Zeeshaun Sheikh

Design of a Near Zero Energy Tiny House in Finland - Case Minitalo

Metropolia University of Applied Sciences

Bachelor of Engineering

Sustainable Building Engineering

Thesis

31 May 2018

Metropolia

Author Title Number of Pages Date	Zeeshaun Sheikh Design of a Near Zero Energy Tiny House in Finland - Case Minitalo 31 pages + 32 appendices 31 May 2018
Degree	Bachelor of Engineering
Degree Programme	Civil Engineering
Professional Major	Sustainable Building Engineering
Instructors	Sergio Rossi, Senior Lecturer

The objective of this thesis was to produce a conceptual design of a near zero energy tiny house in Finland. Although near zero energy buildings exist in Finland, tiny houses were a relatively new concept. The purpose was to combine the two concepts to achieve an overall sustainability and ecological objective.

Firstly, the concept of a near zero energy building was established to understand the design approach and technologies used. Next the concept of a tiny house was explored and real life cases were studied for both concepts.

Finally an ongoing tiny house project in Helsinki called Minitalo was utilized as a model for the design. An energy simulation was performed on three versions of the model. A benchmark model was made to find the annual space and domestic hot water heating, electricity demand and load of a small residential house in Finland. Followed by three planned models created according to the architect's design with energy supplied from three different sources. Finally a modified model with improvisations to the building envelope of the planned model was made. The results showed the purchased and primary energy demand for each model and when it has achieved the near zero energy status. The thesis can be a design guide for future near zero energy small residential buildings.

Keywords	near zero energy buildings, tiny house, passive house, sustainability, low energy house, minimalist, small house

Metropolia

Contents

1 Introduction

Global warming and climate change are issues that have been discussed extensively in the last decade. However, there have been some controversies lately concerning this issue. Most scientists in the field have provided ample evidence proving the process and warned that the rate we are consuming non-renewable resources, such as fossil fuels, threaten the existence of the flora and fauna, the ecosystem and even the existence of us, human beings. (Union of Concerned Scientists, 2018.) Some politicians, on the other hand, believe that neither climate change nor global warming are a threat, or even occurring. (The Guardian, 2018.) Nonetheless, many people seem to agree that intelligent management and minimization of the usage of non-renewable resources would be wise.

The question is where to begin when discussing intelligent management and minimisation of non-renewable resources. The easiest and most obvious solution is to replace the reliance on non-renewable resources with renewable ones Ψ. While the renewable energy production industry has been growing exponentially in the last decade, it is still not readily available and very costly for most countries. (European Environment Agency, 2017.) As a result non-renewable sources are still widely used and due to this there has to be more intelligent management on energy consumption. (Union of Concerned Scientists, 2017.) Therefore, increasing renewable energy production while decreasing and minimizing reliance and the usage of non-renewable sources would be wise.

According to the Energy Performance of Buildings Directive (EPBD) released by the European Union, buildings consume about 40% of the total energy consumption and 36% of CO_2 emissions in the EU. (Energy efficiency of buildings 2018.) With such a substantial amount of energy being used for buildings, efforts to greatly minimise consumption of energy as much as possible are necessary.

An initiative would be to design better buildings to increase their energy performance. However, factors such as thermal comfort and indoor air quality should not be compromised when designing better performing buildings. Building design and planning have improved tremendously and with new developing building technologies and materials, the potential to design and build even better buildings in the future is growing and this could potentially minimize a big portion of the usage of non-renewable energy.

Besides the technical aspects, social aspects could also potentially minimize energy usage significantly. One such social aspect is the tiny house movement. The movement, also inspired by the minimalist movement, advocates building and living in tiny houses to minimize and reduce an individual's carbon footprint to be more ecological. Recent economic circumstances also helped spark the movement but a majority of the people in the movement is just looking for a greener and more sustainable lifestyle. (The tiny life, 2018.)

In chapter 2 the concept of near zero energy buildings is explained from the design aspects to the technologies and systems. A case study of a Near Zero Energy (NZE) house in Finland is explored to study the practicality and application of the concept. In chapter 3, the idea and motivation behind tiny houses is described. A case study to understand the motivation of the owners of the tiny houses is discussed. In the fourth chapter, the concept of designing a near zero energy tiny house is explored and explained. Following that, a planned tiny house called the Minitalo is used as a model for the design of a near zero energy tiny house. Three versions of the model are created and energy simulations are performed with the software IDA ICE to calculate the purchased and primary energy demand. Finally the results of the simulations are introduced and discussed in the final chapter.

2 Near Zero Energy Buildings

2.1 The Passive House Standard and Low Energy Buildings

Before discussing the topic of near zero energy buildings, first the concept of low energy buildings needs to be explored. One of the earliest concepts of low energy buildings is the Passivhaus standard which began in May 1988 when a research project was started by Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the Institut für Wohnen und Umwelt (Institute for Housing and the Environment, Germany). The Passive house institute states that a passive house is “a building standard that is truly energy efficient, comfortable and yet affordable at the same time”. (Feist, 2018.)

The evaluation criteria for a residential building to be certified a passive house are a heating demand or total cooling demand (in climates that require cooling) of 15 kWh/(m²a) or less or, alternatively, a heating load and a cooling load of 10 W/(m²) or less. A renewable primary energy demand (Passive house classic) for heating, cooling, hot water, auxiliary electricity, domestic and common areas electricity of 60 kWh/(m²a) or less. An air tightness pressure test result number n_{50} of 0.6 h^{-1} or less and thermal comfort must be met and not more than 10% of the hours in a year must the temperature be more than 25 degrees Celsius. (Feist, 2018.)

The first pilot project for a passive house is the Kranichstein passive house, Darmstadt, Germany, built in 1990. It was Europe’s first inhabited multi-family house to achieve a documented heating energy consumption of below 10 kWh/(m²a), a consumption level confirmed through years of detailed monitoring. (Feist, 2018.) According to the European Environment Agency, the average household’s energy consumption for space heating in 2010 in Europe was 125 kWh/(m²a) (European Environment Agency, 2010.) A Passive house design clearly reduces the space heating energy consumption as established from the Kranichstein case it reduced almost 90 percent of the average energy consumption.

Other low energy houses and standards in Europe besides the passive house are the Niedrigenergiehaus in Germany with an energy demand of 50 kWh/(m²a) for space heating. (Oekologisch-Bauen, 2018.) In Switzerland, the Minergie standard has an energy requirement of 42 kWh/(m²a) for space heating and the Minergie-P that is equivalent to the passive house standard. (Minergie, 2018.) In comparison, the passive house standard clearly has the most stringent requirement and therefore aptly named as an ultra-low energy standard. In the United States, a program called Energy Star is the largest low energy house program. Houses consuming at least 15% less energy than standard new homes are awarded the energy star certificate. (Energy Star, 2018.)

Another way that low energy houses may reduce the consumption of energy is by using low energy equipment and home appliances such as LED light bulbs, washing machines and driers with ecolabel certification that consume less energy to operate. These equipment and appliances are usually more costly than the typical equipment and appliances with lower energy rating. However, in the long term they are more economical as they reduce the overall energy consumption.

Table 1 below lists the design features such as the building envelope material composition, window type and the heat recovery ventilation system of the house. (Feist, 2018.)

Table 1. Design features of the Kranichstein Passive House (Feist, 2018).

Building component	Description	U-value W/(m²K)
Roof	Grass roof: Humus, non-woven filter, root protective membrane, 50mm formaldehyde-free chip board; Wooden light-weight beam (I-beam of wood, stud link of hardboard), counter lathing, sealing with polyethylene sheeting bonded without jointing, gypsum plasterboard 12.5 mm, wood-chip wallpaper, emulsion paint coating, entire cavity (445 mm) filled with blown-in mineral wool insulation.	0.1
Exterior wall	Fabric reinforced mineral render; 275 mm of expanded polystyrene insulation (EPS) (installed in two layers at that time, 150+125 mm); 175 mm sand-lime brick masonry; 15 mm continuous interior gypsum plastering; wood-chip wallpaper, emulsion paint coating	0.14
Basement ceiling	Surface finish on fiberglass fabric; 250 mm polystyrene insulation boards; 160 mm concrete; 40 mm polystyrene acoustic insulation; 50 mm cement floor finish; 8-15 mm of parquet, adhesive; sealing solvent-free	0.13
Windows	Triple-pane low-e glazing with Krypton filling: U_g-value 0.7 W/(m²K). Wooden window with polyurethane foam insulated framework (CO2-foamed, HCFC free, handcrafted)	0.7
Heat recovery ventilation	Counter flow air-to-air heat exchanger; Located in the cellar (approx. 9°C in the winter), carefully sealed and thermally insulated, the first one to use electronically commutated DC fans.	heat recovery rate approx. 80%

Passive houses generally cost more than typical new houses of similar design and attributes. However the added cost of a passive house means that the house is more valuable and in the long term is more economical as it reduces annual energy usage for space heating. The key to achieving the passive house status is good planning during the design process. (Feist;Pfluger;Kah;& Kaufman, 2013.)

2.2 Net and Near Zero Energy Building Comparison

While a passive house's main objective is to lower the energy demand, its goal is not to be totally independent of non-renewable resources. Even though passive houses consume very little energy they may still consume energy from a non-renewable source. Net zero energy buildings on the other hand are designed with low energy house standards, such as the passive house. In addition the energy demand for heating, cooling, ventilation, domestic hot water and electricity are supplied from a renewable source either produced on site or supplied from the grid. (World Green Building Council, 2018.) In a nutshell, they are high performing buildings that utilize building physics concepts, material science knowledge and renewable resources technologies. In comparison, they are similar to a hybrid electric car that is powered by electricity from both renewable sources such as solar and non-renewable sources such as petrol in an effort to reduce the usage of the latter.

Location and climate are two important factors in the design of a net zero energy building. Finland's climate poses some challenges for the design of such buildings as the long winters demand more energy for heating and the little sunlight is a challenge for the production of renewable energy, such as solar photovoltaic panels. On the other hand, if a building is designed to compensate this, it might pose a problem during the summer since the thick thermal insulation may cause overheating. According to the EU's EPBD released, all new buildings in the EU must be nearly zero-energy buildings by 31 December 2020. (European commision, 2018.) However, no clear or specific primary energy requirements of a building was mentioned for it be considered a near zero energy building.

2.3 Design Aspects and Technical Systems

Designing a near zero energy house encompasses aspects of a low energy house coupled with renewable energy production systems. The first aspect typically looked into is the building envelope and its thermal capacity and resistance. Building material such as concrete for example has a higher thermal mass compared to timber. (Concrete Thinking, 2018.) Thermal mass is a material's ability to store or retain heat and could be compared to a battery in a sense that it has the ability to store heat during the day and release it at night. This may be useful as the building material can provide some heating at night from the releasing of the heat.

Low energy houses require thermal insulation. The use of appropriate insulating material with appropriate thickness is the key to providing good thermal resistance to the envelope. Common insulation materials used are soft insulation, such as mineral wool, or more rigid insulation, such as Extruded Polystyrene Insulation (XPS) or Expanded Polystyrene insulation (EPS). These materials have a high thermal resistance or R-value, which is calculated by multiplying the thickness of the material by the thermal conductivity or the lambda value (λ). To find the overall heat transfer coefficient of the building element, or the U-value, formula (1) below is used. (Feist;Pfluger;Kah;& Kaufman, 2013.) The thermal conductivity for the insulation material ranges from 0.028 to 0.045 W/m·K The choice of the insulation material depends on the combination of the building structure, construction material, desired thermal performance and the budget. Equation (1) below shows how the U-value of a building element is calculated from the passive house-planning package (PHPP). (Feist, 2018.)

$$\mathrm{U} = \frac{1}{\mathrm{Rsi} + \mathrm{R1} + \mathrm{R2} + \cdots + \mathrm{Rn} + \mathrm{Rse}} \qquad (1)$$

R_{si} is the thermal resistance at interior surfaces in compliance with ISO 6946.
R_{se} is the thermal resistance at exterior surfaces in compliance with ISO 6946.
R_1-R_n are the thermal resistance of individual construction layers, 1 - n.

Once the U-value of the building element is determined the thermal loss of the building has to be determined to find the heat loss rate. Equation (2) on the nxt page is used to determine the thermal loss of the building envelope from the National Building Code of Finland, regulations and guideline for energy efficiency D3. (National Building Code of Finland, 2012.)

Airtightness, or preventing air from leaking out from or into the house is another key factor in the design of a low energy building. This is because the heated air escapes through gaps, holes, cracks and other openings. Therefore the more airtight the building is the better it is for heat preservation. High quality workmanship during the building phase or installation of windows is important to ensure good airtightness of the building. In addition, the use of a water vapor barrier or an air barrier in the building envelope increases the airtightness.

$$\sum \text{Hder} = \sum(\text{U external wall x A external wall}) + \sum(\text{U upper wall x A upper wall}) + \sum(\text{U base floor x A base floor}) + \sum(\text{U window x A window}) + \sum(\text{U door x A door}) \quad (2)$$

ΣH_{der} is the total sum of the specific thermal loss of the building component, W/K
U is the thermal transmittance coefficient of the building component, W/(m^2K)
A is the area of the building component, m^2.

To measure the airtightness of a house, a pressurization or a blower door test could be performed with a 50 Pa pressure difference between the interior and exterior of the building. The test gives the n_{50} number, which indicates the percentage of air change per hour (1/h) of the building. The passive house requirement for n_{50} is 0.6 1/h. Equation (3) below from the passive house designer manual is used to find the n_{50} rate. (Hopfe & McLeod, 2015)

$$\text{n50} = \frac{\text{V50}}{\text{Vn50}} \quad (3)$$

n_{50} is the number of air changes per hour at a pressure differential of 50 Pa (h^{-1}),
v_{50} is the mean volumetric air flow at a pressure differential of +/- 50 Pa (m^3/h),
v_{n50} is the net air volume within the building (as defined by BS EN 13829:2001 and PHI) (m^3).

If a house is airtight, it could affect the indoor air quality. If the ventilation is not designed or sized well, the result can be poor indoor air quality. Near zero energy (NZE) houses equipped with a mechanical ventilation system with a heat exchanger would provide an airtight building with sufficient amount of supply air into the house, and efficiently extract the exhaust air while providing thermal comfort. The electricity consumption for most systems with such combinations is usually quite low. Therefore, the decision to install a mechanical ventilation system in an airtight NZE house would be optimum. (Wolfgang Feist, 2013.)

According to the low energy house design guide to achieve the status of a near zero energy building, the energy demand of the house must be supplied with the maximum amount of renewable resources. The most common systems utilized by single family houses to generate renewable energy are a photovoltaic solar panel system, a solar thermal system, a geothermal heat pump system, an air to air/water heat pump system and a wind turbine system. Technically, the choice of system depends on factors such as location, climate and ground condition. However, there are also other factors, for example economic considerations and government policies that could affect the decision. (World Green Building Council, 2018.)

2.4 Near Zero Energy Houses in Finland

Lanttitalo, which literally translates as ‘coin house’, named for its energy saving ability. It is a near zero energy house that was built in 2012 in Tampere, Finland.

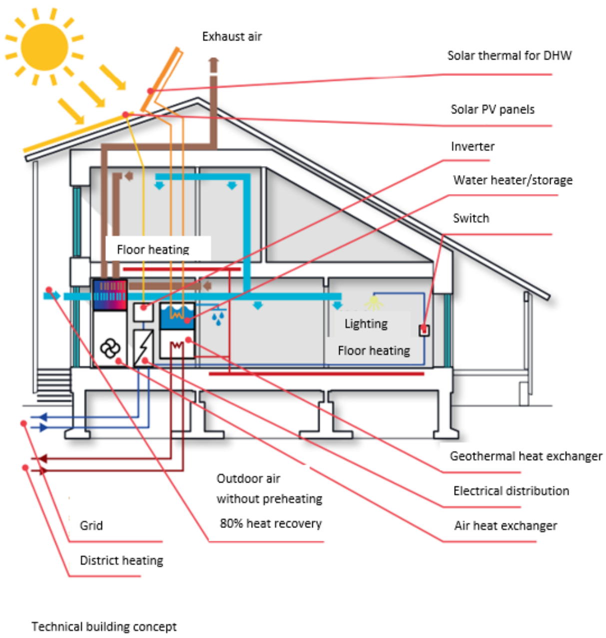


Figure 1. Lanttitalo technical building concept (Lanttitalo, 2018).

It was a joint development project between Sitra, an independent public foundation for research and development, ARA, a housing finance and development center, TA-Yhtymä Oy, a company in the real estate business, construction and housing sector, and Aalto University. Lanttitalo has an energy rating or E value of -1, which means it produces a little more energy than it consumes annually. Therefore, it is a positive energy house rather than a near zero one. It is a wooden detached house with 2 stories and designed to have 4-5 rooms depending on the layout. It also has a kitchen, a sauna, a green garden and a living area of 139 m². Figure 1 below shows the technical solutions of the Lanttitalo. (Lanttitalo, 2018.)

Lanttitalo is powered by solar energy over the summer while in the winter it is heated with district heat and electricity. The energy efficiency of the house is based on careful design and implementation. The house is well insulated, has high heating efficiency and a ventilation system with low electricity consumption.

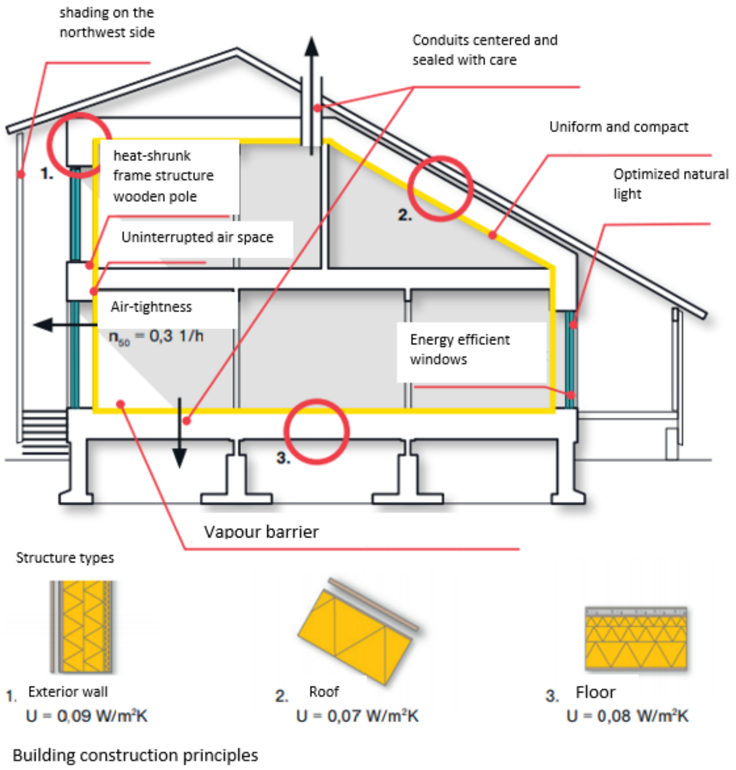


Figure 2. Lanttitalo building envelope (Lanttitalo, 2018).

Figure 2 above shows Lanttitalo's building envelope details. The heating of the house is produced by solar heat collectors and electricity produced by solar photovoltaic panels. Geothermal heat pumps were considered for the heating of the house and it would have provided a lower E value. However, it would have been considerably more expensive than district heating and a less costly investment decision had to be made. (Lanttitalo, 2018.)

The space heating in Lanttitalo is supplied by district heating combined with locally produced solar energy that is distributed to room-specific floor heating. It has 8m^2 of solar thermal collectors, producing 40 percent of the domestic hot water with the balance supplied by district heating. In addition, it has 60 m^2 of efficient solar photovoltaic panels. The design is compact and the thermal insulation consists of 450 mm thick insulation in the walls and 510 mm in the floor and roof. Lanttitalo is built with an airtightness of n_{50} = 0.3 1/h and avoids of cold bridges. (Lanttitalo, 2018.)

The windows of Lanttitalo are the best available in the market with a U value of 0.7 W / m^{2}K. The orientation of the windows is placed specifically so that the utilization of natural light is maximized without causing overheating indoors. The house has a ventilation unit with rotary heat recovery exchanger and an annual efficiency of 80%. Most of the lighting use LED light bulbs and, additionally, the house is equipped with energy-efficient appliances and machines. It also boasts automatic sensor detection switches that reduce the energy consumption to a minimum when the house is vacant. (Lanttitalo, 2018.)

The consumption of energy is monitored in real time. The system measures the energy yield and total consumption by device group, i.e. how much energy goes into ventilation, household appliances, plugs, and lighting. The measurement system has a good user interface to make it easier for non-technical individuals to understand the system. In addition to consumption, the room temperature, the moisture values of the structures and the movement of air in the ventilation modes are measured. (Lanttitalo, 2018.)

3 Tiny House

3.1 Sustainability of a Tiny House

Besides a technical solution to build more ecological houses, such as the near zero energy house described in the previous chapter, a solution from the social aspect called the tiny house movement, also known as the small house movement is another ecological solution. The movement is predominant in North America although it is starting to gain momentum in Europe with central European countries such as Germany, Netherlands, Belgium and the UK taking the lead. The growth is generally slower in Europe due to more stricter and more stringent building regulations and laws. (The tiny life, 2018.)

The movement started in the late 90’s and early 2000’s, mainly because the members wanted a lifestyle that is more environmentally friendly and ecological through a smaller carbon footprint. The minimalist movement, a movement that advocates owning less possessions and having a much simpler lifestyle in order to let individuals have more time and freedom, has also inspired the tiny house movement. The financial crisis and economic downturn in the USA in the last decade that caused major problems, such as homeowners defaulting on their mortgages and some even becoming homeless, spurred the movement as it is a more affordable lifestyle. Figure 3 below shows an example of a tiny house that is mobile called "Acacia” in Quebec, Canada. (The tiny life, 2018.)

Figure 3. Mobile tiny house called "Acacia” in Quebec, Canada (The tiny life, 2018).

No clear definition on the dimensions of a tiny house has been stated. However, most tiny houses range of between 20 m^2 to 50 m^2. There are numerous versions of tiny houses with many different features. Some are built in a permanent location while some are placed on a trailer, making the house mobile. A tiny mobile house is an interesting concept, giving one the flexibility to move whenever and wherever one chooses to. There are of course numerous challenges associated with a mobile home such as electricity and water supplies, but at the rate of technological advancement today, solutions to these challenges are surely found in the near future.

At the moment if one chooses to have a nomadic lifestyle, the options are to find a place to live at every place or buying and living in a recreational vehicle (RV). This may not be the most ecological nor the most economical solution. There is a gap in the market to provide people choosing a nomadic lifestyle with a good quality home that is mobile. Figure 4 lists some facts about the tiny house movement. (The tiny life, 2018.)

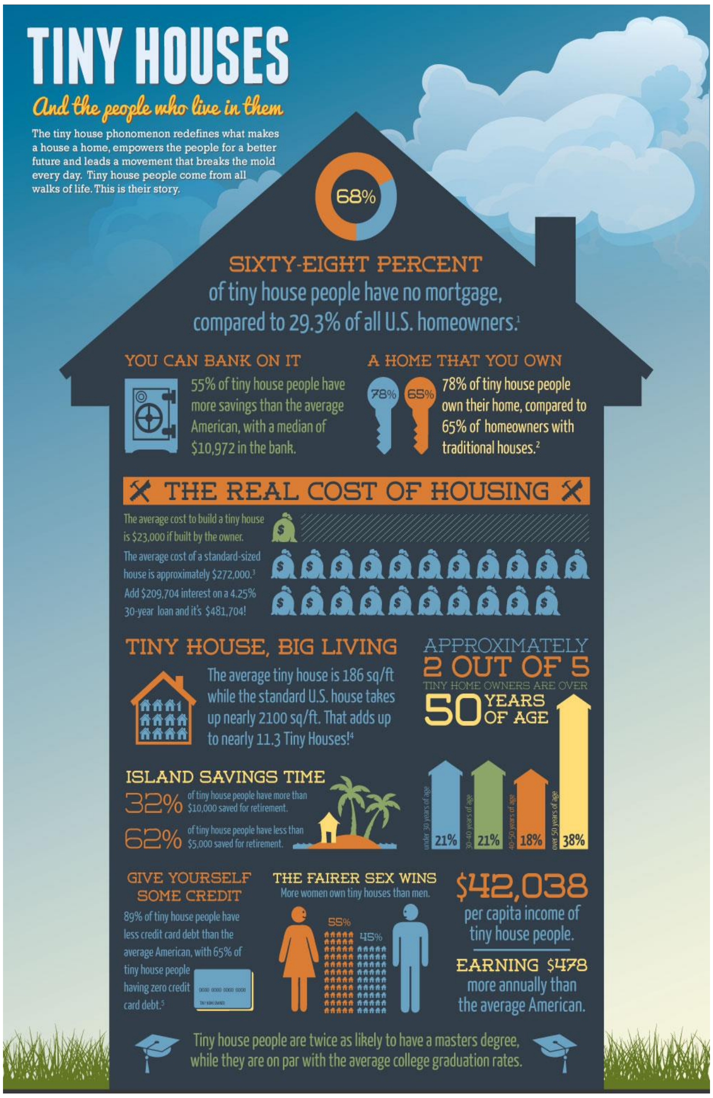


Figure 4. Facts about tiny house (The tiny life, 2018).

According the website thetinylife.com, “For most Americans about half of their income is dedicated to the roof over their heads; this translates to 15 years of working over their lifetime just to pay for it, and because of it 76% of Americans are living paycheck to paycheck”. A tiny house potentially prevents the above from happening as it is much cheaper therefore freeing home owners from such a huge financial burden. As the world’s population is growing, and cities getting more crowded with high rise buildings, tiny houses also pose a solution to this problem. With the mobile houses, owners could move to a better location as soon as the current location is not suitable. (The tiny life, 2018.)

3.2 Tiny Houses in Finland

Tiny houses in Finland are mostly holiday homes and summer cottages. Tiny houses have recently been built for permanent and year-round occupation, inspired by the tiny house movement. One such example is a moveable 15m^2 tiny house that was built by its owner Henri Lokki. The house only costs € 5,000 to build and the project lasted two years, six of which were construction days. All material used in the house is ecological. For example, sheep wool was used for insulation and the rest of the material is mainly recycled. Electricity is supplied from the grid, but in the summer a solar thermal system provides a portion of the heating demand. Although this might be suitable for a single person, it might not be suitable for a family to live in. Figure 5 below shows Lokki and his house (Rasi, 2017.)

Figure 5. Henri Lokki and his 15m^2 tiny house (Rasi, 2017).

An example of a tiny house made for a family in Finland is called “Minitalo” or mini house by a Helsinki-based architecture company Arkkitehtuuritoimisto oy. It is a detached single family tiny house with two versions of the Minitalo: a high and a low model. The high version has a total height of 6.38m and the low house is almost 5m high. However, they both have the same length and width for the building envelope. The price range for the Minitalo starts from € 78,187 to € 106,911 which is at least 50% less than the cost of a typical single-family house in Finland. Figure 6 shows a 3D rendered image of the higher model of the Minitalo. (Arkkitehtuuritoimisto oy, 2018.)

Figure 6. 3D render of Minitalo (Aito Arkkitehtuuritoimisto oy, 2018).

Every Minitalo is prefabricated in a factory and transported to the plot when completed. The floor plans, sections and details can be found in appendix (1). The houses also come in different finishes and layouts. The first Minitalo to be built is in the planning stages and set to be built before the end of 2018. (Aito arkkitehtuuritoimisto oy, 2018.)

4 Design of a Near Zero Energy Tiny House

4.1 Compactness Ratio

Combining the technical aspects of minimizing the usage of non-renewable energy, such as building a near zero energy house, and the social aspect of building a tiny house might seem counterproductive. A large near zero energy house would have a lower heat loss rate while the heat loss rate of a tiny house is much higher. (Burrell, 2015.) However, a tiny house reduces the usage of building materials and energy demand. The idea of a near zero energy tiny house is based on finding a balance between these two factors.

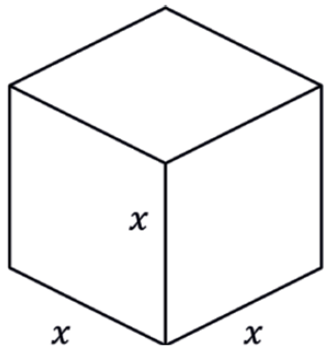
The biggest challenge for a tiny house is the high heat loss rate when compared to a larger sized house. The high heat loss rate is the result of the smaller surface area compared to a larger house. In the passivhaus designer manual, it is explained as the compactness ratio or the surface area to volume ratio (SA/V). Houses with similar U-values, window areas and orientations still feature very different heating and cooling demands simply due to the higher SA/V ratio of a smaller house. Figure 8 below shows the mathematical demonstration and the different ratios of building types. (Hopfe & McLeod, 2015.)

This can be demonstrated mathematically by considering the SA/V equation for a cube (equation 1).

$$S/AV_{cube} = \frac{6x^2}{x^3} = \frac{6}{x} \quad [1]$$

where:

S/AV_{cube} is the surface area to volume ratio of a perfect cube (regular hexahedron), and
x is the length of one side of the cube (m).
Thus it can be seen that the larger the dimension (x), the smaller the SA/V ratio.



3.2
Surface area to volume ratio of a compact cube form

Figure 7. Mathematical demonstration of the SA/V ratio (Hopfe & McLeod, 2015).

Multi-story buildings have SA/V ratios from 0.7 to about 0.3 while small single-story buildings such as a single-family house has a ratio from 0.7 m^{-1} to 1 m^{-1}. According to the manual, “a SA/V ratio of 0.7 m^{-1} for a small domestic dwelling may is approaching the upper limit beyond which in a Central European climate may become uneconomic (or incur additional costs) in order to comply with the Passivhaus standard”. (Hopfe & McLeod, 2015.)

In this thesis, SA/V ratios between a new typical sized single-family house in Finland with a floor area of 120 m^2 and a tiny house with a floor area of 42 m^2 both with a wall height of 2.7 m were calculated and compared for analysis. The larger house had a SA/V ratio of 1.26 m^{-1} while the tiny house’s ratio increased by 20% to 1.51 m^{-1}. The detailed calculations can be found in Appendix (2). Figure 8 below shows an illustration of different building variants and their SA/V ratios.

According to Elrond Burrell, an architect, passive house designer and director of VIA architecture based in New Zealand a similar indicator to the surface are to volume (SA/V) ratio is the heat loss form (HLF) factor which is the ratio of the surface area to the treated floor area (SA/TFA). (Burrell, 2015.)

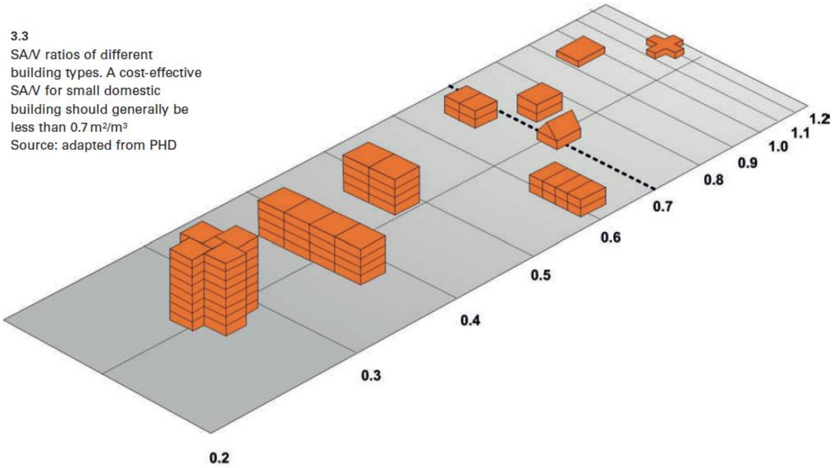


Figure 8. SA/V Ratios of different building types (Hopfe & McLeod, 2015).

It is mainly used to compare the compactness of building with different shapes and forms that have the same treated floor area (TFA). The HLF factor is generally between 0.5 and 5 with a lower number indicating a more compact building.

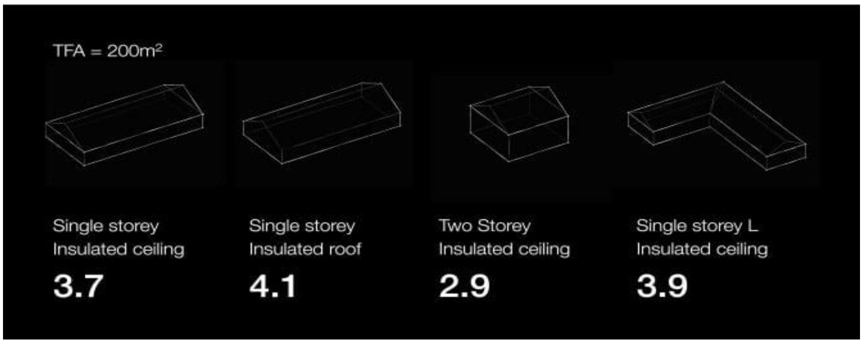


Figure 9. Heat loss form factor of different building variants illustration (Burrell, 2015).

Passive house buildings should aim to achieve a HLF factor of 3 or less. Figure 9 above compares buildings with the same TFA but with different heat loss form factors. (Burrell, 2015.)

The thesis made a similar comparison as to the surface area to volume (SA/V) ratio for the heat loss form (HLF) factor. In this case, the HLF for two tiny houses models with similar shapes but different number of stories were calculated. The first model has a single story and the second model has two stories but both having the same treated floor area (TFA) of 42 m^2. The calculations established that the single-story house had a HLF factor of 4.09 while the two-story house has a factor of 4.86. Evidently, a single-story house is the better choice in terms of the rate of heat loss, due to the lower HLF factor. Detailed calculations can be found in Appendix (2).

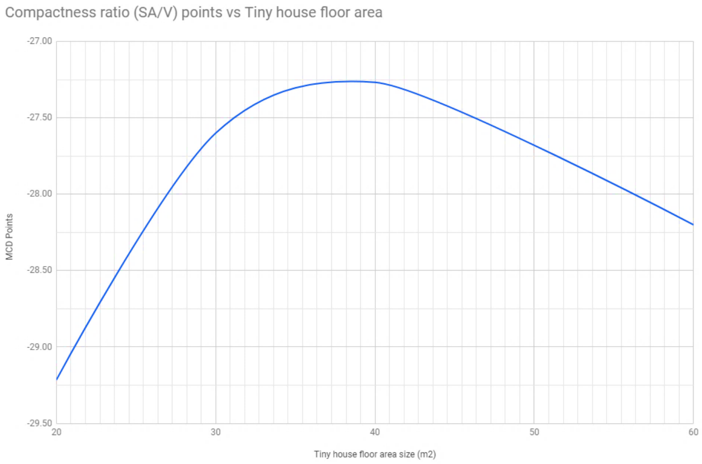


Figure 10. Compactness ratio points vs. tiny house floor area.

Finding the optimum floor area size and building variant would minimize the possibility of heat losses in a tiny house. The goal in doing these calculations for various houses is to find a balance between designing a house with a floor area big enough so that it would not require too much energy for space heating and a floor area small enough to save on building material. The total energy consumption of a well-designed tiny house would still be considerably smaller compared to a much larger house on an absolute level.

To find the optimum treated floor area (TFA) for tiny houses, this thesis analysed the surface area to volume (SA/V) ratio and fixed TFA area of a tiny house by creating a multi-criteria decision based on a points system. The TFA closest to zero MCD points was found to be the optimum floor area. Detailed calculations can be found in Appendix (2). From figure 10 above, based on the results of the analysis for tiny houses with a maximum size of 60 m^2, the TFA closest to zero MCD points or the optimum TFA was from 37 - 40 m^2.

4.2 Case study: Minitalo

This thesis used the Minitalo project mentioned in the previous chapter as a model for the design of a near zero energy tiny house in Finland. Architect Maria Klemetz and client Janne Kilpinen were contacted and kindly agreed to cooperate. The house is planned to be built on Vienankatu 10, east Helsinki. The ‘High’ model with 2 floors and a floor area of 44 m^2 was chosen to be built. Mr. Kilpinen had purchased two units, A and B in which A is for himself to live in while the other he plans to sell. The construction of house A is planned to begin late 2018 while house B is planned to be built in 2019. Mr. Kilpinen was interviews about his decision to live in a tiny house. His objective for purchasing the Minitalo was to lower his overall carbon footprint and live a more ecological lifestyle by minimizing his living space. (Kilpinen, 2018.)

The Minitalo was not designed to be neither a passive nor a near zero energy house. Therefore, energy simulations were preformed to calculate the energy demand. Energy simulation software IDA ICE from company EQUA was used to calculate the energy demand for all the models. However, before the models were made the first factor that was considered was the shape of the house.

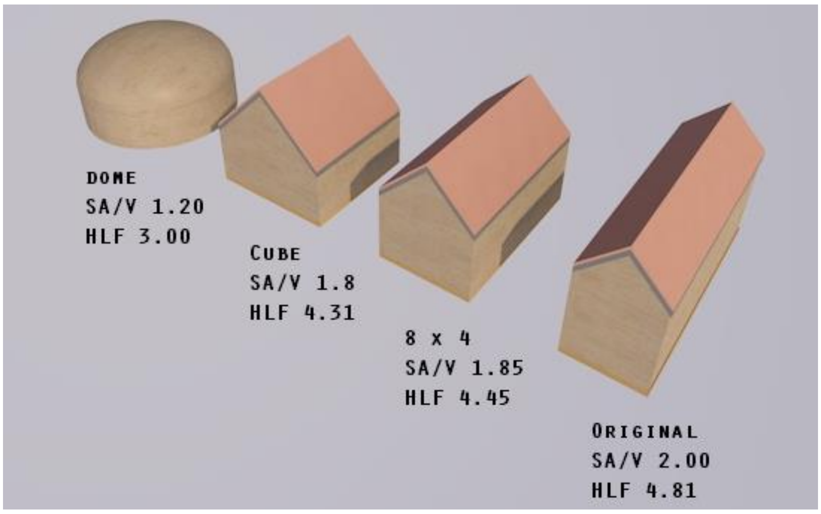


Figure 11. Different building variants of the Minitalo.

The rectangular shape of the Minitalo has a surface area to volume (SA/V) ratio of 2.0. The ratio could be improved if the shape was more compact i.e. more like a cube. Three different building variants iterations of the house were made to calculate and analyse the SA/V ratio. Figure 11 above shows the different variants of the Minitalo made and their

SA/V ratios and heat loss form factors. Detailed calculations can be found in Appendix (2). From the model iterations, the dome shaped was established to have the best SA/V ratio of 1.20, which is a 40 % decrease from the original. This information was suggested to the architect as it improves the heat loss factor by a significant amount. However, the architect's reason for the rectangular shape of the Minitalo was transportability. Since it is prefabricated in a factory and transported to the site by a trailer, for the ease of logistics it has to be that particular size and shape.

5 Simulation Models

5.1 Benchmark Model

The benchmark model was created to calculate the purchased energy, primary energy for heating and electricity demand for a new house in Finland built in accordance to the rules and guidelines for energy efficiency of buildings from the national building code of Finland, D3. (National Building Code of Finland, 2012.) The results for the benchmark model was then compared to the planned models and the modified model.

$$\mathrm{qv, air\ leakage} = \frac{\mathrm{q50}}{3600 \cdot \mathrm{x}} \mathrm{A} \qquad (4)$$

q_{50} is the air leakage number of the building shell, $m^3/(hm^2)$
A is the surface area of the building shell (including floor), m^2
X is the factor, which is: 35 for one-story buildings; 24 for two-story buildings; 20 for three-story buildings and four-story buildings and 15 for five-story buildings or higher
3600: factor which converts air flow from unit m^3/h to unit m^3/s.

The first feature of the benchmark model that was explored was the air-tightness. A typical air leakage number, q_{50}, for a small house, 2.0 h^{-1} was designated to the benchmark model.

Equation (4) above from the national building code of Finland, D3 was used to find the air leakage flow $q_{v,\ air\ leakage}$ (m^3/h) which gave a result of 0.083 m^3/h for the benchmark model. (National Building Code of Finland, 2012.)

The models were created in energy simulation software IDA ICE with the Finnish localisation standards applied. Table 2 below lists the building components and details for the benchmark model.

Table 2. Details, features and results for the benchmark model.

Minitalo details	**Description**	**Version**
		Benchmark
Space heating	Source	District heat (0.94)
Technology	Type	Ideal heater
Domestic water	Source	District heat (0.94)
Electricity	Source	Grid
Ventilation	Type	Mechanical
Flow rate (m3/h)	Value	0.083
Heat recovery efficiency	Value	55%
External Walls	U-value (W/m2K) from Finnish Building Code, D3	0.17
Roof		0.09
Floor		0.17
Windows		1.00
Building shell air leakage number, q50	Value	2.0

Purchased energy is the amount of energy the house requires to purchase and the primary energy is the amount of the energy the source or the plant needs to produce. The models were simulated over a period of one year to attain an annually based report. Table 3 below shows the benchmark model's energy demand results from the IDA ICE software simulation. The detailed IDA ICE report can be found in Appendix (4).

Table 3. Results for the energy demand of the benchmark model.

RESULTS		
Overheating	Value	10 %
Purchased energy	Total (kWh)	10,505.00
	kWh/m2	177.40
Primary energy	Total (kWh)	9,265.00
	kWh/m2	156.50

The IDA ICE report shows a total annual purchased energy demand of 177 kWh/m^2 and a primary energy demand of 156 kWh/m^2 which was below the E value of 204 kWh/(m^{2}a) specified in the national building code, D3, for a small separate house with a net area of under 120 m^2. (National Building Code of Finland, 2012.)

Figure 12 below shows the E values required for different buildings from the regulations and guidelines for energy efficiency of Buildings from the National Building Code of Finland.

The E values of a new building must not exceed the following values (kWh/(m^2a)):

Class 1	Separate small house	204 when $A_{net} < 120\ m^2$
		$372 - 1.4 \cdot A_{net}$ when $120\ m^2 \leq A_{net} \leq 150\ m^2$ and
		$173 - 0.074 \cdot A_{net}$ when $150\ m^2 \leq A_{net} \leq 600\ m^2$ and
		130 when $A_{netto} > 600\ m^2$

Figure 12. Energy efficiency requirements of a small house from D3 national building code of Finland (National Building Code of Finland, 2012).

Since the energy demand results of the benchmark model it satisfies the energy requirements of the regulations and guidelines for energy efficiency of the National Building Code of Finland, it was considered as a reliable model to be used as a benchmark model to compare the planned models and modified models of the Minitalo.

5.2 Planned Model for Minitalo

The planned model was created according to the architect’s design. However, the space heating (SH) and domestic hot water (DHW) systems for the Minitalo were not planned by the architect. Therefore, three versions of the planned model with different energy sources for SH and DHW were created to analyse the energy demands for each version. The first planned model was designed with a district heat source. The second model was designed with an electricity source from the grid for SH and DHW energy. In addition, an on-site solar photovoltaic panels system generating renewable energy to offset the electricity usage from the grid was also included. The third model was designed with an air to water heat pump with also an on-site solar photovoltaic panels system to offset the electricity usage from the grid.

All three planned models had improved windows, thermal insulation and build workmanship compared to the benchmark model. Therefore, an improved airtightness of the building envelope, q50, value of 1.0 $m^3/(h.m^2)$ was assigned to all the planned models.

To find the appropriate supply and extract airflow rate for the Minitalo, the Finnvac guide for dimensioning the ventilation of residential buildings in Finland was used. (FINVAC ry, 2017.) The Minitalo has a treated floor area of 44m^2 on the architect's floor plan. However, the area on the second floor of the Minitalo where the pitched roof causes the height to be less than 1.6 meters, was not considered as treated floor area and not included in the floor area.

Table 4. Minimum dwelling air flow rate during normal operation (FINVAC ry, 2017).

Pinta-ala m^2	Ulkoilmavirta dm^3/s					
	1 ah	2 ah	3 ah	4 ah	5 ah	6 ah
20	18					
30	18					
40	18	20				
50	18	20				
60		21	28			
70		25	28			
80		28	28	36		
100			35	36	44	
120			42	42	44	52
150				53	53	53

However, from the space heating perspective, these areas still required heating. Therefore, with that in consideration the total floor area of the Minitalo used for the simulation was 53 m^2 instead of 44 m^2. From table 4 above of the Finvac guide, the outdoor air flow rate for a house with a floor area between 50 m^2 and 60 m^2, and 2 bedrooms is 21 dm^3/s (l/s).

Table 5. Calculations of new ventilation airflow rates for Minitalo.

Minitalo new ventilation flow rates			
Area	**Exhaust air (l/s)**	**Area**	**Supply air (l/s)**
Kitchen	8	Living room	8
Toilet	10	Bedroom 1	6
Technical room	3	Bedroom 2	7
Total	**21**		**21**

The previous flow rates as designed by the HVAC engineer for the Minitalo was 38 l/s for supply air and 40 l/s for exhaust which is clearly oversized for such a small house.

With the new flow rates found above, the supply and exhaust air flowrates of individual rooms were assigned and listed in table 5 above. Typically, bedrooms are designed with a supply air flowrate of 6 l/s per person. However, a lower supply air flowrate was assigned for both the bedrooms in the Minitalo since they do not have internal dividing walls that would be a barrier to the supply air flow.

For the ventilation system, the HVAC engineer had chosen an exhaust air heat pump unit, Nilan, model: VPL 15 TC. The VPL 15 TC unit is not only an air handling unit for the ventilation but also provides heat generation by using the fan to extract air from inside the building. However, the recommended floor area of a building for the VPL 15 TC unit to be used is between 80 m^2 - 190 m^2. Those values are more than double the floor area of the Minitalo which is 44 m^2.

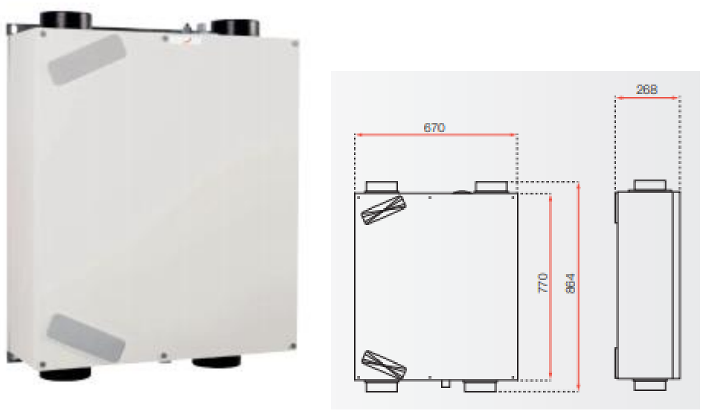


Figure 13. Zehnder ComfoAir 160 air handling unit.

Therefore, The VPL 15 TC unit was considered to be oversized and was not the optimum unit to be used in the Minitalo model. Therefore, a more suitable ventilation air-handling unit was found to replace the VPL 15 TC unit. Figure 13 above shows a photo and dimensions of the Zehnder, ComfoAir 160 unit.

A ventilation unit from German company Zehnder, model: ComfoAir 160 was chosen to replace the Nilan, VPL 15 TC unit. The ComfoAir 160 unit has the three selectable levels of air flowrates between 32 m^3/h (9 l/s) and 160 m^3/h (44 l/s) which makes it suitable for the new flow rates calculated for the house which was 21 l/s. The ComfoAir 160 unit has heat exchanger with a maximum heat recovery rate of 95 %. However, a heat recovery rate of only 85% was used for all the models.

With an air leakage number, q50 of 1.0 $m^3/(h.m^2)$ for the planned model, the infiltration flowrate was calculated using equation (4) which resulted with a value of 0.042 $m^3/(h.m^2)$. Table 6 below is a summary of the building components, technical equipment for all three planned models. All three models were designed with underfloor heating in the bathroom.

Table 6. Details and features for all planned models.

Building service	Description	Version
		Planned
Space heating (floor)	Source	1. District heating 2. Electric 3. Air to water heat pump
Technology		Underfloor heating
Domestic water		1. District heating 2. Electric 3. Air to water heat pump
Electricity		1. Grid 2. Solar PV + Grid 3. Solar PV + Grid
Ventilation	Type	Mechanical
Infiltration flow rate ($m^3/h.m^2$)	Value	0.042
Heat recovery efficiency	Value	85%
External Walls	U-value (W/m2K)	0,15
Roof		0,09
Floor		0,09
Windows		0,64
Building shell air leakage number, q50	Value	1.0

In addition to the floor heating system for space heating, an open flue wood stove from manufacturer Spatherm, model Paso L had been planned to be installed by the architect was included in the planned model. A detailed product information for the wood stove can be found in Appendix (3).

Figure 19 on the next page shows a photo of the Spatherm, Paso L wood stove. (Spatherm, 2018.) As the heating response time for floor heating is slower than other types of space heating, such as water radiators, the wood stove provides a much faster and more responsive heating for the house whenever required. The Paso L has a nomimal heat output of 6.1 kW and 80 % efficiency and has an A+ energy rating.

Figure 14. Open flue wood stove from manufacturer (Spatherm, 2018).

Since the wood supply in Finland is abundant, the wood stove was considered as a sustainable source of heating and would not contribute as a non-renewable source for the space heating of the Minitalo.

5.2.1 District Heating Source for the Planned Model

The first version the source of energy for space heating and domestic hot water was supplied by district heating. The software IDA ICE had an efficiency value for district heating of 0.94 and was used for the calculation for the energy demand for this model.

However, the minimum heat energy that district heating provides could be too much for the Minitalo as district heating is designed for a much larger house. Therefore, district heating as a source of heating for such a small house such as the Minitalo would be impractical. However, the results from the simulation are just used as a reference in this case to be compared to the other planned model results. Table 7 below lists the results of the simulation.

Table 7. The results for the district heating source for the planned model

RESULTS		
Overheating	Value	12 %
Purchased energy	Total (kWh)	7,935.00
	kWh/m2	134.00
Primary energy	Total (kWh)	7464.00
	kWh/m2	126.10

The results for the district heating showed that the planned model had a lower energy demand than the benchmark model. Since cooling was designed for the model, there was slight overheating of 12 % for the Minitalo. However, since the overheating amount was not high, it was not a critical issue and not regarded in the thesis.

5.2.2 Electric and Solar Photovoltaic System for the Planned Model

The second planned model was designed with a fully electric system. The space heating and domestic hot water energy demand was supplied by electricity from the grid. The software IDA ICE had an efficiency value for electricity of 1.0 and was used for the calculation for the energy demand for this model. Table 8 below lists the results for the electricity source.

Table 8. The results for the electricity source for the planned model

RESULTS		
Overheating	Value	12 %
Purchased energy	Total (kWh)	7,573.00
	kWh/m2	84.40
Primary energy	Total (kWh)	12,875.00
	kWh/m2	143.50

A solar photovoltaic (PV) panel system, to generate electricity to offset the usage from the grid, was included in this model. The solar PV system was installed at a 45-degree angle on the south facing side of the roof. A total of 13 panels, connected in series to make 1 string was designed. The solar PV system requires a total area of 20 m^2 and the roof has an area of 26 m^2 so there was abundant space for the solar PV system to be installed. The system provides the house with its annual electricity demand of 10 kWh per day. A detailed list of the technical equipment for the solar PV system can be found in Appendix (3).

The results for the all-electric model show that while the purchased energy has decreased, the primary energy demand increased. Since no cooling was designed for the model as well, there was a slight overheating of 12 % which will not be regarded as critical for the thesis.

5.2.3 Heat Pump and Solar Photovoltaic System for the Planned Model

The third and final planned model was the planned model with an air to water heat pump system for space heating and domestic hot water.

Figure 15. Viessmann Vitocal 222-S heat pump indoor and outdoor unit (Viessmann, 2018).

For this model an air to water heat pump system from manufacturer Viessmann, model Vitocal 222-S was chosen. (Viessmann, 2018.) Figure 15 above shows the indoor unit and outdoor unit of the heat pump.

The software IDA ICE had an efficiency value for heat pumps of 3.5, which was used for the calculation for the energy demand for this model.
This was an improved version of the planned model as heat pumps are more efficient in providing the space heating and domestic hot water demand.

Table 9 below shows the results for the heat pump source.

Table 9. The results for the heat pump source for the planned model.

RESULTS		
Overheating	Value	12 %
Purchased energy	Total (kWh)	3516.00
	kWh/m2	59.5
Primary energy	Total (kWh)	1583.00
	kWh/m2	26.70

The results show that the air to water heat pump with a solar photovoltaic system was sufficient to consider the model to have achieved the near zero energy status. Since no cooling was designed for the model either, there was a slight overheating of 12 % which will not be regarded as critical for the thesis.

5.3 Modified Model for Minitalo

The modified model was created with modifications to the Minitalo's building envelope. The thermal insulation and air-tightness was improved for the modified model. Space is limited in a tiny house and every inch is valuable. Every opportunity to gain as much floor area and volume in a tiny house should be taken. To maximise the floor area of the house while achieving the same U-values for the building envelope, an alternative thermal insulation material was used. One such material is the vacuum insulated panel (VIP). According to manufacturer Kingspan it 'a rigid vacuum insulation board with a microporous core which is evacuated, encased and sealed in a thin, gas-tight envelope, giving outstanding thermal conductivity, with the thinnest possible solution to insulation problems.' Its thermal conductivity has an overall value of 0.006-0.008 W/(m·K). Although it is not a commonly used insulation material in Finland, it has simple installation methods that do not differ from other insulation materials.

The only disadvantage is it is more costly than other insulation materials. Nevertheless, the smaller area of the thermal envelope of tiny house would require lesser insulation. Another disadvantage of VIP is the vulnerability of being punctured as it would lose its thermal capability rendering it useless. (Kingspan, 2018.)

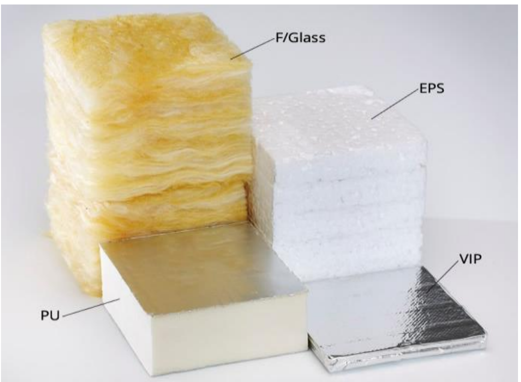


Figure 16. Comparison of different thicknesses of various types of thermal insulation with the same performance (Kevothermal, 2018).

Figure 16 above shows a thickness comparison between VIP and other insulating materials with the same performance. A matrix of typical insulation battens is first fixed in place to the exterior of the property. As VIP are a made to measure product so a specific panel configuration can be designed for any property.

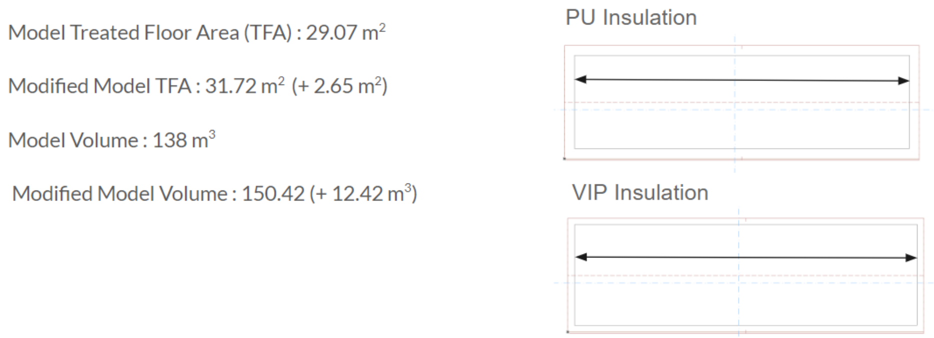


Figure 17. Increase in floor area on 1st floor and volume by using VIP insulation.

These battens create openings for the VIP to sit within whilst a second layer of typical insulation is laid over the top of the VIP and fixed to the underlying battens. This second layer then offers protection to the VIP as well as providing a base for the final finish of the property. (Kevothermal, 2018.)

Figure 17 above shows the increase in first story floor area and total volume of the Minitalo if VIP insulation was used for insulation instead of polyurethane insulation as designed. With the VIP insulation, the floor area of the Minitalo can be increased by 2.65 m^2 on the first floor and a total of 4.0 m^2 for both floors. Although it may not seem much, the increase of approximately 9 % from the planned model would be useful for the Minitalo. For example, the extra space could be used for the placement of the indoor unit of the heat pump and the solar panel equipment.

Table 10 below lists the details of the modified model. Assuming a better air-tightness for the modified model, the air leakage number q50 was reduced to 0.5. This results in the infilration rate to be reduced to 0.021 ($m^3/h.m^2$).

Table 10. Details and features for the modified model.

Building service	**Description**	**Version**
		Modified
Space heating (floor)	Source	Air to water heat pump
Technology		Underfloor heating
Domestic water		Air to water heat pump
Electricity		Solar PV + Grid
Ventilation	Type	Mechanical
Infiltration flow rate ($m^3/h.m^2$)	Value	0.021
Heat recovery efficiency	Value	85%
External Walls	U-value (W/m2K)	0,15
Roof		0,09
Floor		0,09
Windows		0,64
Building shell air leakage number, q50	Value	0.5

The results for the energy simulation for the modified model is the same as the planned modeled with the air to water heat pump and solar PV panels. However, the advantage of the modified model is the increase in floor area and volume of the Minitalo as mentioned earlier.

6 Conclusion[A1]

The results for the annual purchased energy and primary energy for all benchmark, planned and modified models are shown in table 11. From the results, it was established that the planned model with the heat pump and solar photovoltaic system had achieved a near zero energy building status.

In conclusion, modified model was considered as an improved version of the planned model with the heat pump and solar panels that had already achieved the near zero energy building status. The modifications in the modified model were not major so it would be beneficial to do so to have an increased floor area. Due to time constraints, a life cycle cost calculation could not be performed to determine the financial feasibility of each model. However, the renewable energy systems used in all the models are not complicated systems and are typically used in Finland.

Table 11. Energy simulation results for all models.

Description	Version				
	Benchmark	Planned (District Heating)	Planned (Electric + Solar PV)	Planned (Heat Pump + Solar PV)	Modified
Annual Purchased Energy (kWh/m²)	177.4	134.0	84.4	59.5	59.5
Annual Primary Energy (kWh/m²)	156.5	126.1	143.5	26.7	26.7

Investing in building a near zero energy single family house is capital intensive. However, it is financially logical over a long period of time. There are two possible approaches to investing in such a house. The first is the long term financial approach. The objective is to invest capital upfront on better design and technologies to save on monthly utility bills which in the long run would be more economical. The second approach is the environmentalist approach. The objective here is not the economic benefits but rather the environmental benefits. It is possible that making a large investment for such a house may not be financially feasible. However, the goal for this approach is to reduce the usage of non-renewable energy instead, regardless the economic disadvantages.

References

Aito Arkkitehtuuritoimisto oy. (2018). *Design*. Retrieved May 21, 2018, from https://www.minihouse.fi/design

Burrell, E. (2015). *Passivehaus in Plain English & More*. Retrieved April 5, 2018, from https://elrondburrell.com/blog/passivhaus-heatloss-formfactor/

Concrete Thinking. (2018, May 21). *Thermal Mass*. Retrieved May 21, 2018, from Solutions: http://www.concretethinker.com/solutions/Thermal-Mass.aspx

Energy Star. (2018, May 02). *Energy Star*. Retrieved from Energy Star: https://www.energystar.gov/

European commision. (2018, April 20). *Energy efficiency of buildings*. Retrieved April 2, 2018, from European commision: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

European Environment Agency. (2010). *Household energy consumption for space heating per m2 (2010, climate corrected)*. Retrieved April 2, 2018, from https://www.eea.europa.eu/data-and-maps/figures/household-energy-consumption-for-space

European Environment Agency. (2017, December 18). *Renewable Energy in Europe.* Retrieved May 21, 2018, from Publications: https://www.eea.europa.eu/publications/renewable-energy-in-europe

Feist, W. (2018). *About Passive House*. Retrieved April 20, 2018, from Passive house: http://www.passivehouse.com/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm

Feist, W., Pfluger, R., Kah, O., & Kaufman, B. (2013). *Passive house planning package* (8 ed.). Darmstadt: Passive house institute.

FINVAC ry. (2017, Febuary 16). *Opas asuinrakennusten ilmanvaihdon.* Retrieved April 10, 2018, from https://www.sulvi.fi/wp-content/uploads/2018/01/Opas-asuinrakennusten-ilmanvaihdon-mitoitukseen_2017-11-30.pdf

Hopfe, J. C., & McLeod, S. R. (2015). *The Passivhaus Designer's* (2 ed.). New york: Routledge.

Kevothermal. (2018). *About Kevothermal*. Retrieved May 02, 2018, from https://www.kevothermal.eu/about-kevothermal

Kilpinen, J. (2018, April 22). Living in minitalo.

Kingspan. (2018). *OPTIM-R*. Retrieved May 02, 2018, from https://www.kingspan.com/roe/el-gr/products/insulation/insulation-boards/optim-r

Lanttitalo. (2018). *Lanttitalo*. Retrieved April 20, 2018, from http://www.lanttitalo.fi/

Minergie. (2018, May 02). *Minergie*. Retrieved from Minergie: https://www.minergie.ch/

National Building Code of Finland. (2012). Energy Efficiency of Buildings, D3. Helsinki: Ministry of the Environment.

Oekologisch-Bauen. (2018, May 02). *niedrigenergiehaus*. Retrieved from niedrigenergiehaus: https://www.oekologisch-bauen.info/hausbau/energiestatus/niedrigenergiehaus.html

Rasi, M. (2017, April 25). *Henri, 27, rakensi itselleen liikuteltavan minitalon 5000 eurolla.* Retrieved April 5, 2018, from Ilta Sanomat: https://www.is.fi/asuminen/art-2000005185456.html

Spatherm. (2018). *Spatherm, model Paso L*. Retrieved from https://www.spartherm.com/produkte/kaminoefen/product/show/passo-s/

The Guardian. (2018). *How climate scepticism turned into something more dangerous*. Retrieved April 22, 2018, from https://www.theguardian.com/environment/2017/jul/07/climate-change-denial-scepticism-cynicism-politics

The tiny life. (2018). *What Is The Tiny House Movement?* Retrieved 5 April, 2018, from https://thetinylife.com/what-is-the-tiny-house-movement/

Union of Concerned Scientists. (2017, December 20). *Barriers to Renewable Energy Technologies*. Retrieved May 21, 2018, from Renewable Energy: https://www.ucsusa.org/clean-energy/renewable-energy/barriers-to-renewable-energy#.WwJrq9OFPow

Union of Concerned Scientists. (2018). *Global Warming Science*. Retrieved April 22, 2018, from https://www.ucsusa.org/our-work/global-warming/science-and-impacts/global-warming-science#.WvAd5oiFM-V

Viessmann. (2018, May 02). *Heat Pumps*. Retrieved from Viessmann: https://www.viessmann.fi/fi/asuinrakennukset/lampopumput/ilmavesilampopumput/vitocal-222s.html

World Green Building Council. (2018, May 21). *What is Net Zero?* Retrieved May 21, 2018, from Advancing Net Zero: http://www.worldgbc.org/advancing-net-zero/what-net-zero

Appendices

Appendix 1. Minitalo floor plans and views

Seina - Wall

Terassi - Terrace

OH - Living Room

KPH - Bathroom

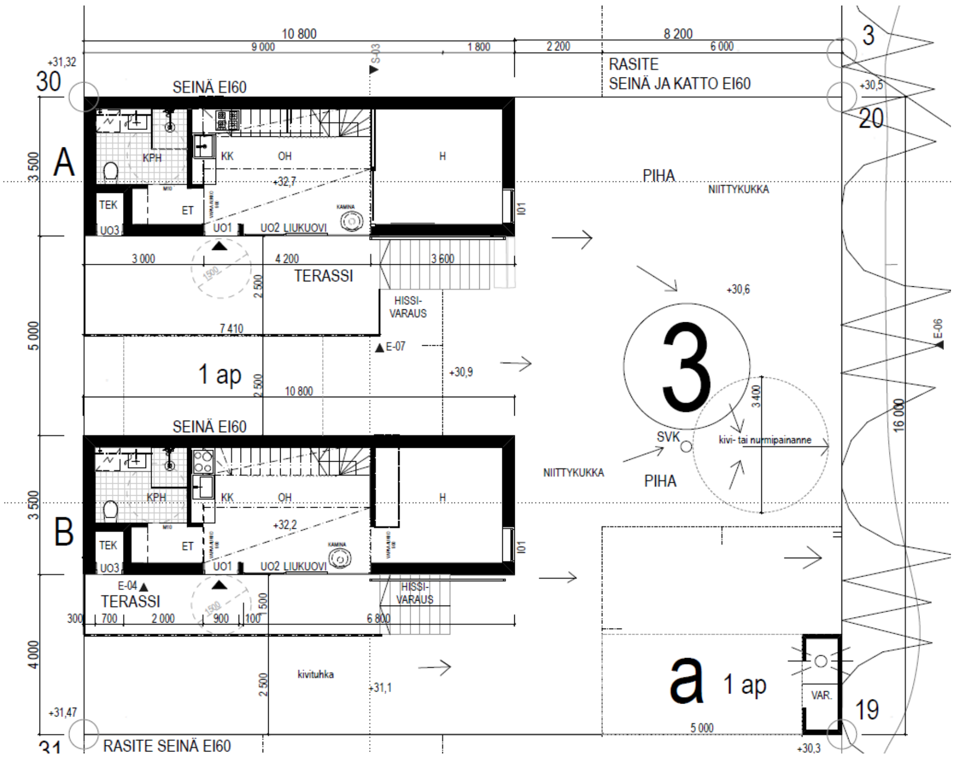
KK - Kitchen

MH - Bedroom

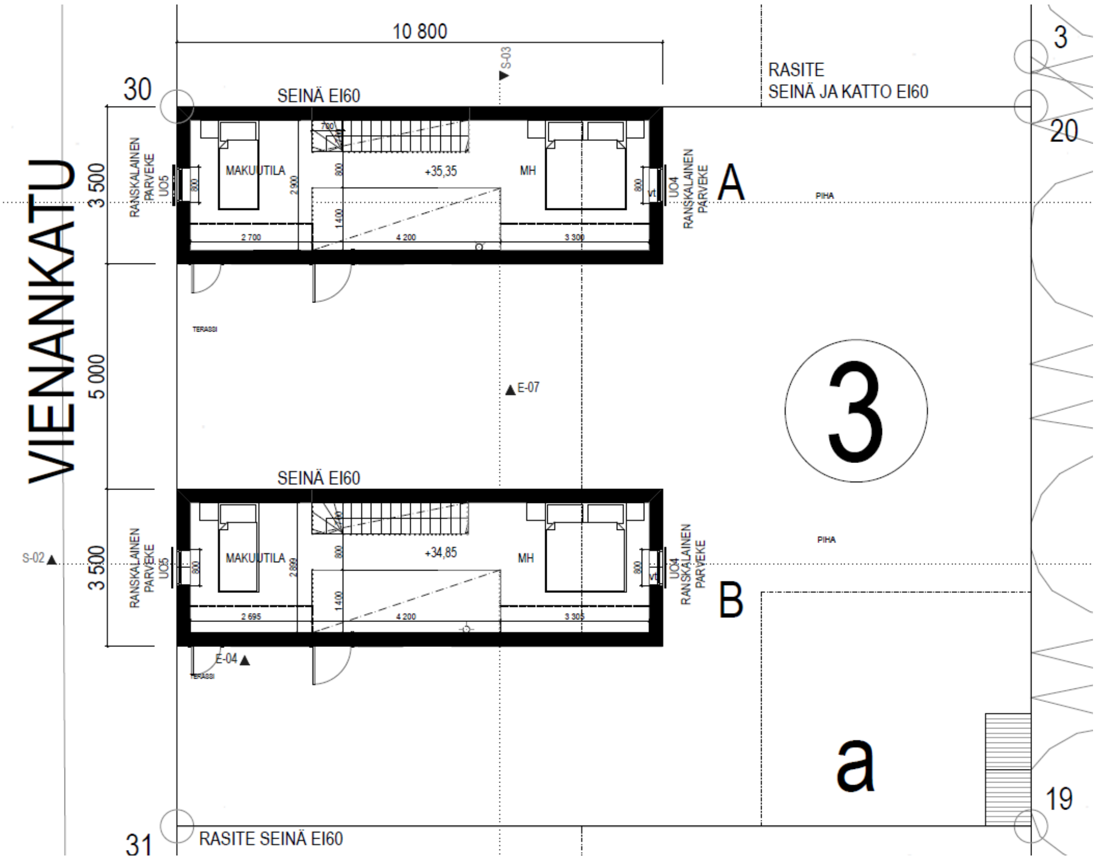
TEK - Technical Room

Piha - Yard

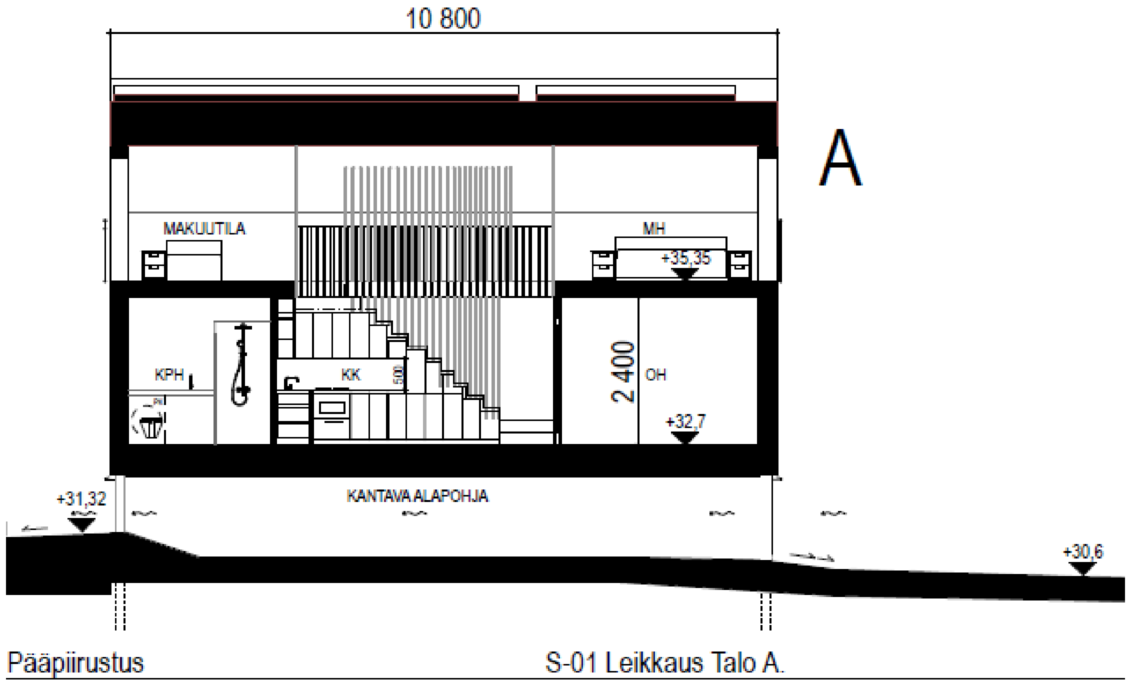
1st floor plan

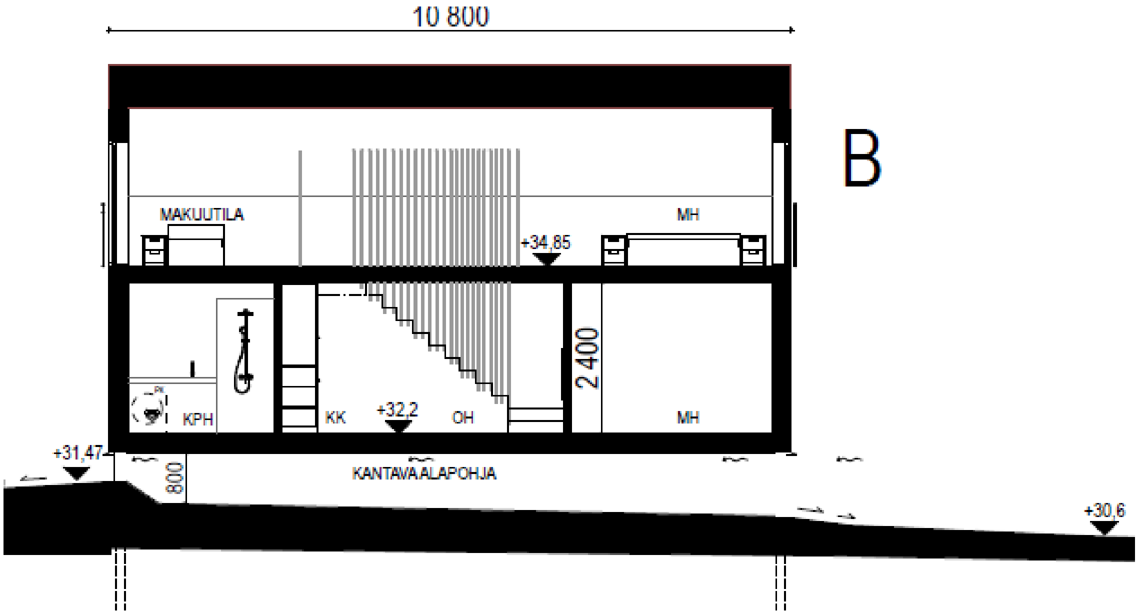


2nd story plan

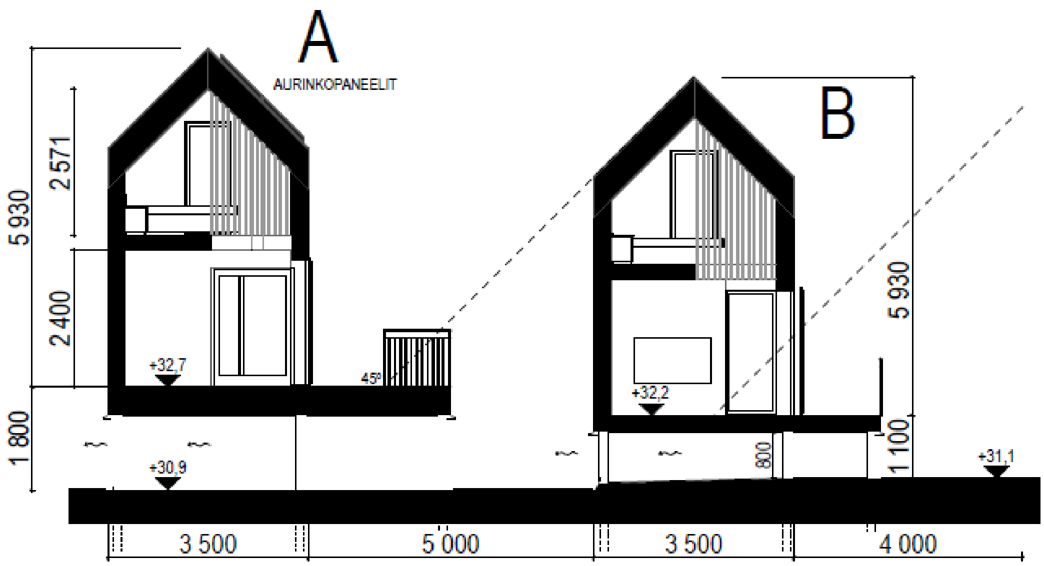


Section view

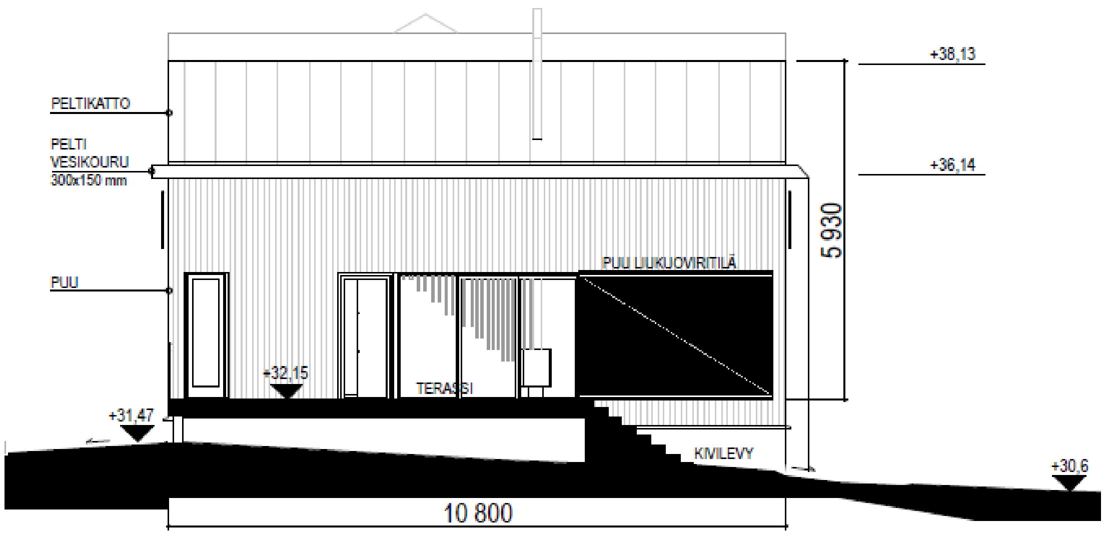




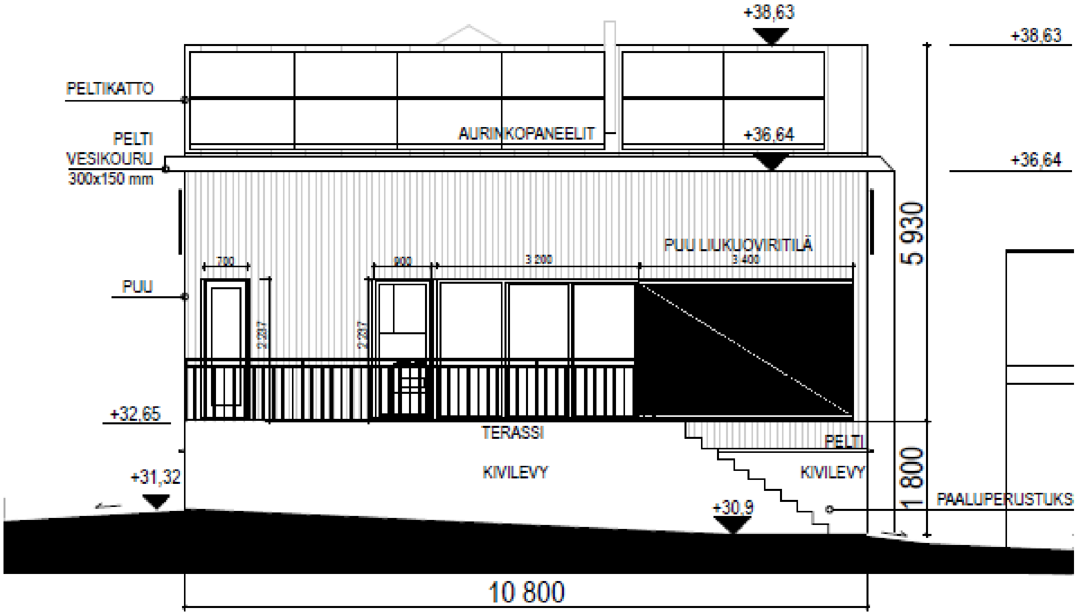
Pääpiirustus S-02 Leikkaus Talo B.

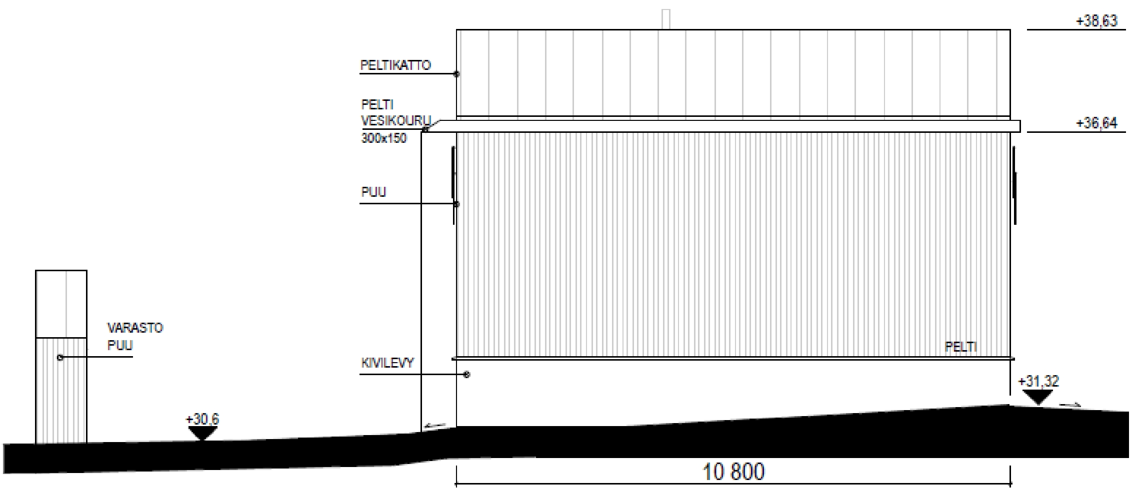


Pääpiirustus S-03 Leikkaus 1:100

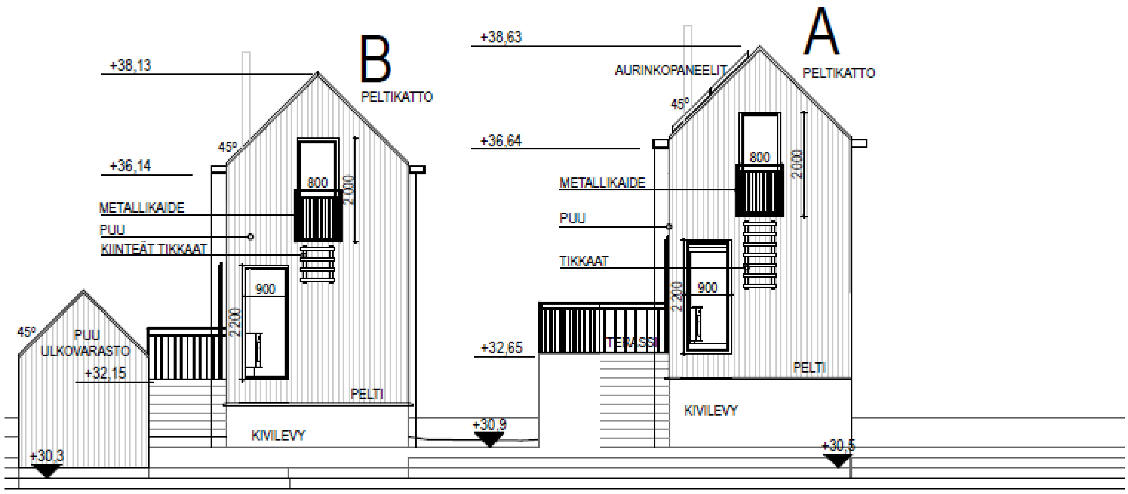


Facade

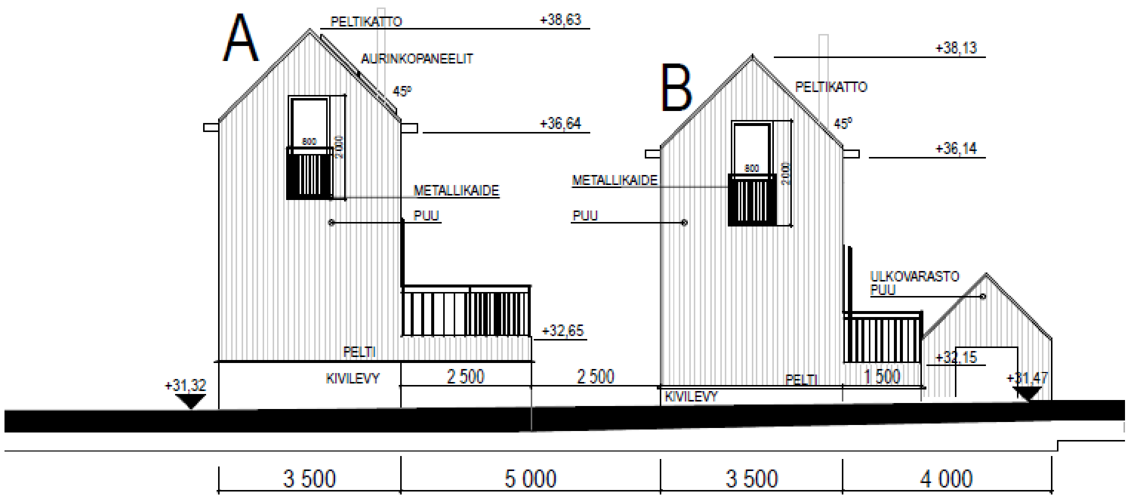




Pääpiirustus Julkisvu Talo A. pohjoisesta 1:100



PÄÄPIIRUSTUS Julkisivu idästä puistosta 1:100



PÄÄPIIRUSTUS Katujulkisivu lännestä 1:100

Appendix 2. Calculations

Calculations to find SA/V ratio for a tiny house vs. a typical house

Single story Tiny house					Typical house		
Internal wall dimensions					**Internal wall dimensions**		
a1,a2	**7.0**	**m**			**a1,a2**	**10**	**m**
b1,b2	**6.0**	**m**			**b1,b2**	**12**	**m**
Treated floor area	**42**	**m2**			**Treated floor area**	**120**	**m2**
Wall height	**2.7**	**m**			**Wall height**	**2.7**	**m**
Volume	**113**	**m3**			**Volume**	**324**	**m3**
Wall surface area					**Wall surface area**		
a1	**18.9**	**m2**			**a1**	**27**	**m2**
a2	**18.9**	**m2**			**a2**	**27**	**m2**
b1	**16.2**	**m2**			**b1**	**32.4**	**m2**
b2	**16.2**	**m2**			**b2**	**32.4**	**m2**
Total	**70.2**	**m2**			**Total**	**118.8**	**m2**
Roof surface area	**59.4**	**m2**			**Roof surface area**	**168**	**m2**
Total internal surface area	**172**	**m2**			**Total internal surface area**	**406.8**	**m2**
SA/V ratio	**1.51**				**SA/V ratio**	**1.26**	

Calculations to find HLF factor for a single story tiny house vs. a 2 story tiny house

Single story Tiny house					2 story Tiny house		
Internal wall dimensions					**Internal wall dimensions**		
a1,a2	**7.00**	**m**			**a1,a2**	**5.00**	**m**
b1,b2	**6.00**	**m**			**b1,b2**	**4.50**	**m**
					Treated floor area for story 1	**22.50**	**m2**
					Treated floor area for story 2	**19.50**	**m2**
Treated floor area	**42.0**	**m2**			**Total floor area**	**42.00**	**m2**
Wall height	**2.70**	**m**			**Wall height**	**2.70**	**m**
					Wall height x no. of floors	**5.40**	**m**
Volume	**113.40**	**m3**			**Volume**	**113.40**	**m3**
Wall surface area					**Wall surface area**		
a1	**18.90**	**m2**			**a1**	**27**	**m2**
a2	**18.90**	**m2**			**a2**	**27**	**m2**
b1	**16.20**	**m2**			**b1**	**24.3**	**m2**
b2	**16.20**	**m2**			**b2**	**24.3**	**m2**
Total	**70.20**	**m2**			**Total**	**102.6**	**m2**
45 deg pitched roof surface area	**59.39**	**m2**			**45 deg pitched roof surface area**	**59.39**	**m2**
Total internal surface area	**171.59**	**m2**			**Total internal surface area**	**203.99**	**m2**
Heat loss form factor	**4.09**				**Heat loss form factor**	**4.86**	

Calculations to find SA/V ratio and HLF factor for a 20 m² house

20 m² Tiny house		
Internal wall dimensions		
a1,a2	**5.00**	**m**
b1,b2	**4.00**	**m**
Treated floor area	**20.0**	**m2**
Wall height	**2.70**	**m**
Volume	**54.00**	**m3**
Wall surface area		
a1	**13.50**	**m2**
a2	**13.50**	**m2**
b1	**10.80**	**m2**
b2	**10.80**	**m2**
Total	**48.60**	**m2**
45 deg pitched roof surface area	**28.28**	**m2**
Total internal surface area	**96.88**	**m2**
Heat loss form factor	**4.84**	
SA/V ratio	**1.79**	

Calculations to find SA/V ratio and HLF factor for a 30 m² house

30 m² Tiny house		
Internal wall dimensions		
a1,a2	**6.00**	**m**
b1,b2	**5.00**	**m**
Treated floor area	**30.0**	**m2**
Wall height	**2.70**	**m**
Volume	**81.00**	**m3**
Wall surface area		
a1	**16.20**	**m2**
a2	**16.20**	**m2**
b1	**13.50**	**m2**
b2	**13.50**	**m2**
Total	**59.40**	**m2**
45 deg pitched roof surface area	**42.42**	**m2**
Total internal surface area	**131.82**	**m2**
Heat loss form factor	**4.39**	
SA/V ratio	**1.63**	

Calculations to find SA/V ratio and HLF factor for a 40 m² house

40 m² Tiny house		
Internal wall dimensions		
a1,a2	**6.70**	**m**
b1,b2	**6.00**	**m**
Treated floor area	**40.2**	**m2**
Wall height	**2.70**	**m**
Volume	108.54	**m3**
Wall surface area		
a1	**18.09**	**m2**
a2	**18.09**	**m2**
b1	**16.20**	**m2**
b2	**16.20**	**m2**
Total	**68.58**	**m2**
45 deg pitched roof surface area	**59.39**	**m2**
Total internal surface area	**165.62**	**m2**
Heat loss form factor	**4.12**	
SA/V ratio	**1.53**	

Calculations to find SA/V ratio and HLF factor for a 60 m^2 house

60 m^2 Tiny house		
Internal wall dimensions		
a1,a2	**8.00**	**m**
b1,b2	**7.50**	**m**
Treated floor area	**60.0**	**m2**
Wall height	**2.70**	**m**
Volume	**162.00**	**m3**
Wall surface area		
a1	**21.60**	**m2**
a2	**21.60**	**m2**
b1	**20.25**	**m2**
b2	**20.25**	**m2**
Total	**83.70**	**m2**
45 deg pitched roof surface area	**84.84**	**m2**
Total internal surface area	**228.54**	**m2**
Heat loss form factor	**3.81**	
SA/V ratio	**1.41**	

Calculations for the optimum TFA size vs compactness ratio

TFA (m2)	**Compactness ratio, SA/V**		
20	1.79		
40	1.51		
60	1.41		
80	1.28		
Compactness ratio point system	**Compactness ratio, SA/V**		**points**
Upper limit	0.2	equals	10
Economic limit	0.7	equals	0
Scale	0.5	proportional to	10
TFA (m2)	**Compactness ratio, SA/V**	**points (higher better)**	
20	1.79	-114	
30	1.63	-81	
40	1.53	-37	
60	1.41	-11	
Tiny house point system			**points**
Upper tiny house TFA limit (m2)	60	equals	0
Lower limit (m2)	0	equals	10
Scale	60.00	proportional to	10
TFA (m2)	**TFA size difference**	higher better	
20	40	66.67	
30	30	50.00	
40	20	33.33	
60	0	0.00	

TFA (m2)	**Compactness ratio, SA/V points (a)**	**TFA size difference points (b)**	**MCD Points (a+b, closest to 0 is optimum)**
20	-35.88	6.67	-29.21
30	-32.60	5.00	-27.60
40	-30.60	3.33	-27.27
60	-28.20	0.00	-28.20

Appendix 3. Technical equipment

Open flue wood stove product details

Properties

Nominal heat output	6,1 kW
Thermal output range	4,5-7,9 kW
Heat contribution to water	-
Efficiency	80 %
Door frame height	540 mm
Door frame width	481 mm
Total height	1636 mm
Total width	Ø 481 mm
Total depth	Ø 481 mm
Flue pipe diameter	150 mm
Door function	hinged
Weight	165 kg
2nd BImSchV.	✓
energy efficiency	A+

Solar photovoltaic system equipment details

Manufacturer	Abi Solar
Model	M60275-D
Dimensions (L x W) mm	1640 x 990
Maximum Power (Pmax)	275W
Maximum Power Voltage (Vmpp)	31.1V
Maximum Power Current (Impp)	8.85A
Open Circuit Voltage (Voc)	38.7V
Short Circuit Current (Isc)	9.12A
Module Efficiency	16.90%

Inverters

Manufacturer	Schneider electric
Model	SW 4048 120/240
Dimension [W x H x D, mm]	418 x 341 x 197

Solar charge controllers

Manufacturer	ABI-Solar
Model	MXC 3kW MPPT
Dimension [W x H x D, mm]	315×165×128

Batteries

Manufacturer	LG Chem
Model	RESU10
Dimension [W x H x D, mm]	452 x 484 x 227
Capacity	189 Ah
Nominal voltage	51.8 V
Type	Lithium-ion Battery Cell

Appendix 4. IDA ICE Simulation Reports

EQUA SIMULATION TECHNOLOGY GROUP		Delivered Energy Report	
Project		**Building**	
Malliinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus D3-2012 mukainen. -Vuotoilma D3-2012 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty D5-2012 arvoilla seuraavasti: -D5 2012 taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, D5-2012 taulukko 6.6 (ja 6.7) -Lämmitysjärjestelmän häviöt, D5-2012 kohta 6.2 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, D5-2012 taulukko 6.2 -Lämpimän käyttöveden häviöt D5-2012 kohta 6.3 (ei varaajaa). Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 31 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden pumpun sähkönkulutus D5 kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D)		Model floor area	59.2 m^2
Customer		Model volume	129.8 m^3
Created by	Sergio Rossi	Model ground area	29.6 m^2
Location	Helsinki (Ref 2012)	Model envelope area	171.6 m^2
Climate file	HKi-Vantaa_Ref_2012	Window/Envelope	7.2 %
Case	benchmark	Average U-value	0.2848 W/(m^2 K)
Simulated	7.5.2018 14.51.13	Envelope area per Volume	1.322 m^2/m^3

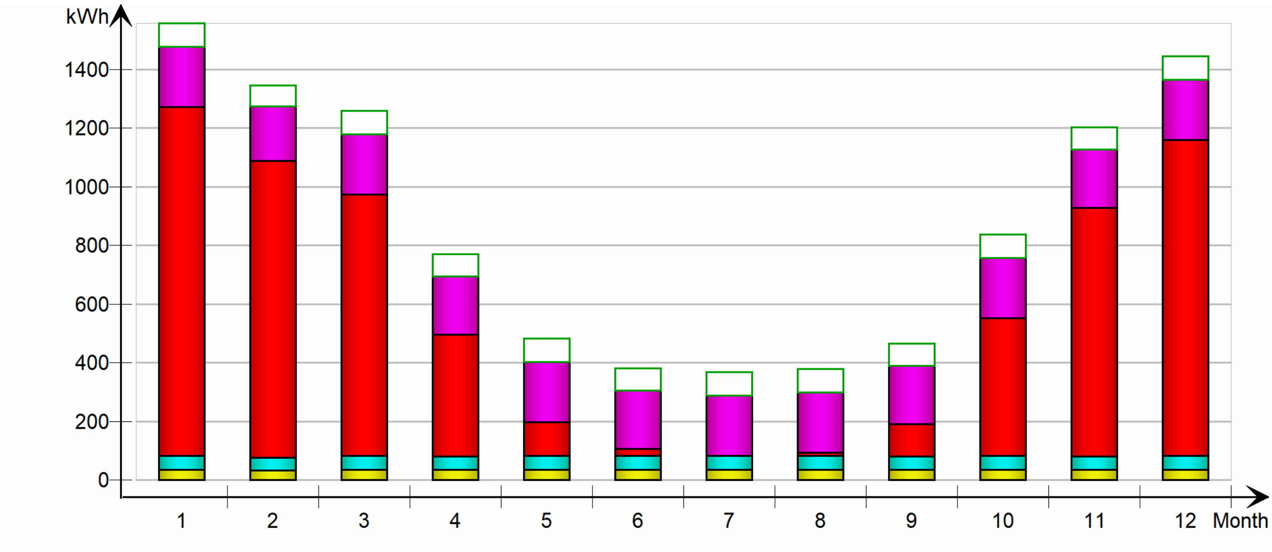
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	10 %
Percentage of hours when operative temperature is above 27°C in average zone	10 %
Percentage of total occupant hours with thermal dissatisfaction	10 %

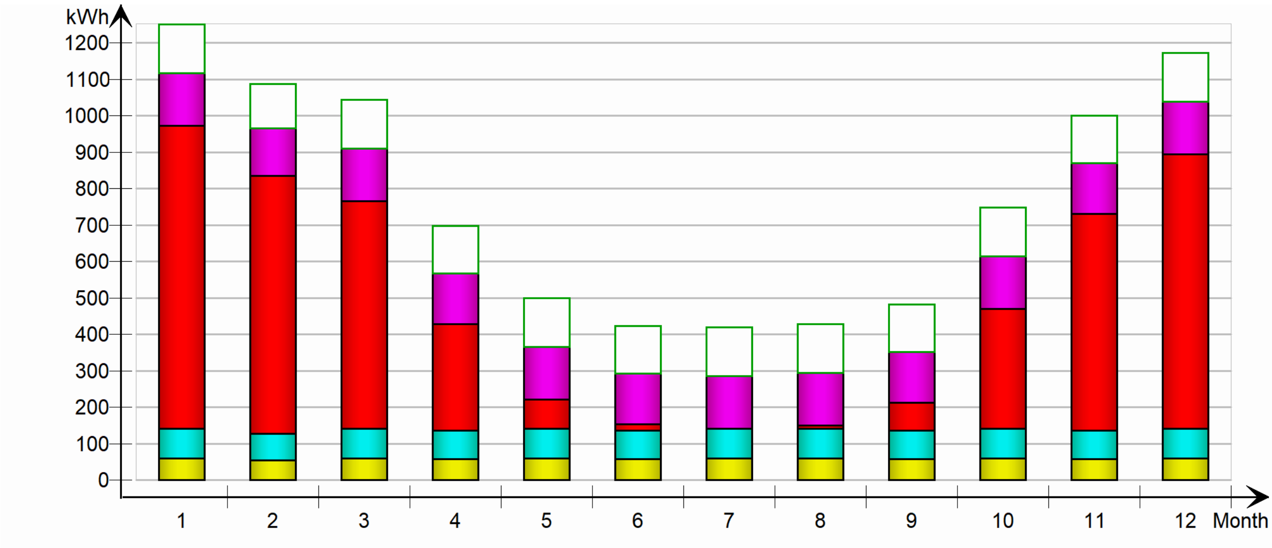
Delivered Energy Overview

	Purchased energy		Peak demand	Primary energy	
	kWh	kWh/m^2	kW	kWh	kWh/m^2
Valaistus, kiinteistö	415	7.0	0.05	705	11.9
Jäähdytys	0	0.0	0.0	0	0.0
LVI sähkö	564	9.5	0.06	959	16.2
Total, Facility electric	979	16.5		1664	28.1
Lämmitys, kaukolämpö	6165	104.1	2.84	4315	72.9
LKV, kaukolämpö	2428	41.0	0.28	1699	28.7
Total, Facility district	8593	145.2		6014	101.6
Total	9572	161.7		7678	129.7
Laitteet, asukas	933	15.8	0.11	1587	26.8
Total, Tenant electric	933	15.8		1587	26.8
Grand total	10505	177.4		9265	156.5

Monthly Purchased / Sold Energy



Monthly Primary Energy



Month	Facility electric						Facility district				Tenant electric	
	Valaistus, kiinteistö		Jäähdytys		LVI sähkö		Lämmitys, kaukolämpö		LKV, kaukolämpö		Laitteet, asukas	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	35.2	59.9	0.0	0.0	47.7	81.1	1189.0	832.3	206.2	144.3	79.3	134.8
2	31.8	54.1	0.0	0.0	43.1	73.2	1012.0	708.4	186.2	130.3	71.6	121.7
3	35.2	59.9	0.0	0.0	47.7	81.1	892.2	624.5	206.2	144.3	79.3	134.8
4	34.1	58.0	0.0	0.0	46.3	78.8	416.3	291.4	199.5	139.6	76.7	130.4
5	35.2	59.9	0.0	0.0	48.0	81.7	114.4	80.1	206.2	144.3	79.3	134.8
6	34.1	58.0	0.0	0.0	46.5	79.1	24.8	17.4	199.5	139.6	76.7	130.4
7	35.2	59.9	0.0	0.0	48.2	81.9	0.0	0.0	206.2	144.3	79.3	134.8
8	35.2	59.9	0.0	0.0	48.1	81.8	11.3	7.9	206.2	144.3	79.3	134.8
9	34.1	58.0	0.0	0.0	46.5	79.0	110.4	77.3	199.5	139.6	76.7	130.4
10	35.2	59.9	0.0	0.0	47.9	81.5	468.6	328.0	206.2	144.3	79.3	134.8
11	34.1	58.0	0.0	0.0	46.3	78.6	848.7	594.1	199.5	139.6	76.7	130.4
12	35.2	59.9	0.0	0.0	47.7	81.1	1077.0	753.9	206.2	144.3	79.3	134.8
Total	414.9	705.3	0.0	0.0	564.1	958.9	6164.7	4315.3	2427.6	1699.3	933.5	1586.9

IDA Indoor Climate and Energy
Version: 4.71
License: IDA40:18MAY/R9A6J (trial license)

SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
Malliinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus D3-2012 mukainen. -Vuotoilma D3-2012 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty D5-2012 arvoilla seuraavasti: -D5 2012 taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, D5-2012 taulukko 6.6 (ja 6.7) -Lämmitysjärjestelmän häviöt, D5-2012 kohta 6.2 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, D5-2012 taulukko 6.2 -Lämpimän käyttöveden häviöt D5-2012 kohta 6.3 (ei varaajaa). Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 31 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden pumpun sähkönkulutus D5 kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D)		Model floor area	59.2 m^2
Customer		Model volume	129.8 m^3
Created by	Sergio Rossi	Model ground area	29.6 m^2
Location	Helsinki (Ref 2012)	Model envelope area	171.6 m^2
Climate file	HKi-Vantaa_Ref_2012	Window/Envelope	7.2 %
Case	2.1 Planned w DH	Average U-value	0.2396 W/(m^2 K)
Simulated	7.5.2018 15.18.03	Envelope area per Volume	1.322 m^2/m^3

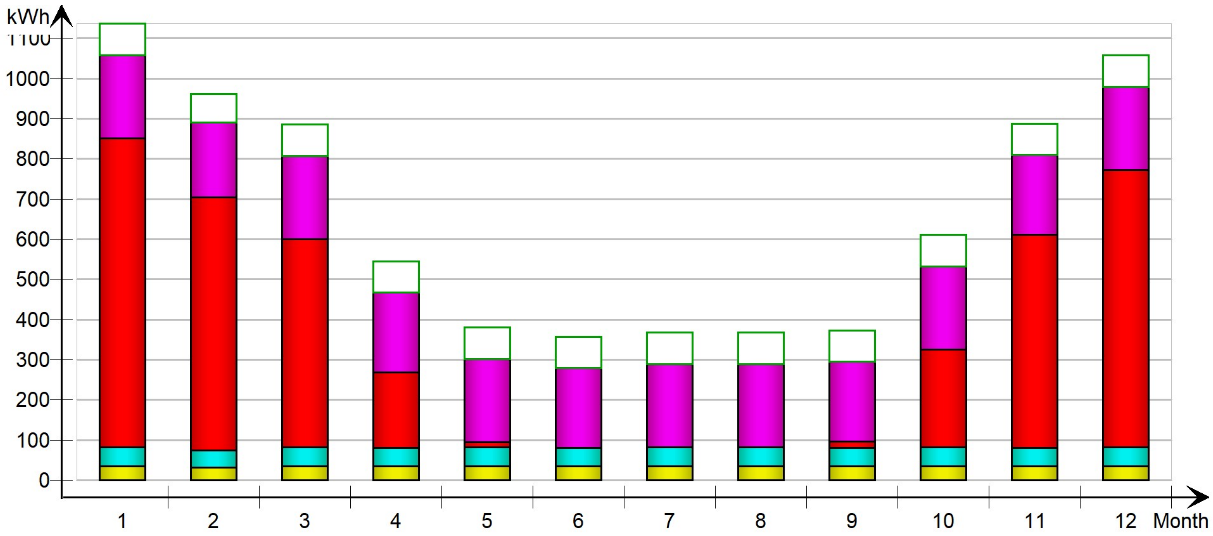
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	16 %
Percentage of hours when operative temperature is above 27°C in average zone	15 %
Percentage of total occupant hours with thermal dissatisfaction	12 %

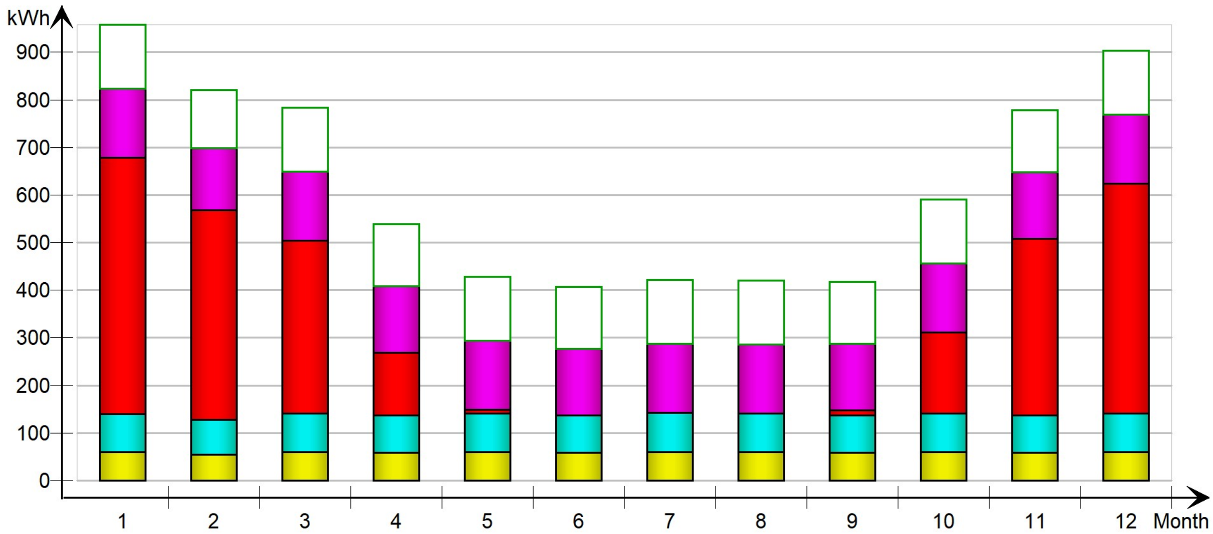
Delivered Energy Overview

	Purchased energy		Peak demand	Primary energy	
	kWh	kWh/m^2	kW	kWh	kWh/m^2
Valaistus, kiinteistö	415	7.0	0.05	705	11.9
Jäähdytys	0	0.0	0.0	0	0.0
LVI sähkö	562	9.5	0.06	955	16.1
Total, Facility electric	977	16.5		1660	28.0
Lämmitys, kaukolämpö	3597	60.8	1.86	2518	42.5
LKV, kaukolämpö	2428	41.0	0.28	1699	28.7
Total, Facility district	6025	101.8		4217	71.2
Total	7002	118.3		5877	99.3
Laitteet, asukas	933	15.8	0.11	1587	26.8
Total, Tenant electric	933	15.8		1587	26.8
Grand total	7935	134.0		7464	126.1

Monthly Purchased/Sold Energy



Monthly Primary Energy



Month	Facility electric						Facility district				Tenant electric	
	Valaistus, kiinteistö		Jäähdytys		LVI sähkö		Lämmitys, kaukolämpö		LKV, kaukolämpö		Laitteet, asukas	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	35.2	59.9	0.0	0.0	47.3	80.5	768.9	538.2	206.2	144.3	79.3	134.8
2	31.8	54.1	0.0	0.0	42.7	72.6	629.8	440.9	186.2	130.3	71.6	121.7
3	35.2	59.9	0.0	0.0	47.4	80.5	518.7	363.1	206.2	144.3	79.3	134.8
4	34.1	58.0	0.0	0.0	46.1	78.4	187.9	131.5	199.5	139.7	76.7	130.4
5	35.2	59.9	0.0	0.0	47.9	81.4	12.2	8.5	206.2	144.3	79.3	134.8
6	34.1	58.0	0.0	0.0	46.5	79.0	0.2	0.1	199.5	139.7	76.7	130.4
7	35.2	59.9	0.0	0.0	48.1	81.8	0.0	0.0	206.2	144.3	79.3	134.8
8	35.2	59.9	0.0	0.0	48.1	81.7	0.0	0.0	206.2	144.3	79.3	134.8
9	34.1	58.0	0.0	0.0	46.3	78.7	16.1	11.3	199.5	139.7	76.7	130.4
10	35.2	59.9	0.0	0.0	47.7	81.1	243.2	170.2	206.2	144.3	79.3	134.8
11	34.1	58.0	0.0	0.0	46.0	78.1	529.8	370.9	199.5	139.7	76.7	130.4
12	35.2	59.9	0.0	0.0	47.4	80.6	690.5	483.4	206.2	144.3	79.3	134.8
Total	414.9	705.3	0.0	0.0	561.5	954.5	3597.3	2518.1	2427.6	1699.3	933.5	1586.9

IDA Indoor Climate and Energy
Version: 4.71
License: IDA40:18MAY/R9A6J (trial license)

SIMULATION TECHNOLOGY GROUP			Delivered Energy Report	
Project			**Building**	
Malliinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus D3-2012 mukainen. -Vuotoilma D3-2012 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty D5-2012 arvoilla seuraavasti: -D5 2012 taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, D5-2012 taulukko 6.6 (ja 6.7) -Lämmitysjärjestelmän häviöt, D5-2012 kohta 6.2 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, D5-2012 taulukko 6.2 -Lämpimän käyttöveden häviöt D5-2012 kohta 6.3 (ei varaajaa). Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 31 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden pumpun sähkönkulutus D5 kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D)			Model floor area	59.2 m^2
Customer			Model volume	129.8 m^3
Created by	Sergio Rossi		Model ground area	29.6 m^2
Location	Helsinki (Ref 2012)		Model envelope area	171.6 m^2
Climate file	HKi-Vantaa_Ref_2012		Window/Envelope	7.2 %
Case	2.3 Planned w all electric+PV		Average U-value	0.2396 W/(m^2 K)
Simulated	7.5.2018 16.15.00		Envelope area per Volume	1.322 m^2/m^3

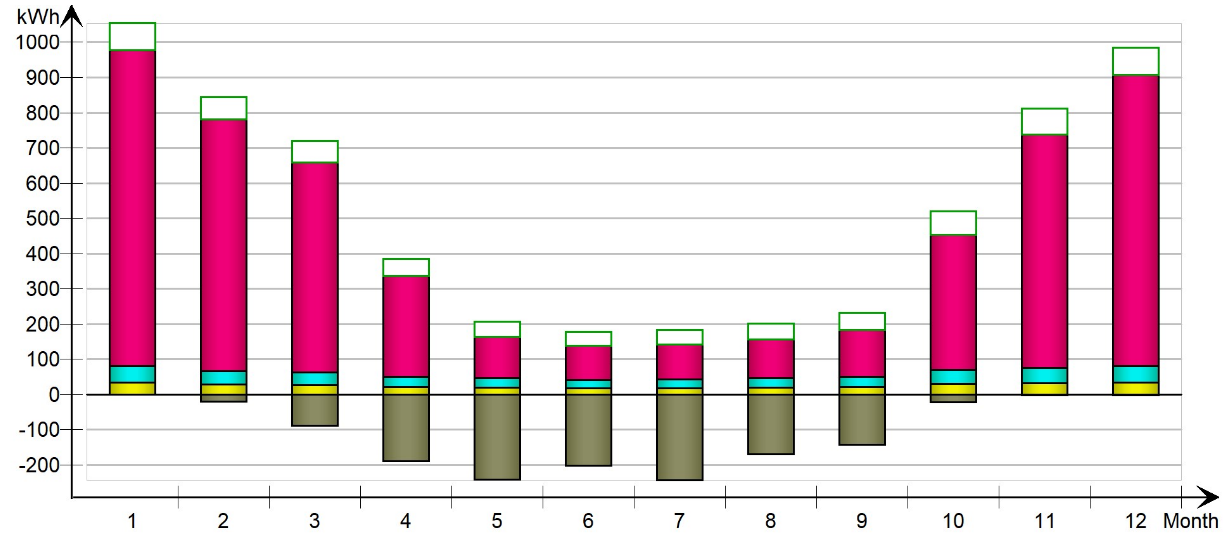
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	16 %
Percentage of hours when operative temperature is above 27°C in average zone	16 %
Percentage of total occupant hours with thermal dissatisfaction	12 %

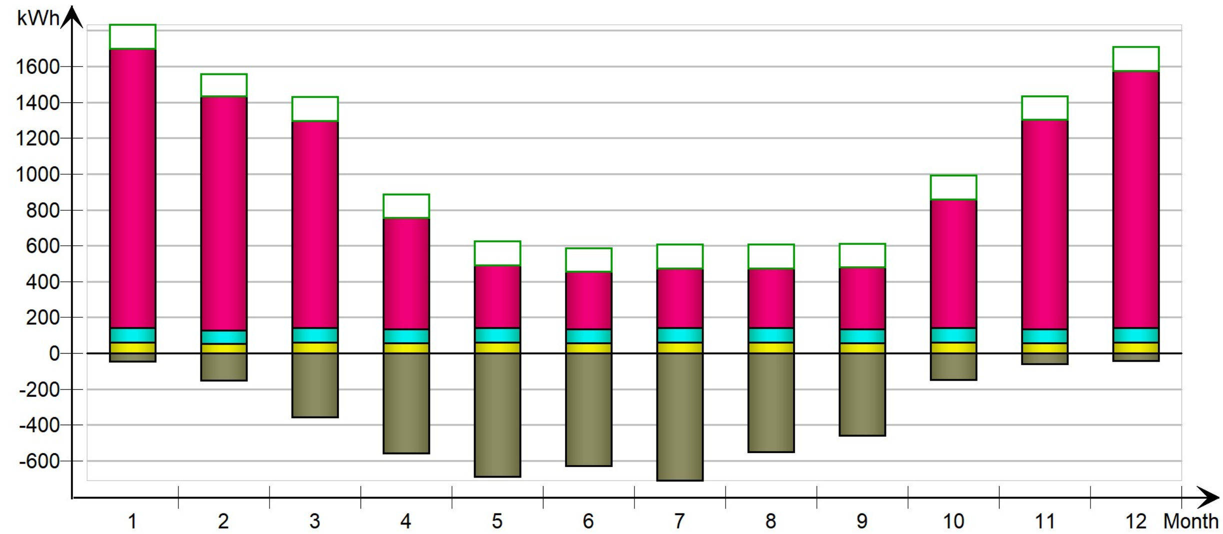
Delivered Energy Overview

	Used energy		**Purchased energy**		**Peak demand**	**Primary energy**	
	kWh	**kWh/m^2**	**kWh**	**kWh/m^2**	**kW**	**kWh**	**kWh/m^2**
Valaistus, kiinteistö	415	7.0	303	5.1	0.05	705	11.9
Jäähdytys	2	0.0	1	0.0	0.0	3	0.1
LVI sähkö	561	9.5	409	6.9	0.06	954	16.1
Sähkölämmitys, kiinteistö	5672	95.9	4920	83.2	2.01	9642	163.0
Total, Facility electric	6650	112.4	5633	95.2		11304	191.1
Total	6650	112.4	5633	95.2		11304	191.1
Laitteet, asukas	933	15.8	682	11.5	0.11	1587	26.8
Total, Tenant electric	933	15.8	682	11.5		1587	26.8
	Generated energy		Sold energy		Peak generated		
Aurinkosähkön tuotanto	-2590	-43.8	-1323	-22.4	-2.54	-4404	-74.4
CHP tuotto	0	0.0	0	0.0	0.0	0	0.0
Total, Produced electric	-2590	-43.8	-1323	-22.4		-4404	-74.4
Grand total	4993	84.4	4992	84.4		8487	143.5

Monthly Purchased/Sold Energy



Monthly Primary Energy



Month	Facility electric								Tenant electric		Produced electric	
	Valaistus, kiinteistö		Jäähdytys		LVI sähkö		Sähkölämmitys, kiinteistö		Laitteet, asukas		Aurinkosähkön tuotanto	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	34.1	59.9	0.2	0.3	45.8	80.4	896.0	1558.1	76.8	134.8	-0.9	-44.9
2	28.0	54.1	0.1	0.3	37.6	72.6	715.3	1305.4	63.1	121.7	-19.4	-151.9
3	27.1	59.9	0.1	0.3	36.5	80.5	595.3	1156.8	61.1	134.8	-88.0	-357.5
4	21.5	58.0	0.1	0.3	29.0	78.3	285.7	623.4	48.4	130.4	-189.0	-557.6
5	19.1	59.9	0.1	0.3	25.9	81.3	116.3	350.0	43.1	134.8	-241.6	-689.2
6	17.6	58.0	0.1	0.3	23.9	78.9	97.2	320.1	39.6	130.4	-202.5	-628.8
7	18.0	59.9	0.1	0.3	24.6	81.8	99.4	330.3	40.5	134.8	-243.3	-710.3
8	20.0	59.9	0.1	0.3	27.2	81.7	110.2	330.3	44.9	134.8	-169.5	-551.1
9	21.5	58.0	0.1	0.3	29.2	78.7	133.5	345.4	48.4	130.4	-143.2	-460.7
10	29.6	59.9	0.1	0.3	40.0	81.1	382.9	717.1	66.6	134.8	-22.5	-148.5
11	32.4	58.0	0.2	0.3	43.7	78.1	661.9	1169.8	73.0	130.4	-2.2	-61.1
12	34.1	59.9	0.2	0.3	45.8	80.5	826.0	1434.8	76.7	134.8	-1.4	-42.0
Total	303.2	705.3	1.4	3.3	409.3	953.9	4919.6	9641.5	682.2	1586.9	-1323.4	-4403.7

Month	Produced electric	
	CHP tuotto	
	(kWh)	Prim. (kWh)
1	0.0	0.0
2	0.0	0.0
3	0.0	0.0
4	0.0	0.0
5	0.0	0.0
6	0.0	0.0
7	0.0	0.0
8	0.0	0.0
9	0.0	0.0
10	0.0	0.0
11	0.0	0.0
12	0.0	0.0
Total	0.0	0.0

IDA Indoor Climate and Energy

Version: 4.71

License: IDA40:18MAY/R9A6J (trial license)

SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
Malliinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus D3-2012 mukainen. -Vuotoilma D3-2012 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty D5-2012 arvoilla seuraavasti: -D5 2012 taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, D5-2012 taulukko 6.6 (ja 6.7) -Lämmitysjärjestelmän häviöt, D5-2012 kohta 6.2 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, D5-2012 taulukko 6.2 -Lämpimän käyttöveden häviöt D5-2012 kohta 6.3 (ei varaajaa). Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 31 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden pumpun sähkönkulutus D5 kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D)		Model floor area	59.2 m^2
Customer		Model volume	129.8 m^3
Created by	Sergio Rossi	Model ground area	29.6 m^2
Location	Helsinki (Ref 2012)	Model envelope area	171.6 m^2
Climate file	HKi-Vantaa_Ref_2012	Window/Envelope	7.2 %
Case	2.5 Planned HP+PV	Average U-value	0.2396 W/(m^2 K)
Simulated	7.5.2018 16.01.37	Envelope area per Volume	1.322 m^2/m^3

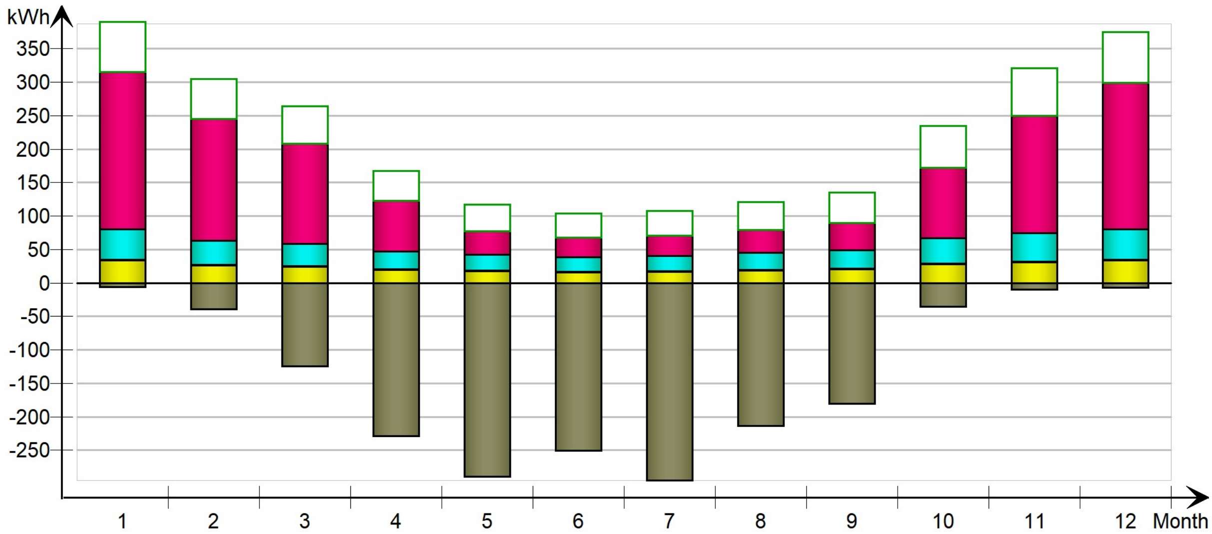
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	16 %
Percentage of hours when operative temperature is above 27°C in average zone	16 %
Percentage of total occupant hours with thermal dissatisfaction	12 %

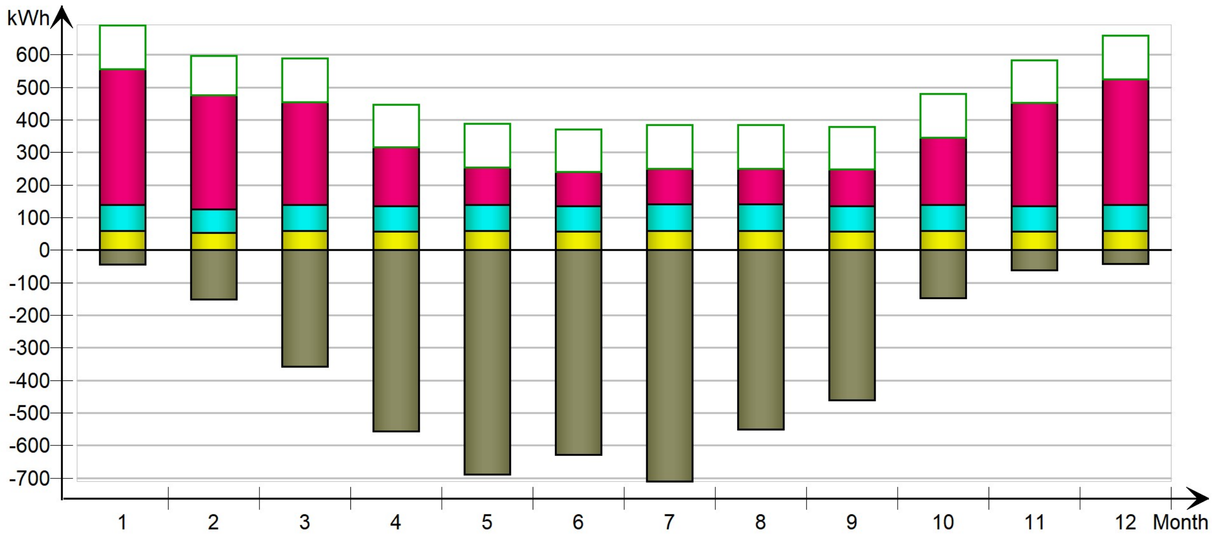
Delivered Energy Overview

	Used energy		**Purchased energy**		**Peak demand**	**Primary energy**	
	kWh	**kWh/m²**	**kWh**	**kWh/m²**	**kW**	**kWh**	**kWh/m²**
Valaistus, kiinteistö	415	7.0	284	4.8	0.05	705	11.9
Jäähdytys	2	0.0	1	0.0	0.0	3	0.1
LVI sähkö	562	9.5	383	6.5	0.06	955	16.1
Sähkölämmitys, kiinteistö	1609	27.2	1305	22.0	0.53	2736	46.2
Total, Facility electric	2588	43.7	1973	33.3		4399	74.3
Total	2588	43.7	1973	33.3		4399	74.3
Laitteet, asukas	933	15.8	638	10.8	0.11	1587	26.8
Total, Tenant electric	933	15.8	638	10.8		1587	26.8
	Generated energy		Sold energy		Peak generated		
Aurinkosähkön tuotanto	-2590	-43.8	-1680	-28.4	-2.54	-4403	-74.4
CHP tuotto	0	0.0	0	0.0	0.0	0	0.0
Total, Produced electric	-2590	-43.8	-1680	-28.4		-4403	-74.4
Grand total	931	15.7	931	15.7		1583	26.7

Monthly Purchased/Sold Energy



Monthly Primary Energy



Month	Facility electric								Tenant electric		Produced electric	
	Valaistus, kiinteistö		Jäähdytys		LVI sähkö		Sähkölämmitys, kiinteistö		Laitteet, asukas		Aurinkosähkön tuotanto	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	33.3	59.9	0.2	0.3	44.7	80.5	234.2	417.0	74.9	134.8	-6.3	-45.0
2	26.2	54.1	0.1	0.3	35.2	72.6	181.9	351.2	59.0	121.7	-38.9	-151.9
3	24.6	59.9	0.1	0.3	33.0	80.5	149.4	317.1	55.3	134.8	-124.2	-357.5
4	19.6	58.0	0.1	0.3	26.4	78.4	75.1	182.6	44.1	130.4	-228.8	-557.6
5	17.3	59.9	0.1	0.3	23.5	81.4	34.3	115.1	39.0	134.8	-289.3	-689.0
6	15.7	58.0	0.1	0.3	21.4	79.0	28.9	106.7	35.3	130.4	-251.0	-628.5
7	16.2	59.9	0.1	0.3	22.1	81.9	29.9	110.1	36.5	134.8	-295.2	-710.6
8	18.1	59.9	0.1	0.3	24.7	81.8	33.4	110.1	40.8	134.8	-213.7	-551.0
9	20.0	58.0	0.1	0.3	27.2	78.7	40.4	113.0	45.1	130.4	-180.2	-460.9
10	27.8	59.9	0.1	0.3	37.6	81.1	104.4	207.2	62.5	134.8	-35.3	-148.2
11	31.3	58.0	0.1	0.3	42.2	78.2	174.8	319.3	70.4	130.4	-9.8	-61.0
12	33.4	59.9	0.2	0.3	44.9	80.6	218.5	386.2	75.1	134.8	-7.5	-42.0
Total	283.6	705.3	1.3	3.3	383.0	954.7	1305.2	2735.6	638.0	1586.9	-1680.2	-4403.1

Month	Produced electric	
	CHP tuotto	
	(kWh)	Prim. (kWh)
1	0.0	0.0
2	0.0	0.0
3	0.0	0.0
4	0.0	0.0
5	0.0	0.0
6	0.0	0.0
7	0.0	0.0
8	0.0	0.0
9	0.0	0.0
10	0.0	0.0
11	0.0	0.0
12	0.0	0.0
Total	0.0	0.0

IDA Indoor Climate and Energy
Version: 4.71
License: IDA40:18MAY/R9A6J (trial license)

EQUA SIMULATION TECHNOLOGY GROUP		**Delivered Energy Report**	
Project		**Building**	
Malliinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus D3-2012 mukainen. -Vuotoilma D3-2012 kohta 4.3.3 ja 2.3.2(tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty D5-2012 arvoilla seuraavasti: -D5 2012 taulukko 3.1-3.3, rakenteiden väliset kylmäsillat (betoniset rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, D5-2012 taulukko 6.6 (ja 6.7) -Lämmitysjärjestelmän häviöt, D5-2012 kohta 6.2 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, D5-2012 taulukko 6.2 -Lämpimän käyttöveden häviöt D5-2012 kohta 6.3 (ei varaajaa). Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 31 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohdon häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden pumpun sähkönkulutus D5 kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D)		Model floor area	59.2 m^2
Customer		Model volume	129.8 m^3
Created by	Sergio Rossi	Model ground area	29.6 m^2
Location	Helsinki (Ref 2012)	Model envelope area	171.6 m^2
Climate file	HKi-Vantaa_Ref_2012	Window/Envelope	7.2 %
Case	3 Modified HP+PV	Average U-value	0.2396 W/(m^2 K)
Simulated	7.5.2018 16.01.37	Envelope area per Volume	1.322 m^2/m^3

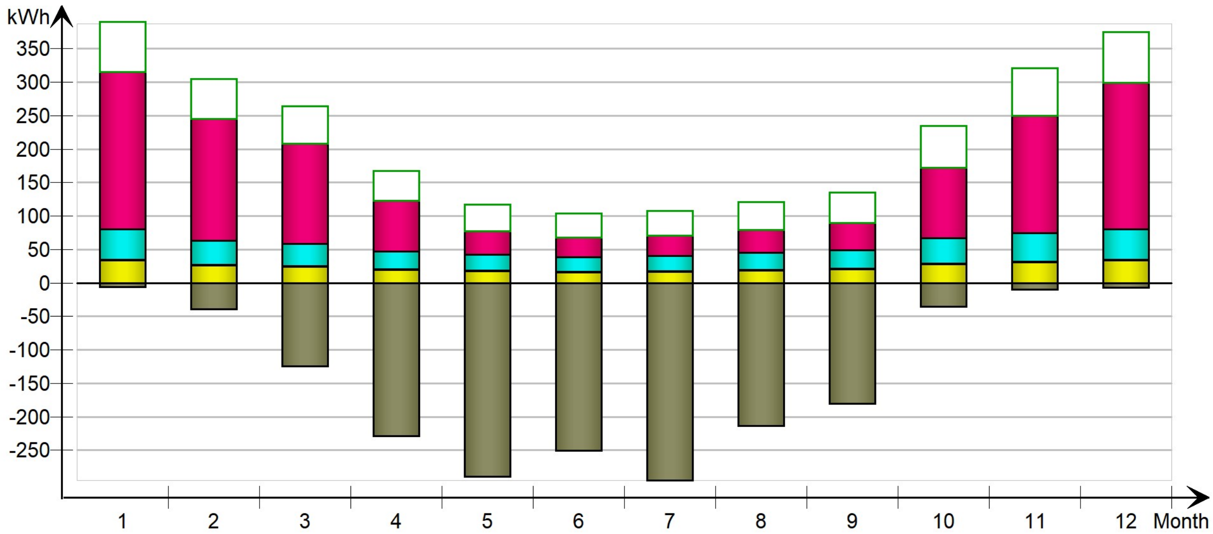
Building Comfort Reference

Percentage of hours when operative temperature is above 27°C in worst zone	16 %
Percentage of hours when operative temperature is above 27°C in average zone	16 %
Percentage of total occupant hours with thermal dissatisfaction	12 %

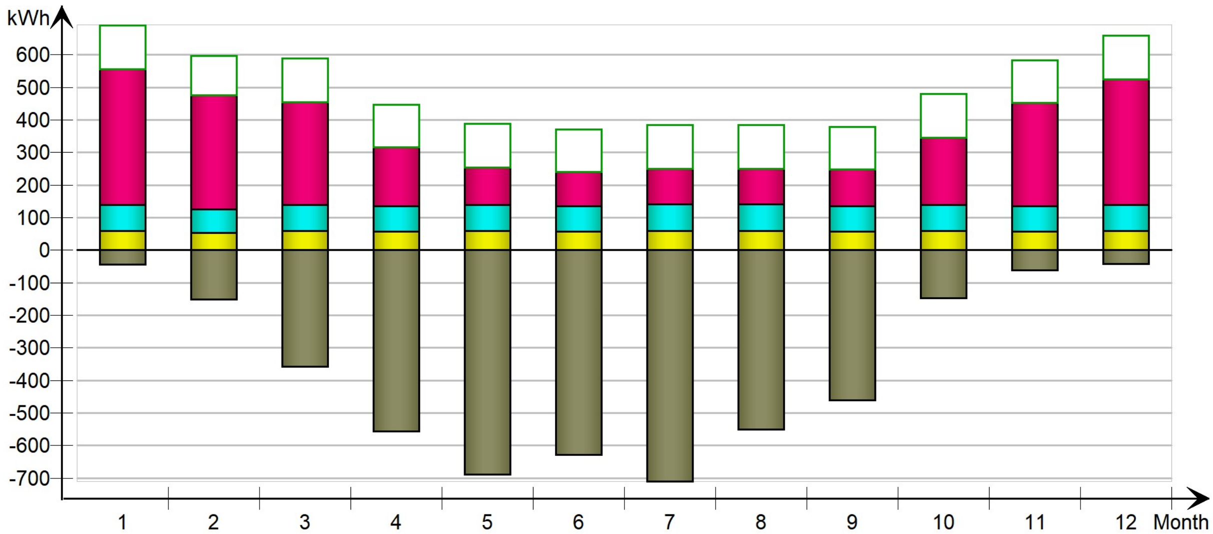
Delivered Energy Overview

	Used energy		**Purchased energy**		**Peak demand**	**Primary energy**	
	kWh	**kWh/m^2**	**kWh**	**kWh/m^2**	**kW**	**kWh**	**kWh/m^2**
Valaistus, kiinteistö	415	7.0	284	4.8	0.05	705	11.9
Jäähdytys	2	0.0	1	0.0	0.0	3	0.1
LVI sähkö	562	9.5	383	6.5	0.06	955	16.1
Sähkölämmitys, kiinteistö	1609	27.2	1305	22.0	0.53	2736	46.2
Total, Facility electric	2588	43.7	1973	33.3		4399	74.3
Total	2588	43.7	1973	33.3		4399	74.3
Laitteet, asukas	933	15.8	638	10.8	0.11	1587	26.8
Total, Tenant electric	933	15.8	638	10.8		1587	26.8
	Generated energy		Sold energy		Peak generated		
Aurinkosähkön tuotanto	-2590	-43.8	-1680	-28.4	-2.54	-4403	-74.4
CHP tuotto	0	0.0	0	0.0	0.0	0	0.0
Total, Produced electric	-2590	-43.8	-1680	-28.4		-4403	-74.4
Grand total	931	15.7	931	15.7		1583	26.7

Monthly Purchased/Sold Energy



Monthly Primary Energy



Month	Facility electric								Tenant electric		Produced electric	
	Valaistus, kiinteistö		Jäähdytys		LVI sähkö		Sähkölämmitys, kiinteistö		Laitteet, asukas		Aurinkosähkön tuotanto	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	33.3	59.9	0.2	0.3	44.7	80.5	234.2	417.0	74.9	134.8	-6.3	-45.0
2	26.2	54.1	0.1	0.3	35.2	72.6	181.9	351.2	59.0	121.7	-38.9	-151.9
3	24.6	59.9	0.1	0.3	33.0	80.5	149.4	317.1	55.3	134.8	-124.2	-357.5
4	19.6	58.0	0.1	0.3	26.4	78.4	75.1	182.6	44.1	130.4	-228.8	-557.6
5	17.3	59.9	0.1	0.3	23.5	81.4	34.3	115.1	39.0	134.8	-289.3	-689.0
6	15.7	58.0	0.1	0.3	21.4	79.0	28.9	106.7	35.3	130.4	-251.0	-628.5
7	16.2	59.9	0.1	0.3	22.1	81.9	29.9	110.1	36.5	134.8	-295.2	-710.6
8	18.1	59.9	0.1	0.3	24.7	81.8	33.4	110.1	40.8	134.8	-213.7	-551.0
9	20.0	58.0	0.1	0.3	27.2	78.7	40.4	113.0	45.1	130.4	-180.2	-460.9
10	27.8	59.9	0.1	0.3	37.6	81.1	104.4	207.2	62.5	134.8	-35.3	-148.2
11	31.3	58.0	0.1	0.3	42.2	78.2	174.8	319.3	70.4	130.4	-9.8	-61.0
12	33.4	59.9	0.2	0.3	44.9	80.6	218.5	386.2	75.1	134.8	-7.5	-42.0
Total	283.6	705.3	1.3	3.3	383.0	954.7	1305.2	2735.6	638.0	1586.9	-1680.2	-4403.1

Month	Produced electric	
	CHP tuotto	
	(kWh)	Prim. (kWh)
1	0.0	0.0
2	0.0	0.0
3	0.0	0.0
4	0.0	0.0
5	0.0	0.0
6	0.0	0.0
7	0.0	0.0
8	0.0	0.0
9	0.0	0.0
10	0.0	0.0
11	0.0	0.0
12	0.0	0.0
Total	0.0	0.0

IDA Indoor Climate and Energy
Version: 4.71
License: IDA40:18MAY/R9A6J (trial license)