Azimuth	0°
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

Overhang_south

Grid-Connected System: Main results

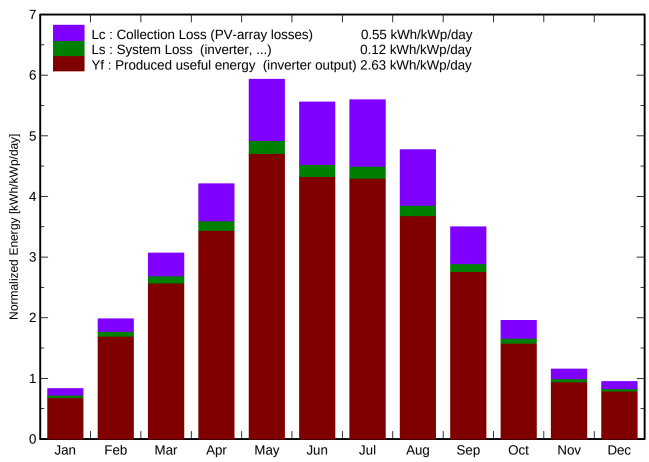
Project : **pv**

Simulation variant : **Overhang_ south**

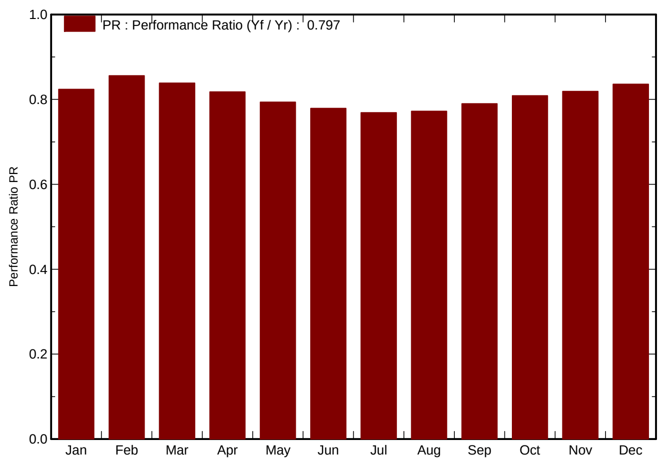
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	39°	azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**230 kWh/year**	Specific prod.	960 kWh/kWp/year
	Performance Ratio PR	79.7 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



Overhang_ south

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	11.0	-1.70	25.7	25.0	5.39	5.09	12.64	11.94
February	28.0	-2.40	55.5	53.8	11.94	11.40	12.99	12.40
March	66.0	0.30	95.0	92.0	20.01	19.13	12.71	12.15
April	106.0	4.70	126.2	122.3	25.90	24.77	12.39	11.85
May	172.0	10.10	183.8	178.0	36.63	35.03	12.02	11.50
June	166.0	13.90	166.7	161.3	32.60	31.16	11.81	11.29
July	169.0	17.00	173.3	167.6	33.47	31.99	11.65	11.14
August	131.0	16.20	147.9	143.3	28.67	27.41	11.70	11.19
September	78.0	13.20	104.9	101.6	20.82	19.89	11.97	11.44
October	37.0	8.70	60.6	58.8	12.36	11.77	12.31	11.72
November	15.0	3.70	34.6	33.6	7.17	6.81	12.50	11.86
December	8.0	0.80	29.4	28.5	6.19	5.90	12.71	12.11
Year	987.0	7.10	1203.8	1165.7	241.16	230.34	12.09	11.55

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

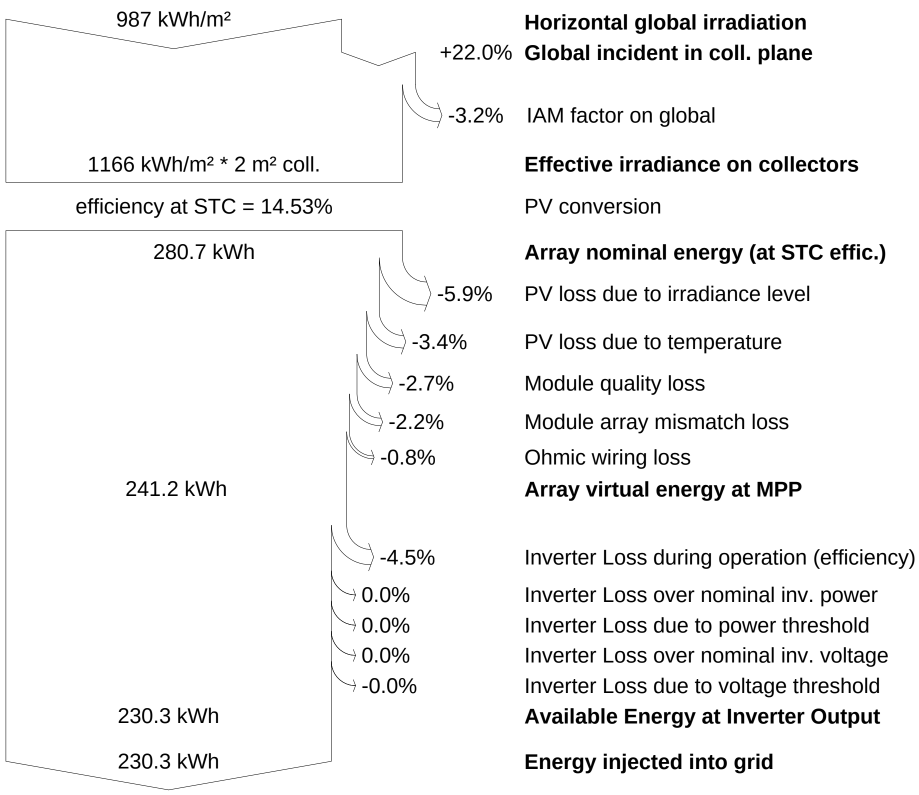
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **Overhang_ south**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	39°	azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



South Facade_ Vertical blinds

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site		**Oslo**	**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**Overhang_ south**			
	Simulation date	13/05/12 14h03		

Simulation parameters

Tracking plane, tilted Axis	Axis Tilt	90°	Axis Azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

South Facade_ Vertical blinds

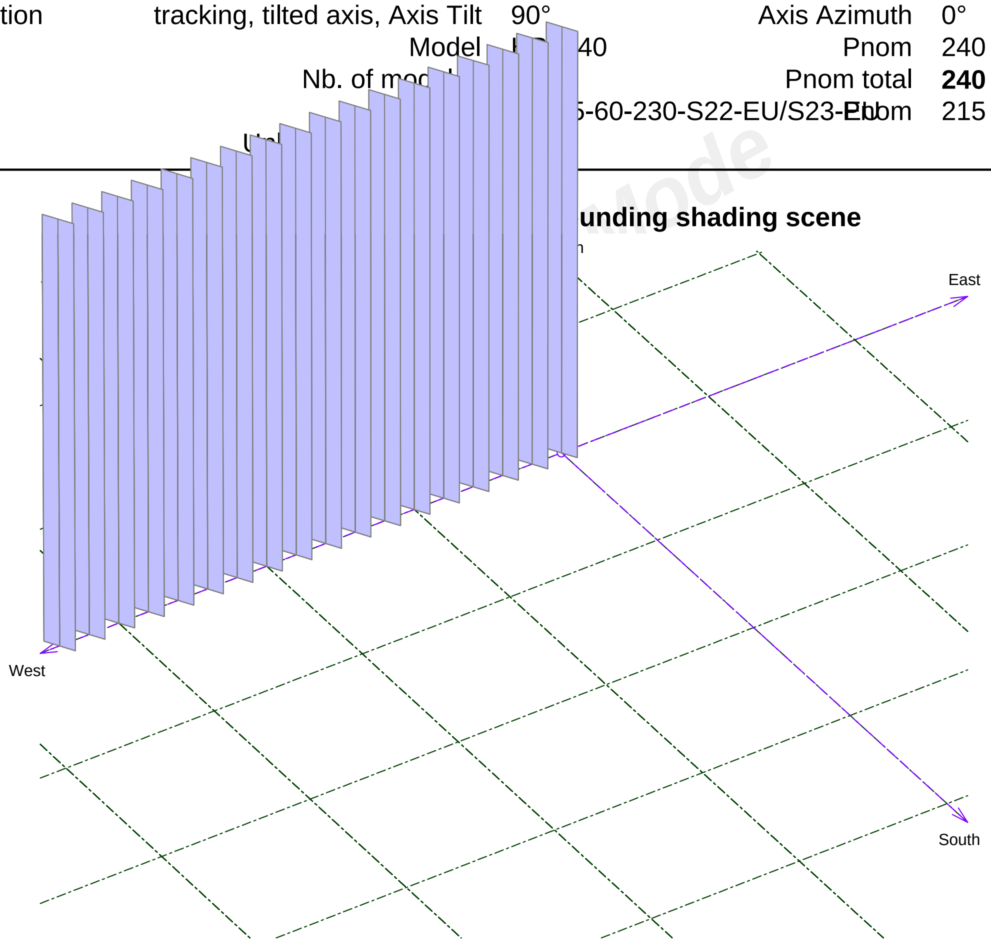
Grid-Connected System: Near shading definition

Project : **pv**

Simulation variant : **Overhang_ south**

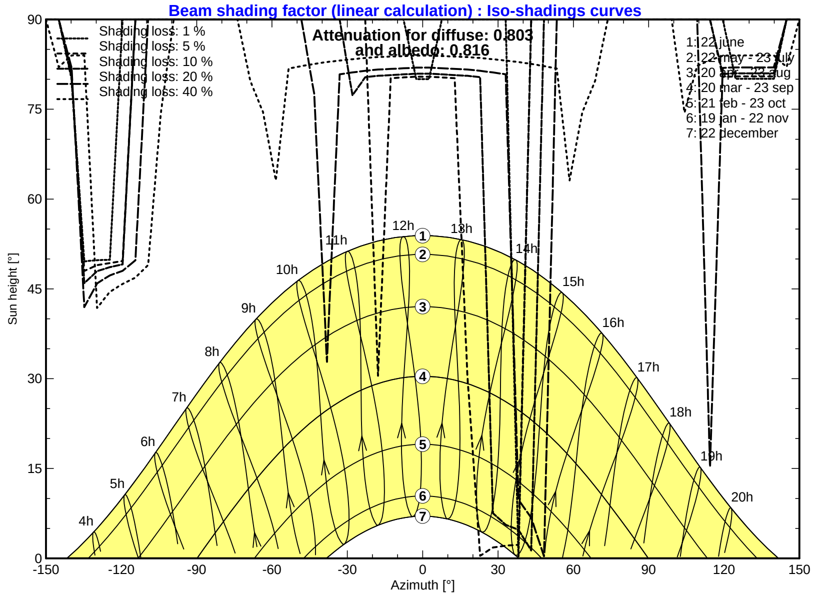
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	40	Pnom	240 Wp
PV Array	Nb. of mod		Pnom total	**240 Wp**
Inverter		5-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unl			

unding shading scene



Iso-shadings diagram

pv: Vertical asl



South Facade_ Vertical blinds

Grid-Connected System: Main results

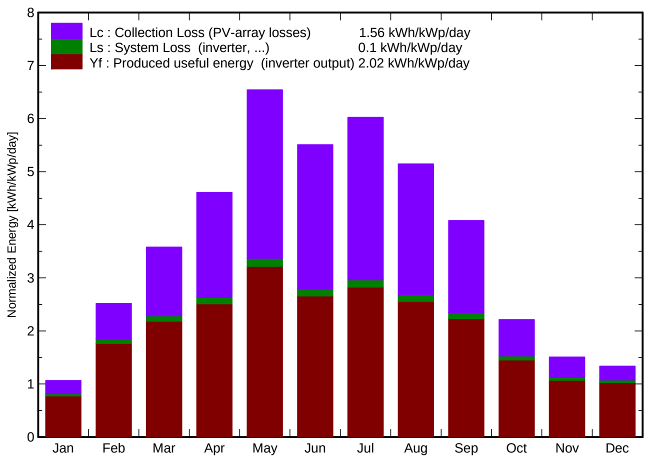
Project : **pv**

Simulation variant : **Overhang_ south**

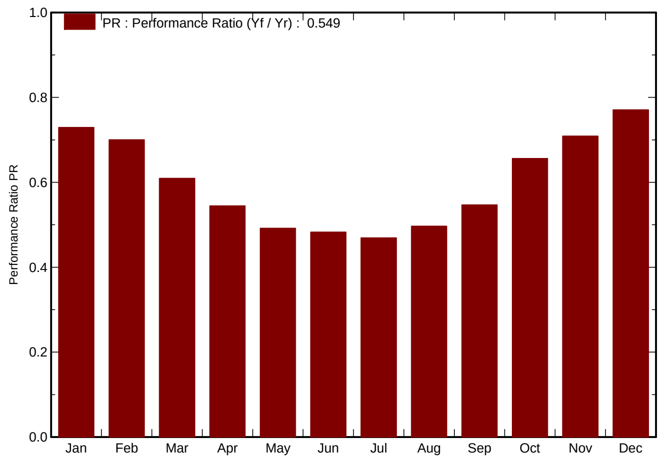
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**177.3 kWh/year**	Specific prod.	739 kWh/kWp/year
	Performance Ratio PR	54.9 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



Overhang_ south

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	11.0	-1.70	33.0	28.3	6.09	5.77	11.15	10.57
February	28.0	-2.40	70.5	56.1	12.41	11.85	10.63	10.15
March	66.0	0.30	111.0	78.3	17.01	16.23	9.25	8.83
April	106.0	4.70	138.3	89.2	18.95	18.08	8.27	7.89
May	172.0	10.10	202.8	120.5	25.05	23.94	7.46	7.13
June	166.0	13.90	165.3	99.0	20.10	19.15	7.34	6.99
July	169.0	17.00	186.7	109.7	22.04	21.03	7.13	6.80
August	131.0	16.20	159.6	99.2	19.96	19.03	7.55	7.20
September	78.0	13.20	122.4	82.2	16.84	16.06	8.31	7.92
October	37.0	8.70	68.6	54.3	11.37	10.81	10.00	9.51
November	15.0	3.70	45.3	37.9	8.08	7.70	10.78	10.27
December	8.0	0.80	41.4	37.0	8.00	7.66	11.67	11.16
Year	987.0	7.10	1344.8	891.5	185.90	177.30	8.34	7.96

Legends:				
GlobHor	Horizontal global irradiation		EArray	Effective energy at the output of the array
T Amb	Ambient Temperature		E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane		EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings		EffSysR	Effic. Eout system / rough area

South Facade_ Vertical blinds

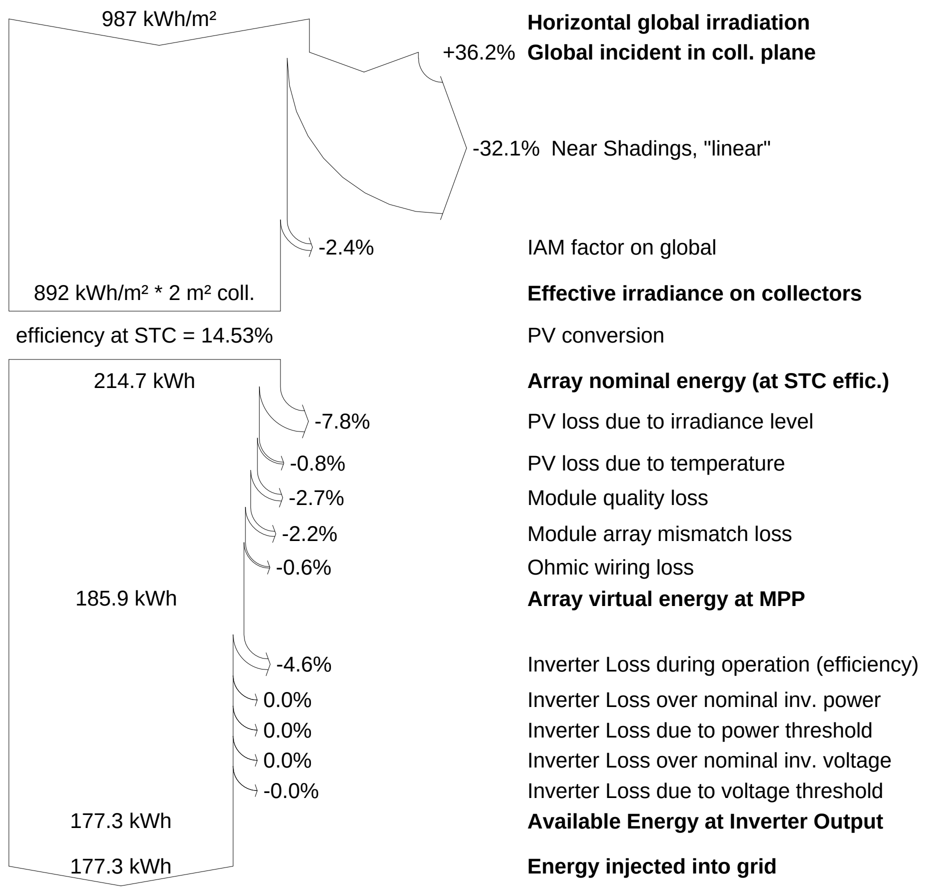
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **Overhang_ south**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



South Facade_ Horizontal blinds

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site	**Oslo**		**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**Overhang_ south**			
	Simulation date	13/05/12 13h26		

Simulation parameters

Tracking plane, Horizontal E-W Axis			Normal azimut to axis	0°
Rotation Limitations	Minimum Tilt	0°	Maximum Tilt	90°
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

South Facade_ Horizontal blinds

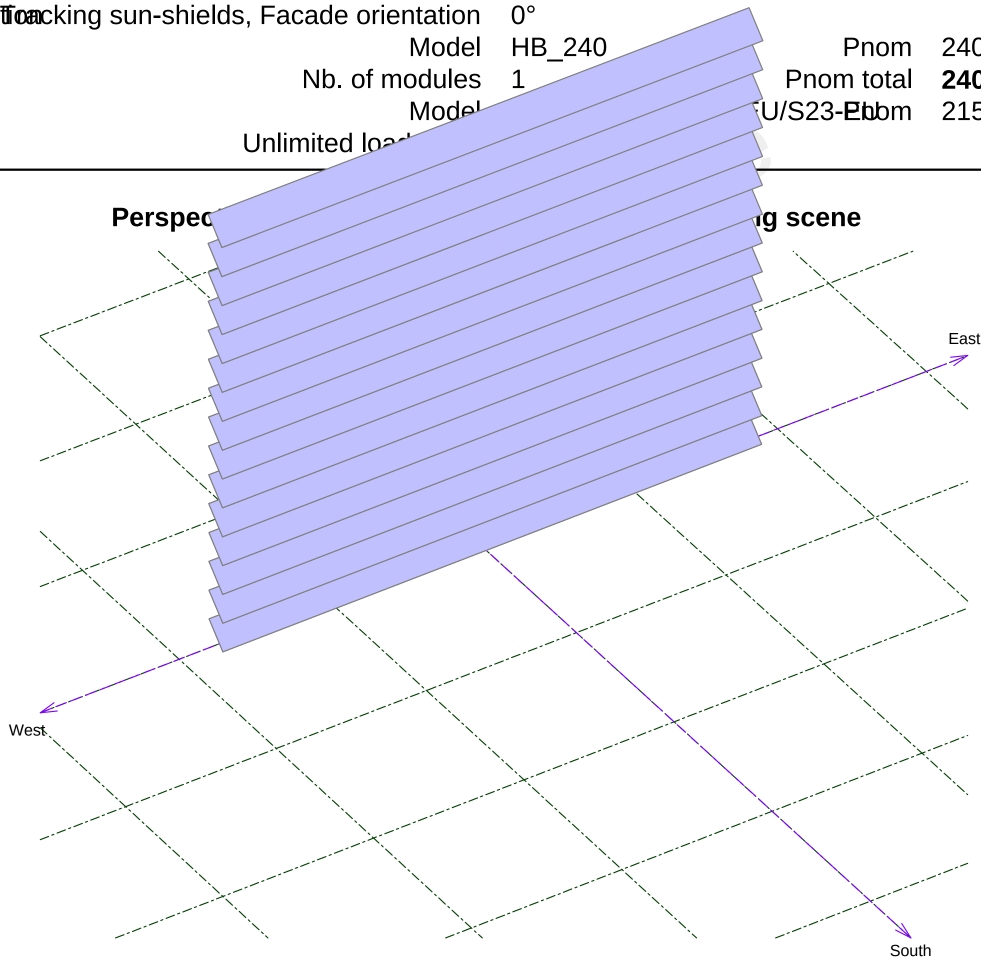
Grid-Connected System: Near shading definition

Project : **pv**

Simulation variant : **Overhang_ south**

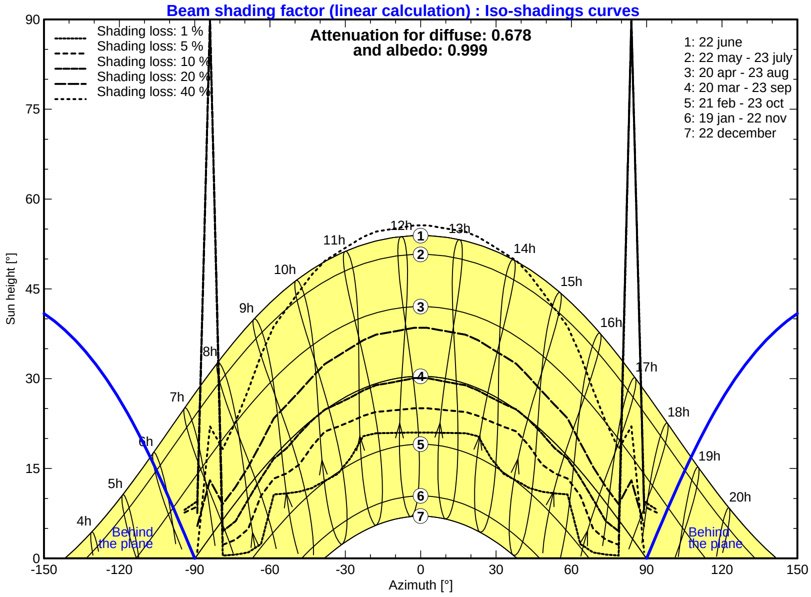
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	0°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	U/S23-EU	Pnom	215 W ac
User's needs	Unlimited loa			

Perspec... g scene



Iso-shadings diagram

pv: Horizontal blind south



South Facade_ Horizontal blinds

Grid-Connected System: Main results

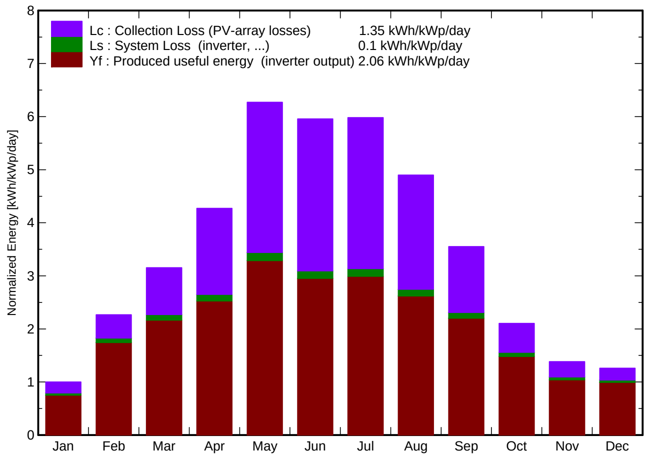
Project : **pv**

Simulation variant : **Overhang_ south**

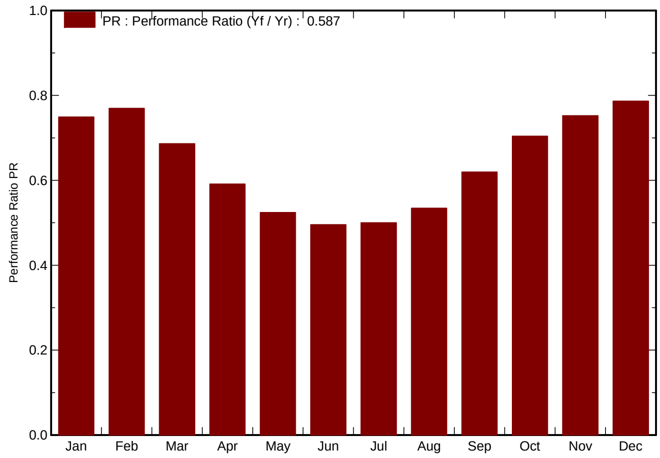
Main system parameters System type **Grid-Connected**
Near Shadings Linear shadings
PV Field Orientation Tracking sun-shields, Facade orientation 0°
PV modules Model HB_240 Pnom 240 Wp
PV Array Nb. of modules 1 Pnom total **240 Wp**
Inverter Model M 215-60-230-S22-EU/S23-EU Pnom 215 W ac
User's needs Unlimited load (grid)

Main simulation results
System Production **Produced Energy** **180.8 kWh/year** Specific prod. 753 kWh/kWp/year
Performance Ratio PR 58.7 %

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



Overhang_ south

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	11.0	-1.70	31.1	27.4	5.89	5.58	11.45	10.85
February	28.0	-2.40	63.4	55.5	12.28	11.72	11.68	11.15
March	66.0	0.30	97.8	77.8	16.88	16.11	10.42	9.94
April	106.0	4.70	128.2	89.8	19.07	18.20	8.98	8.57
May	172.0	10.10	194.4	123.0	25.59	24.45	7.95	7.59
June	166.0	13.90	178.7	109.4	22.28	21.25	7.52	7.18
July	169.0	17.00	185.4	115.9	23.32	22.25	7.59	7.24
August	131.0	16.20	151.9	101.5	20.43	19.49	8.12	7.74
September	78.0	13.20	106.6	81.2	16.63	15.85	9.42	8.98
October	37.0	8.70	65.2	55.4	11.59	11.02	10.73	10.20
November	15.0	3.70	41.5	36.9	7.87	7.49	11.45	10.90
December	8.0	0.80	39.1	35.6	7.71	7.38	11.92	11.40
Year	987.0	7.10	1283.3	909.4	189.53	180.79	8.92	8.50

Legends:

GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

South Facade_ Horizontal blinds

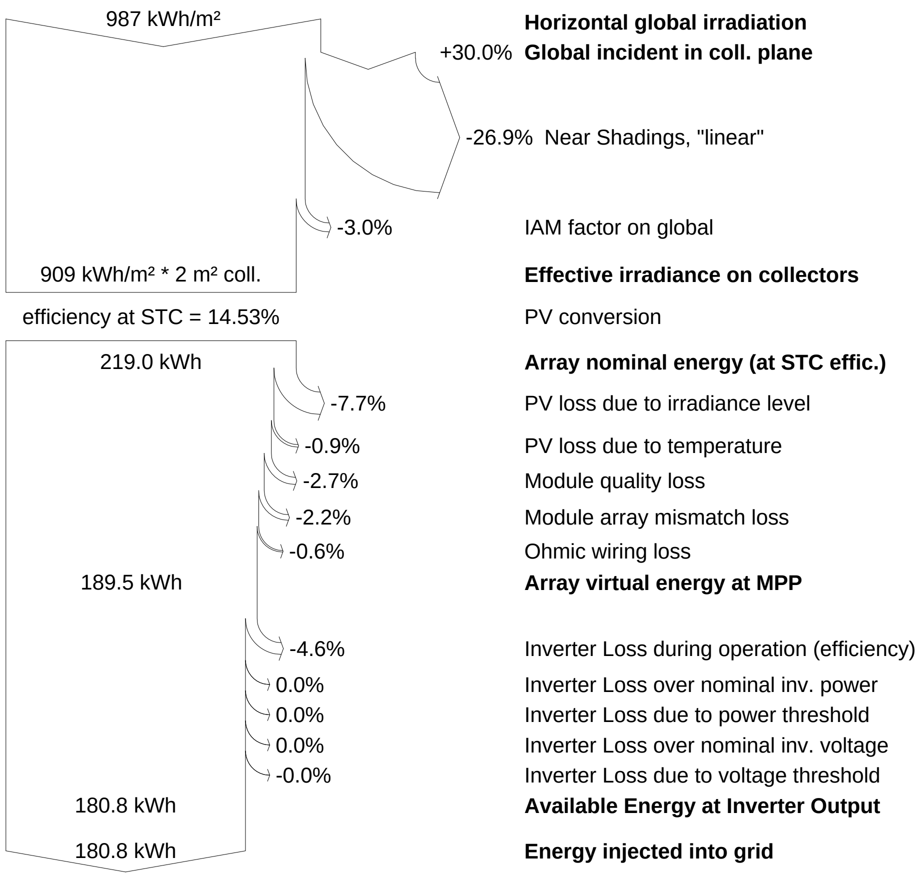
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **Overhang_ south**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	0°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Overhang_ West

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site		**Oslo**	**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**Overhang_ south**			
	Simulation date	13/05/12 12h35		

Simulation parameters

Collector Plane Orientation	Tilt	39°	Azimuth	90°
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²
Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

Overhang_ West

Grid-Connected System: Main results

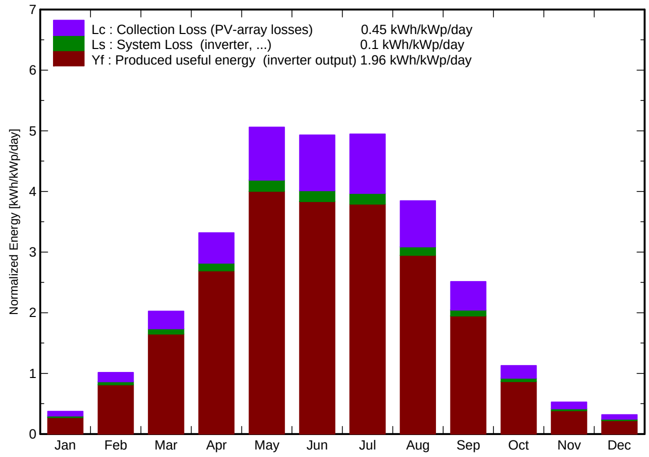
Project : **pv**

Simulation variant : **Overhang_ south**

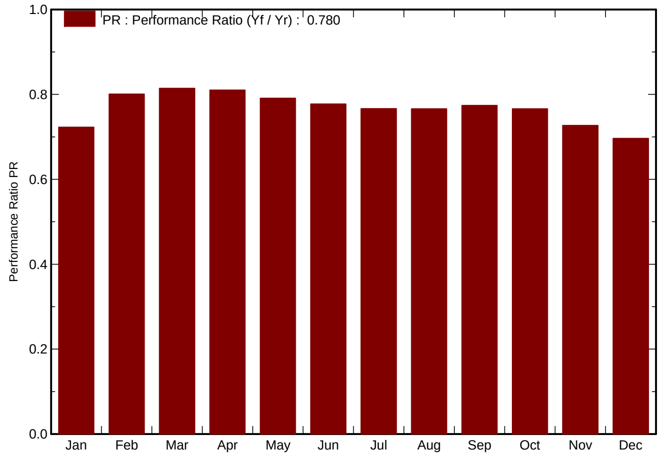
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	39°	azimuth	90°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**171.5 kWh/year**	Specific prod.	715 kWh/kWp/year
	Performance Ratio PR	78.0 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



Overhang_ south

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	11.0	-1.70	11.6	10.9	2.22	2.02	11.52	10.47
February	28.0	-2.40	28.4	26.7	5.80	5.46	12.32	11.60
March	66.0	0.30	62.8	59.9	12.91	12.27	12.41	11.80
April	106.0	4.70	99.6	95.8	20.28	19.37	12.29	11.74
May	172.0	10.10	156.8	151.5	31.14	29.77	11.99	11.46
June	166.0	13.90	148.0	142.9	28.88	27.61	11.78	11.26
July	169.0	17.00	153.3	148.0	29.52	28.21	11.62	11.11
August	131.0	16.20	119.3	114.8	22.97	21.93	11.63	11.10
September	78.0	13.20	75.4	72.2	14.72	14.02	11.78	11.22
October	37.0	8.70	35.0	33.2	6.85	6.44	11.81	11.10
November	15.0	3.70	15.9	14.7	3.00	2.77	11.43	10.53
December	8.0	0.80	9.9	9.0	1.82	1.66	11.08	10.09
Year	987.0	7.10	916.0	879.5	180.12	171.52	11.87	11.30

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Overhang_ West

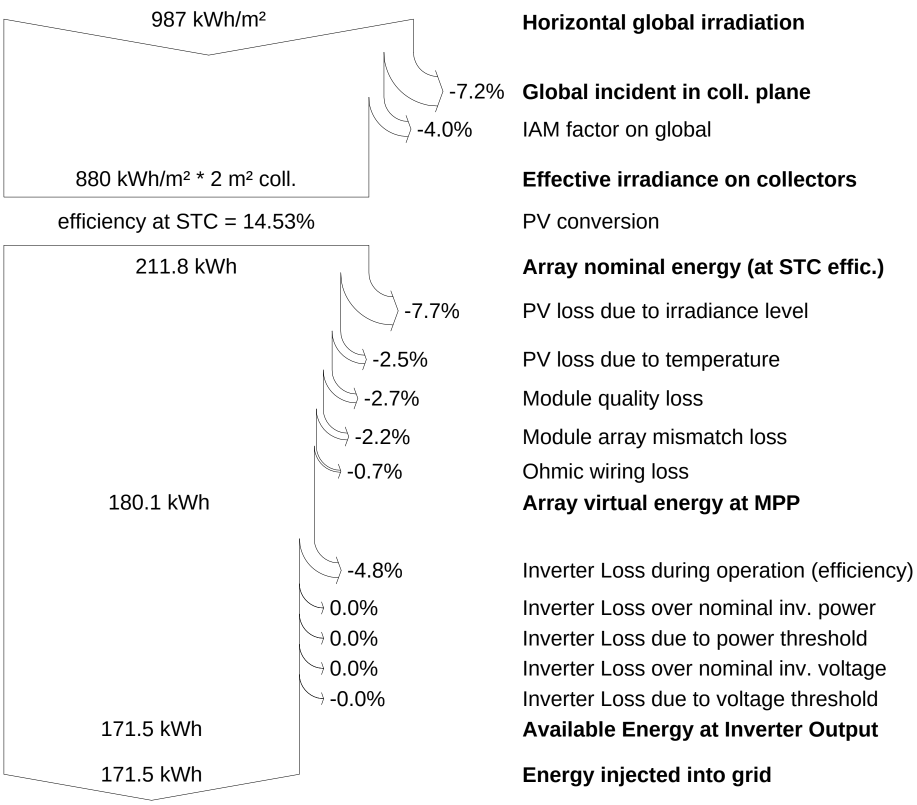
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **Overhang_ south**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	39°	azimuth	90°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



West_vertical blinds

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site	**Oslo**		**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**East_ Horizontal blinds**			
	Simulation date	13/05/12 15h55		

Simulation parameters

Tracking plane, tilted Axis	Axis Tilt	90°	Axis Azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module	Si-poly	Model	**HB_240**		
		Manufacturer	HBL Power Systems Ltd		
Number of PV modules		In series	1 modules	In parallel	1 strings
Total number of PV modules		Nb. modules	1	Unit Nom. Power	240 Wp
Array global power		Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)		U mpp	26 V	I mpp	8.1 A
Total area		Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

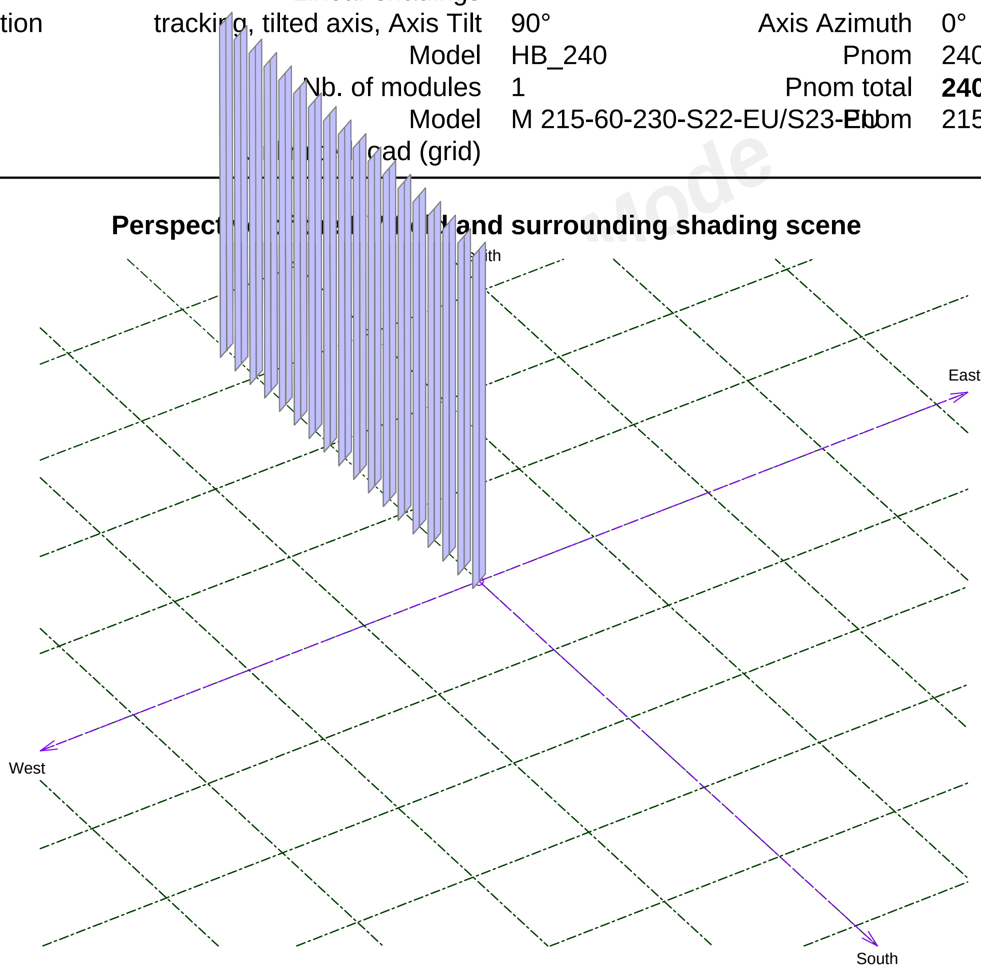
Grid-Connected System: Near shading definition

Project : **pv**

Simulation variant : **East_ Horizontal blinds**

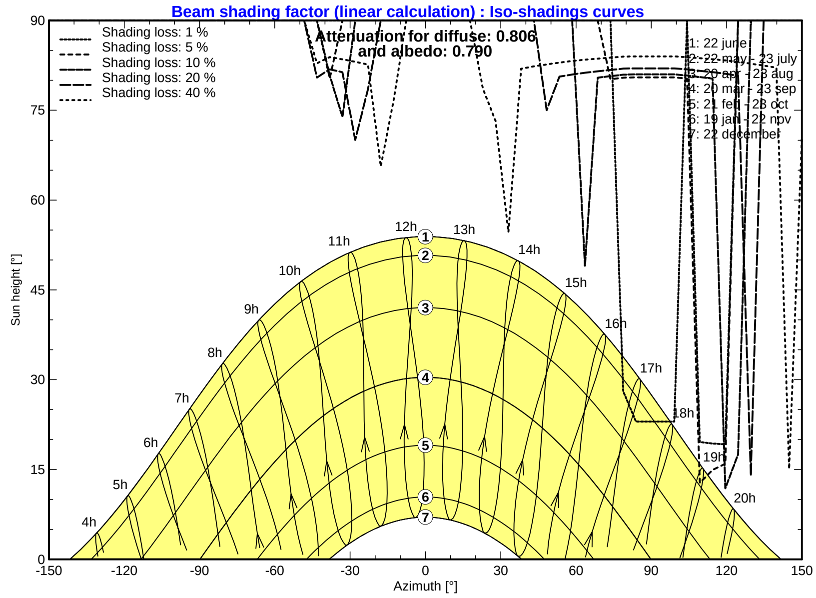
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

pv: Vertical



West_vertical blinds

Grid-Connected System: Main results

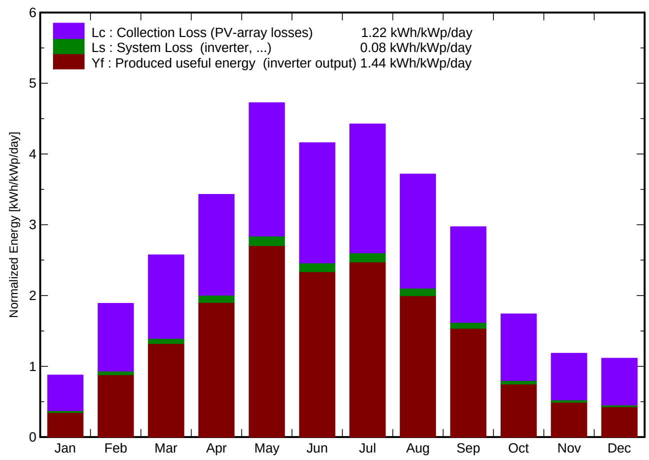
Project : **pv**

Simulation variant : **East_ Horizontal blinds**

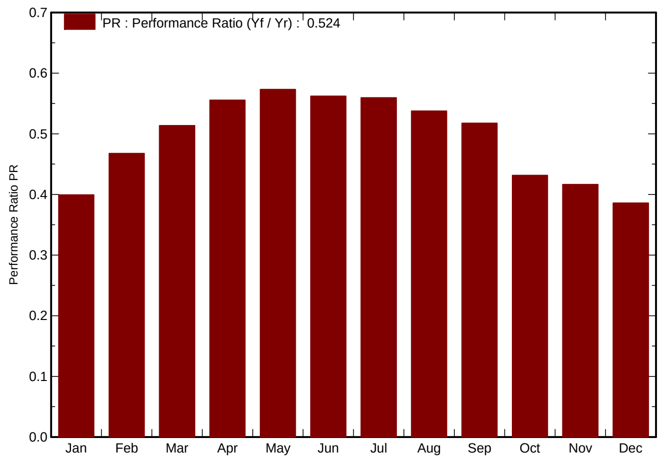
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**125.7 kWh/year**	Specific prod.	524 kWh/kWp/year
	Performance Ratio PR	52.4 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



East_ Horizontal blinds

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	11.0	-1.70	27.1	13.3	2.79	2.60	6.22	5.79
February	28.0	-2.40	52.8	28.9	6.28	5.93	7.18	6.78
March	66.0	0.30	79.8	48.7	10.39	9.84	7.86	7.44
April	106.0	4.70	102.8	68.8	14.44	13.71	8.48	8.05
May	172.0	10.10	146.4	103.3	21.15	20.14	8.72	8.30
June	166.0	13.90	124.7	88.4	17.73	16.83	8.58	8.15
July	169.0	17.00	137.2	97.8	19.38	18.42	8.53	8.11
August	131.0	16.20	115.2	79.0	15.66	14.86	8.21	7.79
September	78.0	13.20	89.1	57.8	11.68	11.07	7.91	7.50
October	37.0	8.70	53.9	29.0	5.96	5.58	6.67	6.25
November	15.0	3.70	35.5	18.2	3.79	3.55	6.44	6.03
December	8.0	0.80	34.5	15.9	3.38	3.20	5.90	5.59
Year	987.0	7.10	999.1	649.0	132.61	125.73	8.01	7.60

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

West_vertical blinds

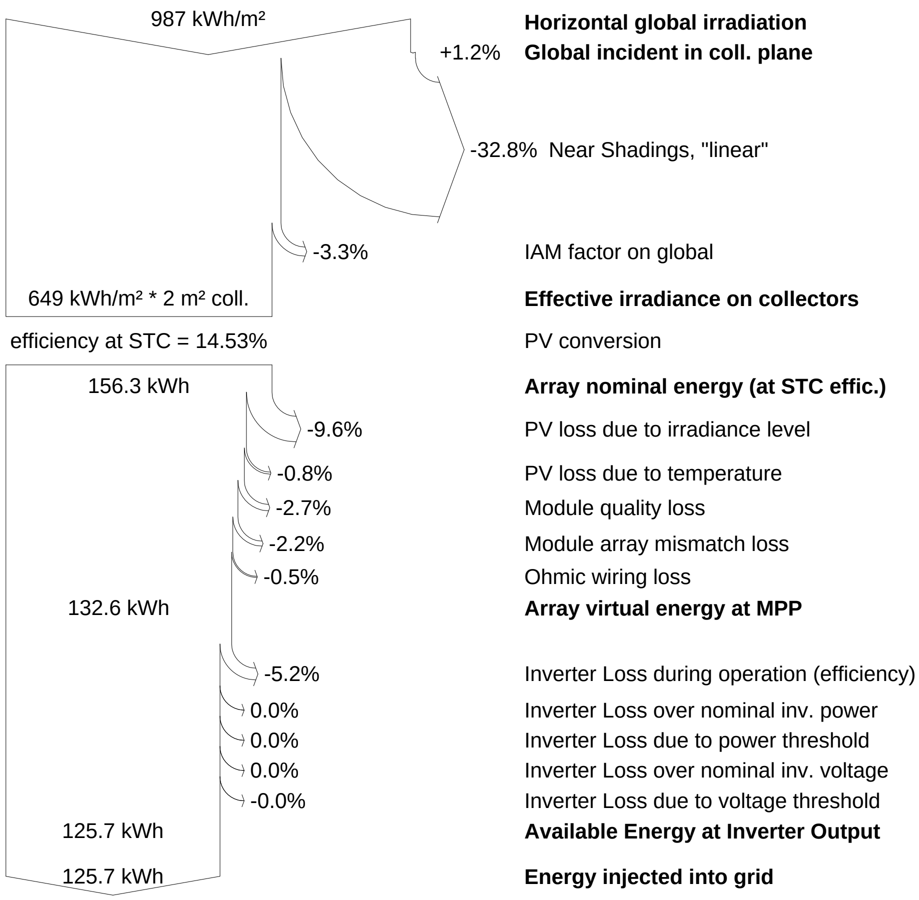
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **East_ Horizontal blinds**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



West facade_ Horizontal blinds

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site	**Oslo**		**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**East_ Horizontal blinds**			
	Simulation date	13/05/12 15h14		

Simulation parameters

Tracking plane, Horizontal E-W Axis			Normal azimut to axis	90°
Rotation Limitations	Minimum Tilt	0°	Maximum Tilt	90°
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module	Si-poly	Model	**HB_240**		
		Manufacturer	HBL Power Systems Ltd		
Number of PV modules		In series	1 modules	In parallel	1 strings
Total number of PV modules		Nb. modules	1	Unit Nom. Power	240 Wp
Array global power		Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)		U mpp	26 V	I mpp	8.1 A
Total area		Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

West facade_ Horizontal blinds

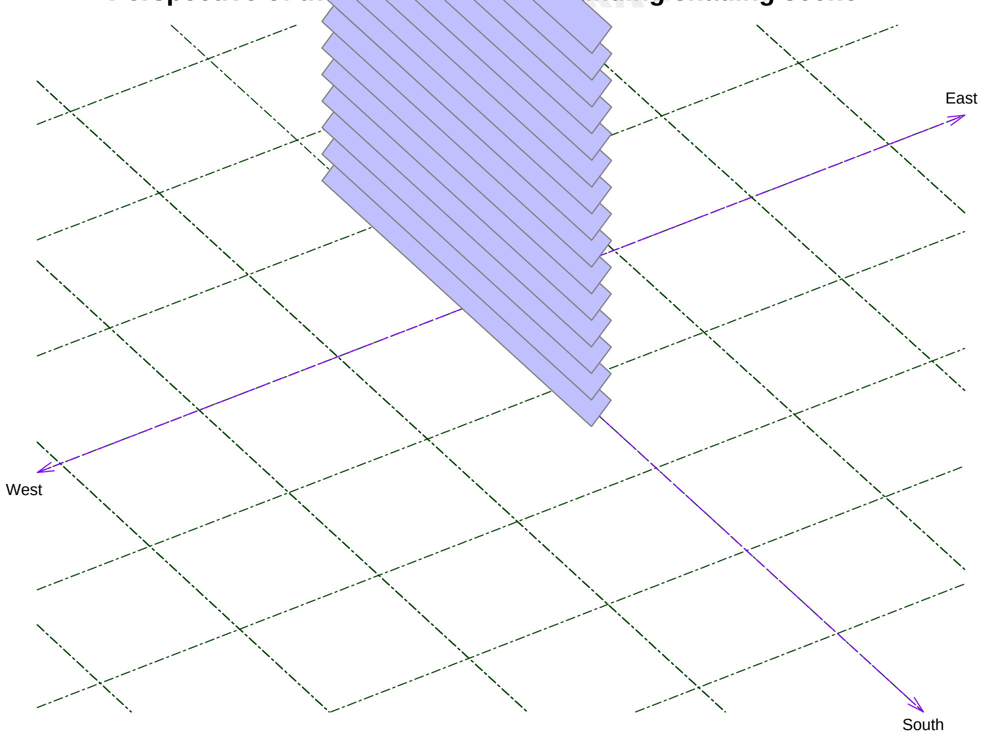
Grid-Connected System: Near shading definition

Project : **pv**

Simulation variant : **East_ Horizontal blinds**

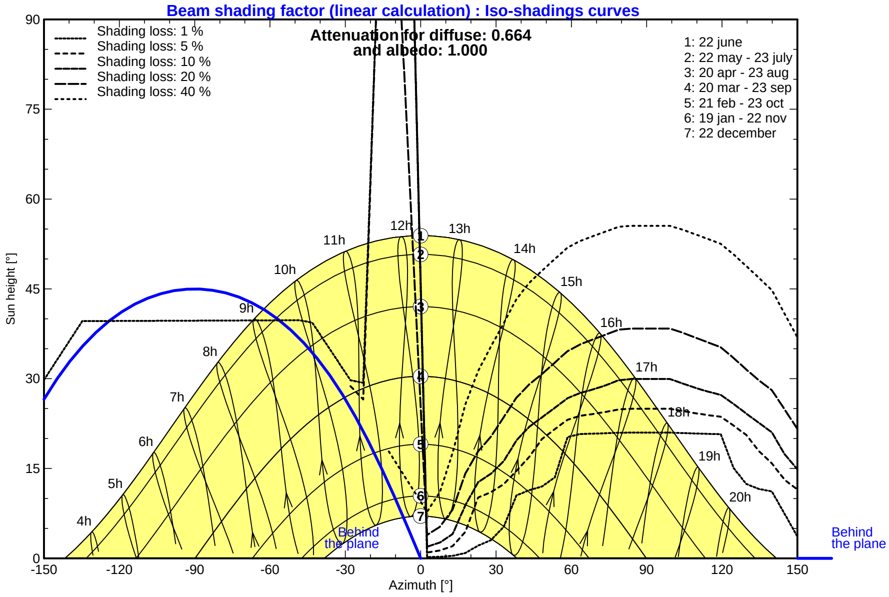
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	90°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb dules	1	Pnom total	**240 Wp**
Inverter	del	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimite			

Perspective of th unding shading scene



Iso-shadings diagram

pv: Horizontal blind south



West facade_ Horizontal blinds

Grid-Connected System: Main results

Project : **pv**

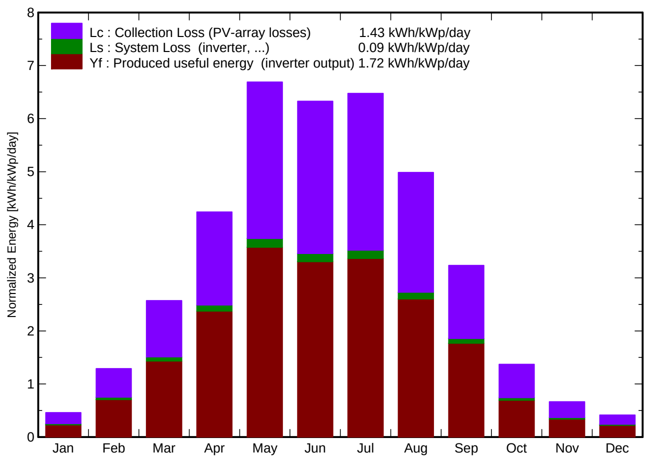
Simulation variant : **East_ Horizontal blinds**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	90°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

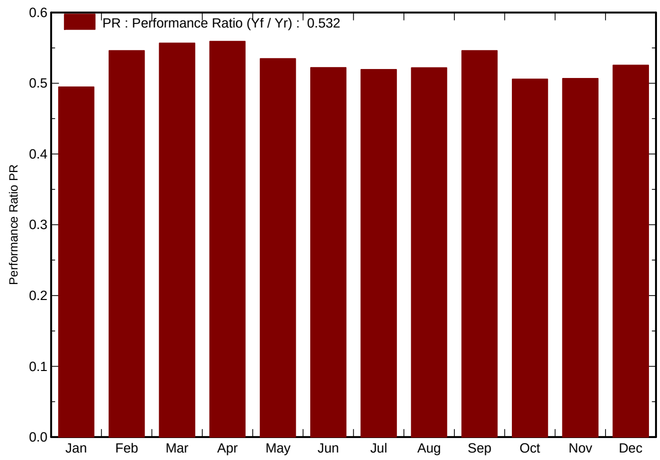
Main simulation results

System Production	**Produced Energy**	**150.9 kWh/year**	Specific prod.	629 kWh/kWp/year
	Performance Ratio PR	53.2 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



East_ Horizontal blinds

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	11.0	-1.70	14.3	9.4	1.88	1.70	7.96	7.17
February	28.0	-2.40	36.1	23.5	5.05	4.74	8.43	7.91
March	66.0	0.30	79.8	52.5	11.23	10.66	8.50	8.06
April	106.0	4.70	127.3	84.6	17.92	17.08	8.50	8.10
May	172.0	10.10	207.4	134.5	27.83	26.61	8.10	7.75
June	166.0	13.90	189.8	122.6	24.90	23.79	7.92	7.56
July	169.0	17.00	200.7	130.7	26.20	25.02	7.88	7.52
August	131.0	16.20	154.6	101.2	20.30	19.36	7.93	7.56
September	78.0	13.20	97.0	65.7	13.37	12.72	8.32	7.91
October	37.0	8.70	42.5	27.1	5.52	5.16	7.84	7.33
November	15.0	3.70	20.0	13.2	2.65	2.44	7.99	7.34
December	8.0	0.80	12.9	8.8	1.79	1.63	8.35	7.61
Year	987.0	7.10	1182.4	773.6	158.65	150.90	8.10	7.70

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

West facade_ Horizontal blinds

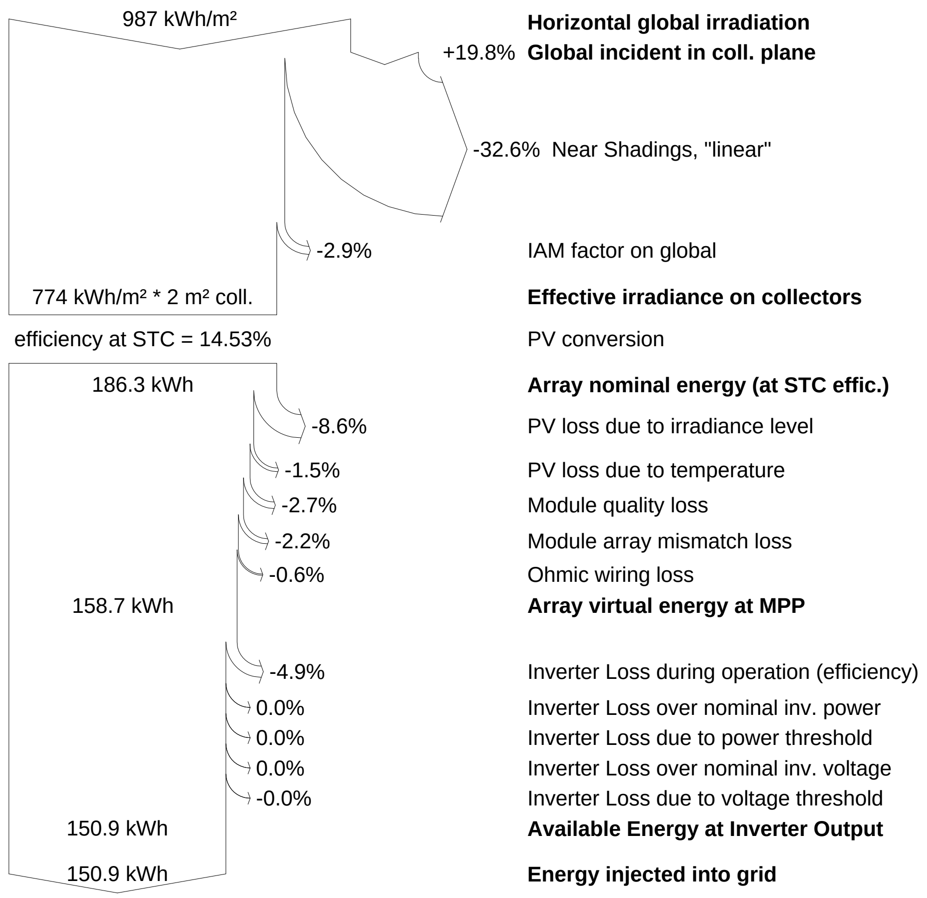
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **East_ Horizontal blinds**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	90°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project : **pv**

Geographical Site	**Oslo**		**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		

Meteo data : Oslo, Synthetic Hourly data

Simulation variant : **Overhang_ south**

Simulation date 13/05/12 12h34

Simulation parameters

Collector Plane Orientation	Tilt	39°	Azimuth	-90°
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

Overhang_ east

Grid-Connected System: Main results

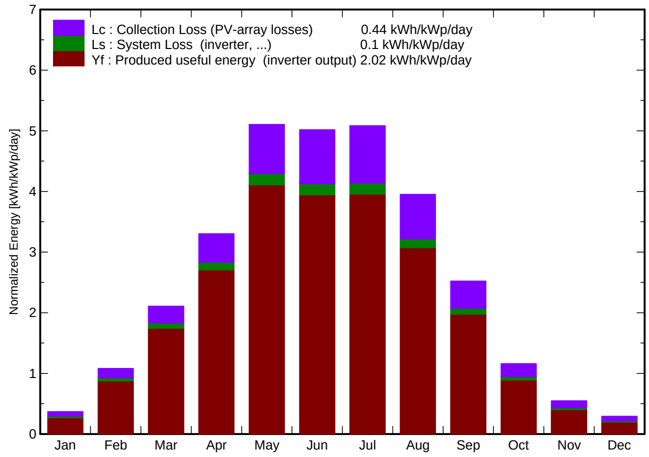
Project : **pv**

Simulation variant : **Overhang_ south**

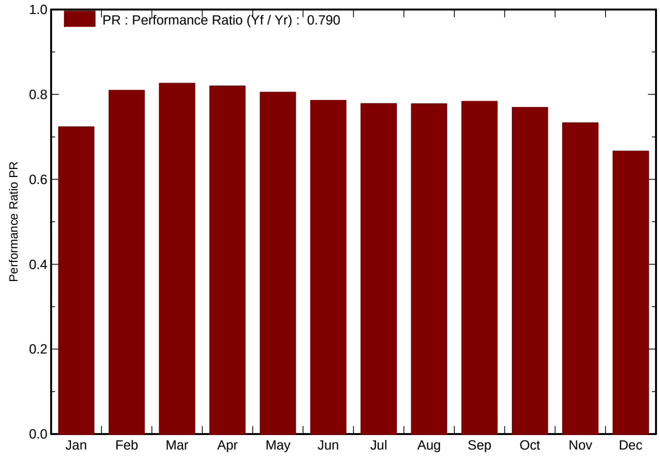
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	39°	azimuth	-90°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**176.8 kWh/year**	Specific prod.	737 kWh/kWp/year
	Performance Ratio PR	79.0 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



Overhang_ south

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	11.0	-1.70	11.5	10.7	2.19	1.99	11.54	10.48
February	28.0	-2.40	30.3	28.5	6.24	5.89	12.43	11.73
March	66.0	0.30	65.4	62.5	13.62	12.97	12.58	11.97
April	106.0	4.70	99.1	95.2	20.41	19.49	12.44	11.88
May	172.0	10.10	158.2	152.8	31.96	30.57	12.19	11.66
June	166.0	13.90	150.5	145.2	29.71	28.39	11.91	11.39
July	169.0	17.00	157.6	152.1	30.79	29.43	11.79	11.27
August	131.0	16.20	122.5	118.0	23.94	22.86	11.80	11.27
September	78.0	13.20	75.6	72.5	14.94	14.22	11.92	11.35
October	37.0	8.70	36.0	34.0	7.05	6.64	11.84	11.14
November	15.0	3.70	16.5	15.3	3.14	2.89	11.51	10.62
December	8.0	0.80	9.1	8.1	1.61	1.46	10.70	9.66
Year	987.0	7.10	932.2	894.9	185.60	176.80	12.02	11.45

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

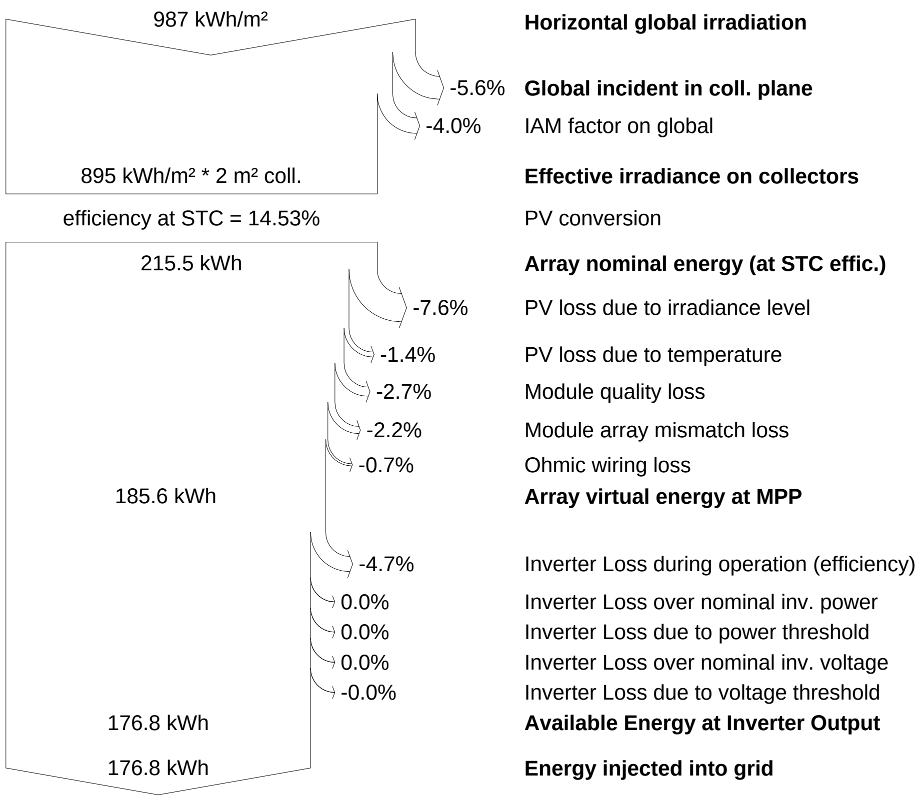
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **Overhang_ south**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	39°	azimuth	-90°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



East_ vertical blinds

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site		**Oslo**	**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**East_ vertical blinds**			
	Simulation date	13/05/12 15h58		

Simulation parameters

Tracking plane, tilted Axis	Axis Tilt	90°	Axis Azimuth	0°
Rotation Limitations	Minimum Phi	-60°	Maximum Phi	60°
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²

Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs :	Unlimited load (grid)

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East_ vertical blinds

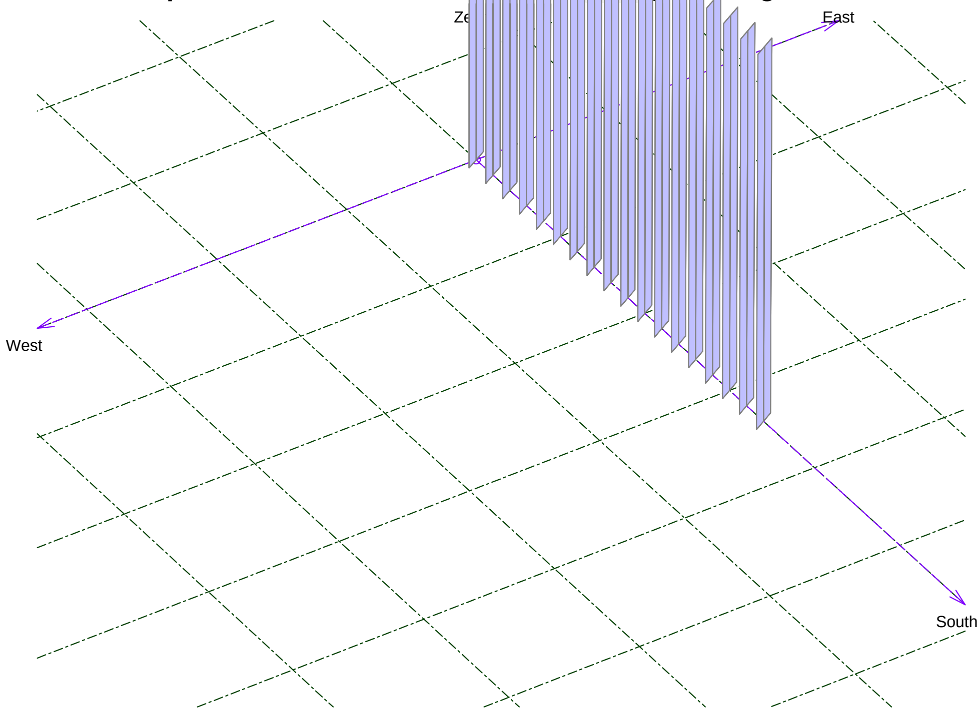
Grid-Connected System: Near shading definition

Project : **pv**

Simulation variant : **East_ vertical blinds**

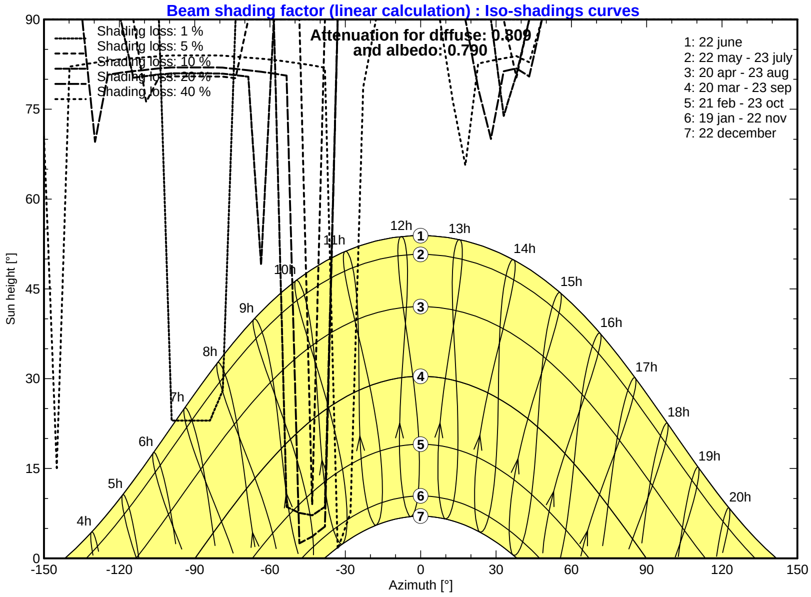
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Mode	HB_240	Pnom	240 Wp
PV Array	Nb. of module		Pnom total	**240 Wp**
Inverter	Mode	-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid			

Perspective of the PV-field a ... ading scene



Iso-shadings diagram

pv: Vertical



Grid-Connected System: Main results

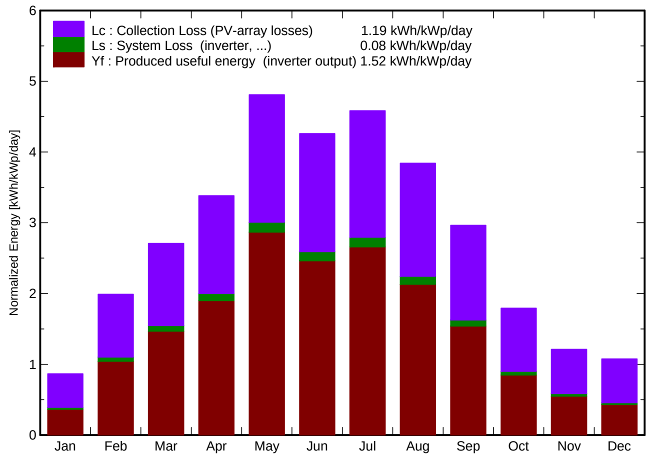
Project : **pv**

Simulation variant : **East_ vertical blinds**

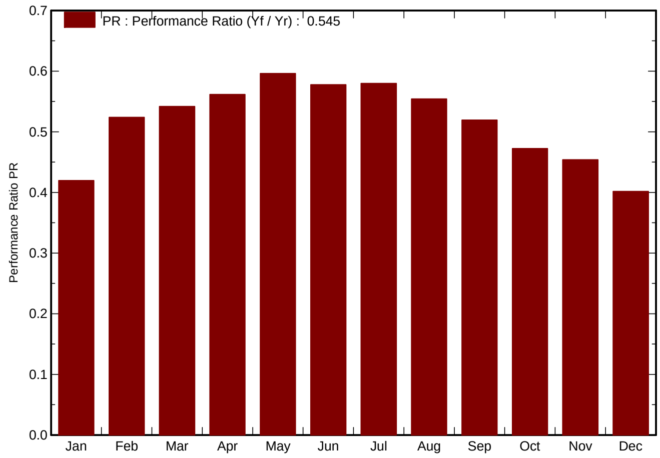
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**133.6 kWh/year**	Specific prod.	557 kWh/kWp/year
	Performance Ratio PR	54.5 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



East_ vertical blinds
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	11.0	-1.70	26.9	13.8	2.90	2.71	6.53	6.08
February	28.0	-2.40	55.7	33.7	7.40	7.01	8.02	7.59
March	66.0	0.30	84.0	53.2	11.51	10.92	8.28	7.85
April	106.0	4.70	101.5	67.6	14.40	13.68	8.57	8.14
May	172.0	10.10	149.1	106.9	22.38	21.33	9.06	8.64
June	166.0	13.90	127.8	91.4	18.67	17.73	8.81	8.37
July	169.0	17.00	142.1	102.8	20.79	19.78	8.83	8.40
August	131.0	16.20	119.1	82.6	16.68	15.85	8.46	8.03
September	78.0	13.20	89.0	57.2	11.70	11.09	7.94	7.53
October	37.0	8.70	55.6	32.4	6.70	6.31	7.28	6.85
November	15.0	3.70	36.4	20.2	4.21	3.96	7.00	6.58
December	8.0	0.80	33.4	16.0	3.40	3.22	6.15	5.82
Year	987.0	7.10	1020.5	677.7	140.77	133.57	8.33	7.90

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

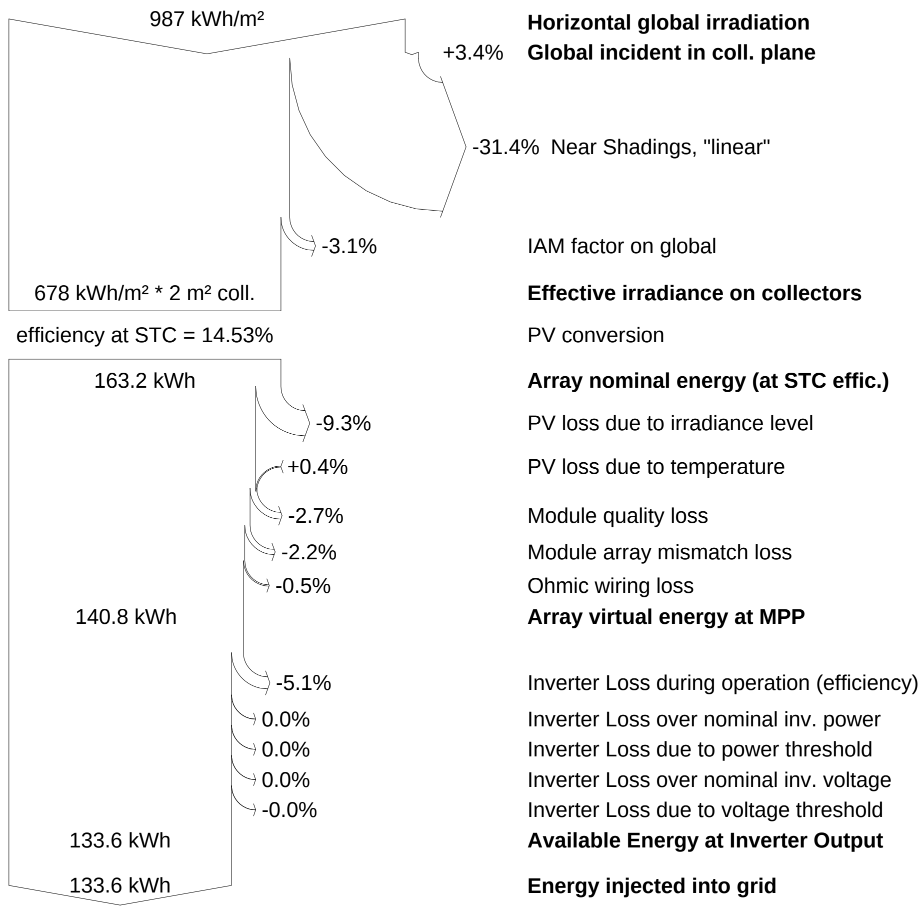
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **East_ vertical blinds**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tracking, tilted axis, Axis Tilt	90°	Axis Azimuth	0°
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



East facade_ Horizontal blinds

Grid-Connected System: Simulation parameters

Project :	**pv**			
Geographical Site	**Oslo**		**Country**	**Norway**
Situation	Latitude	59.5°N	Longitude	10.4°E
Time defined as	Legal Time	Time zone UT+1	Altitude	5 m
	Albedo	0.20		
Meteo data :	Oslo, Synthetic Hourly data			

Simulation variant :	**Overhang_ south**			
	Simulation date	13/05/12 13h31		

Simulation parameters

Tracking plane, Horizontal E-W Axis			Normal azimut to axis	-90°
Rotation Limitations	Minimum Tilt	0°	Maximum Tilt	90°
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**HB_240**		
	Manufacturer	HBL Power Systems Ltd		
Number of PV modules	In series	1 modules	In parallel	1 strings
Total number of PV modules	Nb. modules	1	Unit Nom. Power	240 Wp
Array global power	Nominal (STC)	**240 Wp**	At operating cond.	215 Wp (50°C)
Array operating characteristics (50°C)	U mpp	26 V	I mpp	8.1 A
Total area	Module area	**1.7 m²**	Cell area	1.5 m²
Inverter	Model	**M 215-60-230-S22-EU/S23-EU**		
	Manufacturer	Enphase		
Characteristics	Operating Voltage	22-36 V	Unit Nom. Power	0.215 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	55 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

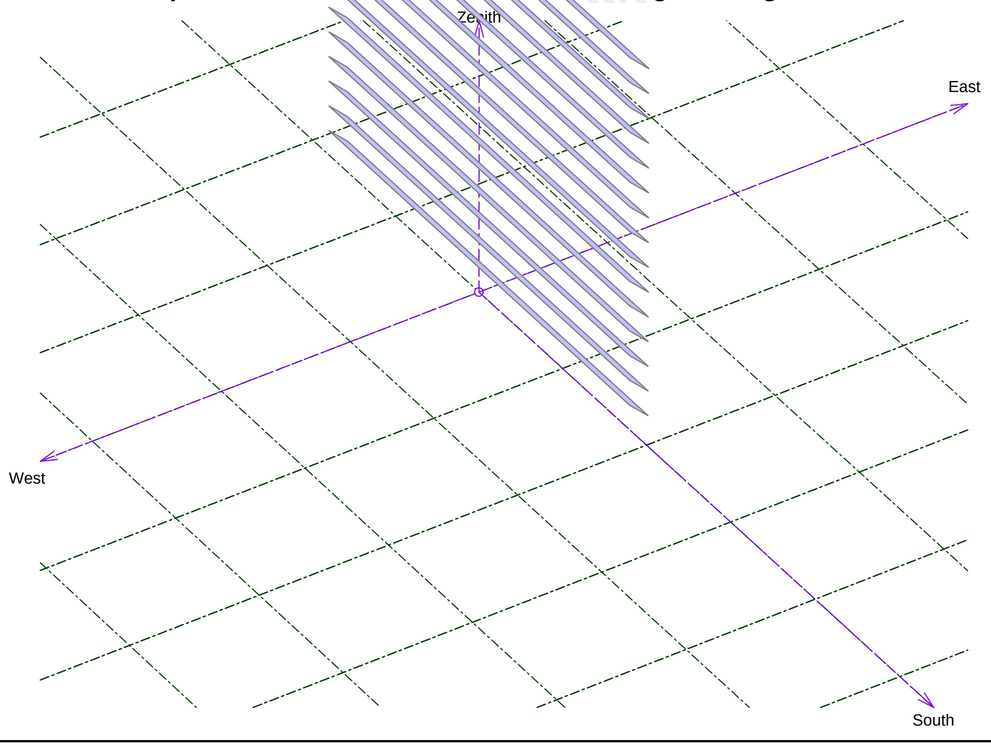
Grid-Connected System: Near shading definition

Project : **pv**

Simulation variant : **Overhang_ south**

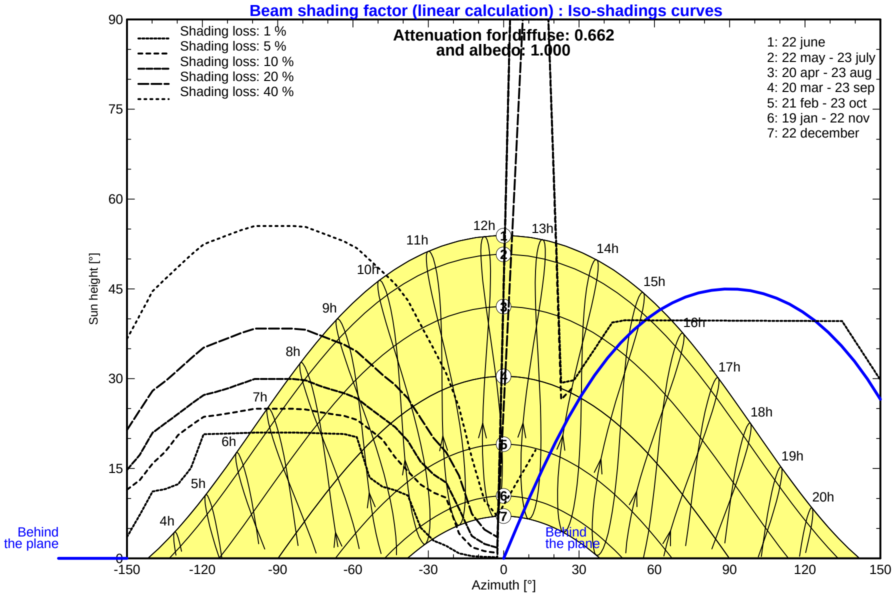
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	-90°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

pv: Horizontal blind south



East facade_ Horizontal blinds

Grid-Connected System: Main results

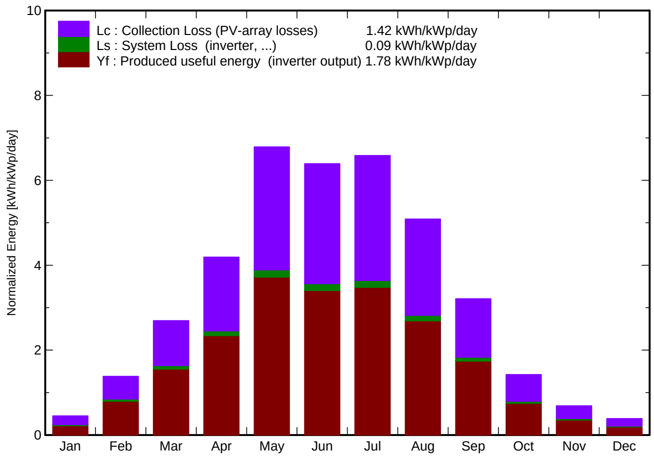
Project : **pv**

Simulation variant : **Overhang_ south**

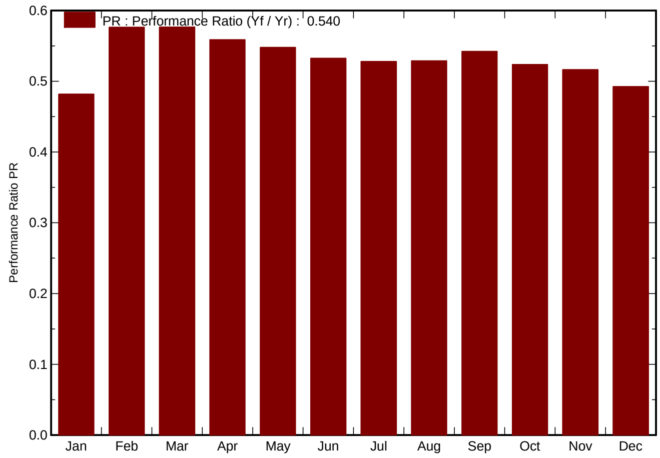
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	-90°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**155.5 kWh/year**	Specific prod.	648 kWh/kWp/year
	Performance Ratio PR	54.0 %		

Normalized productions (per installed kWp): Nominal power 240 Wp



Performance Ratio PR



Overhang_ south

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	11.0	-1.70	14.0	9.0	1.81	1.62	7.78	6.98
February	28.0	-2.40	38.7	26.1	5.69	5.35	8.87	8.35
March	66.0	0.30	83.6	56.2	12.17	11.56	8.79	8.35
April	106.0	4.70	125.7	82.6	17.67	16.85	8.49	8.09
May	172.0	10.10	210.4	138.1	28.94	27.68	8.30	7.94
June	166.0	13.90	191.7	125.2	25.67	24.51	8.08	7.72
July	169.0	17.00	204.1	133.6	27.09	25.87	8.01	7.65
August	131.0	16.20	157.7	103.5	20.98	20.02	8.03	7.66
September	78.0	13.20	96.4	64.4	13.20	12.54	8.27	7.86
October	37.0	8.70	44.1	28.9	5.92	5.55	8.10	7.59
November	15.0	3.70	20.7	13.7	2.79	2.56	8.14	7.48
December	8.0	0.80	12.0	7.8	1.57	1.42	7.88	7.14
Year	987.0	7.10	1199.2	789.2	163.49	155.55	8.23	7.83

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

East facade_ Horizontal blinds

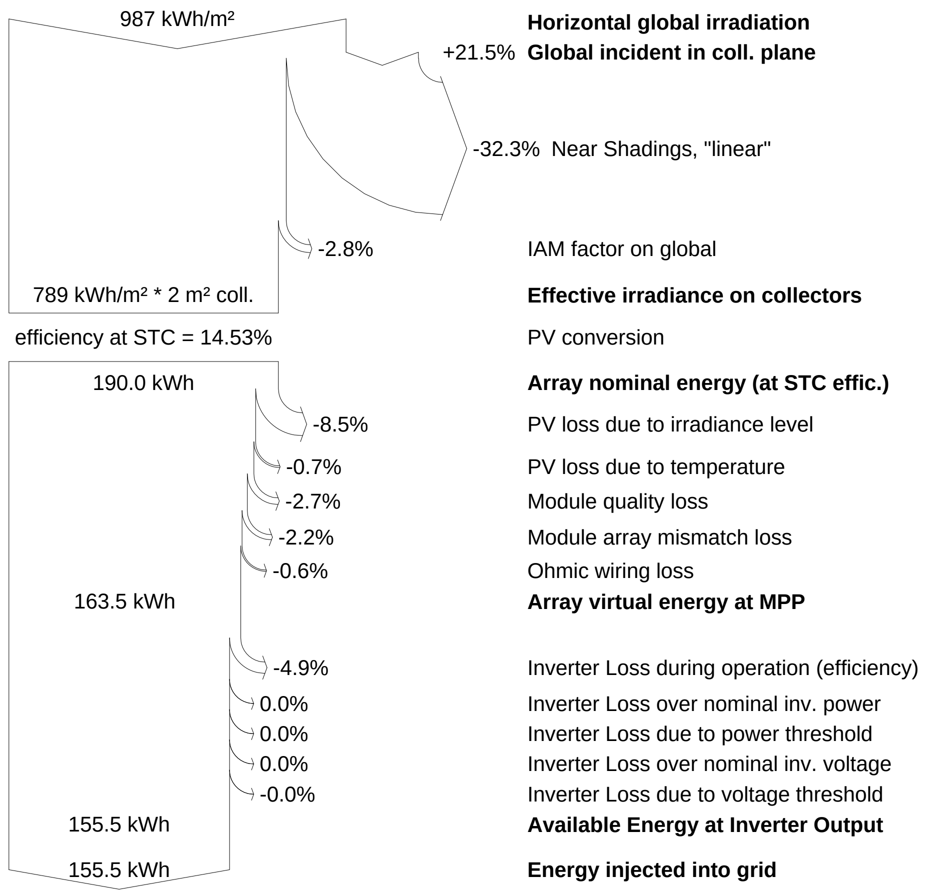
Grid-Connected System: Loss diagram

Project : **pv**

Simulation variant : **Overhang_ south**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking sun-shields, Facade orientation	-90°		
PV modules	Model	HB_240	Pnom	240 Wp
PV Array	Nb. of modules	1	Pnom total	**240 Wp**
Inverter	Model	M 215-60-230-S22-EU/S23-EU	Pnom	215 W ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Appendix 4

SIMIEN

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Resultater årssimulering

Simuleringsnavn: annual
Tid/dato simulering: 23:10 2/6-2012
Programversjon: 5.007
Brukernavn: Student
Firma: Undervisningslisens
Inndatafil: C:\Users\Noora\Desktop\BASIC22.smi
Prosjekt: Office
Sone: Test1

Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	10 kWh	0,3 kWh/m^2
1b Ventilasjonsvarme (varmebatterier)	104 kWh	3,3 kWh/m^2
2 Varmtvann (tappevann)	156 kWh	5,0 kWh/m^2
3a Vifter	279 kWh	8,9 kWh/m^2
3b Pumper	20 kWh	0,6 kWh/m^2
4 Belysning	489 kWh	15,7 kWh/m^2
5 Teknisk utstyr	586 kWh	18,8 kWh/m^2
6a Romkjøling	0 kWh	0,0 kWh/m^2
6b Ventilasjonskjøling (kjølebatterier)	116 kWh	3,7 kWh/m^2
Totalt netto energibehov, sum 1-6	1760 kWh	56,4 kWh/m^2

Levert energi til bygningen (beregnet)

Energivare	Levert energi	Spesifikk levert energi
1a Direkte el.	1720 kWh	55,1 kWh/m^2
1b El. Varmepumpe	0 kWh	0,0 kWh/m^2
1c El. solenergi	0 kWh	0,0 kWh/m^2
2 Olje	0 kWh	0,0 kWh/m^2
3 Gass	0 kWh	0,0 kWh/m^2
4 Fjernvarme	0 kWh	0,0 kWh/m^2
5 Biobrensel	0 kWh	0,0 kWh/m^2
6. Annen ()	0 kWh	0,0 kWh/m^2
Totalt levert energi, sum 1-6	1720 kWh	55,1 kWh/m^2

Simuleringsnavn: annual
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Årlige utslipp av CO_2		
Energivare	Utslipp	Spesifikt utslipp
1a Direkte el.	172 kg	5,5 kg/m²
1b El. Varmepumpe	0 kg	0,0 kg/m²
1c El. solenergi	0 kg	0,0 kg/m²
2 Olje	0 kg	0,0 kg/m²
3 Gass	0 kg	0,0 kg/m²
4 Fjernvarme	0 kg	0,0 kg/m²
5 Biobrensel	0 kg	0,0 kg/m²
6. Annen ()	0 kg	0,0 kg/m²
Totalt utslipp, sum 1-6	172 kg	5,5 kg/m²

Kostnad kjøpt energi		
Energivare	Energikostnad	Spesifikk energikostnad
1a Direkte el.	1376 kr	44,1 kr/m²
1b El. Varmepumpe	0 kr	0,0 kr/m²
1c El. solenergi	0 kr	0,0 kr/m²
2 Olje	0 kr	0,0 kr/m²
3 Gass	0 kr	0,0 kr/m²
4 Fjernvarme	0 kr	0,0 kr/m²
5 Biobrensel	0 kr	0,0 kr/m²
6. Annen ()	0 kr	0,0 kr/m²
Årlige energikostnader, sum 1-6	1376 kr	44,1 kr/m²

SIMIEN

Resultater årssimulering

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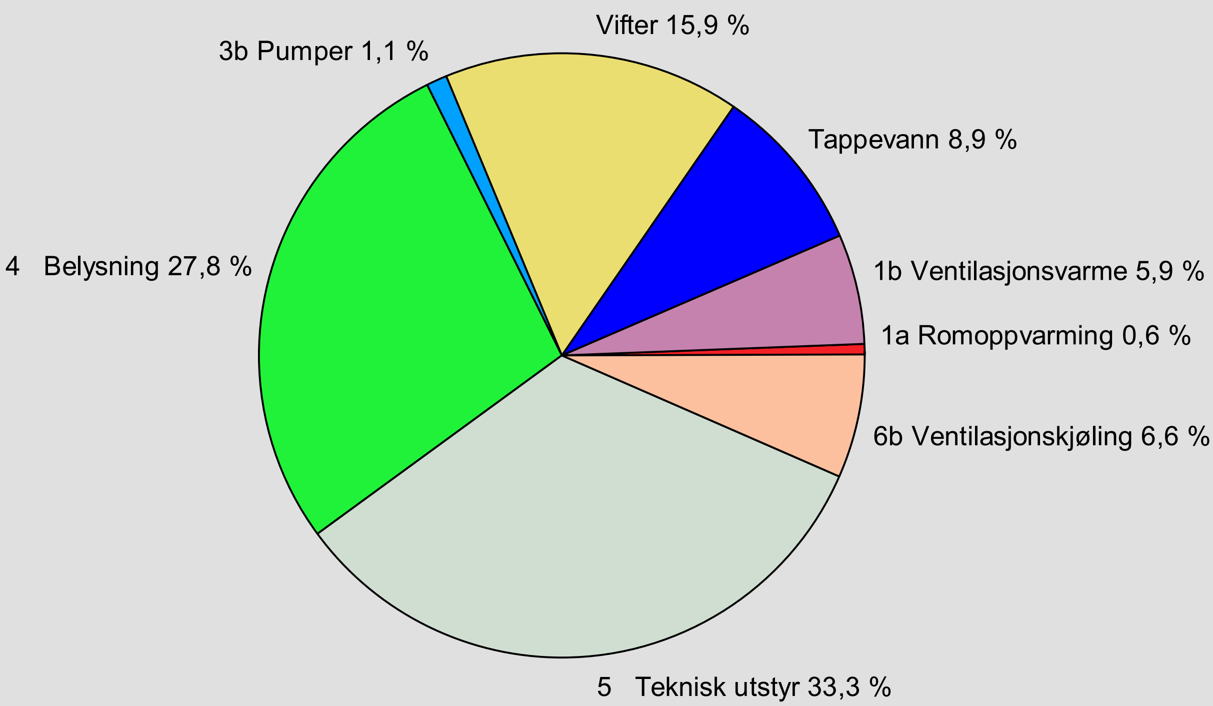
Årlig energibudsjett



1a Romoppvarming	10 kWh
1b Ventilasjonsvarme (varmebatterier)	104 kWh
2 Varmtvann (tappevann)	156 kWh
3a Vifter	279 kWh
3b Pumper	20 kWh
4 Belysning	489 kWh
5 Teknisk utstyr	586 kWh
6a Romkjøling	0 kWh
6b Ventilasjonskjøling (kjølebatterier)	116 kWh
Totalt netto energibehov, sum 1-6	1760 kWh

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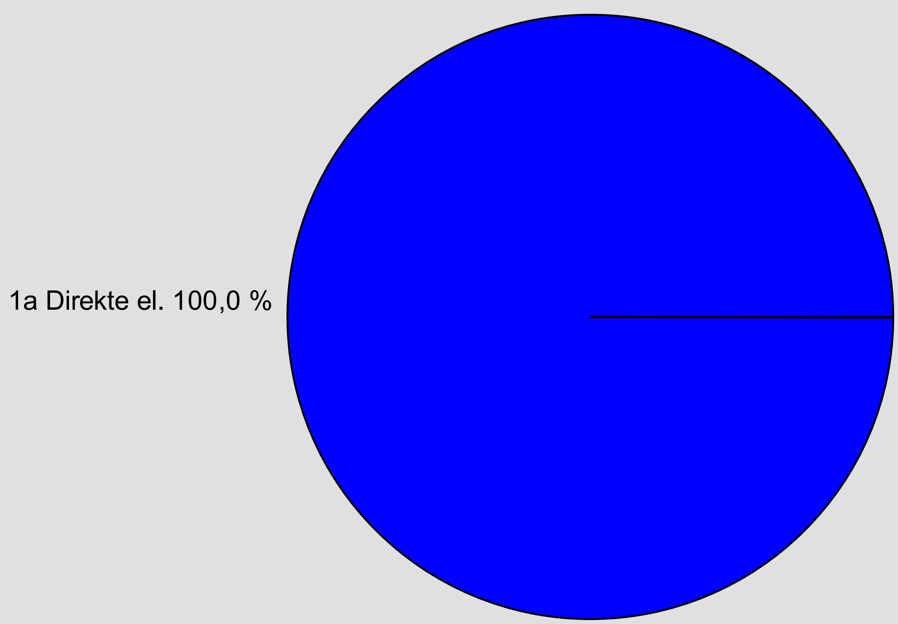
Levert energi til bygningen (beregnet)



1a Direkte el.	1720 kWh
1b El. Varmepumpe	0 kWh
1c El. solenergi	0 kWh
2 Olje	0 kWh
3 Gass	0 kWh
4 Fjernvarme	0 kWh
5 Biobrensel	0 kWh
6. Annen ()	0 kWh
Totalt levert energi, sum 1-6	1720 kWh

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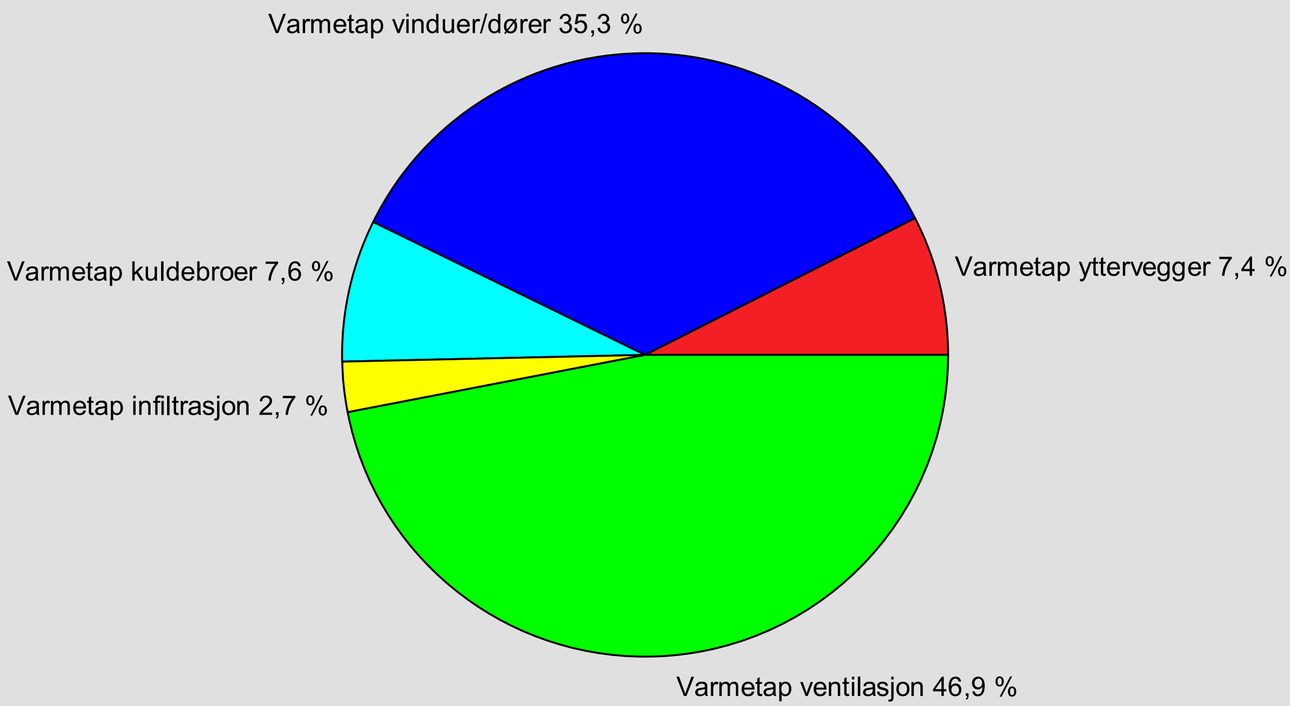
Varmetapsbudsjett (varmetapstall)



Varmetapstall yttervegger	0,03 W/m²K
Varmetapstall tak	0,00 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,00 W/m²K
Varmetapstall glass/vinduer/dører	0,14 W/m²K
Varmetapstall kuldebroer	0,03 W/m²K
Varmetapstall infiltrasjon	0,01 W/m²K
Varmetapstall ventilasjon	0,18 W/m²K
Totalt varmetapstall	0,39 W/m²K

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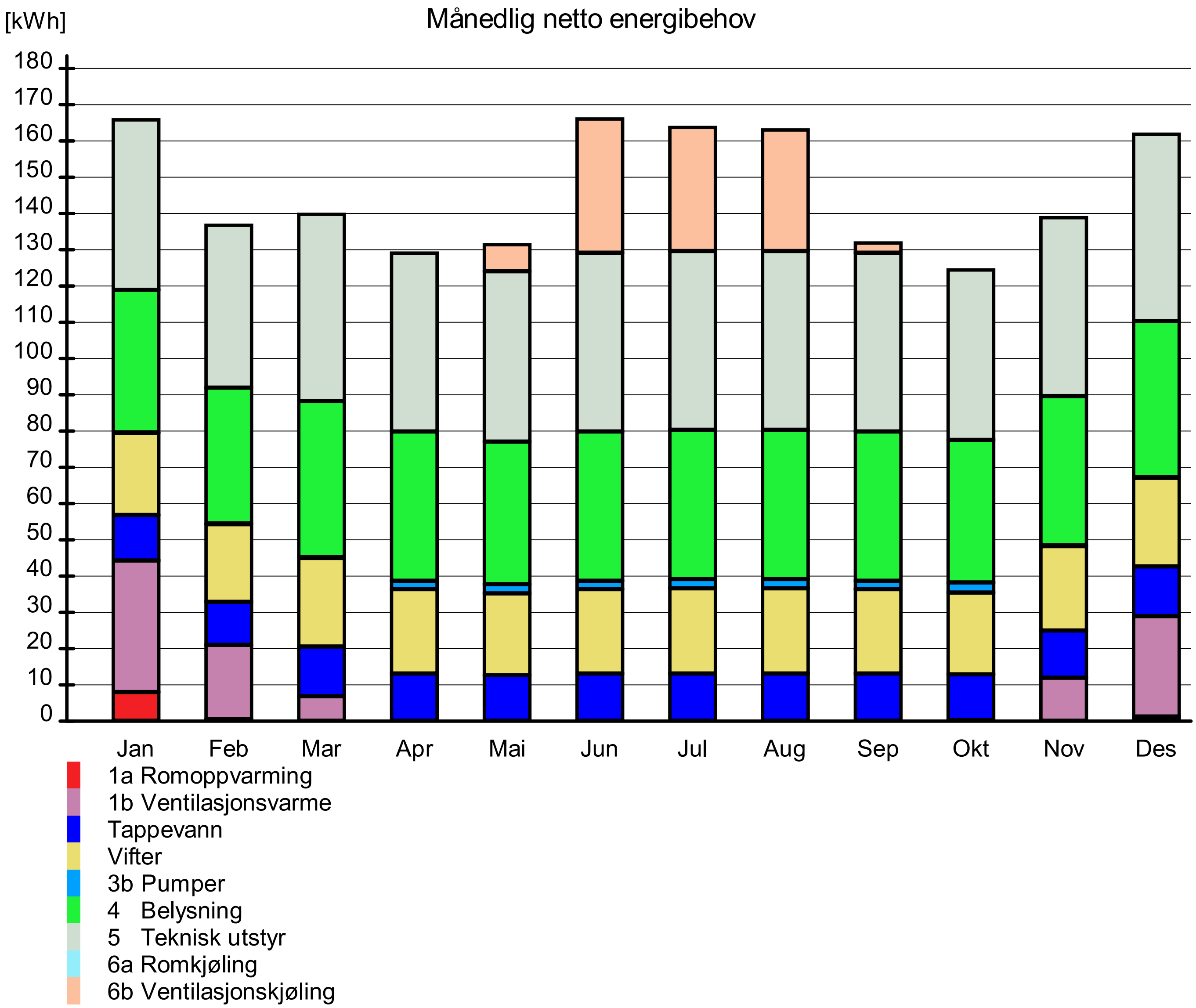

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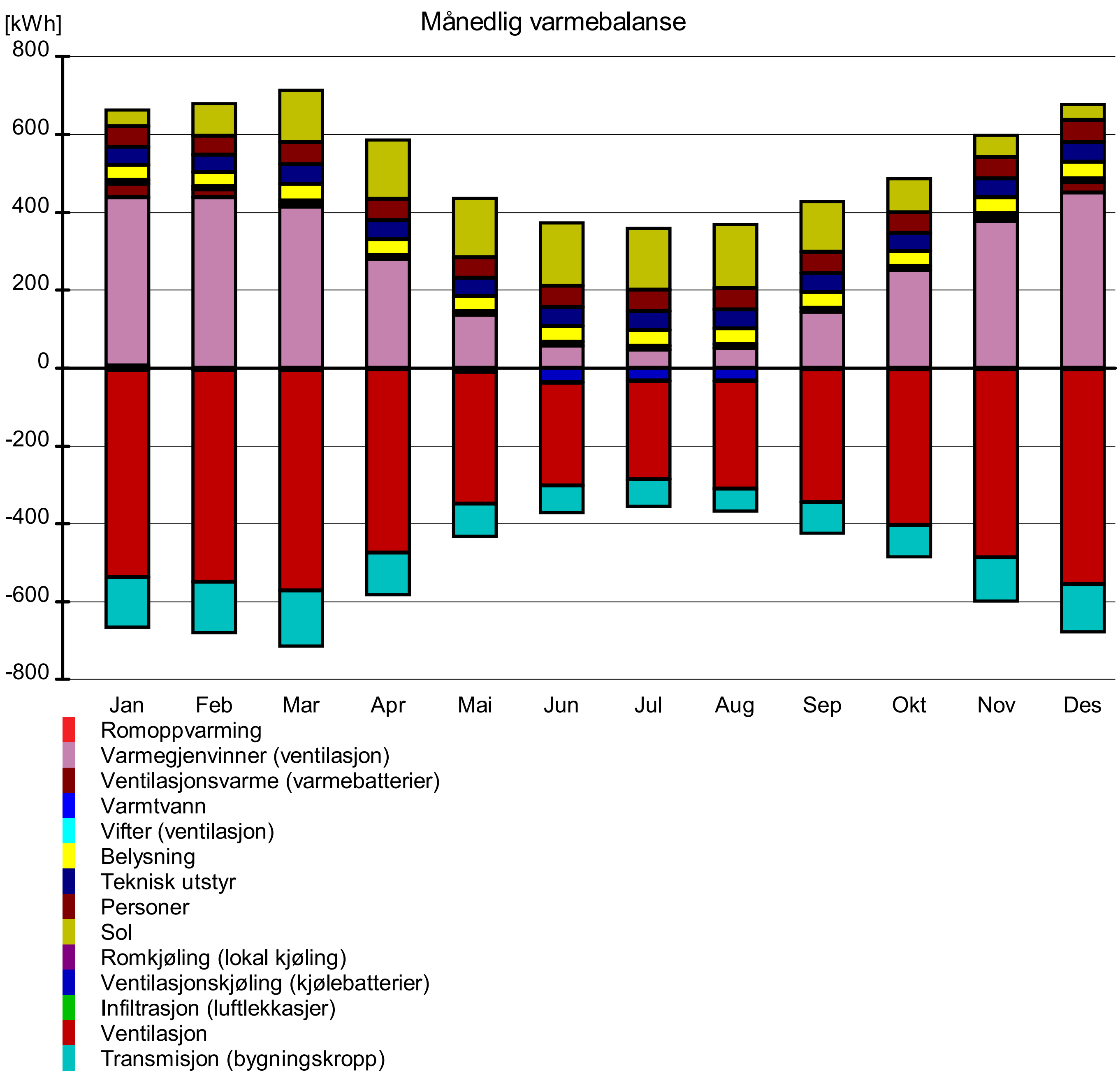

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Månedlige temperaturdata (lufttemperatur)						
Måned	Midlere ute	Maks. ute	Min. ute	Midlere sone	Maks. sone	Min. sone
Januar	-3,7 °C	10,7 °C	-22,0 °C	21,5 °C	26,9 °C	19,0 °C
Februar	-4,8 °C	10,2 °C	-24,7 °C	23,1 °C	28,8 °C	19,4 °C
Mars	-0,5 °C	14,1 °C	-17,7 °C	25,2 °C	31,3 °C	19,9 °C
April	4,8 °C	19,0 °C	-7,6 °C	27,8 °C	32,5 °C	25,4 °C
Mai	11,7 °C	26,4 °C	-1,0 °C	28,9 °C	33,3 °C	25,6 °C
Juni	16,5 °C	30,8 °C	3,5 °C	30,4 °C	33,9 °C	26,6 °C
Juli	17,5 °C	29,8 °C	8,0 °C	29,9 °C	34,4 °C	27,4 °C
August	16,9 °C	32,6 °C	5,2 °C	30,8 °C	34,9 °C	27,5 °C
September	11,5 °C	24,2 °C	-1,2 °C	28,2 °C	32,8 °C	25,0 °C
Oktober	6,4 °C	19,6 °C	-6,8 °C	25,8 °C	32,7 °C	21,1 °C
November	0,5 °C	12,9 °C	-14,7 °C	23,1 °C	27,9 °C	20,0 °C
Desember	-2,5 °C	11,2 °C	-20,9 °C	22,0 °C	25,7 °C	19,3 °C

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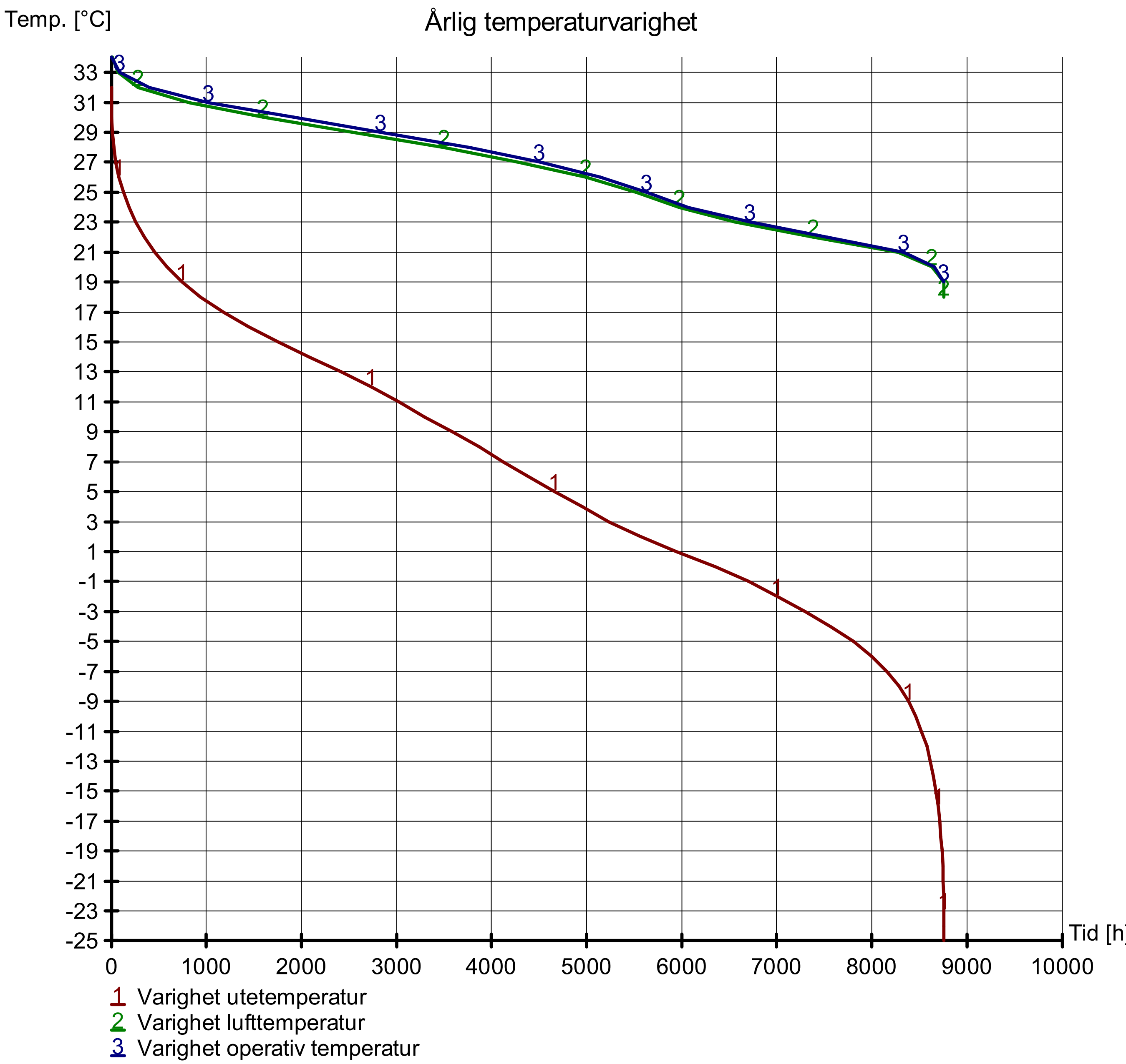

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Resultater årssimulering

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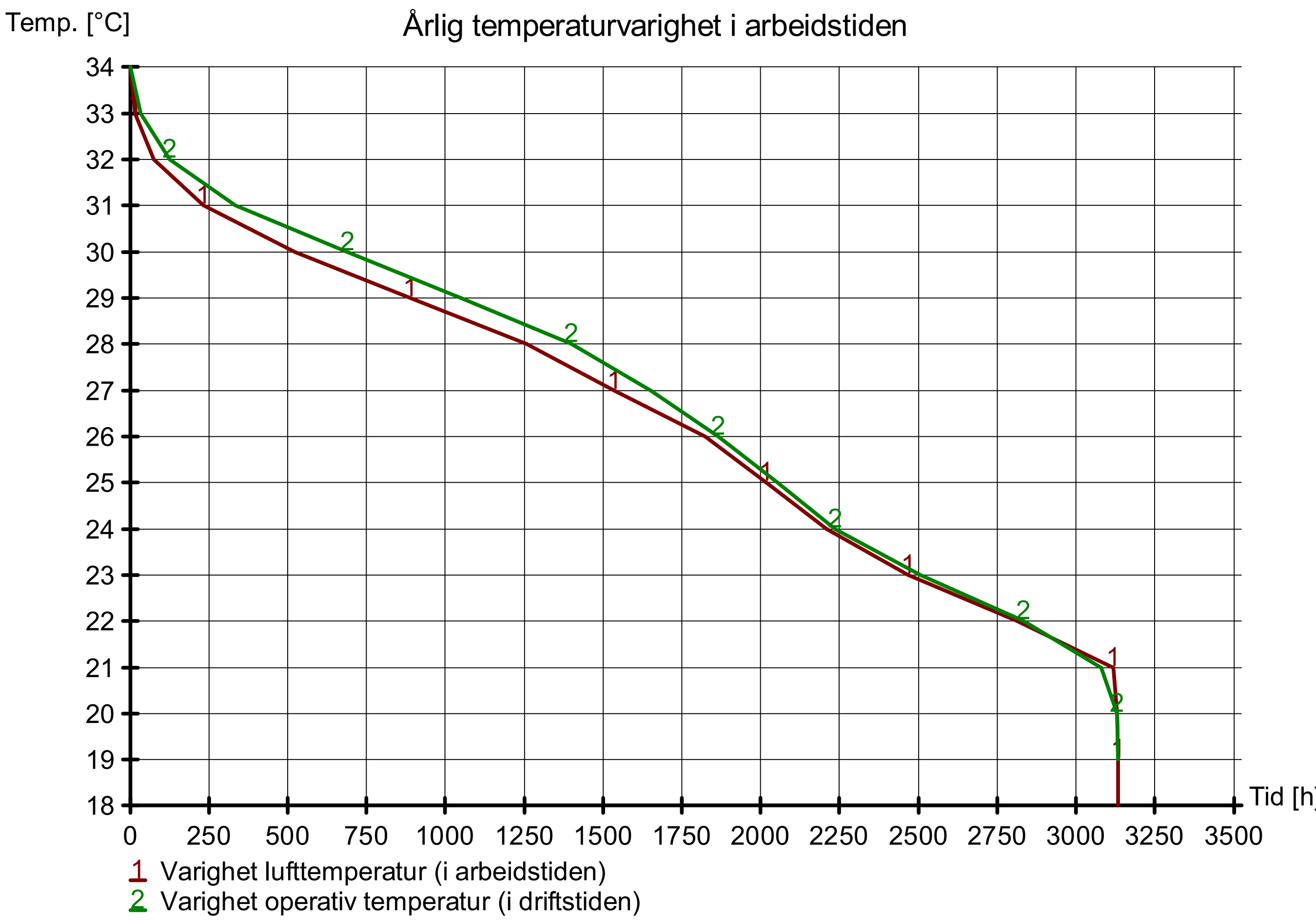

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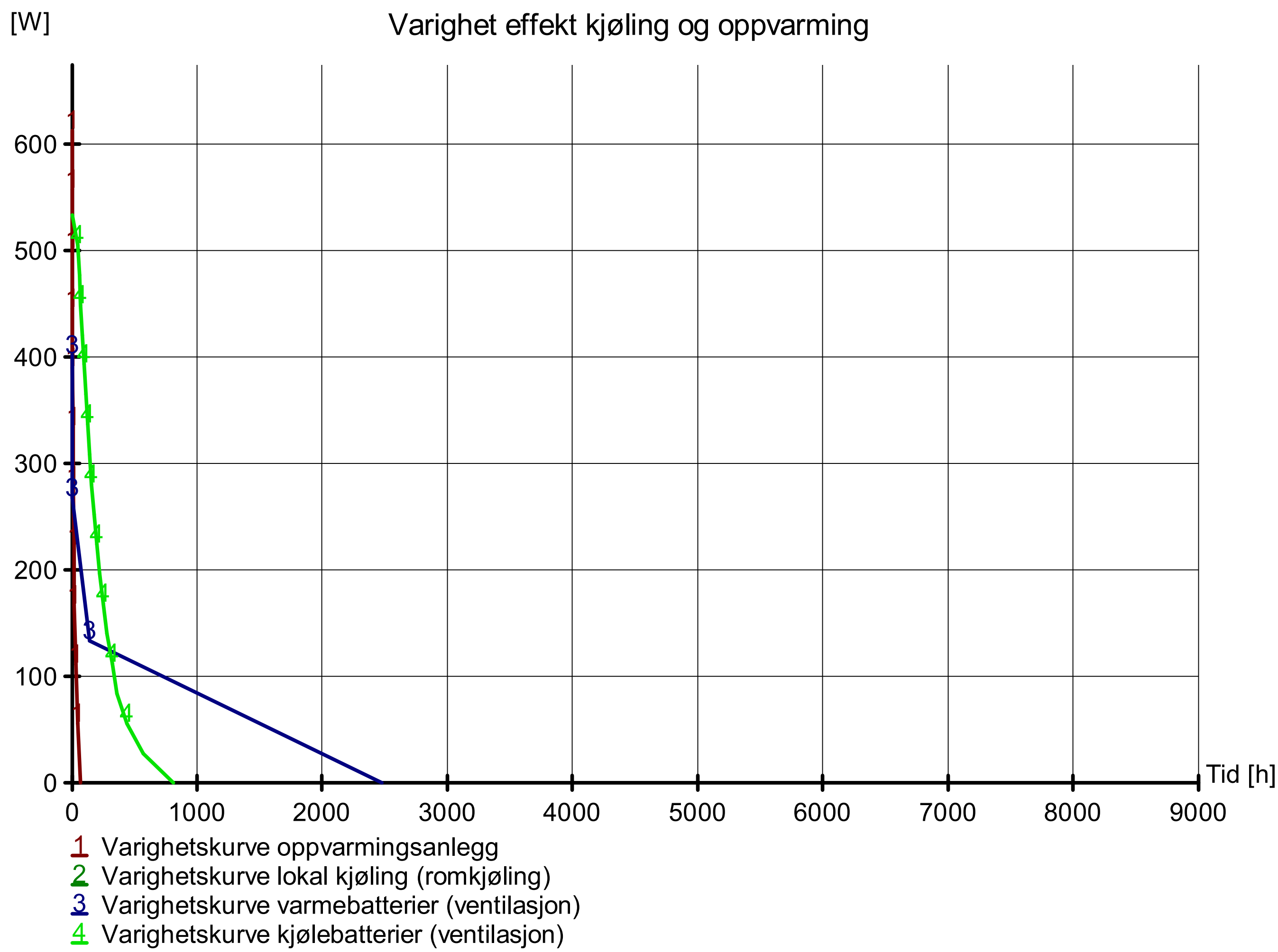

SIMIEN

Resultater årssimulering

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Sone: Test1

Dekningsgrad effekt/energi oppvarming

Effekt (dekning)	Dekningsgrad energibruk
0,6 W (90 %)	100 %
0,5 W (80 %)	100 %
0,5 W (70 %)	99 %
0,4 W (60 %)	99 %
0,3 W (50 %)	98 %
0,3 W (40 %)	97 %
0,2 W (30 %)	95 %
0,1 W (20 %)	89 %
0,1 W (10 %)	71 %

Dokumentasjon av sentrale inndata (1)

Beskrivelse	Verdi	Dokumentasjon
Areal yttervegger [m²]:	8	
Areal tak [m²]:	0	
Areal gulv [m²]:	0	
Areal vinduer og ytterdører [m²]:	5	
Oppvarmet bruksareal (BRA) [m²]:	31	
Oppvarmet luftvolum [m³]:	84	
U-verdi yttervegger [W/m²K]	0,12	
U-verdi tak [W/m²K]	0,00	
U-verdi gulv [W/m²K]	0,00	
U-verdi vinduer og ytterdører [W/m²K]	0,80	
Areal vinduer og dører delt på bruksareal [%]	17,3	
Normalisert kuldebroverdi [W/m²K]:	0,03	
Normalisert varmekapasitet [Wh/m²K]	86	
Lekkasjetall (n50) [1/h]:	0,60	
Temperaturvirkningsgr. varmegjenvinner [%]:	80	

Simuleringsnavn: annual
Tid/dato simulering: 23:10 2/6-2012
Programversjon: 5.007
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Inndatafil: C:\Users\Noora\Desktop\BASIC22.smi
Prosjekt: Office
Sone: Test1

Dokumentasjon av sentrale inndata (2)

Beskrivelse	Verdi	Dokumentasjon
Estimert virkningsgrad gjenvinner justert for frostsikring [%]:	80,0	
Spesifikk vifteeffekt (SFP) [kW/m^3/s]:	1,50	
Luftmengde i driftstiden [m^3/hm^2]	6,0	
Luftmengde utenfor driftstiden [m^3/hm^2]	1,0	
Systemvirkningsgrad oppvarmingsanlegg:	0,90	
Installert effekt romoppv. og varmebatt. [W/m^2]:	130	
Settpunkttemperatur for romoppvarming [°C]	20,0	
Systemeffektfaktor kjøling:	2,50	
Settpunkttemperatur for romkjøling [°C]	0,0	
Installert effekt romkjøling og kjølebatt. [W/m^2]:	17	
Spesifikk pumpeeffekt romoppvarming [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt romkjøling [kW/(l/s)]:	0,00	
Spesifikk pumpeeffekt varmebatteri [kW/(l/s)]:	0,50	
Spesifikk pumpeeffekt kjølebatteri [kW/(l/s)]:	0,60	
Driftstid oppvarming (timer)	12,0	

Dokumentasjon av sentrale inndata (3)

Beskrivelse	Verdi	Dokumentasjon
Driftstid kjøling (timer)	0,0	
Driftstid ventilasjon (timer)	12,0	
Driftstid belysning (timer)	12,0	
Driftstid utstyr (timer)	12,0	
Oppholdstid personer (timer)	12,0	
Effektbehov belysning i driftstiden [W/m^2]	5,00	
Varmetilskudd belysning i driftstiden [W/m^2]	5,00	
Effektbehov utstyr i driftstiden [W/m^2]	6,00	
Varmetilskudd utstyr i driftstiden [W/m^2]	6,00	
Effektbehov varmtvann på driftsdager [W/m^2]	0,80	
Varmetilskudd varmtvann i driftstiden [W/m^2]	0,00	
Varmetilskudd personer i oppholdstiden [W/m^2]	6,70	
Total solfaktor for vindu og solskjerming:	0,45	
Gjennomsnittlig karmfaktor vinduer:	0,20	
Solskjermingsfaktor horisont/bygningsutspring:	0,72	

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Inndata bygning

Beskrivelse	Verdi
Bygningskategori	Kontorbygg
Simuleringsansvarlig	
Kommentar	

Inndata klima

Beskrivelse	Verdi
Klimasted	Oslo
Breddegrad	59° 55'
Lengdegrad	10° 45'
Tidssone	GMT + 1
Årsmiddeltemperatur	6,3 °C
Midlere solstråling horisontal flate	110 W/m²
Midlere vindhastighet	2,2 m/s

Inndata energiforsyning

Beskrivelse	Verdi
1a Direkte el.	Systemvirkningsgrad: 0,90 Kjølefaktor: 2,50 Energipris: 0,80 kr/kWh CO2-utslipp: 100 g/kWh Andel romoppvarming: 100,0% Andel oppv, tappevann: 100,0% Andel varmebatteri: 100,0 % Andel kjølebatteri: 100,0 % Andel romkjøling: 100,0 % Andel el, spesifikt: 100,0 %

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Inndata ekspertverdier

Beskrivelse	Verdi
Konvektiv andel varmetilskudd belysning	0,30
Konvektiv andel varmetilsk. teknisk utstyr	0,50
Konvektiv andel varmetilsikudd personer	0,50
Konvektiv andel varmetilsikudd sol	0,50
Konvektiv varmoverføringskoeff. vegger	2,50
Konvektiv varmoverføringskoeff. himling	2,00
Konvektiv varmoverføringskoeff. gulv	3,00
Bypassfaktor kjølebatteri	0,25
Innv. varmemotstand på vinduruter	0,13
Midlere lufthastighet romluft	0,15
Turbulensintensitet romluft	25,00
Avstand fra vindu	0,60
Termisk konduktivitet akk. sjikt [W/m²K]:	20,00

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Sone: Test1

Inndata rom/sone

Beskrivelse	Verdi
Oppvarmet gulvareal	31,2 m²
Oppvarmet luftvolum	84,0 m³
Normalisert kuldebroverdi	0,03 W/K/m²
Varmekapasitet møbler/interiør	4,0 Wh/m² (Middels møblert rom)
Lekkasjetall (luftskifte v. 50pa)	0,60 ach
Skjerming i terrenget	Moderat skjerming
Fasadesituasjon	En eksponert fasade
Driftsdager i Januar	21
Driftsdager i Februar	20
Driftsdager i Mars	23
Driftsdager i April	22
Driftsdager i Mai	21
Driftsdager i Juni	22
Driftsdager i Juli	22
Driftsdager i August	22
Driftsdager i September	22
Driftsdager i Oktober	21
Driftsdager i November	22
Driftsdager i Desember	23

Inndata fasade/yttervegg

Beskrivelse	Verdi
Navn:	South facade (fasade)
Totalt areal	13,0 m²
Retning (0=Nord, 180=Sør)	180°
Innv. akkumulerende sjikt	Lett vegg Varmekapasitet 3,0 Wh/m²K
Konstruksjon	Egendefinert Uverdi: 0,12 W/m²K

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Inndata vinduselement	
Beskrivelse	Verdi
Navn:	window (Vindu(er) på South facade)
Antall vinduer	2
Høyde vindu(er)	1,50 m
Bredde vindu(er)	1,80 m
Karm-/ramme faktor	0,20
Total U-verdi (rute+karm/rammekonstr.)	0,80 W/m²K
Konstant (fast) solskjerming	Tre lag glass, hvorav to er energispareglass Total solfaktor: 0,45
Overheng	Dybde : 0,20 m Avstand fra vindu: 0,00 m
Vertikalt utspring til venstre	Dybde : 0,20 m Avstand fra vindu: 0,00 m
Vertikalt utspring til høyre	Dybde : 0,20 m Avstand fra vindu: 0,00 m

Inndata skillekonstruksjon	
Beskrivelse	Verdi
Navn:	interior walls (skillekonstruksjon)
Totalt areal	48,1 m²
Konstruksjonstype	Vegg
Innv. akkumulerende sjikt	Trepanel/treplate 15 mm Varmekapasitet 4,6 Wh/m²K
Vendt mot annen sone	Sone med lik temperatur

Simuleringsnavn: annual
Tid/dato simulering: 23:10 2/6-2012
Programversjon: 5.007
Brukernavn: Student
Firma: Undervisningslisens
Inndatafil: C:\Users\Noora\Desktop\BASIC22.smi
Prosjekt: Office
Sone: Test1

Inndata skillekonstruksjon

Beskrivelse	Verdi
Navn:	floor (skillekonstruksjon)
Totalt areal	31,2 m²
Konstruksjonstype	Gulv
Innv. akkumulerende sjikt	Parkett (14 mm) + 22 mm sponplate Varmekapasitet 11,2 Wh/m²K
Vendt mot annen sone	Sone med lik temperatur

Inndata skillekonstruksjon

Beskrivelse	Verdi
Navn:	ceiling (skillekonstruksjon)
Totalt areal	31,2 m²
Konstruksjonstype	Tak
Innv. akkumulerende sjikt	Betong (tykkelse over 100 mm) Varmekapasitet 63,0 Wh/m²K
Vendt mot annen sone	Sone med lik temperatur

Inndata belysning

Beskrivelse	Verdi
Navn:	internal gains (internlaster, belysning)
Effekt/Varmetilskudd belysning	I driftstiden; Effekt: 5,0 W/m²; Varmetilskudd: 100 % Utenfor driftstiden; Effekt: 0,0 W/m²; Varmetilskudd: 100 % På helg/feriedager; Effekt: 0,0 W/m²; Varmetilskudd: 100 % Antall timer drift pr døgn: 12:00

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Inndata teknisk utstyr (internlast)	
Beskrivelse	Verdi
Navn:	internal gains (internlaster, teknisk utstyr)
Effekt/Varmetilskudd teknisk utstyr	I driftstiden; Effekt: 6,0 W/m²; Varmetilskudd: 100 % Utenfor driftstiden; Effekt: 0,0 W/m²; Varmetilskudd: 100 % På helg/feriedager; Effekt: 0,0 W/m²; Varmetilskudd: 100 % Antall timer drift pr døgn: 12:00

Inndata oppvarming av tappevann	
Beskrivelse	Verdi
Navn:	internal gains (internlaster, tappevann)
Tappevann	Driftsdag; Midlere effekt: 0,8 W/m²; Varmetilskudd: 0 %; Vanndamp: 0,0 g/m² Helg/feriedag: Midlere effekt: 0,0 W/m²; Varmetilskudd: 0 %; ; Vanndamp: 0,0 g/m²

Inndata varmetilskudd personer (internlast)	
Beskrivelse	Verdi
Navn:	internal gains (internlaster, varmetilskudd personer)
Varmetilskudd personer	I arbeidstiden: 6,7 W/m² Utenfor arbeidstiden: 0,0 W/m² Ferie/helgedager: 0,0 W/m² Antall arbeidstimer: 12:00

SIMIEN

Resultater årssimulering

Simuleringsnavn: annual
Tid/dato simulering: 23:10 2/6-2012
Programversjon: 5.007
Brukernavn: Student
Firma: Undervisningslisens
Inndatafil: C:\Users\Noora\Desktop\BASIC22.smi
Prosjekt: Office
Sone: Test1

Inndata VAV-Ventilasjon

Beskrivelse	Verdi
Navn:	vav ventilation (VAV)
Systemtype	Prøver å holde romtemperaturen under 23.0 °C
Luftmengde	Maks.: 6.0 $m^3/h/m^2$; Min.: 6.0 $m^3/h/m^2$; Utenfor: 1.0 $m^3/h/m^2$; Helg: 1.0 $m^3/h/m^2$
Tilluftstemperatur	19.0 °C
Annen tilluftstemperatur sommer	Nei
Driftstid	Timer med drift: 12:00
Varmebatteri	Ja Maks. kapasitet: 80 W/m^2
Vannbåren distribusjon til varmebatteri	Delta-T: 30.0 °C SPP: 0.5 kW/(l/s)
Kjølebatteri	 Maks. kapasitet: 17 W/m^2
Vannbåren distribusjon til kjølebatteri	Delta-T: 6.0 °C SPP: 0.6 kW/(l/s)
Varmegjenvinner	Ja, temperaturvirkningsgrad: 0.80
Vifter	Plassering tilluftsvifte: Etter gjenvinner Plassering avtrekksvifte: Etter gjenvinner
SFP-faktor vifter	1.5 $kW/m^3/s$

Inndata oppvarming

Beskrivelse	Verdi
Navn:	space heating (oppvarming)
Settpunkttemperatur i driftstid	21,0 °C
Settpunkttemperatur utenfor driftstiden	19,0 °C
Maks. kapasitet	50 W/m^2
Konvektiv andel oppvarming	0,50
Driftstid	12:00 timer drift pr døgn
Vannbårent oppvarmingsanlegg	Nei