Daylight and thermal comfort in a residential passive house

A simulations study based on environmental classification systems

Master of Science Thesis in the Master's Program Structural Engineering and Building Performance Design

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Cover:
Four different versions of Kuben, the object of this thesis. From top left going clockwise: Photo of a Kuben-building, however without the carport roof (Photo: Emelie Johansson, 2012). The simulation model used for calculations of daylight factor in Velux Daylight Visualizer. The architect's rendering of Kuben (MAAB & Jansson, 2012). The simulation model used for calculations in IDA ICE 4.21.

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ABSTRACT

Construction of passive houses has increased in recent years. The aim of passive houses has traditionally been energy efficiency, which means that the indoor climate faces a risk of being overlooked as these tend to collide. One of these conflicts is between daylight, heating demand and summer thermal comfort. As the use of environmental classification systems increases, indoor climate conditions are emphasized. This requires careful planning and a wide perspective.

This master thesis investigates how indoor climate and energy usage is affected by the choice of windows and shading devices in a passive house. This is particularly interesting since cooling systems rarely are available which lower temperatures during summers, and daylight quality is seldom verified in residential houses. The results were found by simulations of NCC's passive house “Kuben. Among the tested solutions are different types of glass, paints, inclination of window niches, window sizes, and internal and external shading devices. The results of these simulations were compared with passive house criteria and Miljöbyggnad; a growing Swedish environmental classification system based on 15 so-called indicators. Six of these are affected by the window and shading and included in this report.

Different solutions were developed where Kuben retains its passive house properties while achieving the highest level in Miljöbyggnad for the studied indicators. This study shows that by choosing windows with a higher light transmission, more daylight and reduced energy usage can be achieved. Increasing the window area can have the same affect. Both these actions increase the need of shading, where external awnings are the most effective means. Optionally, the building can meet the requirements by increasing the roof overhang and by adding internal solar shading.

All window properties should be considered in early stages to ensure a good final result. It is important to consider the window properties' effect on the need for solar shading. Preferably this process is done by first determining a level of average transmission losses to meet power demands, followed by daylight simulations which affect the choice of windows, which determines the required thickness of insulation of the other parts of the building in order to reach the desired average. Finally, the need for sun protection can be found for the current window size and window attribute.

Key words: windows, shading, g-value, solar heat load, Miljöbyggnad, environmental classification systems, passive house, daylight, daylight factor, solar radiation.

Dagsljus och inomhusklimat i ett passivhus
En simuleringsstudie av ett enfamiljshus baserat på miljöklassningssystem

Examensarbete inom Structural Engineering and Building Performance Design

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SAMMANFATTNING

Byggandet av passivhus har ökat markant de senaste åren. Fokus i passivhus har traditionellt varit energi, och innemiljö riskerar då att bli eftersatt eftersom dessa har en tendens att vara motstridiga. En av de större konflikterna är förhållandet mellan ljusinsläpp, energiprestanda och övertemperaturer sommartid. I och med ökat användande av miljöcertifieringssystem tas innemiljö nu upp som krav, vilket i sin tur ställer krav på projektering och bredare perspektiv.

Denna masteruppstats behandlar de konsekvenser fönster och dess skuggning har för innemiljö och energianvändning i passivhus. Detta är särskilt intressant eftersom kylmaskiner sällan finns som kan sänka inomhustemperaturer sommartid och då dagsljus sällan kontrollerats i bostäder. För att finna resultat har simuleringar gjorts av NCCs typhus Kuben. Bland de testade lösningarna finns olika glastyper, väggfärger, vinklar på fönstersmygar, fönsterstorlekar, inre och yttre rörliga solskydd samt fasta solskydd. Resultaten av dessa simuleringar har jämförts med passivhuskriterier och med Miljöbyggnad. Miljöbyggnad är ett växande helsvenskt miljöklassificeringssystem som ger byggnader betyg utifrån 15 så kallade indikatorer, varav sex påverkas av fönster och skuggning och behandlas i denna rapport.

Olika lösningar har tagits fram som innebär att Kuben både behåller sina passivhusegenskaper och uppnår det högsta betyget i Miljöbyggnad för de undersökta indikatorerna. Lösningarna kan utföras på olika sätt; det går att istället för de monterade fönstren välja fönsterglas med högre ljus transmittans, vilket släpper in mer ljus och minskar energiförbrukningen på grund av ökad solinstrålning, eller att öka fönsterarean. Både dessa åtgärder ställer krav på skuggning för att inte få övertemperaturer, där utvändiga markiser är den effektivaste metoden. Alternativt går det att klara kraven genom att öka takutsprånget samt lägga till invändiga solskydd.

Fönstrets alla egenskaper bör beaktas i tidiga skeden för att kunna säkerställa ett gott slutresultat. Att fönsteregenskaperna påverkar behovet av solskydd är då viktigt att ha i åtanke. Företrädelsevis kan denna process gå till genom att först bestämma en nivå för genomsnittliga transmissionsförluster för att uppfylla effektkrav, följa upp med dagsljussimuleringar vilket påverkar fönsterval, och därefter ta fram lämplig isolerings-tjocklek i övriga konstruktioner för att nå det genomsnittliga U-värdet. Slutligen fastställs behoven av solskydd utifrån det valda fönstrets storlek och egenskaper.

Nyckelord: fönster, skuggning, g-värde, solvärmelast, Miljöbyggnad, miljöklassning, passivhus, dagsljus, dagsljusfaktor, solinstrålning.

Contents

Preface

This master's thesis was performed as a part of the MSc Programme Structural Engineering and Building Performance Design, Chalmers University of Technology. It was conducted at NCC Teknik in Göteborg from January to June 2012.

The topic was introduced by NCC Teknik and originates in the increased knowledge demand due to expansion of environmental classification systems. In this study, indoor climate and daylight simulations were performed for residential buildings, which have been neglected in comparison to offices.

The project was supervised by Paula Wahlgren, PhD at the Division of Building Technology, Chalmers University of Technology, and by Christian Johansson and Anders Ljungberg at NCC Teknik, Göteborg. Thank you for all your assistance and advice along the way!

We would also like to express gratitude to all other personnel, at NCC and sub-contractors, involved in our thesis for being supportive and providing us with required material. EQUA Simulations AB is also appreciated for the licence to use their software, IDA ICE 4.21, free of charge.

Finally, thanks to our family and friends for your support and for putting up with six months of discussions on window glass and blinds.

Göteborg, June 2012

Magnus Heier

Magnus Österbring

Notations

Roman case letters

A_{temp}	Heated area. [m²]
A_{glass}	Glass area. [m²]
A_{room}	Room area. [m²]
A_{window}	Window area, including frame. [m²]
g (-value)	Transmitted energy. Explained in Chapter 5. [-]
g_{system}	g-value for a system containing glass and/or shading devices [-]
U (-value)	Heat transfer coefficient, describes how a building element transports heat. [W/m²·K]
U_g	U-value for glass. [W/m²·K]
U_m	Mean U-value. [W/m²·K]

Abbreviations and acronyms

BBR	"Boverkets Byggregler". A publication by Boverket which regulates construction in Sweden.
clo	Clothing index. A unit for measurement of clothing amount, developed for assessing thermal comfort.
DVUT	"Dimensionerande vinter-utetemperatur". Explained in Chapter 2. [°C]
FEBY	"Forum för energieffektivt byggande". This organization sets demands for passive houses in Sweden.
HVAC	"Heating Ventilation and Air Conditioning".
LT	"Light Transmittance". [%]
met	Metabolic rate. A unit for measurement of activity level, developed for assessing thermal comfort.
PMV	"Predicted Mean Vote". Explained in Chapter 4. [%]
PPD	"Predicted Percentage Dissatisfied". Explained in Chapter 3 and 4. [%]
ST	"Solar Transmittance". Explained in Chapter 4. [%]
SHGC	"Solar Heat Gain Coefficient". Another name for g-value. [-]
SVEBY	"Standardisera och verifiera energiprestanda i byggnader". A program standardizing data for energy calculations in Swedish buildings.
SVF	Solar heat factor. Defined by Miljöbyggnad and explained in Chapter 6. [-]
SVL	Solar heat load. Defined by Miljöbyggnad and explained in Chapter 6. [W/m²]
TST	"Total Solar Transmittance". Another name for g-value. [-]

1 INTRODUCTION

In this chapter, the background of this thesis as well as its purpose and method are explained. Limitations are set, and finally four questions which will be answered are formulated.

1.1 Background

During the last couple of years, buildings using passive house technology have become more and more common. The main purpose of these buildings is, naturally, to save energy by utilizing energy from the sun and minimizing heat losses. The consequence of the two objectives is contradictory in terms of glass area. Windows insulate less than a solid wall and the glass area needs to be minimized to keep energy consumption low. On the other hand, having a small window area also shuts the sun's rays out. Therefore, optimizing the window area and the window to floor area ratio are essential in low-energy housing.

The amount of windows also affect indoor climate in different ways; natural light indoors contribute to wellbeing, but large windows can also cause problems due to thermal radiation from warm or cold glass surfaces or from causing over-temperatures during the summer. It is therefore very important evaluate the indoor climate by performing simulations for this type of highly insulated houses, to maintain acceptable temperatures during both winter and summer.

Office buildings, with high internal loads during the day due to large glass areas and large internal gains, have been the subject of several studies in this field. This is mostly because of the additional cost for cooling and the lowered productivity of employees if indoor climate requirements are not sufficiently met. Residential buildings have been somewhat neglected by studies, but are not necessarily less interesting. The energy consumption during 2010 for heating and hot water in residential housing in Sweden was 63.4 TWh (Energimyndigheten, 2011) compared to 22.4 TWh for facilities, not including industry. Thus the need for energy optimization is great for this area as well, as well as possible problems from having a poor indoor climate where humans live and sleep.

The need for a well-balanced amount of windows has been stressed by most environmental classification systems, including the Swedish “Miljöbyggnad”. When construction companies certify buildings, the customer and user receive a guarantee that the building fulfills the system's requirements, which is a competitive advantage. Therefore, it is of interest from both the consumer's and builder's point of view to find out how the windows and their shading affect the energy consumption and indoor climate, and if an optimization is possible.

1.2 Purpose

The purpose of this master thesis is to find solutions on how the best combination of low energy usage and good indoor climate is attained in a residential passive house, mainly relating to the properties of windows and shading. By doing this investigation, tools or general recommendations can hopefully be given to companies or persons developing very low-energy buildings.

1.3 Method

The evaluation is be done by simulating different cases of window setups in a building. This includes the following; shading of windows, blinds, glass properties (e.g. reflecting films), amount of glass etc. All these parameters are studied with regard to indoor climate and energy. The work is based on existing passive houses and be compared to some of the indicators in Miljöbyggnad, a Swedish environmental classification system for buildings, as well as maintain the passive house requirements.

Calculations and simulations are carried out using several programs including IDA ICE 4.21 for energy and indoor climate, Parasol v6.6 for calculation of solar shading and VELUX Daylight Visualizer 2.6 for daylight simulations.

A building has been provided through NCC Construction Sweden's (abbreviated NCC from now on) project in Vallda Heberg outside of Kungsbacka, the currently largest passive house development in Sweden. The object is a one-family home of 140 m^2 called Kuben (the cube). This building is used in the various numerical simulations, and results from alterations compared to its original performance.

1.4 Limitations

The master thesis will be limited to Swedish residential houses only, and a reasonable selection of the different types of possible solar shading will be made after literature studies. Because of the type of building chosen, any effect of cooling will be omitted since it is fairly uncommon in residences. The simulations are made for passive houses in Gothenburg.

1.5 Questions

These questions will be answered in the scope of this thesis:

- How does the type of windows and solar shading affect the energy usage of a passive house?
- How does the type of windows and solar shading affect the indoor climate conditions of a passive house?
- How can window to floor area-ratio be optimized with regard to energy and indoor climate conditions (including daylight)?
- What factors or connections (glass type, area, solar shading and orientation) can be found to simplify decision making when planning windows in early stages of construction projects?

2 PASSIVE HOUSE TECHNOLOGY

This chapter will cover the development of passive houses in Sweden, and the theory behind their construction. The building chosen for this thesis is a passive house, since this method is continuing to grow more popular and due to the clear definition of what is allowed to be called a passive house. There are several different subtypes of the concept low energy buildings, passive houses being one of these.

2.1 Definition

The definition *Passive house* was developed during the late 80s by collaboration between the Swedish professor Bo Adamson and professor Wolfgang Feist from Germany. The original purpose is still valid; to lower energy consumption and to build sustainable housing. The original definition by Feist is:

"A passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems"
(Passiv Haus institute 2012, after Adamson 1987 and Feist 1988)

This is similar to the current definition, updated with modern methods and more exact formulations:

"A passive house is a building in which thermal comfort [EN ISO 7730] can be guaranteed by post-heating or post-cooling the fresh-air mass flow required for a good indoor quality [DIN 1946]" (Feist, 2006)

The most important factors to consider in a building to achieve passive house properties are however almost unchanged, only the methods to accomplish them have changed. The following are common ways of accomplishing passive houses:

- Improve insulation in the building envelope, including windows
- Utilize energy from the sun for heating during the winter
- Shade the sun during summer to avoid over-temperatures
- Increase thermal mass, in order to dampen indoor temperature changes
- Compact building in order to lower building envelope/heated area ratio
- Place appropriate windows in the different directions
- Harness energy from appliances and inhabitants
- Build air-tight building to reduce losses of heated air
- Use mechanical ventilation with a heat exchanger
  (Passivhuscentrum, 2010)

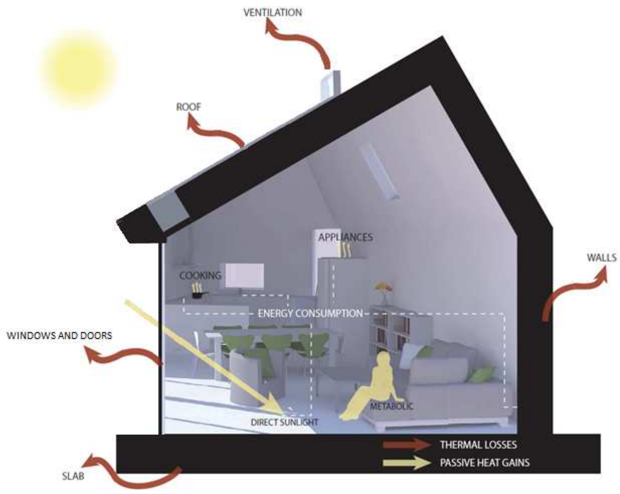


Figure 2.1. Important areas to consider in a passive house

The specific levels for energy consumption, air flows, and installed power varies between countries. The demands for Swedish passive houses are set in FEBY[1], "Forum för Energieffektiva Byggnader", run by "Sveriges centrum för nollenergihus" [2] which is a group appointed by the Department of Energy. Among the members is Hans Eek, architect, who kept on developing the passive house-concept with Feist after Adamson's retirement and co-founded Passivhuscentrum in Sweden, an organization devoted to spreading the idea of passive house technology.

2.2 Swedish demands

Sweden is divided into three geographical zones with different levels of requirements, seen in Figure 2.2 (Boverket, 2011).

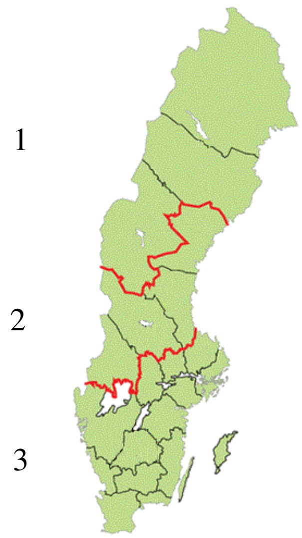


Figure 2.2. Sweden's climate zones according to BBR.

The three following tables contain the demands from the most recent FEBY publication, January 2012, which a building has to fulfill in order to be classified as a passive house in Sweden (Sveriges centrum för nollenergihus, 2012):

[1]English translation: Forum for Energy Efficient Buildings
[2]English translation: The Swedish center for zero-energy housing

- Maximum heat loss number (VFT[3]) at dimensioning winter outdoor temperature (DVUT[4]) for Sweden's three different climate zones according to Boverkets Byggregler (BBR[5]). For buildings smaller than 400m², an additional 2 W/m²A_{temp} is added. The DVUT is a calculated temperature depending on location and the building's heat storage capacity. Examples on DVUT can be found in Appendix E.

Table 2.1. Maximum heat loss number for passive houses in the different zones of Sweden.

[W/m²A_{temp}]	Zone 1	Zone 2	Zone 3
VFT	17	16	15

- Maximum delivered energy, calculated at an indoor temperature of 21°C for the three climate zones. Requirements are different depending on the source of the energy. Electrical energy for heating of buildings is considered less sustainable than district heating. This is the reason for the tougher demands on buildings with this heating method.

Table 2.2. Maximum delivered energy for passive houses with district heating in the different zones of Sweden

[kWh/m²A_{temp}]	Zone 1	Zone 2	Zone 3
District heating	58	54	50
Electrically heated	29	27	25

- Maximum weighed delivered energy, which is the sum of all used energy with regard to its energy form factor. All electrical energy is multiplied by 2.5.

Table 2.3. Maximum weighed energy for passive houses in the different zones of Sweden

[W/m²A_{temp}]	Zone 1	Zone 2	Zone 3
Weighed energy	73	69	65

[3] In Swedish: Värmeförlust-tal
[4] In Swedish: Dimensionerande vinterutetemperatur
[5] English translation: Boverket's Building Regulations

2.2.1 Previous demands

The reference building was developed and built using previous demands, from FEBY 2009. Therefore, these are presented in the following three tables (Sveriges centrum för nollenergihus, 2009):

- The required installed power at dimensioning winter outdoor temperature (DVUT) for the three different climate zones according to BBR: For buildings smaller than 200m², an additional 2 W/m²$A_{temp+garage}$ can be added.

Table 2.4. Maximum required power for passive houses in the different zones of Sweden, according to previous requirements

[W/m²$A_{temp+garage}$]	Zone 1	Zone 2	Zone 3
Power	12	11	10

- Weighed delivered energy, which is the sum of all used energy with regard to its energy form factor. All electrical energy is multiplied by 2 and all sustainable energy, for example by solar panels or windmills, is multiplied by 0.

Table 2.5. Maximum weighed energy for passive houses in the different zones of Sweden, according to previous requirements

[W/m²A_{temp}]	Zone 1	Zone 2	Zone 3
Weighed energy	68	64	60

2.2.2 Differences FEBY 2009 and FEBY 2012

Some major changes include indoor temperature which now is calculated at 21 degrees C instead of 20. In general the data used for calculations have been harmonized with SVEBY, a Swedish program working to streamline input data for energy calculations, to reduce the amount of calculations that needs to be done. Calculation of solar heat load has been added, as overheating during summer was found to be a common problem. Demands regarding windows have changed following technical development and stricter air-leakage demand for smaller buildings have been introduced. Comparing the two versions of FEBY can be misleading as it might seem as the demands have been eased. The changes in calculation procedure have in general left actual demands unchanged.

2.2.3 Other methods of classifications

Many other classifications and terminology for low-energy buildings exist such as near-zero and plus energy buildings. This thesis focuses on the Swedish passive house standard as the building was developed with regard to it.

3 LIGHT

This chapter describes the physical properties of light, and how light is perceived by humans. Following is a description of how health and comfort relates to daylight and the chapter is concluded by describing some of the common ways to measure quality and quantity of light.

3.1 Physical properties

When radiation from the sun, or any light, reaches a glass surface the energy is divided in three ways. One part of the radiation passes through the glass; some light is reflected and the last part is absorbed and transformed to heat. The ratio of light able to pass the glass is called transmittance.

The sun radiates in a wide spectrum, light reaching the earth's surface varies between 300 and 2500 nm, and the light visible to the human eye ranges from 380 to 780 nm. Thus daylight is only a part of the sun's radiation but constitutes about 50% of the energy contained in its rays. Therefore, it has impact on both the daylight and the thermal load placed on the building (Bülow-Hübe & Lundgren, 2005).

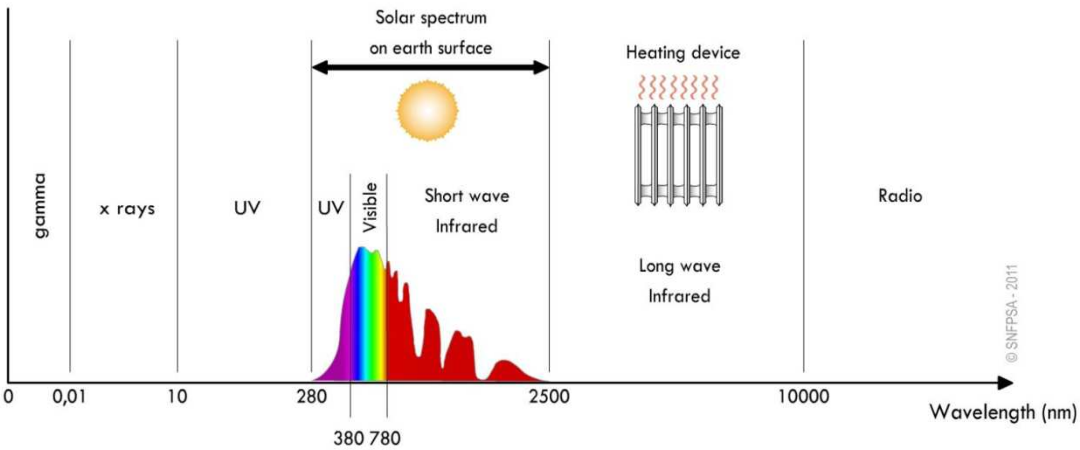


Figure 3.1. The electromagnetic radiation spectrum. The solar spectrum and the visible range can be seen in the middle (ES-SO, 2012).

3.2 Human perception of light

When light reaches the human eye it first passes through the transparent protective layer of the cornea, see Figure 3.2. The second part of this process involves the iris. The iris is a muscular ring which reacts to the light by expanding or contracting, to control the amount of light entering the eye. After the light has been adjusted in intensity it is being focused, which is done by the eye's lens. The lens alters its shape to adjust the eye's focal length. The combined effect of this is a sharp visual image on the retina which is located at the back of the eyeball. Here, the rods and cones create nerve impulses in response to the light which is then processed by the brain (Ander, 2003). The human vision system perceives the luminance (brightness) of objects but is limited by the range of luminance it can detect. The human eye can process information in a spectrum ranging from about 1 up to 100000 lux.

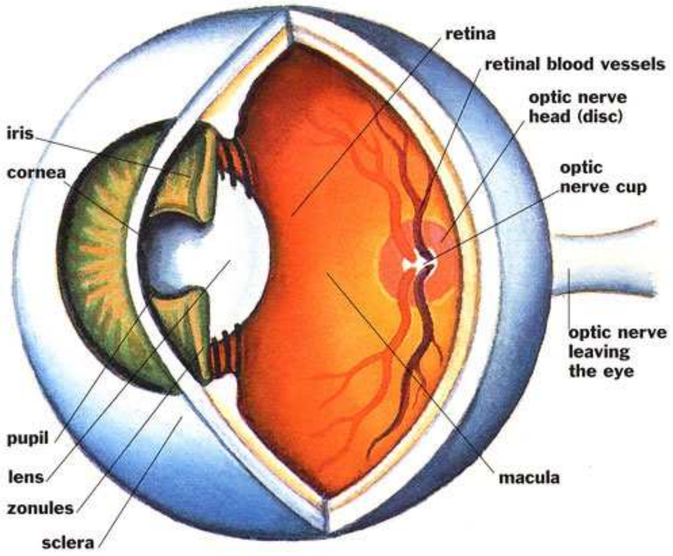


Figure 3.2. The human eye. The iris can adapt the eye to different light conditions by constricting or widening. Therefore, humans are better at recognizing contrast in illumination levels than absolute values (renault-ok, 2012).

The human eye has several ways to adapt to different scenarios. The adaption process has three different parts. As stated above the first response by the eye is to expand or constrict the iris in response to a change in brightness. The iris response time is different depending on if the brightness is increasing or decreasing. It constricts to light five times faster than it expands when dimmer illumination is experienced. The second response is done by the lens as mentioned above. The third and last way this adaption process works is by photochemical adaption. This involves the bleaching and regeneration of the pigments in rods and cones. This takes place under more extreme ranges of illumination. Note that this process, as the response by the iris, differs depending if going toward a brighter or dimmer situation. As with the iris, the adaption process is much slower going to a dimmer situation. The human eye has great potential to adapt to different light settings. This also leads to the fact that it is not proficient at measuring absolute illumination levels. This is not only due to the adaptation process but also a result from the brain automatically comparing relative brightness levels. The result is that an indoor space might seem poorly lit when coming from the outside during a sunny day (Ander, 2003). The result of this process is that the perceptible range of luminance spans over three to four orders of magnitude. This means that for brightness levels below this range no luminous sensation will be experienced. For brightness levels above this range glare sensation will occur (Baker & Steemers, 2002).

3.3 Light and human health

Human exposure to light has a multitude of effects on the body. The skin reacts to exposure to light, in particular to ultraviolet (UV) radiation. This results in an increased production of vitamin D and accompanying absorption of calcium (Ander, 2003). Bright light is needed during mornings to enable the pineal gland, which receives information on light levels from the retina, to cease its production of melatonin. The gland then regulates several important functions through the release of melatonin. The effect of melatonin is to make us sleepy, mainly by reducing stress levels and also to decrease the activity of other bodily functions that might interfere with sleep. Because the pineal gland reacts to strong light, especially during the morning, many of the organs it controls display diurnal (circadian) behavior. While the sleep-wake cycle is the most obvious function the pineal gland regulates other variations in the body are connected to the melatonin levels. These include variations in temperature, sex organs, kidney, insulin production and functions relating to the immune system. The pineal gland influences the brain which regulates our feeling of hunger and thirst. It goes on to also affect our mood and sense of well-being. These cycles experienced by the body are not only affected by daylight.

The cycles still occur even without the stimulus of daylight, but experiments have shown that the perceived day slows down by approximately 1.1 hours in every 24 hours. This means that the effect of daylight is to speed up or slow down these cycles. The process of changing these cycles is described as a phase-shift. Since the circadian cycle is 25.1 hours long without the presence of daylight there is a need for a positive phase-shift of 1.1 hours daily (Baker & Steemers, 2002). One possible effect due to a lack of daylight is what is known as seasonal affected disorder (SAD). Symptoms include depression caused by a lack of daylight as days grow shorter when winter approaches (Ander, 2003). It is very common for people living at high latitudes to experience seasonal changes in mood or behavior to some degree. This is not to be confused with those suffering from SAD who experience this to the extent of being seriously debilitated in winter.

The extent to which a chronic circadian dysfunction due to a lack of daylight causes health issues is still being investigated. It is however likely at the very least to result in impaired mental and physical function. Although living at high latitudes during winter present the largest risk, poor daylight design of buildings may put occupants at risk regardless of location. It is worth mentioning that the most common symptom related to sick building syndrome is lethargy (fatigue), which is one of the effects of circadian dysfunction.

3.4 Light and human comfort

Besides affecting our health, everyday performance of tasks is also very dependent of the lighting conditions, and the visual performance.

The visual performance is measured by the accuracy and speed at which a visual task is done. It is mainly influenced by the following three factors:

- The size of the details to be perceived during the task and the luminance contrast between details and background
- The illuminance of the task
- The visual fatigue state

The third factor, visual fatigue, is directly related to the other two. It occurs when the other two criteria are unsatisfactory for a prolonged time. The result is an impaired visual state due to a change in distance of the near-point. Visual tasks are usually performed at a distance of 0.3m - 0.7m from the eyes, and visual fatigue may cause the near-point to recede to the range where these tasks are performed.

A method has been developed to quantify the visual comfort, in terms of visual performance in workplaces. The idea is to measure the difference between the maximum visual performance a person can achieve and the performance with the actual lighting conditions of the workplace. It has been further developed to account for the visual performance of the whole population. This is then measured as a PPD-index (Predicted Percentage Dissatisfied), which expresses the part of a population experiencing discomfort. The PPD-index for visual comfort starts at 25% PPD. This high value is due to the fact that a large fraction of a population cannot obtain a noticeable difference between the visual performance at optimum conditions and the visual performance for the actual conditions.

Due to the control mechanism of the visual system, discomfort glare can be caused by high luminance contrasts. This does not always mean that the visual performance has decreased. It is mainly a problem that occurs when parts of the retina is hit with high intensity light and thus wants to close the pupil, while the less stimulated part of the retina wants it to open up more. The sensation of glare has been shown to be directly related to the luminance of the glare source and also to the size it occupies in the visual field, its apparent size as viewed by the observer. Due to the control mechanism of the visual system the glare sensation will be reduced if the glare source is located in a surrounding of high luminance.

Human perception of light does not only rely on physiological lighting requirements. Subjective perception is of equal if not larger importance. Studies made in Germany on dwellings have shown a strong connection between daylight levels and window areas as to their impact on visual comfort of the occupants. When it comes to daylight the study found a direct relation between occupant satisfaction and daylight factor. For average daylight factors below 0.9%, occupant satisfaction decreases rapidly. Commonly, values over 2% are regarded as adequate daylight (Tillberg, 2011). Further information on daylight factor will be presented in Section 3.5.1.

Getting light deep into rooms is also a factor that highly contributes to the satisfaction of the occupants. The German surveys concluded that in order to satisfy at least 70% of the occupants, windows should receive direct sunlight for four hours or more during the equinox. The survey went on to demonstrate the correlation between window area and occupant satisfaction. Results show that larger window areas lead to higher occupant satisfaction. A higher limit to window area does not appear to exist, the more the better. They managed to define a lower level at which 70% of the occupants are satisfied; the amount of glass area should be 16% of the floor area or 30% of the wall area (Baker & Steemers, 2002).

3.5 Measuring light

"In that direction from which the light is to be received, let a line be drawn from the top of the obstructing wall, to that part where the light is to be introduced, and if, looking upwards along that line, a large space of open sky be seen, the light may be obtained from that quarter without fear of obstruction thereof…"
– Vitruvius (~40BC)

There are a number of different metrics commonly used when describing light.

- Luminous flux, measured in lumen, is equal to the flux in a steradian from a point source. Luminous flux considers different wavelengths, and therefore it evaluates perceived light by the human eye.
- Luminous intensity, which also is adapted to the human eye. It is the intensity emitted by a light source in a given direction and is measured in candela.
- Luminance, this is the luminous intensity emitted from any surface in a given direction. It is measured in candela/m².
- Illumination, this is measured in Lux. It describes the illumination on a surface (Ander, 2003).

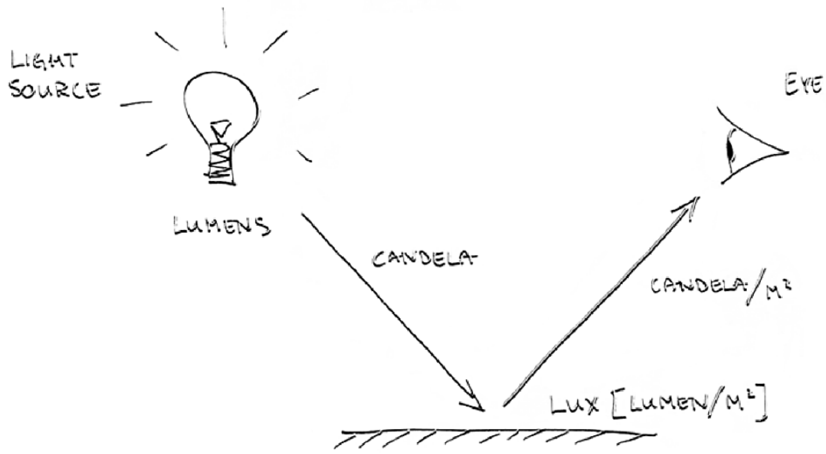


Figure 3.3. Some of the various ways to measure light, and the different units it is measured in (Sandström, 2012).

3.5.1 Daylight factor

As previously mentioned the human eye adapts to different light conditions. Therefore it is more relevant to measure the relative illuminance level than an absolute one. As a result, a better method than measuring illuminance in a room is to describe it as a ratio. This ratio is referred to as the daylight factor (DF). It is usually given as a percentage of the indoor illuminance divided by the outdoor illuminance. DF is given as:

$$DF = SC + ERC + IRC \ [\%] \quad (3.1)$$

In equation 3.1, SC is the sky component, ERC is the externally reflected component and IRC is the internally reflected component. SC is very similar to what Vitruvius described above. It is simply the part of the diffuse light that directly reaches the point considered without being reflected. It is normally measured from a diffuse sky where no direct sunlight is available. To include reflected light, ERC and IRC are added.

These parts can be of significant importance, depending on the layout of the room and the surroundings of the building considered. In urban settings the ERC might play a pivotal role since much of the light can be reflected off of other buildings. The light from the ERC also tends to penetrate deeper into the room as it usually approaches at a lower angle. The IRC component always plays a major part, as the sky component tends to be rather limited, especially when room depth increases. All surfaces reflecting light have previously been illuminated by either the SC or the ERC. As the SC drops rapidly with increasing distance from the window so does the ERC, but in a smaller extent. The IRC on the other hand presents an almost even distribution within a room, depending somewhat on the shape of the room in question.

When these factors are summed up the illumination level in the point considered is found. Simulation programs can greatly simplify these calculations and to allow for greater accuracy, since they are able to consider enough reflections in a multitude of points to give contour images as seen below.

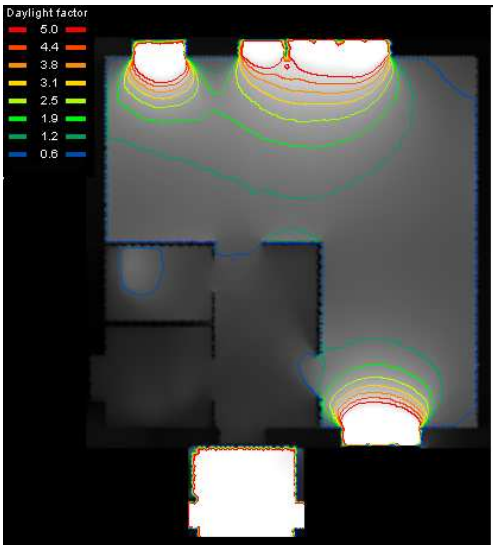


Figure 3.4. ISO-contours of the 1st floor of Kuben.

One could also measure the DF in existing buildings. To do this the illuminance needs to be measured simultaneously outside, under an unobstructed diffuse sky, and at a given point inside. Obvious difficulties include timing, as illuminance levels can change quickly, and to conduct measurements with an as diffuse sky as possible. When the measuring is done the DF is computed as the ratio of the two values obtained. The daylight factor is usually quite small. Outdoor illuminance for a diffuse sky is roughly 12000 Lux, and the expected daylight factor during those conditions is typically a few percent. Daylight factor is the most commonly used metric for quantifying daylight (Baker & Steemers, 2002).

3.5.2 Daylight performance index

Other metrics for daylight have started to emerge. One of those is the daylight performance index (DPI). It prescribes thresholds with a minimum and maximum daylight factor. The maximum value here is thought to avoid over-illumination and problems that follow, such as glare and overheating. The DPI only accounts for the area of the building which has a daylight factor between these two values. Instead of using a standard diffuse sky, the prevailing sky of the location is used, although still diffuse (Baker & Steemers, 2002).

3.5.3 Daylight Autonomy

Daylight Autonomy (DA) is similar to DPI as it measures illuminance in a plane, usually 800 mm above floor height, as an indicator of whether there is sufficient daylight in a space. It is thus not presented as a ratio between indoor and outdoor levels. DPI is suitable for offices, as it determines whether an occupant can work by daylight alone. Calculations are done for the actual climate conditions including direct sunlight on annual basis. The result is then presented as a percentage showing how many hours of the year the definition is fulfilled.

A development of DA is the Useful Daylight Illuminance (UDI) which also is based on work plane illuminance. It adds another demand on what is considered adequate daylight to work in. This is added as an upper threshold so as to avoid glare and overheating issues. The thresholds proposed being below 100 lux and above 2000 lux, where below 100 lux would be to dark and above 2000 lux would lead to visual and/or thermal discomfort. Further variation of this metric exists, where partial credit is given when the provided daylight is below the minimum threshold but still provides some daylight. One purpose of these metrics is to be able to show energy savings potential for daylight control of electric lighting (Reinhart et al, 2006).

4 THERMAL COMFORT

This chapter contains a description of how the human body is affected by the thermal climate surrounding it. It goes on to describe how thermal comfort is measured by Fanger's comfort indices and how this is described in standards. Included is also how thermal comfort affects the human body.

4.1 Thermal climate

The human body tries to keep its temperature around 37°C. It achieves this through several mechanisms: Increased blood flow and sweating can be used to lower the temperature in warm conditions while blood flow is reduced and goose bumps may develop to keep the body warm in colder conditions. The latter provides extra insulation of the skin. Blood flow regulates the surface temperature and thus the heat losses from the skin to the environment. If the body does not manage to raise the temperature due to decreased blood flow and goose bumps, the body will increase its heating activity by shivering. To maintain a balance at 37°C clothes are also used to regulate the insulation of the skin.

The environmental factors affecting the human heat balance are:

- Air temperature
- Mean radiant temperature
- Air velocity
- Relative humidity

Air temperature and mean radiant temperature directly affect the heat balance of the body, while air velocity affects the convective losses from the skin. Relative humidity influences the rate at which sweat evaporates and thus the cooling ability of the body.

There are two more factors influencing the human heat balance. These are the activity level and the clothing level. The activity level is measured as a metabolic rate (met). 1 met is equivalent to a heat production of 58 W/m². The m²-factor refers to the surface area of the person in question. In Scandinavian countries this is assumed to be 1.77 m², making a Swedish person correspond to 102 W. Clothing affects the thermal resistance and is measured in clo. It ranges from 0 (naked) up to about 2.2 for outdoor winter clothing. 1 clo is defined as "underwear with short sleeves and legs, shirt, trousers, jacket, socks and shoes" (Nilsson et al, 2003).

4.2 Measuring thermal comfort

Thermal comfort is usually evaluated with a PPD-index. PPD was briefly discussed in Section 3.4, and is a method that takes into account differences within a population. It establishes the statistical percentage of dissatisfied people one would likely encounter at certain thermal conditions. Since what is perceived as optimum thermal comfort differs between people, the lowest amount of people dissatisfied at any certain condition is 5%.

The factors affecting the thermal load on the body, according to SS-EN ISO 7730:2006, are:

- Operative temperature
- Clothing
- Activity level
- Relative humidity
- Air movement

From these factors a PMV (Predicted Mean Vote) index is determined. It is transferred to a thermal sensation scale. The scale goes from -3 to 3 where neutral is the sensation at 0. Positive numbers represent an increasing thermal discomfort due to heat, and negative numbers due to cold. The PMV is then translated into a PPD-index according to ISO-7730, which means that even at a PMV of zero; the PPD-index will still show 5% dissatisfaction. As with daylight, only assessing physiological conditions is inadequate to accurately account for the perception of thermal comfort. Psychological conditions play a vital role when assessing thermal comfort (Nilsson et al, 2003).

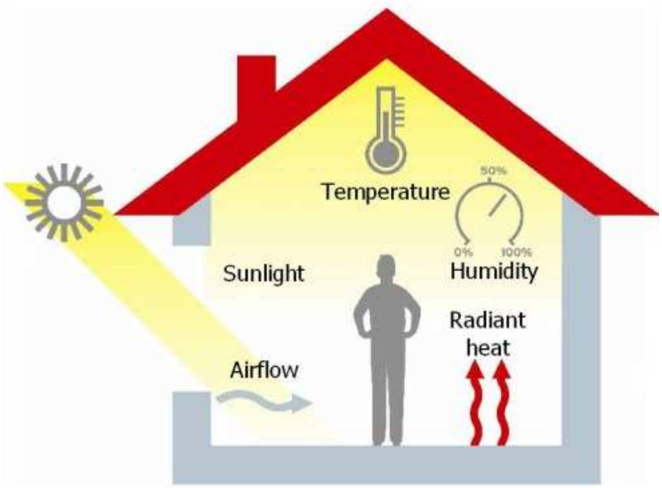


Figure 4.1. Different factors which affect how an indoor climate is perceived (Dynamight, 2012).

An example of such psychological factors can be the perception of control over our thermal environment. If there is a control system that can be adjusted, people are less susceptible to thermal dissatisfaction. This is not to say that the control system actually has to work. If the control systems repeatedly fail, our perception of control will change and so will the thermal dissatisfaction. National and seasonal related differences also play a major role in the perception of the indoor climate. Higher indoor temperatures are generally more accepted during warm outdoor conditions. The thermal standard to which we are accustomed also influences the perception of the indoor climate. This leads to people in countries where the indoor climate is highly controlled to become dissatisfied by a much smaller divergence from the optimum thermal climate.

5 SHADING

There are many kinds of shading devices, which differ in usage and effects. This chapter will describe these various kinds of shading devices and the importance of shading.

5.1 Why shade the sun?

The light from the sun is part of its emitted energy, which can easily be understood considering the temperature changes between day and night. This energy is beneficial for houses during the winter since it lowers the need for artificial heating. However when the outdoor temperature increases, unnecessary additional heating of a building is not wanted. In Chapter 3 and 4, additional information about indoor climate can be found.

To control the flow of energy from the sun, different methods are used. Common among these is that they limit the radiation from the sun, and that this radiation's properties are the same since it originates from the sun.

When radiation from the sun reaches the earth's atmosphere it contains about 1300 W/m². Of this, 15% is absorbed by the atmosphere and emitted as diffuse long-wave radiation. 6% is reflected back into space. The remaining 79% is directly transmitted to the ground (ES-SO, 2012).

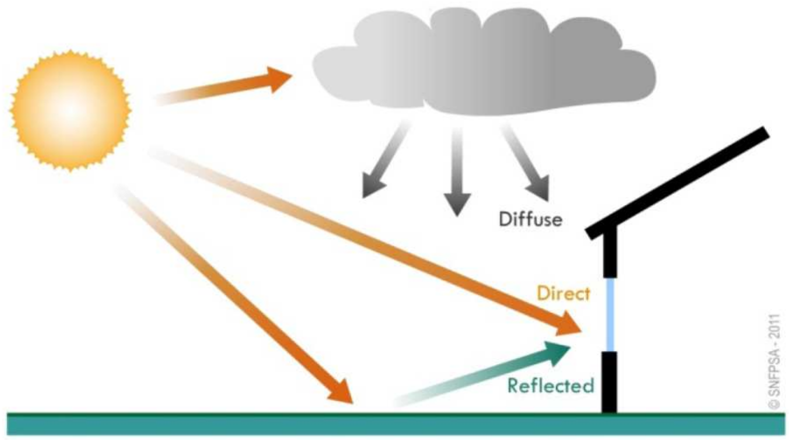


Figure 5.1. The different ways the sun's radiation affects buildings; diffuse, direct or reflected (ES-SO, 2012).

The radiation affecting a construction can therefore be divided into three factors, much like with daylight, in accordance with Figure 5.1 above:

- Direct radiation: The solar radiation which unobstructed can reach the construction.
- Diffuse radiation: The part of the solar radiation which was absorbed by the atmosphere and emitted in all directions.
- Reflected radiation: This is "secondary" direct radiation, which consists of reflections from surfaces or from diffuse radiation from objects along the ground.
  (ES-SO, 2012)

Solar shading devices affect both the light and the thermal radiation from the sun, but not necessarily equally much. This is due to the possibility to control which part of the solar spectrum the shading interferes with. Light with wavelengths over 780 nm is not visible for humans, making all radiation above this limit perceived as heat only. The energy content in solar radiation is distributed to about 2% in the UV-spectra (below 380 nm) and 49% each in the visible and Near IR-spectrum. Because of this, some shading systems can limit the short-wave invisible parts of the radiation while maintaining the amount of visible light (Bülow-Hübe & Lundgren, 2005).

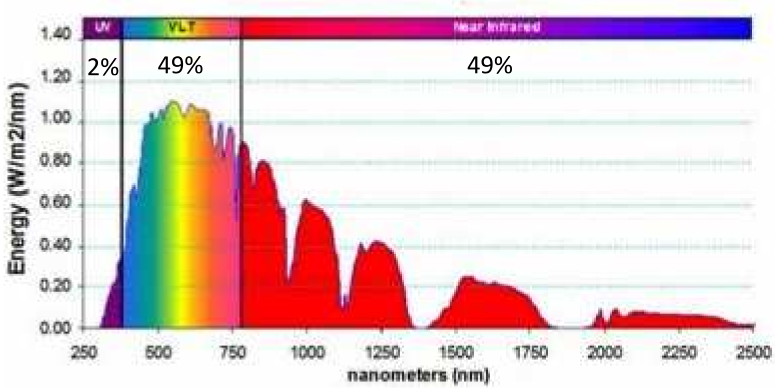


Figure 5.2. The solar spectra and the distribution between UV-, visible- and near infrared light. By obstructing certain wavelengths, shading may not necessarily affect perceived light.

When solar radiation hits a surface there are three different possible outcomes; to be transmitted, reflected or absorbed into the material (see Figure 5.4). This applies to both visible light and total energy content, and due to the need to distinguish between these they are described by individual coefficients. The term for visible light is Light Transmittance (LT) and for energy transmitted Solar Transmittance (ST), both are given as percentages. To measure total energy transmitted (which also includes secondary radiation from absorbed radiation) the coefficient Solar Heat Gain Coefficient (SHGC) is used internationally. Alternative names referring to the same ratio are Total Solar Transmittance (TST) and g-value, a European term. The term g-value will be used in this thesis.

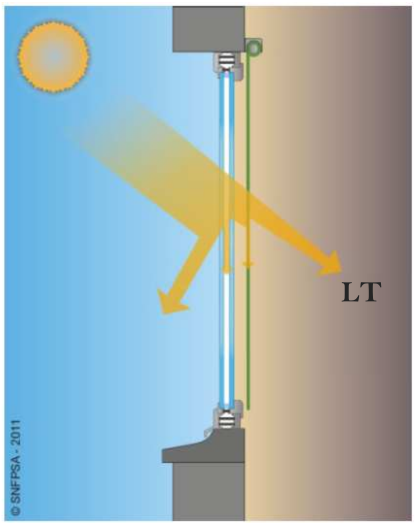


Figure 5.3. The LT- value is the percentage of remaining visible light compared to incoming visible light. In this simplified case light reflects against the glass, and passes a shading blind, reaching an LT-value of about 20% (EN-SO 2012).

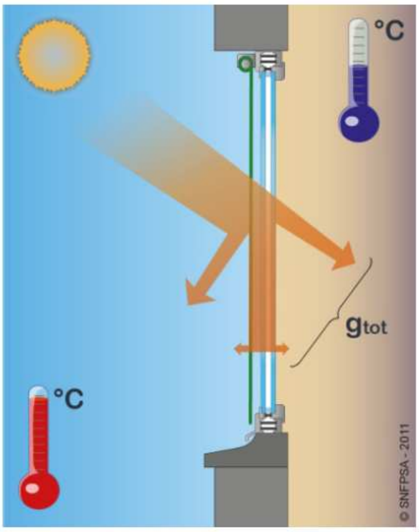


Figure 5.4. The g- value is the ratio of remaining energy versus incoming energy. In this simplified case, it is reflected against an external blind, and absorbed in both the fabric and the glass, where some energy is radiated into the room. The resulting value is about 0.20 (EN-SO 2012).

Shading is most often comprised of many different objects interacting; such as blinds, trees, window glass and so on. An approximation of the total coefficient for a shading system is found by multiplying the different values of the components with each other. The insecurity is due to the g-value being a mean value of the transmitted energy in all wavelengths. This means it is not necessarily multipliable if very different, or narrow spans of wavelengths are affected by a shading device and the glass.

5.2 Orientation and surroundings

The orientation and surroundings are very important for the amount of sunlight that can penetrate into a building. Orientation is important because of the earth's orbit around the sun; the sun shines more on certain sides of a construction. Since Sweden is situated on the northern hemisphere, the southern side is exposed to the strongest sun during the middle of the day, the east and west sides receive morning and evening sun respectively and the northern side only diffuse light.

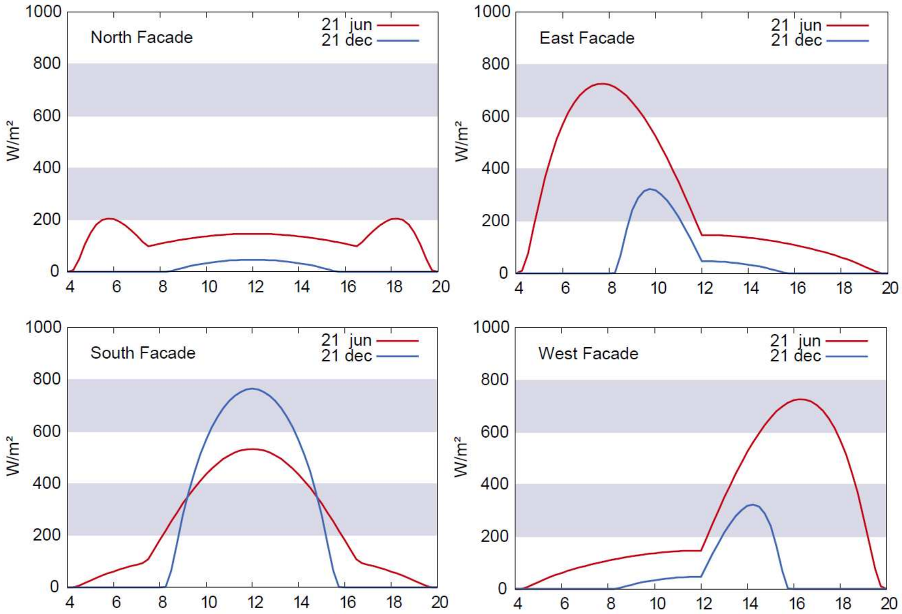


Figure 5.5. The maximum solar irradiance for a vertical surface on latitude 50°N. Sweden stretches from 55°N to 69°N, which change these values slightly depending on location (EN-SO 2012).

The graphs in Figure 5.5 apply for the energy received from the sun. Since the sun sets and rises in what is seen as an elliptical path, the radiation from the sun originates considerably lower towards the horizon from the west and the east than it does from the south (see Figure 5.6). The lower trajectory of light on east and west façades makes it harder to shade with fixed shadings. The point when the sun is at the top of its trajectory is called zenith.

The impact of the surroundings of a building is also very important, in connection with knowledge of orientation. Because of the sun's height over the horizon, neighboring buildings on the east and west will block more energy than buildings to the north (where no direct source exists) and to the south where the angle to the sun is higher. The angle referred to as the *shading angle of the horizon*, commonly measured from half the buildings' height, is the average angle of the shading the horizon constitutes.

The materials in the surroundings can also be important, for example the difference between a concrete and a mirror-glass finish of an opposing building's façade. This must also be considered when assessing light in buildings.

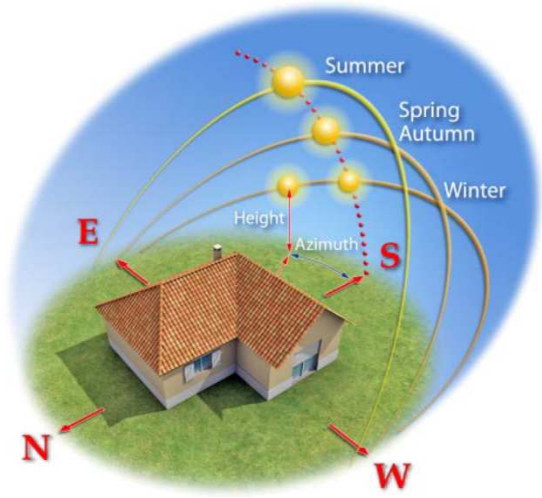


Figure 5.6. The different solar angles during the seasons of the year and definitions.(EN-SO, 2012)

5.3 Windows

As a general rule the better thermal insulation, the lower transmittance. This is because of the additional glass panes which need to be passed, as well as low-emission coatings. Regular clear glass lets almost all wavelengths through in the sun's radiated spectrum. This means that almost all incoming energy is absorbed by the different materials inside the building, resulting in an increased temperature. The surfaces of these materials, in turn, emit radiation in the long wave IR-spectrum which cannot pass through glass and is therefore reflected back into the room. This is normally referred to as the greenhouse effect.

The LT- and g-values differ greatly depending on the glass properties. The amount of panes, the gas in-between them and different low-emission coatings can alter these parameters to suit most situations. When considering a window's effect on daylight, the placement of the window is also of importance. The higher the window is placed in the wall the further daylight will penetrate into the room.

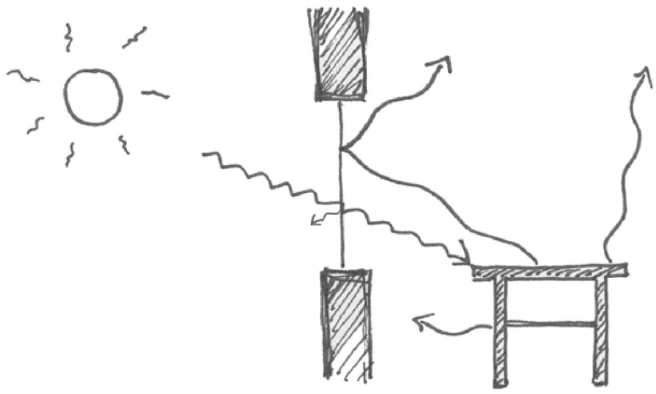


Figure 5.4. The greenhouse effect. Most short-wave radiation passes through the glass and heats the room. Long-wave radiation cannot be transmitted as easily, and the energy remains inside (Sandström, 2012).

5.4 Shading devices

Shading devices come in many shapes and forms. A general distinction can be made based on placement and the control of them. Shading devices are either placed on the inside of a window's glass, between the glass panes or on the outside of the building. They can further be grouped based on how they are controlled. Manual, automatic and fixed shading devices are the possible control strategies. Moveable shading devices have the advantage of being adjustable. They can be controlled to shade the sun when necessary and allow light and heat to enter during colder situations. It is always beneficial to place shading devices on the exterior of a building since the part absorbed in the shading device will not affect the inside.

Fixed shading, usually placed on the outside, will always affect the annual heating demand in a negative way. Although the angle can be optimized, this is an inferior solution, especially when taking daylight into account. The redeeming qualities of fixed shading being that no control system is required and that no moveable parts are used which tend to require maintenance. They are also able to shade direct light while allowing diffuse light in, providing daylight and a view of the outside.

The success of moveable shading is to a large extent based on the effectiveness of the control system. Manual control, being manual, will always deviate from optimal use as the inhabitants handle the control. On the other hand manual control, or the perception thereof, might lead to a higher degree of thermal comfort as described in Chapter 4. Automatic control is usually done by measuring light intensity, a common value when shading is being drawn occurring at 24 kLux (Somfy, 2012). Other control mechanisms include time schedules, control based on the sun's angle and temperature.

Common exterior shading devices include shutters, screens, awnings, blinds and different protruding building parts such as balconies. Being exterior they provide shading depending on the position of the sun, thus the g-value of the shading changes during the day but also during the year depending on the sun's position. They are generally more useful to the south where the angle to the sun is increased and can be entirely ineffective on east and west façades where a low angle to the sun is more common. When discussing interior or intermediate shading devices, blinds of different kinds are by far the most commonly used. In residential houses, additional shading is usually provided by curtains and plants placed on the inside of windows. Screens used on the inside are usually not used as a way to avoid heat but rather glare problems. Using fixed shading devices may lead to a need for internal moveable screens or blinds in order to avoid glare problems or simply to block the view from outside.

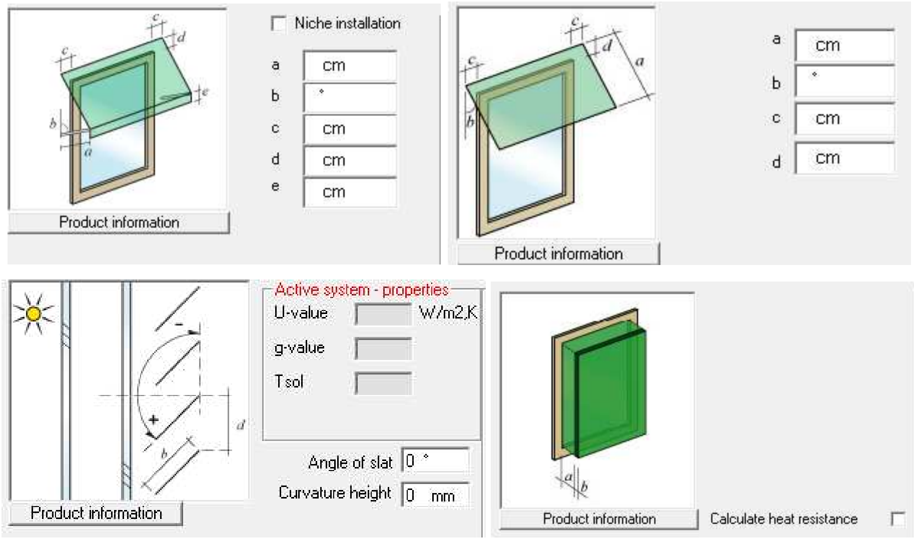


Figure 5.5. Different types of shading devices, demonstrated in the software ParaSol. Top left going clockwise; awning, screen, Venetian blind, shutter.

5.5 Future methods

There are other ways to allow light into the building while limiting the influx of heat. One such way is to use adaptive surface coatings on the windows. These coatings change the g-value of the window, and as such act as a solar shading. The available coatings come in three different variations: thermo chromatic, electro chromatic and photo chromatic coatings. As the names suggest they are controlled by heat, electricity and light respectively.

Other non-traditional ways include transparent insulation. Using transparent insulation materials provide a whole set of new opportunities when designing buildings. The most plausible material at the moment, aerogel, has a relatively low light transmittance but provides a very good U-value. This may provide possibilities for non-traditional windows as sources of light in the future.

6 MILJÖBYGGNAD

Miljöbyggnad is a Swedish environmental classification system, based on existing practice and regulations. It consists of a grading system where both new and existing buildings can be assessed. Several measurements and calculations are assembled into three major areas; indoor climate, materials and energy. The purpose of the system is to promote buildings achieving high grades, thereby increasing the demand for sustainable and healthy housing. Some of its advantages according to its authors are; simplicity, cost efficiency, high demands for high grades and successful adaption to the Swedish governing construction standard, BBR, as well as other minor standards (SGBC 2012a).

The reasons this system was chosen as reference for this study are several. It is a common classifications system used within NCC and other major construction companies. It is reasonably uncomplicated using only 16 parameters, and it is adapted to Swedish conditions and standards.

Miljöbyggnad is made up by sixteen so called "indicators", which are assembled into 12 aspects, which are then in turn translated into the three areas; indoor climate, materials and energy. These can be seen below in Table 6.1. There are four possible grades awarded to the applicants, with translations within parenthesis; KLASSAD (rated), BRONS (bronze), SILVER (silver) and GULD (gold) (SGBC 2012a). KLASSAD is the lowest grade, and means it did not fulfill the classification. BRONS roughly represents a building in line with the demands from BBR.

Table 6.1. Indicators in Miljöbyggnad, and ways to combine them (Translated from Swedish by the authors).

Nr	Indicator	Aspect	Area
1	Energy usage	Energy usage	Energy
2	Heating Power	Required power	
3	Solar heat load		
4	Energy origins	Energy origins	
5	Noise	Sound quality	Indoor environment
6	Radon	Air quality	
7	Ventilation standard		
8	Nitrogen dioxide		
9	Moisture safety	Moisture	
10	Thermal climate, winter	Thermal climate	
11	Thermal climate, summer		
12	Daylight	Daylight	
13	Legionella	Legionella	
14	Documentation of construction materials	Documentation	Materials
15	Phase-out of dangerous substances	Phase-out	
16	Sanitation of dangerous substances	Sanitation	

The relevant parts of Miljöbyggnad for this thesis are those regarding daylight and energy, and combinations of these. Thus the following indicators will be included when making conclusions from simulations; 1, 2, 3, 10, 11 and 12. These are, in order: energy usage, heating power, solar heat loads, thermal climate winter, thermal climate summer and daylight.

6.1 Energy usage

This indicator promotes buildings with a low energy usage. The current limits are set as a percentage of the demands in BBR, which is 90 [kWh/m^2·A_{temp}.year] for the area around Gothenburg 2012. A_{temp} is a building's heated area. Note that these values are valid for buildings not heated electrically.

Table 6.2. Maximum allowed values for energy usage, according to Miljöbyggnad (SGBC, 2012b).

Energy demand (% of BBR)	Bronze	Silver	Gold
[kWh/m^2·A_{temp}.year]	≤90 (100%)	≤67.5 (75%)	≤58.5 (65%)

By the definition set by BBR, these sources are included in the buildings energy usage:

- Heating
- Hot water heating
- Comfort cooling
- Fixed electricity (elevators, fixed lights and so on)
  (Boverket, 2011)

This means that the residents' electricity is not included in this indicator, but may still affect for the included energy by providing extra additional heat that reduces the need for heating. Comfort cooling is not applicable for the chosen project, and is very rarely installed in residential buildings.

To maintain the grade awarded by theoretical calculations, the values have to be verified within 24 months after the building is put in service (SGBC, 2012b).

6.2 Heating power

This promotes buildings with a low requirement for installed heating power. It is also defined in line with BBR. The current values for the different grades are:

Table 6.3. Maximum allowed values for heating power, according to Miljöbyggnad (SGBC, 2012b)

Heating power	Bronze	Silver	Gold
[W/m^2· A_{temp}] at DVUT	≤60	≤40	≤25

This value is calculated at "dimensioning winter outdoor temperature", DVUT[6], as the sum of all heat losses by transmission, leakage and ventilation divided by A_{temp}. DVUT can be calculated using BBR; it represents the statistically reasonable lowest possible winter temperature for different locations. Hot water heating is not included.

[6] In Swedish: Dimensionerande vinterutetemperatur

No additions from solar radiation or internal heat from lights or persons may be benefitted from for this calculation (Boverket, 2011).

To maintain the grade awarded by theoretical calculations, the values have to be verified within 24 months after the building is taken in service (SGBC, 2012b).

6.3 Solar heat load

The purpose of this indicator is to encourage buildings that limit the energy contribution from solar radiation during the summer. This will, in turn, lessen over-temperatures and the need for installed cooling. The following are the values for residential buildings:

Table 6.4. Maximum allowed values for solar heat load, according to Miljöbyggnad (SGBC, 2012b).

Heating power	Bronze	Silver	Gold
[W/m^2]	≤38	≤29	≤18

The solar heat load[7], SVL, is calculated individually by room with a simplified method, stating that the maximum solar radiation totals to about 800 W/m^2. It is only calculated for rooms with windows facing east, south or west. The formula for rooms with windows in only one direction is:

$$SVL = 800\ W/m^2 \cdot g_{syst} \cdot \frac{A_{glass}}{A_{room}} \quad (6.1)$$

For rooms with windows in multiple directions:

$$SVL = 560\ W/m^2 \cdot g_{syst} \cdot \frac{\sum A_{glass;\,E\,\&\,W\,\&\,S}}{A_{room}} \quad (6.2)$$

When calculating g_{system}, movable shading devices may be included as beneficial, this is explained further in Section 9.3. The simplified value 800 may be decreased if the house is shaded by neighboring buildings or similar. Further information about g-values is found in Section 5.1.

In small houses, such as one-family residential buildings, the most critical rooms should be assessed independently of the hours they are supposed to be used. The rooms with the highest SVL are identified until a total of 20% of A_{temp} have been accounted for. The grade for the indicator in total is taken from the room with lowest score, unless more than half of the total assessed area achieves higher results. This will increase the grade one mark.

[7] In Swedish: Solvärmelasttal

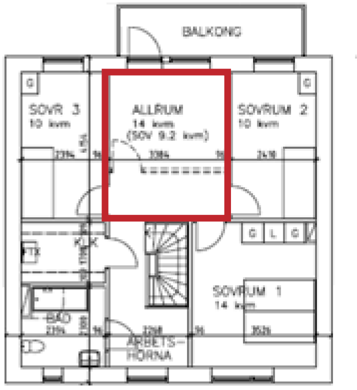


Figure 6.1. An example of Miljöbyggnad's method of weighing area. The marked room is 14 m², which is exactly 20% of the floor's 70 m².

Verification is done by controlling the glass and floor areas in the completed building as well as the installed solutions affecting g_{system} (SGBC, 2012b).

6.4 Thermal climate, winter

This indicator promotes buildings with a good indoor climate during the winter season. The assessment can be made in two ways, with a simpler option available for lower grades in small houses, where the transmission factor[8] (TF, see equation 6.3) can be used instead of the more complex PPD-index. PPD-index is more thoroughly explained in Chapter 4.

Table 6.5. Maximum allowed values for thermal climate winter using calculation method one, according to Miljöbyggnad (SGBC, 2012b).

Thermal climate, winter. (option 1)	Bronze	Silver	Gold
PPD [%]	≤20%	≤15%	≤10%

Table 6.6. Maximum allowed values for thermal climate winter using calculation method two, according to Miljöbyggnad (SGBC, 2012b).

Thermal climate, winter. (option 2, simple method)	Bronze	Silver	Gold
TF [$W/m^2 \cdot K$]	≤0.4	≤0.3	PPD ≤10
Additional requirements	Documented protection against down-draughts, i.e. airflows of <0.15 m/s		TF not accepted

In addition to the demands for GOLD above, to maintain this grade a survey must be taken by the users of the building, and the results from this have to confirm that the indoor climate is perceived as "acceptable" or better during the winter. The indoor climate also has to be verified using measurements and methods described in SS-EN ISO 7726.

[8] In Swedish: Transmissionsfaktor

PPD index is calculated according to the standard SS-EN ISO 7730:2006 and translates, for the numbers above, to a maximum allowance of 10% dissatisfaction of a population for GOLD level. PPD is explained more thoroughly in Chapter 4.

The transmittance factor (TF) describes, simplified, the cooling effect of windows during the winter. It is calculated using the area and U-value of all windows' glass in a room, as well as the room area. The resulting unit is $W/m^2 \cdot K$.

$$TF = U_g \cdot \frac{A_{windows}}{A_{room}} \tag{6.3}$$

The most critical rooms should be identified and calculated separately until their total area is more than 20% of the buildings A_{temp} for small houses. In larger buildings this limit is changed to 20% of the area of a representative and critical floor. The grade for the indicator in total is taken from the room with lowest score, unless more than half of the total assessed area achieved higher results. This will increase the grade one mark (SGBC, 2012b).

6.5 Thermal climate, summer

This indicator has the same properties as *Thermal climate, winter*, but for the warm season. This means that the risk with the indoor climate is over-temperatures, instead of under-temperatures. This indicator also provides two alternative methods; one for all buildings, using PPD index, and one simpler calculation using solar heat factor[9], SVF. The latter is allowed for small residential houses and is presented in Equation 6.4.

Table 6.7. Maximum allowed values for thermal climate summer using calculation method one, according to Miljöbyggnad (SGBC, 2012b).

Thermal climate, summer. (option 1)	Bronze	Silver	Gold
PPD [%]	≤20%	≤15%	≤10%
Additional requirements	Openable windows in schools and residential buildings		

Table 6.8. Maximum allowed values for thermal climate summer using calculation method two, according to Miljöbyggnad (SGBC, 2012b).

Thermal climate, summer. (option 2, simple method)	Bronze	Silver	Gold
SVF [-]	≤0.048	≤0.036	SVF ≤0.025
Additional requirements	Openable windows		

In addition to the demands for GOLD grade above, to maintain this grade a survey must be taken out by the users of the building, and the results must support that the indoor climate is perceived as "acceptable" or better during the summer. The indoor climate also has to be verified using measurements and methods described in SS-EN ISO 7726.

[9] In Swedish: Solvärmefaktor

PPD index is calculated as mentioned above in *Thermal climate, winter*.

The solar heat factor (SVF) is a way of describing the heat radiance from windows that affects the indoor climate. It is calculated using the combined g-value for the window and all shading devices, as well as the window and room areas.

$$SVF = g_{system} \cdot \frac{A_{glass}}{A_{room}} \tag{6.4}$$

When calculating g_{system}, all movable shading devices shall be assumed active. Grading accumulation from rooms to indicator is done in the same way as for *Thermal climate, winter*, including the limit of 20% of A_{temp} or of the area of a critical floor (SGBC, 2012b).

6.6 Daylight

This indicator rewards buildings that provide good access to sunlight. It can be calculated in two ways, one for all buildings and one simpler method for residential buildings (without regard to size of the building). The general method uses a point daylight factor, as described in 3.5.1, and the residential method uses a window glass to floor area ratio[10], AF. The latter is not possible to use to reach GOLD.

Miljöbyggnad's defined point for the daylight indicator is 0.8 m above the floor and 1 m from the darkest side wall, at half the room's depth.

Table 6.9. Minimum allowed values for daylight using calculation method one, according to Miljöbyggnad (SGBC, 2012b).

Daylight (general method)	Bronze	Silver	Gold
Daylight factor [%]	≥1%	≥1.2%	≥1.2%
Additional requirements	-	-	Supported by computer model

Table 6.10. Minimum allowed values for daylight using calculation method two, according to Miljöbyggnad (SGBC, 2012b).

Daylight (simple method)	Bronze	Silver	Gold
AF [%]	≥10%	≥15%	Not possible

In addition to the demands for GOLD above, to maintain this grade a survey must be taken by the users of the building and the survey results support that the level of daylight is perceived as "acceptable" or better.

The term AF is calculated as the ratio between glass area and floor area in each room, and is a simple percentage.

$$AF = \frac{A_{glass}}{A_{room}} \tag{6.5}$$

[10] In Swedish: Fönsterglasandel

If the total solar transmission for the glass in the windows is less than for triple glass panes (or total g-value 0.74) or the window is screened from the horizon by more than 20°, daylight factor needs to be calculated instead.

Grading accumulation from rooms to indicator is done in the same way as for *Thermal climate, winter*, including the limit of 20% of A_{temp} or of a critical floor (SGBC, 2012b).

6.7 Other classification systems

Aside from Miljöbyggnad, many other systems are used to classify buildings. Some fill the same purpose in assessing a building's sustainability and living environment; such as BREEAM and LEED. Many of the parameters considered are identical but the way they are evaluated and what documentation is needed differ. The international equivalents have traditionally been more focused towards office buildings, making Miljöbyggnad more appropriate for residential buildings.

7 KUBEN

The chosen building for this thesis is currently being built outside of Kungsbacka in Vallda. It is being constructed by NCC and was ordered by Eksta Bostads AB, a property development company owned by Kungsbacka municipality.

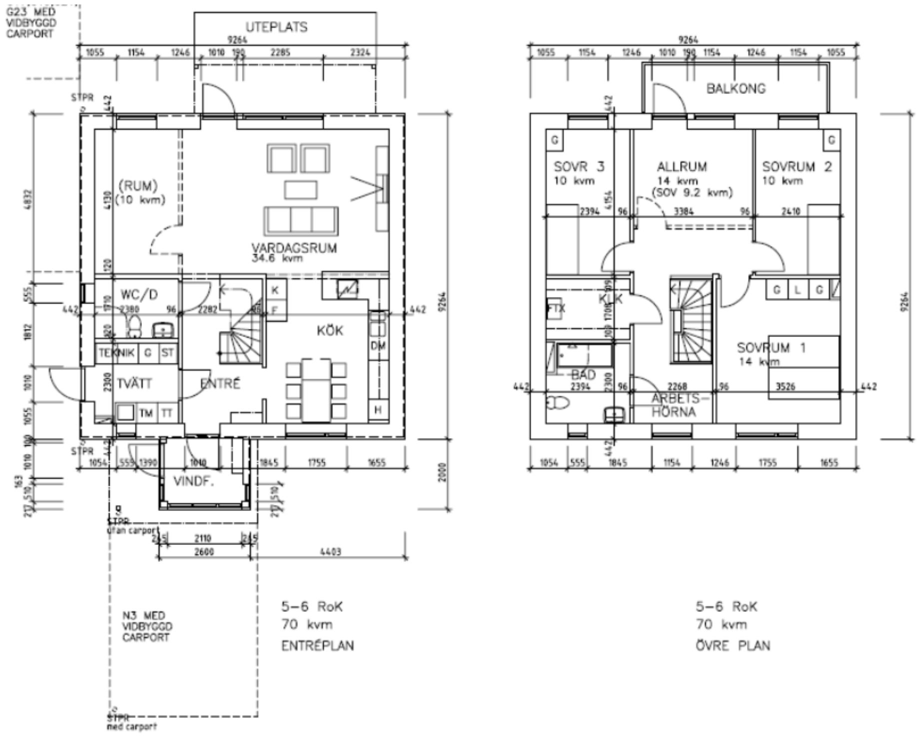


Figure 7.1. Floor plans of Kuben, a total of 140m². The 1st floor is on the left. Note the dotted garage roof extending downwards, above the entrance (NCC, 2012).

Kuben is a two story building, totaling 140 m², with a large combined kitchen and living space on the 1st floor, and three bedrooms and a living space on the 2nd floor. There are in total 26 Kuben-buildings in development in Vallda, the one analyzed in this thesis is number N3, and can be seen in Figure 7.2. There are two different models of the building available depending on the orientation of the building. There are also minor differences in balcony and garage, as well as windows on gable walls for some of the houses. N3, however, represents the most common setup. There is one optional interior wall on each floor in the basic plan (dotted in the drawing). In N3 these are not present; which is also the most common choice (NCC, 2012c).

Figure 7.2. Plan of the area. The object of this thesis, N3, is marked by a circle in the top left (Plan och bygg Kungsbacka & Markgren arkitektur AB, 2012).

7.1 Climate

Vallda is situated about 5 km from the coast at N57°28′1″ E11°59′31″, west of the city of Kungsbacka.

Figure 7.3. Vallda is located west of Kungsbacka (hitta.se, 2012).

The building body for house N3 faces northeast - southwest, the garage and entrance facing northeast. In the area, the reversed direction is equally common, with two exceptions facing due west. Buildings facing another direction than N3 have a slightly different placement of the carport, not further discussed in this report.

7.2 Construction

The building envelope of a passive house is a very important part to ensure its function, thus an as in-depth description as possible will follow. For publication reasons, some constructions will only be described with a U-value.

7.2.1 Walls, roof and ground

Since Kuben is a concept currently in development, NCC is reluctant to reveal the exact structure of the building elements. The resulting data, which is the basis for the simulations, is however presented in Table 7.1 below. In the simulation software, ground properties are included and calculated according to SS-EN ISO 13370:2006. This decreases the U-value by roughly 10% as only the construction and no ground properties are included in the values below. U-values only represent the construction.

Table 7.1. U-values for the different parts of Kuben's envelope.

Element	U-value [W/m²K]
Walls	0.1059
Roof	0.0526
Ground	0.0906

In addition, there are a number of thermal bridges. These were calculated by NCC when Kuben was designed, and are presented in the following table. Thermal bridges for the windows have been recalculated using HEAT 2 Software. The reason for only recalculating these, is that some of the proposed changes will affect this thermal bridge, thus a comparable model was needed.

Table 7.2. Values on thermal bridges for connections in Kuben.

Connection	Thermal bridge [W/(K·m)]
External wall/internal slab	0.0104
External wall/external wall	0.0258
Window/wall	0.0146
Door/wall	0.0146
Roof/external wall	0.0324
External slab/external wall	0.0635
Balcony/external wall	0.0134

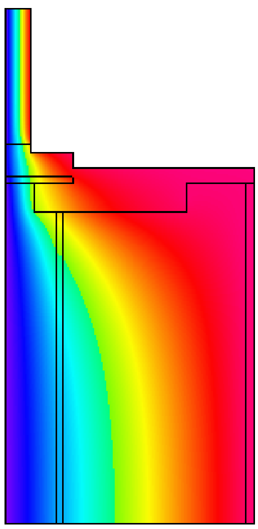


Figure 7.4. The thermal bridge around the connection to the windows, simulated by the authors in HEAT 2.

7.2.2 Windows and doors

The windows in the building envelope of Kuben are highly insulating triple-glazed with argon gas. There are openable and fixed windows, as well as glazed doors.

Figure 7.5. The exterior walls of Kuben. Top right faces the street and bottom right the garden (NCC, 2012).

In Table 7.3, all the different windows in the main building body are presented with LT-, g- and U-values as well as frame ratios. The frame ratio is determined as frame area/window area.

Table 7.3. Properties for all window types in Kuben.

Window [#]	Height [m]	Width [m]	Openable [Y or N]	Area [m²]	Glass area [m²]	Frame ratio [%]	U-value frame [W/m²K]
1	1.39	1.13	Yes	1.57	1.11	29%	0.96
2	0.79	0.53	Yes	0.42	0.20	52%	0.96
3	1.79	1.13	No	2.02	1.70	16%	0.96
4	1.39	0.6	Yes	0.83	0.49	42%	0.97
5	2.09	0.49	No	1.01	0.74	27%	0.98
6	2.09	2.09	No	4.35	3.89	10%	0.95
7 (door)	2.19	0.99	Yes	2.15	1.34	38%	0.97
8 (door)	2.09	0.99	Yes	2.05	1.02	50%	0.97

Table 7.4 below describes the window properties for the building. The U_g-value is the U-value for the glass only. U-values for the entire windows differ slightly depending on the frame ratio.

Table 7.4. Glass properties for "Nordan N-Tech Passiv" Glass, installed in Kuben (Nordan, 2012a).

U_g-value[W/m²K]	0.5
LT-value [%]	58
g-value [-]	0.37

7.3 Other properties

There are several other properties beside the envelope affecting the energy performance and indoor climate in the building. Such properties include indoor temperature as well as gains and losses depending on the residents' behavior. These have been set in accordance to the applicable standards, either FEBY or SVEBY, and are explained more thoroughly below. See appendices for data used in calculations.

The indoor temperature is assumed to be 21° C.

7.3.1 Air flows

Air is extracted and supplied to the rooms according to the following table:

Table 7.5. Air flows in Kuben.(NCC, 2012a)

1st floor	Air flow [l/s]	2nd floor	Air flow [l/s]
Living Room	+23	Bedroom 1	+8
WC	-15	Bedroom 2	+8
Kitchen	-10	Bedroom 3	+8
Laundry	-10	Living room	+8
		Closet	-5
		WC	-15

In total 55 l/s of air is supplied/extracted in the building. This corresponds to 0.39 l/s, m², based on A_{temp}. Heat recovery efficiency for the heat exchanger is 80%, specific fan power is 1.5 kW/(m³/s) and the temperature rise over the fan is 0.5°C according to HVAC documentation (NCC, 2012a). Additionally, air leakage is assumed to be 0.25 l/s at 50 Pa pressure difference. This preliminary data is used for calculations as no measurements have been done yet, and this is what NCC uses as a basis for calculations. The air leakage at 50 Pa is divided by 20 to represent the value at an average pressure difference (Elmroth, 2009).

7.3.2 Internal gains

Different internal gains also have to be taken into account. Following SVEBY and FEBY, internal gains from appliances are assumed to be 30 kWh/m² and year, of which 70% can be considered useful with regards to decreasing the heating demand. Additionally, internal heat generated by the inhabitants is calculated based on 3.51 persons present with an average activity level of 47 W/person, around the clock. Internal gains are calculated slightly different between FEBY and SVEBY, where SVEBY instead assumes 80 W/person but with inhabitants present for 14 hours per day. Following the passive house standard, the resulting value becomes 1.18 W/m^2 (SVEBY-programmet, 2009).

7.3.3 Hot water

According to both SVEBY and FEBY standards, hot water consumption is set as 20 kWh/m² and year. Hot water is not considered to produce any useful internal energy to offset the heating demand. Additionally, energy used for circulation pumps is calculated as 1.01 times the energy usage, in accordance to NCC calculation procedure (NCC, 2012b).

7.3.4 Solar shading

The building has fixed solar shading. A balcony as well as a carport shades the first floor. There is also a soffit (roof overhang) which shades the windows on the second floor. This is situated 18 cm above the window and protrudes 63 cm from the wall.

7.3.5 Voluntary airing

Losses due to voluntary airing of the building can be done in two different ways. In SVEBY 4 kWh/m^2 is added to the heating demand (SVEBY-programmet, 2009). FEBY instead assumes this loss to be a consequence of imperfect control of the heating system, and includes it as an efficiency factor for the heating system assumed to be 0.93 for electric control systems (Sveriges centrum för nollenergihus, 2012). The latter is used for calculations further on.

8 DESCRIPTION OF SIMULATIONS

Simulations are made to investigate the effect of window properties and shading devices on the building Kuben as previously described. While focus is on those parameters, other parameters such as orientation and surface materials are also investigated. These factors are studied using different simulation software. IDA ICE is used for studies concerning heating demand and thermal comfort while Velux Daylight Visualizer is used for daylight studies together with Parasol to find the needed g-values.

The six indicators mentioned in Chapter 6 are the only properties being evaluated. They consist of: annual energy demand, installed power, solar heat load, daylight and thermal comfort for both winter and summer.

8.1 Climate

The climate data file used for the simulations has been recorded in Säve, which have similar conditions to Vallda, with proximity to the ocean and approximately the same longitude. The daylight conditions in Vallda are very close to Stockholm's, this was found by comparing simulation results for these locations. For simplicity, Stockholm was used in the daylight simulation software.

8.2 Variation of parameters

Several parameters have been manipulated to meet the demands set in Miljöbyggnad. These changes were done in two ways; they can be done structured, for example by applying a fixed incremental percentage change to the initial values; or by adapting parameters in compliance with products available on the market. For the second alternative, larger deviations from the incremental changes were allowed.

Table 8.1. All parameters affecting the building, and their respective variations during the simulations. The variations are thoroughly explained in Chapter 9.

Parameters	**Thermal comfort**	**Heating demand**	**Daylight factor**	**Variations**
Evaluated in	IDA ICE/ParaSol	IDA ICE	Velux daylight visualizer	
Window glass area	x	x	x	+10,20,30%
Window placement – height over ground, along walls	x		x	Fixed
Window orientation –N/S/E/W	x	x		n·45°, n=0->7
Building location	x	x	x	Fixed
Window properties (U_g/g/LT-values)	x	x	x	0.6/0.37/63 0.7/0.51/67 0.6/0.52/71 1.1/0.59/79
Thermal mass of building	x	x		Fixed; see Appendix E
Size and shape of rooms	x		x	Fixed
Surface materials (reflectance)			x	80% and 90%
Shading devices (external/internal; movable/fixed; automatic/manual and combinations of these)	x	x	x	Variable
Thermal properties of building (U-value, thermal bridges and so on)	x	x		Fixed
Ventilation	x	x		55 l/s
Air leakage	x	x		0.0125 l/(s·m^2) (envelope area)
Heating power installed	x			2 kW
Indoor climate (Temperature, RH)	x	x		21° C
Habits of occupants (activities, clothes.	x	x		According to SS-EN ISO 7730:2006

8.3 Simulation software

Three programs were used for calculations and simulations. The choices are based on the software recommended in Miljöbyggnad. Parasol for obtaining input to IDA ICE, which is the software used for all energy calculations. Velux Daylight visualizer was used for daylight simulations.

8.3.1 IDA ICE 4.21

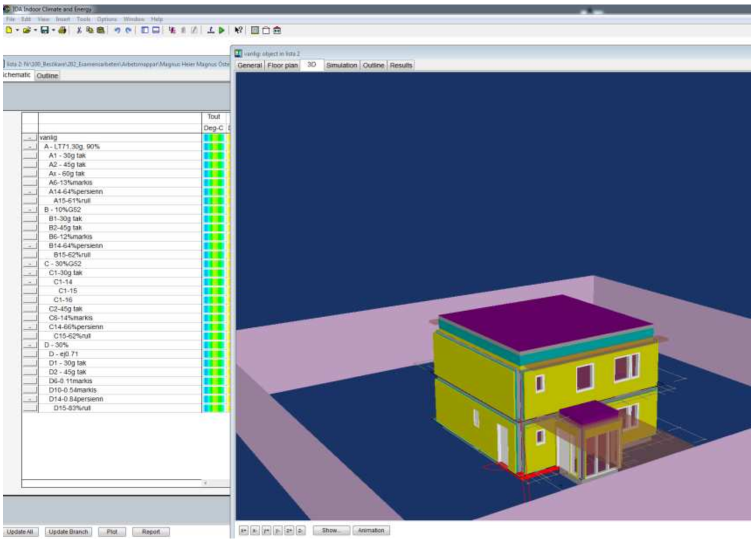


Figure 8.1. IDA.

For simulations of thermal properties of the building (energy- and PPD-calculations), IDA Indoor Climate and Energy 4.21 is used, referred to as IDA ICE. It is a whole year multi-zone simulation software for study of thermal comfort and energy consumption.

8.3.2 Parasol v6.6

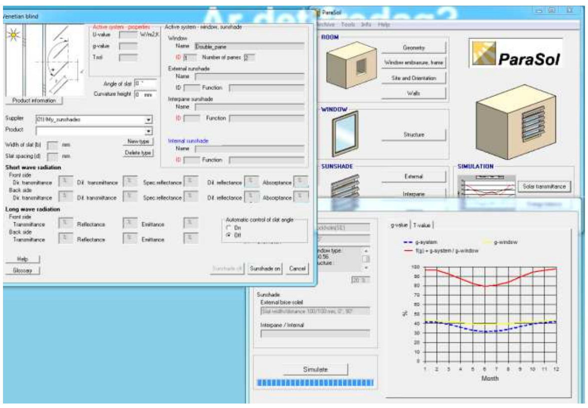


Figure 8.2. Parasol.

ParaSol was developed at LTH as a part of a solar protection project. It calculates g-values on a system level for a combination of shading properties. It contains a database of different products from manufacturers.

8.3.3 Velux Daylight Visualizer 2.6

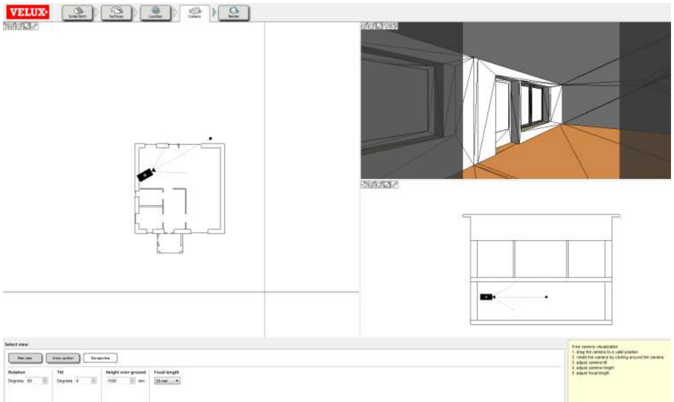


Figure 8.3. Velux.

Velux daylight visualizer is a graphical interface based on photon-mapping which calculates daylight in a number of points. It includes several tools for performing daylight calculations. It and also includes a renderer used for creating photorealistic 3D renderings. Velux presents values by images, with optional ISO-curves for daylight. There is no possibility to extract values by coordinates. Velux also automatically rounds all results to one decimal.

8.4 Simulation workflow

Parameters were varied in order to find optimal solutions for the shading setup. This was done with a step-by-step process, which serves several functions. Firstly, the building is simulated as is. Step two is evaluation; the result from the simulation is compared against the indicators specified in Miljöbyggnad. The evaluation resulted in a specific indicator that was considered to be the most critical and therefore dealt with first. The workflow in Figure 8.4 was then followed. How to follow this method is exemplified in Section 8.5.

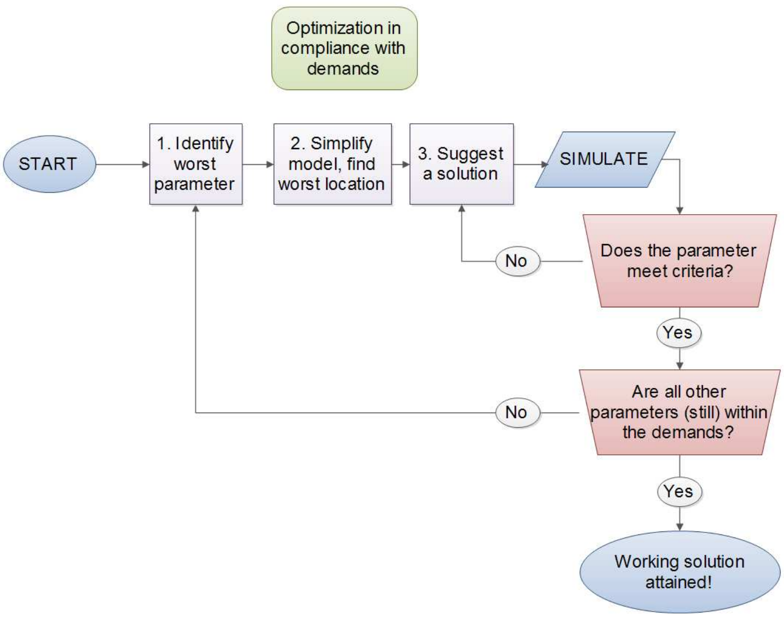


Figure 8.4. The chosen simulation workflow.

8.5 Choice of simulations

To accomplish all demands, a combination of changes may be needed. This was done by combining solutions and applying them to the workflow described above. If several combinations proved successful, they were further investigated as per the workflow, this is a likely scenario as there generally is no unique correct answer. The different parameters used in simulations can be found in Table 8.1.

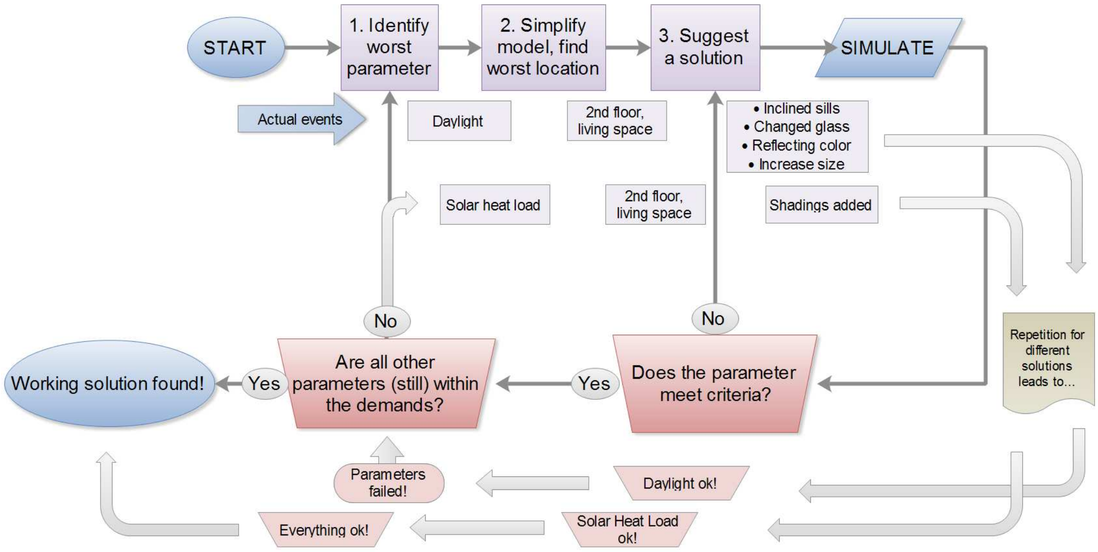


Figure 8.5. How simulations and waypoints turned out, implemented in the workflow.

Simulations of the original building identified daylight as the worst parameter. The model was simplified by investigating the worst rooms and different solutions were tried. Several of the solutions proved successful for daylight but affected other parameters negatively. Solar heat load was identified as the next parameter to be dealt with. Different shading options were tried, until working solutions could be attained.

9 SIMULATION RESULTS

In the first part of this chapter results from the original building, as being built, are presented. These show how it compares to the demands set by Miljöbyggnad and the current passive house standard, FEBY 12. What preliminary calculations have been done to assess the worst possible rooms are also included. This streamlines simulations later on by limiting the analyzed area to the critical locations in the building. The sensitivity of some parameters, such as orientation, is also considered.

Later on, all results from the different proposed modifications to the building are presented. These results will show the effects on the affected indicators. Some of the modifications affect many indicators but not to a significant degree; for example the changes in PPD for the winter case were not large enough to be of interest. These are however still included in summaries.

In the following chapters, both the terms annual *heating demand* and *energy demand* are used. These are not the same; the heating demand is only the required energy to maintain a temperature indoors during cold weather, and the energy demand is a buildings total energy usage calculated according to BBR standard. The reason for the modification is to achieve a comparable number and to include some losses that are overlooked when calculating only the heating demand. To find the annual energy demand, the following factors are added to the annual heating demand which in turn is divided by the heated area of the building:

- Ventilation losses : 633 kWh which is 4.51 kWh/m² (See Section 7.3)
- Forced ventilation in kitchen fan (100l/s): 285 kWh which is 2.03 kWh/m²
- Hot water heating: 20 kWh/m²
- Pumps: An additional 1% of total energy demand
  (SVEBY-programmet, 2009)

9.1 Original construction

In accordance with Miljöbyggnad’s demands of performing calculations for only the living spaces representing the worst case; simplified calculations were carried out to find these rooms. These points of interest would then become focus of the in-depth analysis. Observe that this definition omits hallways, bathrooms and similar spaces since the residents are only temporarily in these spaces.

The worst rooms for solar heat load occur on the second floor in the two small bedrooms and the living area, all facing south. This was found by simulations using IDA ICE, and can be seen in table 9.1. ParaSol models were then developed for these rooms to find the shading effects, and calculations according to Miljöbyggnad were done since the objective is to find out how Kuben can be made to comply with these indicators. As all of these rooms have the same window setup (identical size and shading), only one model in ParaSol was developed. Daylight factor was discovered to be lacking for most rooms, although for the most part in the bedrooms. ISO-curves of daylight factor are shown in Figure 9.2.

Table 9.1. Daylight factors and SVL-numbers for the different living spaces in the original construction, calculated by IDA ICE. The SVL-values are highest in the rooms on the 2nd floor and lowest on the 1st floor.

Room	Daylight Factor [%]	Solar heat load [W/m²]
Bedroom 1	0.8	15.1
Bedroom 2	0.8	16.8
Bedroom 3	0.8	17.6
Living room 2st floor	1.3	21.9
Work area	0.8	15.3
Living room 1st floor	0.9	15.6
Kitchen	1.0	6.9

Table 9.1 above and Figure 9.1 below show solar heat load in all rooms for the orientation of the building. Different orientations will have a major impact and this result is only applicable for the orientation in question.

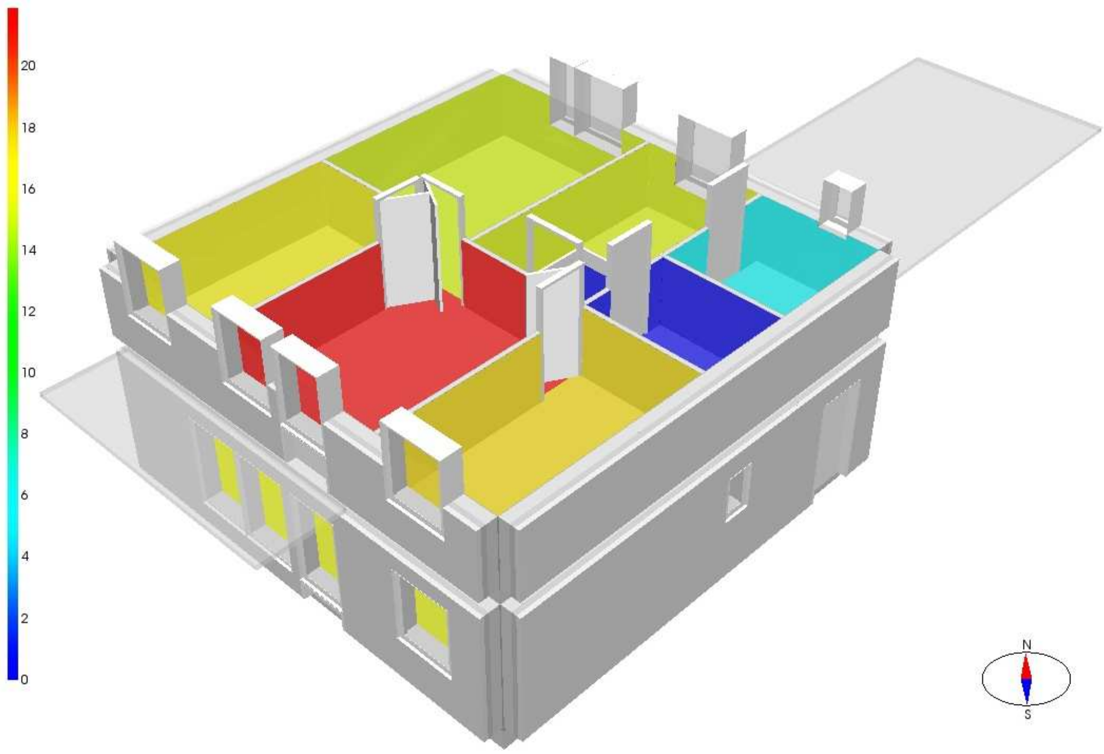
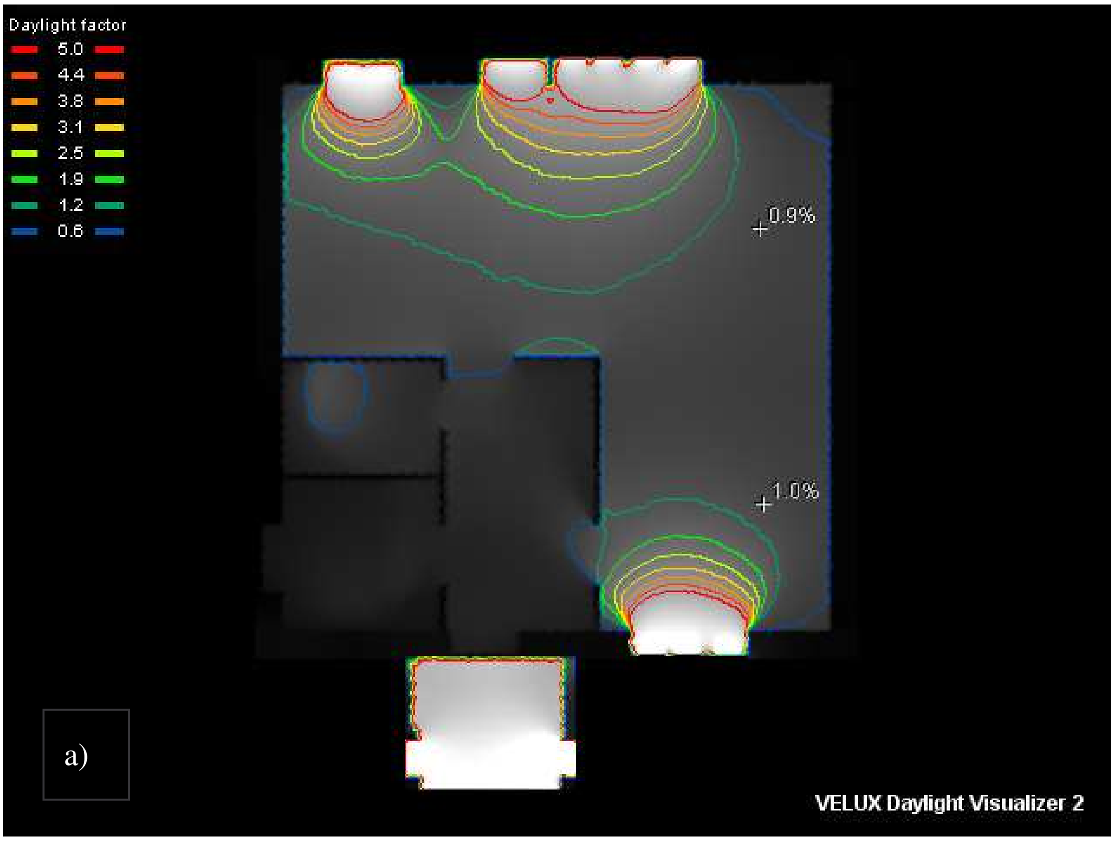


Figure 9.1. Solar heat load calculated in IDA ICE to investigate critical rooms. The living room has the highest levels. The axis' unit is [W/m²].



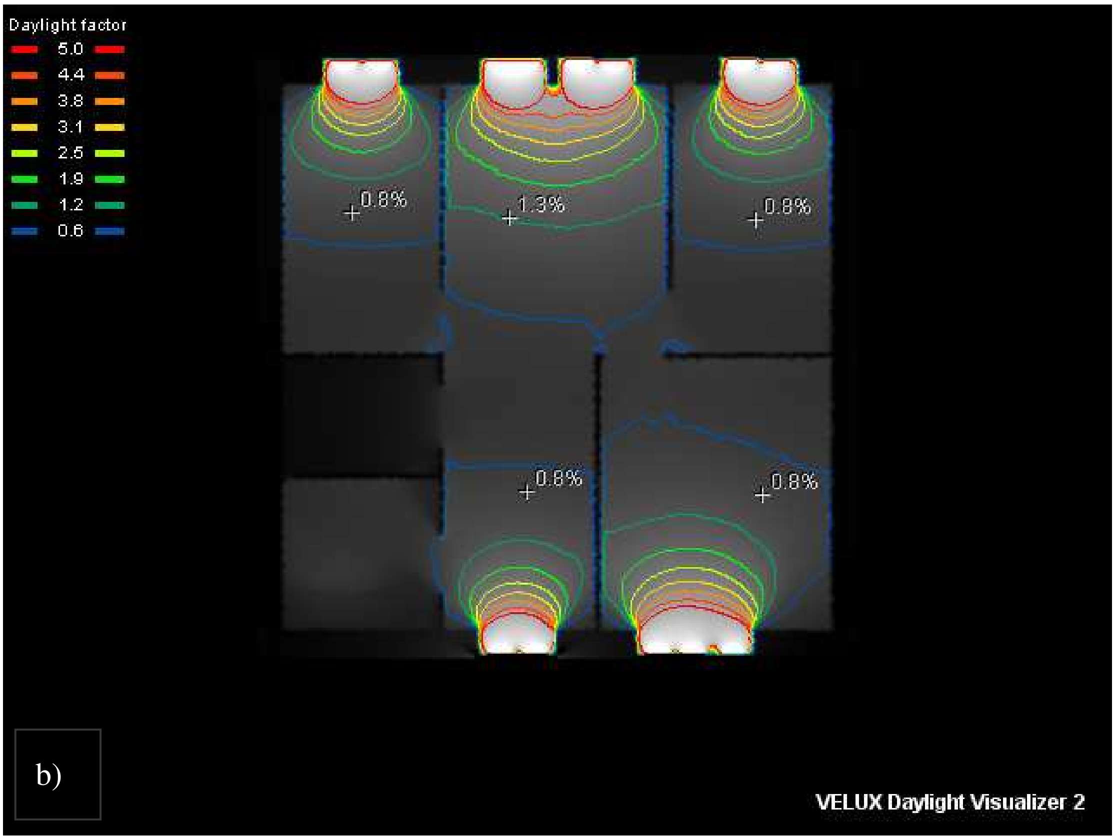


Figure 9.2. Daylight factors for the two floors of the building. The dark green ISO-curve, 1.2%, is Miljöbyggnad's criteria at half the rooms' depth. a)-1st floor. b) 2nd floor.

Table 9.2 below shows the requirements for different classification systems and the resulting grades that the original Kuben construction achieves. For in-depth description of how calculations are performed, see Chapter 2 and 6.

No specific shading was used for energy calculations in this stage; instead of simulating complex movable shading systems, a generic reduction factor of 0.71 was multiplied to the windows' g-value, in compliance with SVEBY calculation standard. This method is however only used for results where daylight factor is the primary indicator investigated. For other indicators, where the g-value is of major importance such as solar heat load and thermal comfort summer, actual window properties are used. From this point on, indicators depending on g-values were based on Parasol simulations. Values may therefore differ from Table 9.1 above, where the values were extracted from IDA ICE simulations.

Thermal climate summer can be calculated in two ways, as described in Section 6.5, where the PPD-method is very much more sensitive to input data. After trying different setups, for example by changing schedules of voluntary airing and clothing level of the residents, the result is that almost any PPD-index can be achieved. This makes PPD an unhelpful indicator. Since the option, to use solar heat factor, does not have the same possibility of being manipulated; assessing SVL was chosen instead for all calculations and comparisons of thermal climate summer. This topic is further developed in the discussion chapter.

Table 9.2. All criteria and indicators of the original building. The daylight factor is furthest from the required value.

	Bronze	Silver	Gold	Passive-house	Achieved	Miljöbyggnad
Energy demand [kWh/m²]	≤90	≤67.5	≤58.5	≤55	49.86	Gold
Installed power [W/m²]	≤60	≤40	≤25	≤17	15.70	Gold
Solar heat load [W/m²]	≤38	≤29	≤18	-	19.88	Silver
Thermal climate winter, PDD [%]	≤20	≤15	≤10	-	8.12	Gold
Thermal climate summer, SVF [-]	<0.048	<0.036	<0.025	≤0.036	0.025	Gold
Daylight [%]	≥1.0	≥1.2	≥1.2	-	0.8	Fail

Daylight factor is by far the most critical. Thermal climate summer and solar heat load are in need of improvement as well. As per the method described in Chapter 8, changes affecting daylight will be implemented first.

9.1.1 Investigation of orientation and horizon angle

Preparatory simulations were made to ensure that the model of Kuben follows the SVEBY standard and is representative to the other houses the development, facing a different direction.

Figure 9.3 below shows how the annual energy demand is affected by the orientation of the house. This thesis' studied building, N3, is angled at 135°, which makes it one of the more energy-efficient buildings.

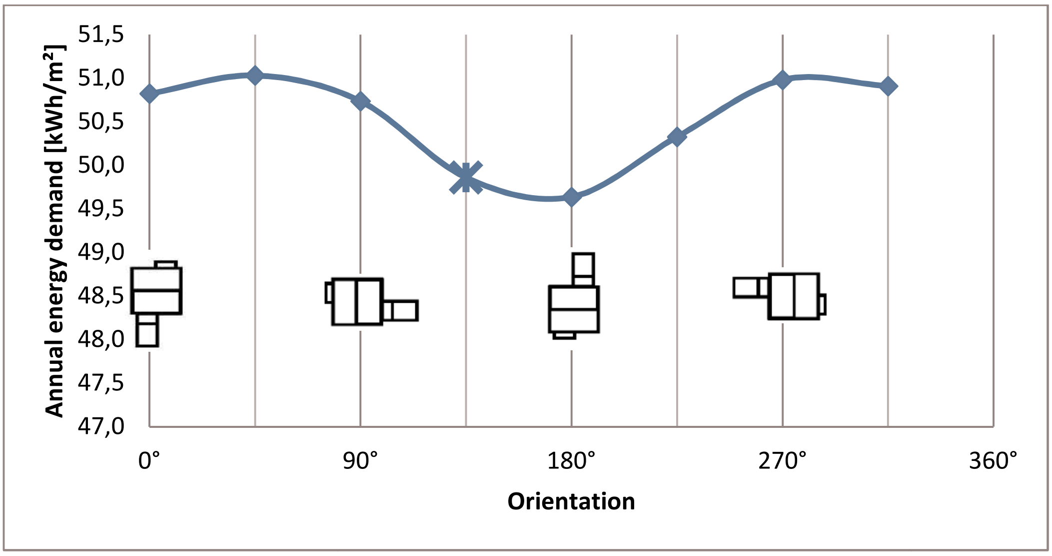


Figure 9.3. Graph depicting the changes in annual energy demand depending on orientation. At 0°, the entrance is due south. This thesis' object faces 135°, and is marked by an asterisk in the graph. Note the Y-axis' scale.

The horizon angle of the building is set to 10°. This is based on simulations where annual heating demand using different angles were compared to the SVEBY calculation guidelines. In Table 9.3 below, values for the standard calculation method and for two of the tested horizon angles are presented. When using the g-value reduction of 0.5 according to SVEBY, no other exterior shading is considered. For the different horizon angles, roof overhangs and the fact that the window is mounted 53 mm inside the wall is taken into account. Kept is also the reduction factor of 0.71 that represent behavior-controlled shading, such as blinds (SVEBY-programmet 2009). The total of these factors should make sure that only the horizon angle is not being accounted for.

The angle that best corresponded to SVEBY was 10°, while still being on the safe side as to not underestimate the shading. The angle was measured from the midpoint of the house, 2.6 m above ground level. Simulations were carried out for two different orientations. One as per the specific orientation for the building, one as the floor plans depicts it. The difference is 135°.

Table 9.3. Comparison between the SVEBY standard calculation method, and simulations with varied horizon angles. Explanations on the columns' headings are found above.

Orientation	0.5·g (SVEBY)	10°	15°
0°	3291 kWh	3339 kWh	3388 kWh
135°	3104 kWh	3205 kWh	3271 kWh

9.2 Daylight

Following the workflow in Figure 8.4, daylight factor is farthest away from complying with the criteria and as such the starting point of the simulation process. Since the criteria in Miljöbyggnad are based on the most insufficient value in the living spaces, this is what is presented. The room with lowest daylight factor is bedroom 2 on the 2nd floor. Several properties that affect the daylight factor have been investigated:

- Inclining the window niche
- Changing the light transmittance of the glass
- Changing the reflectance of surface materials
- Increasing glass area

Most of these properties have secondary effects on other indicators which also have been investigated. These connections can be seen in Table 8.1. The exceptions to this are the simulations with different reflectance of the surface materials; this measure does not have any other significant effect on other indicators. Window placement can also affect daylight but has been omitted as it would be far too easy to "cheat" the system as daylight is only measured in a single point and therefore allows unjust optimization. The results are presented according to the type of change made to the original model.

9.2.1 Inclining the window niche

Inclination of the window niche, see example in Figure 9.4, was varied with 10° intervals between 0° and 30°, and named as follows:

0. Original construction; no window niche inclination
i. 10° window niche inclination
ii. 20° window niche inclination
iii. 30° window niche inclination

Figure 9.4. The inclined window niches can be seen on the left, compared to the original building to the right. The simulations are done for February 9.00 am.

Thermal bridges were recalculated to account for the change in wall construction for this option since the thermal bridges, and therefore the heating demand, will be affected by removing insulation around the windows (see Appendix B).

Table 9.4. The results from inclining the window niche. These daylight factors do not meet the criteria of 1.2%.

Case	0. (Original)	i. (10°)	ii. (20°)	iii. (30°)
Daylight factor [%]	0.8	0.9	0.9	0.9
Annual heating demand [kWh]	3205	3227	3251	3262

As can be seen in Table 9.4, the results only reach 0.9 for all alterations. This is partly due to the rounding that Velux applies; all values from 0.85 to 0.94 are displayed the same when extracting values. This is a major source of error. However it is still obvious that only changing the inclination does not make Kuben meet the indicator's demand of 1.2%.

Positive effects from inclining the window niche can be seen in Figure 9.5. In rooms with more distance to side walls from windows, light can spread more easily. As this solution mainly changes how the light is spread in the room and not the quantity of light, measuring the daylight factor in a single point can have major implications.

Figure 9.5. The bathroom window in October, 9.00 am. The only change between the left and the right is the angles of the window niches. More light pass unobstructedly by using a 30° inclination, at the left.

9.2.2 Glass properties

The glass' properties were changed according to available glass types. The purpose was to increase the light transmittance of the window to increase the daylight factor. This also has implications on the annual heating demand as it affects the g-value and the U-value of the glass. Changing the g-value also affects the solar heat load and the thermal climate during summer.

The window frame is assumed to be the same for all simulations. Actual data for the simulations have been taken from Nordan for the current window and Pilkington for the four variations simulated. A less extreme glass, case vii, was simulated to showcase the importance of this choice.

0. Original – Nordan Ntech passiv
iv. Pilkington Suncool 70/40
v. Pilkington K-glass and optitherm S3
vi. Pilkington optitherm S3 – three glass setup
vii. Pilkington optitherm S3 – two glass setup

The windows used were chosen based on an increase of the LT-value; the original window has a LT-value of 57, and the others increasing numbers according to the last column of Table 9.5 below. The construction of the glass is described as well. Numbers represent thickness, either of the glass or of a gas filled gap. LE stands for low emission coatings, Ar for argon. C, K and S(3) are names of different types of glass.

Table 9.5. Glass properties of the chosen alternative solutions. The LT-value is increased compared to Nordan Ntech, which is installed in the original building.

Type	Construction	U_g [W/m²·K]	g [-]	LT [%]
Nordan Ntech passiv	6LE-16Ar-4-20Ar-4LE	0.5	0.36	57
Pilkington Suncool 70/40	6c(74)-16Ar-4-16Ar-S(3)4	0.6	0.38	63
Pilkington K-glass and optitherm S3	4k-30-4-16Ar-S3(4)	0.7	0.51	67
Pilkington optitherm S3	4-16Ar-S(3)4-16Ar-S(3)4	0.6	0.52	71
Pilkington optitherm S3	6-15Ar-S(3)4	1.1	0.59	79

Simulations of the building with different window properties gave the results in Table 9.6. Results are given for the room furthest from the requirements, where applicable. No glass reaches 1.2% daylight factor, but some are close. Note that all other indicators change considerably when altering the glass. This is due to the changes in U- and g-value, as mentioned above. An identical frame was used for all windows with properties specified by Nordan.

Table 9.6. *Resulting values for on the different indicators when changing window glass. None of these changes achieve a daylight factor of 1.2%.*

Case (U_g/LT/g)	Daylight factor [%]	Annual heating demand [kWh]	Installed power [W/m²]	Solar heat load [W/m²]	Thermal climate summer; SVF [-]
0. (0.5/57/0.36)	0.8	3205	15.70	19.88	0.025
iv. (0.6/63/0.38)	0.8	3307	16.04	21.14	0.031
v. (0.7/67/0.51)	0.9	3274	16.42	27.79	0.035
vi. (0.6/71/0.52)	1.1	3105	16.04	28.51	0.036
i. (1.1/79/0.59)	1.1	3819	17.99	33.37	0.042

This graph shows the correlation between daylight factor and annual energy demand for different glasses and their properties. Note that an increased U-value does not correspond to an increase in annual energy demand, but actually lowers it for the glass with LT 71. This fact combined with the brighter indoor environment makes this glass type very appropriate for housing with small window areas.

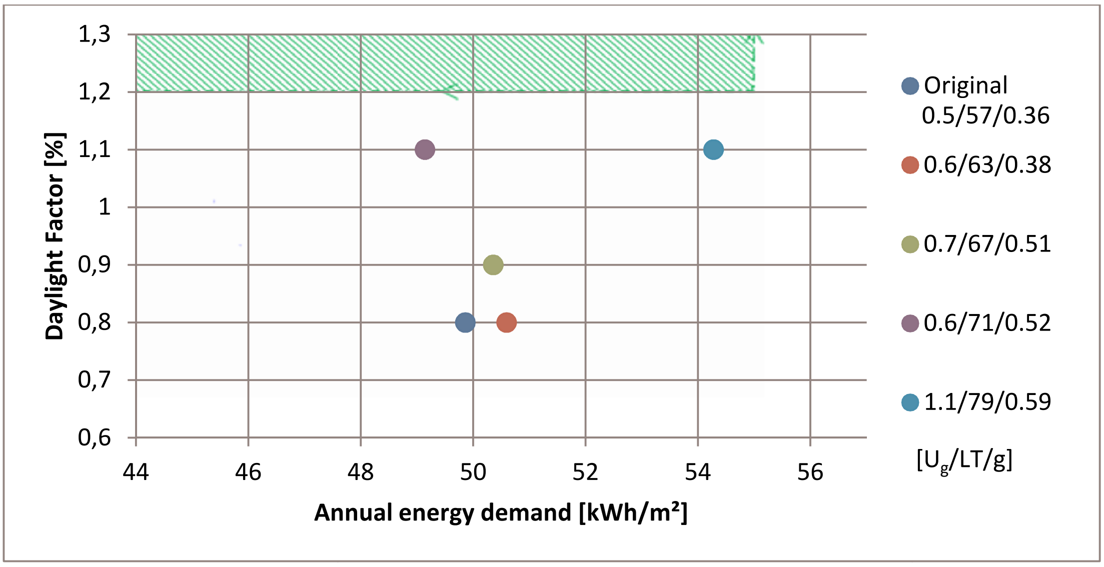


Figure 9.6. The daylight factor in bedroom 2 plotted against annual energy demand for the building. An increased daylight factor does not mean that additional energy is required, as can be seen on 0.6/71/0.52 (purple). Points in the green area fulfil the criteria of daylight factor over 1.2% and annual energy demand less than 55 kWh/m².

9.2.3 Surface materials

Since the color and reflectance of internal surfaces affect the daylight factor, these were altered in order to investigate the consequences in the point selected by Miljöbyggnad. Results are presented below, depending on the chosen materials of the inside surfaces. Since only the lighting conditions are changed when altering the surfaces, all other indicators beside daylight are omitted in Table 9.7. The following paints were tested:

0. Original; matte white color on walls and ceiling with 84% overall reflectance in the color spectrum. Bright wooden flooring
viii. All surfaces changed to 90% reflectance – highly reflecting paint
ix. All surfaces changed to 100% reflectance – theoretical investigation

Table 9.7. Results from changing the surfaces' reflections and materials. As can be seen, none reach 1.2% daylight factor.

Case	0. (Standard)	viii. (90% reflectance)	ix. (100% reflectance)
Daylight factor [%]	0.8	0.9	1.0

Only changing surface materials does not make the building reach the required 1.2%. The 100% reflectance option is included to serve as an upper limit of what is possible by changing the reflectance; it is not a real possibility as there are no such paints.

9.2.4 Window sizes

The windows total area, glass and frame, were increased to let more daylight in. This was done in three steps with an addition of 10% each according to Figure 9.7

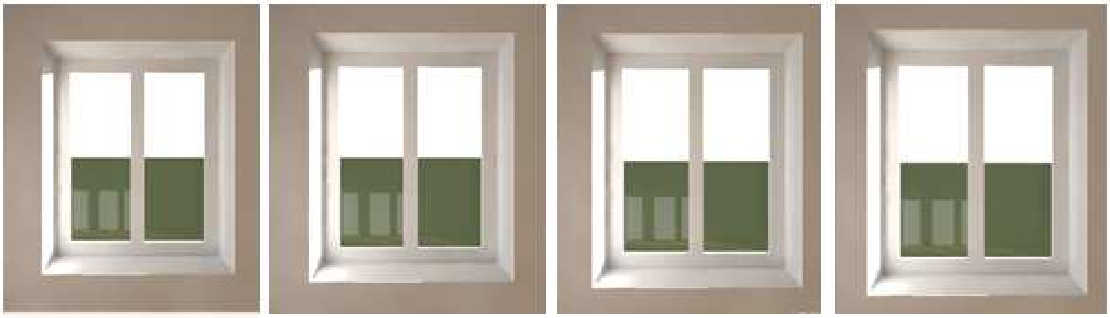


Figure 9.7. Increasing the window size. From left to right: Original, 10%, 20% and 30%.

x. 10% window area added

xi. 20% window area added

xii. 30% window area added

As daylight simulations are done for the worst room, in this case both on the 2nd floor, the altered window is 1.4m·1.1m (#1 in Table 7.3). Since the frame width was kept the same, the relative glass area increases. The resulting areas are displayed in Table 9.8.

Table 9.8. The resulting window and glass areas when increasing the windows 10%, 20% and 30%.

	Original window	10 % added	20% added	30% added
Total area [m²]	1.62 (-)	1.78(10%)	1.94 (20%)	2.10 (30%)
Glass area, and relative increase [m²]	1.15 (-)	1.28 (12%)	1.42 (24%)	1.56 (36%)

The results from changing the area of the windows are presented in Table 9.9 below. Increasing window area is clearly beneficial for daylight.

Among the other indicators note that the annual heating demand decreases at first, and then increases. This is most likely caused by the window area being increased on all sides of the building, including the north façade. When the window area is increased only slightly, the energy gain from the area facing south affect heating the most, and lowers it. The losses on the north façade eventually influence the most, however, and increase the heating demand.

Table 9.9. Results on indicators from increasing window area. By adding 30% a daylight factor of 1.2% is reached.

Code	0. (Original)	x. (10% added)	xi. (20% added)	xii. (30% added)
Daylight factor [%]	0.8	1.0	1.1	1.2
Annual heating demand [kWh]	3205	3179	3296	3353
Installed power [W/m²]	15.70	15.91	16.13	16.36
Solar heat load [W/m²]	19.88	22.77	25.43	28.13
Thermal climate summer, SVF [-]	0.025	0.028	0.031	0.034

Increasing the window area significantly changes the daylight factor in the point considered (half the room depth). The graph in Figure 9.8 shows how the daylight factor declines with increasing room depth. Simulations were made 800 mm above the floor, 1 m from the darkest wall in accordance with Miljöbyggnad.

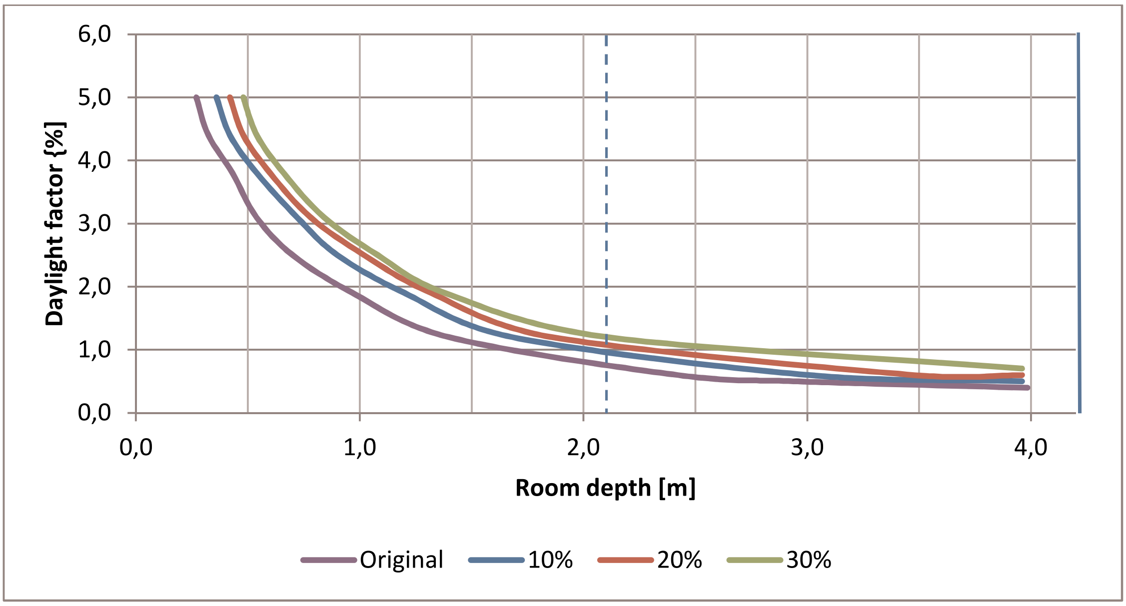


Figure 9.8. The impact of increasing window area in bedroom 2, by depth. The values are taken 0.8m above the floor and 1 m from the darkest wall. The gap between the curves is the greatest close to the window at 0 m.

Figure 9.8 shows the effect on daylight factor from increasing the windows' area, along the depth of bedroom 2. The difference is greater close to the window, placed at 0 m, than further into the room. This means that the average daylight factor may increase more than a point value at 50% room depth, when the area close to the window with proportionally high values raises the mean value.

9.2.5 Combined results

Some combinations of the simulation setups described above were conducted to see if two, or more, partial solutions would reach the demand of 1.2% daylight factor. Only one of the measures tested so far managed to reach the target, so a combination of measures is generally needed to fulfill the daylight criteria.

Combined results for increased window area and window niche inclination are omitted since larger window areas eliminate the need for window niche inclination, for the room considered. This depends on the distance between the measurement point and the window, and the fact that window niche inclination spreads light toward the sides of a window and not further into a room. This is further developed in Section 9.2.1. The following combinations were however tested:

- vi. & iii; 0.6/0.71 glass and 30 degrees window niche inclination
- vi., iii. & viii; 0.6/0.71 glass, 30 degrees window niche inclination and 90% surface reflection
- vi. & x; 0.6/0.71 glass and 10% increased area
- vi. & xi; 0.6/0.71 glass and 20% increased area
- vi. & xii; 0.6/0.71 glass and 30% increased area
  [U_g/g]

Table 9.10. Some combinations of previous possible solutions. As can be seen, this is efficient enough to reach 1.2% daylight factor, although solar heat load increases as a consequence.

Combinations	Daylight factor [%]	Annual heating demand [kWh]	Solar heat load [W/m²]	Thermal climate summer, SVF [-]
0. (Original)	0.8	3205	19.88	0.025
vi. & iii	1.1	3160	26.80	0.035
vi., iii. & viii	1.2	3160	26.80	0.035
vi. & x	1.2	3147	30.08	0.039
vi. & xi	1.4	3188	34.65	0.043
vi. & xii	1.5	3239	38.16	0.048

The criteria of 1.2% was reached for several of the combinations, the most interesting of these are compared to the criteria for passive houses and the GOLD level for Miljöbyggnad in Table 9.12. Kept in that table is also the standard building for reference. As can be seen, while daylight has improved, there are other factors that have decreased. It is worth mentioning once again that for some proposed changes, annual heating demand decreases. Four interesting combinations are selected which reach the criteria by different means; these can be seen in Table 9.11.

Table 9.11. Simplification into new case notation, which will transfer into the next section.

Previous notation	Description	New notation
vi., iii. & viii	U_g/LT 0.6/71, window niche inclined 30 degrees and 90% surface reflectance	A
vi. & x	U_g /LT 0.6/71 and 10% increase in window size	B
vi. & xii	U_g /LT 0.6/71 and 30% increase in window size	C
x	U_g /LT 0.5/57 and 30% increase in window size	D

Table 9.12. Comparison of working solutions for daylight with the other parameters and the criteria set by both the Passive House standard and Miljöbyggnad level gold. The solar heat load is too high for all solutions.

Parameter	Daylight [%]	Energy [kWh/m²]	Installed power [W/m²]	Solar heat load [W/m²]	Thermal climate winter, PPD [%]	Thermal climate summer, SVF [-]
Gold level	≥1.2	≤58.5	≤25	≤18	≤10	<0.025
Passive house	-	≤55	≤17	-	-	≤0.036
Original	0.8	49.86	15.70	19.88	8.12	0.025
A	1.2	49.53	16.18	26.80	8.14	0.034
B	1.2	49.44	16.29	30.08	8.15	0.038
C	1.5	50.10	16.80	38.16	8.18	0.048
D	1.2	50.92	16.36	27.64	8.15	0.035

As can be seen in the table, and by applying the set workflow, see Figure 8.4, the next parameters to be focused on are solar heat load and thermal comfort during the summer. These are calculated in the same manner except for a factor of 800. The consequence of this is that as long as the solar heat load indicator is fulfilled thermal climate summer will also be satisfactory. The four solutions referenced as A-D will therefore be further developed with regard to solar heat load in the following section.

9.3 Solar heat load and thermal comfort

The different solutions complied with daylight criteria are adapted in an effort to make the solar heat load reach adequate levels. This will be done by adding solar shading, since a lower g-value will decrease the solar heat load (see Chapter 5). Other factors influencing the solar heat load are glass and room area. Since both these two factors are fixed, one by blueprint and one in the previous section, they are from now on left unchanged.

The g-value for the original building is 0.221, which includes the window's g-value of 0.36 and a roof overhang of 63 cm. This means that 22.1% of the sun's radiated energy is transferred into the room, through the windows. As a reference, the required g-value is calculated to 0.2 for the upstairs living room to reach a solar heat load below 18 W/m², for the original window to floor ratio. The increasing glass areas used to comply with the daylight indicator will further reduce this value. See Equation 6.1. The graph in Figure 9.9 below shows the required g-value for the remaining shading system to reach the desired SVL-number depending on cases A-D.

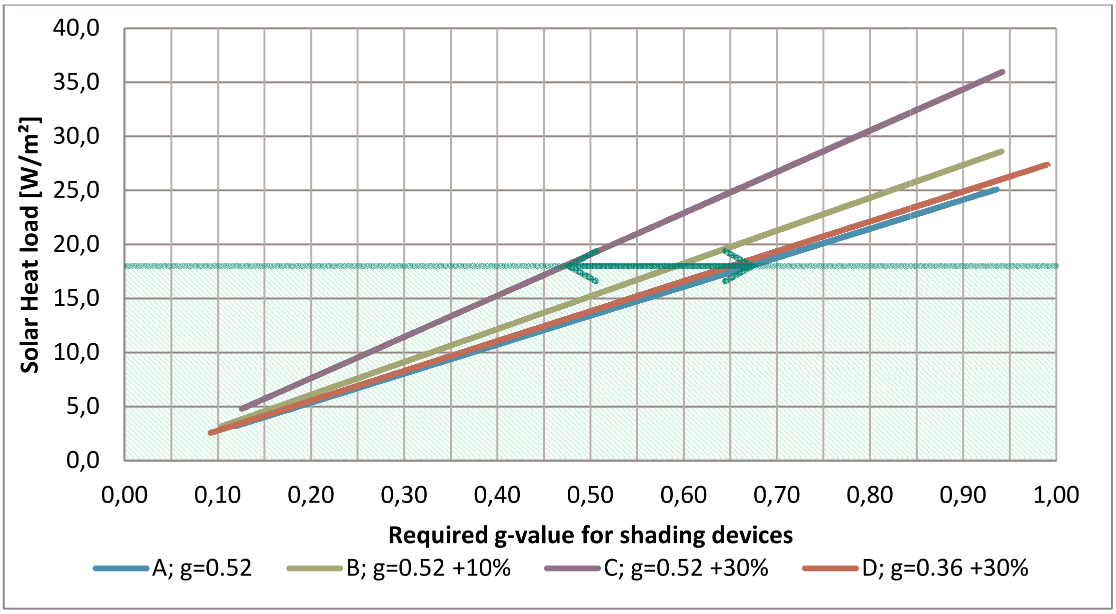


Figure 9.9. The different cases, and the development of SVL-numbers by g-values. Values are taken from simulations and the trend lines plotted. There is a large span marked by the green arrow which makes the different cases reach below 18 W/m² and into the green area, where the criteria is met.

From the graph, window size and properties can be seen to greatly affect the demand on the remaining g-value to reach the required solar heat load of 18 W/m², marked by a horizontal green line. The difference between case A and case D is very small. This is due to the increase in window area roughly compensating the increased g-value.

Note that generic g-values for shading devices, for example found in tables in SVEBY, is not enough to determine if the shading device is able to fulfill the solar heat load demand. In general, simulations of the shading device in combination with the actual window used are needed. This is further developed in Chapter 10.

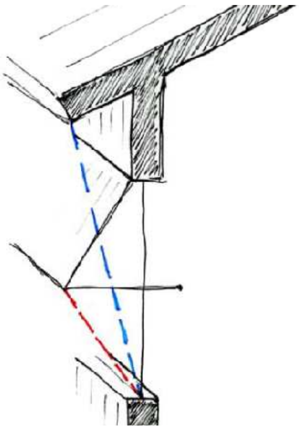


Figure 9.10. The shading angle is measured from the bottom of a window. The blue line marks the angle to the soffit, and the red to a shading awning (Sandström, 2012).

The existing roof overhang is equal to a 21.7° shading angle for the original window size, measured from bottom. The simulated room is still bedroom 2, making the window 1.39 m·1.13 m (#1 in Table 7.3). The windows are installed 53 mm into the wall, which provides some additional shade. However, due to rounding off in the software, 50 mm had to be been used in all simulations. These two effects are included in Table 9.13 below, which is used as a comparison to find the change in g-value for the different shadings. Glass with a g-value of 0.52 is not used in the existing building but rather needed for comparison reasons later on.

Table 9.13. g-values for the windows in Kuben. The total g-values are reference when new g-values are simulated for different solutions later on.

Case	g-value glass [-]	g-value system [-]	g-value soffit [-]
Original	0.284	0.221	0.78
A	0.395	0.298	0.75
B	0.393	0.304	0.77
C	0.392	0.312	0.80
D	0.282	0.226	0.80

9.3.1 Fixed shading devices

Other angles on this roof overhang were tested, and results are presented in Table 9.14 on the next page. Since shading angles above 45° are improbable due to the length of the required extension, only two angles are simulated. The required lengths for these are different due to the different window-height among the cases, see Table 9.8. Note that cases A-D all have a soffit length of 63 cm in base versions, independent of actual angle.

0. Original: 21.7°, 63 cm
1. 30 degrees (A:98 cm, B:102 cm, C & D:110 cm)
2. 45 degrees (A:158 cm, B:165 cm, C & D:177 cm)

The original building's results are included along with all new results below. Notation is made by combining the letter for each case with the number of the shading device. This procedure will continue throughout the rest of the report.

Table 9.14. Results on indicators caused by fixed shading devices.

Shading setup	g-value system [-]	Solar heat load [W/m²]	Annual heating demand [kWh]	Daylight factor [%]
Original (0)	0.221	19.88	3205	0.8
A	0.298	26.80	3160	1.2
A.1	0.242	21.77	3192	1.0
A.2	0.176	15.83	3247	0.9
B	0.304	30.08	3147	1.2
B.1	0.239	24.08	3180	1.1
B.2	0.176	17.23	3240	0.9
C	0.312	38.16	3239	1.5
C.1	0.239	29.24	3176	1.4
C.2	0.176	21.53	3346	1.1
D	0.226	27.64	3353	1.2
D.1	0.166	20.31	3382	1.1
D.2	0.123	15.05	3446	0.9

For cases A, B and D, a 45° shading angle makes the living room pass the solar heat load criteria.

The energy demand initially decreases for case A. This is explained by the higher g-values of the windows, which compensate the expected increase in heating demand due to more shading compared to the original case.

Results show that fixed shading alone produces a working solution for solar heat load in only one of the cases above, D.2. This solution would however decrease daylight levels below the requirements. Case C.1 is the only new solution fulfilling daylight demands, however not fulfilling solar heat load demands. A combination with moveable shading for this option will therefore be tried later on.

9.3.2 Movable shading devices

Movable shading does not affect the daylight factor, since residents are assumed to remove movable shading when required, in order to increase light. This should make movable shading a suitable choice since the hardest requirement to reach is daylight. All movable shading have been added to the original building, which means the fixed shading of 63 cm is present for all simulations with one exception. It was excluded with the awnings since the shading angles are significantly higher than those of the fixed soffit. This can be seen in Figure 9.10.

For annual heating demand simulations the generic shading coefficient of 0.71 advocated by SVEBY, is replaced by actual values from ParaSol. The values used are the lowest values during summer, which are then used for the whole year. This procedure fulfills calculations of solar heat load as those should be calculated for the worst case during the year. On the other hand, it puts annual heating demand simulations on the safe side as more sun would generally be transmitted during the winter due to lower incident angle.

For annual heating demand, simulating with a reasonable control system is of importance. The shadings will be drawn when the solar radiation reaches 100 W/m² on the external window surface. This value is used by manufacturers of control systems, and was therefore used for the following simulations as well.

Figure 9.11 below contains all simulations made, presented according to main case as stated above. A total of 15 shading devices were simulated for each of the four cases, divided as follows:

- 2 types of external awnings with 4 angles each; 30°, 45°, 60° and closed
- 2 types of internal blinds (venetian blinds), both with 0° or 80° slat angles
- 3 different internal roller-blinds

The graph in Figure 9.11 below shows how the g-value for the different shadings depend on the case studied. The different shadings types studied have been visualized as an interval to show which g-values that can be expected from a shading type for a particular window. These g-values are however only ensured for the current setups; as can be seen on the stretched and diverse intervals it is difficult to predict what g-value a shading device will result in. An illustration of a closed awning can be seen in Figure 9.13.

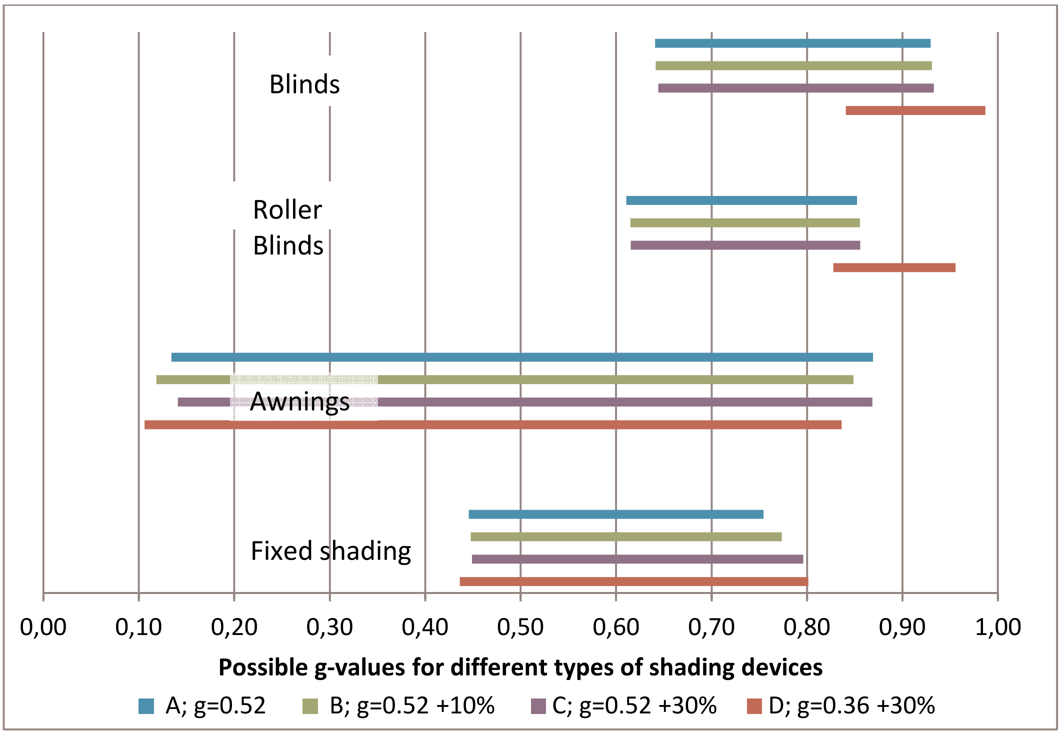


Figure 9.11. The span of g-values for the different tested types of shading devices, depending on case. Case D, with a different glass type, can be seen differing much against the other three for both internal shadings.

It is clear from the graph that the g-value of the window highly influences the obtainable g-values from internal shading devices; both the range and minimum g-value devices are highly affected. External shading devices are however largely unaffected by the choice of window properties and size. Note that for internal shading devices, obtainable g-values are substantially lower for case A than for case D. Bear in mind that Figure 9.9 earlier in this chapter showed that case A and case D require roughly the same g-value to reach the solar heat load demands, which mean that the suitable solutions for these two cases may be very different. Figure 9.12 shows the same shading devices for the different cases, but with solar heat load instead of g-values.

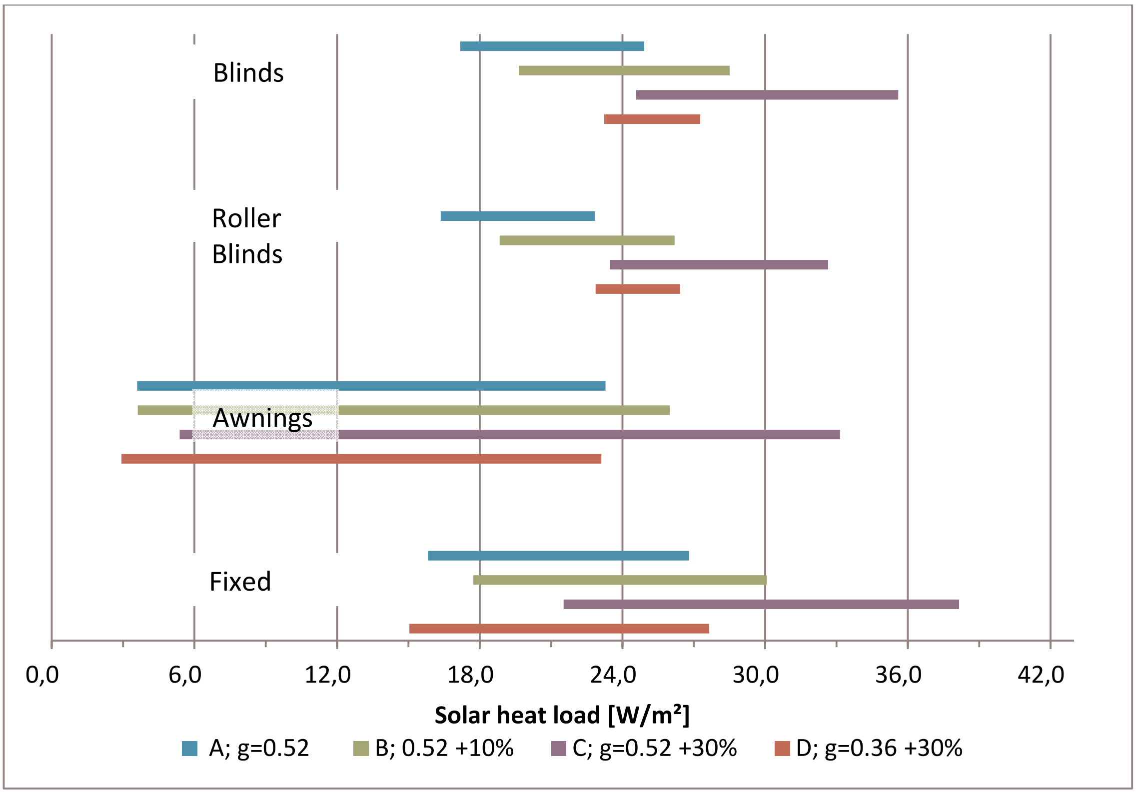


Figure 9.12. The span of SVL-values for the different shading devices, depending on case. Case D has a smaller span for both internal shading devices. Case C does not reach below 18 W/m² by any other means than by using awnings.

In Figure 9.12, which shows solar heat load for incorporations of different shading devices, the differences between the cases become more apparent. A larger deviation among the cases for internal shadings can be seen, as window size becomes a major factor. A larger window/floor-ratio causes the solar heat load to rise; which is elementary when looking at how it is calculated in Miljöbyggnad, see Chapter 6. However, reduced window area also leads to a smaller span with obtainable solar heat load for internal shading devices.

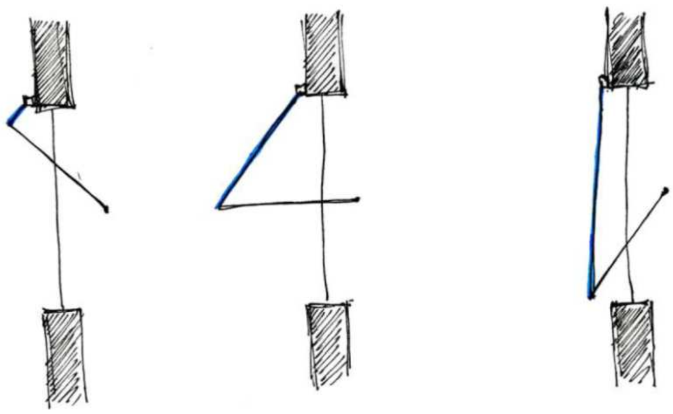


Figure 9.13. Different possible shading angles when using awnings. The awning to the right can be regarded as completely closed, since no sky can be seen (Sandström, 2012).

Three shading devices out of the 15 above were selected for complete simulations, and are presented below in Table 9.15. These three were chosen since at least one of the cases A-D, by only using this solution, reached a solar heat load below 18 W/m². They are also the solutions with the lowest solar heat load in each category of shading devices. Therefore, the three setups correspond to the points furthest to the left in Figure 9.14 below, for each type respectively.

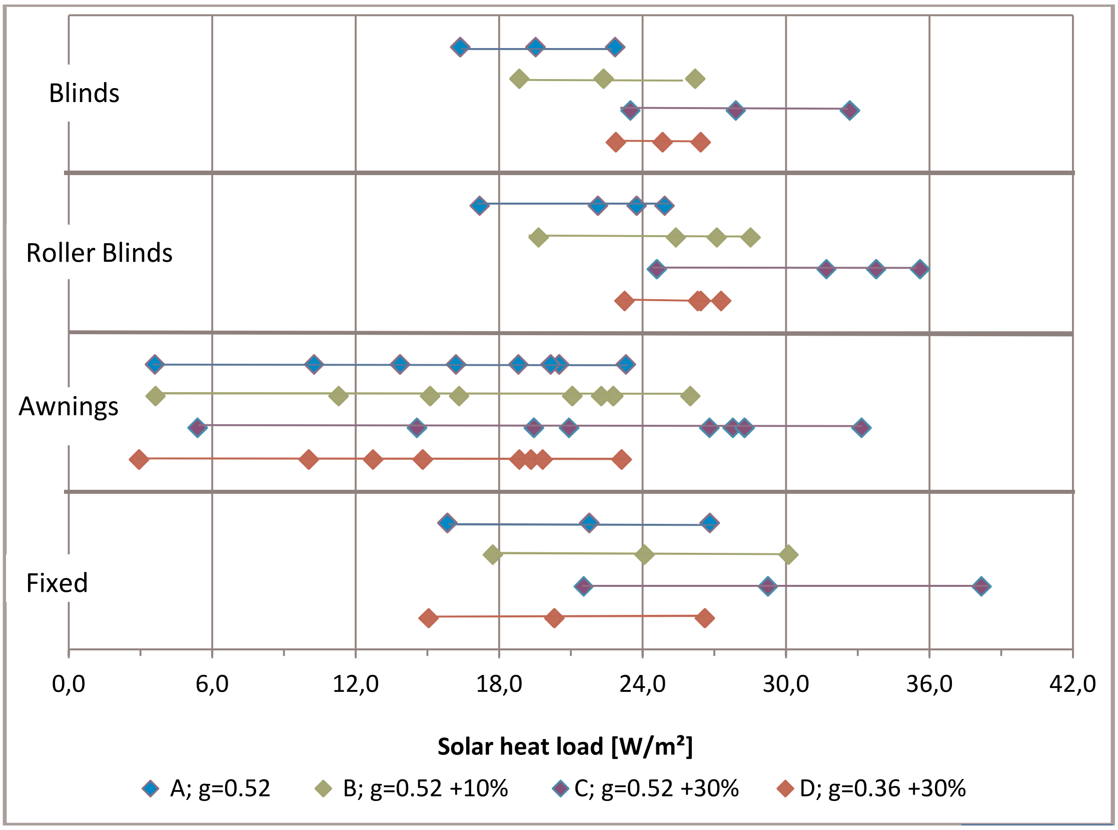


Figure 9.14. The simulated SVL-values for the different shading devices, depending on case. Every point represents one tested setup. The solutions with lowest resulting values have been used for complete simulations.

The selected setups are:

3. Awning, made by Sandatex - model Para 6, completely closed
4. Bright blind (high reflection), angled 80°
5. Roller-blind, made by Dickson-Constant - model Samoa 4246, completely closed

Table 9.15. Results on indicators dependant of movable shading devices.

Shading setup	g-value system [-]	Solar heat load [W/m²]	Annual heating demand [kWh]
Original building	0.221	19.88	3205
A.3 (awning)	0.040	3.60	3372
A.4 (blind)	0.191	17.18	3056
A.5 (roller-blind)	0.182	16.37	3071
B.3	0.036	3.63	3366
B.4	0.195	19.64	3041
B.5	0.187	18.70	3050
C.3	0.044	5.38	3465
C.4	0.201	24.59	3104
C.5	0.192	23.49	3124
D.3	0.024	2.94	3477
D.4	0.190	23.24	3158
D.5	0.187	22.87	3145

Table 9.15 shows that closing awnings is a very efficient way to lower unwanted radiation from the sun, as all cases combined as "X.3" have a solar heat load of less than 6 W/m²; a third of the demand. For internal shadings, the annual heating demand decreases which might seem contradictory. The explanation is that the generic shading factor of 0.71 advocated by has been replaced with a factor controlled with a schedule and thus not continuously active. This allows the windows to let more energy into a building when the sun is beneficial and less energy when there is a danger of over temperatures.

9.3.3 Combinations of shading devices

In order to improve the fixed shadings that did not reach desired levels, combinations of fixed and moveable shadings are certainly possible. Since C.1 is the only new fixed shading that met the daylight demands, this is the only model further developed here. Others have no chance of passing daylight criteria and are therefore not possible complete solutions. The following three combinations were simulated, all additions to case C.1:

6. Fixed roof overhang of 30° and internal bright blind, angled 80° (C.1 and C.4)
7. Fixed roof overhang of 30° and closed internal roller-blind; Dickson-Constant - samoa 4246 (C.1 and C.5)
8. Fixed roof overhang of 30° and closed internal roller-blind; Dickson-Constant - opaque m005 (C.1 and a new roller-blind model)

Table 9.16. Results on indicators with combined systems of shading devices.

Shading setup	g-value system [-]	Solar heat load [W/m²]	Annual heating demand [kWh]
C.6, (overhang and blind)	0.153	17.89	3154
C.7, (overhang and roller-blind)	0.145	16.95	3173
C.8 (overhang and roller-blind)	0.173	20.23	3109

Two of these modifications are able to comply with the indicator for solar heat load. Noteworthy is that the annual heating demand decreases. The reason is, as previously, due to the generic shading coefficient being replaced.

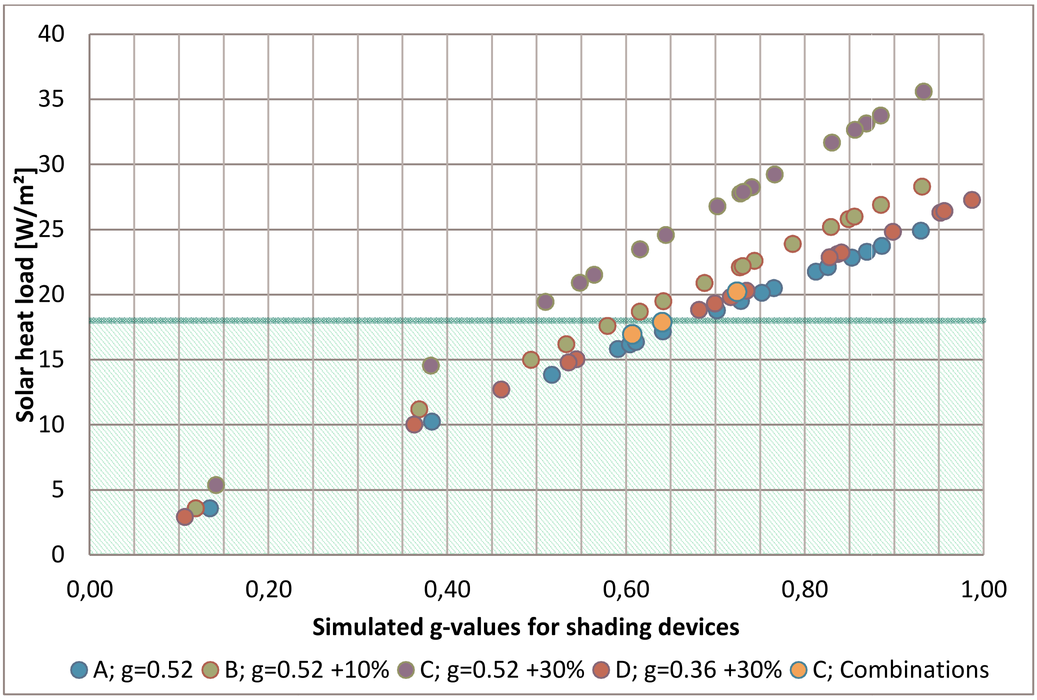


Figure 9.15. All simulated cases of shading systems, depending on case. Points in the green area reach the demand of SVL less than 18 W/m².

Figure 9.15 shows all the different simulated shadings and which g-values they provide for the different cases. Two different angles of awnings are clearly visible around 0.1 and 0.4 g-value, which effectively make awnings the most efficient way to shade the sun out of the tested devices. Higher g-values are obtained for fixed shading, roller blinds and blinds. Points in the green area marks solutions reaching below 18W/m², so several solutions provide sufficient shading to meet the requirements. Only a few of these comply with daylight requirements, however, as most fixed shadings fail to allow light into the building.

9.4 Working solutions

To summarize the results, the different working solutions will be presented. Increasing window size and/or increasing LT-value enable the building to comply with daylight demands, and the increased solar heat load from those changes can be handled by different shading options.

- If external moveable shading (in this case, awnings) is chosen, any of the four cases will present a working solution (A.3, B.3, C.3, D.3).
- If internal shading devices are to be used only case A presents a working solution. Case A has a higher reflecting wall paint and the window niches are inclined (A.4 or A.5).
- If the roof overhang is extended, case C also presents working solutions combined with optional internal shading (C.6 or C.7).

Final results for these solutions are presented in Table 9.17 below. The first part contains the requirements and the original, the middle part the solutions comprising internal shading devices, and the final one shows the different cases with a closed awning.

Table 9.17. Summary of working solutions made up by combinations with different internal shading (A.4-C.7) and external awnings (A.3-D.3), and their results for all assessed indicators. Different means of comparison are included at the top.

Parameter	Daylight [%]	Solar heat load [W/m²]	Energy [kWh/m²]	Installed power [W/m²]	Thermal climate winter, PPD [%]	Thermal climate summer, SVF[-]
Miljöbyggnad, level Gold	≥1.2	≤18	≤58.5	≤25	≤10	<0.025
Passive house	-	-	≤55	≤17	-	≤0.036
Original	0.8	19.88	49.86	15.70	8.12	0.025
A .4	1.2	17.18	48.79	16.18	8.14	0.021
A .5	1.2	16.37	48.89	16.18	8.14	0.020
C.6	1.4	17.89	49.49	16.80	8.18	0.022
C.7	1.4	16.95	49.63	16.80	8.18	0.021
A.3	1.2	3.60	51.06	16.18	8.14	0.0045
B.3	1.2	3.63	51.02	16.29	8.15	0.0045
C.3	1.5	5.38	51.73	16.80	8.18	0.0067
D.3	1.2	2.94	51.81	16.36	8.15	0.0037

There are several possible solutions all of which depending on movable, mostly external, shading.

It can be concluded that it is certainly possible to both follow passive house standards and achieve a high environmental classification, which is a way to ensure good buildings.

10 DISCUSSION

Several interesting thoughts have emerged during the course of this thesis, most of which are presented in this chapter. Firstly, window properties will be discussed, then shading devices and lastly Miljöbyggnad and problems with how the indicators are simulated.

10.1 Window properties

Specifying window size and glass properties is a very complex issue due to the number of factors it affects. A common problem when trying to comply with environmental classification systems such as Miljöbyggnad is the contradicting demands. A high daylight factor means large windows with high light transmittance, while solar heat load prescribes small windows with low g-values. Annual heating demand and installed heating effect further benefit from small window areas. These parameters lead to an optimization process that is iterative in nature, making it somewhat slow and almost impossible if factors such as daylight are considered too late in the project. To just state a glass areas to use would be an over-simplification, but to choose a glass area can lead to restrictions in choosing the most appropriate windows. The opposite is also possible; specifying a type of window to find a required glass area. It is essential that these parameters are evaluated early in the process to allow for optimization. Our working concept of focusing on one parameter at a time works reasonably well when considering revisions late in the project, but when designing from scratch a more holistic approach might be preferable.

Our suggestion would be to start by deciding on what level of demands the building should comply with. Step 2 would then be to look at installed power demands and calculate a required U_m-value. This would have to include an estimation of ventilation and air-leakage losses. Step 3 would involve a basic window placement including areas. A starting point for this step could be to use a glass to floor ratio of 15%. Step 4 would require a daylight analysis of the building, which gives the required light transmission value for the windows, for that particular size and placement. Several window options could then be suggested based on LT- and U-values, that is required to comply with the U_m-demand. Step 5 is to use these different U-values to determine a required thickness for the other construction parts. At step 6, solar heat load is considered which determines what shading is required for the building. This process is illustrated in Figure 10.1.

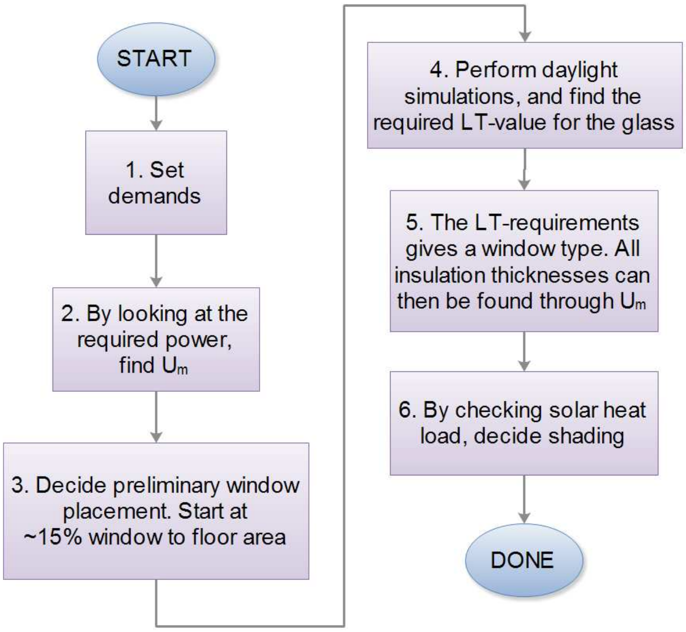


Figure 10.1. A suggestion on design path to find a good window configuration, in early stages of a project design. Some steps may require iteration, for instance if there is no possibility to achieve daylight requirements with the chosen window placement.

Since the original building was quite far from reaching the goals set in the classification system, the **window to floor ratio** chosen for the specified glass type can be questioned. The LT-values of the glass <u>have to</u> be considered when deciding these areas, or the experience of the finished building may deviate from the architect's vision. The combination of g-value and LT-value is also interesting, since not all of the radiation included in the g-value is "useful" as visible light for humans. A proportionally high LT-value and low g-value will result in a large part of the energy transmitted being visible light which maximizes the quality of the indoor environment.

The windows current construction comprises decorative **crossbars**, effectively blocking 10% of the glass area. This is not a good solution for the daylight environment. Which quality weighs more in passive houses, decorative bars or the indoor light conditions should be discussed by the client and/or architect prior to construction.

Besides bedroom 2, **hallways** and **bathrooms** have very poor daylight, but due to the specifications in Miljöbyggnad, these were omitted from calculations. Large improvements are made here as well if the proposed changes are done throughout the building, for all windows. It is not necessary to comply with the environmental classification standard but will contribute to a better daylight situation.

The **window niche inclination** has a very small impact on the heating demand but provides a fair amount of additional daylight, but not necessarily in the point specified. This is further discussed in Section 10.3. The unchanged heating demand can easily be comprehended as the thermal bridge already exists and thus the removed part of the wall has little insulating effect. Perhaps what this proposal accomplished is to lessen the sensation of the thick walls, especially in the bathrooms.

A simple solution such as using wall paint with **higher reflectance** will improve daylight conditions. This solution combined with carefully choosing suitable windows considering not only the **U-value** but **also g- and LT-values** is needed if low glass to floor area ratios is to be maintained. Results also show that a higher U-value for the glass can be completely offset by an increased g-value when it comes to heating demand. This is highly dependent on orientation and cannot be used as a general rule when choosing windows, but may prove beneficial when large windows are facing south. Careful considerations must however be done to avoid overheating.

After the simulation part of this study and out of interest in the **economics** involved, the window manufacturer Nordan was asked to approximate the difference in price between the original windows used and a window with glass corresponding to the one recommended in this thesis, with U_g/g of 0.6/0.52. The latter turned out to be about 20% cheaper due to simpler coatings and materials (Nordan, 2012b). Combined with the fact that this window decreases energy demand and increases daylight, this would be a better choice in future projects.

10.2 Shading

With regard to daylight, moveable shading devices are always preferable, and can be more effective than fixed shading considering the annual heating demand as well. The efficiency is very dependent on the way manual interactions with the shading device are simulated. As stated, simulations of the control in this thesis are based on sun intensity. Using this type of control system for simulations has several disadvantages, such as being unable to use moveable shading during nights to affect night-time radiation. To compensate for the sun intensity being measured on the inside of the glass, the threshold at which shading is drawn was adjusted depending on the glass type simulated; the used threshold was simply multiplied with the g-value of the glass. This technique is reasonable, as shading devices might be drawn to avoid glare issues. The method of using sun intensity as a control for shading systems is not completely accurate as people need to be at home in order to use solar shading when no automation is present. This cannot be taken into account other than changing the threshold, which also introduces an error as radiation is highest in the middle of the day when many are at work. For annual heating demand, results are on the safe side as the shading device is used more than it likely will be in the real building.

Among the simulated shading devices, several advantages and disadvantages can be found. **Awnings** are the most flexible due to the ability to control their angle from perpendicular to completely covering the window. Exterior shading devices have the advantage of absorbing and reflecting the incoming radiation on the outside of the building, making them more effective in general. A disadvantage of exterior shading devices are their exposed installation making them sensitive to strong winds. Furthermore, moving parts outdoors are being subjected to heavy wear. This is somewhat the opposite of internal **blinds** and **roller-blinds**; reflected energy has to be transmitted back through the window not to heat the building, but the shading devide is protected on the inside of the building. The radiation absorbed in the shading device will is trapped inside, since it is transmitted as long-wave radiation which only slowly passes the glass.

Simulations in ParaSol produce g-values for each month, which can vary greatly depending on the shading device. This has not been taken into account as only one value can be used in IDA ICE. The g-value chosen for annual heating demand calculations is the lowest g-value obtained, which is for July. Comparing g-values to

SVEBY's generic shading coefficient shows that internal shading devices are overestimated in SVEBY, especially for glass with a low g-value. Once again this is not a major problem as it puts annual heating demand calculations on the safe side. For solar heat load calculations, using these values are however not on the safe side.

To reach solar heat load demands, either adjustable awnings or a combination of fixed and internal shadings can be used. A **combination** of awnings and internal shading presents the same effect. For glare reasons internal moveable shading should always be available even if external shading devices are present; this way glare issues can be avoided while still benefitting from heat gains during heating season. Utilizing external shading devices to combat glare issues will have a severe impact on the heating demand. Large windows, or windows with a high g-value, may require external shading to reach sufficiently low g-values as internal shading devices may not be able to provide the shading required.

Out of the working solutions, the most versatile shading system is the awnings. The others involve more complex parameters, such as making the residents unable to redecorate by changing wall paint without lowering daylight performance when using reflective paint.

10.3 Miljöbyggnad

The original solution has poor daylight compared to the value stated in Miljöbyggnad. The way the daylight factor is measured in the environmental classification system affects what measures are effective to increase it. It is unclear why daylight factor in one single point is preferred; for office buildings, measuring daylight in certain points might be adequate for investigating daylight on work spaces. Perhaps it is done in this way to make hand calculations possible. Since measuring is done in a single point Miljöbyggnad's method is very sensitive to manual errors in terms of finding that point and extracting values from it correctly, depending on the simulation software used. In Velux, the program suggested in Miljöbyggnad, the point has to be manually placed.

The way daylight factor is measured also affects to which degree solutions are helpful. Since the daylight factor quickly diminishes with increasing distance from the window, measuring the daylight factor in a point at half the room's depth can be either beneficial or detrimental depending on the layout of the room. The comparable international environmental classification systems usually use an average daylight factor measured over the area of the room, which is less sensitive to manual errors. To achieve Miljöbyggnad's desired daylight levels, several of the solutions had to be implemented at the same time.

Depending on the layout of the room, certain window placements will be benefitted from the measuring point used in Miljöbyggnad. Placing windows close to the corners or using roof windows as to increase the daylight in the point specified may produce unwarranted results. This may be an acceptable solution for some cases but it is not a general, sufficient, tool to use to ensure good daylight. These methods are more a way of cheating the system.

Daylight factor is a measure of quantity during the worst possible conditions. It does not measure the quality of light as too much light will lead to overheating and glare problems. Nor does it consider what happens during less cloudy weather. Cultural differences may play a role in what quality of daylight is. Considering the Nordic climate with limited light during winter, to maximize daylight may be the best solution for the residents' well-being. Hopefully more emphasis is placed on daylight in projects, considering the effects when it lacks; especially for buildings at Sweden's latitude.

There are two alternative options in Miljöbyggnad to assess thermal comfort during summer: PPD and solar heat load. One of the most influential factors affecting PPD is the inhabitants' habits regarding voluntary ventilation of the building, which is very difficult to accurately simulate due to lack of statistics. Another important parameter is the amount of clothes the residents are wearing; as there is no cooling installed the indoor temperature's lower limit is the outside temperature, and the only way to adjust the indoor climate is to change the metabolism, clothing or airing the building out. To translate any given situation accurately into simulations software is therefore very problematic, and results can be adjusted according to the will of the operator since there are few restrictions. The conclusion is that PPD is not a very effective measurement of summer indoor climate in residential buildings. PPD should only be used when cooling is available, as is intended.

The alternative method suggested by Miljöbyggnad, solar heat load, also lacks in some regards. It is based on the maximum solar heat load, which is dependent on whether the shading device is used or not. Assuming manual control, this places a high degree of responsibility on the inhabitants. Using the solar heat load as a measure of thermal comfort may lead to solutions promoting smaller window/floor area ratios, which have disadvantages mentioned in the previous section. Since thermal comfort depends on many factors, described in Chapter 4, solar heat load alone is neither an accurate measurement of thermal comfort, nor indoor temperature. A complimentary demand regarding indoor temperature to achieve the highest grade could be added in Miljöbyggnad, such as duration limits on over temperatures. We decided that, having these two choices for summer indoor climate, using solar heat load as a measure of thermal comfort was more suitable for the building investigated. This was mainly done as more reliable data was available for simulations of solar heat load.

The factors used to calculate solar heat load are included twice in Miljöbyggnad, once considering thermal comfort (indicator 11 in Table 6.1) and a second time considering cooling load (indicator 3). This differs somewhat from the main idea of keeping this environmental classification system as simple as possible. It is also perplexing that these two demands, calculated using the same data, differs when it comes to the grading since the demand for indicator 3 is harder to reach. This can be interpreted as greater emphasis being placed on limiting the cooling demand than meeting thermal comfort criteria. Perhaps removing indicator 3 for buildings where cooling is not normally installed, such as residential houses, should be considered.

11 CONCLUSIONS

First of all, it is certainly possible for passive houses to achieve the highest grade in the environmental classification system Miljöbyggnad. However, to do so require careful planning and design. General guidelines to help during early design are difficult to create; a direct result of the conflicting objectives in designing good buildings. In this chapter, the thesis' questions will be answered and other important conclusions that were drawn along the way are presented.

- How does the type of windows and solar shading affect the energy usage of a passive house?

The increase in energy usage due to an increased U-value of the window may be completely offset by an increased g-value due to increased solar radiation, but is highly dependent on orientation. An increase in U-value or increased window size will have a negative impact on installed power demands due to lowered mean U-value of the envelope. All shading devices will have a negative impact on heating demand since solar gain is reduced. Using moveable shading devices could theoretically remove this effect but requires a high-performing control system. Fixed shading devices can be optimized to reduce this effect but only to a certain degree.

- How does the type of windows and solar shading affect the indoor climate conditions of a passive house?

Windows with low g-value limits the use of internal shading systems and may make internal shading inadequate to reach indoor climate conditions. Using moveable shading is always preferable when it comes to daylight. Large windows with a higher g-value may require external shading as it is more effective than internal shading. This should then be combined with internal shading in order to control glare.

- How can window to floor area-ratio be optimized with regard to energy and indoor climate conditions (including daylight)?

A starting point for window to floor area ratio should be about 15%. This is highly dependent on the glass used and to a certain degree the layout of the room. In order to allow for deeper daylight penetration, windows should always be placed as high as possible on the wall. The suggested path below could be used instead of solely a ratio, as it is more adaptive.

- What factors or connections can be found to simplify decision making when planning windows (type, area, solar shading and orientation) in early stages of construction projects?

As windows affect many factors the process of determining window size, glass properties and shading devices is iterative in nature. Our suggestion is to start by determining a suitable demand for installed power to be reached. This places restrictions on the U_m-value and thus narrows the window choice depending on how insulated the building is. A daylight analysis should then be made to investigate required LT-values for the windows. When windows have been specified, solar heat load is investigated to specify the shading needed. The entire concept of this suggestion can be found in Section 10.1.

12 CONTINUED WORK

During this thesis, a number of ideas have emerged that could be developed into new studies. These are based on problems along the way or ideas developed during discussions around the results.

- Investigate the difference in daylight simulation software. How does the free Velux simulator without grid and only manual extraction of values measure compared to other software with more advanced functions.

- Improve our suggested design process. The focus of this thesis was originally to find simple connections, and to do a comparative study of possible choices. It would be interesting to see what a thesis devoted to the window design process would find out.

- To look at a wider perspective of building optimization, unbound to classification systems. This could easily be combined with the suggestion above. We feel that following Miljöbyggnad's indicators when optimizing the building can restrict thinking in some ways. An example of this is the point value for daylight requirements discussed in Section 10.1. To be free of a standard to follow might lead to other results than those found by us.

- Assess Miljöbyggnad in general, and the calculation methods used. Examples of procedures that were questioned by us are the use of PPD in residential buildings and the point value for daylight requirements. The double uses of the factors in the SVL- and SVF-values are also interesting.

- Study the habits of the inhabitants in residential buildings regarding the use of solar shading and voluntary ventilation. The lack of valid statistics regarding these has been a major complication when trying to simulate the system. This would benefit all designers of ventilation systems as well as give more accurate value for energy demand and over temperatures.

- Investigate the possibilities of other means of light than traditional windows. There are, for instance, transparent insulation materials available that could function as a source of diffuse light if build into a wall. Roof windows in these types of material might also work, depending on moisture resistance, light transmittance and so on.

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Figures

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Appendix A – Daylight simulations

All daylight simulations were done in Velux Daylight Visualizer (Velux). The 3D model was made in Google Sketchup according to drawing material, and imported to Velux. In Velux, there are some parameters that should be set beside the geometry; which are presented below for the original case. Alterations to this model are presented in Chapter 9.

- Location; set to Stockholm according to Section 8.1.
- Indoor surface materials affecting bedroom 2. These are presented in Table A.1 below.

Table A.1. Surface materials in Kuben, simulated in Velux

Building part	Color	Properties
Walls	White matte	84% reflectance, 0% specularity
Ceiling	White matte	84% reflectance, 0% specularity
Window niche	White semi-gloss	84% reflectance, 10% specularity
Floor	Bright polished wood	84% reflectance, 15% specularity
Window glass	Translucent glass	57% transmittance in the entire spectra

The simulations are done in highest possible resolution, at the setting “low” regarding number of pixels. This allows maximum number of reflections but at the same time minimizes the simulation time. Since all simulations are done for a zoomed area of the 2^{nd} floor, an ensured extraction of values is equally high as for simulations with more points but larger area.

Values were extracted by applying a template marking the point specified by Miljöbyggnad in Section 6.6. ISO-curves were manipulated to show 1.2% daylight factor as a mean of checking if Velux built-in rounding off was on the safe side or not.

Appendix B – Annual energy demand

Annual energy demand is calculated using definitions set by BBR. The definition includes annual heating demand, hot water and certain energy related to the property such as elevators. Annual heating demand is simulated using IDA ICE 4.21 with a few additions. Losses due to voluntary airing, kitchen fan ventilation and energy required for circulation pumps are added on afterwards.

Fixed external shading was modeled as building bodies. Control of movable shading depends on solar radiation on the inside of the glass at a level corresponding to 100 W/m² on the outside of the glass. Data used for simulations in IDA ICE can be found below. All other parameters were kept at default values.

Table B.1. Input data to IDA ICE.

Category	Value	Origin
Indoor temperature	21	SVEBY
Heated floor area	140.4 m²	NCC
Envelope area	305.93 m²	NCC
Construction	As per chapter 7	NCC
Thermal bridges	As per chapter 7	NCC/simulated
Heating system	Ideal heaters, COP 0.93	FEBY 12
Ventilation airflow	55 l/s	Andersson och Hultmark
Fans	SFP 1.34, rotating heat exchanger with 80 % efficiency. Temperature rise of 0.5 degrees over supply fan. Supply temperature at 20 degrees.	Andersson och Hultmark
Air Leakage	Fixed at 0.0125 l/s,m² envelope area	NCC
Internal loads from occupants	1.178 W/m² (3.51 persons producing 47 W each on average)	FEBY 12, number of persons from SVEBY
Internal loads from machines	2.397 W/m² (30 kWh/m²,year of which 70% is beneficial)	SVEBY
Window properties	As per chapter 9, g-value multiplied by 0.71 when no internal shading is specified. Multiplied with 0.5 when no internal or external shading is specified.	NorDan, Pilkington, SVEBY
Outdoor climate	Climate file for Gothenburg, Säve-1977	ASHRAE
Kitchen fan	100 l/s 30 min each day	Assumed
Airing	Assumed to be incorporated in the efficiency of the heating system (0.93)	FEBY
Hot water	20 kWh/m²	SVEBY/FEBY
Pumps	Calculated as 1 % of energy demand	NCC

Appendix C – Solar heat load calculations

The solar heat load calculations were done by introducing g-values to IDA ICE. Since the g-value is a reduction factor for all glass area, only window #1 (Table 7.3) was simulated. It was put at actual height over the balcony, to account for reflections properly, and 50 mm into the wall. The soffit was simulated by adding a solid screen with the soffits' geometry. When awnings were simulated, the soffit was excluded as described in Section 9.3.2.

All four different cases' geometries were constructed, and simulations of the fifteen different shading devices conducted for each case as well as certain combination. This is described in Chapter 9, and the results are presented in Table C.1 to C.3 below.

The column noted "change" shows the reduction factor for each particular shading system, compared to the base setup of each case with only the window niche and the soffit present. This reduction factor was used for energy calculations in IDA according to a schedule depending on solar radiation. Shading was activated when the measured radiation on the inside of the glass corresponds to 100 W/m² on the outside. The solar heat load (SVL) was calculated according to Equation 6.1.

Table C.1. Results from Parasol regarding Case A and Case B.

Shading device			A; g=0.52			B; g=0.52 +10%		
			g_{system}	Change	SVL	g_{system}	Change	SVL
Original	50 mm deep and 63 mm soffit	Glass only	39,5			39,3		
		System	29,8	75,4%	26,8	30,4	77,4%	30,1
External	Soffits	30°	24,2	81,2%	21,8	23,9	78,6%	24,1
		45°	17,6	59,1%	15,8	17,6	57,9%	17,7
	Awnings: Low: Sandatex para 6	Low reflectance, 30°	20,9	70,1%	18,8	20,9	68,8%	21,1
		45°	15,4	51,7%	13,9	15,0	49,3%	15,1
		60°	11,4	38,3%	10,3	11,2	36,8%	11,3
		Completely shut	4,0	13,4%	3,6	3,6	11,8%	3,6
	High: Santatex para 15	High reflectance, 30°	25,9	86,9%	23,3	25,8	84,9%	26,0
		45°	22,8	76,5%	20,5	22,6	74,3%	22,8
		60°	22,4	75,2%	20,1	22,1	72,7%	22,3
		Completely shut	18,0	60,4%	16,2	16,2	53,3%	16,3
Internal	Venitian blinds	Dark, 0° blade angle	27,7	93,0%	24,9	28,3	93,1%	28,5
		80°	24,6	82,6%	22,1	25,2	82,9%	25,4
		Bright, 0° blade angle	26,4	88,6%	23,7	26,9	88,5%	27,1
		80g	19,1	64,1%	17,2	19,5	64,1%	19,6
	Roller-blinds	Opaque m005	21,7	72,8%	19,5	22,2	73,0%	22,4
	Brand: Dickson-Constant	Samoa 4246	18,2	61,1%	16,4	18,7	61,5%	18,8
		Sunvision 8857	25,4	85,2%	22,8	26,0	85,5%	26,2

Table C.2. Results from Parasol regarding Case A and Case B.

Shading device			C; g=0.52 +30%			D; g=0.36 +30%		
			g_{system}	Change	SVL	g_{system}	Change	SVL
Original	50 mm deep and 63 mm soffit	Glass only	39,2			28,2		
		System	31,2	79,6%	38,2	22,6	80,1%	27,6
External	Soffits	30˚	23,9	76,6%	29,2	16,6	73,5%	20,3
		45˚	17,6	56,4%	21,5	12,3	54,4%	15,0
	Awnings: Low: Sandatex para 6	Low reflectance, 30˚	22,7	72,8%	27,8	15,4	68,1%	18,8
		45˚	15,9	51,0%	19,4	10,4	46,0%	12,7
		60˚	11,9	38,1%	14,6	8,2	36,3%	10,0
		Completely shut	4,4	14,1%	5,4	2,4	10,6%	2,9
	High: Santatex para 15	High reflectance, 30˚	27,1	86,9%	33,1	18,9	83,6%	23,1
		45˚	23,1	74,0%	28,3	15,8	69,9%	19,3
		60˚	21,9	70,2%	26,8	16,2	71,7%	19,8
		Completely shut	17,1	54,8%	20,9	12,1	53,5%	14,8
Internal	Venitian blinds	Dark, 0˚ blade angle	29,1	93,3%	35,6	22,3	98,7%	27,3
		80˚	25,9	83,0%	31,7	21,5	95,1%	26,3
		Bright, 0˚ blade angle	27,6	88,5%	33,8	21,6	95,6%	26,4
		80˚	20,1	64,4%	24,6	19	84,1%	23,2
	Roller-blinds Brand: Dickson-Constant	Opaque m005	22,8	73,1%	27,9	20,3	89,8%	24,8
		Samoa 4246	19,2	61,5%	23,5	18,7	82,7%	22,9
		Sunvision 8857	26,7	85,6%	32,7	21,6	95,6%	26,4

Table C.3. Results from Parasol regarding combined shadings for Case C.

Shading devices	Combinations of Case C		
	g_{system}	Change	SVL
30 soffit and bright blind 80	15,3	64,0%	17,9
30 soffit and opaque 4246	17,3	72,4%	20,2
30 soffit and sunvision 8857	14,5	60,7%	17,0

Appendix D – Thermal comfort winter

Thermal comfort winter is calculated in IDA ICE 4.21, but with different settings than for annual energy demand calculations. Internal gains from equipment and lighting as well as gains from the sun are set to zero. Calculations are performed for one day, a "synthetic" winter day, for the selected location. The simulation uses the day continuously until the error between the simulated values are very low. Sensors for thermal comfort are placed in rooms considered as living space, meaning all hallways and bathrooms are omitted. Sensors are placed 1 m in front of the largest window in each room, 0.8 m above the floor to account for radiation from the glass surface. Table D.1 show the most important data used for calculations.

Table D.1. Changed data when simulating thermal comfort (winter) compared to energy demand.

Category	Value	Origin
Activity level	1.2 Met (roughly 100 W)	SVEBY
Clothing level	Fixed, 1.0	Assumed
Number of persons	1 in each room, 7 in total	Assumed
Installed power	2 kW	Andersson och Hultmark
Schedule	No smoothing applied, inhabitants always present	Assumed
Heater	Ideal heater with no long-wave heat emission is chosen to simulate the system as the building is heated by air.	Assumed

For all simulations thermal comfort winter is largely unaffected as small window areas with a low U-value is used. As such, no further results will be shown.

Appendix E – Installed power

Installed power, which corresponds to the heat loss number in the passive house standard, is calculated by first finding the time constant of the building. The time constant is calculated by following the formulae below.

$$T = \sum(m_i \cdot c_i) / HT \quad (E.1)$$

Where $\sum(m_i \cdot c_i)$ is the thermal mass of the building, explained on the next page, and HT is the heat loss coefficient calculated according to EN

$$HT = \sum U_m \cdot A_{env} + \rho \cdot c \cdot q_{leak} + \rho \cdot c \cdot q_{vent} \cdot (1- v) \quad (E.2)$$

Where ρ is density, c is the specific heat capacity, v is the efficiency of the heat exchanger, q_{leak} and q_{vent} are losses depending on leakage and ventilation respectively and A_{env} is the envelope area.

Losses due to air leakage are calculated according to EN ISO 13789:2008.

$$q_{leak} = q_{50} \cdot e / (1 + f/e ((q_{sup} - q_{ex}) / q_{50})^2) \quad (E.3)$$

$q_{sup} - q_{ex}$, is the difference between supply and exhaust airflow [l/s].

q_{50} is the air leakage at 50 Pa pressure difference between inside and outside [l/s].

The coefficients e and f are wind related. Kuben is in a suburban environment and have multiple sides exposed, thus values for e and f can be found in Table E.1.

Table E.1. Wind coefficients, taken from the FEBY calculation method (Sveriges centrum för nollengergihus, 2012).

Wind coefficients, e and f		Multiple sides exposed	One side exposed
Coefficient e	Open landscape or high rise buildings	0.1	0.03
	Suburban environment	0.07	0.02
	Buildings in the forest or buildings of average height in the city	0.04	0.01
Coefficient f		15	20

The following values are now set:

$$f = 15$$

$$e = 0.07$$

$$q_{50} = 0.25 \text{ l/s, per m}^2 A_{env} = 0.25 \cdot 306 = 76.5 \text{ l/s}$$

These values input into Equation E.3 presents a q_{leak}:

$$q_{leak} = 5.35 \text{ l/s}$$

Some additional calculations regarding losses due to air transport are calculated, since q_{vent} is known. These will be inserted into Equation E.2.

$$\rho \cdot c \cdot q_{leak} = 1200 \cdot 1 \cdot 0.00535 = 6.4 \text{ W/K}$$

$$\rho \cdot c \cdot d \cdot q_{vent} \cdot (1- v) = 1200 \cdot 1 \cdot 0.055 \cdot (1- 0.8) = 13.2 \text{ W/K}$$

The next step is to multiply the mean U-value to the surrounding area

$$\sum U_m \cdot A_{env} = 0.1467 \cdot 306 = 44.9 \text{ W/K}$$

All values are now known, and HT is calculated by use of Equation E.2.

$$HT = \sum U_m \cdot A_{env} + \rho \cdot c \cdot q_{leak} + \rho \cdot c \cdot q_{vent} \cdot (1- v)$$

$$HT = 64.6 \text{ W/K}$$

The thermal mass of the building, $\sum(m_i \cdot c_i)$ in Equation E.1, is found in Table E.2 below. Columns 3-6 are multiplied into the value in column 7.

Table E.1. Thermal mass of Kuben.

Building part	Material	Area [m²]	Thickness [m]	ρ [Kg/m³]	C_p [J/kg]	Thermal mass [J/K]
Floor	Concrete	70	0.1	2400	880	14 784 000
Interior wall	Gypsum	178.8	0.0125	700	800	1 251 397
Bedroom wall	Gypsum	50.2	0.025	700	800	703 444
Bedroom external wall	Gypsum	44.6	0.034	700	800	848 384
Nomal external wall	Gypsum	97.9	0.009	700	800	493 788
Roof	Gypsum	70	0.0125	700	800	490 000
Total						18 571 014

Now, the time constant can be calculated by Equation E.1.

$$T = \sum(m_i \cdot c_i) / HT = 18571014 / (64.6 \cdot 3600) = 79.9 \text{ h} = 3.3 \text{ days}$$

Following tables in FEBY a time-constant of 3.3 days for a building in Säve equals a dimensioning winter outdoor temperature (DVUT) of -13.03 degrees.

Installed power can finally be calculated as:

$$Q = HT \cdot (21 - DVUT) / A_{temp} \qquad \text{(E.4)}$$

$$Q = 64.6 \cdot 34.03 / 140.4 = 15.7 \text{ W/m}^2$$