



**CHALMERS**  
UNIVERSITY OF TECHNOLOGY



## Adaptive sustainable changes of two Swedish villas

– With focus on energy efficiency and lifestyle

Master's thesis in MPDSD

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Gothenburg, Sweden Spring 2015

## ABSTRACT

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Master's thesis Spring 2015  
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Cover:  
[Olsson, H. (2015) Photos of Villa Miatorp (upper photo) and Villa Arild  
(below) [Photos] Helsingborg & Arild: Photos from my private collection]

Göteborg, Sweden 2015

The purpose of the thesis is to encourage and inspire a sustainable improvement and refurbishment of existing villas and show how the specific building can be improved in the best way possible, without neglecting its historical or architectural values.

This thesis is important for the sustainable development of existing villas. The majority of the inhabitants in Sweden are today living in a villa that they own. Therefore it is very relevant to focus on a development of this part of the building stock, which I feel is left out today.

The thesis is interesting for all villa owners with interest in improving their villas in a sustainable way to save energy, money and environment. It is also an interesting topic, seen in the wider perspective, since it is contributing to a development of a major part of the existing building stock in Sweden.

The thesis shows how to transform two of the most common villa types in Sweden, one brick villa and one wooden villa, into more sustainable homes. This is presented with one design proposal for each villa that is very well adapted to the specific situation; considering the site, the building and its usage.

The proposals have been developed in cooperation with experts within construction, refurbishment and calculation. Through these discussions the perfect balance between energy efficiency, preservation of historical/architectural values and its function was developed. The transformation is responding to my definition of sustainability and it is also preserving the original character of the building to the greatest extent possible.

Since the two villas are very different the thesis is about improving their weaknesses. The focus of the proposal for the wooden villa is functional and includes changes of lifestyle to reduce energy use/person. The proposal for the brick villa is instead focusing on technical and functional solutions to reduce energy use/m<sup>2</sup>. An optimization proposal is also presented for the brick villa, with additional inspiring solutions which were not the main focus in the design proposal.

The result shows how to achieve great improvements of the sustainability in two different villas, with affordable and small changes, adapted to the specific building. The two proposals show how to approach sustainable improvements in two different ways, to reduce the environmental impact by reducing the energy use and choosing materials with low embodied energy.

## FOREWORD

I faced my master thesis with two things very clear in my mind; I wanted to use my thesis as a stepping stone for my future work and I wanted to deep dive within the topic residential buildings. The main reason for choosing residential buildings was my own interest and the belief that the “home” is one of our most important buildings which plays a big role through our whole life, and we can therefore make a huge impact in many ways by improving it.

The time went by fast and some periods were tough but the work was very interesting to do. My hopes are that this is the beginning of something really important for all of us and that my thesis can inspire people to bring up the discussion about adaptive sustainable changes of existing villas and thereby plant a seed for the future.

I wish to thank my examiner Liane Thuvander for all her help and Maja Kovacs for being an inspiration in the beginning of my thought process. I also want to thank Carl Molander and Anders Ekberg at *White* and Markus Lundborg at *Energi & Klimatrådgivningen Göteborg* for their participation in meetings and interest in my thesis. I am also very grateful for the interesting and giving discussions during the final seminar and want to thank the internal jury member Anna Kaczorowska and the external jury member Karin Nyquist for putting a lot of time and commitment into very useful comments and critique.

And last but not least a special thanks to my tutor Suzanne Hansen at *White* who has always been there, supporting me and guiding me through my master’s thesis.



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## 1. INTRODUCTION

- My definition of sustainability
- The structure of the booklet
- Background
- Why is it done?
- What is it about?
- How is it done?

### MY DEFINITION OF SUSTAINABILITY

To live sustainable means that we live in balance to be able to continue living in the same way for all eternity. We don't take more of the nature's resources than it can handle to produce or replace. We use the land in a good way instead of consuming it.

Even though economic profit is highly prioritized today there are other factors which are at least as important, for example the environment, interaction with the surroundings, diversity and well-being for each individual. It is important to consider individual values to achieve well-being. To like and feel good in our home and the surroundings makes us want to take care of it, which is important in a sustainability aspect.

The home, where most of us spend a lot of our spare time is the place where we relax and socialize with the people we care the most about, is therefore very important for our well-being. A sustainable home has the qualities which are needed for its user's well-being, it is adapted to the individual values. Therefore there is no template of right or wrong. But good flexibility can broaden the alternatives and the target group and in that way become more sustainable. A sustainable home is also prepared for unexpected situations. Even if the needs or trends are changed, the villa can be adjusted without drastic methods. That's why renovation, transformation or improvement of the villa encourages a sustainable pattern, to reuse what we already have.

## BACKGROUND

I grew up in a villa and spent most of my time playing in the garden. I made bark boats to play with in the pond, harvested fresh berries and apples in the fall and assisted my dad when he renovated the house. What I experienced developed into a **future dream**; to be able to offer my future family and children the same qualities. But if I fulfill my dream of living in a villa, will my future family be less sustainable than others?

The way we have been living the past centuries is not sustainable and the environmental impact has now started to result in **fast changes** of the **environment** and **climate**. We are therefore in need of drastic changes to prevent catastrophic outcomes. Today, the level of carbon dioxide is **35 % higher** than before the industrial revolution due to burning fossil fuels and deforestation. The dramatic increase of the greenhouse gas concentration leads to increased temperature, glaciers receding and sea levels rising (Azar, 2008).

**40 % of the total energy** use in Sweden is used to heat the building stock, warm water included. Oddly enough the energy use per m<sup>2</sup> is actually lower in villas/single-family housing than in multi-family housing. A reason for this is that the residents in single-family housing are more aware of the costs. To reduce the energy use in all buildings is an important environmental issue (Gross, 2010).

The governmental goal is to have **reduced the energy use** in the housing and service sector by 20 % year 2020 compared with the energy use 1995, 2050 should the energy use in the sector be reduced by 50 %. 2020 the sector should **neither be dependent on fossil fuel** and at the same time the use of renewable energy sources should be increased (Governmental proposition, 2005).

*“If I fulfill my dream of living in a villa, will my future family be less sustainable than others?”*  
- Hanna Olsson, 2015

*“Global climate change is already upon us.”*  
- Christian Azar, 2008

*“We can all agree on that we need to save energy and switch to renewable energy sources, so that we in the future can achieve a sustainable society in the long term.”*  
- Holger Gross, 2010

*“It is the energy that we are not using that is the cheapest.”*  
*“All buildings are unique and require their own solution.”*  
- Leif Kumlin, 2011

## WHY IS IT DONE?

Since I started my master studies within architecture, I’ve been questioning more and more, if the villas will fit in our picture of a sustainable future. During these years a lot of focus has been put on developing the cities and how to densify. I find it quite strange that such a small part of the discussion has been about how to develop the less dense areas, such as villas, despite **50 % of the Swedish inhabitants**, see figure 1, and **70 % of the Swedish families** live in a villa today (SCB, 2014).

The lower graph, see figure 2, shows the average living area per person. One big problem in villas is the huge heated area per person in households with less than four people. The target groups with biggest area per person are **single living persons** and after that couples without children (SCB, 2015).

This can really be an opportunity to show how these groups can **save money** and **reduce the environmental impact** by renting out a part of their villa to reduce the heated area per person.

The purpose of the thesis is to raise the discussion about not only to develop the dense areas but also to develop the rest of the building stock, in this case villas. I want to **inspire and motivate** villa owners to improve their homes in a sustainable way and I want to **encourage the education** of architecture to put more focus in this area.

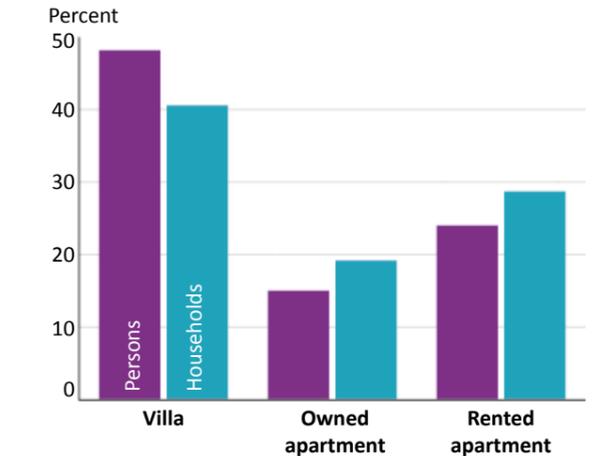


Fig. 1. Swedish inhabitant's way of living (SCB, 2014)

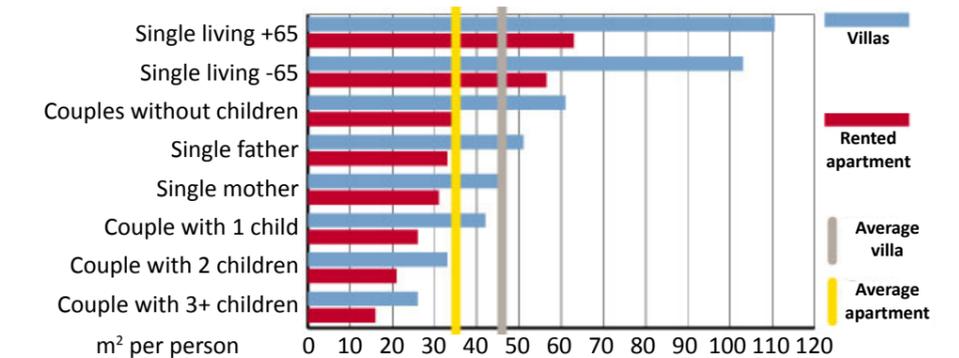


Fig. 2. Average living area in square meters per person (SCB, 2015)

The subject in this thesis is responding to the current discussions about sustainable improvement and issues connected to improving villas. During the course *Design for sustainable development in a local context* year 2013 in Tidaholm the issues were discussed; it is often a problem to develop villas in the country side due to **low land value** and **low profit** when renovating the house.

**46 % of the Swedish municipalities** reported that they have a problem with housing shortage, according to a survey made of Boverket. And **65 % of the Swedish inhabitants** live in municipalities with housing shortage (SCB, 2012).

With the given number of how big part of the existing building stock that the villas actually represent, it seems unreasonable to tear down all existing villas to build new villas just because the new ones are more efficient. That is not a sustainable approach and it is contradicting the fundamental argument, turning it into double standards since using materials/resources sparse and efficient is also an important part of sustainability.

We can work towards a more sustainable living by **reducing the heated area per person** by living more people in the same villa, for example renting out a part of the house to students or single households. Since **young people are affected the most** by the housing shortage villa owners could make a huge positive impact by **renting out** a room or two (SCB, 2012).



Fig. 3. *One tonne life*. Source and more info: [www.onetonnelife.com](http://www.onetonnelife.com)

The picture above shows one example of what others have done within the field. **“One tonne life”**, see figure 3, is a project with cooperation between A-hus, Vattenfall and Volvo with the goal to reduce the carbon emissions to 1 tonne per person and year. It was **an experiment** of how to use technical systems and solutions so that the family could keep on living with almost the same life style as before but with lower environmental impact. Within the testing period of 6 months they reduced their emissions from 7 to 1,5 tonne per person. But note that this is a new building and not a refurbishment project (One tonne life, 2011).

## WHAT IS IT ABOUT?

In this thesis two approaches of sustainable changes are shown for two different **villas in Sweden** from early 20<sup>th</sup> century, one brick villa and one wooden villa.

The villas were selected because I had **good contact with the owners**, as my relatives. And the villas fit perfectly into my thesis since they are **very different**, an attribute that I was looking for, to be able to try out different approaches of sustainable changes and to see how my ideas could be adapted.

One approach is to **minimize the energy use/m<sup>2</sup>** which is suitable for Villa Miatorp that already has low living area per person. Since there are more ways than the chosen ones to reduce the energy use/m<sup>2</sup> an additional chapter of **optimization** changes is added to the design proposal of Villa Miatorp. This chapter is including **inspirational ideas** and changes that might be more suitable in the future than in the current situation.

The second approach is to **reduce the energy use per person** by reducing the heated living area per person, which is suitable for Villa Arild that today has an enormous living area per person.

It is important that both proposals are realistic, inexpensive, include safe and tested materials or methods and preserving architectural and historical values. Focus has been on finding solutions which require small changes but give a big positive impact.

In Sweden the word villa is used for **common single-family housing** that can vary in size but is normally smaller than 200m<sup>2</sup>. It should be pointed out that the usage of the word “villa” in this thesis should not be confused with the definition of villa in many other countries where it might represent a mansion or a bigger country-house.

RESEARCH QUESTIONS: (see the answers at page 57)

- How can the energy efficiency be improved with small interventions in an old brick villa with high energy use/m<sup>2</sup>, such as Villa Miatorp?
- How can we adapt and change the usage to reduce the living area and energy use per person in existing villas, such as Villa Arild?
- How can this master’s thesis encourage an increased interest in improving the sustainability of existing villas?

**Villa Miatorp** is a brick villa from 1930 and has a dense building body with separated rooms. The owners (two persons) and three students are today living in the house.  
Living area: 158 m<sup>2</sup>



Fig. 4.

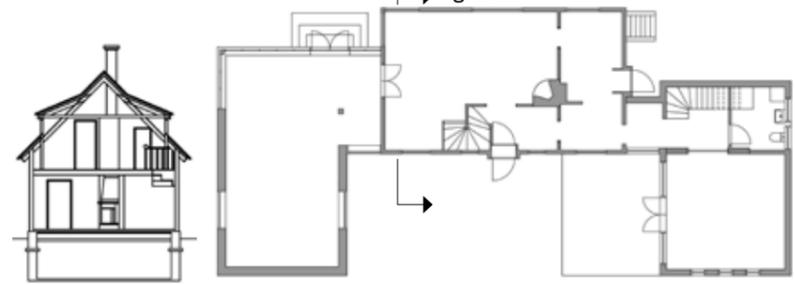


See complete plans on page 28-31.

**Villa Arild** is a wooden villa built 1937 and expanded two times into three attached building bodies with mainly open plan. Only one person (the owner) is living in the house today.  
Living area: 206 m<sup>2</sup>



Fig. 5.



See complete plans on page 52-55.

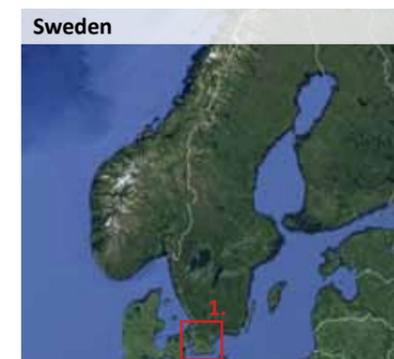


Fig. 6-9. Source: www.maps.google.se



One example of what was analyzed is the **energy use**. For villa Miatorp it was clearly shown that the energy use per square meter was **50 % higher** due to the **poor building envelope**. The energy use excluding electricity was 67 % higher than the average which means that the energy use would need to be reduced by 85 % or more to reach the passive house standard.

Note that the average is not the optimal value. Reaching the average value does not mean that the improvement is enough. The requirement of a passive house is in south of Sweden an energy use of 30 kWh/m<sup>2</sup> or less, excluding electricity (Samuelsson, M and Lüddeckens, T, 2009). This is 75 % lower than the average villa.

For Villa Arild the energy use per person was extremely high, **140 % higher** than the average. This is mostly due to the enormous living area per person.

**Average villa:** (Energimyndigheten, 2015)  
Average annual energy use/person: **8881 kWh**  
Average annual energy use/m<sup>2</sup>: **161 kWh**  
Average annual energy use/m<sup>2</sup> excluding electricity: **121 kWh - 75 % higher**

**Villa Miatorp:** (Energy usage 2014, from owners)  
Average annual energy use/m<sup>2</sup>: **243 kWh - 50 % higher**  
Average annual energy use/m<sup>2</sup> excluding electricity: **202 kWh - 67 % higher**

**Villa Arild:** (Energy usage 2013, from owners)  
Average annual energy use/person: **21750 kWh - 140 % higher**

The analysis led to defined focuses for each building of what needs to be changed for it to become more sustainable according to my definition of a sustainable villa, see page 7+15. The dialog with the owners is an important part of both proposals to raise awareness and interest.

For Villa Miatorp reduced energy use per square meter and environment friendly and healthy materials is a focus.

For Villa Arild the main focus is to reduce energy use per person, since only one person is living there today. The plan in Villa Arild also needs to be re-arranged and changed to fit more residents.

**Focus in Villa Miatorp:**

- To give the users a better and more stable indoor climate & decrease the energy use/m<sup>2</sup>.
- Support and create a dialog with the users.
- Continue to use environment friendly and healthy materials.

(Read more on page 26)

**Focus in Villa Arild:**

- Decrease the energy use/person by fitting more people into the house.
- Support and create a dialog with the users.
- The plan of the villa is re-arranged and adapted to more residents.

(Read more on page 50)

## HOW IS IT DONE?

In the analysis it was found out that Villa Miatorp has district heating, exhaust air in bathrooms and kitchen, recycling on the lot, 2-pane windows, shared laundry room, a greenhouse and the household is growing vegetables in the garden. They also have a lot of hobby rooms in the basement which they use frequently, see figure 10-13.



Fig.10. Shared laundry room



Fig.11. 2-pane windows



Fig.12. Growing vegetables in the garden



Fig.13. Workshop in the basement

Villa Arild has a visible load bearing wooden structure in the old house, 2-pane and 3-pane windows, a view of the ocean, only bins for organic and combustible waste, geothermal heating, a fireplace in the old building, a crawl space under the biggest part of the building and there is a shed in the garden with sauna, storage and a workshop, see figure 14-17.



Fig.14. Visible wooden beams



Fig.15. 2 & 3-pane windows



Fig.16. Shed with sauna, storage and workshop



Fig.17. Fireplace in the middle building body

To be able to analyze the sustainability of the villas I first had to define my own **definition of sustainability**, see page 7.

After I refined my definition of sustainability it could be narrowed down to what a **villa needs** to be sustainable. This was developed into **five pillars** which were used to analyze the villas and finally develop the design proposals:

- Well-being of its users
- Environment friendly and healthy materials
- Low energy use per person
- The building is encouraging a sustainable lifestyle
- The building has high flexibility and adaptability

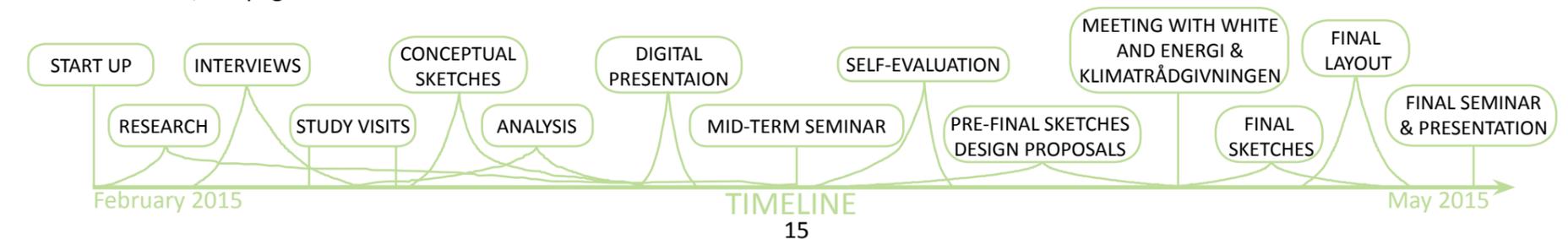
A lot of **research was done** and **interviews** of teachers working within the field. A couple of **study visits** were essential to analyze the two villas and at the same time the villa owners were interviewed. After the visit a summary of the **analysis** was made and then a period of sketching **conceptual ideas** of how to improve the villas started. The household in Villa Miatorp also made a **diary of activities** and usage of the house during one week, see page 20.

During the thesis work dialogs and contact with **experts** was extremely important. Following contacts are specialists within the field; environmental consultant and simulation/calculation expert at White and an energy advisor at Göteborgs stad.

After the mid-term seminar all contacts were brought together in a **meeting** to discuss the thesis work and the issues of renovation and materials in general. After that a lot of calculations and the **final sketches** and decisions for the proposals were made.

Different **materials** were investigated further and the embodied energy, cost, insulation properties and health effects were **calculated and compared** before the final decision was made.

All diagrams and calculations were made by the author except the percentage heat loss reduction of the proposal of the window where the software **Pilkington Spectrum** was used to calculate the percentage reduction of the U-value.



## THE STRUCTURE OF THE BOOKLET

### INTRODUCTION

The introduction is a brief summary of the whole thesis work. It is bringing up the most important attributes of the buildings.

### VILLA MIATORP

A detailed analysis of Villa Miatorp. Following are the design and optimization proposals presented including parts of the process. This villa is the primary focus in the thesis where most time has been prioritized.

### VILLA ARILD

A detailed analysis of Villa Arild. Following is the design proposal presented including parts of the process. This villa the secondary focus in the thesis due to a decision made after the analysis.

### CONCLUSION

A summary of the results of the proposals is presented. In this part the two villas and the different approaches of sustainable changes are also reflected upon.

### APPENDIX

All arguments, the process and decisions concerning changes of the building envelope presented in detail.

### MY ROLE AS AN ARCHITECT

It has been my job as an architect to analyze the buildings and through a continuous dialog with the owners and experts within the field come up with proposals of how to improve the villas. Since their location, usage and materials are very different it has also been important to consider the differences and adapt the proposals to what suits the specific building the best. Another important part has been to sort all the gathered information, see it with critical eyes and then choose the best solution for the situation and the big picture. I have learned a lot during this thesis, about materials, calculations of heat losses and the building envelope.

### TARGET GROUP VILLA OWNERS

Since the target group of the thesis work is villa owners and especially the owners of the example villas it was important to adapt the booklet and how the results were presented. I believe that to achieve as big impact as possible, the information needs to reach the villa owners and the results need to be very clear and readable. The aim of the booklet is to inspire as many people as possible; villa owners, architects and architect students. Therefore it has been structured to give a good overview of the proposals and ideas. More detailed calculations and motivations of most decisions are therefore put in the appendix in the end for those who wish to read further.

## 2. ANALYSIS OF VILLA MIATORP

- Location and surroundings
- The story of the building
- Function and usage of the building today
- Architectural and historical values
- Materials and building envelope
- Technical systems
- Energy use
- SWOT - Strengths, Weaknesses, Opportunities & Threats
- Goals of how to improve the sustainability of the villa

## LOCATION AND SURROUNDINGS

Villa Miatorp is located in south of Sweden in the city of Helsingborg, see figure 18-19. The area is a mix of villas, multi-family housing and some companies and supermarkets (d). The area is surrounded by several public transport stations; buses (b, c and f) and train (a) within 400 meters. It is about 3 km to the central station and the city center. The closest beach and possibilities to swim in the ocean is reached within 1,5 km.

It is a calm area with a lot of families and mostly mid-income to low-income inhabitants. The average income for the inhabitants in the area Miatorp (295600:-/year) is 14 % lower than the average for Helsingborg (343200:-/year) (Helsingborgs stad, 2012). Most of the buildings in the area were built in the 1920s or later. The eastern part of Miatorp is dominated by villas in 1920s classicism with square shaped plans, steep pitched roofs



Fig. 18-19. Source: www.maps.google.se

and dark brick facades, see figure 21, or bright plaster, see figure 20. In the western villa area the houses are a bit older with mostly bright plastered facades and gambrel roofs (Ranby, 2005).



Fig. 20. Gambrel roof with bright plastered facade.



Fig. 21. Pitched roof with dark brick facade.



Fig. 22. Old photo of Miatorp around 1940s north west of the area (g). The field was used for horseback riding, recreational area and circus (HD, 2011).

## THE STORY OF THE BUILDING

When the villa was built in 1930 it was a home for three families. It was later changed to also include a milk store in today's kitchen. The load bearing beams under the kitchen floor is therefore lower than in the rest of the house to make the store more accessible from the outside.

In the 70s the owners made a trend renovation of the house, adding wooden panel on walls and lowering the ceiling. They also removed the wooden frames/trims around the windows to achieve a modern expression.

When the current owners bought the house in 1990 they restored the original expression and removed the wooden panels. The kitchen floor was also raised to the same level as the rest of the ground floor.

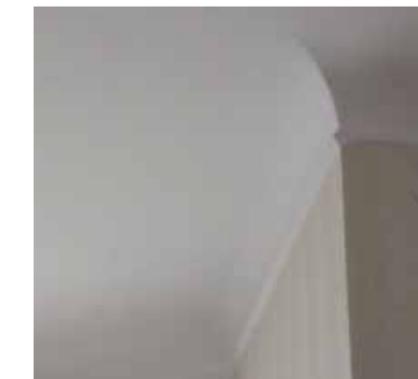


Fig. 23. The original ceiling on the ground floor with soft edges.



Fig. 24. Today's expression of the 2-pane windows.

Today the Olsson family lives in Villa Miatorp and the household currently consists of two adults who have been married for 38 years. They have three children which all are grown up and moved out. The total amount of people living in the house is five since the upper floor is rented out to three students.

1990 when the family bought the house they had two children and a third was on its way. The reason of moving was that their previous home (a rented row house) had little privacy due to neighbours, increasing rent and not enough of space for a fifth family member.

The reason of buying this house was that it was located close to school and relatives. The price level in the area was also quite good and the house had a recently renovated kitchen and a new heat pump.

During the 24 years that Mr. and Mrs. Olsson lived in the house they renovated a lot and they did a big part of the renovation themselves. Following were renovated or changed; new insulation in the angled roof on the upper floor, replacing doors, installed exhaust air in bathrooms and kitchen, replaced oil heating system with district heating, installed a reused tiled fireplace and a new chimney, added drain around the foundation, new storm water system, repaired the roof in the bay window/under the balcony due to leakage and they also restored original walls and ceiling (From interview with Mr. & Mrs. Olsson the 27<sup>th</sup> of February 2015, interviewed by author).

## FUNCTION AND USAGE OF THE BUILDING TODAY

Today's function of the building is only residential. The ground floor is used by the owners and the upper floor is rented out to three students, see complete plans on page 28-31.

To map the usage of the building household Olsson, the owners, made a diary of their activities during one week. They noted which rooms that were used, for how long time and what their main activity in that specific room was, see summary below.

It was clearly shown that the most used rooms were the bedroom and the library. The library is used as a second bedroom and during the day it is used as a working place or relax room. The household use the library more than the living room due to the comfortable temperature in the library, since the frequently used fireplace is located there.

Average time spent in different rooms by household Olsson

Room		Main activities
Bedroom	23,8 %	Sleeping, reading, knitting, listening to radio, cleaning
Kitchen	10,5 %	Cooking, eating, baking
Library	43,1 %	Reading, eating, sleeping, writing, having guests
Living room	7,8 %	Tv, having guests, relaxing
Basement	1,8%	Hobbies, laundry
Garden/Outdoor	13 %	Gardening, visiting relatives
Usage of car (km)	194	Supermarket, visiting relatives, church

The living room is colder and only used when they are having guests and need more space or when the household is watching tv. The usage of the rooms varies a bit over the year. At the time that the diary was made (25<sup>th</sup> of february - 3<sup>rd</sup> of march) it was quite cold and this makes the library a better choice when they want to relax, read or have a cup of coffee.

The third most used space is outdoor/garden. They like to spend a lot of time in the garden both during spring, summer and fall. Olsson is also visiting their grand children or relatives quite often and therefore leave the house.

Since some relatives live far away the usage of the car is quite high. They also have activities outside of the home a couple of days a week, such as shopping and visiting church.

## ARCHITECTURAL AND HISTORICAL VALUES

Villa Miatorp has a typical exterior of a 1920s villa with a gambrel roof (1), plastered brick facade (2) and plastered socle (3). Due to the gambrel roof more space could be gained in the loft. As the typical 1920s villa this house has a warm bright facade color and white wooden joinery decorations. The windows are symmetrical and placed regularly, see figure 25-27.

The entrance has a clear classicist touch with pillars (4) on each side. The socle is plastered and simple pilasters (5) are marking the corners with out sticking simple capital (6), see figure 26-27.

The windows have double hung sash, divided in six squares (7), with white mullions (8) and are opened to the outside, see figure 28.

Analysis based on (Björk et al, 2009)



Fig. 25. Gambrel roof, (1). Plastered warm colored facade (2).



Fig. 26. Pillars on each side of the entrance highlighten it (4).



Fig. 27. Plastered socle (3). Pilasters (5). Simple capital (6).



Fig. 28. Six squares in windows (7). White mullions (8).



## ENERGY USE

### Average villa: (Energimyndigheten, 2015)

Living area: 149 m<sup>2</sup>  
Living area/person: 55,2 m<sup>2</sup>  
Total annual energy use: 23980 kWh  
Electricity: 6000 kWh  
Hot water: 4500 kWh  
Heating: 13480 kWh  
Average annual energy use/person\*: **8881 kWh**  
Average annual energy use/m<sup>2</sup>: **161 kWh**

### Average apartment: (Area from SCB, 2012. Energy from Eon, 2014)

Living area: 70 m<sup>2</sup>  
Living area/person: 26 m<sup>2</sup>  
Total annual energy use: 12000 kWh  
Electricity: 3000 kWh  
Hot water: 2500 kWh  
Heating: 2500 kWh  
Average annual energy use/person\*: **4444 kWh**  
Average annual energy use/m<sup>2</sup>: **171 kWh**

### Villa Miatorp 2014: (Energy usage 2014, from owners)

Living area: 158 m<sup>2</sup>  
Living area/person: 31,6 m<sup>2</sup>  
Total annual energy use: 38422 kWh  
Electricity: 6554 kWh  
Hot water: (included in heating (district heating))  
Heating: 31868 kWh  
Average annual energy use/person: **7684 kWh - 16 % lower**  
Average annual energy use/m<sup>2</sup>: **243 kWh - 50 % higher**

For villa Miatorp the average energy use **per person is 16 % lower** than for the average villa. This is mainly because the average living area per person is less than in the average villa (31,6 m<sup>2</sup> per person instead of 55,2m<sup>2</sup>). The energy use per square meter is **50 % higher** most likely because of the **poor building envelope** and heat losses from ventilation.

It is also interesting to investigate how much energy per person the students consume compared with the owners. 2008 before they rented out the upper floor to students the household consisted of 3 people. As showed below the energy use when 5 people live in the house only increased by 15 %, while the energy use per person is decreased by 20 % which results in energy savings per person. The electricity use is almost the same.

### Villa Miatorp 2008: (Energy usage 2008, from owners)

Energy use for heating and water 2008: 27750 kWh (9250 kWh/person)  
Electricity use 2008: 6389 kWh

\*According to SCB 2014 the average amount of persons in each household is 2,7. To calculate the energy use per person the total energy use was divided with 2,7. Note that this is the ratio for the whole country and all dwellings. It should therefore not be trusted completely when measuring energy/person since more persons live within each household if they live in a villa compared with living in an apartment. The average can therefore be higher than what is shown in the average apartment and lower than what is shown in the average villa.

## SWOT - STRENGTHS, WEAKNESSES, OPPORTUNITIES & THREATS

To find the values in the building a swot-analysis was made. It was important to see the whole picture and evaluate all values before making the proposals to get insight and understanding of the owner's perspective not to lose important values.

### Strengths:

- The use of the building has changed over the years but the building is still fulfilling its function and responds to the needs of its users.
- Good connection to the surroundings, close to all areas and public transport.
- Fits many different types of households.
- Many possibilities of performing different activities within the building and in the surrounding garden.
- Genuine and healthy materials. The roof tiles have never been changed and still fill their function, 85 years later.
- The solid heavy brick wall protects the building from overheating during summer by storing the heat in the wall.

### Weaknesses:

- Lack of insulation, only a double brick facade. Cold during winter.
- The same heated area all year around.
- The house is not actively working with encouraging a sustainable life style.

For example, the analysis of Villa Miatorp was useful when finding and locating the main problems in the building envelope which then were improved in the proposal.

### Opportunities:

- Farming in the garden
- Self-sufficiency such as solar cells and compost heating
- The wide air gap in the outer wall makes it possible to improve the building envelope without changing the looks of the facade.

### Threats:

- A lot of moisture in the basement, risk for mold if the ventilation is insufficient.
- Owners are getting older, the size of the house and the garden might be too big to take care of in the future.

Main goals for Villa Miatorp:

- To give the users a better and stable indoor climate and at the same time decrease the energy use/m<sup>2</sup>. Since not all parameters are possible to measure, such as ventilation heat losses and heat gains from usage, the focus will be to reduce the heat losses in the building envelope as much as possible. But the changes should be well-motivated and inexpensive.
- Continue to use environment friendly and healthy materials when repairing the building or making additions. Added materials should be tested and known for not being unhealthy.
- The original character and architectural values are preserved.
- Additions are possible to restore.

Sub-goals for Villa Miatorp:

- The building is actively showing the current environmental impact and how different choices affect it. (The thesis itself shows this by presenting how much of the heat losses that can be prevented easily.)
- The villa should encourage the users, more than today, to live a sustainable lifestyle.
- To compensate for energy losses which are a problem with the building's original state, the building can be complemented with renewable energy production to reduce the environmental impact that the energy losses will lead to. For example, solar/wind/water-energy or heating with compost.

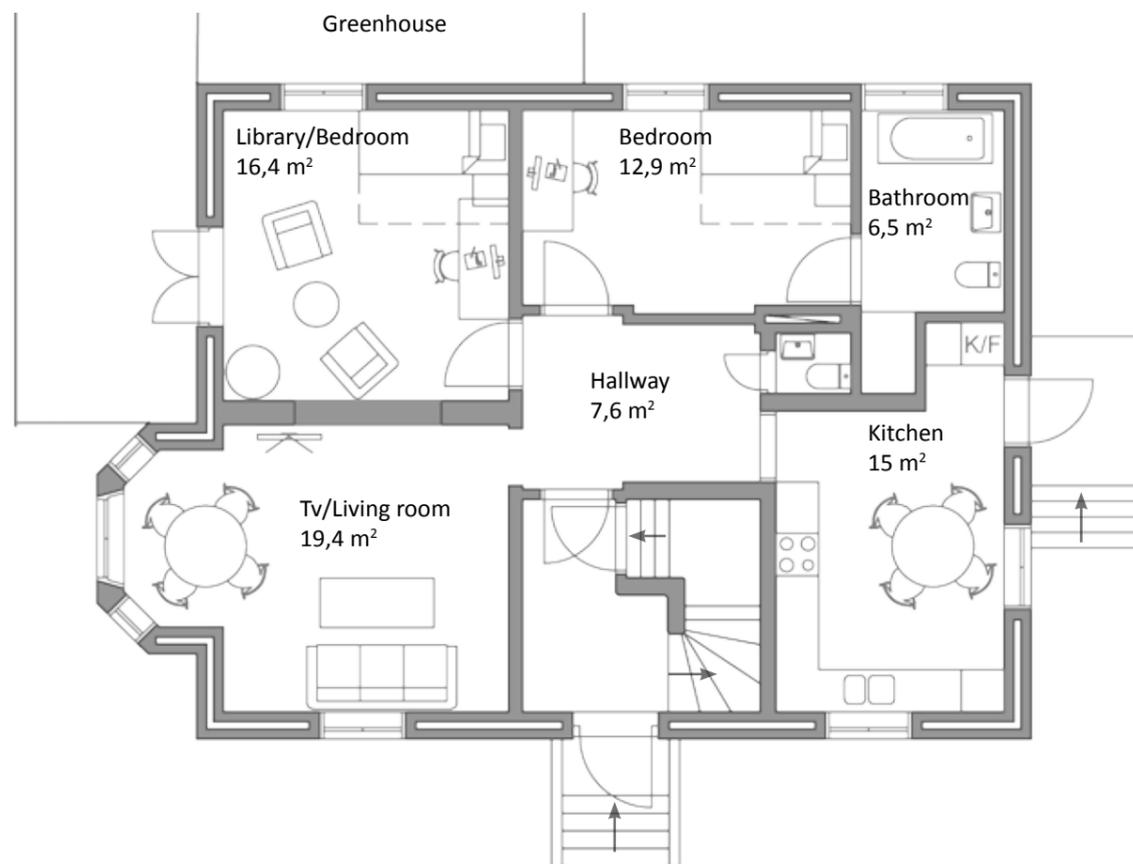
### 3. DESIGN PROPOSAL OF VILLA MIATORP



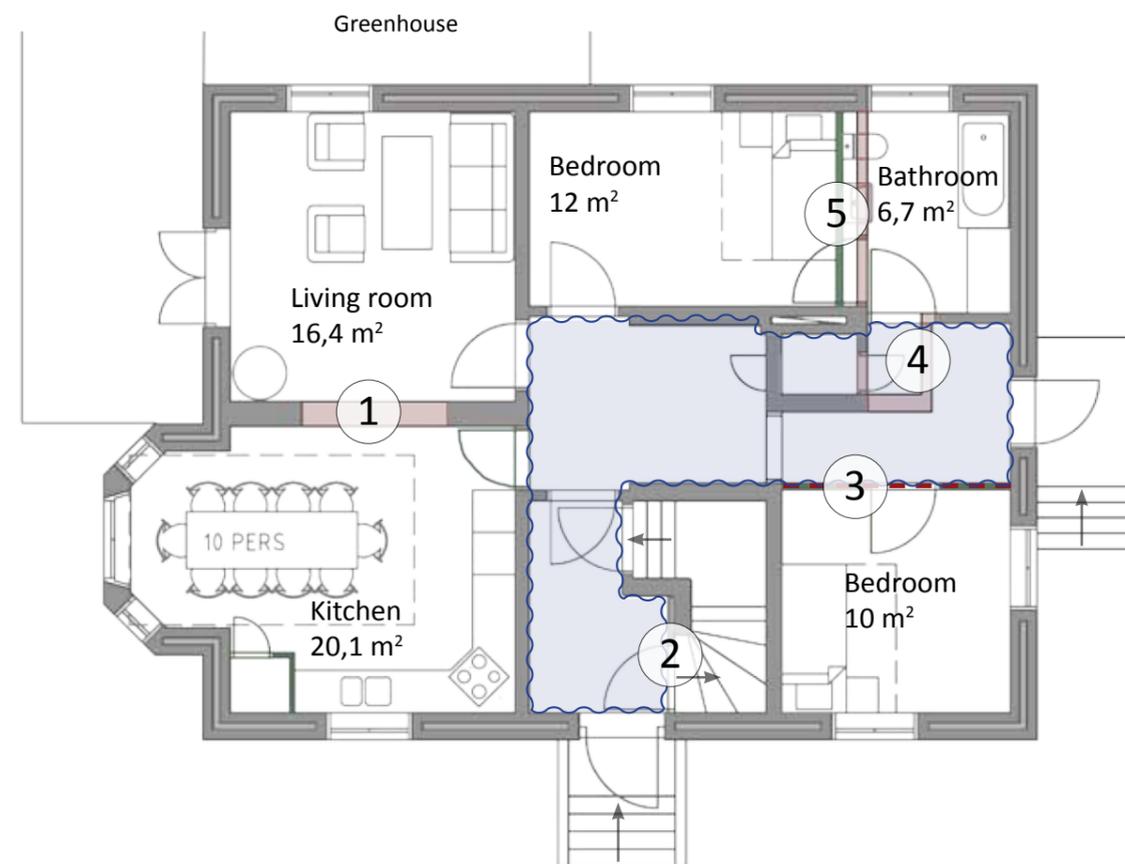
Fig. 35. Cut through building

## CHANGES OF THE USAGE AND FUNCTIONS

Current ground floor, 1:100



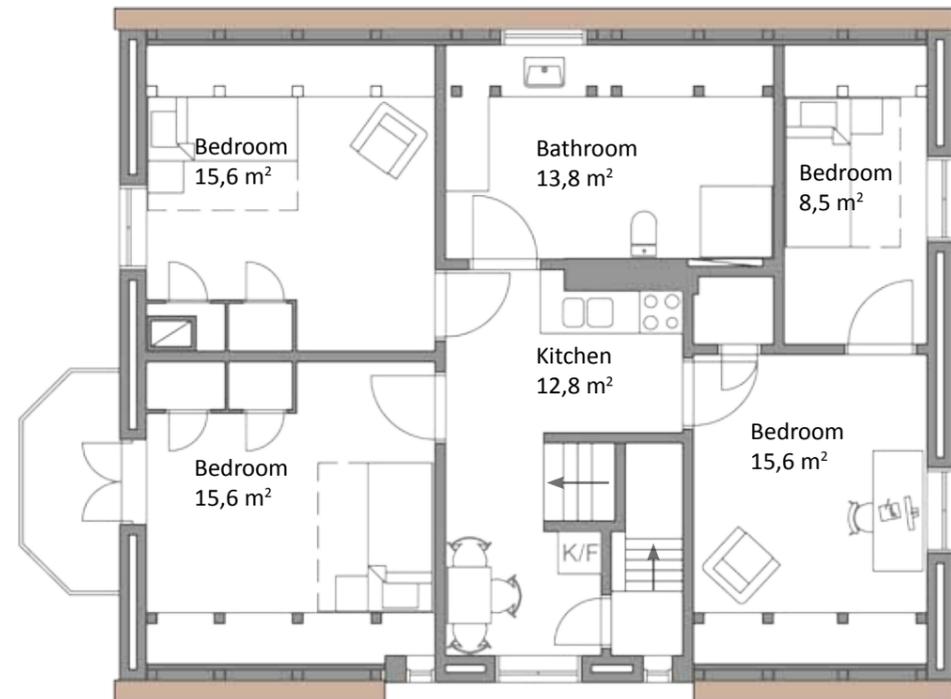
Proposal ground floor, 1:100



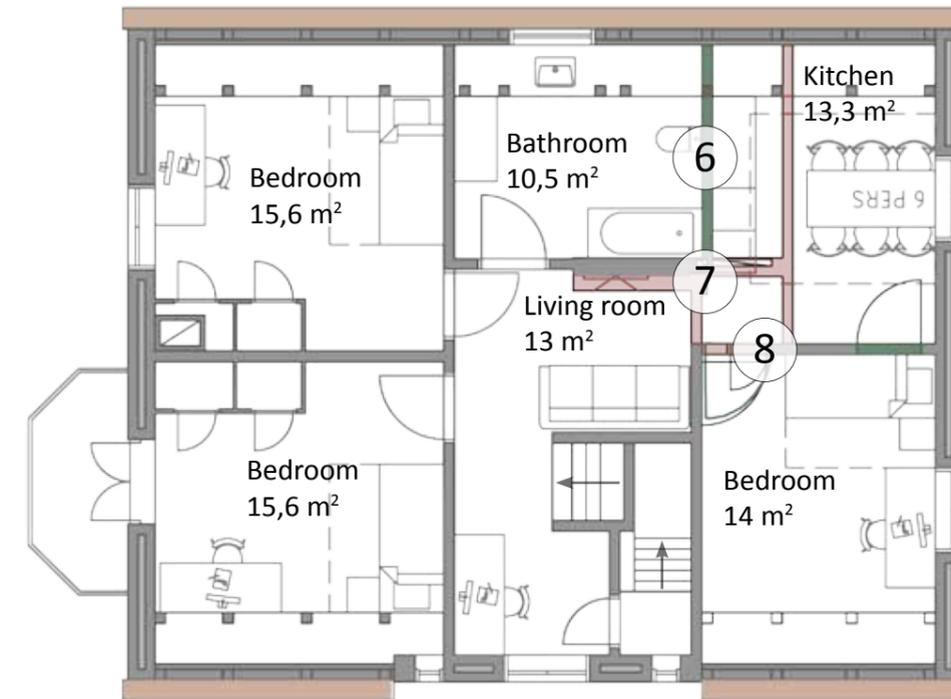
1. Filling in wall is removed, opening restored
2. Door and wall added, separating the air in the staircase with the air in the hallway
3. New wall giving the house one extra bedroom
4. Load bearing wall is changed, replaced with load bearing beam
5. Wall is moved and makes the bathroom bigger but the bedroom smaller

- New walls
- Removed walls
- ~ Temperature zone 16-18°

Current upper floor, 1:100



Proposal upper floor, 1:100



6. Wall is moved and is making the bathroom smaller but creating space for a proper kitchen
7. Removed walls/part of old chimney, if necessary replaced with load bearing beam. New opening for kitchen
8. Door is moved from hallway to kitchen to give the possibility to furnish and use the hallway

- New walls
- Removed walls



Fig. 36. A view from the outside in the SketchUp model that was made during the thesis work.



Fig. 37. Cut of the plan in the basement, no changes.



Fig. 38. Cut of the plan in ground floor, kitchen moved, 1 bedroom added and bigger hallway.



Fig. 39. Cut of the plan in the upper floor, a proper kitchen installed, bigger common areas and smaller bathroom.

## CHANGES OF TECHNICAL SYSTEMS AND BUILDING ENVELOPE

The U-value indicates the insulation quality. A low U-value results in less heat loss.



Fig. 40. Outer wall

Air gap filled with Perlite insulation.  
(Read more in appendix page 68-70)

Window: 2-pane window in two sections.  
U-value window including frame: 2,5

Wall:  
Inside (left)  
15 Plaster  
120 Brick  
110 Expanded Perlite Granular insulation  
120 Brick  
15 Plaster  
Outside (right)

**U-value wall with Perlite filling: 0,36**  
(current u-value 1,64, not including the parts with massive brick (5%))  
**U-value wall average: 0,4**  
(current u-value 1,62)  
U-value window: 2,5

- Reducing heat losses through wall with insulation by 78 %.
- Reducing the total heat losses of the building envelope by 52 %

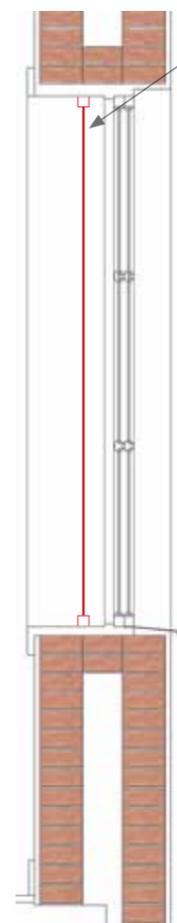


Fig. 41. Outer wall

Added third pane on the inside.  
(Read more in appendix page 71)

Window: 2-pane window in two sections.  
U-value window including frame: 1,5

Wall:  
Inside (left)  
15 Plaster  
120 Brick  
110 Expanded Perlite Granular insulation  
120 Brick  
15 Plaster  
Outside (right)

U-value wall: 0,36  
**U-value window: 1,5**

- Reducing heat losses through windows by 40 %.
- Reducing the total heat losses of the building envelope by 8 %
- In combination with improvement of the wall the heat loss of the whole building envelope will be reduced by 59 %

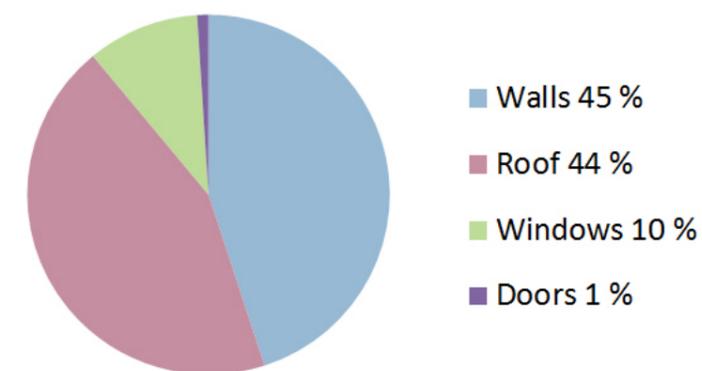


Fig. 42. Areas of the building today

Figures 42-44 show the most critical parts of the building envelope today. It is clear that the outer walls are leaking a lot of heat since they represent 45 %, see figure 42, of the area but stand for 68 %, see figure 43, of the total heat loss. Even if the roof represents 44 % of the area it is only responsible for 10 % of the heat loss. This really points out how bad the insulation properties are of the wall today. The windows are the second biggest leakage, which also was expected since they are old 2 pane and double air windows.

What can be learned from this is that in this particular house we can achieve the biggest impact of heat loss reduction by improving the outer walls. If the building envelope should be improved further the windows and the roof should be improved as a second step, see figure 44.

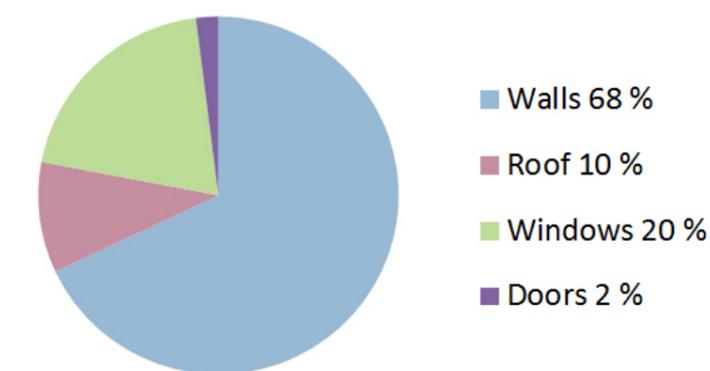


Fig. 43. Total heat losses of the building today

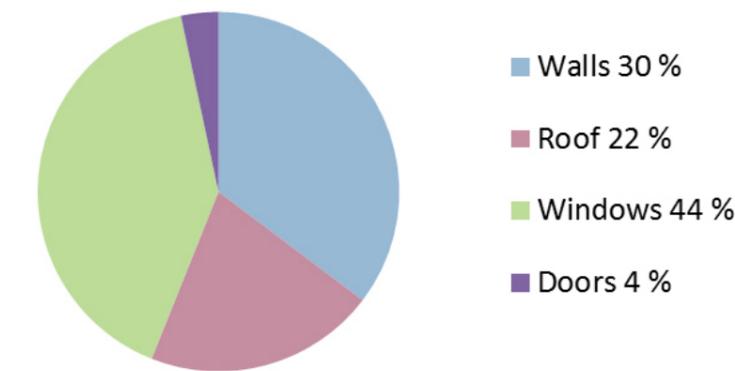


Fig. 44. Total heat losses of the building after improvements of the outer walls, by filling the air gap with Perlite

Additional 190 mm Ekofiber insulation in the horizontal roof (a). 45mm mineral wool on the inside of the angled roof (b) and the old insulation (Kolstybb) is replaced with 120 mm Ekofiber (c).

(Read more in appendix page 72-73)

- New U-value horizontal roof: **0,1** (current value 0,26)
- New U-value angled roof: **0,18** (current value 0,23)
- Reducing heat losses in roof by **45 %**
- Reducing heat losses of the whole building envelope by **5 %**
- If combined with improvements of walls and windows, gives a reduction of the whole building envelope by **64 %**

**Materials angled roof:**

Inside  
 13 Gyprum board  
 45 Mineral wool added (b)  
 2 Vapor barrier  
 45 Mineral wool  
 95 Mineral wool  
 25 Masonite board  
 35 Air gap  
 22 Wood  
 3 Roofing paper  
 Roofing tiles and attachment  
 Outside

**Materials horizontal roof:**

Inside  
 15 Wood  
 2 Vapor barrier  
 95 Mineral wool  
 190 Void (from lowering ceiling) filled with Ekofiber (a)  
 22 Wood  
 120 Kolstybb replaced with Ekofiber (c)  
 22 Wood  
 Attic

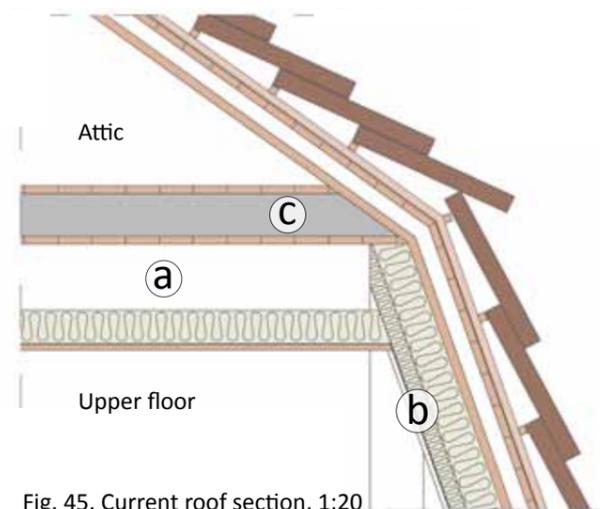


Fig. 45. Current roof section, 1:20

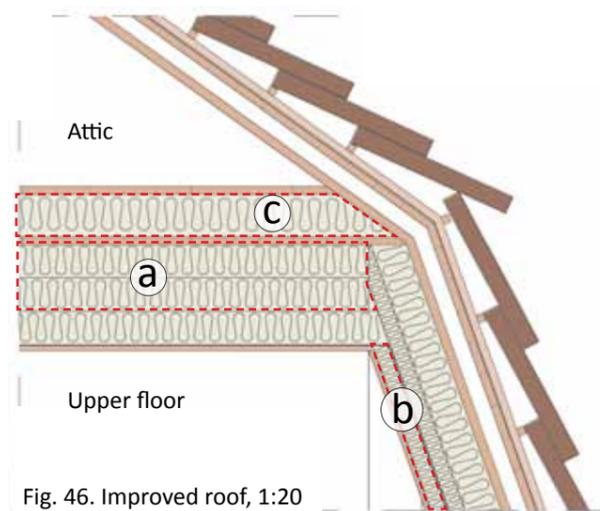


Fig. 46. Improved roof, 1:20

A research was made about different materials (loose insulation (blown), granular/bead insulation (poured), and foam (sprayed)), see page 74-78. These materials were discussed at the meeting at White the 27<sup>th</sup> of April. The discussion ended up in that it would be too risky to use organic material to fill the air gap and there are many uncertainties with foam.

Neither it is fulfilling my goal of using healthy materials with low environmental impact. The remaining non-organic alternatives were plastics or minerals; Polystyrene beads (a), Vermicular granular insulation (b) or Perlite beads (c). It was discussed that these materials would be most suitable for filling the air gap in a brick construction. It is also possible to remove these types of insulation if the result would fail or become unwanted.

In the attic on the other hand, organic insulation would be suitable because of dryer conditions and the insulation is horizontal instead of vertical. With a horizontal insulation there is less risk for insulation gaps due to shrinkage over time.



Fig. 47. Polystyrene beads (EPS)



Fig. 48. Foliated vermiculite



Fig. 49. Expanded Perlite



Fig. 50. Ekofiber

The attic is also not exposed to moisture in the same way as the outer wall. Since loose Ekofiber insulation (d) is cheaper and recycled material it could be a good solution for the attic.

After a throughtout investigation it was decided that Perlite would be the best material to use as cavity fill insulation in the air gap in Villa Miatorp. The loose cellulose insulation Ekofiber was suitable for additional insulation in the attic.

- c. Perlite granular, 0,050 W/m.k, gives U-value 0,36 for wall (Thorpe, 2010)
- d. Ekofiber cellulosa, 0,041 W/m.k gives U-value 0,1 for horizontal roof (Nordiska Ekofiber). The cost for Ecofiber is about 500:- /m<sup>3</sup> (Kumlin, 2011)

(Read more about the materials in Appendix, page 74-78)

## RESULT OF ENERGY USE

- Total heat loss today (walls, windows, roof & doors): **28007 kWh/year**
- Total heat loss after improving the wall: **13563 kWh/year, a reduction by 52 %**
- Total heat loss after improving the wall + windows: **11359 kWh/year, a reduction by 59 %**
- Total heat loss after improving the wall + windows + roof: **10094 kWh/year, a reduction by 64 %**

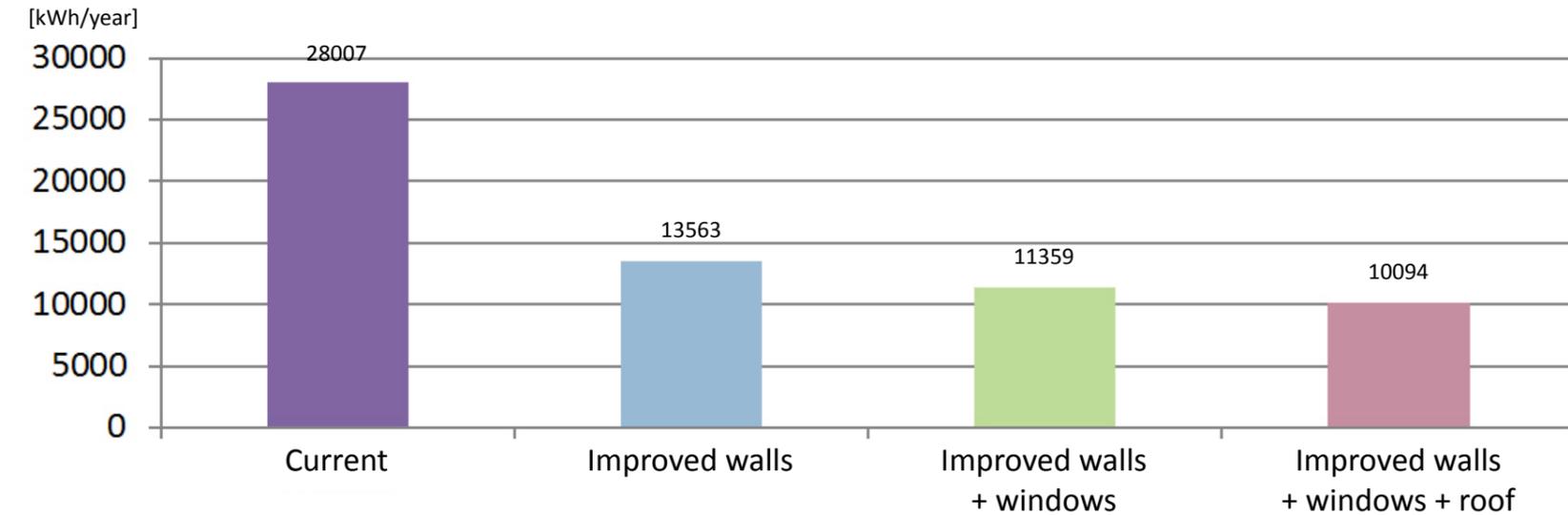


Fig. 51. Total heat losses [kWh/year] of walls, roof windows and doors after each step of improvement. Each step represents the heat loss including the previous step. For example, "Improved windows" also includes the heat loss reduction of improved walls.

## 4. OPTIMIZATION PROPOSAL OF VILLA MIATORP

The purpose with the optimization proposal is to inspire and give a quick overview of additional things that could be implemented or improved in the building to increase its energy efficiency and lower the environmental impact further. But some of the suggestions are expensive or maybe not suitable for the building at this point in time and therefore not included in the design proposal.

It was also not possible to include everything in depth in the thesis and therefore this will be a short addition to bring up inspirational systems or ideas.

### THE BUILDING ENVELOPE

- **Replacing windows and doors** - This can be done when the rest of the building envelope is performing so well that the windows and doors are the weakest spots. But it is very expensive to replace all the windows since the gains from reduced heat losses are not that big in comparison to the cost. It will also lead to losing a part of the character of the building by replacing the nice old windows with new ones. Maybe similar windows but with better properties will be available in the future.
- **Insulate the outside of the brick wall + new facade** - Could also be done to achieve really good insulation properties of the walls. But it has the same bi-effects as the window; losing the character of the building. This is also expensive and a large-scale change to do.
- **Insulating blinders/curtains during night** - Very simple change which can reduce the heat losses through windows during the night. But requires that the users put some time and effort into using them every night.

## 5. ANALYSIS OF VILLA ARILD

### TECHNICAL SYSTEMS

- **Heat exchanger ventilation system** - An advanced ventilation system could be installed but since this is quite difficult and expensive compared with the gains it is not included in the design proposal. But it would give a more stable and comfortable indoor climate in the whole building.
- **Solar panels** - Could be added to compensate for the heat losses of the building. Either to produce electricity or pre-heat warm water. But since the building has district heating today this was seen as a very small sustainability improvement of the building compared with the costs.
- **Compost heater** - Would be a nice addition to the garden since the household loves to garden and they grow some of their food on their own. The bi-products of the farming could be used as free fuel in a compost which could heat water for the building or contribute with heating to the greenhouse to extend the growing season.

### THE LIFE STYLE

- **Reduce consumption** - This is something that I as an architect cannot do for the villa owners, except aiming at not using unnecessary material. This is something that the residents themselves has to change or want to change.
- **Replace all appliances with energy efficient ones** - This could reduce the energy demand, especially if appliances which are used many hours per day are replaced. But the household are already aware of this and they are for example using timers on lamps and turn them off when they leave the room. They also try not to have any appliances on standby.
- **Dryer with heat pump function** - Since there are four households in the villa (one on the first floor and then three students on the upper floor) it can be estimated that the usage of the washing machine and the dryer is quite high. Then it might be a good idea to also replace these, especially the dryer which is using a lot of energy.
- **Bought electricity should be green** - Even though the electricity use is reduced it is important to make sure that the remaining bought electricity is green, from renewable energy sources with low environmental impact. For example, from hydro/wind-power.

- Location and surroundings
- The story of the building
- Function and usage of the building today
- Architectural and historical values
- Materials and building envelope
- Technical systems
- Energy use
- Opportunities/Strengths
- Threats/Weaknesses
- Goals of how to improve the sustainability of the villa

## LOCATION AND SURROUNDINGS

Villa Arild is located in south of Sweden in the north west part of Skåne, along the coast, see figure 52-53. Arild is a rural area with 522 inhabitants (SCB 2010) and there are mostly villas in the area. Arild has a harbour (a) and the closest public transport is by bus (b). “Hotell Rusthållargården” (c) is a restaurant and hotel where the inhabitants gather to celebrate or have parties. The closest grocery store is located in Brunnby 3,4 km away and it takes about 7 min to get there by car, but they have a service that delivers groceries to the front door since many old people live in the area. The closest recycling station is in Nyhamnsläge about 7 km away and it takes about 12 minutes to get there by car.

It is an area with mostly families and elder people. The average income for the inhabitants in the area of Höganäs (the municipality) is (307000:-/year) 9 % higher than the average for Sweden (282000:-/year) (Höganäs, 2012).



Fig. 52-53. Source: www.maps.google.se



Fig. 54. Photo of the harbour and Rusthållargården (d).



Fig. 55. Photo of Rusthållargården.

## THE STORY OF THE BUILDING

The middle building body was built 1937 as a summer house, see figure 58, with a fireplace and a small basement for food storage and room for an oil boiler.

1966 the southern building body was built as an extension of the old building.

1975 Mr Larsson bought the property as a summer house because he and his wife felt surrounded by too many new buildings in their old summer house.

1989 they felt that they wanted to move out to Arild and transform the house into permanent housing. To get more space

they built the northern building body 1989 and they also installed municipal water and sewage since that was a requirement for being allowed to use it as permanent housing.

They have not made any big changes on the house since then except replacing the old oil boiler with geothermal heating in 2004, due to high oil prices.

This has been a place where the whole family and the relatives were gathered to celebrate New year's eve and "Midsommarafton" every year.



Fig. 56. View of "Kullaberg" from the garden. Kullaberg is a known nature reserve with beautiful nature, forests and caves in the mountain.



Fig. 57. Photo of the villa and the shed with Arild and the sea to the right in the background.



Fig. 58. Original drawing of the middle building body when it was built as a summer house in 1937.

## FUNCTION AND USAGE OF THE BUILDING TODAY

Today's function of the building is residential. Mainly the ground floor is used but the guest room in the upper floor is used when the owner's family is visiting and staying for a longer time, see complete plans on page 52-55.

Mr Larsson is using the tv/dining room in the old middle building body the most, simply because it has a fireplace which is providing a good indoor comfort. He also uses the living/bed room and the kitchen. When the weather is nice he likes spending time in the garden or at the porch on the front side.

The northern building body is not used much today since it is very cold in the winter and it provides more space than needed for one person. To reduce the draft and prevent the cold air from this room to spread into the rest of the house the household is closing the glass doors which are separating the building bodies.

The household is very car dependent since it is 1,2 km to the closest bus station, see figure 59. The grocery store in Brunby (g) has a service and delivers food when needed and Larsson also gets help with food from an eldercare service.

When he needs to recycle waste he has to go to Nyhamnsläge (h), 7 km away. He often gets help with this from relatives or the eldercare.

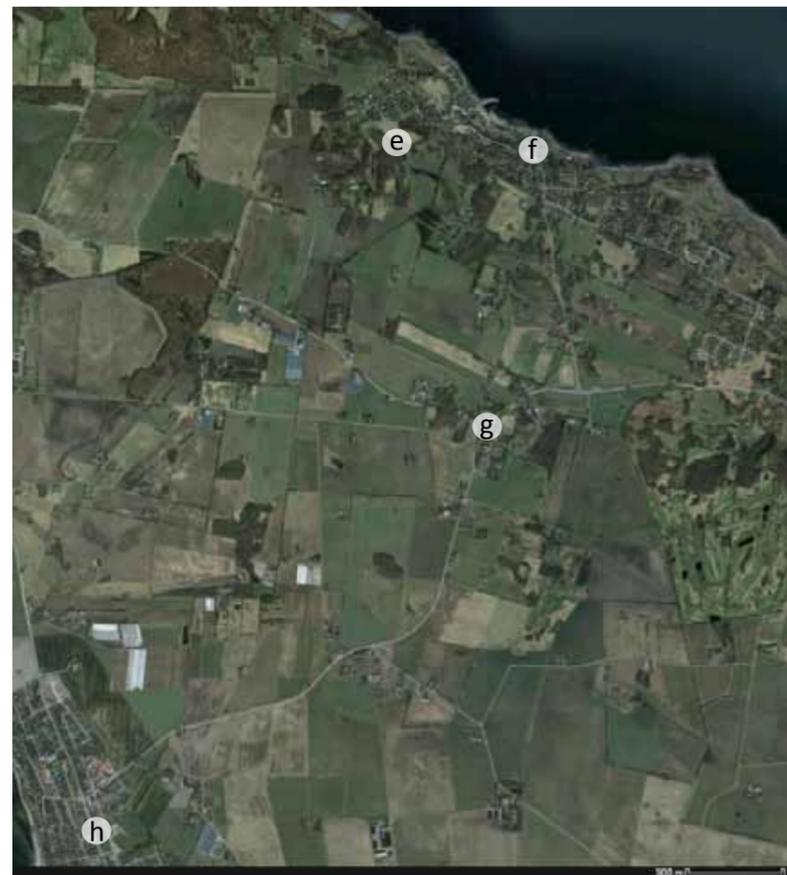


Fig. 59. (e) is the location of Villa Arild. Source: [www.maps.google.se](http://www.maps.google.se)

## ARCHITECTURAL AND HISTORICAL VALUES



Fig. 60.



Fig. 62.



Fig. 61.



Fig. 63.

Since the three building bodies have different year of construction the expression and material thickness differ a bit. But overall the villa has vertical and horizontal wooden panel (a) with white decorations such as windows, doors and even the chimney is painted white (b). Most of the windows have mullions (c) which gives the house an antique expression, see figure 61.

An old well in the garden is today only used as decoration but a nice addition to the house, see figure 60.

In the old building body from 1937 the wooden load bearing beams are visible, see figure 62.

In this room there is also a fireplace which makes this the favorite room of the household, see figure 63.

Analysis based on (Björk et al, 2009)

## MATERIALS AND BUILDING ENVELOPE

Wooden load bearing structure and mineral wool insulation is used in all building bodies but the thickness and details varies a bit since they all got different year of construction.

Figure 64 is a cross-section of the south building body built 1966. To the right is a description of the materials used for the different parts of the building.

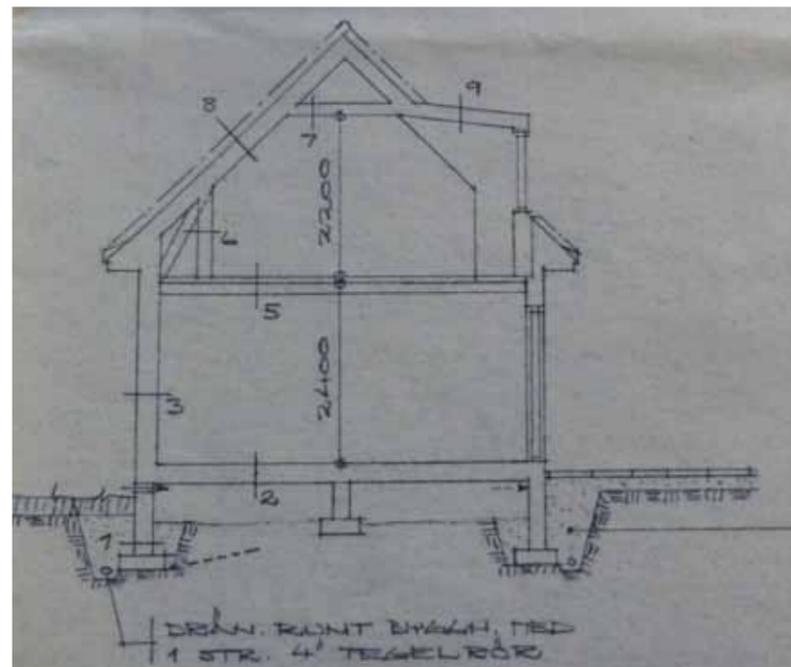


Fig. 64. Section drawing of the south building body

1. Cold asphalt-insulation + 10 mm concrete + 200 mm concrete hollow blocks, socle plastered with cement.
2. Indoor floor + 1/8 " (3 mm) hard wooden fibers + 1" (25,4 mm) wooden planks + Paperboard + 120 mm mineral wool blanket + 2"x6" (50x150mm) beams + Paperboard + Panel.
3. 1"x7" (25x175mm) horizontal wooden panel + Paperboard + 100 mm mineral wool board + load bearing pillars 2"x4" (50x100mm) + wooden panel + 13mm gypsum board.
5. Indoor floor + 1/8 " (3 mm) hard wooden fibers + 25 mm wooden panel + ceiling + 2"x8" (50x200mm) wooden beams.
6. 12 mm asfaboard + 100 mm mineral wool + 2"x4" (50x100mm) beams + 18 mm wooden panel + 13 mm gypsum board.
7. 100mm mineral wool + 18 mm panel + 13 mm gypsum board.
8. Roofing tiles + roof paper + 22 mm panel + 100mm mineral wool + 22 mm panel + 13 mm gypsum board.
9. Metal roofing + roofing paper + 22 mm panel + 100mm mineral wool + 22 mm panel + 13 mm gypsum board.

The insulation in the addition built 1989 is following; 145mm in walls, 180 mm in floor, 220mm under balcony and 220 mm in the roof.

## TECHNICAL SYSTEMS

The year of 2004 a geothermal heating system (a) was installed and replaced the oil heating system. Due to this change the basement got cold and the humidity increased. To prevent mold in the house a dehumidifier was installed in the basement to reduce the humidity.

The heat is then distributed to the whole house to radiators in every room. There are many different kinds of radiators; Section radiators (b), single/double panel radiators (c) and compact radiators (d).



Fig. 65-68. Photos from the analysis of Villa Arild

## ENERGY USE

### Average villa: (Energimyndigheten, 2015)

Living area: 149 m<sup>2</sup>  
Living area/person: 55,2 m<sup>2</sup>  
Total annual energy use: 23980 kWh  
Electricity: 6000 kWh  
Hot water: 4500 kWh  
Heating: 13480 kWh  
Average annual energy use/person\*: **8881 kWh**  
Average annual energy use/m<sup>2</sup>: **161 kWh**

### Average apartment: (Area from SCB, 2012. Energy from Eon, 2014)

Living area: 70 m<sup>2</sup>  
Living area/person: 26 m<sup>2</sup>  
Total annual energy use: 12000 kWh  
Electricity: 3000 kWh  
Hot water: 2500 kWh  
Heating: 2500 kWh  
Average annual energy use/person\*: **4444 kWh**  
Average annual energy use/m<sup>2</sup>: **171 kWh**

### Villa Arild 2013: (Energy usage 2013, from owners)

Living area: 206 m<sup>2</sup>  
Living area/person: 206 m<sup>2</sup>  
Total annual energy use: 21750 kWh  
Electricity: included  
Hot water: included  
Heating: included  
Average annual energy use/person: **21750 kWh - 140 % higher**  
Average annual energy use/m<sup>2</sup>: **106 kWh - 35 % lower**

For villa Arild the average energy use **per person was 140 % higher** than the average. This is mainly because the average living area per person is almost four times bigger than in the average villa (150 m<sup>2</sup> more per person).

The energy use per square meter was **35 % lower** most likely because of the **relatively good building envelope** and a geothermal heating system. The energy use of 21750 kWh is not the actual energy use, it is only the bought energy. The efficiency of the geothermal heating system is at least three times more, this means that for every kWh electricity that is used for the geothermal pump it will provide at least 3 kWh energy in hot water.

Let us say that the electricity used for appliances and lighting in the house is 5000 kWh of the 21750 kWh. Then the 16750 kWh that is left is used for the geothermal pump. Its actual energy value is about three times more, around 50000 kWh/year. This shows that the household is actually less sustainable and use more energy than first interpreted.

\*According to SCB 2014 the average amount of persons in each household is 2,7. To calculate the energy use per person the total energy use was divided with 2,7. Note that this is the ratio for the whole country and all dwellings.

## SWOT - STRENGTHS, WEAKNESSES, OPPORTUNITIES & THREATS

To find the values in the building a swot-analysis was made. It was important to see the whole picture and evaluate all values before making the proposals to get insight and understanding of the owner's perspective not to lose important values.

### Strengths:

- Big garden
- Nice view of the sea
- Close to nature
- Very calm and quiet area
- Good conditions for hobbies

### Weaknesses:

- Car dependency
- Heat losses/person
- No recycling on the lot
- 1,2 km to the closest public transport
- Quite separated from other people, can contribute to a feeling of isolation and unsafety in case of an accident

For example, the analysis of Villa Arild was useful in the changes of the plans since it showed that the residents in this area are car dependent and therefore the plans were re-arranged to fit one additional big household instead of several smaller ones to minimize car usage.

### Opportunities:

- Farming in the garden
- Self-sufficiency such as solar cells and compost heating

### Threats:

- Many of the qualities might get lost if surroundings are built on in the future
- Owner is getting older, the size of the house and the garden might be too big to take care of in the future.

## GOALS OF HOW TO IMPROVE THE SUSTAINABILITY OF THE VILLA

### Main goals for Villa Arild:

- The energy use per person is decreased by reducing the living area per person.
- The living area per person is reduced in the best way possible, the plan of the house is adapted to at least one more household. Since the residents are car dependent, the most sustainable solution is to aim for as few households as possible but with as many persons as possible, because then less cars are needed.

### Sub-goals for Villa Arild:

- The villa should encourage the users, more than today, to live a sustainable lifestyle.
- It should actively show the current environmental impact and how different choices affect it.
- Continue to use environment friendly and healthy materials when repairing the building or making additions.

## 6. DESIGN PROPOSAL OF VILLA ARILD



Fig 69. Photo of Villa Arild.

### TODAY:

- 1 resident
- 206 m<sup>2</sup> per person
- 21750 kWh/year per person



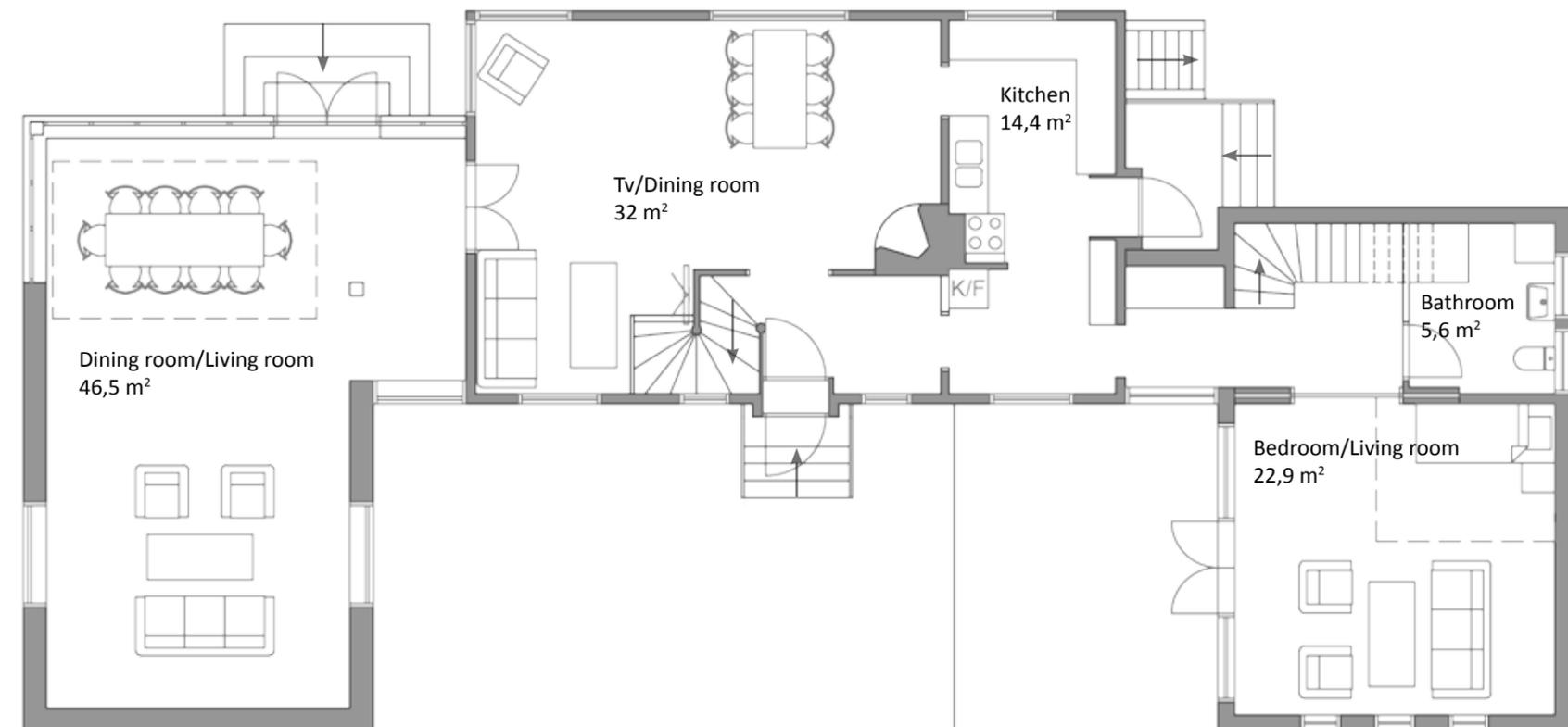
### PROPOSAL:

- 6-9 residents
- 23 - 34 m<sup>2</sup> per person
- 3000 - 4500 kWh/year per person (total energy increased to supply more residents with electricity and warm water)



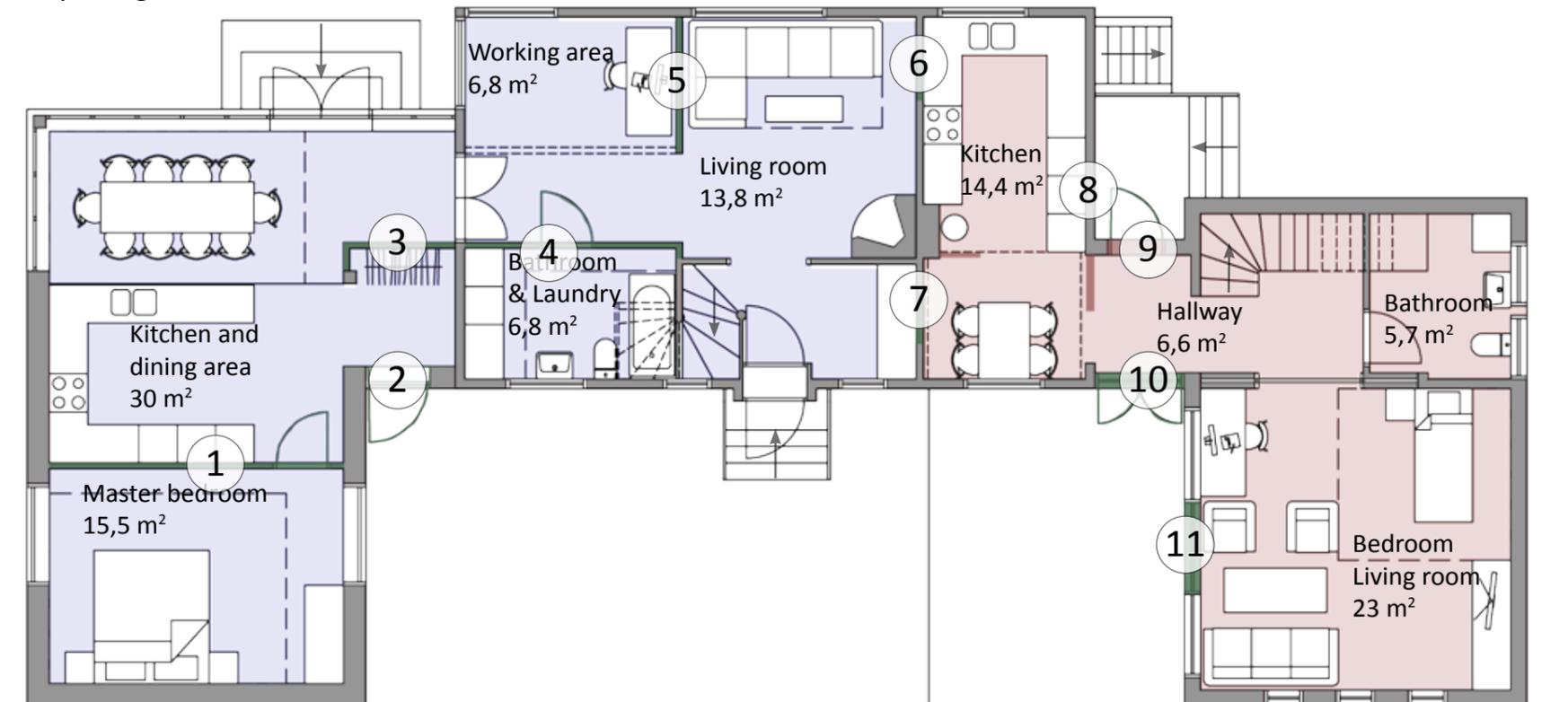
## CHANGES OF THE USAGE AND FUNCTIONS

Current ground floor, 1:100



52

Proposal ground floor, 1:100

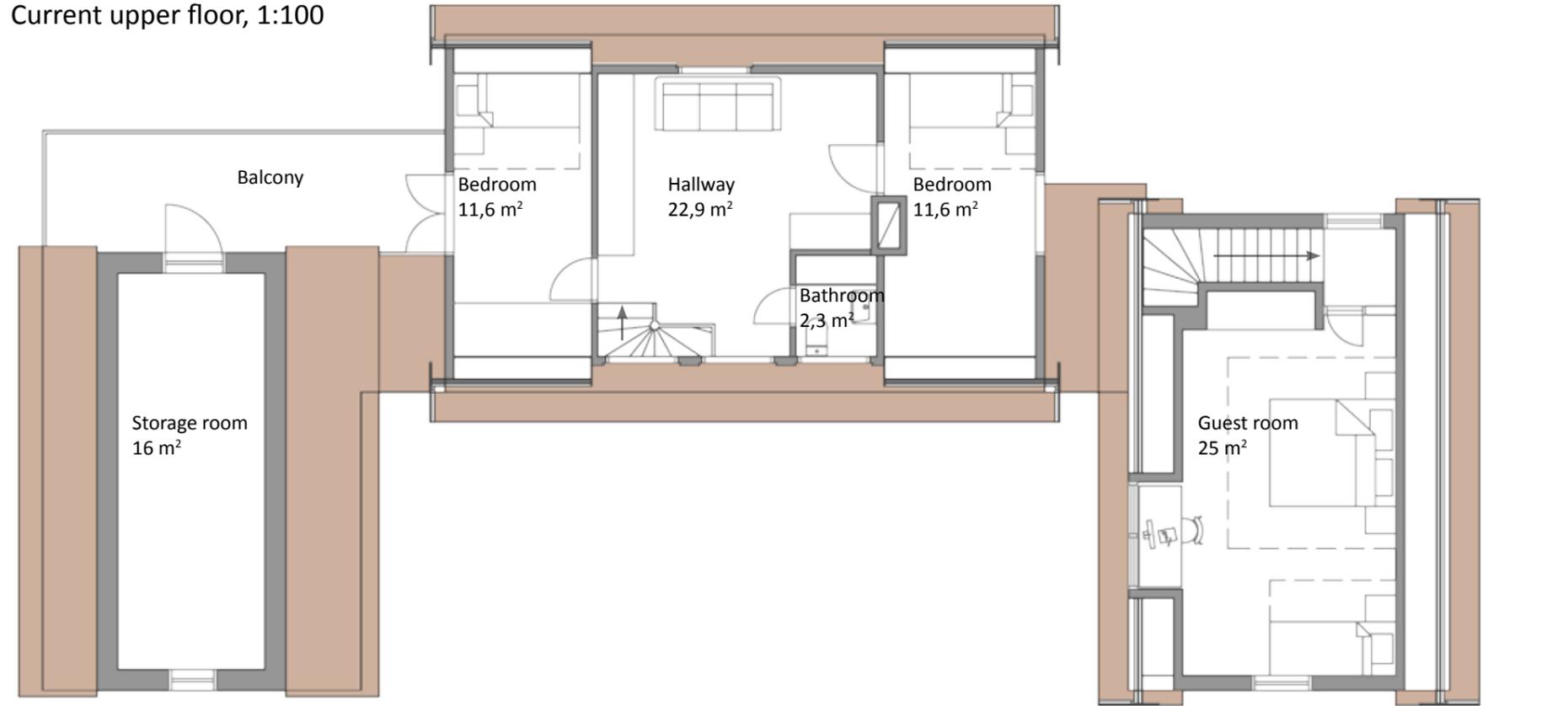


1. New wall
2. New entrance directly to kitchen
3. New wall and hallway
4. New wall and an accessible bathroom with washing machine
5. New separating wall
6. Filled door opening

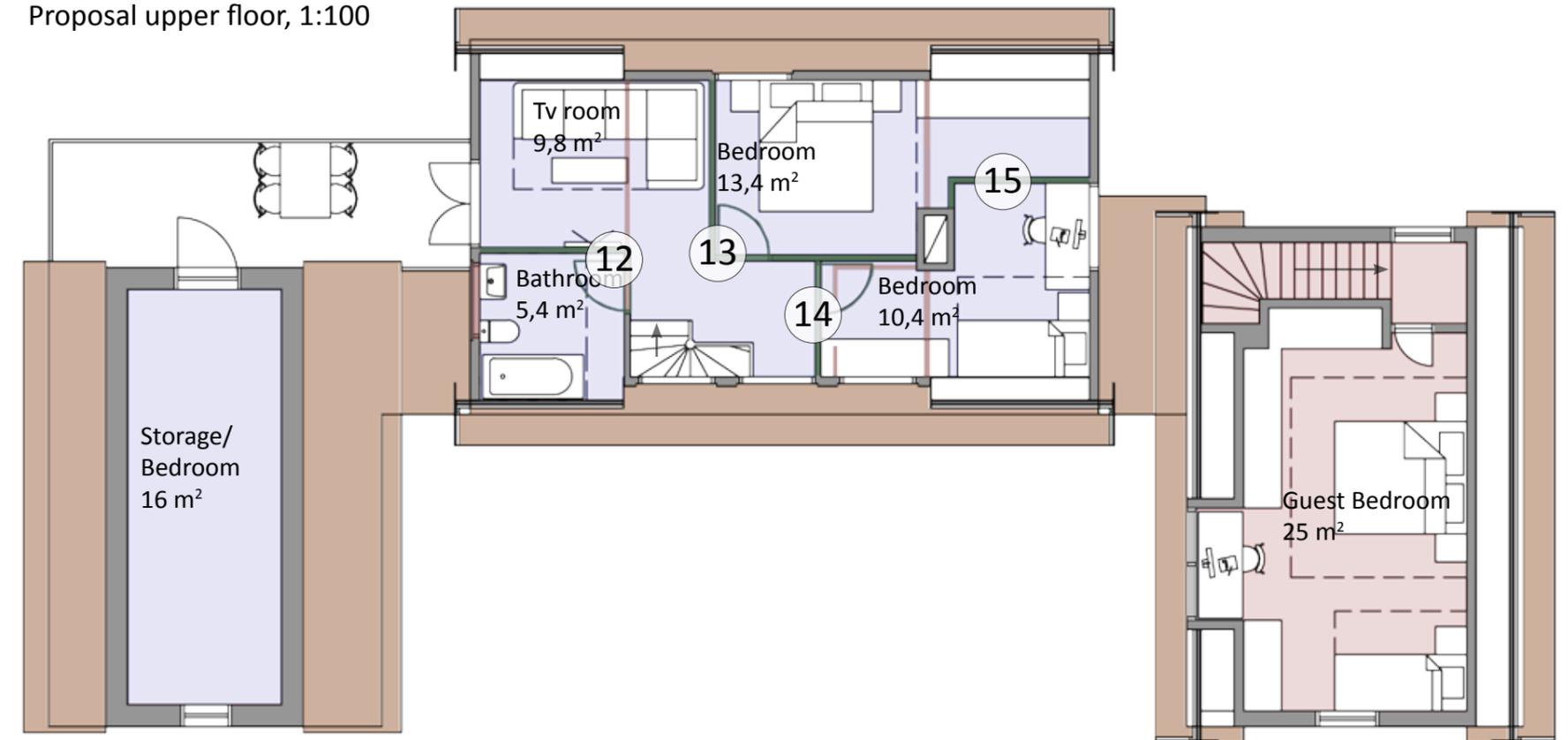
7. Filled door opening
  8. Filled entrance door opening
  9. New main entrance for red household
  10. New porch door for red household
  11. Filled porch door opening replaced with window
- New walls  
— Removed walls

53

Current upper floor, 1:100



Proposal upper floor, 1:100



- 12. New wall and bathroom
- 13. New wall and master bedroom
- 14. New wall to small bedroom
- 15. New wall between small bedroom and "walk-in closet"

Total area/household:  
 Blue apartment = 134 + 16 m<sup>2</sup>  
 Red apartment = 78 m<sup>2</sup>

- New walls
- Removed walls

## RESULT OF ENERGY USE

### Current annual energy use/year:

- Total energy use = 21750 kWh
- Energy use/m<sup>2</sup> = 106 kWh
- Energy use/person = 21750 kWh

### Proposal annual energy use/year:

(With 6 residents in 2 different households)

- Total energy use = 21750 kWh + 5000 kWh\* energy for added household = 26750 kWh
- Energy use/m<sup>2</sup> = 130 kWh
- Energy use/person = 4458 kWh  
**(reduction by 80 %)**

### Proposal annual energy use/year:

(With 9 residents (3 guests for the owner))

- Total energy use = 21750 kWh + 7000 kWh\* energy for added household = 28750 kWh
- Energy use/m<sup>2</sup> = 140 kWh
- Energy use/person = 3194 kWh  
**(reduction by 85 %)**

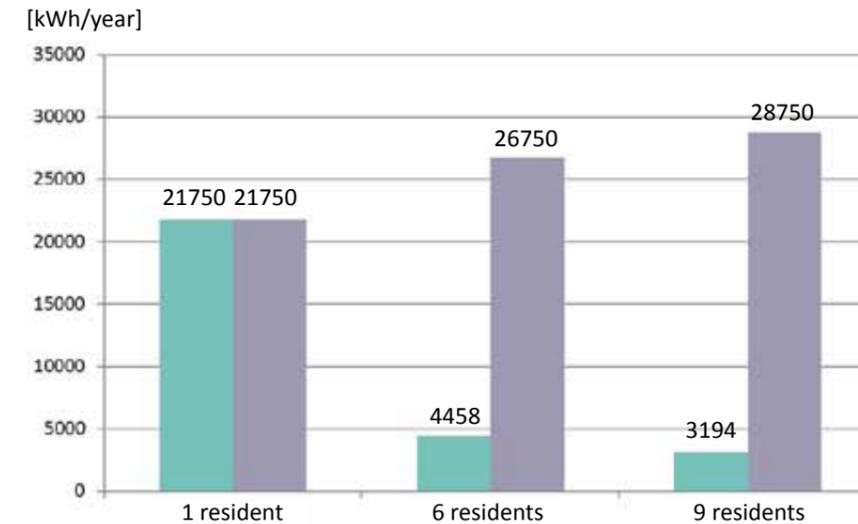


Fig. 70. The left staple represents the energy use/person which decreases with number of persons and the right represents the total energy use which increases with number of residents.

The results show an enormous reduction of the energy usage per person.

\* Estimated addition of how much one additional household would increase the total energy use. Since not much more electricity would be used the main increase would be energy for heating warm water.

## 7. CONCLUSIONS

This thesis has been very interesting to work through. The dialogs with the owners, experts and specialists have been useful and a big part of the result. This shows how important the communication and cooperation is when making sustainable transformations, but also other architectural projects.

The thesis shows that the chosen villas can be improved a lot with small and simple changes. By adapting the sustainable changes to the specific building, site and usage a lot can be done without changing its character or losing architectural values. Following I present my conclusions and the answers of the research questions that I have been working with during my thesis:

- How can the energy efficiency be improved with small interventions in an old brick villa with high energy use/m<sup>2</sup>, such as Villa Miatorp?

This is clearly answered in the design proposal of Villa Miatorp. Without changing the character of the building the heat losses of the building envelope can be reduced by 64 %. By transforming weaknesses into opportunities new solutions can be seen. The construction of the brick wall was first seen as a weakness, since it is very hard to insulate on either outside or inside to make a sustainable transformation. But it was then taken into advantage that the air gap in the wall could be filled with a suitable material to achieve huge reductions without affecting the building in a negative way.

- How can we adapt and change the usage to reduce the living area and energy use per person in existing villas, such as Villa Arild?

It shows that the proposed change made a huge positive difference in the energy use per person. Without expensive solutions, simply by changing some inner walls and installing appliances for a second household, the energy use per person can be reduced by 85 %.

- How can this master's thesis encourage an increased interest in improving the sustainability of existing villas?

It is important to clearly show how easy it is to improve the sustainability in existing villas. Especially in old buildings that have a poor building envelope, because they can easily achieve huge improvements. But also in villas with reduced household size. The importance of inspiring villa owners to reduce their living area per person and at the same time reduce their costs and environmental impact is something we should focus a lot more on, both as working architects and in the architectural education.

## SUMMARY OF THE RESULTS

By reducing the heated living area per person or the heat losses of the building we can save a lot of energy and money. In Villa Miatorp the payback time of the insulation material for the walls was less than 1,5 years (work and shipping costs not included), read more about the comparison of the materials in appendix page 74-78.

With this in mind it could be seen as throwing the money away by not making any improvements. I think that this is often the case, that villa owners can save a lot of money and the environment but most of them do not know how to do it in a safe and affordable way and therefore choose not to do anything.

Imagine how much we could reduce the energy use of all residential buildings if this information was more accessible and spoken of.

### Villa Arild (Fig. 70):

- Reduction of the energy use per person by 80-85 %

### Villa Miatorp (Fig. 51):

- Reduction of the heat losses of the building envelope (walls, windows, roof & doors) by 64 %

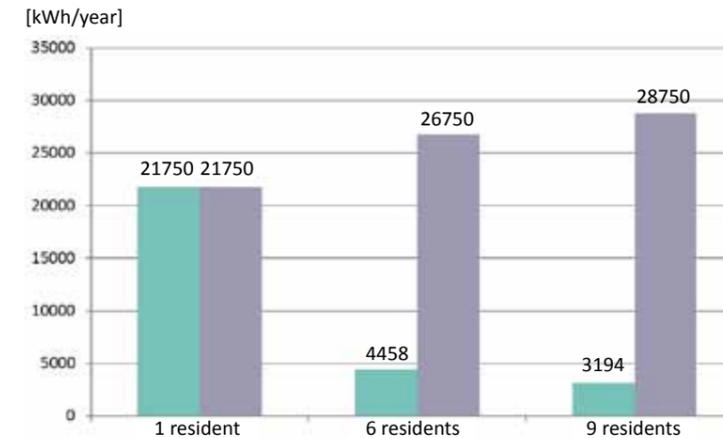


Fig. 70. The left staple represents the energy use/person and the right represents the total energy use.

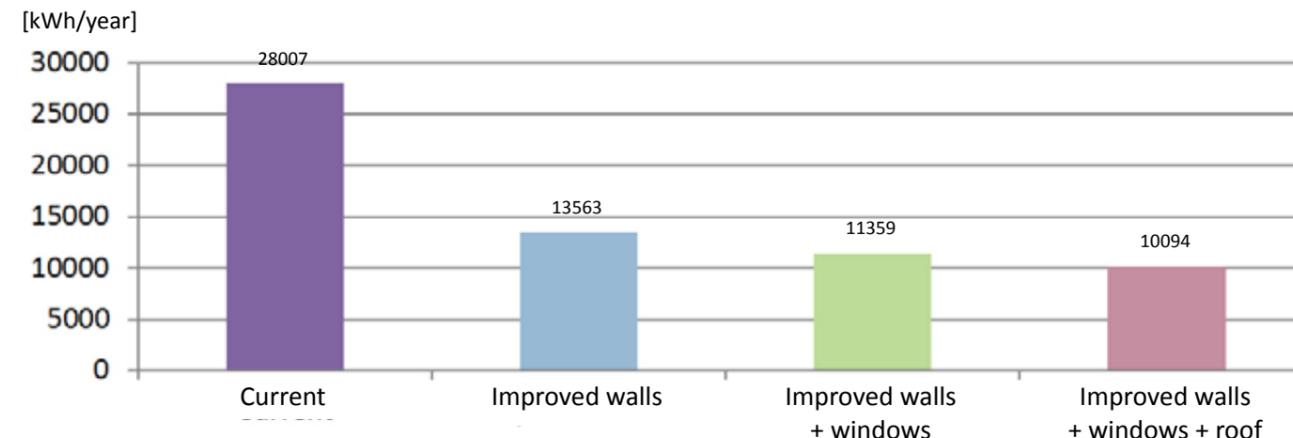


Fig. 51. Total heat losses [kWh/year] of walls, roof windows and doors after each step of improvement. Each step represents the heat loss including the previous step. For example, "Improved windows" also includes the heat loss reduction of improved walls.

## COMPARISON AND REFLECTION OF MIATORP AND ARILD

Since the starting point and the conditions of the two villas were very different the focus of the design proposals and the results are very different as well.

Two different villas were chosen for this purpose; to be examples of two approaches of sustainability and sustainable changes. The differences have been supporting a discussion during the whole thesis of how to adapt the changes to the specific villa as good as possible. There is no template of how to improve every type of villa but the thesis show solutions for these two examples.

I have chosen to work with what I see as the main approaches which gives the greatest reduction of environmental impact. The first approach was to reduce all unnecessary heat losses by improving the building envelope and making the plan more efficient and functional. The second approach was to reduce energy use per person by reducing heated living area per person. Both approaches are equally important to achieve a sustainable home.

In Villa Miatorp the first approach was the relevant one since the living area per person was already very low. In Villa Arild both approaches needs so be worked with but since the first approach was already discussed in Villa Miatorp and due to time limits it was decided that the second approach about reducing living area per person would be the focus in Villa Arild.

Since Villa Miatorp is a brick villa the improvement suggestions had to be adapted, which means that the added insulation material inside the brick wall had to be non-organic. It was also important not to add a material which was preventing the wall to breathe. The water that can go through the outer wall has to be able to dry out to prevent damages or mold in the wall.

It is also not possible to insulate a brick villa on the outside and still keep the same facade, which is easier with a wooden house such as Villa Arild where the facade can be disassembled and then put up again on top of the added insulation. The locations of the villas are also very different. Villa Miatorp is located very close to the city centre with good connections by public transport. Villa Arild is the opposite, a villa in a rural area and the residents are pretty much car dependent. This is why the villas are suitable for different kinds of household changes.

Villa Miatorp, as it is today, can be partly rent out to students or households without a car. In Villa Arild it is more suitable with a bigger household, for example a family that can share a car and thereby also reduce the amount of cars needed.

Both types of villas can be related to two of the biggest issues that villa owners have today. One issue is related to the household that gets smaller because the children move out and the parents are suddenly living alone in a big house. Another issue is the cost of having a big house after retiring and also having a lot of indoor space that is not being used.

For other villas and households this might result in other main focuses depending on their conditions. But all transformations should still be prioritized in the same way. Even though the solutions in the two example villas are different, the main goals of both villas have been the same; to minimize waste and reduce energy usage. How to prioritize is presented in a triangle, see figure 71. This shows what we should prioritize in every transformation project; to reduce energy use because reducing has the biggest impact.

The energy usage can be reduced by improving the building envelope (less energy needed to compensate for heat leakage), reduce the heated area per person, improve the heating system, lower the indoor temperature or change lifestyle and consumption patterns.

Reuse is second most effective. We need to consume and we will never stop consuming but by consuming reused material or objects instead of new we can lower our environmental impact. The third step is to recycle what we cannot reduce or reuse and turn it into new useful objects. The last step is disposal and also the least sustainable step.

While developing the proposals for the villas I had this triangle in mind and I think it is useful for every improvement we do, if we want to achieve sustainability.

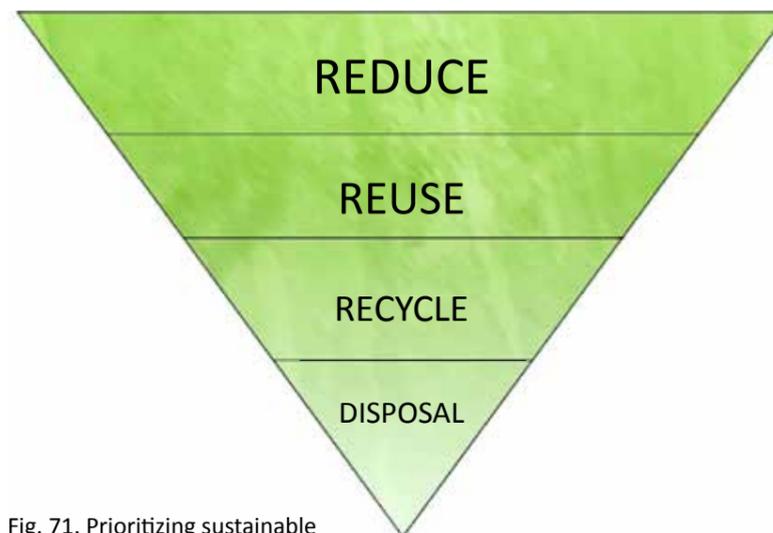


Fig. 71. Prioritizing sustainable

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- Figure 40-41.** Graphs made by the author (2015).

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- Figure 70.** Graph made by the author (2015).
- Figure 71.** Illustration made by the author (2015).

## 9. APPENDIX - Materials and calculations

### Areas for Villa Miatorp:

- Outdoor wall area: 156 m<sup>2</sup> (148,5m<sup>2</sup> with air gap (95%) and 7,5m<sup>2</sup> massive brick wall (5%)) – **45 % of total building envelope**
- Roof area: 153 m<sup>2</sup> (90 m<sup>2</sup> roof between attic and upper floor (59 %), 63 m<sup>2</sup> angled roof upper floor (41 %)) – **44 %**
- Window area: 29 m<sup>2</sup> – **10 %**
- Door area: 4 m<sup>2</sup> – **1 %**
- Total building envelope area: 344 m<sup>2</sup>

### Heat conduction coefficient $\lambda$ :

Ekofiber<sup>1</sup> - 0,041 W/mK  
Perlite<sup>2</sup> - 0,050 W/mK  
Mineral wool<sup>3</sup> - 0,037 W/mK  
Plaster<sup>3</sup> - 1,0 W/mK  
Wood<sup>3</sup> - 0,14 W/mK  
Facade brick<sup>3</sup> - 0,6 W/mK  
Gypsum board<sup>3</sup> - 0,25 W/mK  
Glass<sup>3</sup> - 0,025 W/mK  
Peat<sup>4</sup> – 0,14 W/mK (closest found to “kolstybb”)

### Formula:

Uiso =  $\lambda$ /thickness of the material in meters  
U for layers =  $1/(R_{se}+1/U_{iso}+R_{si})$   
Add  $1/U_{iso}$  for each material layer  
Rse = 0,04  
Rsi = 0,13

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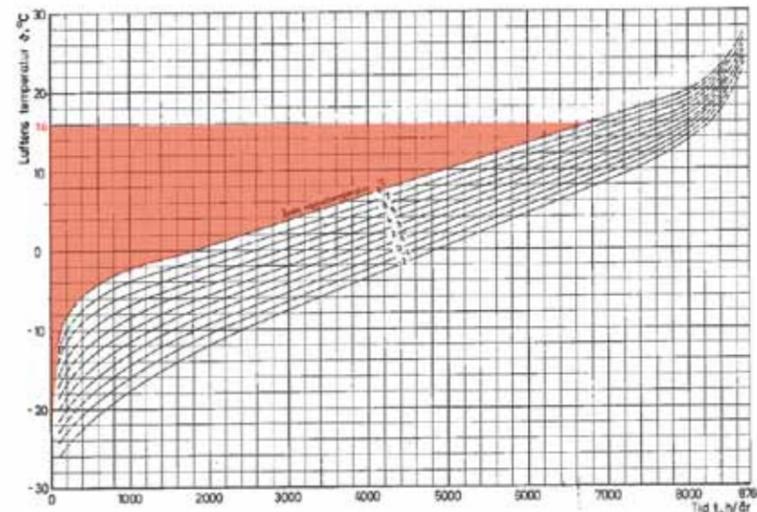


Fig. 72. Degree hours, the average temperature in Helsingborg is 8,3°C. Considering that the building will start getting heated when the outdoor temperature goes below 16 °C. The hours that the building needs to be heated will then be 76000 h per year (colored field).

(Source: Carl Molander, calculation specialist at White Architects)

Total heat losses (including walls, roof, windows and doors): **28007 kWh/year**

- Walls = 724 kWh (massive) + 18509 kWh (air gap) = **19233 kWh** (68 %)
- Roof = 1101 kWh + 1710 kWh = **2811 kWh** (10 %)
- Windows = **5510 kWh** (20 %)
- Doors = **453 kWh** (2 %)

Current U-values of the different parts of the building:

- Walls = 1,27 (massive brick around openings) + 1,64 (with air gap) = Average **1,62**
- Roof = 0,23 (angled) + 0,25 (horizontal) = Average **0,24**
- Windows (including frame) = **2,5**
- Doors = **1,49**

New U-values of the different parts of the building:

- Walls = 1,27 (not changed) + 0,36 (added Perlite) = Average **0,4**
- Roof = 0,1 (angled) + 0,18 (horizontal) = Average **0,13**
- Windows (including frame) = **1,5**
- Doors = **1,49** (Not changed)

## Outer wall

Heat losses wall, massive brick 5% ( $\lambda$ /thickness(m)):

Inside  
 15 Plaster - 66,7  
 120 Brick - 5  
 110 Brick - 5,45  
 120 Brick - 5  
 15 Plaster - 66,7  
 Outside

Total average U-value for wall:

$$1/(0,04 + 1/66,7 + 1/5 + 1/5,45 + 1/5 + 1/66,7 + 0,13) = 1/(0,04 + 0,015 + 0,2 + 0,18 + 0,2 + 0,015 + 0,13) = 1/0,79 = \mathbf{1,27}$$

$$(U\text{-value} * \text{area} * \text{Hours that the building is heated annually}) = 1,27 * 7,5 * 76000 \text{ h}$$

Annually the walls without air gap are leaking **724 kWh**

Heat losses wall, with air gap 95% ( $\lambda$ /thickness(m)):

Inside  
 15 Plaster - 66,7  
 120 Brick - 5  
 110 Air gap -  
 120 Brick - 5  
 15 Plaster - 66,7  
 Outside

Total average U-value for wall:

$$1/(0,04 + 1/66,7 + 1/5 + 1/5 + 1/66,7 + 0,13) = 1/(0,04 + 0,015 + 0,2 + 0,2 + 0,015 + 0,13) = 1/0,61 = \mathbf{1,64}$$

$$(U\text{-value} * \text{area} * \text{Hours that the building is heated annually}) = 1,64 * 148,5 * 76000$$

Annually the walls with air gap are leaking **18509 kWh**

U-values wall total:

Total average U-value for wall:

5 % = 1,27

95 % = 1,64

100 % = 0,064 + 1,56 = **1,62**

724 kWh + 18509 kWh = 19233 kWh

**Annually the walls are leaking 19233 kWh**

## Roof

Heat losses angled roof 41 % ( $\lambda$ /thickness(m)):

Inside

13 Gypsum board - 19,23

2 Vapor barrier -

45 Mineral wool - 0,82

95 Mineral wool - 0,39

25 Masonite board - 5,6

45 Air gap -

22 Wood - 6,36

3 Tar paper -

Roofing tiles -

Outside

Total average U-value for angled roof:

$1/(0,04+1/19,23+1/0,82+1/0,39+1/5,6+1/6,36+0,13)$

$= 1/(0,04+0,052+1,22+2,56+0,18+0,16+0,13)=1/4,34 = \mathbf{0,23}$

(U-value \* area \* Hours that the building is heated annually) =

$0,23 * 63 * 76000 = 1101 \text{ kWh}$

**Annually the roof is leaking 1101 kWh**

Heat losses roof between upper floor and attic 59 %

( $\lambda$ /thickness(m)):

Inside

15 Wood – 9,33

2 Vapor barrier -

95 Mineral wool - 0,39

190 Air gap -

22 Wood - 6,36

120 Peat (Kolstybb) – 1,17

22 Wood – 6,36

Attic

Total average U-value for angled roof:

$1/(0,04+1/9,33+1/0,39+1/6,36 +1/1,17+1/6,36+0,13)$

$= 1/(0,04+0,11+2,56+0,16+0,85+0,16+0,13) = 1/4 = \mathbf{0,25}$

(U-value \* area \* Hours that the building is heated annually) =

$0,25 * 90 * 76000 = 1710 \text{ kWh}$

**Annually the angled roof is leaking 1710 kWh**

U-values roof total:

Total average U-value for wall:

41 % = 0,23

59 % = 0,25

100 % = 0,0943 + 0,1475 = **0,24**

1101 kWh + 1710 kWh = 2811 kWh

**Annually the walls are leaking 2811 kWh**

## Windows & Doors

Heat losses windows including frame

( $\lambda$ /thickness(m)):

10 Big windows (1550x1300mm)

2 Small windows (1300x1300mm)

2 Glass doors (2000x1600mm + 2000x1300mm)

Total window area: **29 m<sup>2</sup>**

1 window total area = 2,015 m<sup>2</sup> = 100 %

120 Wooden frame - 1,17 - 0,21 m<sup>2</sup> = 10 %

55 Wooden mullion - 2,54 - 0,44 m<sup>2</sup> = 22 %

300 Wooden frame - 0,47 - 0,23 m<sup>2</sup> = 12 %

4 Glass pane - 6,25 - 1,128 m<sup>2</sup> = 56 %

Average U-value:

$0,1 \times 1,17 + 0,22 \times 2,54 + 0,12 \times 0,47 + 0,56 \times 6,25$

$= 0,117 + 0,5588 + 0,0564 + 3,5 = 4,232$

$1/(1/4,232+0,04+0,13) = 1/(0,236 +0,17) = 1/0,4 = \mathbf{2,5}$

(U-value \* area \* Hours that the building is heated annually) =

$2,5 * 29 * 76000 = 5510 \text{ kWh}$

**Annually the windows are leaking 5510 kWh**

Heat losses doors ( $\lambda$ /thickness(m)):

2 Wooden doors (2000x1000mm)

Total window area: **4 m<sup>2</sup>**

Inside

70 Wood - 2

Outside

Total average U-value for wall:

$1/(0,04+1/2+0,13) = 1/ 0,67 = \mathbf{1,49}$

(U-value \* area \* Hours that the building is heated annually) =

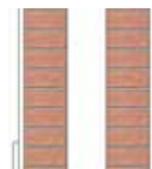
$1,49 * 4 * 76000 = 453 \text{ kWh}$

**Annually the doors are leaking 453 kWh**

## Improvement of Outer walls

By filling the air gap in the brick wall 95 % of the wall can be improved. Perlite has been chosen as the most suitable material for this purpose, since it is cheap, short payback time, healthy, tested material used for more than 50 years and it has good insulation properties, see investigation of materials page 74-78.

- K-value Perlite 0,050 W/mK
- Gives the wall an average U-value of 0,4 instead of 1,62
- Reduces the heat losses through walls with air gap by 78 %
- Reduces the heat losses of the whole building envelope by 52 %
- 148,5 m<sup>2</sup> of the outer wall will be insulated with Perlite. Since the air gap is 0,11 m wide 16,335 m<sup>3</sup> insulation material will be needed.



Current outer wall, 1:20  
No insulation and air gap of 110 mm between the bricks. The bricks are plastered on the outside, both sides.



Proposal outer wall, 1:20  
Added insulation in the air gap. 110 mm Perlite granular insulation between the bricks.

Fig. 73-74.

Heat losses wall (95% of the wall has an air gap which will be filled with Perlite):

Inside

15 Plaster - 66,7

120 Brick - 5

110 Air gap filled with Perlite – 0,05/0,11 = 0,45

120 Brick - 5

15 Plaster - 66,7

Outside

Average U-value for the wall:

$$1/(0,04 + 1/66,7+1/5+1/0,45+1/5+1/66,7+0,13) = 1/(0,04$$

$$0,015+0,2+2,22+0,2+0,015+0,13)= 1/2,8 = 0,36$$

$$(U\text{-value} * \text{area} * \text{Hours that the building is heated annually}) =$$

$$0,36 * 148,5 * 76000 = 4063 \text{ kWh/year}$$

Annually the walls with air gap are leaking 4063 kWh

(reduction by 14446 kWh/year, - 78 %)

New wall total heat losses:

Total average U-value for wall:

$$5 \% = 1,27 \text{ (not changed)}$$

$$95 \% = 0,36$$

$$100 \% = 0,0635 + 0,342 = \mathbf{0,4}$$

$$724 \text{ kWh} + 4063 \text{ kWh} = 4787 \text{ kWh}$$

**Annually the walls are leaking 4789 kWh (-14444 kWh = 52 % reduction of the whole building envelope)**

The walls are clearly in need of improvement by adding insulation. There are three different options:

- The first option is to insulate on the outside of the existing facade and then add an additional facade on top of that. This means a great reduction of cold bridges since the whole wall can be insulated evenly. The thickness of added insulation is also flexible. But doing this means that less sun light will reach the inside. The architectural and historical values of the plastered brick facade will also get lost. This is why insulation on the outside is not an option in this proposal.
- The second alternative is to insulate on the inside which means that the original facade can be kept. But this method is very risky since insulation on the inside of the construction will cool it down which can lead to damages of the bricks due to increased moisture in the walls.

If this was done it would be extremely important not to add too much insulation. Not much would be possible to add if problems want to be avoided. Insulation on the inside also means that some of the living area is used for this purpose. This type of additional insulation will not reduce the main cold bridges in corners, at floor plan joints etc. This option clearly seemed too risky for this specific building.

- The third and last option was to fill the air gap in the wall with insulation. Since the building has a double brick load bearing cavity wall this solution is possible. The air gap is 110 mm wide and recommended width for cavity wall filling is at least 50 mm. This option was clearly the most suitable solution for this building and the option that I chose to work further with.

Multiple materials were investigated to find the most suitable for this building; loose fill insulation such as mineral wool, Ekofiber and glass fiber, granular/bead insulation such as EPS beads, Vermiculite or Perlite and different types of foam. All materials were discussed during a meeting with experts and specialists the 27<sup>th</sup> of April (Suzanne Hansen Architect, Carl Molander Calculation specialist, Anders Ekberg Environmental consultant and Markus Lundborg Energy advisor).

## Improvement of Windows

It was agreed upon that there are many risks with injecting foam in this type of building. Since the foam gets really hard after installation it cannot follow the movement of the building as it expands/shrinks due to changes in weather or temperature. This can result in cracks in the foam which makes it less insulating. A big disadvantage with foam is that it is not possible to remove if something goes wrong or if the result becomes something that was not intended.

Loose cellulose insulation also has its risks when it comes to shrinkage over time which reduces its effectiveness, especially if used as a vertical insulation, for example in walls. It can also be hard to fill the whole air gap. And most cellulose materials are organic or can absorb water which can damage the wall or enable and facilitate mold growth.

In the end it was clear that the best remaining materials would be some kind of bead/granular insulation. The materials that were investigated further were therefore EPS (Polystyrene beads), Vermiculite and Perlite. A throughout investigation of these materials can be found on page 74-78. After the investigation, Perlite was clearly seen as the best motivated material since it had relatively good insulation properties, good sound insulation, inexpensive, a material without health risks for the users and its non-organic properties.

Properties of Expanded Perlite granular insulation:  
K-value: 0,050 W/mK  
Cost: 918: -/m<sup>3</sup>

What kind of insulation is suitable in the outer wall?

- Non-organic since it is a brick wall
- Breathable
- Flexible, should be able to expand/shrink a bit when the building does the same due to temperature changes etc.
- Should be possible to remove if the results are not wanted
- A material with known health effects that does not outgas toxins. Preferably tested and used during many years.
- Resistant to fire, mold, vermin and water.



Fig. 49. Expanded Perlite

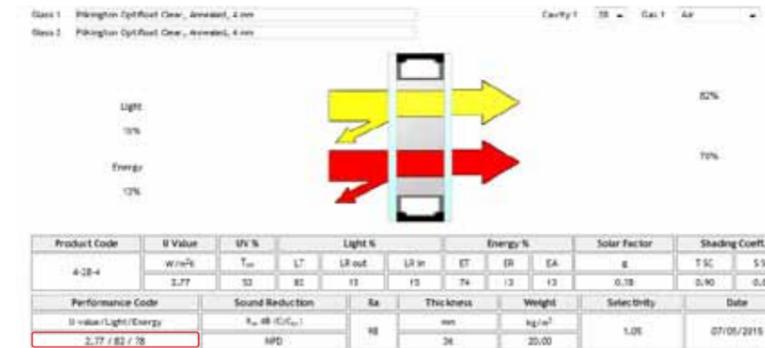


Fig. 75. Calculation from Pilkington Spectrum, 2-pane window. Source: Pilkington Spectrum

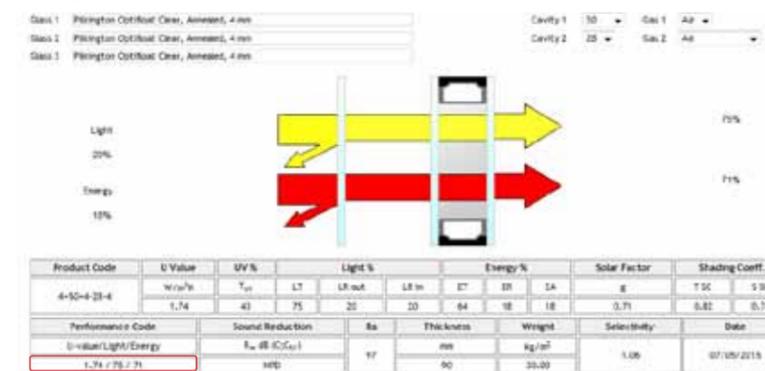


Fig. 76. Calculation from Pilkington Spectrum, 2-pane window + 1 added glass pane. Source: Pilkington Spectrum

When calculating the improvement of the windows the software *Pilkington Spectrum* was used. Similar window types as the current ones in Villa Miatorp was used to calculate the percentage of improvement by adding 1 extra glass pane on the inside.

Replacing all the windows seem unnecessary since they are well functioning and well maintained. It is also very expensive to replace the windows and the payback time is very long since the reduction of the heat losses is not that high.

But to improve the indoor comfort and reduce the draft something should be done with the windows. A decision was made to keep the old nice windows and instead add an extra pane on the inside.

According to Pilkington Spectrum the reduction of the U-value will be from 2,8 to 1,7 (- 40 %), see figure 75-76. The same percentage was then used for calculating the reduction of the window U-value in Villa Miatorp.

(U-value 2,5 - 40 % = new **U-value of 1,5** for window including frame. This gives **annual heat losses of 3306 kWh** instead of 5510 kWh, a **reduction by 2204 kWh (-40%)**)

## Improvement of Roof

The roof is divided in two different types. The first area is the horizontal insulated roof between the upper floor and the attic (90 m<sup>2</sup>). The second area is the angled roof covering the upper floor (63m<sup>2</sup>). The roof is today only leaking 10 % of the whole heat loss, see figure 43 page 35, but after improving the walls the roof will represent 22 % of the heat losses of the building envelope, see figure 44.

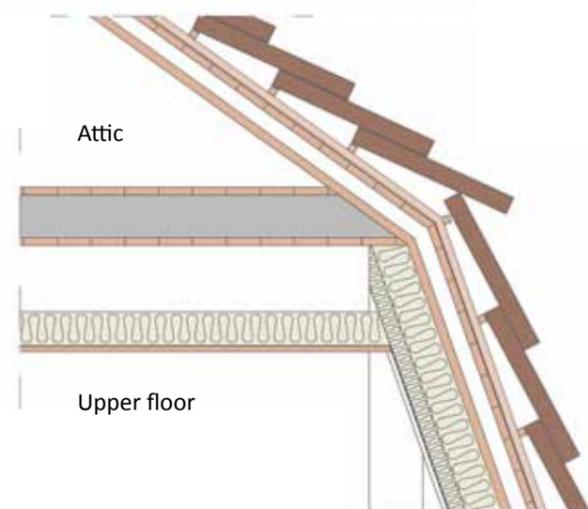


Fig. 45. Current roof section, 1:20

Both parts of the roof can be improved without too big changes. The angled roof can easily be improved by adding 45 mm mineral wool on the inside.

The horizontal roof can be improved by filling the current void with Ekofiber, see figure 77, and another addition could be to replace the old "Kolstybb" insulation with Ekofiber as well, see figure 46. In my proposal I have chosen the last one, see figure 46.

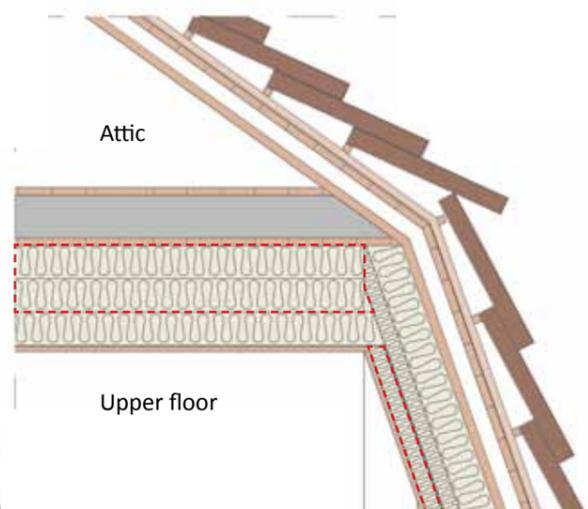


Fig. 77. Alternative roof (+ 190 mm Ekofiber in horizontal roof and + 45 mm mineral wool in angled roof), 1:20

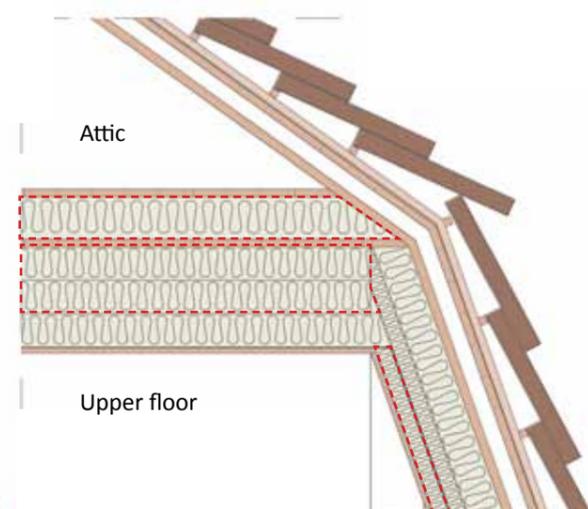


Fig. 46. Improved roof (replacing old kolstybb insulation with 120 mm Ekobiber + 190 mm Ekofiber in horizontal roof and + 45 mm mineral wool in angled roof), 1:20

Heat losses angled roof 41 % ( $\lambda$ /thickness(m)):

Inside  
 13 Gypsum board - 19,23  
 45 Mineral wool - 0,82 (Added)  
 2 Vapor barrier -  
 45 Mineral wool - 0,82  
 95 Mineral wool - 0,39  
 25 Masonite board - 5,6  
 45 Air gap -  
 22 Wood - 6,36  
 3 Tar paper -  
 Roofing tiles -  
 Outside

Total average U-value for angled roof:

$$1/(0,04+1/19,23+1/0,82+1/0,82+1/0,39+1/5,6+1/6,36+0,13)$$

$$= 1/(0,04+0,052+1,22+1,22+2,56+0,18+0,16+0,13)=1/5,6 = \mathbf{0,18}$$

(U-value \* area \* Hours that the building is heated annually) =  
 0,18 \* 63 \* 76000 = 862 kWh

**Annually the roof is leaking 862 kWh (-239 kWh = 22 % reduction of the heat losses through angled roof)**

Heat losses horizontal roof between upper floor and attic 59 % ( $\lambda$ /thickness(m)):

Inside  
 15 Wood – 9,33  
 2 Vapor barrier -  
 95 Mineral wool - 0,82  
 190 Air gap filled with Ekofiber - 0,22  
 22 Wood - 6,36  
 120 "Kolstybb" replaced with Ekofiber - 0,34  
 22 Wood – 6,36  
 Attic

Total average U-value for angled roof:

$$1/(0,04+1/9,33+1/0,82+1/0,22+1/6,36 +1/0,34+1/6,36+0,13)$$

$$= 1/(0,04+0,11+1,22+4,54+0,16+2,94+0,16+0,13) = 1/9,3 = \mathbf{0,1}$$

(U-value \* area \* Hours that the building is heated annually) =  
 0,1 \* 90 \* 76000 = 684 kWh

**Annually the angled roof is leaking 684 kWh (-1026 kWh = 60 % reduction of the heat losses through horizontal roof)**

New roof, total heat loss:

Total average U-value for wall:  
 41 % = 0,18  
 59 % = 0,1  
 100 % = 0,0738 + 0,059 = **0,13**  
 862 kWh + 684 kWh = 1546 kWh

**Annually the walls are leaking 1546 kWh (reduction by 45 % of the roof)**

## Material investigation

The purpose of the material investigation is to compare different materials which are seen to be the most suitable for filling the air gap in a brick wall to improve the building envelope of Villa Miatorp. The materials which are compared were seen as the most interesting materials at the meeting at White in Gothenburg the 27<sup>th</sup> of April 2015 and were therefore chosen to be investigated further.

Further investigation of following materials:

- EPS (Expanded polystyrene beads)
- Vermiculite granular insulation
- Perlite granular insulation

Following factors are investigated and compared:

- The function (Heat conductivity, installation, maintenance)
- Risks for the users (toxins, fumes)
- Risks for the building (water, fire, vermin)
- Embodied energy (Carbon released through the whole lifecycle of the material)
- Cost and payback time

Summary:

The embodied energy (EE) of the EPS is 186 % higher than the already existing mineral wool insulation in the building. The EE of Vermiculite and Perlite has a wide range but the average value for Vermiculite is 8 % higher and Perlite is 80 % higher than mineral wool. Since the range of Vermiculite is much less

than Perlite, Vermiculite can be seen as a more reliable material when it comes to lowest EE.

Since the EPS has many disadvantages when it comes to depletion and pollution risks, very high EE, melting and outgassing toxic fumes in case of fire and difficulties to recycle, it can be considered as not an option. The remaining minerals have very similar properties when it comes to heat conductivity (Vermiculite 0,063 W/mK and Perlite 0,050 W/mK), fire and moisture resistance (Thorpe, 2010).

The biggest disadvantage with Vermiculite is that there is a chance of containing asbestos, depending on where it was mined. But most of the vermiculite in the currently operating vermiculite mines is not in the risk zone. Perlite on the other hand is a known tested material without any health risks. It neither contains any asbestos (InspectApedia).

The cost of the materials is practically the same except the cost for the Vermiculite which is more than 200 % higher compared with the others, see figure 80.

To make it easier to understand the differences a well-known material (mineral wool) was also compared, even though this material is not suitable for cavity filling in this building, see figure 78.

Since the weight and density of the materials differs the information was recalculated into MJ/m<sup>3</sup>. Then the EE of the exact volume that was needed for the different materials could be compared. As mentioned in the calculations of the wall 95% of the wall has an air gap which will be filled. This represents 16,335 m<sup>3</sup> (148,5m<sup>2</sup> outer wall x 0,11 m air gap width = 16,335 m<sup>3</sup>). The graph 80-81 are based on the specific house Villa Miatorp and the EE of the materials that would be needed to fill the whole air gap.

Fig. 78 (upper right). A comparison of the Embodied energy (EE) [MJ/kg] of the three chosen materials.

Fig. 79 (lower right). A comparison of (EE) [MJ/m<sup>3</sup>] of the materials. For Vermiculite and Perlite the EE was varying (blue is the minimum EE and red is the maximum) depending on varying size of the minerals and therefore different density depending on the batch.

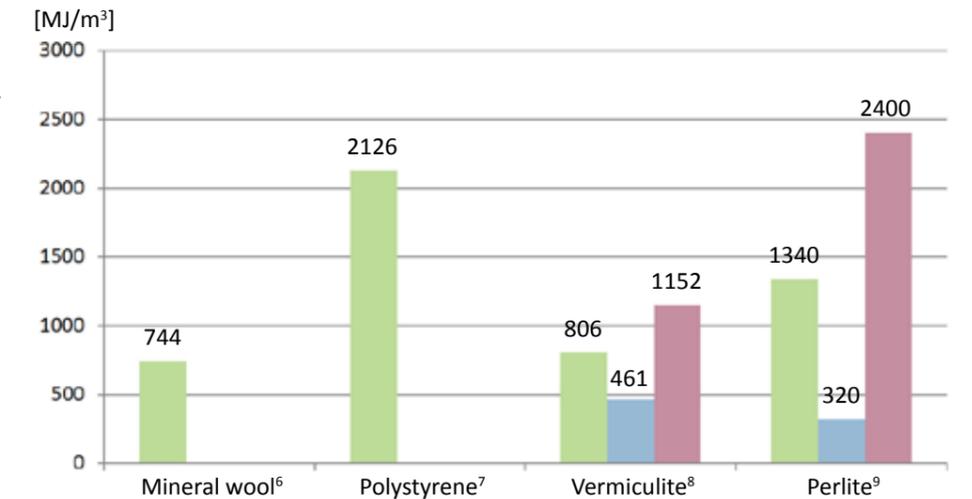
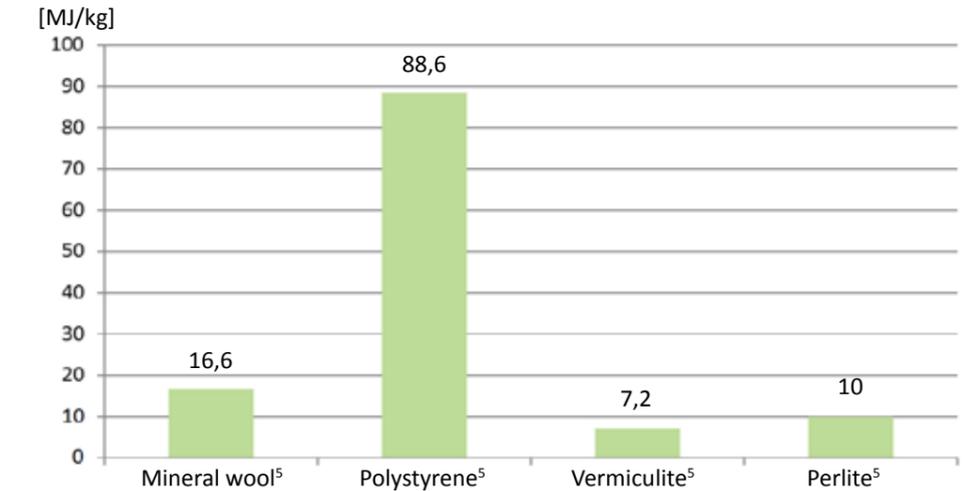
5. Hammond & Jones, (2011). *Inventory of Carbon & Energy (ICE)*. Version 2.0a. Online at: <http://web.mit.edu/2.813/www/readings/ICEv2.pdf.old> (Acc 07.05.15)

6. FSI, Fabrication specialties Inc, n.d. *Density of Roxul (2,8 pcf) used in the calculation*. At: <http://www.fabricationspecialties.com/materials/mw/> (Acc 07.05.15)

7. The engineering toolbox, n.d. *Density for Polystyrene expanded beads*. At: [http://www.engineeringtoolbox.com/density-materials-d\\_1652.html](http://www.engineeringtoolbox.com/density-materials-d_1652.html) (Acc 07.05.15)

8. INPRO - Engineered mineral solutions, n.d. *Density range of Vermiculite*. At: <http://www.perlite.co.nz/vermiculite/> (Acc 07.05.15)

9. Blue pacific minerals, n.d. *Density range of Perlite*. At: <http://www.bpmnz.com/perlite/> (Acc 07.05.15)



The cost of the materials was compared but not including the installation cost and shipping (this was considered as almost the same investment since the installation process of the materials is estimated to be similar).

The cost is almost the same for all the materials, except the Vermiculite which is about three times higher. Since the heat conductivity of the materials is almost the same as well it leads to a much longer payback time of the Vermiculite, almost five years, compared with the other materials which have a payback time of between one and two years.

#### Heat Conductivity of the materials:

- Today only air gap in 95 % of the wall, gives U-value 1,64
- Mineral wool: 0,037 W/mK<sup>3</sup>, gives U-value 0,28
- EPS Polystyrene beads: 0,040 W/mK<sup>10</sup>, gives U-value 0,29
- Vermiculite: 0,063 W/mK<sup>2</sup>, gives U-value 0,42
- Perlite: 0,050 W/mK<sup>2</sup>, gives U-value 0,36

10. National Insulation Association, n.d. *Heat conductivity of EPS beads*. At: <http://www.nia-uk.org/consumer/understanding-insulation/cavity-wall-insulation/with-eps-beads/> (Acc 07.05.15)  
 11. Byggmax, n.d. *Cost of mineral wool/kg*. At: <https://www.byggmax.se/isolering/mineralull/isoleringssulle-p16006> (Acc 07.05.15)  
 12. Foamerica, n.d. *Cost of EPS Polystyrene beads*. At: <http://www.foamerica.com/ProductDetails.asp?ProductCode=VIRGIN9> (Acc 07.05.15)  
 13. Bradford building supplies, n.d. *Cost of Vermiculite/100Ltr*. At: <http://www.bradfords.co.uk/details/vermiculite-insulation> (Acc 07.05.15)  
 14. Hometown Perlite, n.d. *Cost of Expanded Perlite*. At: [http://www.hometownperlite.com/Masonry\\_fill\\_details.html](http://www.hometownperlite.com/Masonry_fill_details.html) (Acc 07.05.15)

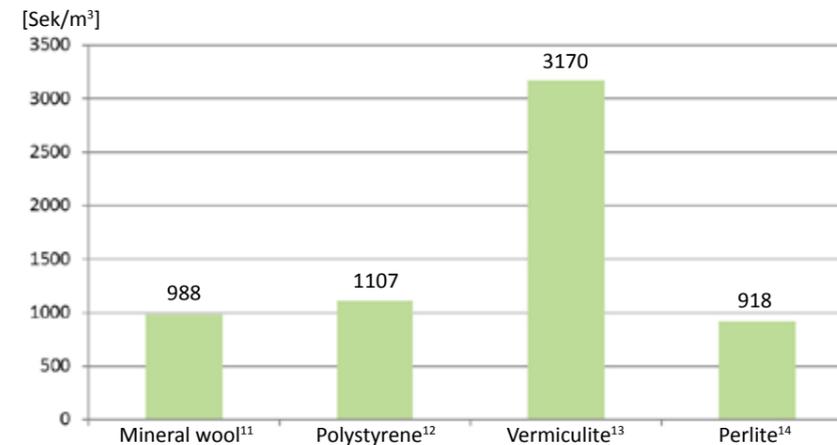


Fig. 80. A comparison of the cost of filling the cavity with the three materials.

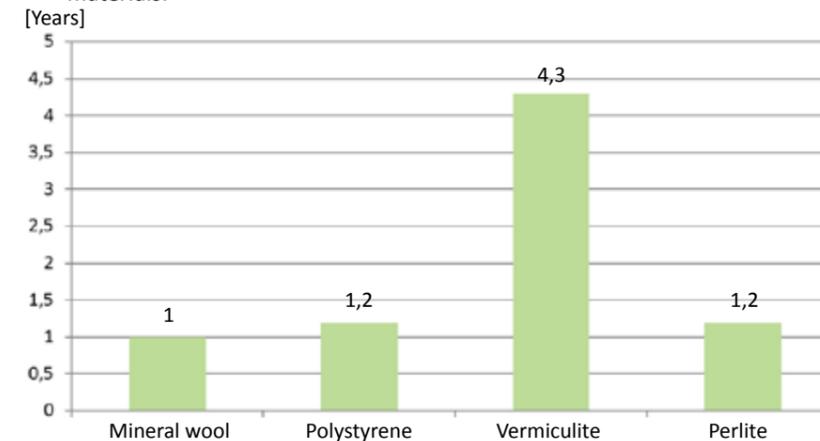


Fig. 81. A comparison of the payback time of the materials based on how much they reduce the heat losses and the average cost/kWh for the months september-april (2014-2015) given from the owners.

	Mineral wool	EPS Polystyrene beads	Vermiculite	Perlite
Function	$\lambda = 0,037 \text{ W/mK}^3$	$\lambda = 0,040 \text{ W/mK}^{10}$	$\lambda = 0,063 \text{ W/mK}^2$	$\lambda = 0,050 \text{ W/mK}^2$ Very similar to Vermiculite <sup>2</sup>
Risk sfor users	-	Protective gear needed during installation <sup>15</sup> Creating toxic fumes when burned <sup>15</sup>	Can contain asbestos <sup>16</sup>	None Can work as nuisance dust for the workers, as for similar processes of other minerals <sup>17</sup>
Risks for building	-	Melting in case of fire <sup>15</sup> Non-breathable, not recommended for old breathable buildings <sup>15</sup>	None	None
EE MJ/m³ & Lifecycle	744 MJ/m³	2126 MJ/m³ Contributing to pollutants and resource depletion, plastics <sup>15</sup>	806 (461-1152) MJ/m³ Non-renewable, mined <sup>2</sup>	1340 (320-2400) MJ/m³ Less than 1% of the reserve has been used during the past 60 years
Cost & Payback time	988:-/ m³ Payback time 1,3 years, see figure 80-81.	1107:-/ m³ Payback time 1,48 years, see figure 80-81.	3170:-/ m³ Payback time 4,68 years, see figure 80-81.	918:-/ m³ Payback time 1,27 years, see figure 80-81.

2. Thorpe, D. (2010) *Sustainable home refurbishment; The Earthscan Expert Guide to Retrofitting Homes for Efficiency*. New York: Earthscan.  
 Online version at: [https://books.google.se/books/about/Sustainable\\_Home\\_Refurbishment.html?hl=sv&id=3kLLZBKa5zAC](https://books.google.se/books/about/Sustainable_Home_Refurbishment.html?hl=sv&id=3kLLZBKa5zAC) (Acc 07.05.15)  
 3. *Jernkontorets energihandbok*. At: <http://www.energihandbok.se/konstanter/varmeledningsformaga-och-u-varden-for-olika-material> (Acc 07.05.15)

15. Sustainable Building Resouce. *Comparison between conventional insulations*. At: [http://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&cad=rja&uact=8&ved=0CGMQFjAH&url=http%3A%2F%2Fwww.sustainablebuildingresouce.co.uk%2Ffileserve%2Ffileserve%2F1778%2F32c17545f56ee4a6cbbf004377cba1283c2ed84%2F&ei=E\\_VBVZ\\_ZH6WfygOwt4CQAw&usg=AFQjCNEzDq-6L\\_yaJPobBgie2PKM\\_tgZjA&sig2=8YjS2ePxV4XMqf4EkZ0tw](http://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&cad=rja&uact=8&ved=0CGMQFjAH&url=http%3A%2F%2Fwww.sustainablebuildingresouce.co.uk%2Ffileserve%2Ffileserve%2F1778%2F32c17545f56ee4a6cbbf004377cba1283c2ed84%2F&ei=E_VBVZ_ZH6WfygOwt4CQAw&usg=AFQjCNEzDq-6L_yaJPobBgie2PKM_tgZjA&sig2=8YjS2ePxV4XMqf4EkZ0tw) (Acc 07.05.15)  
 16. InspectApedia, n.d. *Vermiculite*. At: [http://inspectapedia.com/insulation/Vermiculite\\_Insulation.php](http://inspectapedia.com/insulation/Vermiculite_Insulation.php) (Acc 07.05.15)  
 17. The Perlite Institution, n.d. [Website] At: <https://perlite.org/industry/insulation-perlite.html> (Acc 07.05.15)

## REFERENCES - Appendix Graphs and Illustrations

After the investigation it was clear what kind of material to use. Perlite was clearly the best alternative because it does not have that many disadvantages compared with the other materials. It also seemed to be the most sustainable alternative in the big picture since it is naturally occurring and has no health risks for the users, two parameters that are highly valued in my definition of what a sustainable villa is. Perlite is also inexpensive and will reduce the heat loss almost as much as the mineral wool and the EPS would, see figure 82.

Ekofiber which is recycled and impregnated newsprint will be used as additional insulation in the horizontal roof between the attic and the upper floor. The reason for choosing this material is that it has properties that are well suitable for that location, the conditions are also suitable for this material. It is recycled which means less use of material and it is renewable.

### Useful websites:

- Converter: [www.convertworld.com/en/density/Pound+per+cubic+foot.html](http://www.convertworld.com/en/density/Pound+per+cubic+foot.html)
- Engineering toolbox: <http://www.engineeringtoolbox.com>
- Pilkington Spectrum: [http://spectrum.pilkington.com/?country\\_code=SV](http://spectrum.pilkington.com/?country_code=SV)

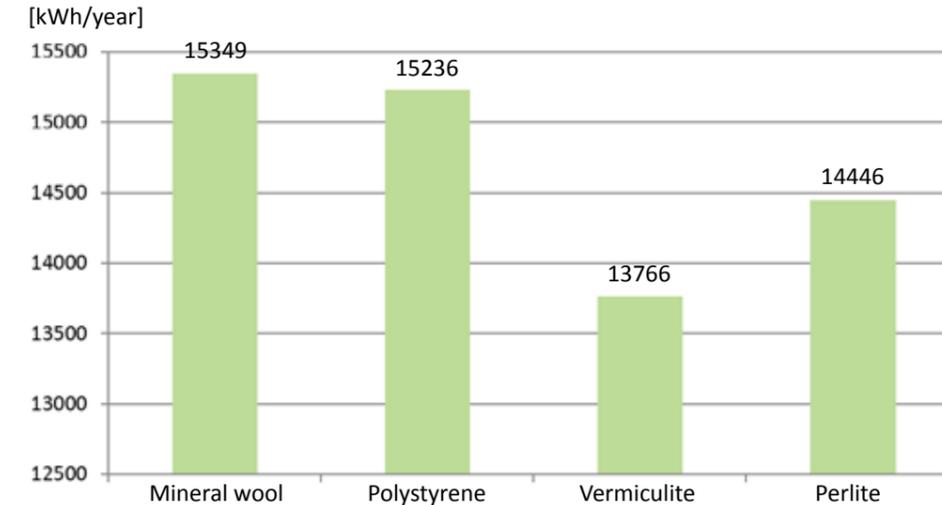


Fig. 82. A comparison of the Heat loss reduction per year (the higher the better).

**Figure 72.** Graphs of "Gradtimmer". From Carl Molander, n.d.

**Figure 73-74.** Section drawings of Villa Miatorp made by the author. (2015)

**Figure 75.** Calculation of a 2 pane window. At: [http://spectrum.pilkington.com/?country\\_code=SV](http://spectrum.pilkington.com/?country_code=SV)

**Figure 76.** Calculation of a 2 pane window with added glass pane. At: [http://spectrum.pilkington.com/?country\\_code=SV](http://spectrum.pilkington.com/?country_code=SV)

**Figure 77.** Section drawings of Villa Miatorp made by the author. (2015)

**Figure 78-82.** Graphs related to Villa Miatorp made by the author. (2015)



My wish is that this thesis was interesting for you as a reader and that it gave you some new ideas and inspiration. I also hope it will contribute to an increased interest in sustainable villa improvements, both for active architects and for architect students.

Do you have any questions regarding the thesis? Or are you just interested in the subject and want to share ideas? Then you are most welcome to contact me.

Best regards  
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