CHALMERS

# Enhancement of Villa Vänern

## Achieving the grade GOLD in the Swedish environmental classification system Miljöbyggnad.

*Master of Science Thesis in the Master's Programme Design for Sustainable Development*

JESPER JOHANSSON
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Department of Civil and Environmental Engineering
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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013
Master's Thesis 2013:23

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Cover:
Image of Villa Vänern photographed by Peab, 2012.

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## ABSTRACT

Villa Vänern is a 120 m$^2$, two stories villa. It comes in three different types: detached house, row house and terraced house. Peab is one of the Nordic countries largest construction company and has recently made a decision that all of their self-developed projects are to be certified according to the demands of the environmental certification system Miljöbyggnad.

Miljöbyggnad is built up of 15 indicators, which are categorized into 11 aspects. The aspects are graded and combined into three area grades, which are Energy, Indoor climate and Materials and chemicals.

An earlier study shows that Villa Vänern achieves the grade SILVER as a final grade in Miljöbyggnad. Peab is now interested to see how can Villa Vänern be developed to get GOLD on all criteria's in Miljöbyggnad. The measurable indicators that don't meet the annual energy usage of 82,7 kWh/m$^2$, the design heating power demand of 29,89 W/m$^2$, solar heat gain and the thermal climate during winter and summer. The solar heat gain and the thermal climate is room dependent and vary in the different rooms.

The enhancement of Villa Vänern made in this report consists of changing the orientation of the building, upgrading the window with a more energy efficient glazing unit and frame, suggesting solar shading, adding one layer of insulation in the wall and at last reducing the temperature set points from 22-25°C to 20-26°C.

The analysis made in this report shows that it is possible to enhance Villa Vänern to achieve GOLD on all indicators in Miljöbyggnad with quite small measures. A cost estimation together with Peab shows that if around 49 000 SEK is invested in Villa Vänern it achieves the grade GOLD.

The changes to the enhanced Villa Vänern are thought through so the occupants have the same or a better living quality in the building after the changes has been made.

Key words: Energy efficient building, Miljöbyggnad, energy demand, heating power demand, solar heat gain, solar shading, Peab, Villa Vänern, Sustainable development, sustainable building, energy simulations, IDA ICE.

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## SAMMANFATTNING

Villa Vänern är en 120m$^2$ stor tvåplans villa som kan uppföras på tre olika sätt; fristående, radhus eller kedjehus. Peab, en av nordens största byggnads entreprenörer, har nyligen beslutat att samtliga egenutvecklade projekt skall certifieras enligt kraven i Miljöbyggnad.

Miljöbyggnad är uppbyggt av 15 indikatorer som kategoriseras i 11 aspekter som vägs ihop till tre områdesbetyg; Energi, Innemiljö och Material.

En tidigare studie visar att Villa Vänern uppfyller kraven för SILVER som slutbetyg i Miljöbyggnad. Peab är nu intresserade av: Hur kan Villa Vänern utvecklas för att uppfylla GULD på samtliga indikatorbetyg i Miljöbyggnad?. De mätbara indikatorer som inte uppfyller kraven är Energianvändning, 82,65 kWh/m$^2$, Värmeeffektbehov, 29,89 W/m$^2$, solvärmelast och termiskt klimat sommar. Det två sistnämnda indikatorerna är rumsberoende och varierar för varje rum.

Förbättringar gjorda på Villa Vänern i denna rapport är; orienterings förändring, energieffektivare fönster, solskydd, ytterligare ett lager isolering och slutligen en förändring av inomhustemperaturen till ett spann mellan 20-26°C.

Analyser gjorda i denna rapport visar att det är möjligt att uppfylla betyget GULD på samtliga mätbara indikatorer i Miljöbyggnad, med relativt små medel. Ett kostnadsöverslag tillsammans med Peab visar att en investering på 49 000 SEK är tillräcklig för att uppfylla kraven för GULD.

Samtliga förändringar är gjorda så att de boendes levnadsstandard ska bestå eller bli till det bättre.

Nyckelord: Energieffektiva byggnader, Miljöbyggnad, energianvändning, värmeeffektbehov, solvärmelast, solskydd, Peab, Villa Vänern, Hållbar utveckling, Hållbara byggnader, energisimulering, IDA ICE.

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# Preface

During the period of September 2012 to May 2013 we have worked with this Master's Thesis. It is an interdisciplinary thesis in the field of civil engineering and architecture.

At first we would like to thank our supervisor at the department of civil and environmental engineering Angela Sasic Kalagasidis and Paula Femenias at the department of architecture for tutoring and help throughout the process. And a special thanks goes to Henrik Persson and Peab for having us at their office part time during the project and for sharing information.

We have learned a lot during the project both about the field of topic and the organisation of Peab, which we have learned to know.

We hope that you as the reader will enjoy this work and find it usefull.

Göteborg, June 2013

Jesper Johansson
Tommie Månsson

# 1 Introduction

In Sweden different methods are used to reduce the energy demand in buildings such as building regulations. The Swedish building regulations, BBR, have quite recently decreased allowed energy usage, for non-electrical heated buildings in climate zone III in Sweden, with 18% to 90 kWh/m$^2$ (Boverket, 2012).

The general public has developed a greater interest in questions concerning energy efficient buildings. This increases the pressure on construction contractors to deliver buildings fulfilling not only the normal living conditions but to serve a building achieving the new demands of low energy demand. One way to achieve this is by certifying the building in an environmental certification system.

The building sector in Sweden has jointly developed an environmental certification system adapted for the Swedish building regulations named Miljöbyggnad. It addresses three areas, which are Energy, Indoor climate and Materials and chemicals.

To meet the general and public demand Peab has recently made a decision that all of their self-developed villa projects are to be certified according to the demands of Miljöbyggnad.

One of Peab's most popular villas is Villa Vänern. The originally intent was not to design a building according to the demands of Miljöbyggnad. But when the decision was made in 2012 that all of their self developed buildings should be certified according to Miljöbyggnad a study was made by WSP Environmental to see how Villa Vänern meets the demands of Miljöbyggnad. This study shows that the building achieves the final grade SILVER in Miljöbyggnad.

Peab is now interested to see how Villa Vänern could be enhanced to meet the demands for a GOLD graded building in Miljöbyggnad, which this master's thesis is thought to answer.

## 1.1 Purpose

The purpose with this master's thesis is to analyse and show how Villa Vänern could be enhanced to meet the demands of certification grade GOLD in Miljöbyggnad.

## 1.2 Boundaries

This master's thesis only focus on measurable indicators in Miljöbyggnad, which do not reach the demand of certification grade GOLD or indicators directly affected by the enhancement.

## 1.3 Method

The development of Villa Vänern was performed with a three-part-approach. The first part was to get a comprehensive picture of Villa Vänern and Miljöbyggnad. By study drawings and documents from both Peab and SGBC, Swedish green building council, knowledge where gained both about Villa Vänern and Miljöbyggnad.

During the autumn of 2012 a study where made by WSP Environmental on Villa Vänern showing the current certification grade. This study was used as basis to decide the field of focus for the enhancements. The measurable indicators with a grade lower than GOLD where chosen as indicators with enhancement potential.

Part two was to create an energy reference model with high level of detail. The reference model was used to simulate the reference building and to compare the enhancements. The building energy simulation was performed in IDA Indoor climate and energy 4.2 here fore written as IDA ICE 4.2. The simulations in IDA ICE gave us knowledge about the annual energy usage, the heating power demand, the thermal climate during heating and cooling season and about the solar heat gain.

Input data to the model was collected from building drawings and interviews with employees at Peab. Complementary input data for thermal bridges was calculated in the software Comsol. Comsol is used for two and three-dimensional calculations of heat transfer in building details.

When the reference model was created the analysis where divided into different parts, addressing different changes to the building. To assess the impact of the different changes on the building the simulations was compared to the reference model and the demands in Miljöbyggnad in an empirical study. Part two also analysed the changes in an end user perspective.

To evaluate the end user perspective we used thermal comfort data from the energy reference model regarding indoor environment and a Velux model regarding the daylight conditions. An estimation of the investment cost where also made to see if the enhancement is economically justifiable.

Finally in part three the chosen enhancement in consideration with the measurable indicators in Miljöbyggnad and with the end user perspective was simulated and a new certification grade was calculated.

## 1.4 Abbreviations

$A_{temp}$ - Total heated floor area

BBR - ‘Boverkets ByggRegler’. Swedish building regulations.

DVUT - Outdoor design temperature during winter according to BBR.

G-value – The amount of long wave radiation passing through windows.

HRV – Heat Recovery Ventilation system using a heat exchanger to pre heat the supply air.

HVAC –Heating Ventilation and Air Conditioning

$L_t$-value – Amount of light passing, light transmittance coefficient

PEAB - Building contractor in Sweden

PPD - Predicted percentage dissatisfied. Used to indicate how the occupants are dissatisfied with the indoor climate, measured in %.

SVEBY – A developing group for energy efficient buildings in Sweden

U-value – How much heat that is passing through one square meter of material for each degree of temperature difference on the opposite sides, measured in $W/m^2K$

# 2 Sustainable Building

There are different theories about how a sustainable building should be constructed, used and demolished. This chapter serves to communicate a definition of a sustainable building according to theories of sustainable development combined with the demands of Miljöbyggnad and our own interpretations.

Sustainable building is a notion developed from the more general term sustainable development, which was introduced in Our Common Future (NE, 2012a) where it is defined as

> *"… development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

During a conference in Rio 1992, it was decided that 'Sustainable development' should be the guidelines for further development globally and locally. This decision created a plan of action called Agenda 21, which was signed by 180 states. It also created the climate convention that aims to lower the energy use and consumption of fossil fuel (NE, 2012b).

When addressing questions concerning sustainability it's common to use three fields named: Economy, Environment and Social. A common way to visualize sustainable theory is with an Euler diagram as in Figure 1 below.

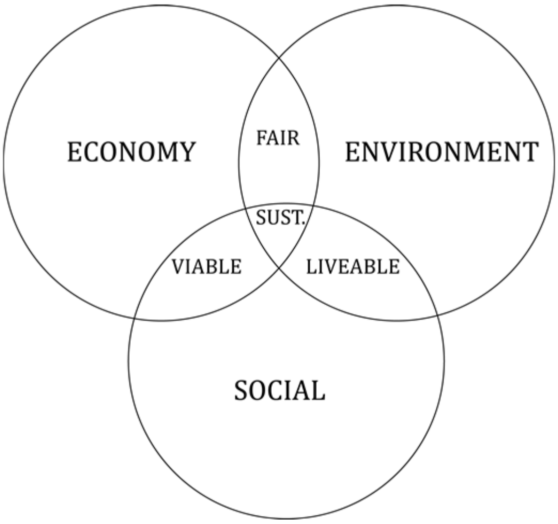


Figure 1. Euler diagram showing the different aspects and unions of sustainability.

The figure shows that it's only when all three fields are in balance that it becomes sustainable. For example if a product only meet the demands of social and economic sustainability, it's "fair" but not sustainable in the long term. The figure is also basis for forthcoming enhancements of Villa Vänern. Enhancement made should be done according the theories of sustainable building.

The following citations describe what a sustainable economy is according to (businessdictionary.com, 2012).

> *”…the use of various strategies for employing existing resources optimally so that that a responsible and beneficial balance can be achieved over the longer term.”.*
>
> *”Economic development that does not sacrifice the future quality of life for short-term gains, and helps maintain the ecological processes on which all life depends. ”*

A sustainable environment is when there is no increased concentration in the ecosphere of substance extracted from the bedrock or produced by society (Naturliga Steget, 2012). Also resources must not be mined and consumed faster then they are regenerated. Also there’s no forced displacement of nature with physical means.

The environmental sustainability is closely connected to materials in buildings. Above mentioned criteria’s demands that used materials should have a longer lifespan than the renewing process in nature would have on the same quantity. In a building also the embodied energy and the annual energy usage of the structure should be designed to meet high demands, without decreasing the comfort and the social sustainability qualities.

According to (Halliday, 2008) an ideal material should contribute to passive form environmental control, be produced with minimum processing and transportation, strive for good health and contain non-toxic substances for less pollution.

Social sustainability is according to the Redcross (2013):

> *“…about building a long-term stable and dynamic society where basic human needs are met.”*

In Chapter 3 Miljöbyggnad is introduced, where one of the biggest areas addressed is the indoor environment. In buildings health and safety should never be neglected for economical gains. This also implies to enhancements of the building. The building should imply that the occupants have the same or a better living quality in the building after the changes has been made.

It is also important that a building be designed and oriented according to its surroundings and the path of the sun to obtain maximum possible social, ecological and economical value. Energy for technical solutions should be minimized by having the indoor comfort ensured by passive design such as natural ventilation, solar heat gain, solar shade etc. when possible. Other needs can, if necessary, be fulfilled by technical solutions.

# 3 Miljöbyggnad

This chapter serves an introduction to Miljöbyggnad, which is an environmental certification system. It is developed by the Swedish building sector together with authorities, banks, insurance companies and universities (SGBC, 2012). It covers areas, which are considered to affect buildings environmental impact and users health.

Miljöbyggnad acts as a driving potential towards a more efficient use of energy, to improve the indoor environment and to reduce the usage of hazardous building materials (SGBC, 2012). These factors are grouped into three different areas called, Energy, Indoor environment and Material and chemicals. All indicators including the measurable and affected ones are described in detail in APPENDIX A.

The main factors that characterize Miljöbyggnad are cost efficiency, simplicity, the ability to reuse already created project documents and it follows the guidelines and requirements set by the Swedish building regulations, BBR (SGBC, 2012).

The process for certifying with Miljöbyggnad is built up in a way that reduces the need of extra work to certify a building, which keeps the additional cost to a low level compared to other environmental assessment systems (SGBC, 2012).

## 3.1 The structure of Miljöbyggnad

Miljöbyggnad is built up with 15 indicators categorized into 11 aspects. The aspects are graded and combined into three area grades, as shown in Table 1 below.

To promote good buildings Miljöbyggnad is using a system of grades that consist of: BRONZE, SILVER and GOLD. A building can also be graded as RATED, which is given if BRONZE is not reached.

Table 1. The structure of Miljöbyggnad.

| INDICATOR | ASPECT | AREA | GRADE |
|---|---|---|---|
| Annual energy usage | Energy usage | Energy | FINAL GRADE |
| Heating power demand | Power demand | | |
| Solar heat gain | | | |
| Energy source | Energy source | | |
| Acoustic environment | Acoustic environment | Indoor environment | |
| Radon concentration | Air quality | | |
| Ventilation standard | | | |
| Nitrogen dioxide | | | |
| Moisture safety | Moisture | | |
| Thermal climate winter | Thermal climate | | |
| Thermal climate summer | | | |
| Daylight | Daylight | | |
| Legionella | Legionella | | |
| Documentation of building materials | Documentation of building materials | Material and chemicals | |
| Phasing out hazardous substances | Phasing out hazardous substances | | |

## 3.2 The aggregating grading system

The final grade is aggregated and can only be one step above the lowest indicator grade, meaning that the lowest acceptable grade is SILVER in one aspects to fulfil the requirements of a GOLD graded building.

Each indicator is graded by a set of criteria's as shown in APPENDIX A. The grade of each aspect is set by the lowest of the indicators grades. The area grade is also set by the lowest of the aspect grades, but it is possible to increase the grade one step if over 50% of the indicators grades are higher.  The final grade of the building is then set by the lowest grade of the areas (SGBC, 2012).

# 4 Description of Villa Vänern, the studied building

The following chapter gives a general introduction of the Villa Vänern concept and the technical platform, which the building is based on. It will also give a short introduction to the site Östra Ängarne, where the reference building is located. It is also giving a brief introduction to the pre-study made by WSP Environmental 2012.

## 4.1 The concept Villa Vänern

The main idea with Villa Vänern concept is to have a building with a fixed footprint of 6,1 x 10 m and possibility to add an additional extension in the early planning stage, without deciding what kind of house type it should be (PEAB, 2012). By doing that Peab can work with a parallel marketing investigation while continuing the work preparing the ground and building. Villa Vänern comes in three different kind of housing: detached house, row house and terraced house.

The floor plan has a flexible layout, which can be changed according to clients needs. The different floor plans serves a living area between 120 - 129 m$^2$. The flexibility of Villa Vänern gives a wide range of target groups, which Peab defines as following:

- Young couple with one child.
- Middle age couple with one to three children.
- Former divorced couple with varying amount of children at home.
- The active couple without children.

The outside expression of Villa Vänern can be personalized with three different kinds of roofs and with three different façade materials, allowing nine unique appearances.

## 4.2 Principle drawings of studied design

This chapter will present Villa Vänern in its basic design where drawings and elevations of the reference building are shown. The studied design is the 120 m$^2$, two-floor villa design.

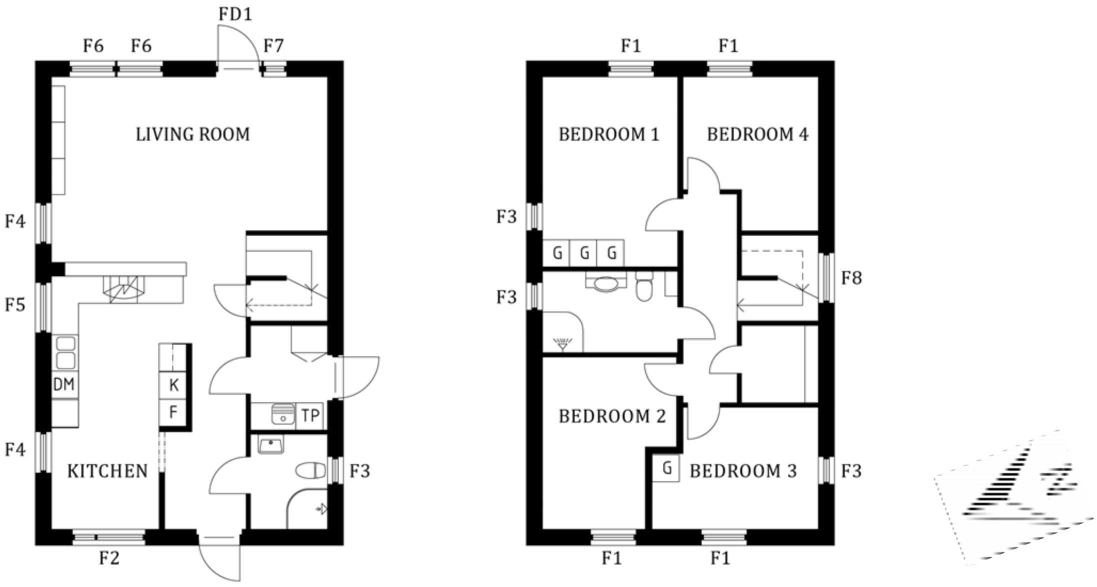
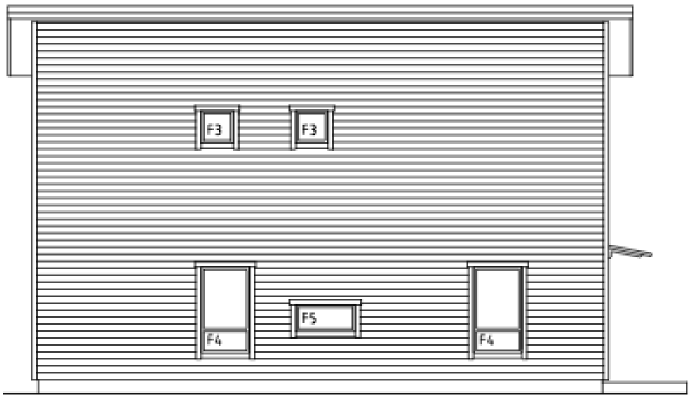


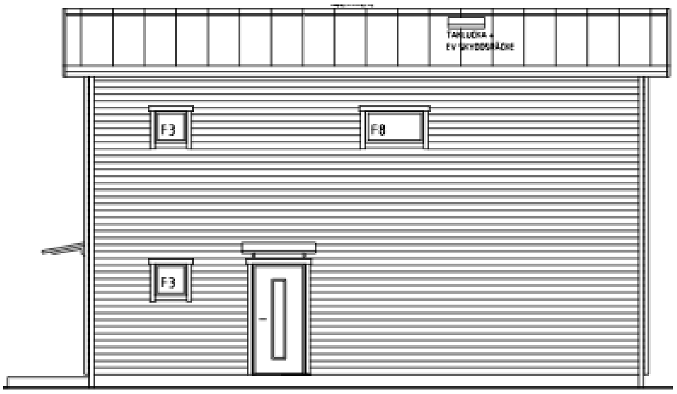
Figure 2. Villa Vänern floor plans (PEAB, 2012).

WEST FAÇADE



NORTH FAÇADE

EAST FAÇADE



SOUTH FAÇADE

## 4.3 Site description of the studied building

The site where the reference building is located is Östra Ängarne. It is located 25km north of Göteborg in the east part of Nödinge. The landscape is hilly with large areas of forest surrounding in the east and the river Göta älv passing in the west. A journey to Göteborg takes about 12 min with train and 20 min by car.

Figure 3. Eniro map of Nödinge showing the location of Villa Vänern.
[Accessible]: < http://kartor.eniro.se/query?what=maps&search_word=&geo_area=nödinge-nol&from=>
2013-05-06

The climate condition at site is considered to be the same as the climate conditions at the weather station in Landvetter, Göteborg. This is further used in Chapter 5 where an energy reference model is created for analysis of Villa Vänern.

## 4.4 The technical platform used in Villa Vänern

All villas developed by Peab are based on the same technical platform. This ensures that every building maintains the same quality and increases the efficiency of the construction.

The technical platform consists of a framework describing structural elements, detailed connections, choice of material and technical solutions for the building.

### 4.4.1 Structural elements

Starting from the bottom of the building the house is resting on a reinforced ground slab isolated with 400 mm of EPS as show in Figure 4. In the ground slab floor heating is casted to heat the first floor.

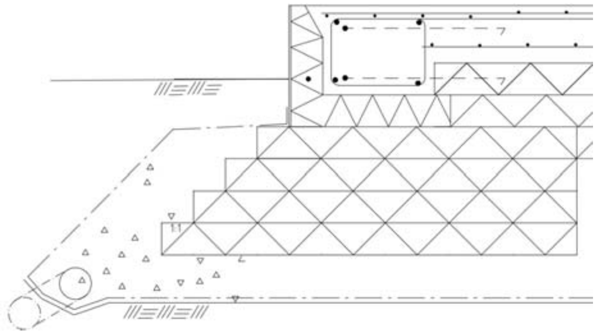
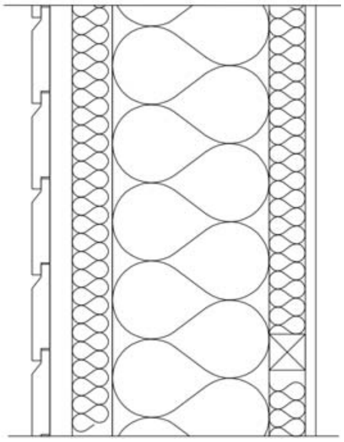


Figure 4. Section of the slab stiffener against ground (Peab, 2012).

The external wall is a three-layer construction with 240 mm mineral wool insulation. The structure from inside and out are shown in Figure 5.



Inside

| | |
|---|---|
| 13 | Gypsum board |
| 45 x 45 | Mineral wool + studs |
| 0,11 | Vapour barrier |
| 45 x 195 | Mineral wool + studs |
| 0,20 | Wind barrier |
| 50 | Façade panel |
| 28 x 70 | Laths |
| 22 x 120 | Horizontal panel |

Outside [mm]

Figure 5. Structure of the exterior walls (Peab, 2012).

The roof structure is built up with roof trusses, studs, paperboard, laths and tiles. It is insulated with 500 mm loose mineral wool shown in Figure 6.

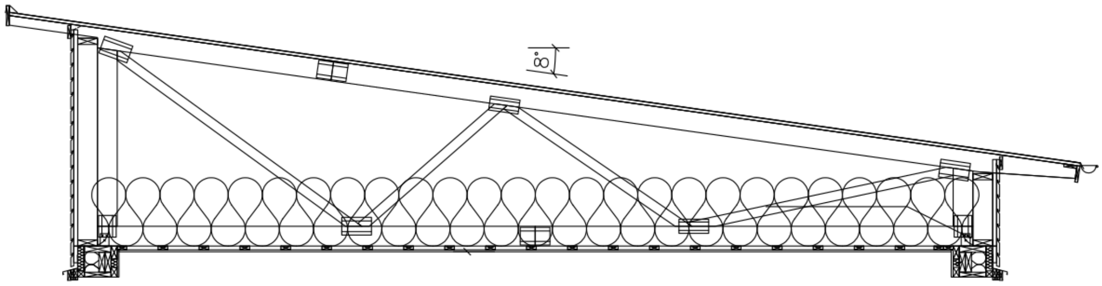


Figure 6. The structure of the roof (Peab, 2012).

### 4.4.2 Windows and doors

The windows used in Villa Vänern are three pane windows with argon filled gaps, which gives an compound u-value of 0,9 W/m$^2$K. The glazing unit has a u-value of 0,6 W/m$^2$K, a g-value of 0,51 and an $L_t$ value of 0,72. The aluminium cladded timber frame has a u-value of 1,7 W/m$^2$K with varying ratio to window area. For details regarding sizes see APPENDIX B.

The exterior doors have a u-value of 1,2 W/m$^2$K.

### 4.4.3 HVAC

In Villa Vänern district heating is used and the heat is distributed by waterborne floor heating on the first floor and with waterborne radiators on the second floor. Both floors have preheated supply air where heat is recovered from the exhaust air with a HRV system as Figure 7 illustrates below.

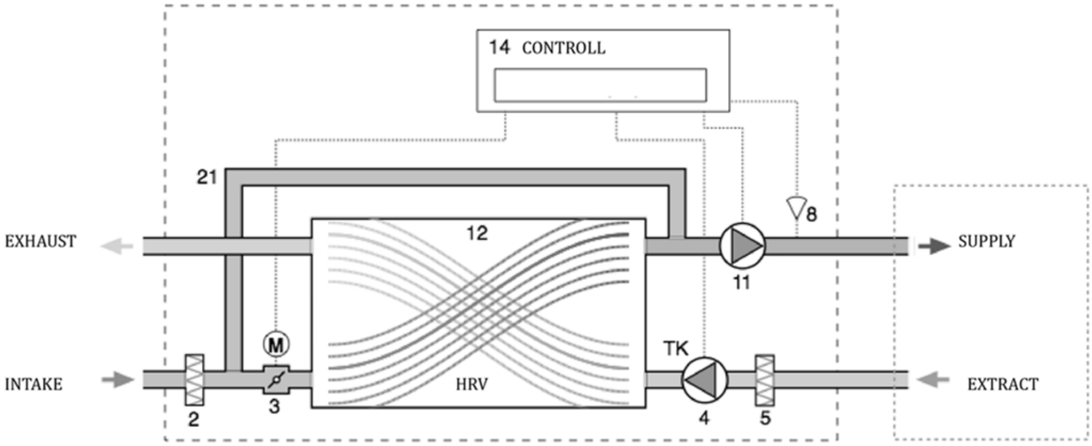


Figure 7. Translated principle sketch of the HRV system used in Villa Vänern. 2 - Filter, 3 - By-pass valve, 4 - Fan, 5 - Filter, 8 - Thermostat, 11 - Fan, 12 - Heat exchanger, 14 - Control panel, 21 - By-pass channel.
Accessible: <http://www.rec-indovent.se> 2013-02-14

### 4.4.4 Infiltration

The exterior walls are constructed with an internal installation zone where electrical installations is placed. This allows an intact air tight layer.

The internal slab rests on a suspension cable instead of resting on the external wall. This helps to reduce the thermal bridge and also allows for a connection, which keeps the air tight layer in the exterior wall intact.

Villa Vänern heated with district heating and the HRV unit has an air tightness of approximately 0,3 l/s, $m^2$ at 50 Pa.

## 4.5 Earlier study of Villa Vänern

During autumn of 2012 a study made by WSP Environmental, commissioned by Peab, on Villa Vänern and how the prerequisites and the probability to certificate Villa Vänern in Miljöbyggnad are. The outcome from this study was a report showing how Villa Vänern performs on the different indicators of Miljöbyggnad.

The report made by WSP acts as a substrate to our pre-study and together with the building input data the basis for potential development areas on Villa Vänern are derived.

Table 2. Miljöbyggnad grade matrix based on the results from WSP's pre-study.

| INDICATOR | ASPECT | AREA | GRADE |
|---|---|---|---|
| Annual energy usage | Energy usage | Energy | FINAL GRADE |
| Heating power demand | Power demand | | |
| Solar heat gain | | | |
| Energy source | Energy source | | |
| Acoustic environment | Acoustic environment | Indoor environment | |
| Radon concentration | Air quality | | |
| Ventilation standard | | | |
| Nitrogen dioxide | | | |
| Moisture safety | Moisture | | |
| Thermal climate winter | Thermal climate | | |
| Thermal climate summer | | | |
| Daylight | Daylight | | |
| Legionella | Legionella | | |
| Documentation of building materials | Documentation of building materials | Material and chemicals | |
| Phasing out hazardous substances | Phasing out hazardous substances | | |

# 5 Methodology of analysis

This chapter serves to acts as a basis to understand Villa Vänern's performance in different aspects, where simulation models have been created for deeper understanding. The different models and software's used are described and all simulations and gained information used in this project are shown in Table 3 below.

Table 3. Table showing simulations and gained information.

| Type of simulation | Energy usage | Heating power demand | Transmission losses | Solar heat gain | PPD-summer | PPD-winter | Operative temp. | Daylight |
|---|---|---|---|---|---|---|---|---|
| Reference Model | x | x | x | x | x | x | x | x |
| Orientation 10 deg | x | x |  | x | x | x | x |  |
| Orientation 55 deg | x | x |  | x | x | x | x |  |
| Orientation 145 deg | x | x |  | x | x | x | x |  |
| Orientation 190 deg | x | x |  | x | x | x | x |  |
| Orientation 235 deg | x | x |  | x | x | x | x | x |
| Orientation 280 deg | x | x |  | x | x | x | x |  |
| Orientation 325 deg | x | x |  | x | x | x | x |  |
| Window u-value 0.5, g 0.51. | x | x | x | x | x | x | x | x |
| Window u-value 0.7, g 0.51. | x | x | x | x | x | x | x |  |
| Window u-value 0.8, g 0.51. | x | x | x | x | x | x | x |  |
| Window Lt 57, g 0.36, u 0.5 | x | x | x | x | x | x | x | x |
| Window Lt 59, g 0.42, u 0.7 | x | x | x | x | x | x | x | x |
| Window Lt 64, g 0.46, u 0.8 | x | x | x | x | x | x | x | x |
| Window Lt 67, g 0.54, u 0.7 | x | x | x | x | x | x | x | x |
| G - value 1.0, u 0.6 | x |  |  | x | x |  |  | x |
| G - value 0.2, u 0.6 | x |  |  | x | x |  |  | x |
| G - value 0.1, u 0.6 | x |  |  | x | x |  |  | x |
| Latitude Kiruna | x | x |  | x | x | x |  |  |
| Latitude Sthlm | x | x |  | x | x | x |  |  |
| Latitude Karlstad | x | x |  | x | x | x |  |  |
| Latitude Malmö | x | x |  | x | x | x |  |  |
| Latitude Östersund | x | x |  | x | x | x |  |  |
| Wall insulation 150 mm | x | x | x |  |  | x | x |  |
| Wall insulation 195 mm | x | x | x |  |  | x | x |  |
| Wall insulation 330 mm | x | x | x |  |  | x | x | x |
| Wall insulation 420 mm | x | x | x |  |  | x | x |  |
| Ground insulation 300 mm | x | x | x |  |  | x | x |  |
| Ground insulation 500 mm | x | x | x |  |  | x | x |  |
| Ground insulation 600 mm | x | x | x |  |  | x | x |  |
| Roof insulation 300 mm | x | x | x |  |  | x | x |  |
| Roof insulation 400 mm | x | x | x |  |  | x | x |  |
| Roof insulation 600 mm | x | x | x |  |  | x | x |  |
| Temperature change | x | x | x |  | x | x | x |  |

## 5.1 Creating a reference energy model

The reference energy model is created in IDA ICE 4.2. Listed below are the studied indicators:

- Annual energy usage
- Design heating power demand
- Solar heat gain
- Thermal climate winter
- Thermal climate summer
- Daylight conditions

In Chapter 5.4 two simplified method are presented to verify the solar heat gain and design heating power demand result.

IDA ICE uses dynamic simulations to see how the building performs in the annual climate. The reference energy model is used to analyse Villa Vänern in its basic design, and to act as a reference model where results of different changes is compared with initial result.

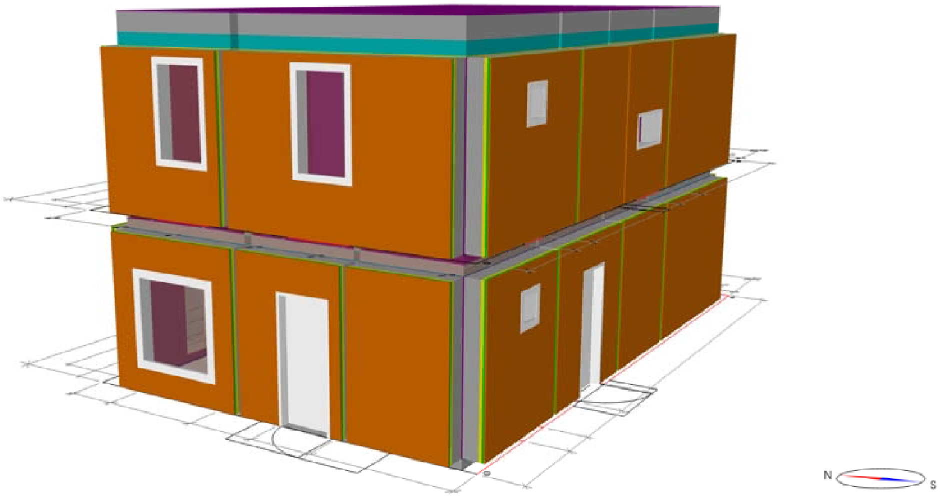


Figure 8. Render from IDA ICE 3D-model, used in the simulations.

### 5.1.1 Input data for the reference energy model

The reference model takes different parameters into consideration. In the tables below input data for simulations and calculations of the reference model is summarized by categories.

Table 4. Building and site input data.

| OBJECT | VILLA VÄNERN |
|---|---|
| **Location, climate zone** | Göteborg, climate zone III |
| **Climate file** | Gothenburg, Landvetter. ASHRAE[1] 2001 |
| **Indoor temperature demands:** | 22 - 25 ° C |
| **DVUT, Göteborg (τ =1)** | -14,6 ° C |
| **Principle for heating** | District heating |
| **Principle cooling:** | Airing to ventilate overheating (> 25° C) |
| **Principle air distribution:** | Mechanical exhaust air system and HRV-system. |

Table 5. Table showing the building physics data used in the reference model.

| BUILDING PHYSICS DATA | |
|---|---|
| **U-value exterior wall** | 0,147 W/m$^2$ K |
| **U-value roof** | 0,086 W/m$^2$ K |
| **U-value ground slab** | 0,073 W/m$^2$ K |
| **U-value glazing** | 0,6 W/ m$^2$ K |
| **U-value window frame** | 1,7 W/ m$^2$ K |
| **G-value window** | 0,51 |
| **U-value doors** | 1,2 W/ m$^2$ K |
| **$A_{temp}$** | 120 m$^2$ |
| **Area exterior walls** | 136 m$^2$ |
| **Area ground slab** | 61 m$^2$ |
| **Area windows** | 20,76 m$^2$ |
| **Area doors** | 3,3 m$^2$ |
| **Thermal bridges** | See chapter 5.1.2 |
| **Infiltration at 50 Pa** | 0,3 l/s m$^2$ |
| **Mean u-value ($U_m$)** | 0,25 W/m$^2$K |

Table 6. Table showing data regarding the reference model.

| HVAC-INSTALLATIONS | |
|---|---|
| **Air flow** | 0,35 l/s m$^2$ |
| **Specific fan power** | 0,667 kW/m$^3$, s for exhaust air<br>1 kW/m$^3$, s for supply air |
| **Temperature efficiency heat for exchanger** | η = 79,5 % |
| **Operation time ventilation** | 24h, 365 days/year |

---

[1] IDA ICE is connected to the US department of Energy and a database called EnergyPlus. EnergyPlus uses climate data from the ASHRAE organisation. ASHRAE is a society focusing on building systems, energy efficiency and indoor climate and helps users around the world with knowledge promoting sustainable buildings (ASHRAE, 2013).

Table 7. Table showing Sveby standard values used in the reference model.

| INTERNAL GAINS, STANDARD VALUES ACCORDING TO SVEBY | |
|---|---|
| **Residential electrical power including lighting installations.** | 30 kWh/m$^2$,<br>70 % could be count as free heat |
| **Operation time equipment** | 24h, 365 days/year |
| **Hot water consumption** | 20 kWh/m$^2$ |

Table 8. Table showing the occupant parameters used in the reference model.

| OCCUPANT PARAMETERS | |
|---|---|
| **Number of persons** | 0,03 persons/m$^2$ (3,6 total) |
| **Attendance time persons** | Full attendance, 19:00-07:00<br>Half attendance, 15:00-19:00<br>No attendance, 07:00-15:00 |
| **Metabolism rate** | 1,25 MET (active target group) |
| **Clothing level** | 0 - 3,1 clo |

### 5.1.2 Complementary input data to the reference energy model

Because of the high detail level of the reference energy model the thermal bridges are calculated instead of using default values from IDA ICE. The thermal bridges of Villa Vänern are the exterior wall corner, internal slab to wall connection, roof to external wall connection, the window perimeter and the ground slab edge.

The thermal bridges has been evaluated in COMSOL and then implemented in IDA ICE as linear thermal bridges. A brief description of assumptions and simplifications can be found under each chapter below. Impact of nails and screws are neglected in all models and all material properties are considered constant.

#### 5.1.2.1 Exterior corner thermal bridge

The exterior wall corner detail is modelled in 3D as purlins, columns and insulation combined in more than two directions. Below a section and a screenshot of the model is shown.

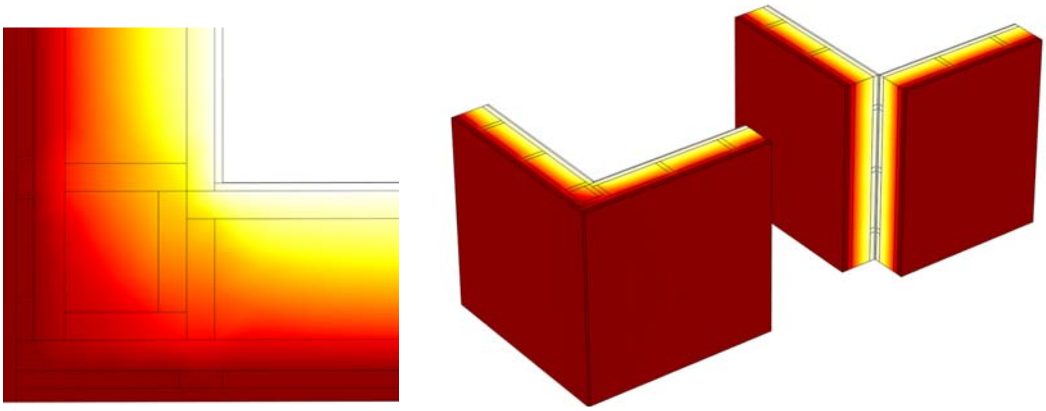


Figure 9. Screenshot from Comsol showing temperature gradient in simplified model made for calculations of thermal bridge in exterior wall corner.

The assumptions made are that the vertical airflow in the exterior air gap is 0,01 m/s. The height width and depth of the model is 1,8m to create a semi-infinite domain. This is made so that the edges do not affect the corner.

From the calculations the given result is a linear thermal bridge, $\Psi_{\text{Ext.wall corner}}$, with a heat flux of 0,037 W/mK.

#### 5.1.2.2 Thermal bridge of window perimeter

The window perimeter detail is modelled in 2D considering the whole perimeter to be equal. The model used is shown in figure below.

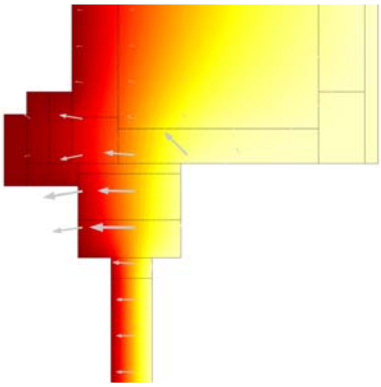


Figure 10. Screenshot from Comsol showing temperature gradient and heat flux arrows in simplified 2D model of window perimeter.

The assumption made is that there is no air movement between frame and sill.

From the calculations the given result is a linear thermal bridge, $\Psi_{\text{Window perimeter}}$, with a heat flux of 0,023 W/mK.

#### 5.1.2.3 Exterior wall to roof thermal bridge

The exterior wall to roof connection detail is simplified and modelled in 2D without considering the roof trusses acting as point thermal bridges every 1200mm. The model used is shown in figure below.

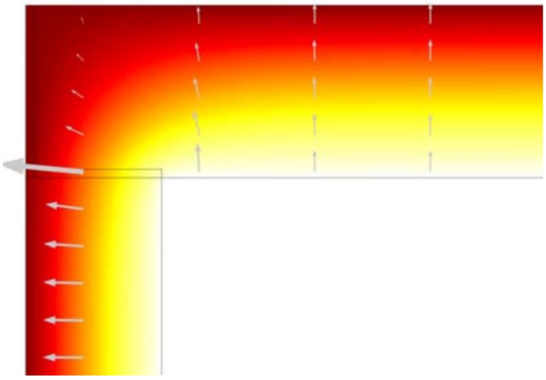


Figure 11 Screenshot from Comsol showing temperature gradient and heat flux arrows in roof to external wall detail.

From the calculations the given result is a linear thermal bridge, $\Psi_{\text{roof}}$, with a heat flux of 0,026 W/mK.

#### 5.1.2.4 Internal slab to wall thermal bridge

The internal slab to wall connection are modelled in 3D and considered to be equal around the building. The un-insulated part of the internal slab has an air movement of ~0,001 m/s due to convection.

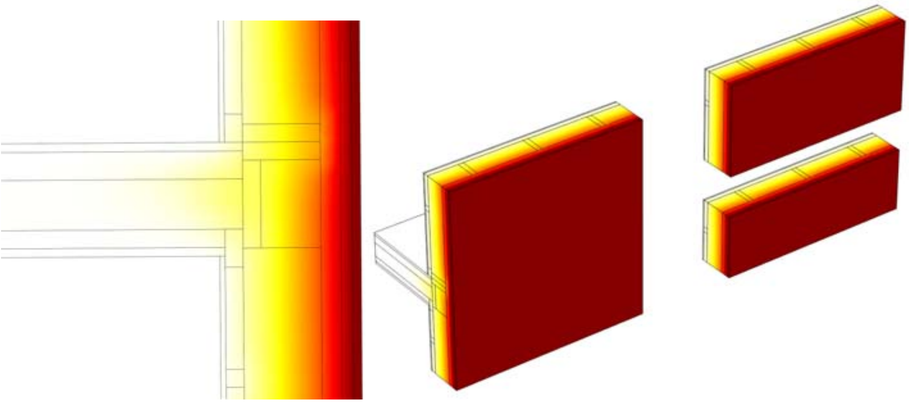


Figure 12 Screenshot from Comsol showing temperature gradient in simplified model made for calculations of thermal bridge in connection between internal slab and exterior wall.

From the calculations the given result is a linear thermal bridge, $\Psi_{\text{Internal slab}}$, with a heat flux of 0,098 W/mK.

#### 5.1.2.5 Ground slab edge thermal bridge

The slab edge is modelled in 2D. In the calculation model, the ground is considered to be homogeneous clay and the wall is considered to be one layer.

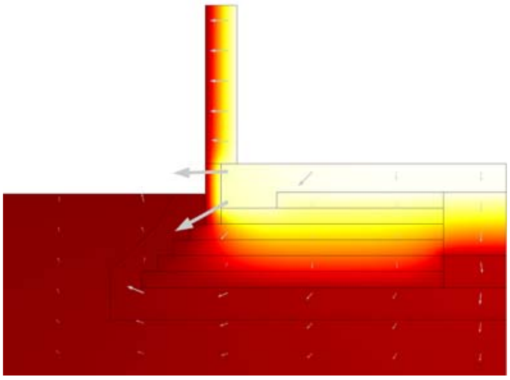
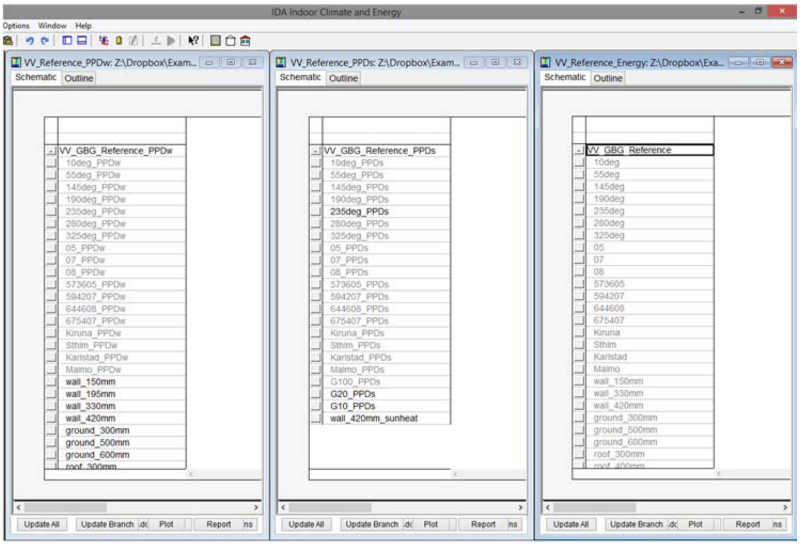


Figure 13 Screenshot from Comsol showing temperature gradient and heat flux arrows of slab edge.

From the calculations made, the result was a linear thermal bridge, $\Psi_{\text{Slab edge}}$ with a heat flux of 0,080 W/mK.

## 5.2 The structure of IDA ICE simulations

IDA ICE has the possibility to re-use the reference model, which means that the same model is used for each simulation. This is called branch- or version modelling. This means that all the versions containing new changes are referenced to the parent model, which means that a complete new model doesn't have to be created for each change. The parent models have been divided into three types of simulations: annual energy, heating design and cooling design Figure 14. Together the total amount of simulations reaches around 100.



VV_GBG_Reference_PPDw
10deg_PPDw
55deg_PPDw
145deg_PPDw
190deg_PPDw
235deg_PPDw
280deg_PPDw
325deg_PPDw
05_PPDw
07_PPDw
08_PPDw
573605_PPDw
594207_PPDw
644608_PPDw
675407_PPDw
Kiruna_PPDw
Sthlm_PPDw
Karlstad_PPDw
Malmo_PPDw
wall_150mm
wall_195mm
wall_330mm
wall_420mm
ground_300mm
ground_500mm
ground_600mm
roof_300mm

VV_GBG_Reference_PPDs
10deg_PPDs
55deg_PPDs
145deg_PPDs
190deg_PPDs
235deg_PPDs
280deg_PPDs
325deg_PPDs
05_PPDs
07_PPDs
08_PPDs
573605_PPDs
594207_PPDs
644608_PPDs
675407_PPDs
Kiruna_PPDs
Sthlm_PPDs
Karlstad_PPDs
Malmo_PPDs
G100_PPDs
G20_PPDs
G10_PPDs
wall_420mm_sunheat

VV_GBG_Reference
10deg
55deg
145deg
190deg
235deg
280deg
325deg
05
07
08
573605
594207
644608
675407
Kiruna
Sthlm
Karlstad
Malmo
wall_150mm
wall_330mm
wall_420mm
ground_300mm
ground_500mm
ground_600mm
roof_300mm
roof_400mm

Figure 14. Screenshot showing the branch models in IDA ICE. The three types of simulations are annual energy and heating/cooling design simulations.

The annual energy simulations show how the building performs on a yearly basis. The heating design simulation calculates the design heating power demand at winter design day. Since the building doesn't have any cooling system the cooling design day is only used for describing the PPD-summer value.

## 5.3 Selected days of interest

In the following three chapters the specific design days are described. In annual simulations data from the year is retrieved. To allow daily analysis and comparison of these results, specific days of the month have been selected as described in Chapter 5.3.3. For seasonal design of the building artificial days has been simulated in IDA ICE as described in Chapter 5.3.1 and 5.3.2.

### 5.3.1 Winter design day

The winter design day is an artificial extreme winter day with a constant ambient outdoor temperature corresponding to DVUT. No solar and internal heat gain is allowed in the calculation.

### 5.3.2 Summer design day

The summer design day is an artificial extreme summer day with a synthetic, periodic, climate based on design values for the specific location is used.

### 5.3.3 Monthly design days

For detailed analysis and comparison of changes one day every month is picked as a monthly design day. The day picked is the day that corresponds best to the average climate of the month. An example of a design day is presented below in Figure 15 and climate from all monthly design days can be found in APPENDIX D.

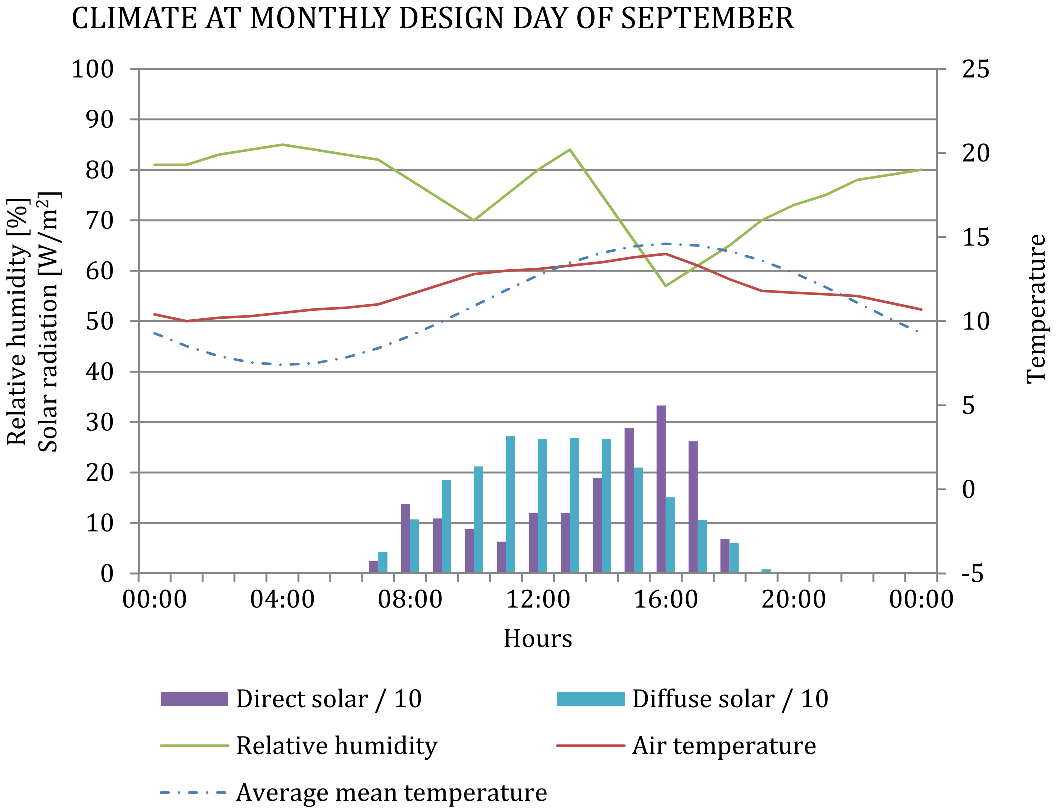


Figure 15. Figure showing the climate of monthly design day of September. The blue line is presenting the calculated average day of September.

## 5.4 Simplified calculation methods for verifying simulations result

Miljöbyggnad allow some simplified calculations methods to be used instead of simulation tools for analysing the building performance. In this report the simplified methods is mainly used for verifying the results from energy and solar heat gain simulations. The simplified solar heat gain calculation is used as an estimate of needed solar shading. The methods used and allowed are further described below and in APPENDIX C.

### 5.4.1 Heating power demand

The heating power demand is defined as the sum of the heat losses from transmission, infiltration and ventilation distributed on the heated area in the building (see equation 1 &2).

The heating power demand is calculated at the winter design day described in Chapter 5.3.1.

$$P_{Total} = P_{Trans} + P_{Infiltration} + P_{Vent}\ [W] \tag{1}$$

$$Heating\ power\ demand = \frac{P_{Total}}{A_{Temp}} \left[\frac{W}{m^2}\right] \tag{2}$$

### 5.4.2 SVL

The simplified solar heat gain method, SVL, is the approximate peak in power of solar radiation transported though windows divided by specific room area as shown in equation 3 and equation 4. The calculation is made for each room and it's the 20 most exposed percentage of floor area that determinates the grade.

For rooms having windows facing both south and east or west equation 4 is used.

$$SVL = 800 \times g_{Syst} \times \frac{A_{Glazing}}{A_{Floor}}\ [W/m^2] \tag{3}$$

$$SVL = \max\begin{cases} 560 \times g_{Syst} \times \frac{A_{Glazing}}{A_{Floor}} + 560 \times g_{Syst} \times \frac{A_{Glazing}}{A_{Floor}} \\ 800 \times g_{Syst} \times \frac{A_{Glazing}}{A_{Floor}} \end{cases} [W/m^2] \tag{4}$$

## 5.5 Creating a daylight model

The daylight model is created in Velux Visulizer 2. Assumptions are that a bright material on walls and in the ceiling is used. On the floor it is assumed that a bright wooden floor is used. These assumptions affect the daylight factor since the elements reflects the daylight from the windows in different ways.

The windows setup used in the simulation model are specified in APPENDIX B.

# 6 Sensitivity analysis of Villa Vänern

As presented in the introduction chapter the analysis of Villa Vänern is an empirical study, where only one parameter is changed at the time. This chapter analyses the response of Villa Vänern when changing the orientation, location, windows, envelope and occupant parameters separately. The choice of studied indicators is based on WSP's pre-study shown in Chapter 4.5, the analysis of the reference model in Chapter 6.1 and the basis of sustainable building presented in Chapter 2.

Indicators taken into consideration are:

- Annual energy usage
- Design heating power demand
- Solar heat gain
- Thermal climate winter
- Thermal climate summer
- Daylight conditions

Above-mentioned indicators are the measurable and the ones affected by changing a parameter. A detailed reference energy model of the existing Villa Vänern was made as described in Chapter 5, this to compare outcome of different changes against.

## 6.1 The reference model of Villa Vänern

To see how Villa Vänern performs in its basic design on all studied indicators, an analysis of the energy reference model is presented in the following chapter. The results from simulating the reference model, for the measurable indicators in Miljöbyggnad are summarized in Table 9 below. More detailed description for each indicator follows in respective chapter.

Table 9. Villa Vänern in its basic design - grades in Miljöbyggnad.

| | VILLA VÄNERN | MILJÖBYGGNAD GOLD |
|---|---|---|
| Annual energy usage | 82,7 kWh/$m^2$ | 58, 5 kWh/$m^2$ (≤ 65 % of BBR) |
| Heating power demand | 29,9 | ≤ 25 W/$m^2$ |
| Solar heat gain[2] | 53,6 W/$m^2$ | 18 W/$m^2$ |
| Thermal climate summer[3] | 15 % | 10 % |
| Thermal climate winter[3] | 5 % | 10 % |
| Daylight | > 1,2 | > 1,2 |

---

[2] Based on maximum value for the Living room.

[3] Simulated in the Living room.

### 6.1.1 Annual energy usage

The Annual energy usage shows that Villa Vänern in its basic design uses 82,7 kWh/m$^2$ per year, which corresponds to Miljöbyggnad grade BRONZE. The demands on the annual energy usage are depending on where in Sweden the building is located, which will be handled in chapter 6.3. If Villa Vänern should be graded as GOLD the demand is 58,5 kWh/m$^2$ per year in Göteborg.

The energy usage is a sum of three different categories: HVAC auxiliary, heating and domestic hot water. The HVAC auxiliary is a measure of how much energy pumps and fans in the air handling unit uses. Heating is the energy used for heating the indoor environment and domestic hot water is the energy used for heating up the hot water. In Figure 16 below each categories share of total energy usage is visualised in a pie chart showing the annual energy consumption and fraction.

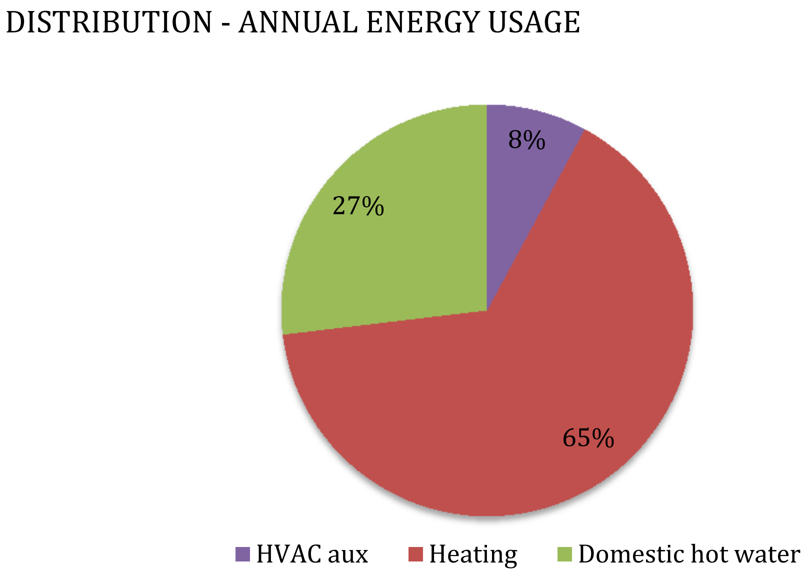


Figure 16. Pie chart showing annual energy usage divided in HVAC auxiliary, heating and domestic hot water.

The fans and pump used in simulations is default equipment from IDA ICE corresponding to 6,5 kWh/m$^2$ per year and the domestic hot water usage is a estimated value from SVEBY set to 20 kWh/m$^2$ per year. Since the energy for hot water and HVAC auxiliary is fixed values no further analysis will be made on these, only the energy for heating is further analyzed.

To get a more detailed view of heat flows in Villa Vänern, a monthly energy balance is made as shown in Figure 17. The "*Envelope & Thermal bridges*" are the transmission losses. The "*Mech, supply air*" corresponds to ventilation losses the "*Infiltration & Opening*" are losses from airing and infiltration. "*External Window & Solar*" are the window energy balance with solar heat gain included. "*Occupants*" and "*Equipment*" are the internal gains from respective category. "*Local heating units*" are the energy supplied by waterborne floor heating and radiators. The "Net losses" are distribution losses in the system, which contributes to heating the building. The heat gain and losses from the "*Internal Walls and Masses*" are considered to be zero.

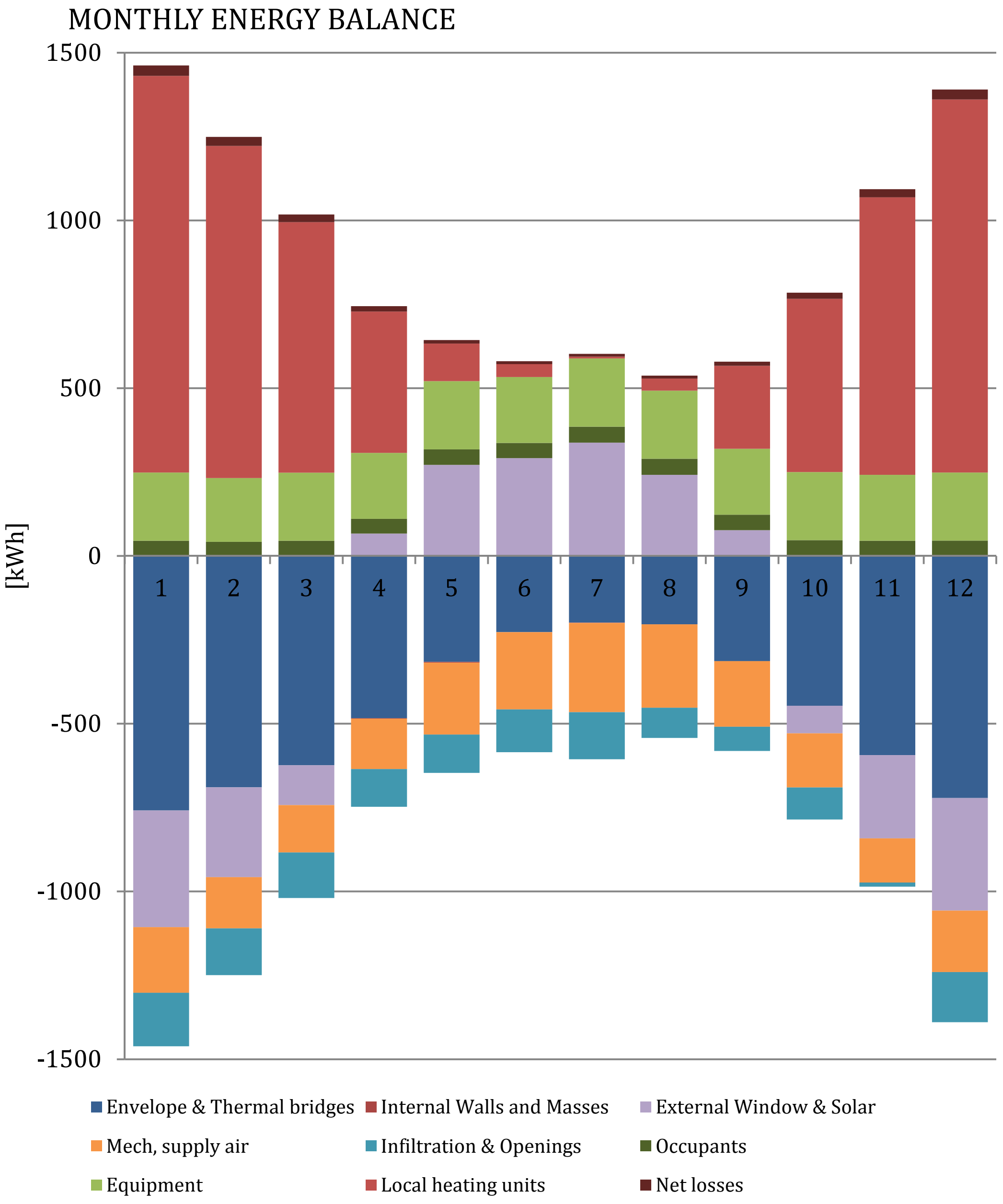


Figure 17. Bar chart from IDA ICE showing monthly energy balance of the reference model.

In the monthly energy balance from IDA ICE it can be noted that almost no energy is used for heating during June, July and August. Also the energy gain from windows from May to September is clearly visible.

The increase of supply air losses during the summer is because of an activation of the by-pass function in the air-handling unit to cool the building, see Figure 7 in Chapter 4.4.3 for details.

The main part of losses, annually, is the "*Envelope & Thermal bridges*". During winter an increase of losses through windows can be noted. The increase is damped as the energy balance takes solar heat gain through windows into account in "*External Windows & Solar*". The transmission losses of the envelope including windows are shown in Figure 18.

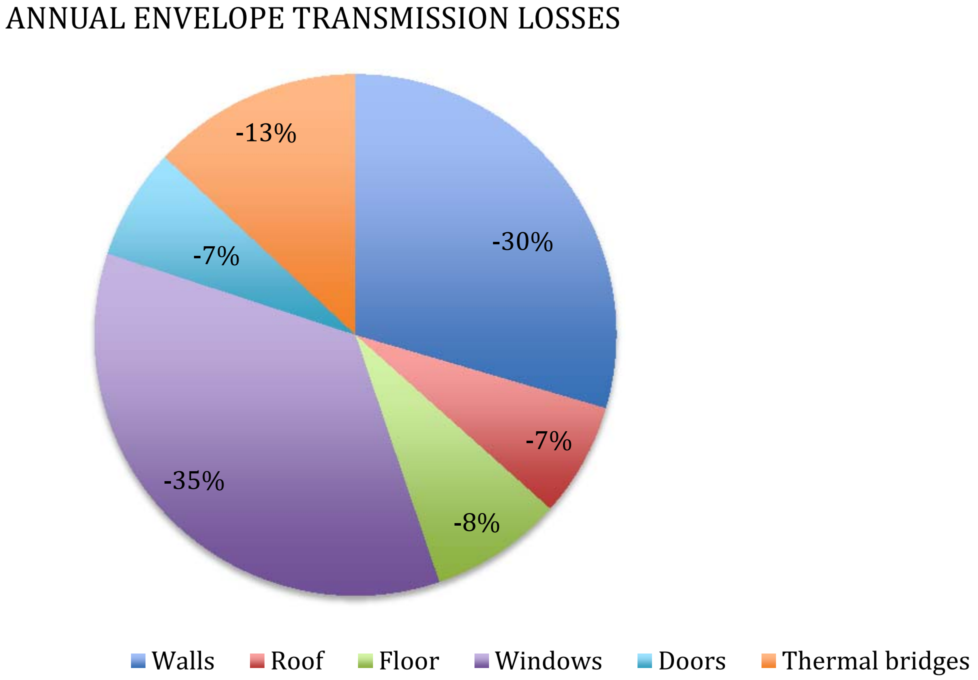


Figure 18. The annual envelope transmission distribution.

The annual envelope transmission pie chart indicates where further investigations are preferred. The windows and doors represents 42% of the transmission losses, but covers less than 10% of the envelope area, which indicates certain enhancement potential.

The most detailed analysis of Villa Vänern is the daily energy usage for heating, which is presented as in Figure 20. These analysis is used for comparing changes over specific days every month. The relative humidity and temperature of the design day is presented in Figure 19 as well as the solar radiation on a horizontal surface. A decreace of heating power as the outdoor temperature and solar radiation increaces can be noted as two deflections in the heating power graph.

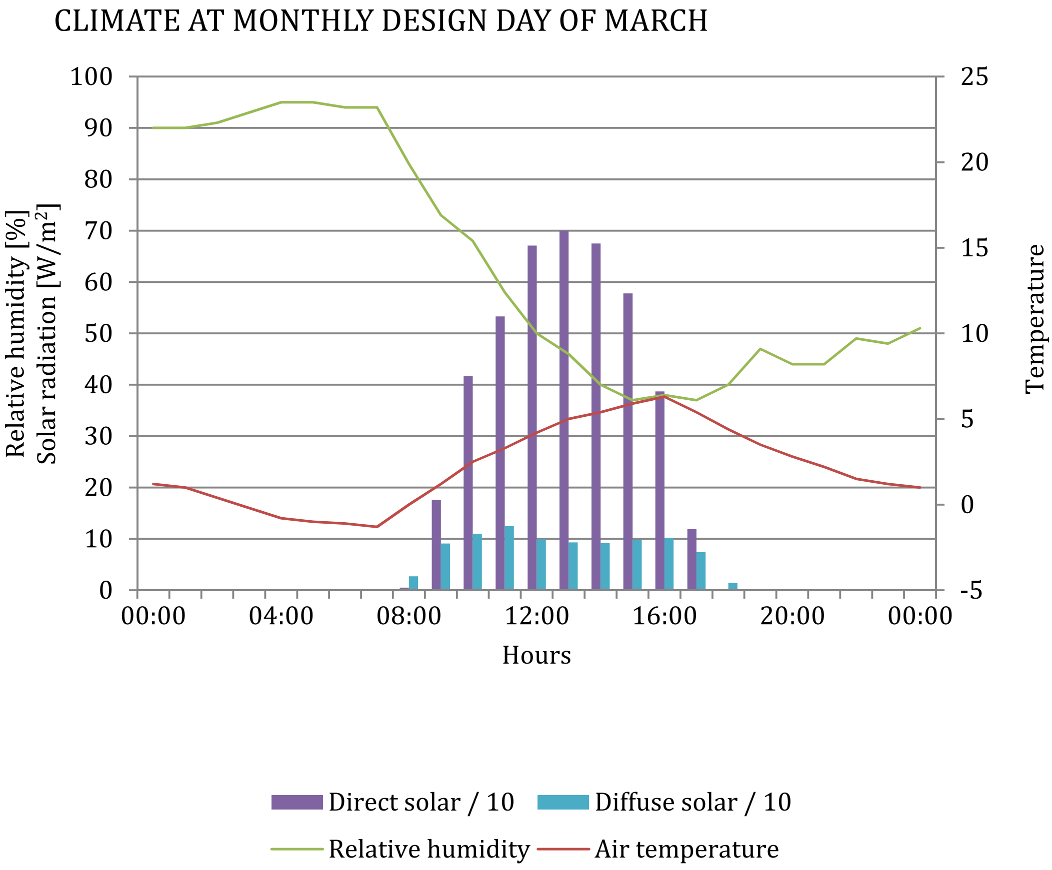


Figure 19. Graph showing climate data and mean monthly temperature of design day in March

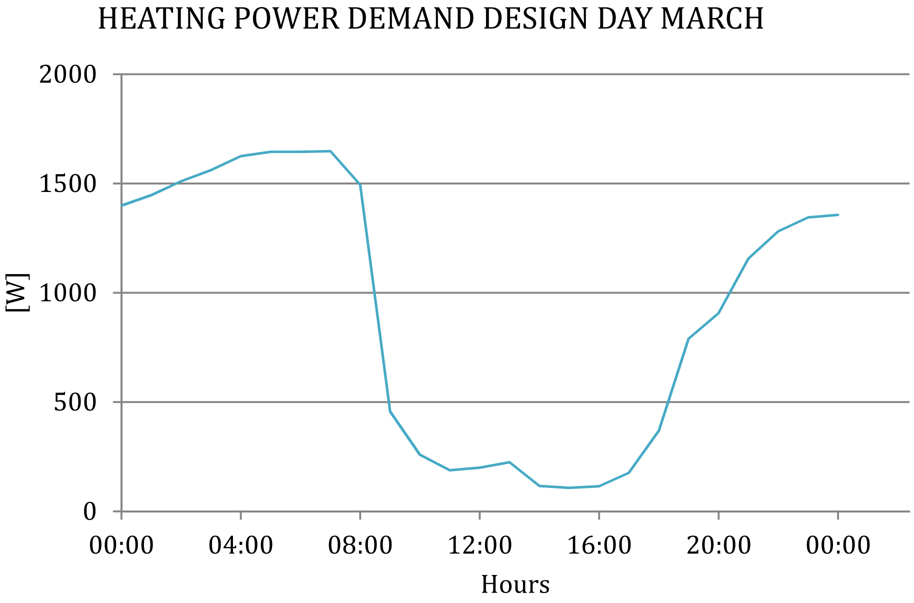


Figure 20. Graph showing heating power demand of the reference model at the design day of March.

### 6.1.2 Heating power demand

In the reference model the design heating power demand is 29,9 W/m$^2$, which is approximately 5 W/m$^2$ higher than allowed for Miljöbyggnad grade GOLD.

### 6.1.3 Solar heat gain

The reference building is partly shaded from solar heat gain by its orientation. It is also protected by the windows solar transmission coefficient, g-value, of 0,29 corresponding to internal blinds and glazing, which protects the indoor against solar radiation. By the simplified method SVL an estimation of solar heat gain is made and presented in Table 10 below. This protection is not sufficient to meet the demands of Miljöbyggnad GOLD. Also the results from simulating the solar heat gain during a summer design day are presented to verify and show difference.

Table 10 Showing result and input data for SVL calculation of the reference model.

| ROOM | SVL [W/m²] | SIMULATIONS [W/m²] | MILJÖBYGGNAD GOLD DEMAD |
|---|---|---|---|
| **LIVING ROOM** | 45,2 | 53,6 | 18,0 W/m² |
| **KITCHEN** | 34,7 | 33,0 | |
| **BEDROOM 1** | 20,6 | 24,0 | |
| **BEDROOM 2** | 26,1 | 28,7 | |
| **BEDROOM 3** | 27,9 | 32,1 | |
| **BEDROOM 4** | 27,9 | 32,0 | |

### 6.1.4 Thermal climate

The thermal climate during winter design day is constant at a PPD of 5%, which is the lowest possible value of PPD. This indicates that Villa Vänern in its basic design is sufficient insulated to create a comfortable indoor climate during the winter.

The thermal climate during summer design day is corresponding to a PPD of 11,6%. As visible in graph bellow it is during the peak of solar radiation and operative temperature at 17:00 that increases the PPD.

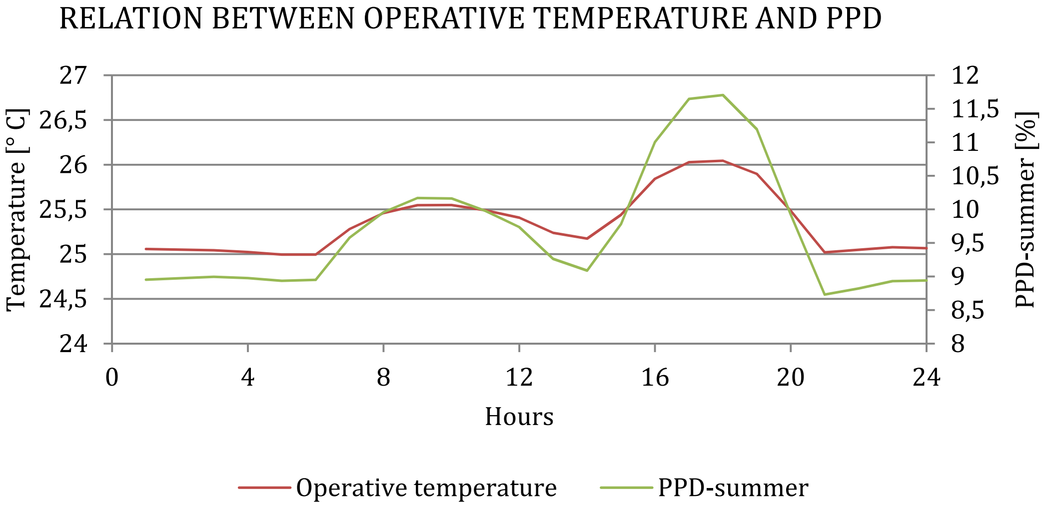


Figure 21. Figure showing the relation between operative temperature and the PPD value.

### 6.1.5 Daylight factor

The daylight factor is the ratio between the indoor and outdoor illumination given in percent. The daylight conditions in the reference building are shown in Figure 22 and Figure 23 below. The daylight factor is 2,0 % on the first floor and 1,3 % on the second floor. For details about the daylight factor see APPENDIX A.

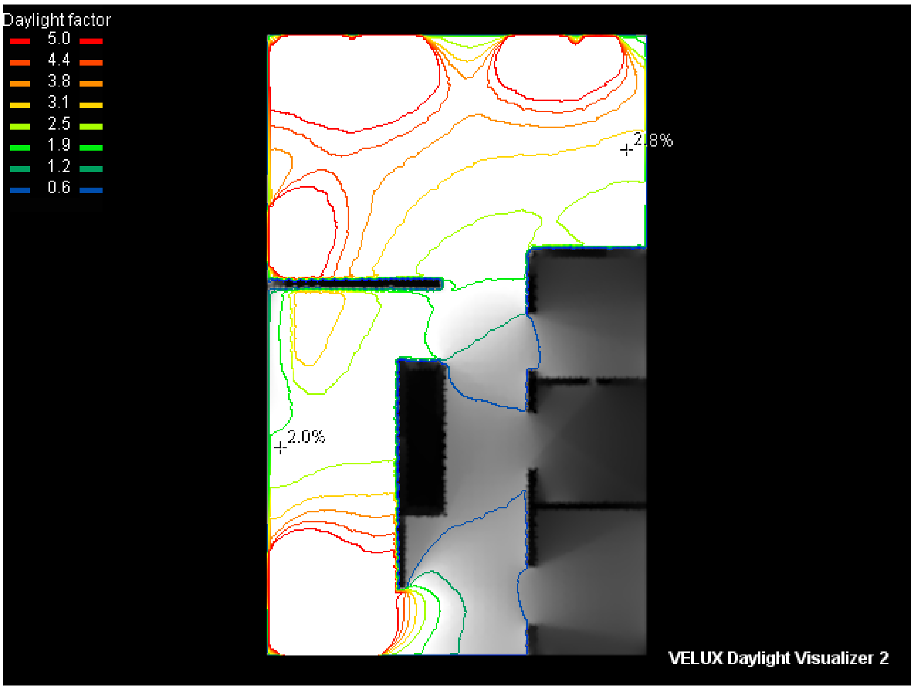


Figure 22. Daylight simulation - reference building. Ground floor.

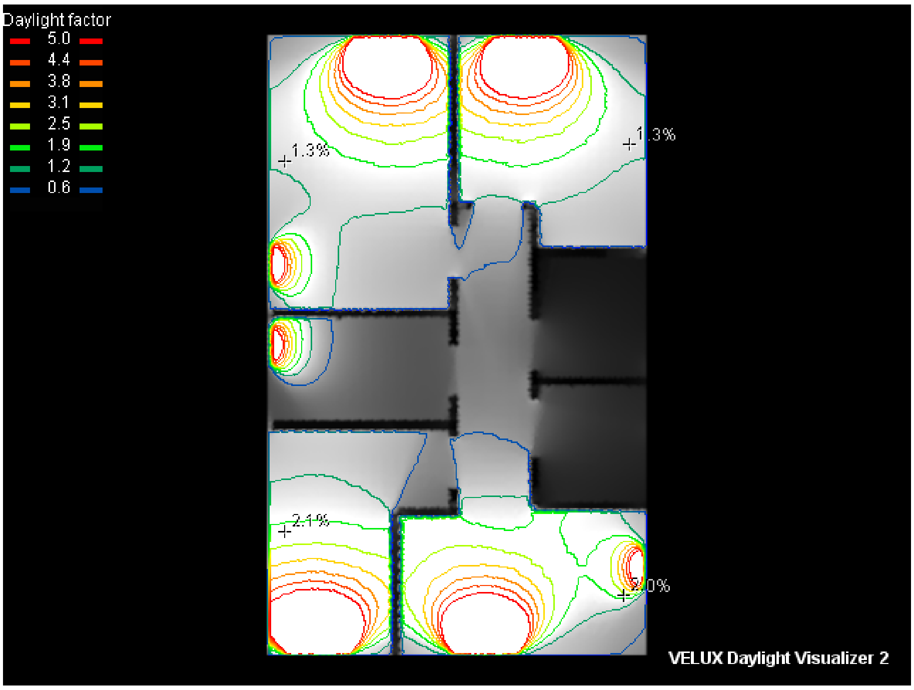


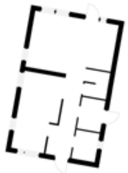
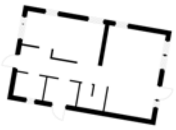
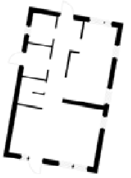
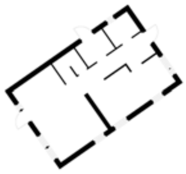
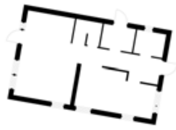
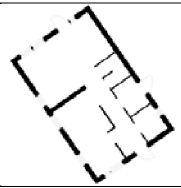
Figure 23. Daylight simulation - reference building. Second floor.

## 6.2 Orientation

To see the response of rotating Villa Vänern with a fixed floor plan and window setting an analysis of the building is presented in the following chapter.

When rotating the reference model of Villa Vänern the solar heat gain through windows is the most affected parameter. This contributes to change of inside surface temperatures, which affect the PPD in summer as the operative temperature changes. It also affects the annual energy usage as the solar heat gain changes. The rotation that is most beneficial for Villa Vänern is 235° from north-south axis which reduces the annual energy usage by ~2,5 kWh/m$^2$ per year. The result from simulations of different orientations is summarized in Table 11 on the next page and followed by detailed analyse.

Table 11. Table showing the result of simulations with different orientation of the reference model.

| N | ROTATION | ANNUAL ENERGY USAGE | WINDOW ENERGY BALANCE | HEATING POWER DEMAND[4] | SOLAR HEAT GAIN[5] | PPD-SUMMER |
|---|---|---|---|---|---|---|
| | | [kWh/m$^2$] | [kWh/year] | [W/m$^2$] | [W/m$^2$] | [%] |
| 10° |  | 82,0 | -107 | 29,9 | **22,3** | 12,0 |
| 55° |  | 82,5 | -137 | 29,9 | 43,2 | 12,0 |
| **100°<br>Ref.** |  | 82,7 | -119 | 29,9 | 53,6 | **11,6** |
| 145° |  | 81,8 | 78 | 29,9 | 50,0 | **11,6** |
| 190° |  | 80,1 | 299 | 29,9 | 43,8 | 13,7 |
| 235° |  | **79,9** | **430** | 29,9 | 55,2 | 14,7 |
| 280° |  | 80,8 | 277 | 29,9 | 53,4 | 13,4 |
| 325° |  | 81,4 | 78 | 29,9 | 40,4 | 11,9 |

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[4] The heating design simulation doesn't consider solar heat gain through windows therefore this value is constant.

[5] Maximum solar heat gain through the windows in the Living room from simulation.

### 6.2.1 Annual energy usage

When rotating the reference model of Villa Vänern the annual energy usage changes due to the changed amount of solar heat gain. Figure 24 below shows the annual energy use per square meter depending on orientation. The graph indicates a maximum value of 82,7 kWh/m$^2$ when rotated 100°, as the reference model. The minimum value of 79,9 kWh/m$^2$ appears at an orientation of 235°, making a difference of approximately 2,5 kWh/m$^2$ per year.

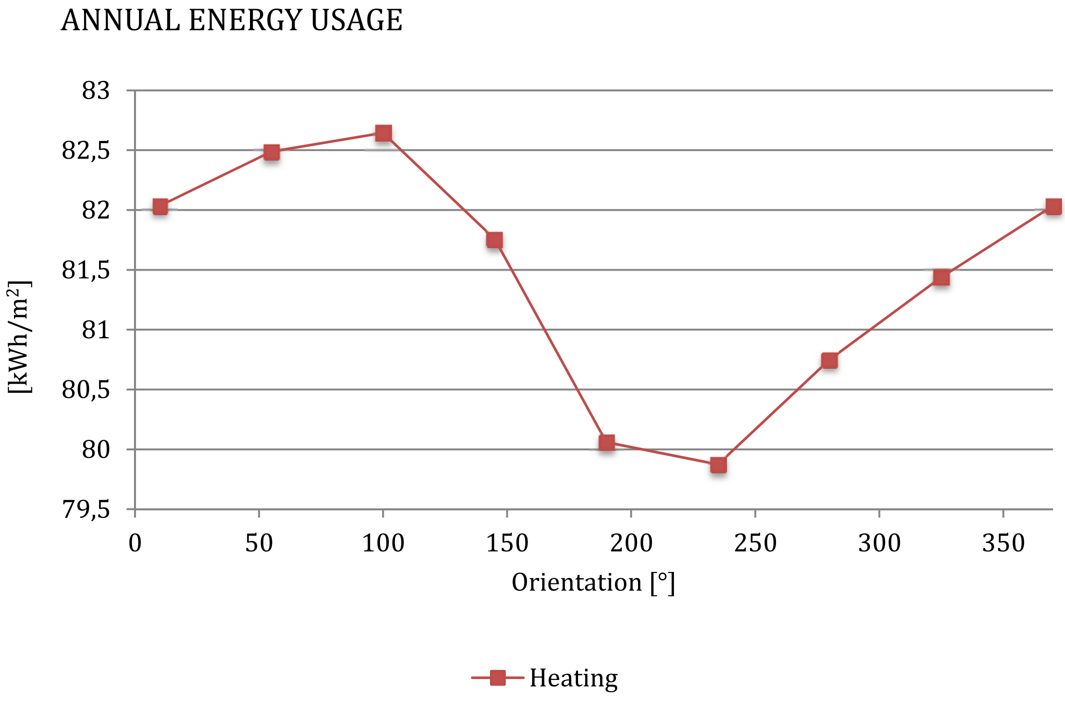

Figure 24 Figure showing annual energy usage per square meter when rotating the reference model of Villa Vänern.

In the monthly energy balance, shown in Figure 25 and also to be read out from Table 11 the window heat balance is the most affected parameter. It contributes to some overheating during warm summer days, which is handled by ventilation thru the windows as the increased infiltration indicates.

This energy balance can be compared with the monthly energy balance for the reference model on page 25.

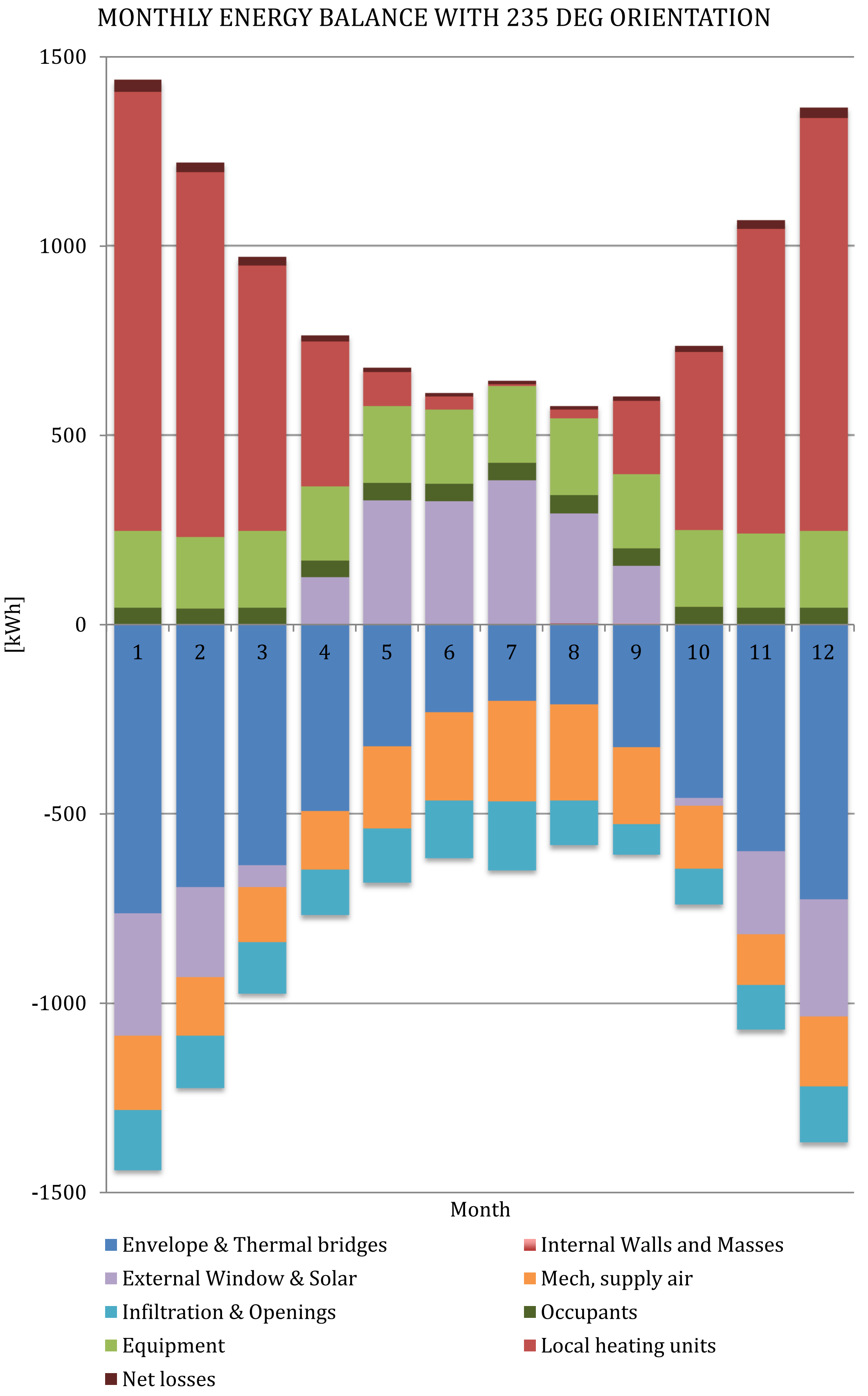

Figure 25. Bar chart showing monthly energy balance of the 235 rotated reference model.

In figure below the design day of March, as shown in Figure 19, is compared to the graph of heating power demand when rotating the model. The area under the graph corresponding to the daily energy usage is lower when rotated 235°. Also the time of low heating power is extended and delayed as the sun enters the building later.

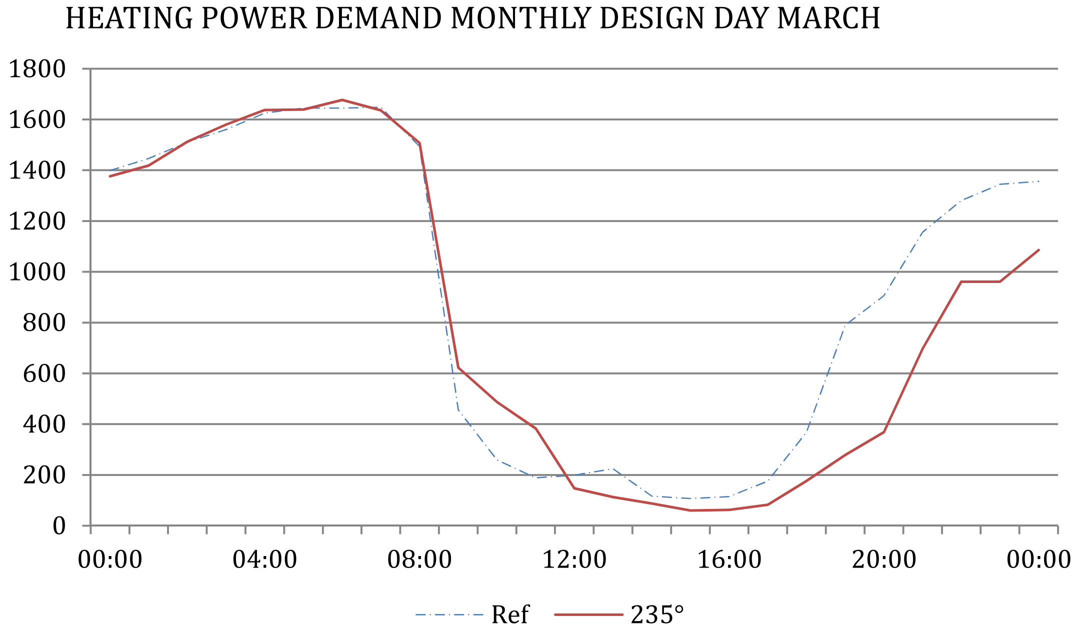

Figure 26. Figure showing heating power demand for both 100° reference building and the rotated 235° at the design day of March.

### 6.2.2 Heating power demand

As the heating design calculations at winter design day are performed without taking solar heat gain in consideration the design heating power is not affected by rotation of the model.

### 6.2.3 Solar heat gain

The effect of rotation on solar heat gain is visible in Figure 27 below where it is possible to read out a maximum value of over 50 W/m$^2$ in the living room, creating a need of solar shading. The figure also shows that it is not possible to achieve Miljöbyggnad GOLD only by rotating the model as most rooms are above the required level at all times.

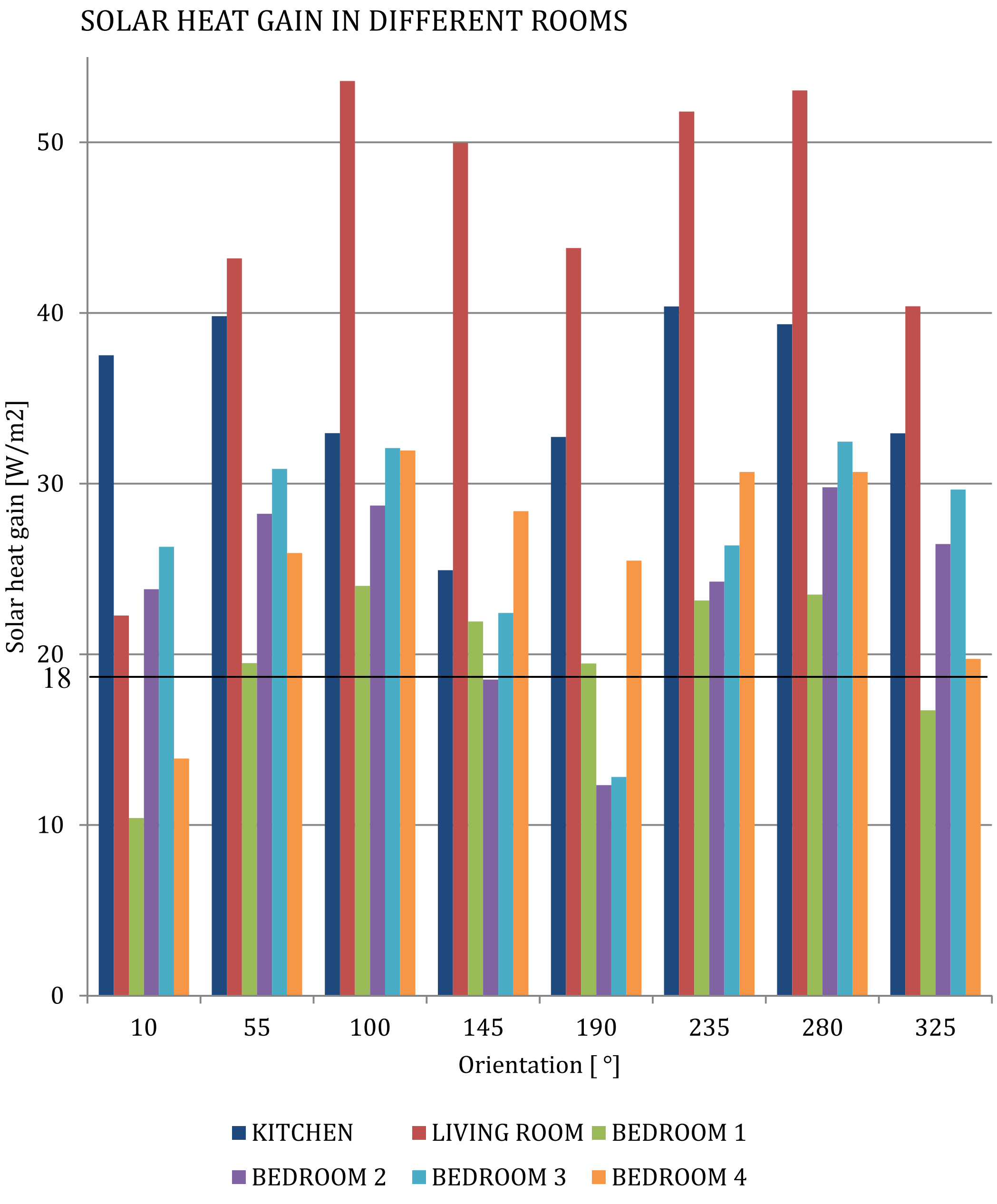

Figure 27. Figure showing maximum solar heat gain for each room of interest, from simulation of different orientations. The demand of 18 W/m$^2$ is marked with the black line.

The figure also shows that in the 10° or 190° rotation two rooms will meet the 18W/m$^2$ demand. This is because the affected rooms will be located to the north, which does not allows critical daily solar heat gain to get through the windows.

### 6.2.4 Thermal Climate

During the winter design day the PPD level is kept constant at 5% in all orientations. Meaning no PPD-optimization is possible as it is at its minimum in all orientations.

During the summer design day the results of PPD-summer is varying as shown in in Figure 28 below.

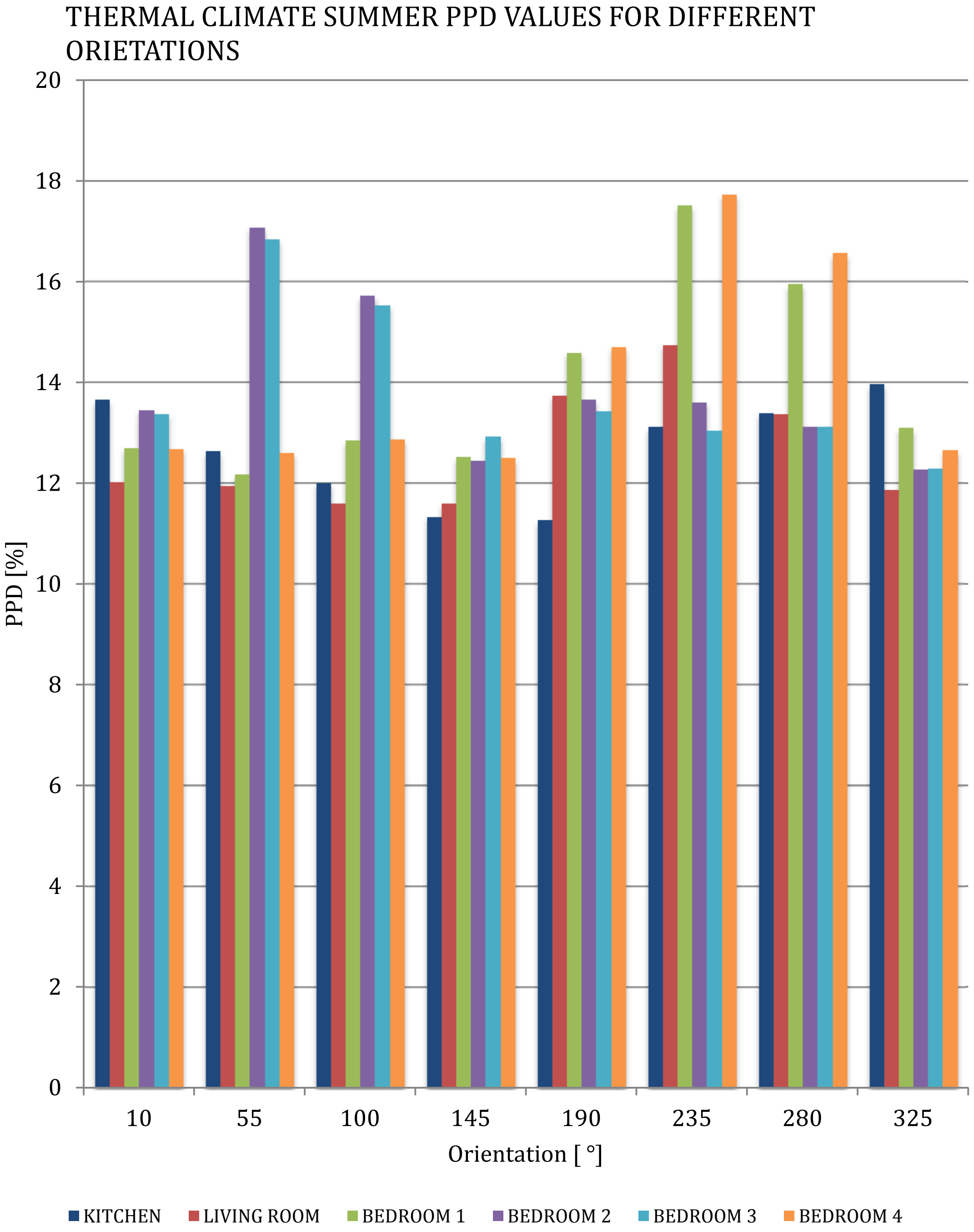

Figure 28. Stacked bar chart showing maximum PPD of each room of interest during summer design day at varying orientation.

### 6.2.5 Daylight factor

The orientation have an impact on the daylight factor that is why the daylight factor and is therefore simulated with the new orientation. In Figure 29 and Figure 30 below the daylight factors is shown for the 235 degrees rotated reference model. The daylight factor is still more than 1,2 % on both floors after the rotation.

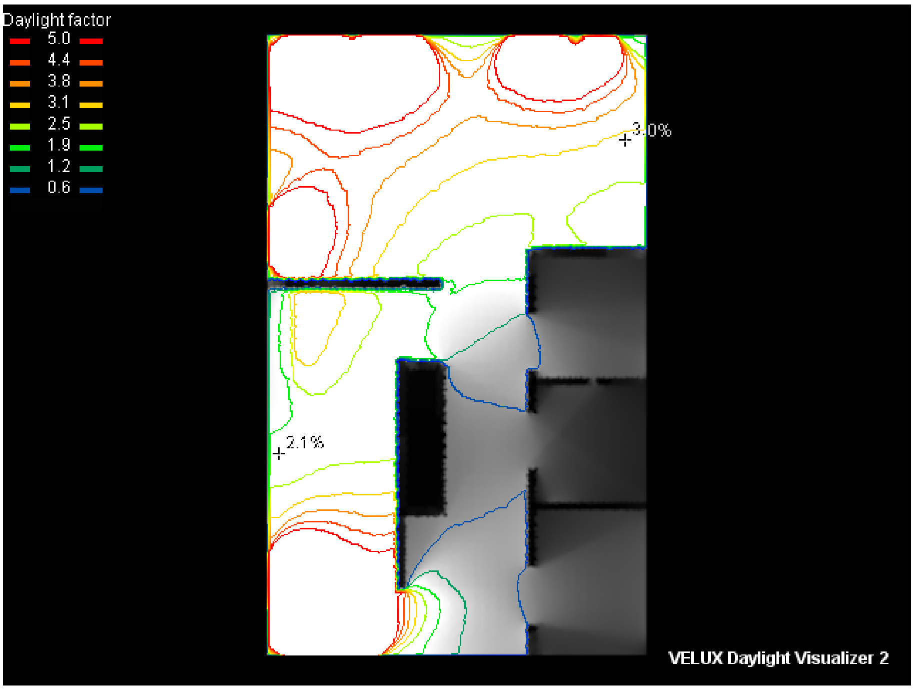

Figure 29. Daylight simulation - 235 degrees rotated reference building. Ground floor.

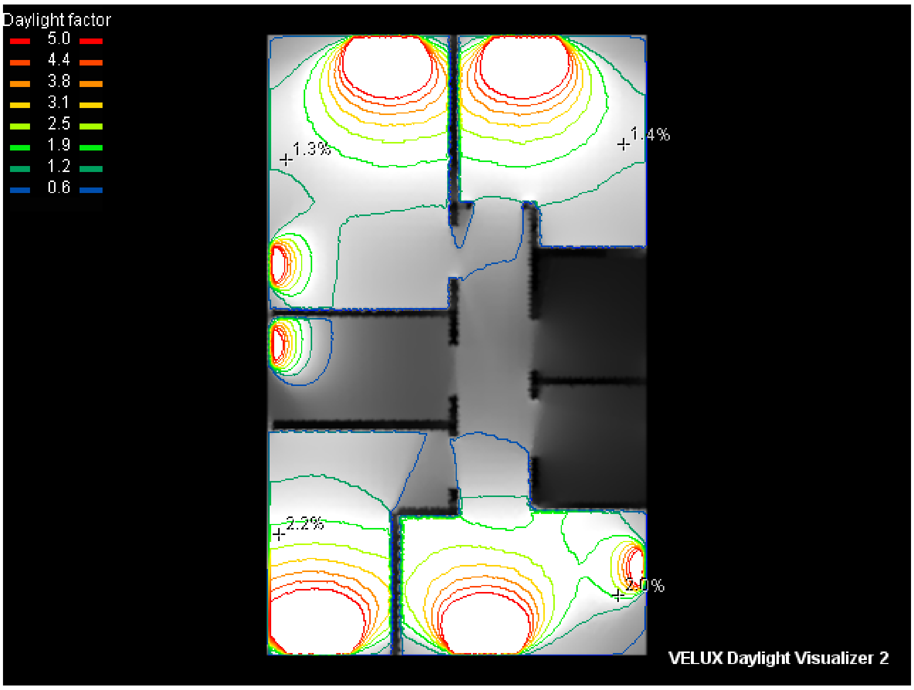

Figure 30. Daylight simulation - 235 degrees rotated reference building. Second floor.

## 6.3 Location

To verify the possibility to build Villa Vänern in different parts of Sweden an analysis of how the location affect the studied indicators is presented in the following chapter. When placing the reference model of Villa Vänern at different locations in Sweden the demands by Miljöbyggnad are changing and so are the values on the annual energy usage, the heating power demand.

A summary of the results from simulations made is presented in Table 12 below.

Table 12. Summary of results from simulations with different location.

| LATITUDE MOVEMENT | LOCATION | ANNUAL ENERGY USAGE [kWh/m$^2$] | HEATING POWER DEMAND[1] [W/m$^2$] | SOLAR HEAT GAIN[2] [W/m$^2$] | PPD$_{SUMMER}$ [%] |
|---|---|---|---|---|---|
|  | KIRUNA | 134,2 | 48,3 | 53,0 | 9,70 |
| | ÖSTERSUND | 101,4 | 42,5 | 53,2 | 9,60 |
| | KARLSTAD | 87,5 | 35,5 | 53,5 | 10,3 |
| | STOCKHOLM | 84,8 | 33,1 | 53,5 | 12,5 |
| | GÖTEBORG | 82,7 | 30,0 | 53,6 | 11,5 |
| | MALMÖ[6] | 74,4 | 26,4 | 53,6 | 10,1 |

The most obvious parameter that changes is the temperature variation over the year. The graph in Figure 31 the temperatures of Malmö, Göteborg and Kiruna. The graph of Kiruna is offset in time to allow easier comparison of climate.

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[6] It is estimated that Malmö and Copenhagen have the same weather conditions, due to no weather data found for Malmö.

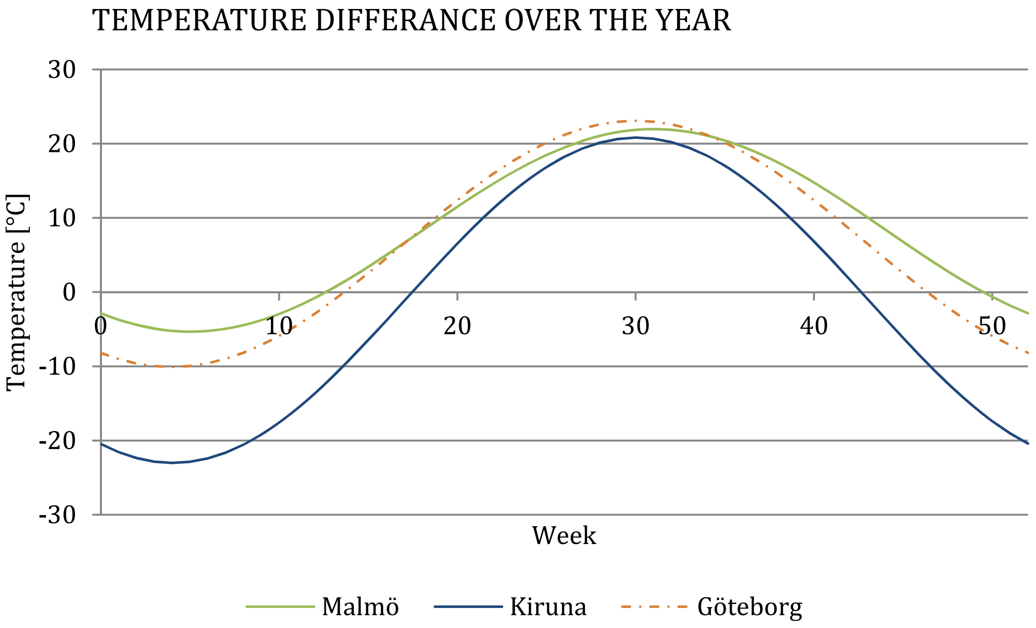

Figure 31. Figure showing the annual mean temperature for Malmö Göteborg and Kiruna in Sweden. Horizontal axis shows week number.

The solar radiation affects the annual energy usage, the solar heat gain and thermal climate is also changing due to location. A map showing the global solar radiation in Sweden is presented in Figure 32 to show the difference depending on location.

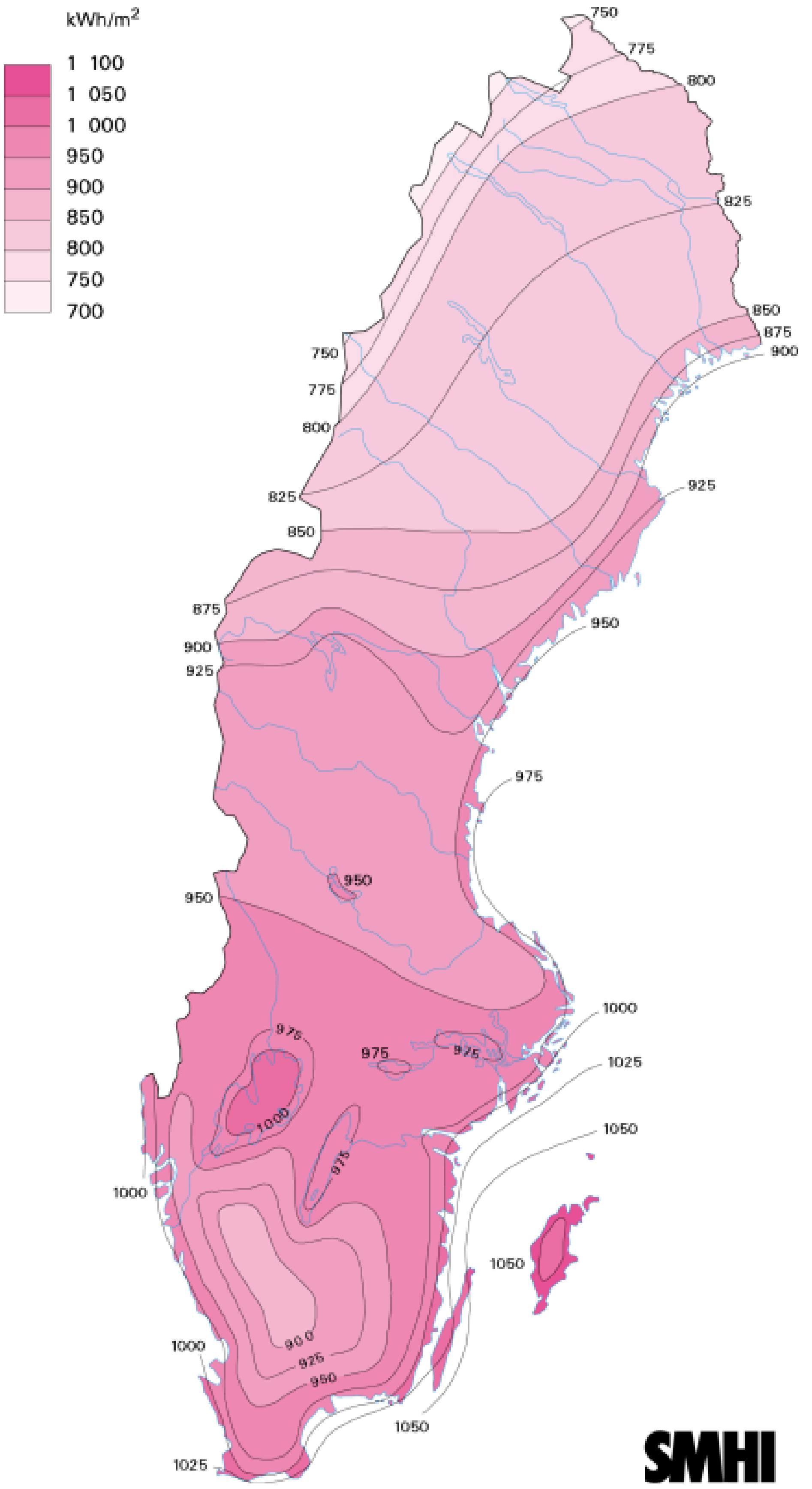

Figure 32 Map showing global solar irradiation over Sweden.
Accessible: <http://www.smhi.se>  2013-04-11

### 6.3.1 Annual energy usage

There are different demands regarding annual energy usage depending on where in Sweden the building is located. There are three different climate zones, and the demand for annual energy usage is based on those zones. In Figure 33 below it is shown how Villa Vänern in its basic design meet the annual energy usage of Miljöbyggnad.

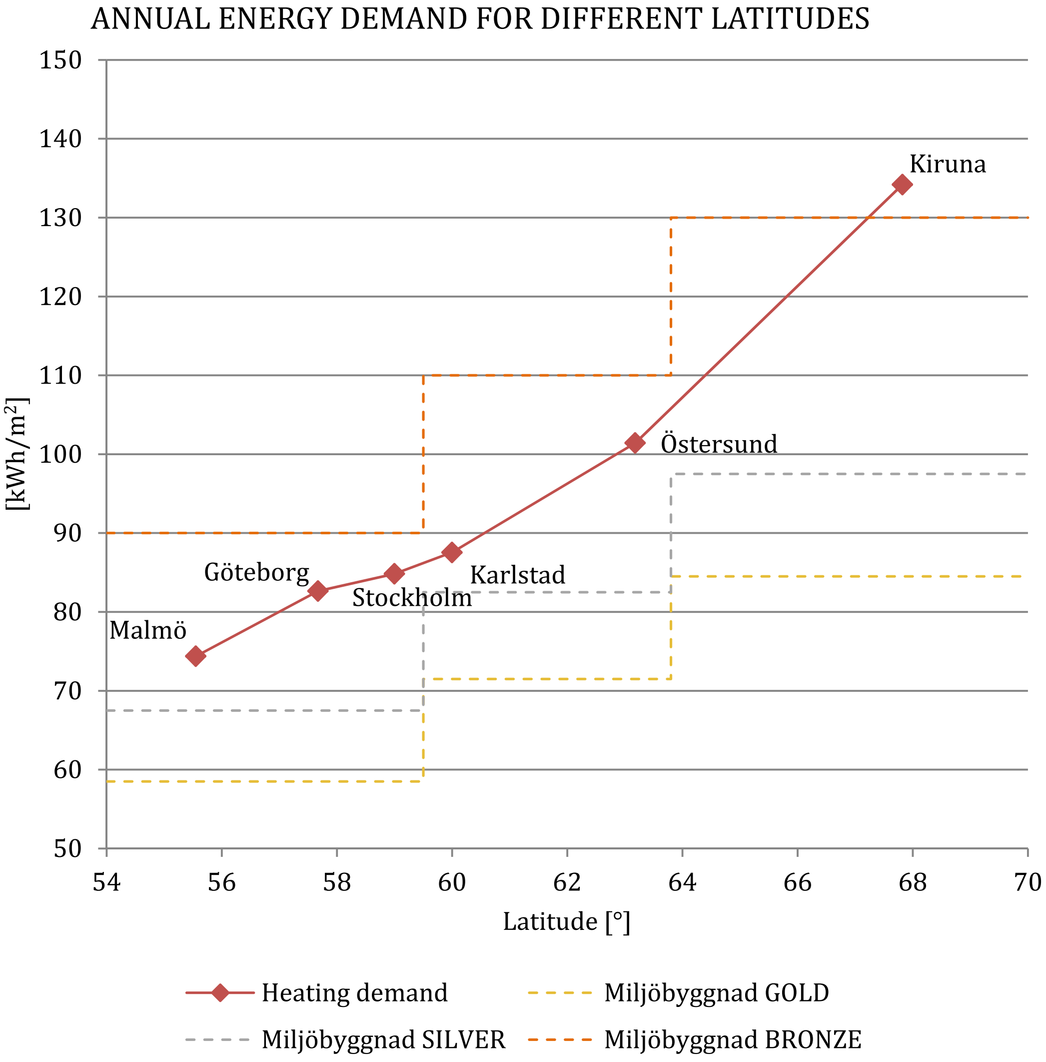

Figure 33. Figure showing the annual energy usage depending on different locations in Sweden.

The figure shows that Villa Vänern meets the demands for Miljöbyggnad BRONZE in every studied location except for Kiruna.

### 6.3.2 Heating power demand

Different locations have different DVUT, affecting the outdoor temperature at winter design day. In Figure 34 below the maximum heating power demand corresponding to specific locations in Sweden is shown.

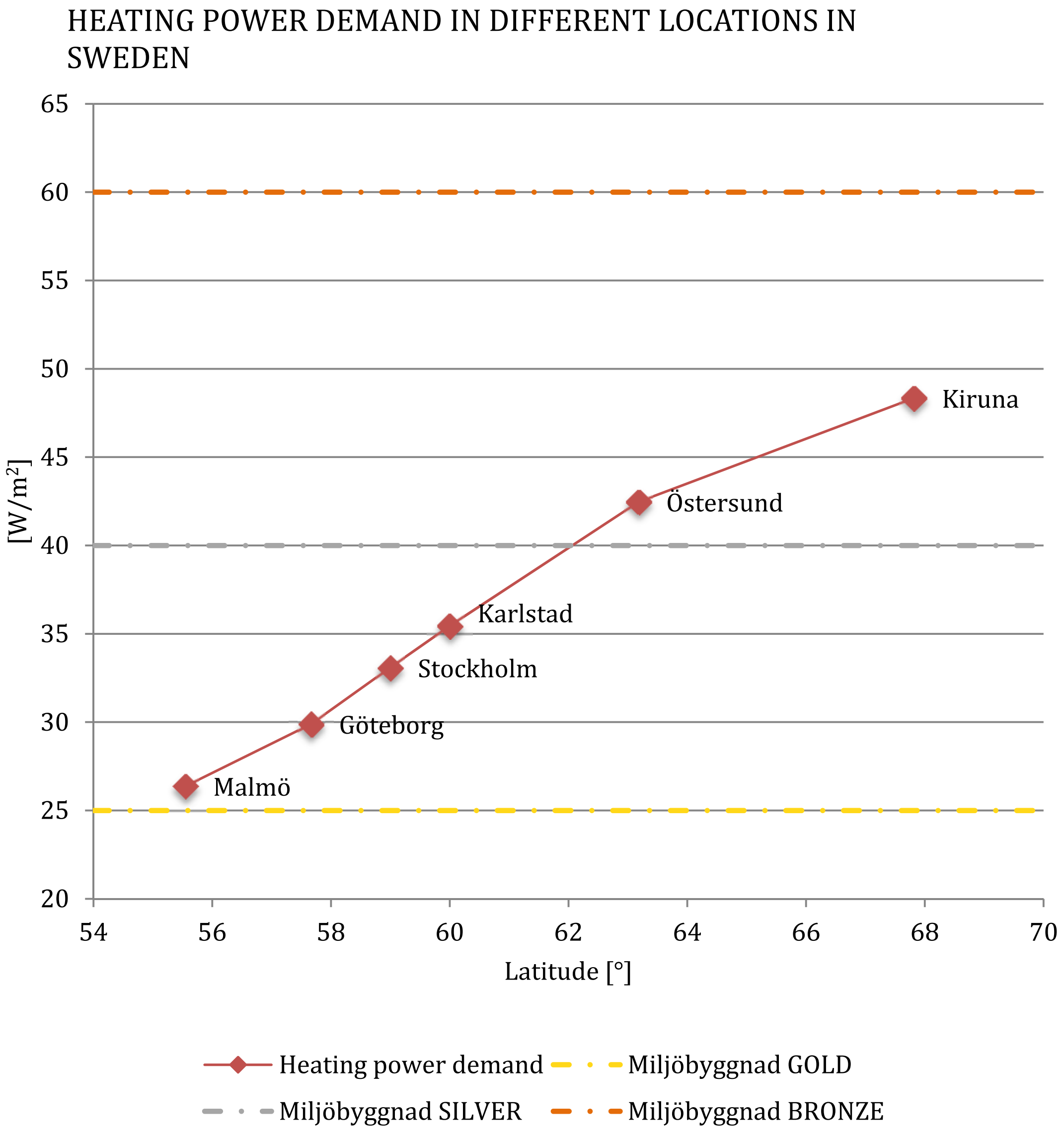

Figure 34. The heating power demand for different locations in Sweden.

The figure shows that Villa Vänern meets the demands for Miljöbyggnad SILVER in all studied location except Östersund and Kiruna. Miljöbyggnad do not take location into consideration when setting the demands for different grades. GOLD is fixed at 25 W/$m^2$ independent of location.

### 6.3.3 Solar heat gain

A difference in peak solar heat gain of less then 1% between all locations in Sweden as shown in table below has been derived from simulation. This indicates equal need of solar shading independent of location.

| LOCATION | SOLAR HEAT GAIN[7] [W/m$^2$] | MILJÖBYGGNAD GOLD DEMAND |
|---|---|---|
| KIRUNA | 53,0 | 18,0 W/m$^2$ |
| ÖSTERSUND | 53,2 | |
| KARLSTAD | 53,5 | |
| STOCKHOLM | 53,5 | |
| GÖTEBORG | 53,6 | |
| MALMÖ | 53,6 | |

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[7] Maximum solar heat gain through the windows in the Living room from simulation.

## 6.4 Windows

To see how the performance is affected by changing specific parameters of the windows an analysis of g-value, u-value and solar shading change is presented in the following chapter.

The windows in Villa Vänern are in its basic design a three-pane argon filled glazing unit with two low-emissivity coated panes. It has a u-value of 0,6 W/m$^2$K, a g-value of 0,51 and an Lt-value of 0,72. The frame is an aluminium cladded timber frame with a u-value of 1,7 W/m$^2$K. By changing these parameters different indicators in Miljöbyggnad are affected. The u-value and the g-value are connected to the annual energy usage, heating power demand, solar heat gain and the thermal climate. And the Lt-value is connected to the daylight indicator.

The total window u-value can be changed in the simple case in two ways, by changing glazing unit or by changing the frame. These two structures can be modified in many different ways. A modern three pane glazing unit has minimum u-value of approximately 0,5 W/m$^2$K with common techniques.

The g-value is a measure of how much solar heat gain that can transport through the windows. A high g-value allows utilizing free energy from the sun to heat the rooms. In Miljöbyggnad there is a demand of how much solar heat gain that is allowed, which is limited to 18 W/m$^2$ for the grade GOLD.

There are different ways of changing the g-value. One option is to change the glazing characteristics to get a higher or lower g-value, another is to use different kinds of solar shading technics. By using an active solar shade the g-value can be lowered during times of high solar radiation without missing out on positive impact during non-peak hours. To illustrate the effect of g-value change, a series of graphs are presented and explained in the following chapters.

### 6.4.1 Annual energy usage

The annual energy is affected by both the g- and the u-value of the glazing unit. Simplified the u-value keeps the heat inside and the g-value lets the energy from the sun in. In the graph bellow in Figure 35 the blue line corresponds to windows with fixed g-value of 0,51. Marks placed around correspond to windows with shifting g-value as shown in legend.

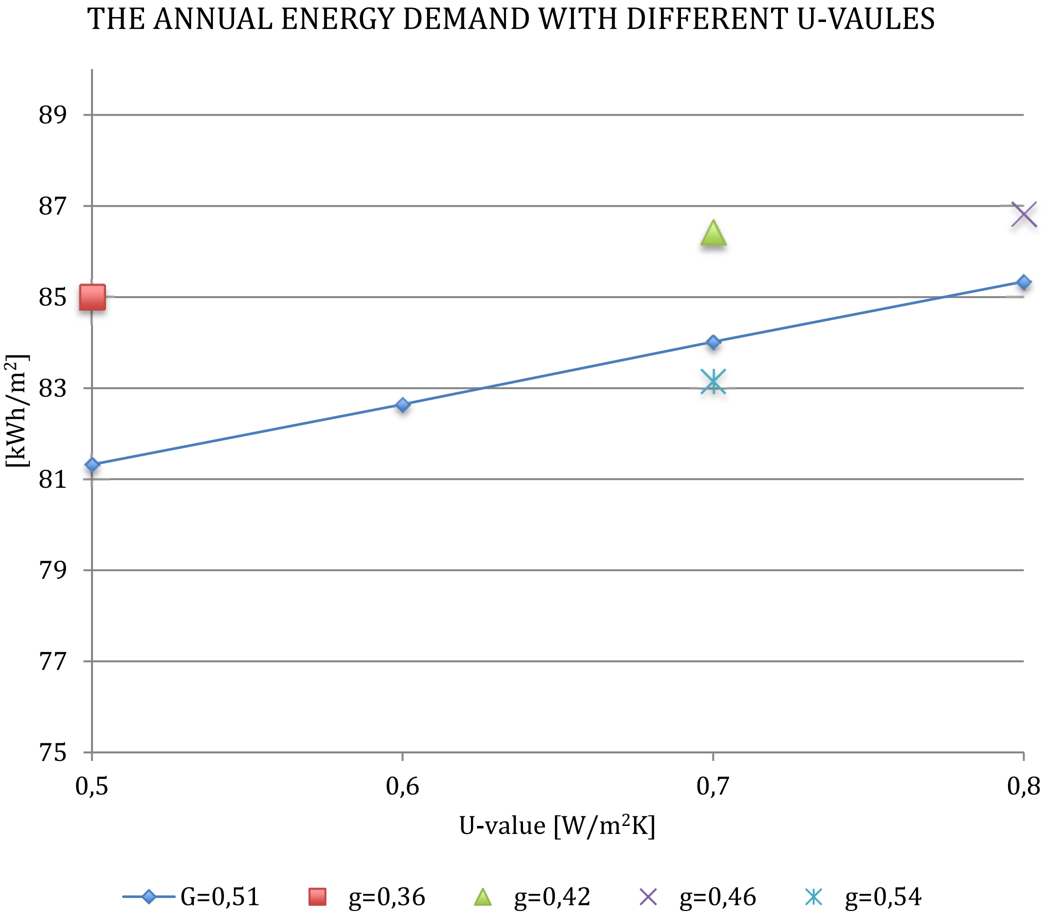

Figure 35 The annual energy usage depending on u- and g-value

Show in Figure 35 is that the solar protective glazing unit with a g-value of 0,36 contributes to a higher annual energy usage due to reduced solar heat gain.

### 6.4.2 Heating power demand

By changing the u-value from 0,6 to 0,5 W/m$^2$K the heating power demand at winter design day decreases to 29,5 W/m$^2$. If the u-value instead increases to 0,8 W/m$^2$K the heating power demand increases to 30,7 W/m$^2$, visible in Figure 36.

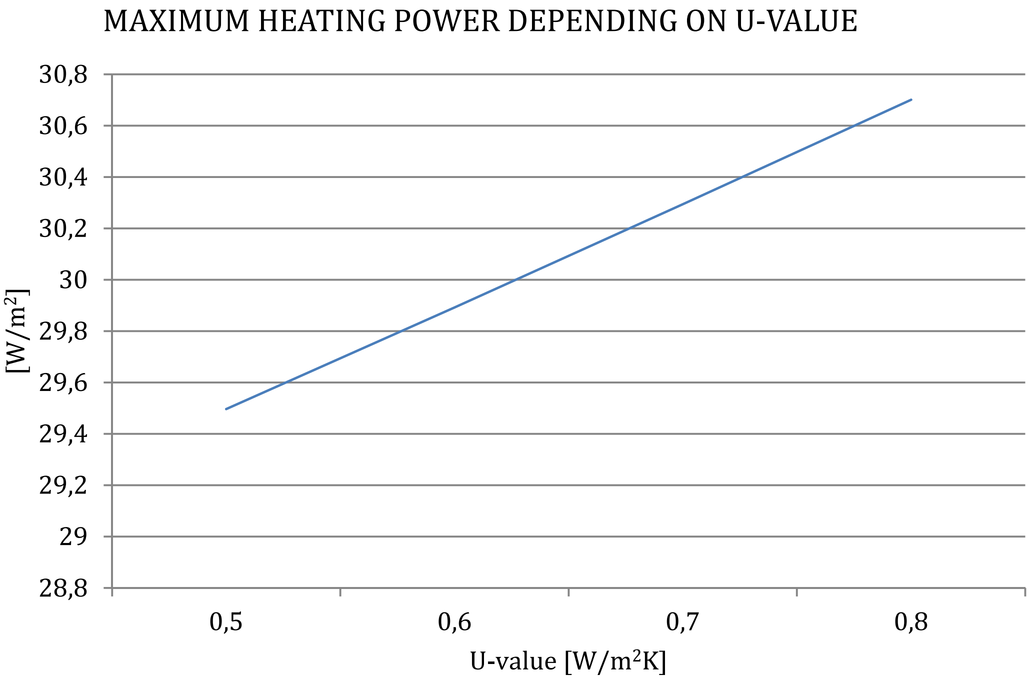

Figure 36 Figure showing the heating power demand at winter design day depending on u-value

### 6.4.3 Solar heat gain

At monthly design days during winter November to February the solar radiation never reaches the limit of 18W/m$^2$ even with a theoretical window with a g-value of 1,00, letting all solar heat through, as visible in Figure 37. This is because the solar intensity is low in Sweden during wintertime as show in Figure 38.

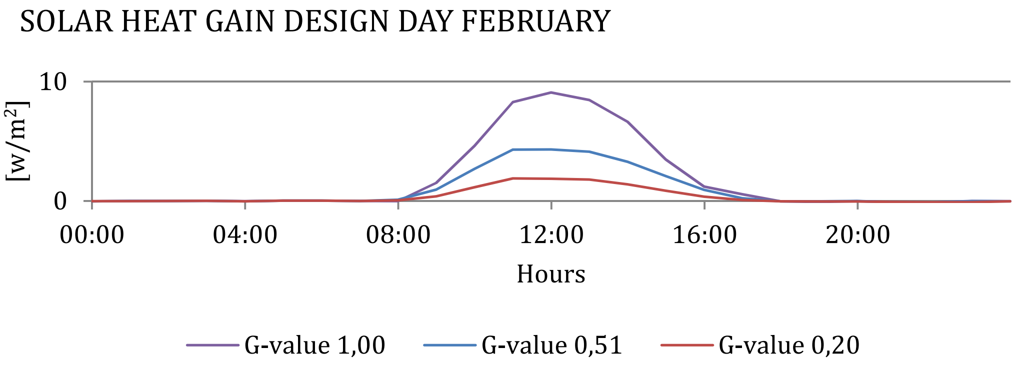

Figure 37. Solar heat gain during design day of February

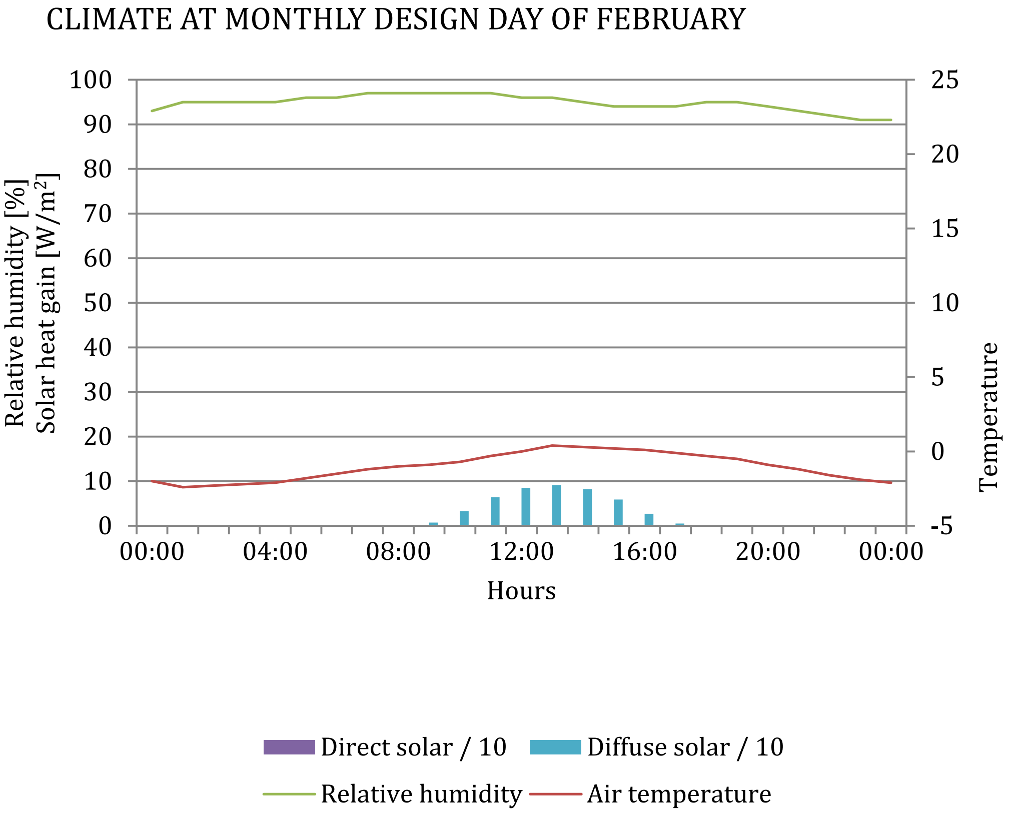

Figure 38. Climate at monthly design day of February.

During design days of March, April, May, September and October the solar heat gain needs to be limited by more than internal blinds in the reference model. A g-value of 0,20 is sufficient to keep solar heat gain at a level under 18 W/m$^2$.

By using the internal blinds in Villa Vänern's basic design a $g_{syst}$ of 0,29 is obtained, which is sufficient at most hours of the year as shown in figures below.

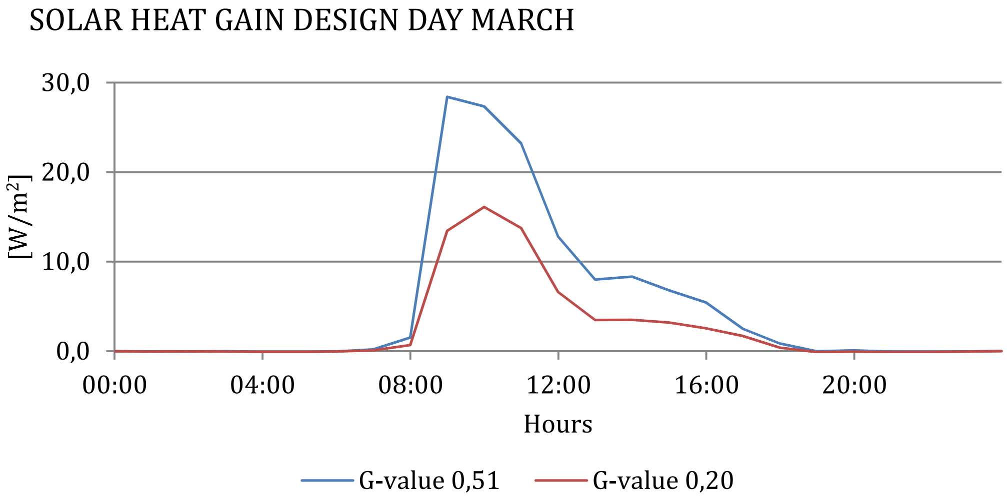

Figure 39. Solar heat gain during design day of March with different g-values

During summer months an even higher solar radiation occurs, requiring a solar shade with g-value as low as 0,11 in the living room to full fill the demands of GOLD grade this can be seen by interpolation in the figure and has been confirmed by calculations.

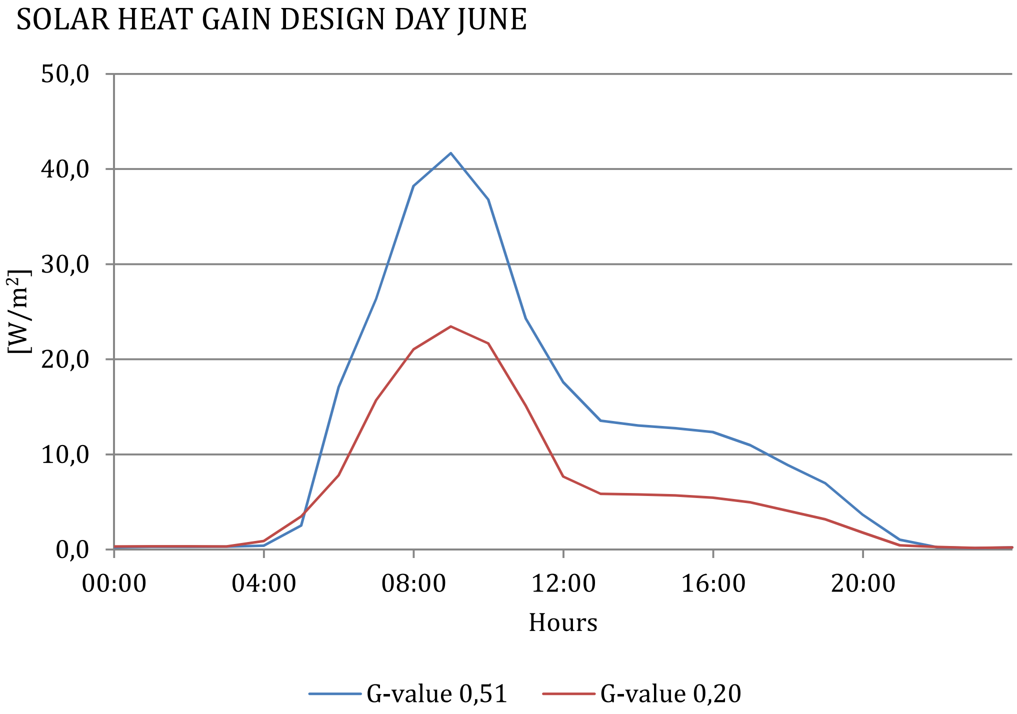

Figure 40. Figure showing solar heat gain depending on g-value for monthly design day of June.

A way of protecting the building from the solar heat gain is with a shading device. The shading device reduces the g-system-value, $g_{syst}$, by adding a shading coefficient. The $g_{syst}$ is the result of multiplying the g-value for the glazing and the solar shading device. For example the glazing in the living room lets through 51 % of the solar heat gain, by adding the vertical exterior blind only 14 % of that amount of heat gain is allowed to get though the shading device. This implies that a total 7% percentage of the solar heat gain gets into the room.

### 6.4.4 Thermal climate

The PPD during summer design day is most affected by an increased g-value, as solar heat gain increases the operative temperature inside the building. In Figure 41 the effect of changing g-value is visible.

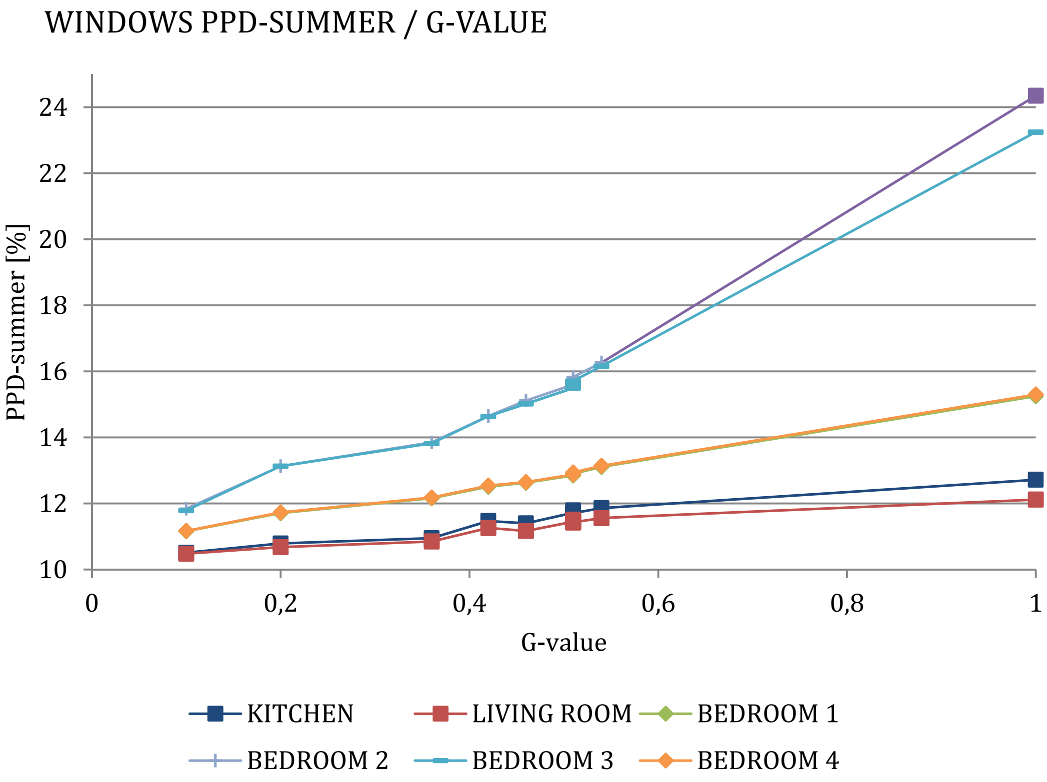

Figure 41. Figure showing the relation between g-value and PPD at summer design day.

During winter design day a low u-value gives a higher inside surface temperature of the windowpane compared to window with higher u-value, as visible in Figure 42.

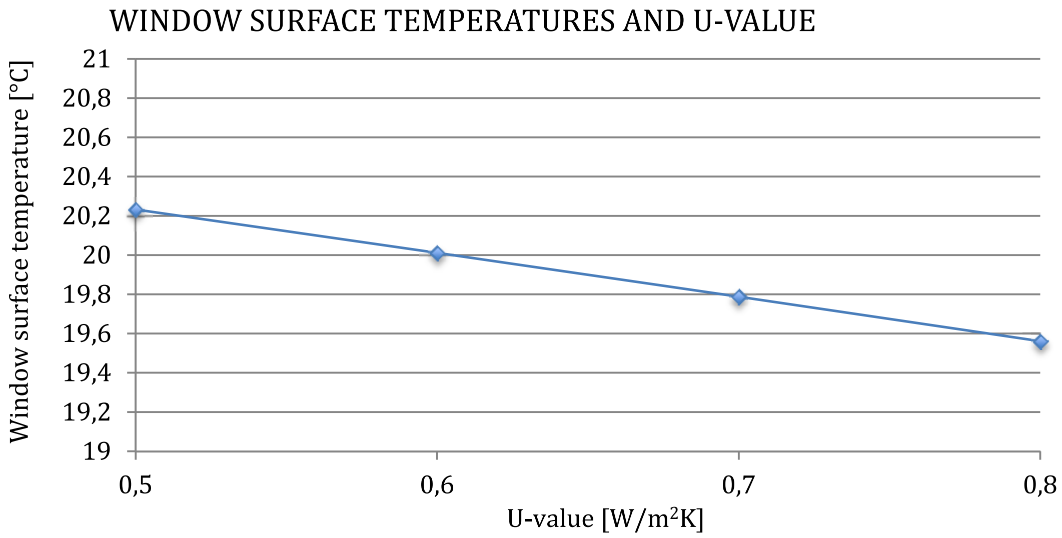

Figure 42. Figure showing the different surface temperature in relation with the u-value.

The difference between u-value 0,8 to 0,5 is almost one degree on the surface temperature affecting the operative temperature close to the window.

## 6.5 Building envelope

To see the affect of changing the insulation thickness of the building envelope details an analysis of the building envelope is presented in the following chapter.

By increasing the thickness of the building envelope the u-value decreases, lowering both the annual energy usage and the peak heating power demand. The building envelope includes exterior wall, ground slab and roof. Both the walls and the roof are facing directly towards the outdoors climate causing large temperature difference during winter and almost no during summer.

The ground slab faces the ground, which has a much slower response to temperature changes. Causing the change in heat losses to ground to be constant over days as visible in Figure 43 below.

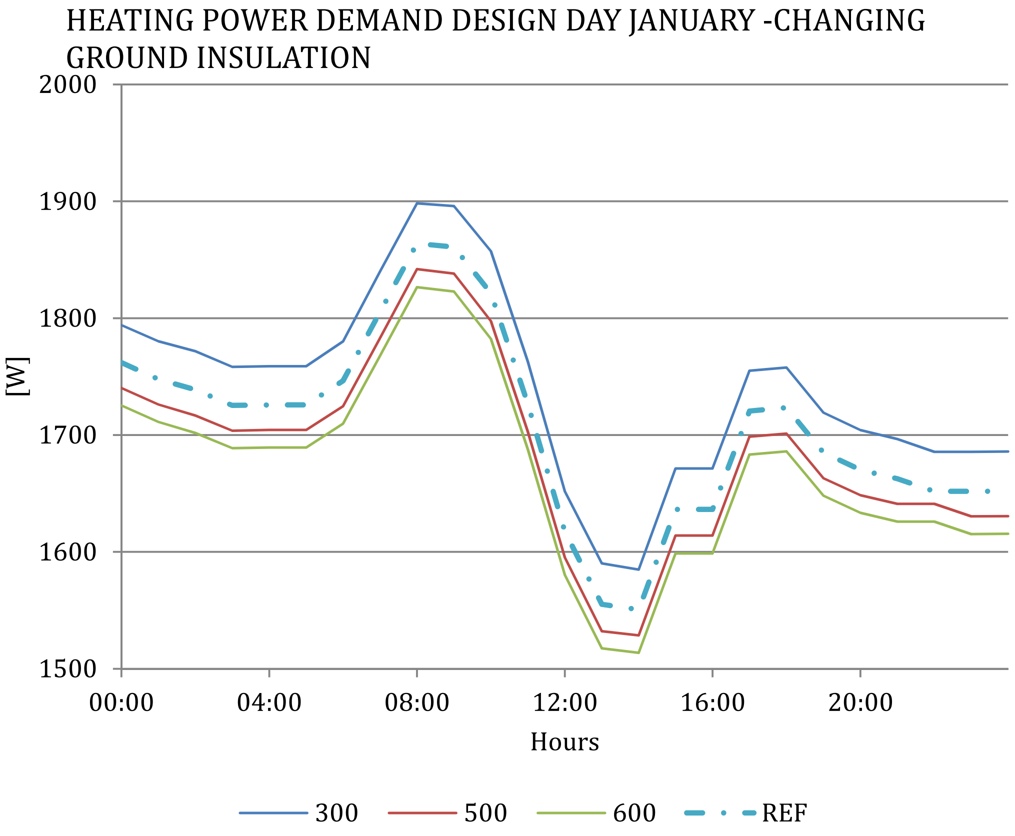

Figure 43. Figure showing effect of changing thickness of the ground insulation at monthly design day of January.

For the walls and roof the effect is changing with the temperature difference. In Figure 44 below the effect of changing the wall insulation thickness is shown. During the morning there is a larger effect than in the evening because of larger temperature difference between indoor and outdoor.

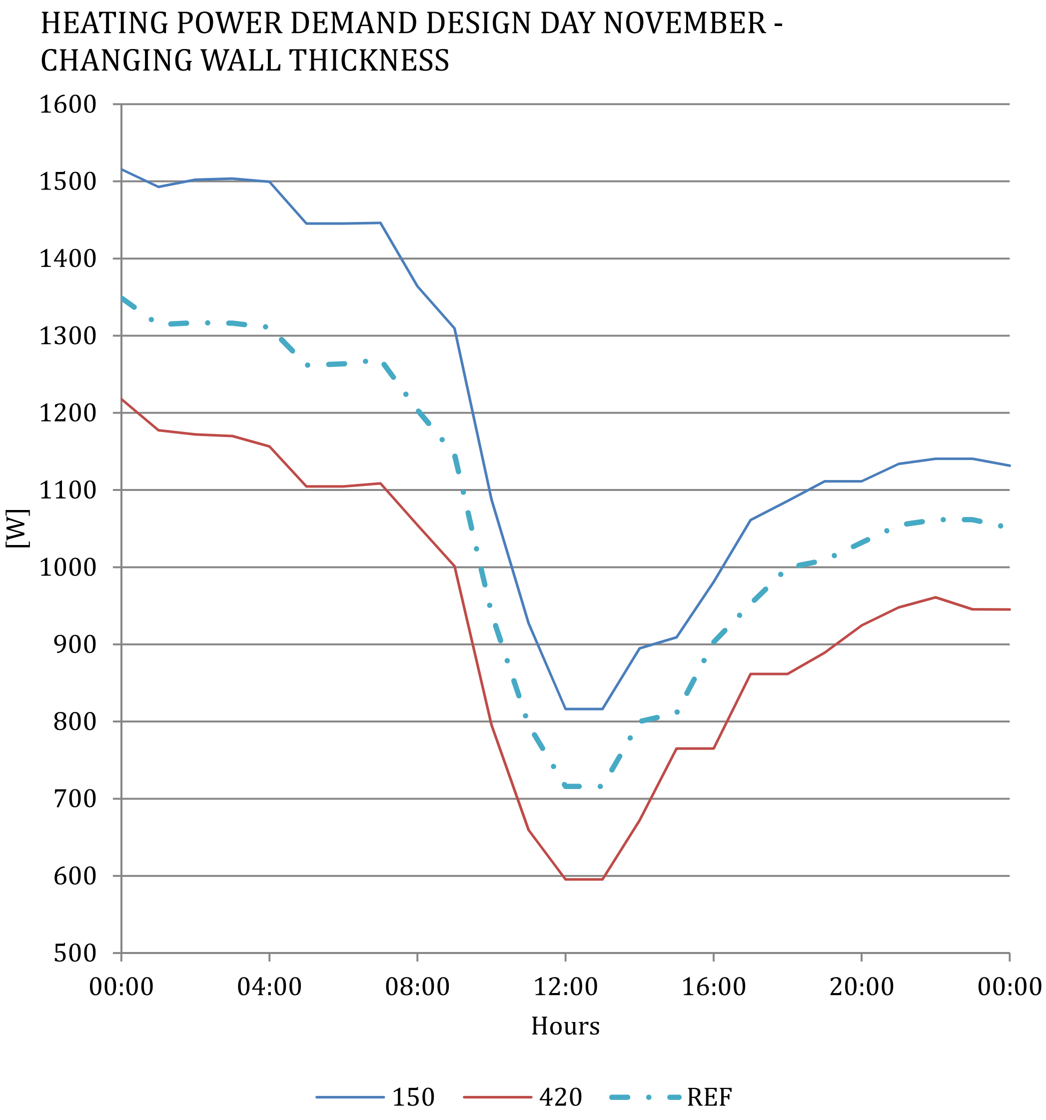

Figure 44. Figure showing the effect of changing the thickness of the wall insulation at monthly design day of November.

### 6.5.1 Annual energy usage

The effect of changing thickness in different parts of the building envelope is showed in the Figure 45 below. On the horizontal axis the change of thickness in millimeter is denoted and the yearly energy demand per square meter is denoted on the vertical axis. To help reading the graph an example is if the roof thickness is increased by 100 mm the annual energy usage is decreased by approximately 1 kWh/m$^2$.

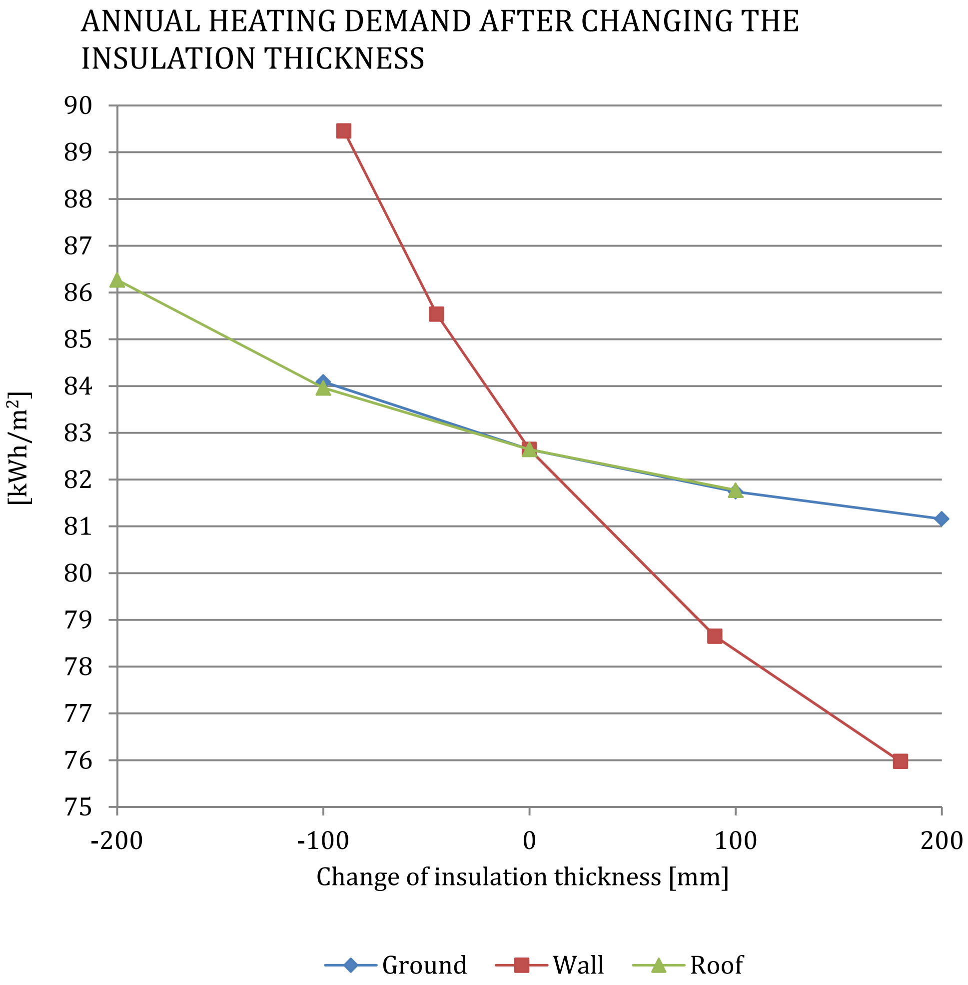

Figure 45. The annual energy usage in relation to change of insulation thickness of the envelope.

By multiplying the change in thickness with respective areas a graph showing the change of annual energy use per added or removed cubic meter of insulation is created. The result of such calculation is presented in Figure 46.

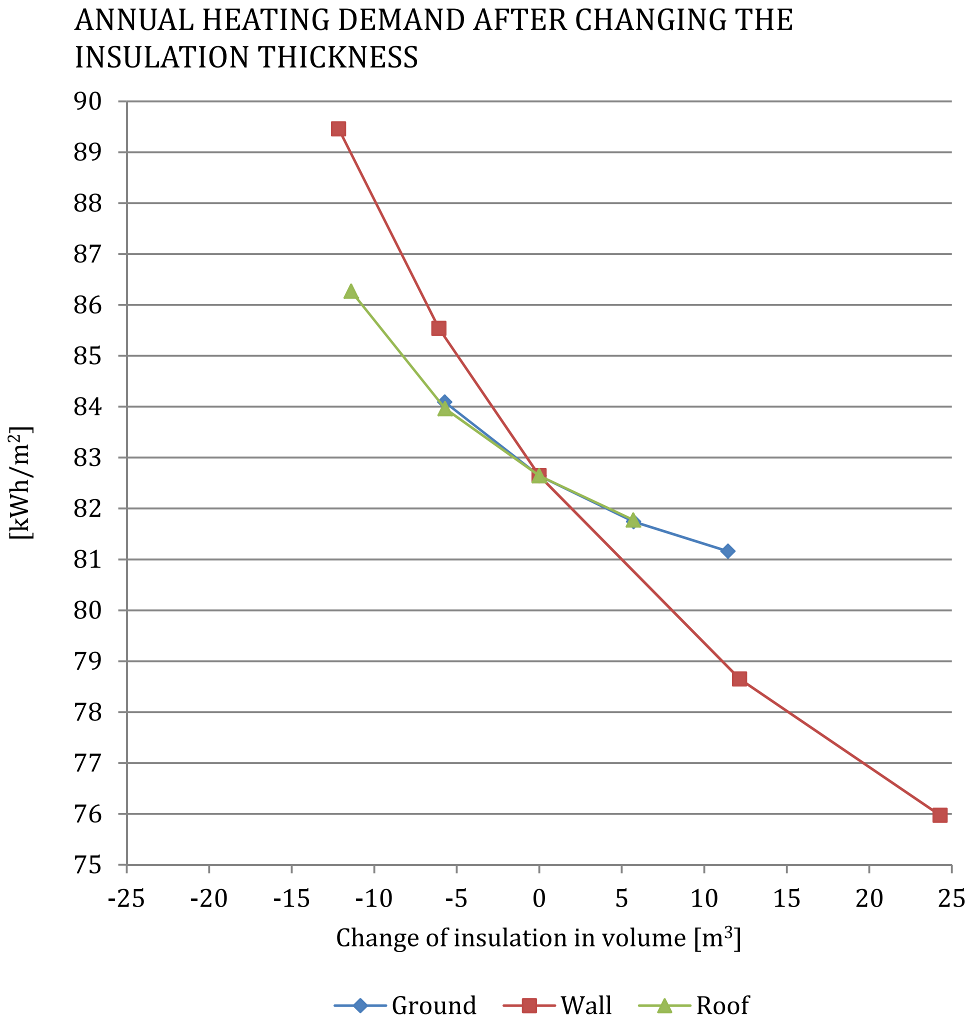

Figure 46. The annual energy usage in relation to change of insulation volume in the envelope.

### 6.5.2 Heating power demand

By changing the thickness of the envelopes different parts, the u-value and area is changed. The heating power demand as described by a simplified equation in Chapter 5.4.1 show that the u-value and envelope area affects the heating power demand. From simulations the figure below shows the effect when changing the thickness of the insulation in the walls, roof and ground.

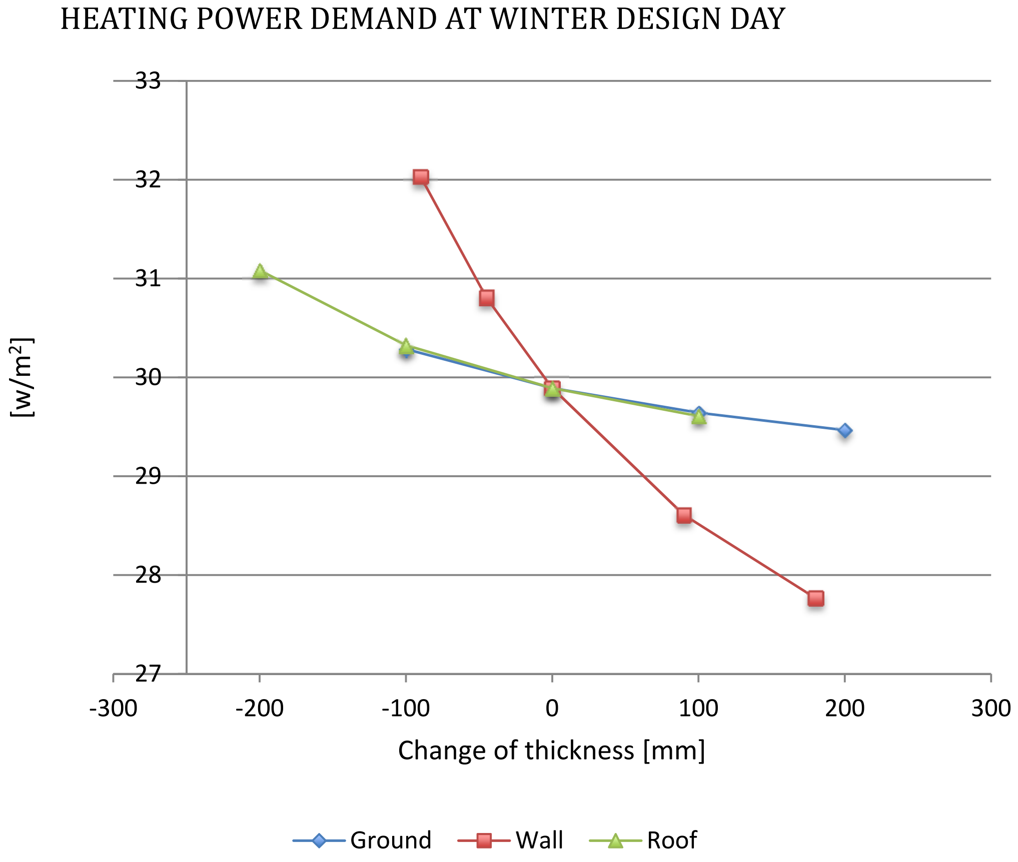

Figure 47. Figure showing effect on heating power demand on winter design day when changing envelope thickness.

From figure above it’s possible to read out that the change in wall thickness will affect the heating power demand at winter design day most.

### 6.5.3 Sun heat gain

As the windows are placed in the exterior part of the wall the sun heat gain is not reduced by increasing the wall thickness. Only the penetration depth for the direct solar heat gain is affected, which the calculation model will neglect. Therefore no results will be presented.

### 6.5.4 Thermal climate

The walls in the reference model provides a thermal climate during winter with a PPD of 5%, no optimization is possible. During summer the thermal climate is higher than 10%, but no difference between different wall, roof and ground thickness is possible to read out. The thicknesses affect the u-value, which only has a limited effect on the operative temperature as the temperature difference between inside and outside is small, causing only limited heat loss.

### 6.5.5 Daylight factor

The insulation thickness in the walls has an impact on the daylight factor. Therefore the daylight factor is simulated with the new wall thickness. In Figure 48 and Figure 49 the daylight factor after changing the wall thickness is shown. The daylight factor is still more than 1,2 % on both floors after increasing the wall thickness.

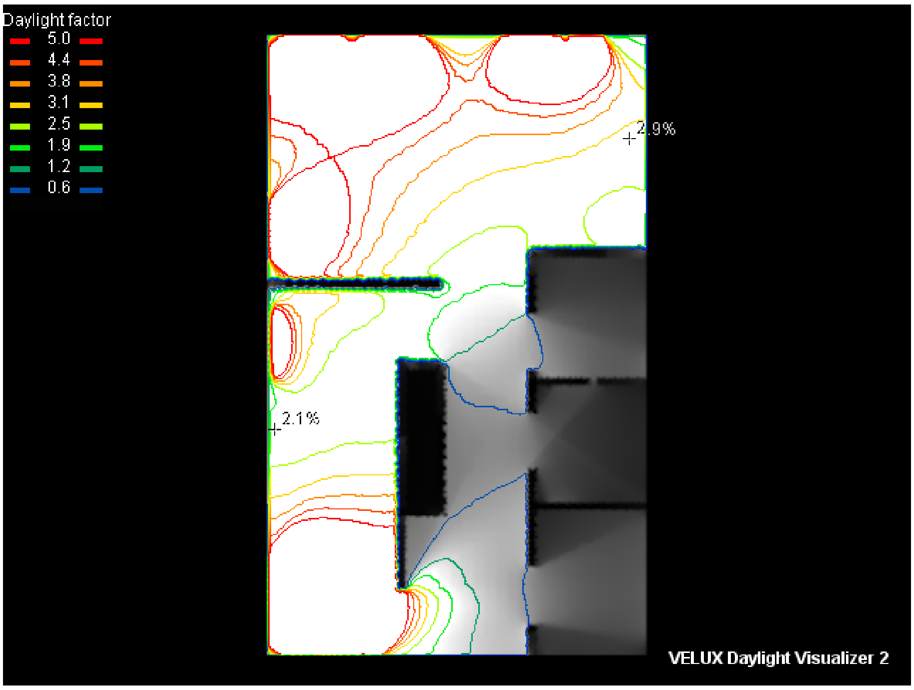

Figure 48. Daylight simulation - Insulation thickness of 330mm. Ground floor.

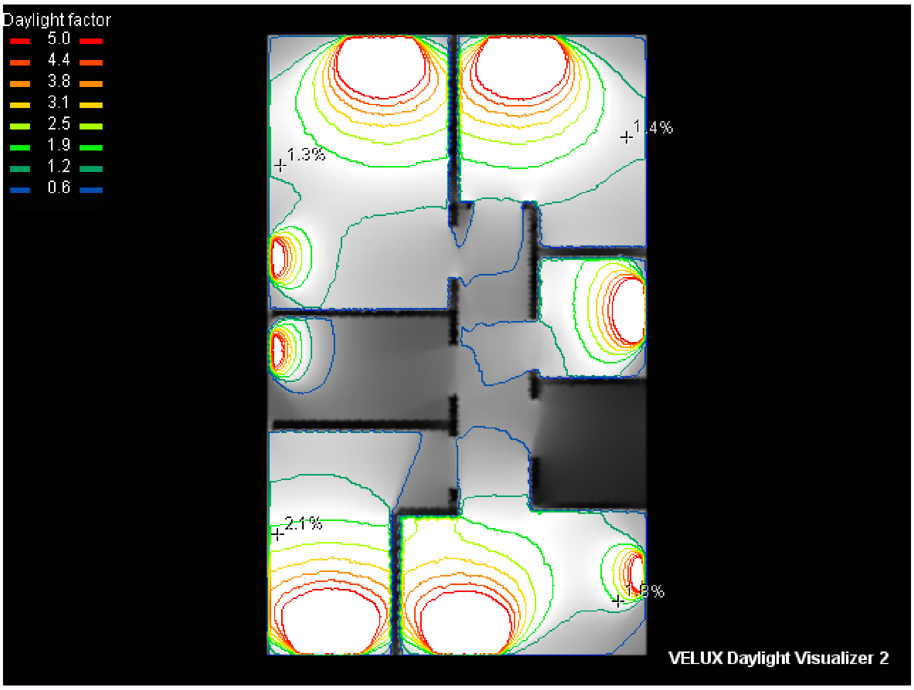

Figure 49. Daylight simulation - Insulation thickness of 330mm. Second floor.

## 6.6 Changing the occupant parameters

To see how the occupant parameters affect the energy performance and thermal climate of Villa Vänern an analysis of the parameters is presented in the following chapter.

The model used for calculations has some assumptions and estimations of parameters affected by the occupants. This creates uncertainties in the result from calculations as the hot water usage, metabolism, level of clothing, number of occupants etc. affects a lot. In the following chapter there parameters will be discussed and further analysed.

### 6.6.1 Metabolism and clothing level

The model for the thermal climate depends on several different factors: air temperature, surface temperature, air velocity, relative humidity, level of clothing and metabolism.

The satisfaction level of thermal climate can be predicted with the PPD index. By changing the activity level in the calculation, the PPD during summer is substantially better as visible in Figure 50.

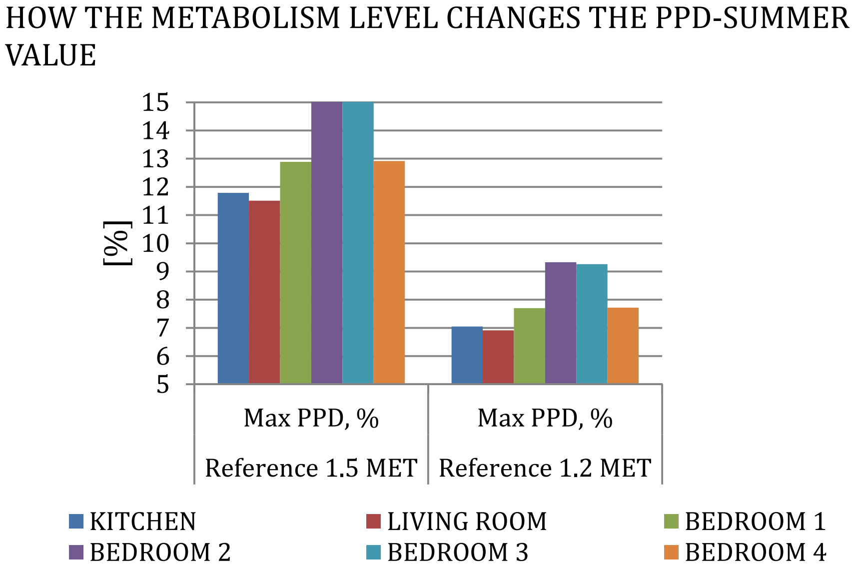

Figure 50. Figure showing the PPD-summer value after changing the metabolism rate during the summer design day.

### 6.6.2 Hot water consumption

The domestic hot water usage in the model of Villa Vänern is a standard value from SVEBY fixed at 20 kWh/m$^2$ annually, independent of number of occupants and their lifestyle.

In reality this parameter is depending on the occupants lifestyle, which means that the value for the hot water usage can be alternating a lot.

### 6.6.3 Occupant and equipment schedule

The energy used by the occupants electrical equipment is a standard value from SVEBY fixed at 30 kWh/m$^2$. The presence of occupants is considered as shown in Figure 51. By changing the presence of occupants, shown in Figure 52, and distributing the energy usage for the equipment to be larger during presence and lower during times of absence the heating power demand is affected shown in Figure 53.

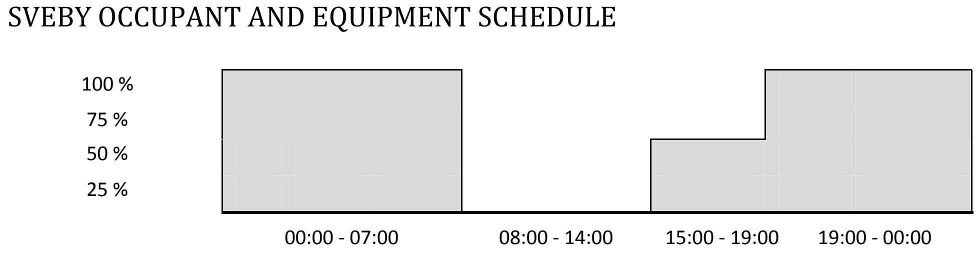

Figure 51. Figure showing schedule used for presence of occupants in reference model.

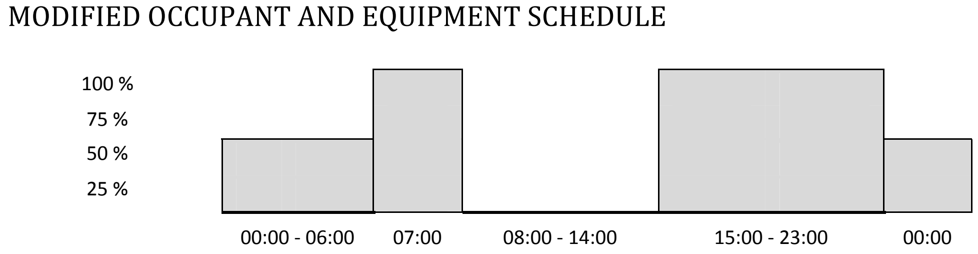

Figure 52. Figure showing the modified schedule used for presence of occupants in reference model.

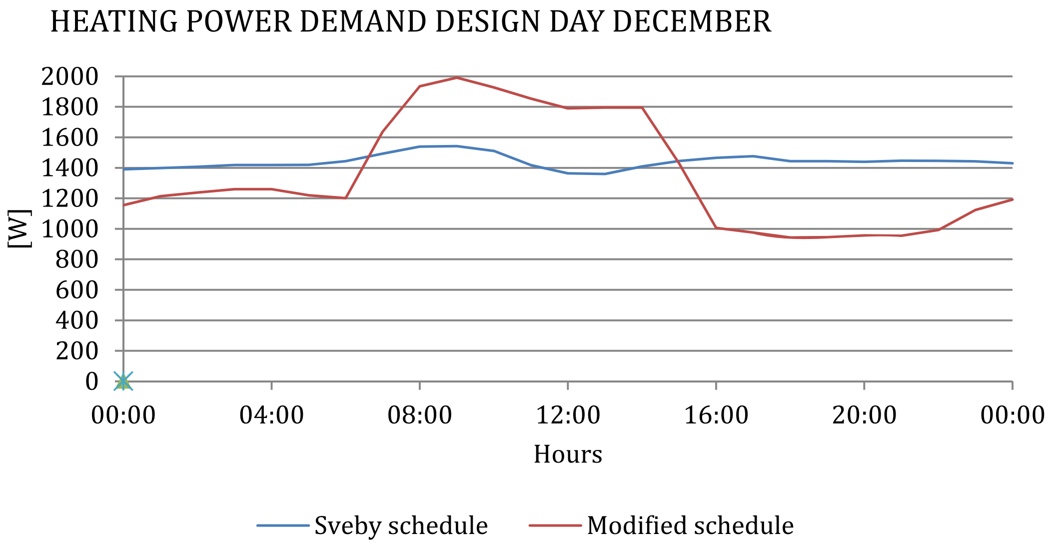

Figure 53. Figure showing the heating power demand during December monthly design day

### 6.6.4 Change of indoor temperature

The temperature difference between indoor and outdoor is the driving potential for heat transfer through the envelope. The temperature difference can be lowered by allowing a larger span of accepted indoor temperatures than 22-25°C as in Peab's technical platform. A change to 20-26°C, as recommended by VVS Tekniska Föreningen (Ekberg, 2006), decreases the annual energy usage to 73 kWh/$m^2$. In Figure 54 below the decrease of the heating power demand is shown.

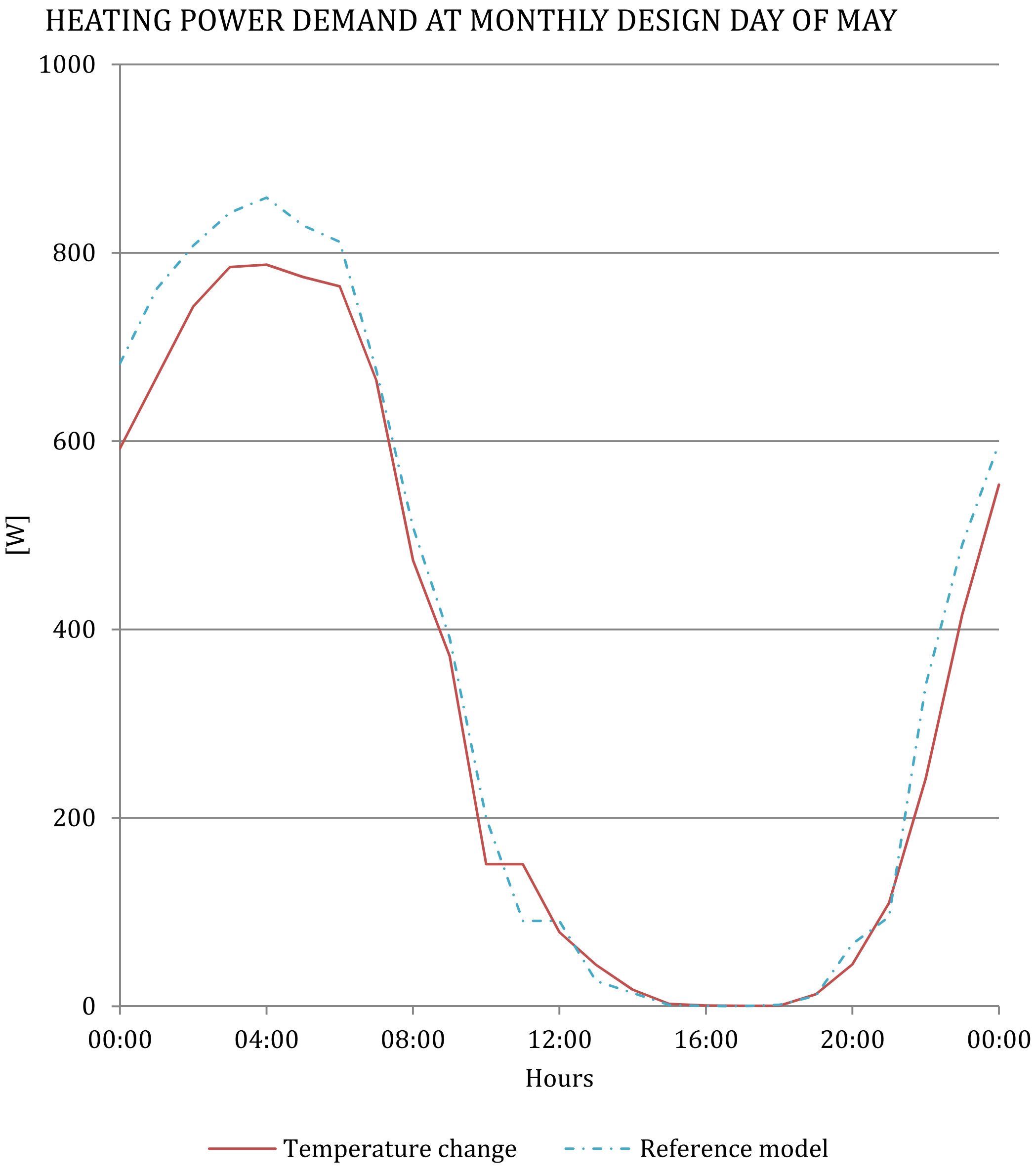

Figure 54. The heating power demand affected by the temperature change at monthly design day of May.

# 7 Enhancement of Villa Vänern

The following chapter could be seen as step-by-step guidelines when developing a new Villa Vänern. In the earlier chapters the effect of different changes of Villa Vänern was analysed separately to gain knowledge for an optimal enhancement of the building. In this chapter the result from different enhancements is presented and step-by-step combined into a final enhancement meeting the demands of Miljöbyggnad GOLD on all studied indicators.

As visible in Table 2 on page 12 the energy usage, heating power demand, solar heat gain, and thermal climate winter does not fulfil the demands of GOLD for the measurable indicators. As mentioned in the boundaries of the thesis the measurable indicators not fulfilling GOLD and the indicators directly affected by the enhancements will be adjusted.

The results of the energy usage are visualized in charts, showing a representative day of the year were the effect of the change is visible. Tables will also be used in the end of all chapters to summarize the effect of the change that has been made.

The reference model is adjusted to be more realistic. In Chapter 6.6 fixed values for occupant heat transmission and equipment energy was used. In the following chapter schedules are used instead. This results in peaks energy gains from occupants and equipment in the mornings and the evenings. The maximum value that the occupants have in metabolism is estimated to 1.25 MET and the maximum effect of the equipment is according to Sveby 5,76 W/m$^2$. Below an illustration of the schedules used for the simulations is shown.

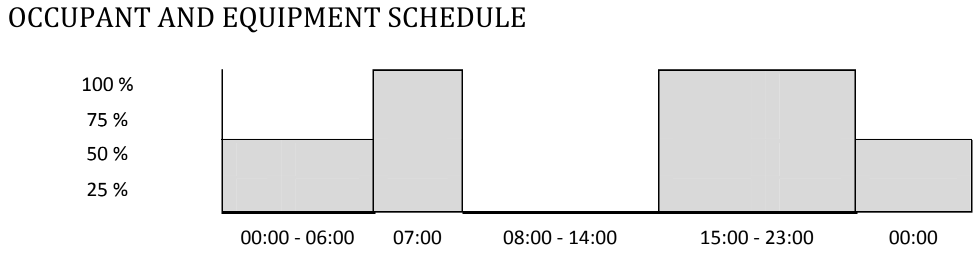

Figure 55. Figure showing the modified schedule used for presence of occupants in reference model.

Below in Table 13 a summary of the result for annual energy usage and heating power demand after each enhancement is shown. In each chapter a more detailed presentation of the results is made.

Table 13. A summary of the results from the optimization of Villa Vänern.

| TYPE OF ENHANCEMENT | ANNUAL ENERGY USAGE [kWh/m²] | DEMAND MILJÖBYGGNAD GOLD | HEATING POWER DEMAND [W/m²] | DEMAND MILJÖBYGGNAD GOLD |
|---|---|---|---|---|
| Reference | 77,3 | 58,5 | 27,7 | 25,0 |
| Orientation | 75,1<br>*-3,0%* | | 27,7 | |
| Glazing unit | 73,9<br>*-4,4%* | | 27,4<br>*- 1,3 %* | |
| Building envelope | 68,0<br>*-12,0%* | | 25,6<br>*- 7,5 %* | |
| Window frame | 63,9<br>*-17,0%* | | 24,3<br>*- 12,4 %* | |
| Temperature change | 57,1<br>*-26,0%* | | 23,4<br>*- 15,7 %* | |

## 7.1 Orientation

As mentioned in Chapter 6.2 - analyse of orientations, the 235° orientation was the most beneficial considering energy usage.

The 235° orientation allows more sun to enter the kitchen during morning hours and moves the natural placement of a porch to southwest. As the bedrooms windows are oriented in all orientations the master bedroom is preferably switched to one of the east bedrooms.

The graph below shows the heating power at the monthly design day of March. By rotating the model a larger area of glass is exposed to the sun for a longer time during afternoon. This offsets and extends the time of lower energy consumption as the rooms are partly heated by the sun, allowing the annual energy consumption to decrease by 2,78 kWh/m$^2$, year.

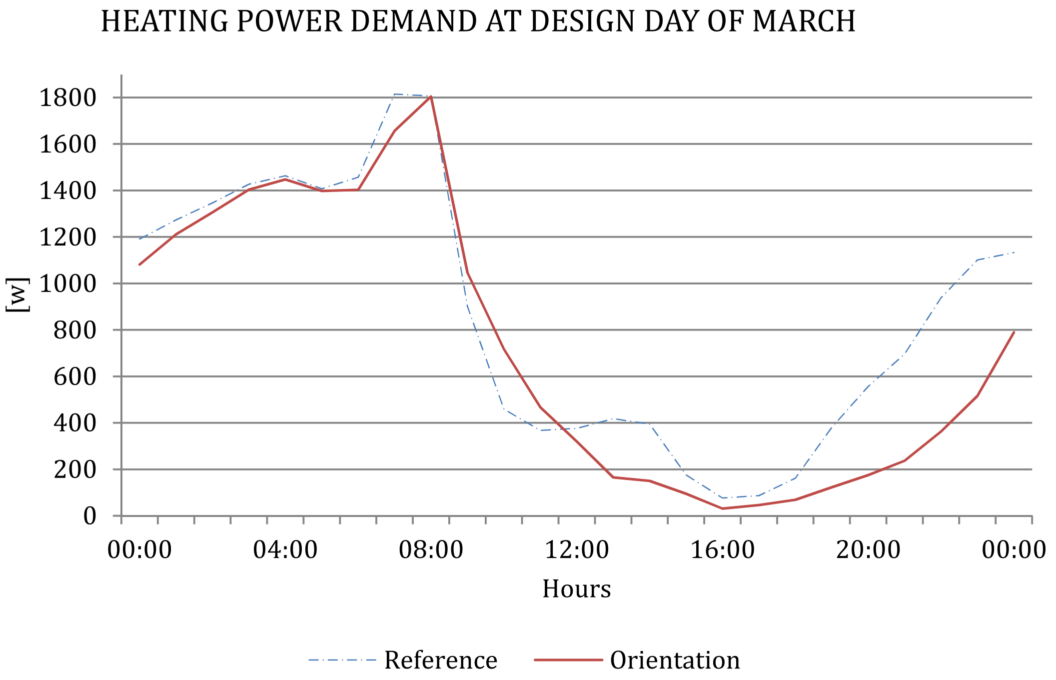

Figure 56. The heating power demand after the orientation has been changed.

Summarized in Table 14 below the result by changing the orientation is shown.

Table 14. Result from changing the orientation to 235°. The green colour indicates enhancement but not yet achieved goal, while red indicates deterioration. Indicators that are not affected by the change have the achieved the grade BRONZE, SILVER or GOLD color.

| INDICATORS | VILLA VÄNERN | ENHANCED VILLA VÄNERN | MILJÖBYGGNAD GOLD |
|---|---|---|---|
| Annual Energy Usage | 77,3 kWh/m$^2$ | 75,1 kWh/m$^2$ | 58,5 kWh/m$^2$ |
| Heating Power Demand | 27,7 W/m$^2$ | 27,7 W/m$^2$ | ≤ 25 W/m$^2$ |
| Solar heat gain[8] | 53,6 W/m$^2$ | 55,2 W/m$^2$ | 18 W/m$^2$ |
| Thermal climate summer[9] | 15 % | 17,7 % | 10 % |
| Thermal climate winter[7] | 5 % | 5 % | 10 % |
| Daylight | > 1,2 % | > 1,2 % | 1,2 % |

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[8] Based on maximum value for the Living room from simulation.

[9] Simulated in the Living room.

## 7.2 Glazing and solar shading

To further reduce the energy demand the glazing in the windows are changed to a unit with a u-value of 0,5 w/m$^2$K. A higher g-value would be to prefer to further decrease the annual energy usage, but it will at the same time cause over heating and high solar heat gain during summer.

Since Villa Vänern does not achieve GOLD in solar heat gain with its original 0,51 g-value window and calculations shows that it can not meet the demand if internal blinds are installed the only option is to shade the solar heat gain from outside with an external shading device. Therefore the glazing unit chosen strives to have as low u-value as possible and at the same time have a high g-value to gain free energy.

A glazing unit from the manufacture Pilkington with a u-value of 0,5 and a solar transmittance coefficient of 0,51 is selected. The lower u-value reduces the heating power by lowering the transmission losses. The g-value allows the building to benefit from the free solar energy. The $L_t$ value is the same as in the reference model.

The low u-value also allows the occupants to use a larger part of the living area as the window surface temperature increases. This reduces or eliminates cold draught and increases the operative temperature.

The figure below show the reduced energy consumption due to reduced transmission losses. The decrease is depending on the temperature difference between inside and outside; therefore it decreases during the day because of the higher outdoor temperature.

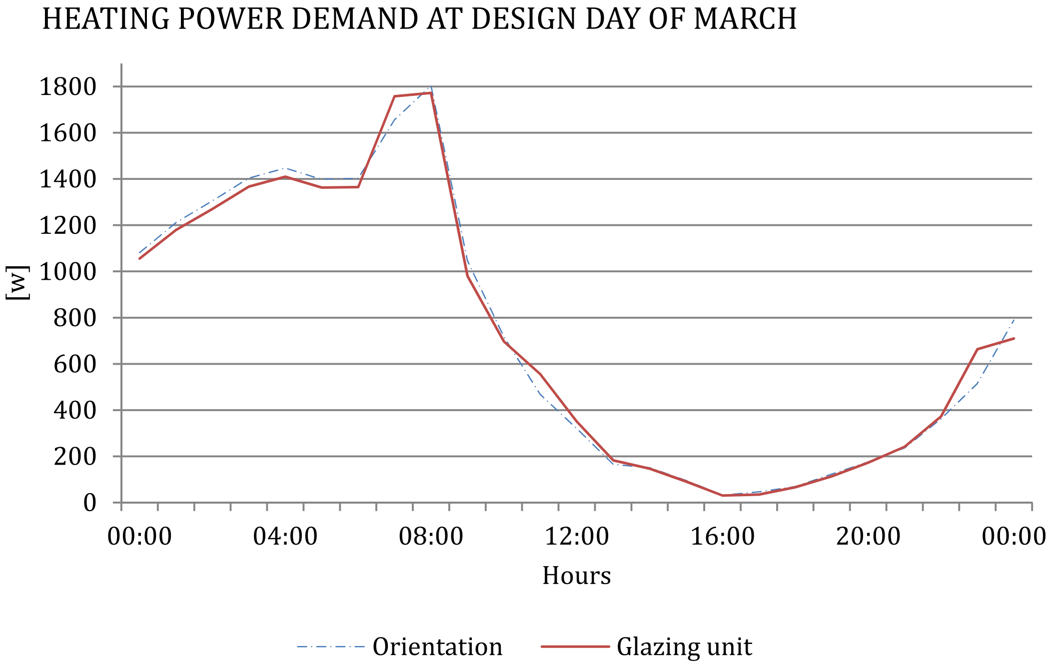

Figure 57. Figure showing the heating power demand during monthly design dag march after the glazing unit has been changed.

To fulfil the requirements of solar heat gain in Miljöbyggnad solar shading must be installed. The internal blinds only in combination with the selected glazing unit gives a g-value of 0,29, which result in a maximum solar heat gain higher than allowed for GOLD grade.

The structure of Villa Vänern as it is today does not allow a horizontal marquise to be installed. Therefore external vertical blinds are selected for all windows. Also the lower glazing part of the door of the living room must be covered. This reduces the maximum solar heat gain to 15,5 W/m$^2$ in the living room, which meets demands of Miljöbyggnad grade GOLD.

The vertical blind is an active shading device, which allows the occupants to take advantage of the positive solar heat gains during the heating season, while shading the windows when needed to protect the rooms from overheating.

If the structure of the living room wall would allow horizontal marquis, the lower part of the glazed door can be kept and the vertical blinds could be removed. This would create an outdoor room with access from the living room. The horizontal solar shade gives a solar heat gain value of 13,9 W/m$^2$ in the living room. This implies that the horizontal solar shade will give a better solar heat gain value since the glass door will have better solar shading and also give better social qualities by creating the outdoor space. In Table 15 below calculated and simulated solar heat gain shows the grades for the different rooms in Villa Vänern after using vertical solar shading on all the windows except the glass door towards the outdoor space.

Table 15. Solar heat gain in Villa Vänern after sun shading.

| ROOM | SVL [W/m$^2$] | SIMULATIONS [W/m$^2$] | MILJÖBYGGNAD GOLD DEMAD |
|---|---|---|---|
| **LIVING ROOM** | 15,5 | 15,0 | 18,0 W/m$^2$ |
| **KITCHEN** | 6,46 | 8,42 | |
| **BEDROOM 1** | 5,06 | 4,82 | |
| **BEDROOM 2** | 6,42 | 5,11 | |
| **BEDROOM 3** | 6,84 | 5,52 | |
| **BEDROOM 4** | 6,84 | 6,44 | |

In Table 16 below the results from glazing and solar shading is presented. As show in the table Villa Vänern now achieve the grade GOLD on the solar heat gain and the PPD-summer value.

Table 16. Result from changing the glazing unit and applying solar shading. The green color indicates enhancement but not yet achieved goal, while red indicates deterioration. Indicators that are not affected by the change or have achieved the grade have BRONZE, SILVER or GOLD color.

| INDICATORS | LAST ENHANCEMENT | ENHANCED VILLA VÄNERN | MILJÖBYGGNAD GOLD |
|---|---|---|---|
| Annual Energy Usage | 75,1 kWh/m$^2$ | 73,9 kWh/m$^2$ | 58,5 kWh/m$^2$ |
| Heating Power Demand | 27,7 W/m$^2$ | 27,4 W/m$^2$ | ≤ 25 W/m$^2$ |
| Solar heat gain[10] | 51,8 W/m$^2$ | 15,5 W/m$^2$ | 18 W/m$^2$ |
| Thermal climate summer[11] | 17,7 % | 7,6 % | 10 % |
| Thermal climate winter | 5 % | 5 % | 10 % |
| Daylight | > 1.2 | > 1.2 | 1.2 |

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[10] Based on maximum value for the Living room.

[11] Based on result from the Living room.

## 7.3 Building envelope

Villa Vänern in its current enhanced design still has a higher energy demand than the demands for Miljöbyggnad grade GOLD. Since the transmission losses stands for the largest share of energy losses as shown in Figure 17 on page 3 the insulations thickness is changed in the ground, roof and walls. In Table 17 below the change in u-value by increasing the insulations thickness is shown. The reduced u-value results in a lower energy demand and power demand.

Table 17. Differences in u-value when changing the insulation thickness.

| ENVELOPE DETAIL | VILLA VÄNERN | | ENHANCED VILLA VÄNERN | |
|---|---|---|---|---|
| | U-VALUE | THICKNESS | U-VALUE | THICKNESS |
| Wall | 0,15 W/m²K | 240 mm | 0,12 W/m²K | 330 mm |
| Roof | 0,09 W/m²K | 500 mm | 0,07 W/m²K | 600 mm |
| Ground | 0,07 W/m²K | 400 mm | 0,06 W/m²K | 500 mm |

Shown in Figure 58 below the change in u-value affect the energy usage most favourable during the night, this is because the difference in temperature is highest at that time. This also reflects in the annual usage. Most of the energy is saved during the winter season.

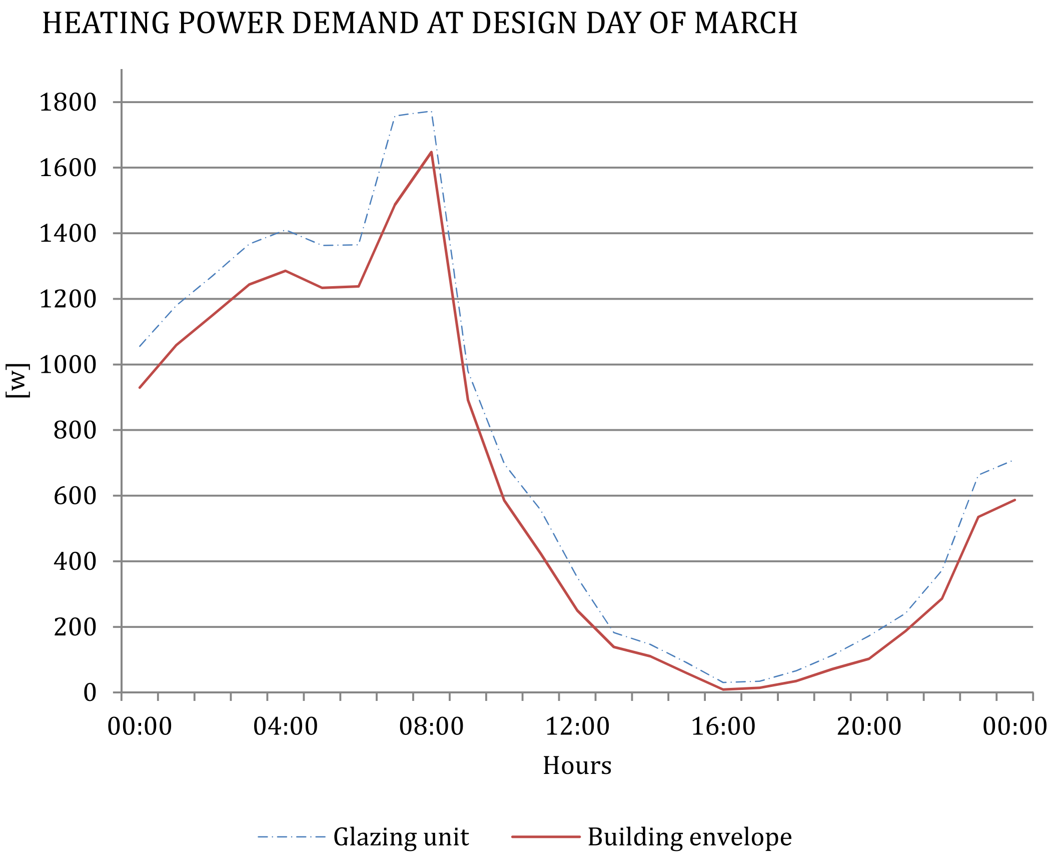

Figure 58. The heating power demand after the envelope has been changed.

It is not only the energy usage that is affected by increasing the insulations thickness. The thicker walls increase the width of the windowsills, allowing the occupants to use it in other ways, for example with decorations and can also be used for seating. Shown in Chapter 6.5.5 the daylight factor is still graded GOLD and is not affected by the thicker walls.

Summarized in Table 18 below the result from changing the insulation thickness is shown.

Table 18. Result from changing the building envelope. The green color indicates enhancement but not yet achieved goal, while red indicates deterioration. Indicators that are not affected by the change or have achieved the grade have BRONZE, SILVER or GOLD color.

| INDICATORS | LAST ENHANCEMENT | ENHANCED VILLA VÄNERN | MILJÖBYGGNAD GOLD |
|---|---|---|---|
| Annual Energy Usage | 73,9 kWh/m$^2$ | 68,0 kWh/m$^2$ | 58, 5 kWh/m$^2$ |
| Heating Power Demand | 27,4 W/m$^2$ | 25,6 W/m$^2$ | ≤ 25 W/m$^2$ |
| Solar heat gain[12] | 15,5 W/m$^2$ | 15,5 W/m$^2$ | 18 W/m$^2$ |
| Thermal climate summer[13] | 7,6 % | 5,7 % | 10 % |
| Thermal climate winter | 5 % | 5 % | 10 % |
| Daylight | > 1,2 % | > 1,2 % | 1,2 % |

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[12] Based on maximum value for the Living room.
[13] Based on result from the Living room.

## 7.4 Window frame

At the previous step of enhancement Villa Vänern still has a higher energy demand than allowed for Miljöbyggnad grade GOLD. In the windows used in Villa Vänern the frame is the most critical detail. With a u-value of 1,7 W/m$^2$K the frame doesn’t correspond to the standard the rest of the building, a lot of energy gets through the frame. In the enhanced Villa Vänern a window frame with a u-value of 1,2 W/m$^2$K is chosen instead. It’s still an aluminium cladded timber frame but made for higher demands of a passive house.

On the market there are other efficient frames, for example the well insulated alternatives made out of PVC, which are neglected because of environmental and economic reasons as mentioned in Chapter 2.

In the Figure 59 below the heating power demand after changing the window frame is shown.

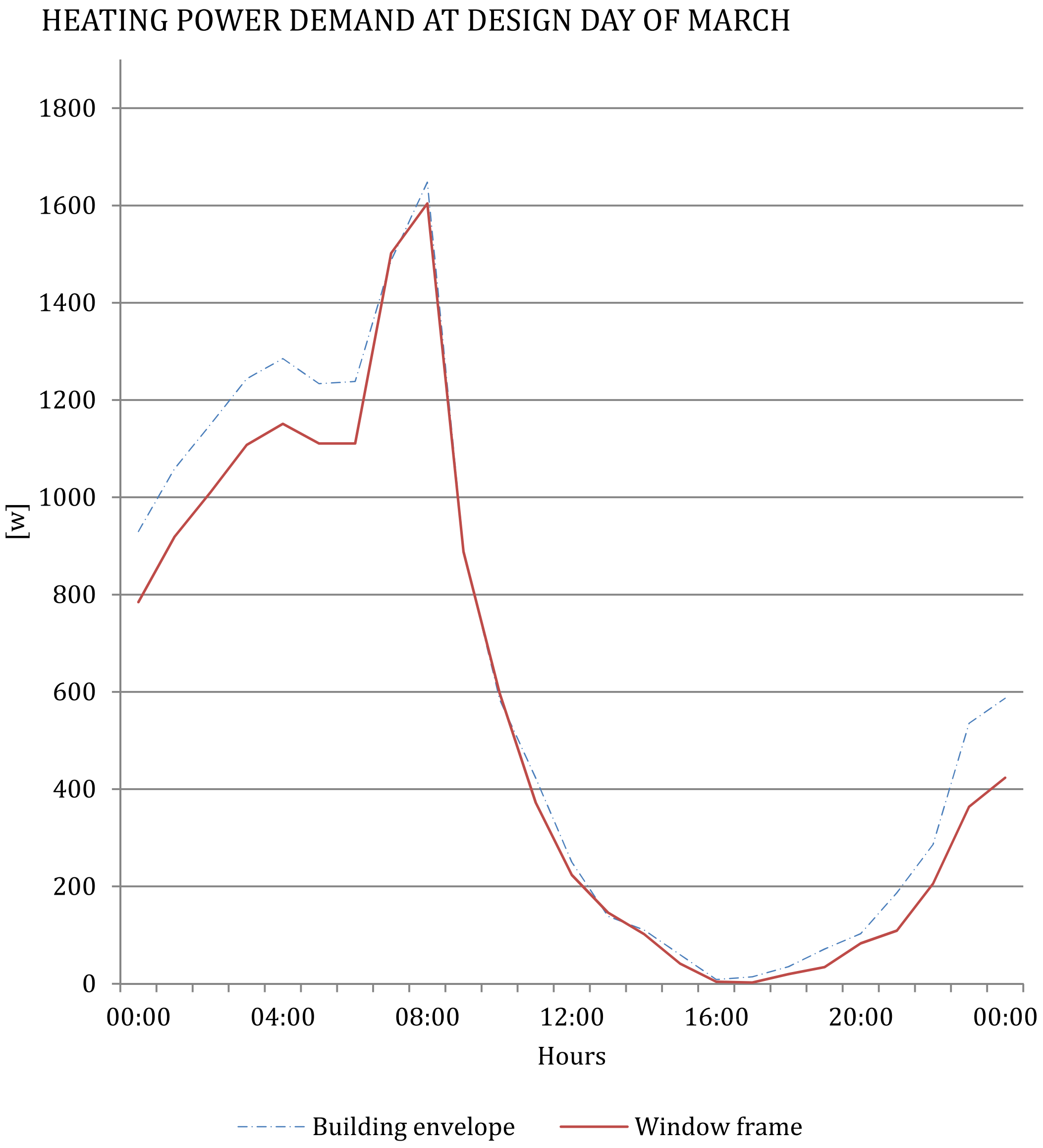

Figure 59. The heating power demand after the window frame has been changed.

Summarized in Table 19 below the result from changing the window frame is shown.

Table 19. Result from changing the window frame. The green color indicates enhancement but not yet achieved goal, while red indicates deterioration. Indicators that are not affected by the change or have achieved the grade have BRONZE, SILVER or GOLD color.

| INDICATORS | LAST ENHANCEMENT | ENHANCED VILLA VÄNERN | MILJÖBYGGNAD GOLD |
|---|---|---|---|
| Annual Energy Usage | 68,0 kWh/m$^2$ | 63,9 kWh/m$^2$ | 58, 5 kWh/m$^2$ |
| Heating Power Demand | 25,6 W/m$^2$ | 24,3 W/m$^2$ | ≤ 25 W/m$^2$ |
| Solar heat gain[14] | 15,5 W/m$^2$ | 15,5 W/m$^2$ | 18 W/m$^2$ |
| Thermal climate summer[15] | 5,7 % | 5,8 % | 10 % |
| Thermal climate winter | 5 % | 5 % | 10 % |
| Daylight | > 1,2 % | > 1,2 % | 1,2 % |

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[14] Based on maximum value for the Living room.

[15] Based on result from the Living room.

## 7.5 Temperature change

Villa Vänern in its current design still has a larger energy demand than allowed for Miljöbyggnad grade GOLD. The indoor climate in Villa Vänern should be 22-25°C according to Peab technical platform. According to VVS tekniska föreningen as mentioned in Chapter 6.6 the recommended indoor temperature should be 20-26°C. By changing the set temperature in the winter season the temperature difference leads to a lower energy usage. In Figure 60 below the heating power demand is shown during the March monthly design day. The temperature change is the most efficient enhancement, reducing the energy usage with almost 15 % from last enhancement.

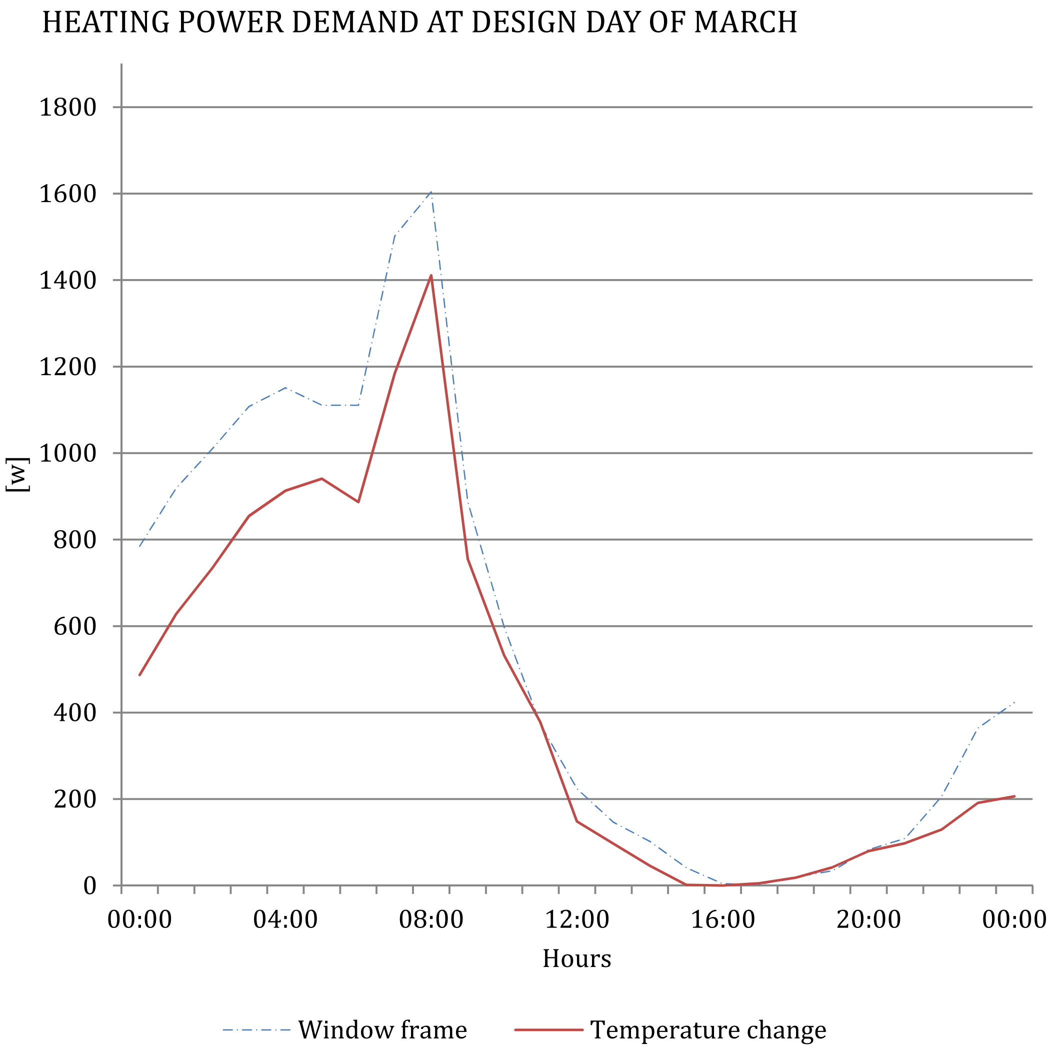

Figure 60. The energy usage after changing the indoor temperature to 20-26° C.

Since Villa Vänern have floor heating and well insulated windows the operative temperature will still be sufficient and the temperature change is justified.

Summarized in Table 20. below the result from changing the indoor temperature is shown. All indicators are now GOLD!

Table 20. Result from changing the indoor temperature. The green color indicates enhancement but not yet achieved goal, while red indicates deterioration. Indicators that are not affected by the change or have achieved the grade have BRONZE, SILVER or GOLD color.

| INDICATORS | LAST ENHANCEMENT | ENHANCED VILLA VÄNERN | MILJÖBYGGNAD GOLD |
|---|---|---|---|
| Annual Energy Usage | 63,9 kWh/m$^2$ | 57,1 kWh/m$^2$ | 58, 5 kWh/m$^2$ |
| Heating Power Demand | 24,3 W/m$^2$ | 23,4 W/m$^2$ | ≤ 25 W/m$^2$ |
| Solar heat gain[16] | 15,5 W/m$^2$ | 15,5 W/m$^2$ | 18 W/m$^2$ |
| Thermal climate summer[17] | 5,8 % | 5,8 % | 10 % |
| Thermal climate winter | 5 % | 5 % | 10 % |
| Daylight | > 1,2 % | > 1,2 % | 1,2 % |

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[16] Based on maximum value for the Living room.

[17] Based on result from the Living room.

## 7.6 Compiled results of enhancements

Shown in the matrix below are the summarized indicator grades and the final grade for Villa Vänern after the enhancements. Villa Vänern now achives the final grade GOLD in Miljöbyggnad.

Table 21. Miljöbyggnad grade matrix based on the enhancements of Villa Vänern.

| INDICATOR | ASPECT | AREA | GRADE |
|---|---|---|---|
| Annual energy usage | Energy usage | Energy | FINAL GRADE |
| Heating power demand | Power demand | | |
| Solar heat gain | | | |
| Energy source[18] | Energy source | | |
| Acoustic environment | Acoustic environment | Indoor environment | |
| Radon concentration | Air quality | | |
| Ventilation standard | | | |
| Nitrogen dioxide | | | |
| Moisture safety | Moisture | | |
| Thermal climate winter | Thermal climate | | |
| Thermal climate summer | | | |
| Daylight | Daylight | | |
| Legionella | Legionella | | |
| Documentation of building materials | Documentation of building materials | Material and chemicals | |
| Phasing out hazardous substances | Phasing out hazardous substances | | |

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[18] Grade depending on energy contract.

## 7.7 Economy

To estimate if all these changes are profitable a calculation of the investment has been made. Costs and figures have been estimated together with Peab.

The investment cost is estimated as Table 22 and Table 23 shows. The total investment cost is about 49 000 SEK. The investment results in a lowering of the energy usage from 82,7 kWh to 57,1 kWh.

To see how the investment affect the monthly interest cost and how the energy cost is reduced an estimated calculation is made. The interest cost is based on 2 250 000 SEK as an initial cost of Villa Vänern. To see how sensitive the investment is the interest rate is estimated to 3,5% and 5% and the energy price are set to 0,70 SEK/kWh and 0,90 SEK/kWh.

By changing the windows to a more energy efficient glazing unit the price of the window increases. In Table 22 below the extra cost is estimated. In Chapter 7.7 an estimated investment calculation is made.

Table 22. Estimated cost for changing the glazing unit.

| **WINDOW** | |
|---|---|
| 800 SEK | *Extra cost for small window* |
| 5 | *Number of small windows* |
| 1000 SEK | *Extra cost for large window* |
| 11 | *Number of large windows* |
| **15 000 SEK** | *Total extra cost for windows* |

The thicker walls also implies that a larger ground slab have to be constructed, which will result in a higher price of the building. Summarized in Table 23 below the extra cost for increasing the insulation thickness is estimated.

Table 23. Estimated cost for increasing the insulation thickness. The prices and amount is estimated by Peab.

| | |
|---|---|
| **WALL** | |
| 100 SEK | *Extra cost per* $m^2$ |
| 136 | *Wall* $m^2$ |
| 13 600 SEK | *Total* |
| 100 SEK | *Each window recesses* |
| 16 | *Number of windows* |
| 1 600 SEK | *Total* |
| **15 200 SEK** | Total wall cost |
| **GROUND** | |
| 100 SEK | *Extra layer EPS per* $m^2$ |
| 74 | *Ground total* $m^2$ |
| 7 400 SEK | *Total cost for extra EPS* |
| 1 650 SEK | *Cost for bigger ground slab* |
| **9 050 SEK** | *Total ground cost* |
| **ROOF** | |
| 200 SEK | *Extra cost per roof trusses* |
| 9 | *Number of roof trusses* |
| 1 800 SEK | *Total extra cost for roof trusses* |
| 2 000 SEK | *Extra work cost* |
| 180 SEK | *Cost per* $m^3$ *insulation* |
| 7 | *Number of extra* $m^3$ *needed* |
| 1 260 SEK | *Extra cost for insulation* |
| **5 060 SEK** | *Total extra cost for roof* |

Table 24. Estimated extra cost for the investment.

| **TOTAL INVESTMENT COST** | |
|---|---|
| **44 310 SEK** | *Total investment cost* |
| **48 741 SEK** | *+ 10 % margin* |
| **INTEREST AND ENERGY COST** | |
| 2 250 000 SEK | *Initial cost of Villa Vänern (75 % of 3.000.000)* |
| 3,5% | *Interest rate* |
| 5 year | *Calculation period* |
| 82,65 *kWh* | *The total energy usage in Villa Vänern* |
| 0,70 SEK | Cost per kWh |
| 57,13 *kWh* | *The total energy usage in Villa Vänern after enhancement* |

An investment calculation shows that if the interest rate are on a 3,5 % level the investment is profitable. Shown in Table 25 below the investment reduces the monthly cost by 36 SEK per month.

Table 25. Monthly cost calculated, interest on 3,5% and kWh price on 0,70 SEK/kWh

| | **BASIC DESIGN** | | **ENHANCED DESIGN** | |
|---|---|---|---|---|
| | Interest cost | Energy cost | Interest cost | Energy cost |
| | 6 563 SEK | 579 SEK | 6 705 SEK | 400 SEK |
| **Total:** | 7 141 SEK | | **7 105 SEK** | |

If the price on the energy goes up to 0,90 SEK per kWh the investment is even more profitable. The monthly cost is then decreased by 88 SEK, shown in Table 26 below.

Table 26. Monthly cost calculated, interest on 3.5% and kWh price on 0,90 SEK/kWh

| | **BASIC DESIGN** | | **ENHANCED DESIGN** | |
|---|---|---|---|---|
| | Interest cost | Energy cost | Interest cost | Energy cost |
| | 6 563 SEK | 744 SEK | 6 705 SEK | 514 SEK |
| **Total:** | 7 306 SEK | | **7 219 SEK** | |

Instead if the interest rate is on a 5 % level it is not profitable to invest 48.741 SEK to lower the energy usage. This is shown in Table 27 below. The total monthly cost is 24 SEK more expansive in the enhanced design comparing to the basic design.

Table 27. Monthly cost calculated, interest on 5% and kWh price on 0,70 SEK/kWh.

| | **BASIC DESIGN** | | **ENHANCED DESIGN** | |
|---|---|---|---|---|
| | Interest cost | Energy cost | Interest cost | Energy cost |
| | 9 375 SEK | 579 SEK | 9 578 SEK | 400 SEK |
| **Total:** | **9 954 SEK** | | 9978 SEK | |

# 8 Discussion

While analysing, discussing the effects of enhancements in Villa Vänern, many questions about to certify or not comes into mind. We will answer some with our thoughts and leave some open, just raising the question.

First question would be, what are the benefits of a certified house compared to a non-certified? The certification on its own is a confirmation for the customer that the building is an environmental friendly building of high standard. And for the landlords and other stakeholders it's a way of promoting the company as a sustainable company that meets the high demands of the classification systems.

When designing the certified building all documents have been reviewed by examiner, ensuring that it is accurate. This gives the customer an extra feeling of safety as its double-checked. When in future a reparation or extension is relevant, complete documentation is guaranteed. Also the certification pushes the development of the building sector further, to meet the demands in a sustainable way.

Also the question if it is economically justifiable on its own to certify or must ecological and social impact be used for promotion? When adding all enhancements to Villa Vänern, the extra investment is economically justifiable as the total monthly cost actually is lowered. But if comparing the total investment of a low-cost building with a energy usage of 90kWh/m$^2$ with a enhanced Villa Vänern with a energy usage of 58 kWh/m$^2$ and a price tag around 2 300 000 SEK a low-cost building of the same size would have approximately 2500 SEK higher annual energy cost but covers a increased initial investment of 70 000 SEK. So, economy on its own can't justify low energy buildings as villas of 120m$^2$ for less then 2 230 000 SEK exists.

When more aspects than economy are taken into account, is it justifiable then? Yes of course! There is no price tag on the effects the extra energy consumption and non thought trough choice of materials has on nature, some would say. Also the higher quality of life, when living in a safe and comfortable indoor climate is hard to put a price on. Others that don't value nature or indoor climate won't see these savings as benefits.

But how about two identical buildings, where the only difference is that one has been certified as Miljöbyggnad GOLD and the other has not? Why invest money to certify an already good building? Will it be more attractive? As mentioned before it is a confirmation that building is of high quality and can for example be beneficial when selling the building.

Another question concerning a more specific part in Miljöbyggnad, the thermal climate during winter and summer. To meet the demands of Miljöbyggnad GOLD during summer the PPD-value must be less or equal to 10% at moment of maximum solar heat gain and internal heat gains. The PPD-value is depending on the indoor climate, the clothing level and activity level of occupants. The indoor climate is calculated from simulations, but the activity level and clothing of occupants are regulated to be "the expected clothing and activity level at summer / winter". So if the indoor temperature while seated for breakfast in shorts and t-shirt is 30°C the building meets the demands of GOLD grade, as the PPD is less then 10%. Same situation happens during a winter day, a indoor temperature of 13°C while standing in a light bossiness suit result in a GOLD grade in Thermal Climate Winter.

If using the PPD-index value to set a grade the clothing and activity must be regulated in Miljöbyggnad. For example a set of different occupant groups with certain type of clothing and activity level during winter also depending on indoor temperature should prevent such cases as presented in last paragraph.

Discussion about there are many different options to enhance VV. No technical solution, low tech. Physical changes.

# 9 Conclusion

The intention with Villa Vänern in the design phase was not to design a building that should be certified according to Miljöbyggnad, but this analysis shows that with quite small adjustments the grade GOLD could be a reality. From WSP's pre-study it can be read out that it is on the energy area that Villa Vänern fails. It meets the initial demands from BBR but reaches only Miljöbyggnad SILVER. Shown by the analysis is that with an estimated investment cost of around 49 000 SEK Villa Vänern could be enhanced to achieve the grade GOLD.

The enhancement of Villa Vänern made in this report consists of changing the orientation of the building, upgrading the window with a more energy efficient glazing unit and frame, suggesting exterior solar shading, adding one layer of insulation in the wall and at last reducing the temperature set points from 22-25° C to 20-26° C.

The changes to the enhanced Villa Vänern are thought through so the occupants have the same or a better living quality in the building after the changes has been made.

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