

# COMPARATIVE ANALYSIS OF ENERGY SIMULATION METHODS

Case study: Single-family house



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ABSTRACT

Finnish building industry is in the constant search for engineering tools and solutions that would allow to simulate energy consumption in a project prior to its construction. The market presents a great variety of both digital and manual energy simulation methods. In this thesis, three such methods were analysed with the intent to find out what key factors should be considered when choosing one. The chosen methods include a manual method described in the Finnish Building Code 2012, Green Building Studio cloud-based service and IDA Indoor Climate and Energy software. The methods were individually tested on a newly built single-family house provided by the Sheet Metal Centre. The methods were later weighted against each other in terms of their result accuracy, time consumption, user interface and freedom of input.

The ability to simulate house indoor environment via a 3D modelling tool is an important factor. This was best exemplified with the study of the manual method described in the Finnish Building Code. FBC method, having no means to simulate house environment with regards to its layout, position and shape performed worse when accounting for heating needs of the house.

The conformity of the method with Finnish standards is perhaps the most important factor when working on a project based in Finland. This was best exemplified with the results received from Green Building Studio.

IDA has met both of the above-mentioned criteria and, as a result, IDA performed better than the other two methods. However, its results were not fully accurate due to limited data about the project.

**Keywords** energy simulation, SMC, Finnish Building Code, GBS, IDA ICE.

**Pages** 58 pages including appendices 20 pages

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# 1 INTRODUCTION

## 1.1 Background

As the world becomes more and more globalized the energy needs will keep rising. This calls for a solution that would allow better management of available fuels and resources in order to satisfy ever growing energy demand. European Union in that regard operates under 2020 climate and energy package of legislation, which sets as its goals to improve energy efficiency and use of renewable fuels by 20% by the year 2020 (Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, 2012). Traditionally, the building sector has been responsible for a large chunk of energy consumed worldwide. For the year 2017, buildings and the construction sector combined were responsible for 36% of global energy consumed and nearly 40% of total CO<sub>2</sub> emissions (International Energy Agency, 2017). Meanwhile in Finland, in the year 2016 electricity use in households amounted to 67 terawatt hours. Out of this, 68% of energy went to heating. Moreover, both heating energy consumption and the total energy consumption rose by 12% and 9% respectively compared to the previous year (Statistics Finland, 2016).

The Finnish building industry, driven by the desire to optimize its energy designs and need to comply with EU regulations, is in the constant search for engineering tools and solutions that would allow to simulate and measure energy needs in a project prior to its construction. The market presents a great variety of such tools that perform simulations with a varying degree of complexity, sophistication and conformity. For example, simulations may be performed on a monthly, daily or hourly basis. Depending on the algorithm, they may or may not have 3D modelling tools that allow to simulate house indoor environment, its geographical location, angle and shape, shading factor, soil condition, building materials used, cold bridge effect etc. It should also be noted that in some instances, energy analysis must be performed on a structure for which available information is limited. Information that is unknown mainly comes from energy standards used in a country. Thus, depending on standards used in the method, the results may differ significantly.

This study aims to perform a comparative analysis of three selected energy simulation methods and tools of varying degree of complexity, sophistication and conformity and see how they will perform with a limited set of information available for the reference object.

## 1.2 Aim

Energy simulations will be performed on a reference object provided by the Sheet Metal Centre (a newly built single-family house in Central Finland). The three selected energy simulation tools include energy analysis method described in the Finnish Building Code 2012, Autodesk Green Building Studio cloud-based energy analysis service and IDA Indoor Climate and Energy software version 4.8.

The method described in the Finnish Building Code conforms with the Finnish energy standards but lacks a 3D modelling tool and, in theory, cannot fully simulate house environment. With this method it is the aim to study how a lack of sophisticated 3D modelling tool can affect the results.

Autodesk Green Building Studio while having no 3D modelling tools of its own, takes all the necessary information about house environment from Revit model. However, GBS is based on ASHRAE standards and American building practices that in theory can render its results incorrect for Finland. With this method the aim is to study how a lack of conformity can affect the results.

IDA Indoor Climate and Energy method has a 3D modelling tool of its own and it can be conformed to Finnish standards via a downloadable extension. Yet, as was mentioned above, information about the project is limited. With this method the aim is to study how a lack of information can affect the results.

## 1.3 Outline

Following study is divided into seven chapters. The first chapter, Introduction, states the relevance of this study and sets the goals for successful completion. The second chapter, Reference object, familiarizes readers with the reference object and monitoring data recorded for it, which will be used in this study as the baseline for comparison. The third chapter, Energy Analysis according to the Finnish Building Code, simulates energy consumption following the method described in Finnish Building Code. The fourth chapter, Energy Analysis via Autodesk GBS, simulates energy consumption via Autodesk Green Building Studio cloud-based service. The fifth chapter, Energy Analysis according to IDA ICE, simulates energy consumption via IDA Indoor Climate and Energy software. The sixth chapter, Comparative analysis. The results received in three previous chapters are weighted against each other and compared. The results are then discussed. Finally, the seventh chapter, Conclusion, sums up the entire thesis.

## 2 REFERENCE OBJECT

### 2.1 Object description

In order to conduct necessary investigation a reference object is required. For this study the reference object is a newly built single-family house situated in North Karelia region in Finland on the northernmost shore of Lake Pyhäselkä only about three kilometres westwards from Joensuu city centre (see Figure 1). The house was chosen as the reference object for two main reasons. First of all, in the year 2017 the energy consumption of this house was monitored and recorded. Secondly, the house was built in Finland and it is relatively new, thus it must comply with the Finnish Building Code and energy regulations.

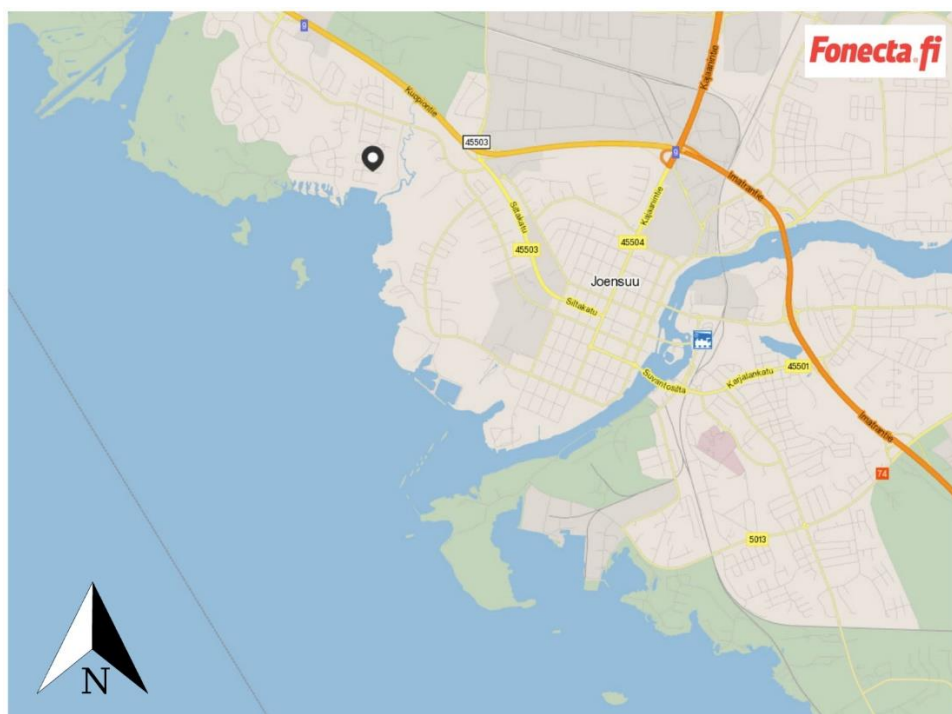


Figure 1. Map showing the location of a house with the black dot (Fonecta.fi)

The house is built on a plot of land 1045.5 m<sup>2</sup> in area at an angle of 15 degrees. A two-storey high house is made of two separate structures: the living quarters that have an area of 120 m<sup>2</sup> and storage facility of 19 m<sup>2</sup> all under one pitched roof of 23.7° angle. At its highest peak the house is 7.76 meters in height. The attic is currently sealed off and not in use, which means that the ceiling with its thick insulation layer acts as a heat barrier instead of roof. The plot is surrounded with other privately-owned homes of similar size and height that do not cause any shading effect on the property. The views of the house and its layout can be seen in the Figures 2 and 3 below.



The house was built on a well-insulated concrete ground slab. The walls were made from light weight aerated concrete blocks with polystyrene filling. On the second floor, the walls and the roof were made from wood materials. Structural elements used in the house and their respective U-values are listed in Table 1 below. The numbers were taken from the blueprint 'Leikkaus A-A' available in Appendix 1.

Table 1. Structural elements and their respective U-values

Structural element	U-value [W/(m <sup>2</sup> K)]
Ground slab	0.11
Ground slab (1m around the edges)	0.15
Outer wall (house)	0.12
Outer wall (storage)	0.23
Ceiling / Roof	0.08
Doors	0.8
Windows (MSEA type)	0.67
Windows (MEKA type)	0.7

The temperature inside is kept at 23 °C in living quarters and 10 °C in the storage. The storage is only heated in winter months. The house uses radiant floor heating with water tubes submerged into concrete flooring at a depth of about 20 mm. The heat is supplied by the ground source heat pump model NIBE F1245 with a power output of 6 KW which runs on a 360 meters long ground loop placed in the yard at a depth of 1.2 meters (NIBE, 2010).

The house is mechanically ventilated at a nominal air flow of 60 l/s with a counter-flow heat exchanger model ILOXAIR Optima 129 (ILOXAIR, 2016). The incoming temperature varies depending on the season, but it is generally within the radius of +15 °C and +18 °C. The hot water circuit for preheating automatically turns on when the temperature outside is below -5 °C to prevent fan freezing. Water for preheating is directly supplied from a separate ground loop placed in the yard. As for the storage, the air flow there does not exceed 20 l/s. The specifics of a heat exchanger used in storage are unknown, but a safe estimate puts its temperature exchange ratio at 0.4.

Finally, it is known that the house has a fireplace unit which is occasionally used for heating during colder months of the year.

## 2.2 Monitoring data

Monitoring data was gathered in the year 2017 (see Table 2). This data features two sets of numbers: monthly purchased energy for the heat pump in kilowatt hours (kWh) and monthly total power consumption of the household also in kilowatt hours (kWh). From this, a third set of

numbers can be deduced – power spent on other needs per month, which is a difference of two previous numbers.

Table 2. Monitoring data for the year 2017

Month	$E_{HP,heating}$ [kWh]	$E_{other}$ [kWh]	$E_{total}$ [kWh]
January	350	198	548
February	350	181	531
March	313	209	522
April	284	201	485
May	204	170	374
June	110	197	307
July	80	259	339
August	90	75	165
September	170	171	341
October	225	213	438
November	294	189	483
December	314	244	558
Total	2784	2307	5091

Additionally, 1.5 stacked m<sup>3</sup> of birch tree logs were burned in the fireplace with an intent to heat up the area.

By looking at the table above, several deductive arguments can be made:

- Yearly heat pump energy consumption alone is almost equal to energy consumption for all other needs combined (54.7% against 45.3%).
- Heat pump energy consumption increases as the mean temperature outside decreases, with the lowest energy consumption registered in Summer and highest energy consumption registered in winter.
- In summer months (July, August), the amount of energy consumed by the heat pump was the lowest at around 80 kWh and 90 kWh respectively. The assumption is that the energy during these months was primarily used for heating domestic water and not for heating spaces.
- In winter months (January, February), the amount of energy consumed by the heat pump was the highest at around 350 kWh each. The assumption is that these months experienced the lowest outside temperatures in the year. The assumption was confirmed by the Finnish Meteorological Institute (Finnish Meteorological Institute, 2018).
- In August, energy consumption for other needs dropped significantly (3.5 times lower compared to July, 2.5 times lower compared to mean monthly consumption). The assumption is that the owners were on a prolonged vacation during this month and the house was left empty. The assumption was later confirmed by the owner.
- Other than in August, energy consumption for other needs stayed fairly the same throughout the year with mean monthly consumption of 190 kWh.

### 3 ENERGY ANALYSIS ACCORDING TO THE FINNISH BUILDING CODE

The first method to be investigated is the energy analysis method as described in the Finnish Building Code. This is a conservative method that allows to perform analysis even when necessary information is incomplete. This is possible due to the incorporation of table values that reflect mean industry data. The method utilizes mean monthly values and thus, it can only estimate energy consumption per month. With sufficiently high daily temperature fluctuations it can render such results as inadequate, which is why it needs to be tested.

#### 3.1 Finnish Building Code description

The Land Use and Building Act (132/1999) states the general purpose of the Finnish Building Code (Chapter 1, Section 13). The Finnish Building Code (later will be referred to as FBC) contains further regulations and guidelines concerning building construction, service and maintenance that are not covered by The Land Use and Building Act (Ympäristöministeriö, 2017). While regulations are mandatory and must be followed, guidelines are not, and other approaches than those suggested may be applied if met the requirements set for building (Land Use and Building Act 132/1999, n.d.).

FBC consists of seven parts lettered from A to G. For the purposes of this research only parts that cover thermal insulation (Part C4), energy management (Part D3) and calculation of building's energy needs (Part D5) are required.

##### **C4: Thermal Insulation**

FBC Part C4 discusses various designs and implementation of thermal insulation in building components and structures. It also covers the effects produced by cold bridges in places where building components meet. The guidelines are further supplied with the list of materials and their respective thermal properties. These thermal properties include density, specific heat capacity and the thermal conductivity factor of the material.

##### **D3: Energy Efficiency of Buildings**

FBC Part D3 provides necessary terminology, categorises buildings into classes, sets the energy requirements for newly built structures and gives basic data needed for conducting an energy analysis. The data includes the Finnish weather condition by regions, typical indoor climate, types of thermal loads, water consumption and utilisation factors. This data is to be used in case no other project specific data is available.

## D5: Calculation of Power and Energy Needs for Heating of Building

FBC Part D5 presents an energy analysis method based on monthly levels of energy consumption. The method allows to ascertain the following values: heating energy needs, other energy needs, heat loads, heating energy consumption, other energy consumption and electricity consumption. The method follows a rigid structure of first establishing the building's energy needs and heat loads. Their difference factored by the system's energy efficiency ratio will determine the building's heating energy consumption. Heating energy consumption is then further factored by the system's electricity demand to establish the building's electricity consumption. Resulting figures show the electricity consumption per month for heating, ventilation, lighting and running other electrical appliances.

### 3.2 Energy Analysis calculation

Since the reference object consists of two separately standing structures; the house and storage facility, energy analysis, when needed, was performed separately for them.

Equations taken from FBC were numbered as they appear in FBC Part D5 year 2012. Equations rewritten to suit the author's specific needs were marked with '\*' sign. Equations made by the author were numbered starting from one. Only parameters for which the values were manually set by the author are mentioned. Fixed parameters as well as a full description of the equations used in the chapter can be found in Appendix 2.

#### 3.2.1 Heating energy needs

According to the guidelines presented in FBC Part D5, energy need for space heating can be calculated using Equation (3.2).

$$Q_{space} = Q_{conduct} + Q_{air\ leakage} + Q_{supply\ air} + Q_{make-up\ air} \quad (3.2)$$

#### Conduction heat loss

To accurately assess conduction heat loss through the building shell, conduction heat losses through individual building components must be calculated first. Building components include ground floor, outer walls, ceiling/roof, windows, doors and thermal bridges. Heat lost through a building component was calculated using Equation (3.4).

$$Q_{component} = \sum U_i A_i (T_{in} - T_{out}) \Delta t / 1000 \quad (3.4)$$

- Temperature outside was taken from the Finnish Meteorological Institute for the year 2017 (Finnish Meteorological Institute, 2018).

- Temperature below the floor was taken as a sum of monthly outdoor temperature and monthly ground temperature. Mean monthly ground temperature is available in FBC Part D5, Table 3.4.
- Conduction heat losses in the storage during warmer months of the year (from May until September) were left unaccounted as the temperature outside was higher than the temperature inside.

### Air leakage heat loss

Air leakage (also known as ‘air infiltration’) can be both inward and outward and is driven by differential pressures across the building envelope due to the effects of insufficient air tightness of that envelope, external wind and mechanical ventilation systems (Guyot, Schild, & Carrié, 2010). The air leakage heat loss was calculated using Equations (3.8; 3.9; 3.10). For the values used in the equations, please, refer to Table 3.

$$Q_{air\ leakage} = \rho_i c_{pi} q_{air\ leakage\ flow} (T_{in} - T_{out}) \Delta t / 1000 \quad (3.8)$$

$$q_{air\ leakage\ flow} = \frac{q_{50}}{3600 * x} A \quad (3.9)$$

$$q_{50} = \frac{n_{50}}{A} V \quad (3.10)$$

Table 3. Set parameters for Equations (3.9; 3.10)

Parameter	Value	Taken from
$n_{50}$	2	FBC Part D5, Table 3.5 (for ‘Good air impermeability’)
$x$	35	FBC Part D5 (for one-storey building)

### Heating of supply air

Energy requirements for heating of supply air cannot be assessed without evaluating the air flow first. According to the owner the air flow of ventilation unit in the house is 60 L/s. The air flow of ventilation unit in the storage was assumed at 20 L/s. Heating of supply air is calculated using Equation (3.14). For the values used in the equation, please, refer to Table 4.

$$Q_{iv, supply} = t_d t_v \rho_i c_{pi} q_{supply} (T_{in} - T_{inb}) \Delta t / 1000 \quad (3.14)$$

Table 4. Set parameters for Equation (3.14)

Parameter	Value	Taken from
$q_{supply, house}$	0.06 m <sup>3</sup> /s	Given
$q_{supply, storage}$	0.02 m <sup>3</sup> /s	Educated assumption
$t_d$	1	FBC Part D3, Table 3 (for separate small house)
$t_v$	1	FBC Part D3, Table 3 (for separate small house)
$T_{inb}$	17 °C	Educated assumption

## Heating of make-up air

The following calculations were made under the assumption that the air supplied is equal in volume to the air exhausted, since the needs for make-up air are miniscule and will not affect the results greatly.

## Results

The following Tables 5 and 6 contain the results for heating energy needs, which include conduction heat losses, air leakage heat losses, energy need for heating of supply air and energy need for space heating.

Table 5. Heating energy needs of the house

Month	$Q_{conduct}$ [kWh]	$Q_{air\ leakage}$ [kWh]	$Q_{iv, supply}$ [kWh]	$Q_{space}$ [kWh]
January	1312.692	154.568	448.510	1915.769
February	1223.522	142.945	382.629	1749.096
March	1127.725	130.301	436.418	1694.445
April	1040.868	118.950	398.402	1558.221
May	802.273	90.736	303.903	1196.911
June	484.355	54.625	182.957	721.938
July	349.454	41.148	137.816	528.418
August	352.334	42.730	143.117	538.181
September	577.880	70.451	235.963	884.295
October	841.952	102.869	344.541	1289.362
November	970.876	117.929	394.982	1483.788
December	1085.482	130.301	436.418	1652.202
Total	10169.413	1197.554	3845.657	15212.625

Table 6. Heating energy needs of the storage facility

Month	$Q_{conduct}$ [kWh]	$Q_{air\ leakage}$ [kWh]	$Q_{iv, supply}$ [kWh]	$Q_{space}$ [kWh]
January	238.676	19.802	97.018	258.478
February	226.526	18.654	91.392	245.180
March	175.063	14.214	69.638	189.276
April	151.388	12.109	59.328	163.498
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	89.562	7.897	38.688	97.459
November	137.686	11.874	58.176	149.561
December	167.576	14.214	69.638	181.790
Total	1186.477	98.764	483.878	1285.242

- Zero occurs in the results when the temperature outside is higher than the temperature inside.

### 3.2.2 Other energy needs

#### Energy needs for ventilation

The method presented in FBC Part D5 allows to calculate net heating energy need for ventilation only for systems with constant controlled air volume (D5 Suomen rakentamismääräyskokoelma, 2012).

The project has two ventilation units discussed in detail in Chapter 2 'Reference object'. Their net heating energy needs for ventilation were assessed separately using Equations (3.11; 3.12; 3.13). For the values used in the equations, please, refer to Table 7.

$$Q_{iv} = t_d t_v \rho_i c_{pi} q_{supply} \left( (T_{inb} - \Delta T_{fan}) - T_{recov} \right) \Delta t / 1000 \quad (3.11)$$

$$T_{recov} = T_{out} + \frac{\Phi_{recov}}{t_d t_v \rho_i c_{pi} q_{supply}} \quad (3.12)$$

$$\Phi_{recov} = \eta_{exchanger} t_d t_v \rho_i c_{pi} q_{exhaust} (T_{in} - T_{out}) \quad (3.13)$$

Table 7. Set parameters for Equations (3.11; 3.13)

Parameter	Value	Taken from
$\Delta T_{fan}$	0.5 °C	FBC Part D5
$\eta_{exchanger,house}$	0.6	FBC Part D5 Table 3.3 (for a counter-flow heat exchanger)
$\eta_{exchanger,storage}$	0.4	Educated assumption

#### Energy need for domestic hot water

The house is connected to the water distribution network that supplies it with cold water. Cold water is then heated by the heat pump condenser to the temperature appropriate for domestic use. The heated water is stored in 180 L water tank. The energy need for domestic hot water is calculated using Equations (3.18; 3.19). For the values used in the equations, please, refer to Table 8.

$$Q_{dhw,net} = \rho_v c_{pv} V_{dhw} (T_{dhw} - T_{dcw}) / 3600 \quad (3.18)$$

$$V_{dhw} = n V_{dhw,spec,person} \Delta t / 1000 \quad (3.19)$$

Table 8. Set parameters for Equations (3.18; 3.19)

Parameter	Value	Taken from
$T_{dhw}$	55 °C	FBC Part D3
$T_{dcw}$	5 °C	FBC Part D3
$n$	2 people	Given
$V_{dhw,spec,person}$	50 dm <sup>3</sup> /per person per day	FBC Part D5

### Energy need for lighting and electrical appliances

The storage facility was excluded from this round of calculations as its energy need for lighting and electrical appliances is insignificantly small.

Energy needs for lighting and electrical appliances are calculated separately and later combined using Equations (4.1; 4.1\*). For the values used in the equations, please, refer to Table 9.

$$E_{lighting} = k \Sigma P_{light} A_{house} \Delta t f / 1000 \quad (4.1)$$

$$E_{appliances} = k \Sigma P_{app} A_{house} \Delta t / 1000 \quad (4.1^*)$$

Table 9. Set parameters for Equations (4.1; 4.1\*)

Parameter	Value	Taken from
$k_{light}$	0.1	FBC Part D3 Table 3
$k_{app}$	0.6	FBC Part D3 Table 3
$P_{light}$	8 W/m <sup>2</sup>	FBC Part D3 Table 3
$P_{app}$	3 W/m <sup>2</sup>	FBC Part D3 Table 3
$f$	0.9	FBC Part D5 (for a room-specific switch control)

### Results

The following Table 10 contains the results for Chapter 3.2.2 'Other Energy needs'. These include energy need for ventilation, energy need for domestic hot water and energy need for lighting and electrical appliances.

Table 10. Other energy needs of the house

Month	$Q_{iv,house}$ [kWh]	$Q_{iv,storage}$ [kWh]	$Q_{dhw,net}$ [kWh]	$E_{light\&app}$ [kWh]
January	171.366	55.235	180.833	219.538
February	168.241	52.147	163.333	198.292
March	73	38.807	180.833	219.538
April	42	32.717	175.000	212.456
May	0	0	180.833	219.538
June	0	0	175.000	212.456
July	0	0	180.833	219.538
August	0	0	90.417	109.769
September	0	0	175.000	212.456
October	0	20.237	180.833	219.538
November	38	32.026	175.000	212.456
December	73	38.807	180.833	219.538
Total	566.836	269.975	2038.750	2475.111

- Zero in the results can mean two things, either the heat exchanger covers the needs for additional heating or that the outside air is already hot enough.

- Energy needs for August were reduced, as the owners were absent for about two weeks.

### 3.2.3 Heat loads

The storage facility was excluded from this round of calculation as none of the above-mentioned heat loads are present in it.

Heat loads include all potential heat gains that are either intentional or occur as a side product of day to day activities in the house. This is the energy that has a potential to be reused for heating, thus significantly cutting down on house's overall energy needs.

Heat loads from people, lighting and electrical appliances, solar radiant energy, domestic hot water storage are calculated using Equations (5.1; 1; 5.4; 5.5; 2; 3). For the values used in the equations, please, refer to Table 11.

$$Q_{people} = k n \phi_{person} \Delta t / 1000 \quad (5.1)$$

$$Q_{light\&app} = E_{light\&app} \quad (1)$$

$$Q_{solar} = \Sigma G_{rad,hor} F_{dir} F_{trans} A_{win} g \quad (5.4)$$

$$g = 0.9 g_{permeation} \quad (5.5)$$

$$Q_{dhw,storage,load} = \frac{Q_{dhw,storage,loss}}{2} \quad (2)$$

$$Q_{dhw,storage,loss} = \frac{Q_{dhw,storage,loss,year}}{365} \Delta t \quad (3)$$

Table 11. Set parameters for Equations (5.1; 5.5; 6.4)

Parameter	Value	Taken from
$k_{person}$	0.6	FBC Part D3 Table 3
$\phi_{person}$	2 W/m <sup>2</sup>	FBC Part D3 Table 3
$n$	2 people	Given
$G_{radiant,horizontal}$	-	FBC Part D3, Annex 2, Table L2.3
$F_{direction}$	-	FBC Part D3, Annex 2, Table L2.3
$F_{transmittance}$	0.75	FBC Part D5 (for windows with no shade or permanent curtains)
$g_{permeation}$	0.7	FBC Part D5 Table 5.1 (for triple-glazed windows)
$Q_{dhw,storage,loss,year}$	830 kWh	FBC Part D5 Table 6.3b (for 150 L water tank)

## Heat load from a fireplace

Not much is known about a specific type of fireplace installed in the house. However, it is safe to assume that the fireplace is used conventionally for burning wood with an intent to heat up the house. Most likely, it is a pre-ordered brick chamber that slowly releases heat up to 30 hours upon the initial usage. Jalanti fireplace model that doubles as a baking oven from Tulikivi manufacturer was used as a reference object for a fireplace (Tulikivi, n.d.).

It is known that during the monitoring season, one and a half stacked cubic meters (1.5 stacked m<sup>3</sup>) of birch tree logs were burned in the fireplace. (Alakangas, Erkkilä, & Oravainen, 2008) state that 1 stacked m<sup>3</sup> of birch tree releases approximately 1700 kWh of heating energy. Thus, 1.5 stacked m<sup>3</sup> of birch tree would release 2550 kWh of heating energy.

It is assumed that the fireplace was used evenly during the heating season. It is also assumed that the fireplace heating only took place during colder months of the year, those include months from November till March.

Heat load from a fireplace is calculated using Equation (4).

$$Q_{firepalce} = \frac{Q_{fireplace,total}}{\Delta t_{heating\ season}} \Delta t_{month} \quad (4)$$

## Energy recovered from heat loads

Heat load energy recovered for heating is calculated using Equations (5.10; 5.11; 5.14; 5.13; 5.15; 5.16).

$$Q_{int.heat} = \eta_{heat} Q_{heat\ load} \quad (5.10)$$

$$\eta_{heat} = \frac{1-\gamma^a}{1-\gamma^{a+1}} \quad (5.11)$$

$$\gamma = \frac{Q_{heat\ load}}{Q_{space}} \quad (5.14)$$

$$a = 1 + \frac{\tau}{15} \quad (5.13)$$

$$\tau = \frac{C_{building}}{H} \quad (5.15)$$

$$H = \frac{Q_{space}}{(T_{in}-T_{out})\Delta t} 1000 \quad (5.16)$$

$C_{building}$  - Building's interior effective thermal capacity is estimated to be 110 Wh/(m<sup>2</sup> K) based on the table values available in FBC Part D5, Table 5.5 for a small house with 'Medium-heavy II' type of construction.

## Results

The following Table 12 contains the results for Chapter 3.2.3 'Heat loads'. These include heat loads per month and energy recovered from heat loads.

Table 12. Heat loads and recovered energy

Month	$Q_{heat\ load}$ [kWh]	$Q_{int.heat}$ [kWh]
January	884.281	884.187
February	950.687	950.205
March	1176.931	1169.150
April	777.826	777.559
May	958.032	937.644
June	882.916	703.914
July	894.546	527.634
August	634.450	522.271
September	699.270	687.216
October	496.440	496.431
November	877.526	876.341
December	862.877	862.508
Total	10095.784	9395.059

### 3.2.4 Heating energy consumption

Energy consumption is a quotient of net energy needs and the system's efficiency factor. This relation is shown for space heating with Equations (6.1; 3.1), for ventilation with Equation (6.1\*), for domestic hot water with Equation (6.4). For the values used in the equations, please, refer to Table 13.

$$Q_{heating,space} = \frac{Q_{space,net}}{\eta_{space}} \quad (6.1)$$

$$Q_{space,net} = Q_{space} - Q_{int.heat} \quad (3.1)$$

$$Q_{heating,iv} = \frac{Q_{iv}}{\eta_{iv}} \quad (6.1^*)$$

$$Q_{heating,dhw} = \frac{Q_{dhw}}{\eta_{dhw}} \quad (6.4)$$

Table 13. Set parameters for Equations (6.1; 6.1\*; 6.4)

Parameter	Value	Taken from
$\eta_{space}$	0.84	FBC Part D5 Table 6.2 (for radiant floor heating system)
$\eta_{iv}$	1	FBC Part D5 Chapter 6.2.2 (efficiency of ventilation machine battery)
$\eta_{dhw}$	0.85	FBC Part D5 Table 6.3 (for systems without hot water circulation pipe)

## Results

The following Table 14 contains the results for Chapter 3.2.4 'Heating energy consumption'. These include energy consumption for space heating, energy consumption for ventilation and energy consumption for domestic hot water.

Table 14. Total heating energy consumption

Month	$Q_{heating,space}$ [kWh]	$Q_{heating,iv}$ [kWh]	$Q_{heating,dhw}$ [kWh]
January	1482.051	171.366	352.423
February	1176.725	168.241	351.966
March	768.745	73.442	283.238
April	1030.926	42.232	274.102
May	327.414	0	283.238
June	0	0	274.102
July	0	0	283.238
August	0	0	141.619
September	190.390	0	274.102
October	990.500	0	283.238
November	846.518	38.112	274.102
December	1104.701	73.442	283.238
Total	7917.971	566.836	3358.606

- Zero occurs in the results when energy recovered from heat loads fully covered the energy needs for that month. In the summer months, the house experienced energy surplus. However, this surplus was later dismissed as there was no effective way of storing the recovered energy.

### 3.2.5 Purchased energy

The monitoring data only provides records of monthly purchased energy for the house. Thus, previously received results must be converted into purchased electrical energy. Monitoring data provides three sets of values: monthly purchased energy for the heat pump, monthly purchased energy for other needs and the total power consumption of a house. The heat pump is only liable for heating spaces and water. The total power consumption of a house includes energy consumed by the heat pump, ventilation, lighting and other appliances.

The heat pump's purchased energy consumption is calculated using Equation (6.17). The values used in the equation can be found in Table 15.

$$E_{HP} = \frac{Q_{heating,space}}{SPF_{space}} + \frac{Q_{heating,dhw}}{SPF_{dhw}} \quad (6.17)$$

Purchased energy for ventilation units is calculated using Equations (7.1; 7.2). The values used in the equations can be found in Table 15.

$$E_{iv} = SFP_{iv} q_{supply} \Delta t \quad (7.1)$$

$$SFP_{iv} = \frac{P_{iv}}{q_{supply}} \quad (7.2)$$

Table 15. Set parameters for Equations (6.17; 7.2)

Parameter	Value	Taken from
$SFP_{space}$	3.5	FBC Part D5 Table 6.13 (for heating spaces)
$SFP_{dhw}$	2.3	FBC Part D5 Table 6.13 (for heating domestic water)
$P_{iv,house}$	60 W	Given
$P_{iv,storage}$	20 W	Educated assumption

Total purchased energy is calculated using Equation (2.1).

$$E_{total} = E_{HP} + E_{iv} + E_{light\&app} \quad (2.1)$$

## Results

The following Table 16 contains the results for Chapter 3.2.5 'Purchased energy'. The results were rearranged to be compatible with the monitoring data presented in Chapter 2.2 'Monitoring data'. Table 16 includes purchased energy for heat pump, purchased energy for other needs and total purchased energy. The purchased energy for other needs is the sum of purchased energy for ventilation and energy need for lighting and electrical appliances. This relation is shown in Equation (2.1\*).

$$E_{other} = E_{iv} + E_{light\&app} \quad (2.1^*)$$

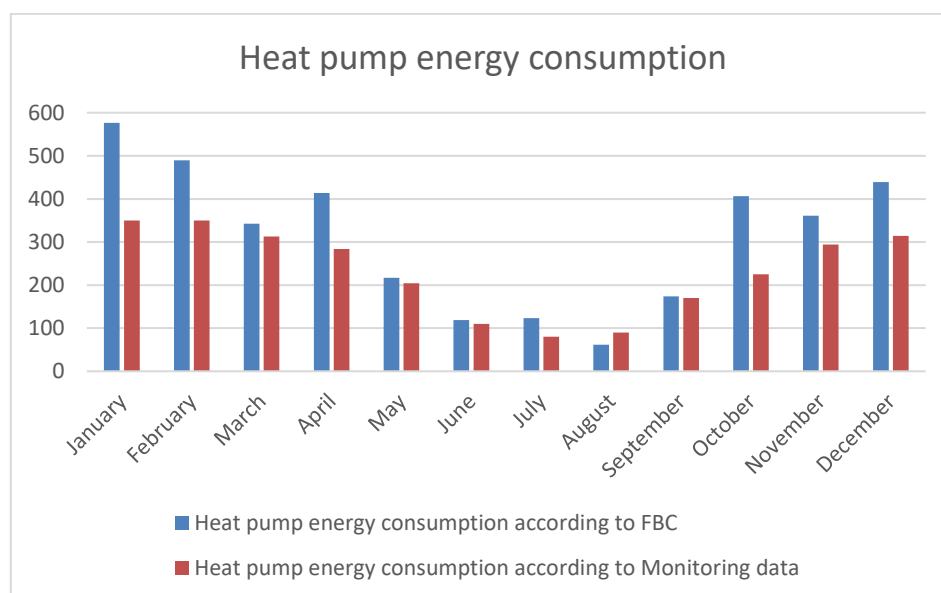
Table 16. Purchased energy

Month	$E_{HP}$ [kWh]	$E_{other}$ [kWh]	$E_{total}$ [kWh]
January	576.671	313.778	890.448
February	489.236	283.412	772.648
March	342.788	313.778	656.566
April	413.725	303.656	717.381
May	216.694	313.778	530.472
June	119.175	303.656	422.830
July	123.147	313.778	436.925
August	61.574	204.009	265.582
September	173.572	303.656	477.228
October	406.147	313.778	719.925
November	361.037	303.656	664.693
December	438.776	313.778	752.554
Total	3722.541	3584.711	7307.252

### 3.3 Results according to FBC method

Energy analysis was limited to numbers presented in the monitoring data. While the numbers received via FBC method were significantly higher than the numbers presented in monitoring data, FBC managed to correctly portray the general yearly trend for energy consumption, which adds legitimacy to its results. On average, the results received in Chapter 3.2.5 'Purchased energy' were 44% higher than in the monitoring data. The results for heat pump energy consumption were only 34% higher, while the results for energy consumption for other needs were on average 55% higher than the numbers recorded in the monitoring data. Such deviations in the results can be explained in a variety of ways. Later in this chapter, results in the order that they were received will be explained.

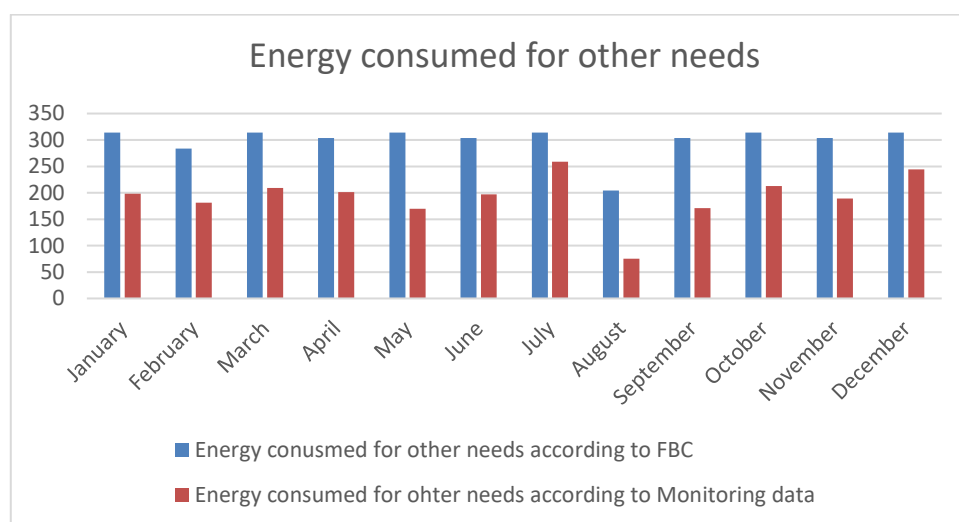
#### Purchased energy for heat pump



Month	$E_{HP,according\ to\ FBC}$ [kWh]	$E_{HP,actual}$ [kWh]
January	576.671	350
February	489.236	350
March	342.788	313
April	413.725	284
May	216.694	204
June	119.175	110
July	123.147	80
August	61.574	90
September	173.572	170
October	406.147	225
November	361.037	294
December	438.776	314
Total	3722.541	2784

- Results for March, May, June and September were spot on, being on average only 7% higher than the monitoring data, with September results being the closest with only 2% higher.
- August was the only month in which the calculated energy consumption was smaller than the actual energy consumption. It is worth remembering that August results were manually cut in half to account for the time the family spent on vacation. Perhaps, the vacation took less time, or that the heat pump kept running despite the family being away.
- Results for January, February, November and December, while showing higher numbers, correctly followed the trend established in the monitoring data. It is believed that higher numbers may be the result of an incorrect annual mean production index selected for the heat pump. The number was taken from FBC Part D5 Table 6.13 and not from the manufacturer. Thus, it is possible that the actual annual production index of heat pump is higher with a lower energy consumption.
- The only two months the results for which did not follow the general trend were April and October. This is attributed to the fact that in this method wood burning in a fireplace was calculated for the period from November until March. The results show that the wood burning could have started as early as in October and lasted until the end of April. If the energy from the fireplace was spread out across a longer period, the results would look much smoother and these spikes in energy consumption for April and October would disappear.

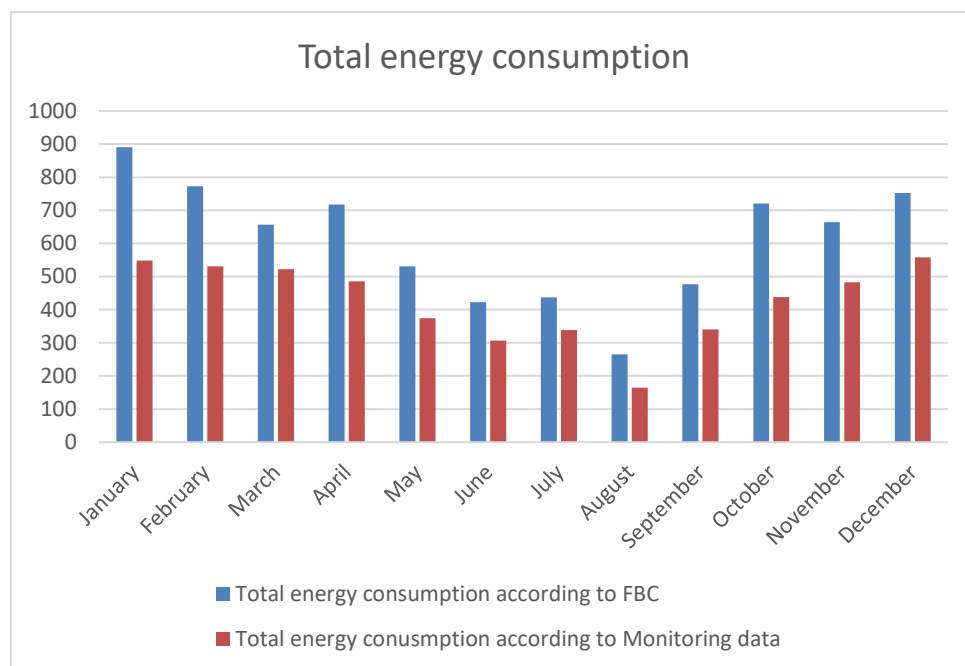
### Purchased energy for other needs



Energy consumption of lighting and electrical appliances was based on average numbers available in FBC Part D5 per square meter. In reality these numbers heavily depend on specific needs on a given day. For example, more lighting was used in the winter months than in the summer months due to availability of natural light. FBC does not account for such

details. This explains why the calculated results do not follow the general trend established in the Monitoring data.

### Total purchased energy for the house



Month	$E_{Total,acoring\ to\ FBC}$ [kWh]	$E_{Total,actual}$ [kWh]
January	890.448	548
February	772.648	531
March	656.566	522
April	717.381	485
May	530.472	374
June	422.830	307
July	436.925	339
August	265.582	165
September	477.228	341
October	719.925	438
November	664.693	483
December	752.554	558
Total	7307.252	5091

Energy Analysis method presented in FBC can be used on both old and new buildings throughout Finland. To account for differences in building practices over the years and different climatic conditions, FBC default values are averaged out. In this study, the reference object was new and expectedly performed better than what was calculated.

## 4 ENERGY ANALYSIS VIA AUTODESK GREEN BUILDING STUDIO

Green Building Studio cloud-based service does not have its own modelling tool, instead relying on models submitted from other compatible programs, such as Autodesk Revit. Compared with other methods selected for this study, GBS's functionality is limited. For example, GBS does not allow to define the heating system; instead the system must be selected from a list of predefined systems. That alone may render the results as inadequate and thus requires investigation. Additionally, being an American product, it will be interesting to see how well it performs in the Finnish weather conditions.

### 4.1 Software description

#### Autodesk Revit

Autodesk Revit (later in text referred to as Revit) is a BIM software developed by Autodesk, an American based multinational corporation. This professional tool is widely recognized in the industry by architects, construction and HVAC engineers and designers as a modelling tool for visual representation of a future construction. Autodesk is also praised for its vast net of utility tools and services that are available and can be used in connection with Revit. One of such utility tools is Autodesk Green Building Studio. Figure 4 below shows the network of tools that can be used in conjunction with Revit.

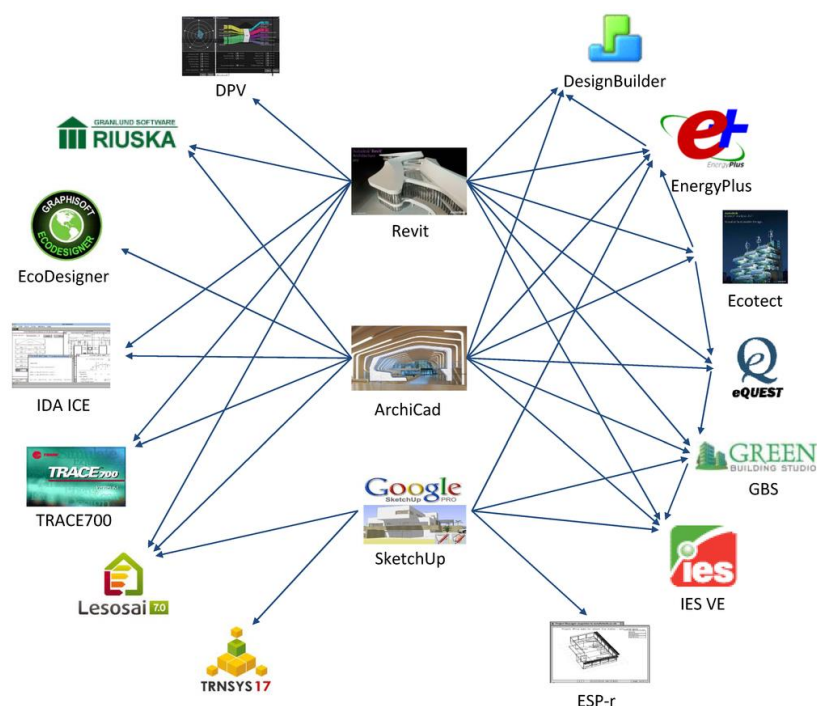


Figure 4. The network of tools that can be used in conjunction with Revit (Bahar, Père, Landrieu, & Nicolle, 2013).

## Autodesk Green Building Studio

Autodesk Green Building Studio (later in text referred to as GBS) is a cloud-based service that performs a whole building's energy, water and carbon analysis. GBS does not have 3D modelling tools, instead relying on an already made models supplied from elsewhere i.e. Revit. GBS operates through gbXML format. It is a purely analytical format that is based on Excel spreadsheets and includes data such as areas of various analytical surfaces, the volumes, building's rotation, thermal transmittance values if available, heating and cooling powers if specified, building's type, scheduling etc. This reliance on gbXML format allows the users to make quick design changes called 'Design Alternatives' in GBS. Design Alternatives can be added upon completing the initial base run to see how individual parameters, such as rotation affect the overall results.

GBS has an extensive database from weather stations around the world (over a million of weather stations in total). This allows GBS to run simulations based on project-specific weather conditions (Autodesk, n.d.).

In conjunction with Revit, GBS is able to run energy simulation based on three different types of models:

- **a). Models made of conceptual masses.** An ideal solution for an early design stage when an architect can still play with the shape and form of a building. GBS will provide a rough yet valuable insight into the effects that glazing, position and rotation cause.
- **b). Models made of room/space elements.** Comes up later in the design process when general geometry has already been set, and building is in the process of being split into wings, sectors, zones, individual apartments and rooms. GBS will give more refined results based on specific values set for each analytical space.
- **c). Models made of building elements.** Includes models where thermal transmittance values for building elements were already set. GBS is supposed to provide an adequate estimate of heating and cooling loads, energy use and lifecycle costs for the building.

This study features a 3D model with defined building elements and spaces within the building. In doing so it is expected to minimize deviations from the monitoring data.

### 4.2 Energy simulation process

The workflow for this method can be described as follows:

- **Step 1: Making 3D model.** This can be done with Revit or with any other compatible software. For the purposes of this study, Autodesk Revit 2017 will be used to create a 3D structural model of a house.
- **Step 2: Defining analytical spaces and zones.** Visually spaces are identical to rooms, but they allow to define settings needed for GBS

analysis. Revit is able to create and analyze spaces on its own, though it is better to define them manually. Manually placed spaces allow to specify their condition type, number of people, electrical loads and occupancy. Zones are made of analytical spaces grouped together. Manually placed zones allow to specify their service type, heating and cooling information (setpoints and incoming air temperature) and air flow.

- **Step 3: Exporting to gbXML.** When the model is finished, it must be converted to gbXML format.
- **Step 4: Creating a new project in GBS.** A new project must be initiated in GBS. GBS allows to define the project's location and other project defaults. If left undefined, GBS will use the information passed from spaces and zones.
- **Step 5: Simulation.** Simulation starts automatically upon submitting gbXML file.
- **Step 6: Analyzing the results.** When simulation is over, GBS allows to view and analyze the results.
- **Step 7: Creating design alternatives (optional).** Design alternatives allow to modify previously made assumptions and see how they affect the results.

#### 4.2.1 3D Model

The 3D model was based on blueprints for the reference object. Modelling proved to be challenging due to software restrictions and contradicting information found in blueprints. A number of design changes had to be made to comply with software restrictions. These design changes are listed in Table 17. Justification for design changes can be found right after Table 17.

Thermal transmittance values (later in text referred to as U-values) for structural elements were taken from blueprints. Revit does not allow to input U-value directly, instead it relies on the thermal conductivity factor ( $\lambda$  value [W/m K]) and thickness of an element. Because of that, U-values were manually converted to  $\lambda$ -factors. The relation between different thermal values is shown in Equation (5).

$$U = \frac{1}{R} \quad R = \frac{t}{\lambda} \quad \lambda = \frac{t}{R} \quad (5)$$

Table 17. Design changes applied to 3D model in Revit

Structural element	Original design		Design changes in Revit	
	House	Storage	House	Storage
Floor	0.15 W/m <sup>2</sup> K (along the edge) 0.11 W/m <sup>2</sup> K (elsewhere)	0.15 W/m <sup>2</sup> K (along the edge) 0.11 W/m <sup>2</sup> K (elsewhere)	0.118 W/m <sup>2</sup> K (uniform ground slab)	0.132 W/m <sup>2</sup> k (uniform ground slab)
Outer walls	0.12 W/m <sup>2</sup> K	0.23 W/m <sup>2</sup> K	-	-

Structural element	Original design		Design changes in Revit	
	House	Storage	House	Storage
Inner walls	100 mm (according to Blueprints)	-	88 mm (according to owner); 2 partition walls deleted	-
Roof/Ceiling	Uninsulated pitched roof; 0.8 W/m <sup>2</sup> K (insulated ceiling)	Uninsulated pitched roof; 0.8 W/m <sup>2</sup> K (insulated ceiling)	0.8 W/m <sup>2</sup> K (flat insulated roof)	0.8 W/m <sup>2</sup> K (flat insulated roof)
Windows	0.67 W/m <sup>2</sup> K (MEKA-type) 0.7 W/m <sup>2</sup> K (MSEA-type)	0.67 W/m <sup>2</sup> K (MEKA-type) 0.7 W/m <sup>2</sup> K (MSEA-type)	1.533 W/m <sup>2</sup> K	1.533 W/m <sup>2</sup> K
Doors	0.8 W/m <sup>2</sup> K	0.8 W/m <sup>2</sup> K	1.936 W/m <sup>2</sup> K	1.936 W/m <sup>2</sup> K
Additional heating solution	Fireplace	-	Fireplace deleted	-

- **Floor.** The floor structure had to be simplified due to software restrictions. GBS was unable to perform energy analysis on a non-uniform structure, as it can only identify one ground slab for each analytical space. Thus, the decision was made to implement two uniform ground slabs with average U-values for the House and Storage.
- **Inner walls.** Early in the modelling process, it was concluded that blueprints contained misleading information regarding the lengths and heights of structural elements. For example, according to blueprints partition walls should be 100 mm thick. In reality, partition walls are 88 mm thick (Leca, n.d.). Additionally, the decision was made to erase two partition walls in the house that did not fully separate spaces.
- **Roof/ceiling.** According to the owner, the roof was left uninsulated. Instead, the insulation was placed directly on top of the attic floor. The attic itself was sealed off. This implies that the ceiling and the attic floor combined act as the upper heat barrier for the house. The same is true for the storage. With that information in mind, thermal properties of the roof were transferred to the ceiling. Unfortunately, GBS failed to recognize the ceiling as the upper heat barrier of the house. After several failed attempts, the decision was made to completely erase the attic and apply the roof directly on top of the first-floor level. Such significant changes in the model's original design may cause serious deviations in energy analysis results.

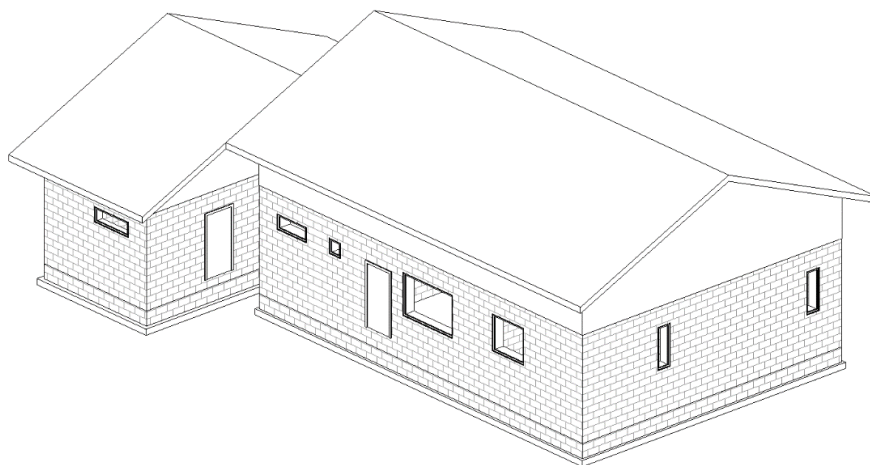


Figure 5. Original design that failed due to GBS software restrictions

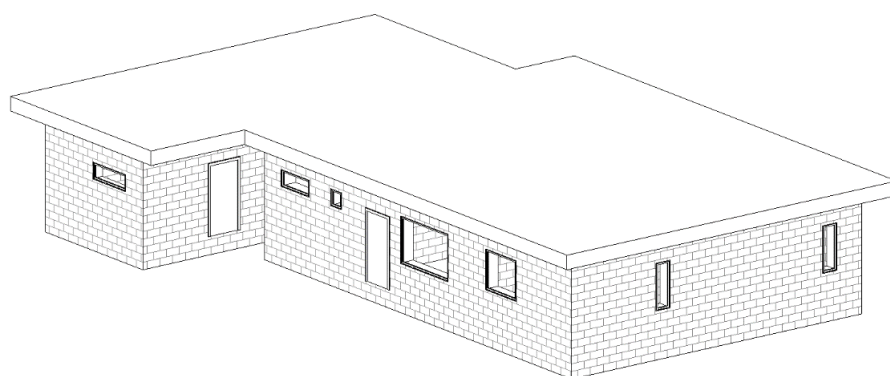


Figure 6. Simplified design with the roof applied on top of the first floor

- **Windows and doors.** The house features triple glazed windows with argon filling supplied by the Finnish manufacturer Alavus Ikkunat Oy (Alavus Ikkunat Oy, n.d.). Revit does not allow to modify thermal properties of windows and doors, instead it provides a list of analytical constructions with predefined thermal properties. Analytical constructions available in Revit proved to be inadequate. While having many options to choose from, none of the windows available in Revit had U-value lower than  $1.5 \text{ W/m}^2\text{K}$ . Windows and doors chosen for the 3D model can be seen in Table 17 above. Both constructions significantly deviate from the original design and will have a negative effect on the energy analysis results.
- **Fireplace.** Due to software restrictions in both Revit and GBS, only one heating solution for the entire project can be specified. Because of that, the fireplace was erased from the model. Since in real life, the fireplace contributes a lot to heating the area (especially in winter months), its exclusion from the model will have a negative effect on the energy analysis results.

#### 4.2.2 Analytical spaces and zones

Spaces were set up via 'Spaces & Zones' toolset, that can be found under 'Analyze' tab. The space arrangement followed an already existing layout of rooms. Each space was confined to and restricted by 'room bounding' elements, e.g., floor, walls, ceiling. All in all, ten spaces were set up in the project: nine in the house, one in the storage. Table 18 lists the spaces that were set up in the project. Their 3D representation can be found in Figure 7.

Table 18. List of spaces set up in the project

<Space Schedule>					
A	B	C	D	E	F
Name	Number	Area	Volume	Condition Type	Occupiable
Space. Bedroom 1 + Close	1	20 m <sup>2</sup>	58.59 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. WC	2	2 m <sup>2</sup>	6.57 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Bedroom 2	3	13 m <sup>2</sup>	37.61 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Bedroom 3	4	12 m <sup>2</sup>	35.12 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Technical hallway	5	7 m <sup>2</sup>	19.47 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Technical room	6	3 m <sup>2</sup>	10.07 m <sup>3</sup>	Heated and cooled	<input type="checkbox"/>
Space. Washing room	7	8 m <sup>2</sup>	22.20 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Sauna	8	3 m <sup>2</sup>	9.77 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Hall	9	52 m <sup>2</sup>	151.49 m <sup>3</sup>	Heated and cooled	<input checked="" type="checkbox"/>
Space. Varasto	10	19 m <sup>2</sup>	51.60 m <sup>3</sup>	Heated	<input type="checkbox"/>

Parameters set and specified for each analytical space can be found in Table 19.

Table 19. Set parameters for each space in Revit

Parameter	House	Storage	Taken from
Occupancy (Yes/No)	Yes	No	Given by the owner
Condition type	Heated and cooled	Heated	Given by the owner
People	57.5 m <sup>2</sup> per person	-	Derived from number of people and area of the house
Sensible heat gain	73.27 W per person	-	Revit default
Latent heat gain	58.61 W per person	-	Revit default
Lighting density	10.76 W/m <sup>2</sup>	-	Revit default
Power density	10.76 W/m <sup>2</sup>	-	Revit default

By choosing the default settings, it was studied how well Revit default values would perform against the Finnish standards.

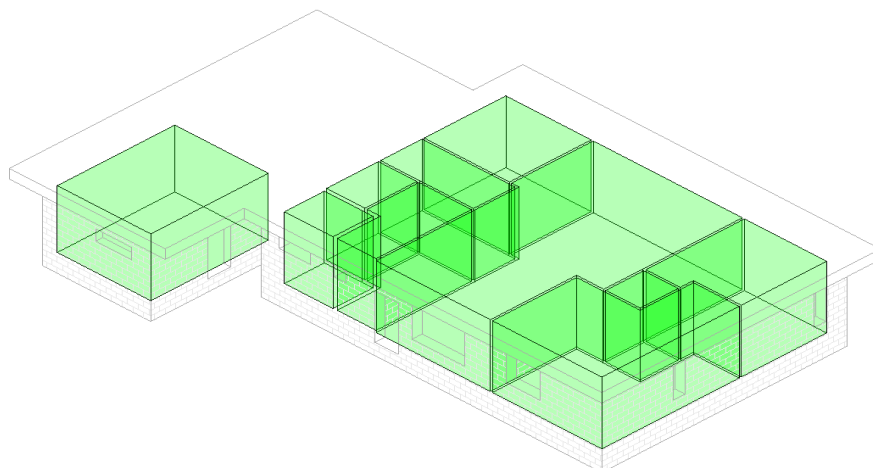


Figure 7. Space arrangement in the model

Spaces grouped together form zones. Zones allow to specify service type, cooling and heating temperatures and outdoor air flow. Two zones named 'House zone' and 'Storage zone' were set up in the project. 'House zone' was made of nine analytical spaces in the house. 'Storage zone' was made of one analytical space in storage. Table 20 below lists the zones that were set up in the project.

Table 20. List of zones set up in the project

<HVAC Zone Schedule 3>							
A	B	C	D	E	F	G	H
Name	Gross Area	Gross Volume	Service Type	Heating Set	Heating Air	Cooling Set	Cooling Air
Default	0 m <sup>2</sup>	0.00 m <sup>3</sup>	<Building>	18 °C	23 °C	26 °C	18 °C
Storage Zone	19 m <sup>2</sup>	51.60 m <sup>3</sup>	Water Loop Heat Pump	5 °C	10 °C	23 °C	12 °C
House Zone	121 m <sup>2</sup>	350.89 m <sup>3</sup>	Water Loop Heat Pump	18 °C	23 °C	26 °C	15 °C

Parameters set and specified for zones can be found in Table 21 below.

Table 21. Set parameters for Zones in Revit

Parameter	House zone	Storage zone	Taken from
Service type	Model 1: Water loop heat pump		Explained below
	Model 2: Radiant floor central heating		Explained below
Cooling setpoint	26 °C	-	Educated assumption
Cooling air temperature	15 °C	-	Given by the owner
Heating setpoint	23 °C	10 °C	Given by the owner
Heating air temperature	26 °C	15 °C	Explained below
Outdoor air	60 L/s	20 L/s	Given by the owner

- **Service type.** Service type defines what kind of HVAC service is available in the zone. The service type must be chosen from a drop-

down list of all services available in Revit. Choosing the appropriate service type proved to be a problem, since the reference object had several independent systems all contributing to its total energy consumption: underfloor water loop heating via heat pump, separate mechanical ventilation units in the house and storage and the fireplace. Revit only allowed to select one service for each zone. Since the monitoring data provides numbers for energy consumption of a heat pump, underfloor water loop heating via heat pump was chosen as the primary service for the model. The closest options that Revit had for such a system were: water loop heat pump, radiant floor central heating. Both were used in the energy analysis.

- **Cooling information.** Cooling information consists of cooling set point and cooling air temperature. The storage was ignored as it was only heated.
- **Heating information.** Heating information consists of heating set point and heating air temperature. It is a requirement in Revit that the heating air temperature must be higher than the heating set point temperature. This arrangement works in projects heated only through mechanical ventilation units, but the reference object used in this study is heated via both the underfloor water loop heating and mechanical ventilation unit that split the air temperature requirements among themselves. To comply with Revit requirements, heating air temperature was set at 26 °C (slightly higher than the heating air set point). The same was done for the storage.
- **Outdoor air information.** Numbers were converted from the known air flows of heat exchangers: 60 L/s in house, 20 L/s in storage.

By this point, it must be acknowledged that the 3D model made in Revit significantly deviates from the original reference object in its design, materials and services. Too many changes had to be made due to software restrictions. Thus, no matter how well Revit model performs in GBS simulation, the results obtained from it cannot be used for a comparative analysis against the results obtained via other energy simulation methods.

The list of software limitations that are expected to render GBS results as incomparable against other simulation methods includes:

- Changes applied to the floor structure.
- Changes applied to the roof structure.
- Revit's poor selection of structural elements available for windows and doors.
- GBS's inability to simulate heat output from a fireplace.
- Differences in FBC and ASHRAE standards i.e. lighting and power density. FBC sets those at 8 and 3 W/m<sup>2</sup> respectively, whereas Revit defaults were 10.76 W/m<sup>2</sup> for each.
- Revit's and GBS's inability to work with complex heating systems that include more than one heating service.
- Revit's poor selection of HVAC service types.
- Revit's restrictions on air temperature input.

To prove the assumption that the model no longer adequately represents the reference object and its energy consumption results will be incomparable, the method was followed through to the end and finished as was originally planned.

### 4.2.3 Export to gbXML

The finished 3D model was converted to gbXML file format and uploaded to GBS cloud-based service.

GBS relies on readings from the nearby weather station. The closest weather station was 218 km away (see Figure 8). Apparently, Revit's weather station coverage did not extend that far to the north. This implies that the information from the weather station will be unrepresentative of the actual weather conditions in the project's location.

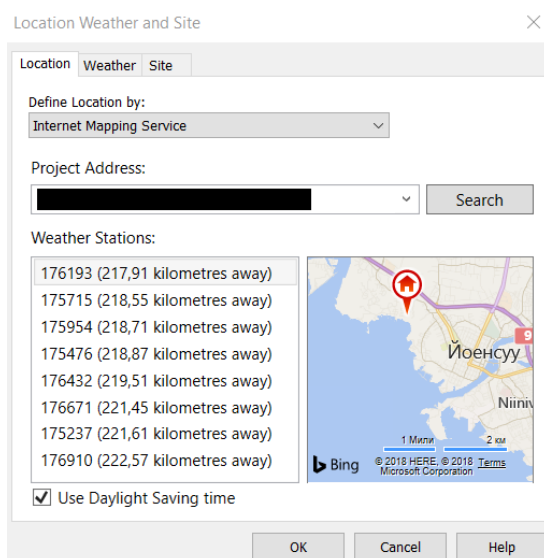


Figure 8. Selecting project's location (the exact location of the house was censored due to privacy reasons)

### 4.2.4 Creating a new project in GBS

Before simulation can be started, a new project must be initiated in GBS. GBS then asks to define certain parameters for this newly initiated project and agree with their 'Terms of Use' (TOU) policy. Parameters defined in GBS can be seen in Table 22 below.

Table 22. Parameters defined in GBS

Building type	Single-family
Operation schedule	24/7 Facility

GBS automatically chose appropriate energy standard - ASHRAE Energy Code for a single-family building type located in Climate Zone 6A.

Additionally, GBS allowed to set up parameters for spaces, zones, building materials, openings and HVAC services. All of this can be done in 'Project Defaults' menu. However, since all the necessary information was already set up in Revit (see Chapters 4.2.1 3D model, 4.2.2 Analytical spaces and zones), this menu was left unchanged.

### 4.3 Results via Autodesk Green Building Studio

Overall, 12 projects were created in GBS with 1051 combined number of runs. The majority of runs (1032) were automatically initiated by GBS and featured minor design alternatives, such as 15° rotation, different materials, different type of service, different operation schedule etc. The rest were manually set up in the way it was described in previous chapters. Several runs failed due to reasons unknown. In such cases, all GBS would respond with was that the issue had occurred related to DOE-2 simulation, which is a building energy analysis engine that both Revit and GBS rely on. According to GBS, the most common error was related to building layers. They were either too thick or too dense. GBS gave no indication of a particular layer that was causing troubles. Two runs that were decided to settle on for the final results are shown in Figure 9 below. The only difference between two final runs was in the service types selected in Chapter 4.2.2 'Analytical spaces and zones'. The water loop heat pump was selected for the run from October 1<sup>st</sup>, and Radiant floor central heating was selected for the run from September 30<sup>th</sup>. These service types were selected based on their resemblance of the original heating solution used in the house.

Actions		Display Options													
Name	Date	User Name	Floor Area (m <sup>2</sup> )	Energy Use Intensity (MJ/m <sup>2</sup> /year)	Electric Cost (/kWh)	Fuel Cost (/MJ)	Total Annual Cost <sup>1</sup>			Total Annual Energy <sup>1</sup>			Compare	Potential Energy Savings	
							Electric	Fuel	Energy	Electric (kWh)	Fuel (MJ)	Carbon Emissions (Mg)			
Project Default Utility Rates														Weather Data: GBS_06M12_02_228240	
Project Default Utility Rates															
Base Run															
<input type="checkbox"/>	Thesis project (same, correct temperature, water loop).xml	10/1/2018 11:42 PM	MrLapatamos	140	862.8	€0.17	€0.01	€2,057	€887	€2,944	11,841	78,262	--		
Base Run															
<input type="checkbox"/>	Thesis project (simp model, sp zn, radiant floor).xml	9/30/2018 9:08 AM	MrLapatamos	140	856.6	€0.17	€0.01	€2,053	€878	€2,930	11,818	77,466	--		

Figure 9. Final energy run in GBS

GBS divided the house's annual energy consumption into two categories: electric consumption (kWh) and fuel consumption in (MJ). By default, GBS placed energy spent on heating spaces and heating water as fuel consumption. Since the reference object had only electric consumption, it was decided to run an alternative run with a fully electric service type. The results for an alternative run are shown in Figure 10.

Actions		Display Options														
Name	Date	User Name	Floor Area (m <sup>2</sup> )	Energy Use Intensity (MJ/m <sup>2</sup> /year)	Electric Cost (kWh)	Fuel Cost (MJ)	Total Annual Cost <sup>1</sup>			Total Annual Energy <sup>1</sup>			Carbon Emissions (Mg)	Compare	Potential Energy Savings	
							Electric	Fuel	Energy	Electric (kWh)	Fuel (MJ)	Energy				
Project Default Utility Rates														Weather Data: GBS_06M12_02_228240		
Project Default Utility Rates																
Base Run																
<input type="checkbox"/>	Thesis project (same, correct temperature, water loop).xml	10/1/2018 11:42 PM	MrLapatamos	140	862.8	€0.17	€0.01	€2,057	€887	€2,944	11,841	78,262	--			
Alternate Run(s) of Thesis project (same, correct temperature, water loop).xml																
<input type="checkbox"/>	Fully electric service	10/8/2018 3:00 PM	MrLapatamos	140	897.7	€0.17	€0.01	€5,243	€194	€5,437	30,182	17,121	--			

Figure 10. Alternative run with a fully electric service type

For reasons unknown, even with the fully electric service type, GBS placed energy consumption for water heating under fuel consumption. It is believed that the issue is with the American building practices and standards where the majority of houses rely on fuel for heating. Nevertheless, electric consumption seems to be at least six times higher than in the monitoring data (30182 kWh against 5091 kWh), not counting energy spent on heating water. This proves the initial statement made in Chapter 4.2.2 'Analytical spaces and zones' that the model made in Revit significantly deviates from the original design and heating solution used in the reference object.

Comparing GBS results with the monitoring data would be unfair, as the model in GBS heated and cooled the house exclusively through the means of its AHU unit. Nevertheless, such a comparison was made. To comply with the monitoring data, energy spent on heating the spaces and heating water was combined. The rest was treated as energy spent on other needs.

The monthly results for the energy consumption of the main heating solution that was specified in GBS can be found in Figure 11.

**Energy spent on heating spaces and water**

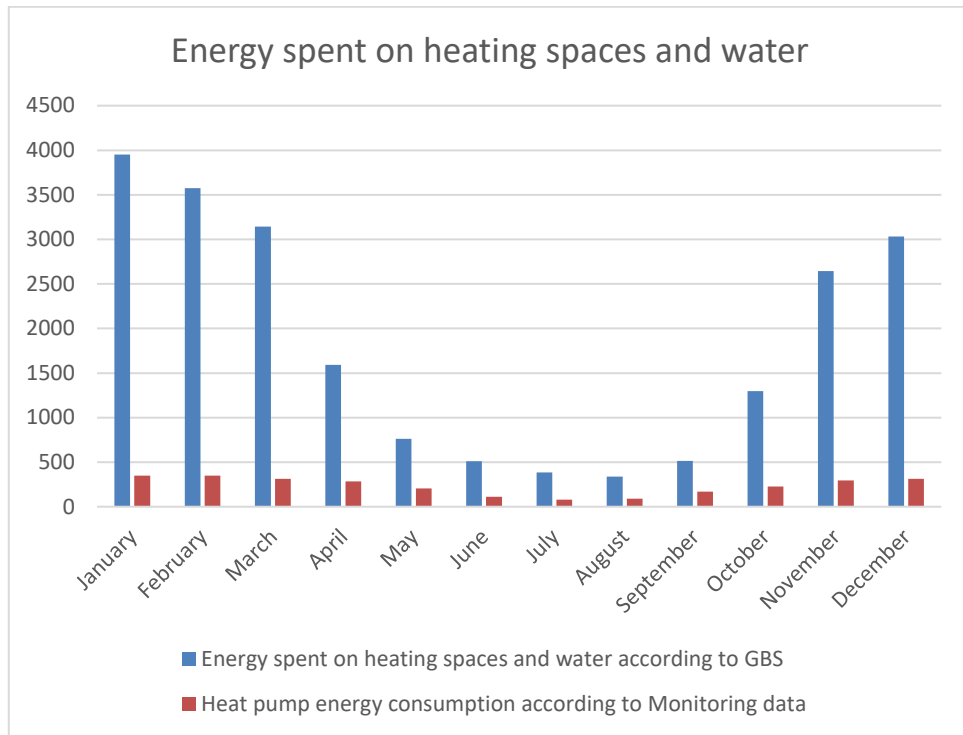


Figure 11. Energy spent on heating spaces and water per month in GBS (Water loop heat pump)

GBS used fuel for heating spaces and water. Numbers above give only a rough estimate of what that energy would be when converted to kWh. Nevertheless, GBS results seem to be many times higher than the monitoring data. Originally, the author specified ‘Water loop heat pump’ as the main heating solution for the project. This raises the question how GBS treat ventilation in the house. Once again, GBS gave little to no explanation on its inner working process. When the model was converted to a fully electric service, the results were different (see Figure 12).

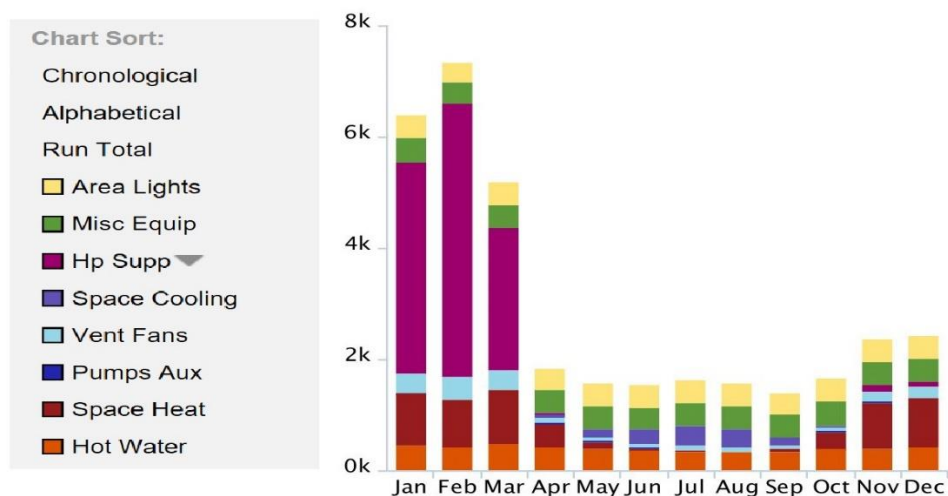


Figure 12. Total energy consumption with a fully electric service type in GBS

In this case, energy spent on space heating was much lower, averaging to about 660 kWh per month (brown on the graph). But then there is 11249 kWh spent on heat pump supply from January to March (purple on the graph). GBS gave no explanation to what the heat pump supply means or where such inflated numbers come from.

The way to make sense of these results is that either:

- a) GBS disregarded the original input and treated the selected service type as a ventilation unit only. In this case, without the help of floor heating and fireplace energy output the demand for the ventilation unit was much higher than it would be in real life. It is also unknown whether GBS considered any heat recovery from the heat exchanger as it was never specified.
- b) Some serious input mistake was made while modelling and that inflated the results so much. Revit model was checked for possible mistakes and none was found.

### Energy spent on other needs

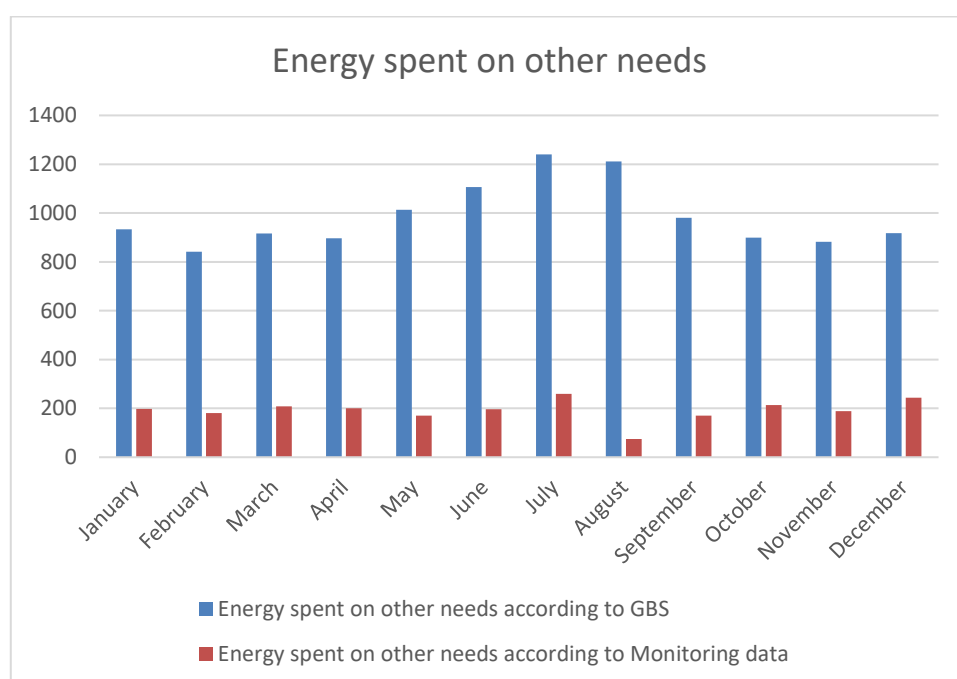


Figure 13. Energy spent on other needs per month in GBS

Other needs in GBS include lighting, miscellaneous equipment, fan power, pump auxiliary power, space cooling via AHU unit. GBS did not allow to specify the reduced consumption for August; thus, in August the difference between the simulated and actual data is the biggest.

While energy spent on lighting and equipment was stationary, the energy spent on ventilation fans and the heat pump's auxiliary devices were dynamic. Therefore, the results fluctuate between the months. The difference in energy standards is evident here. FBC standard states 8 W/m<sup>2</sup>

with 0.1 degree of use for lighting and 3 W/m<sup>2</sup> with 0.6 degree of use for devices. GBS placed these at 10.76 W/m<sup>2</sup> for lighting and 11.03 W/m<sup>2</sup> for equipment.

As can be seen from the results above, no coherent comparison can be made with the monitoring data due to the sheer number of design changes, software limitations and indecisive results.

## 5 ENERGY ANALYSIS VIA IDA ICE PLATFORM

The final method to be investigated is the energy analysis via IDA Indoor Climate and Energy software (later in text referred to as simply IDA). It was chosen for it is the most sophisticated tool out of three and is currently gaining popularity in the Nordic countries. IDA is an equation-based modelling tool which allows to set up the systems with extreme precision. In several countries, IDA can also perform simulations based on country specific energy codes (Finnish localization package\_FBC in case of this study).

### 5.1 IDA ICE description

IDA ICE is software developed by a privately owned Swedish company – EQUA Simulation AB (EQUA Simulation AB, 2018). IDA is capable of running accurate simulations of indoor climate and energy consumption for the entire building and individual zones within it.

For its results, IDA relies on several key functionalities (EQUA Simulation AB, 2018):

- **Usability.** IDA supports an inbuilt graphic engine that allows to model 3D structures and provides immediate tabular feedback for them.
- **Productivity.** IDA supports .IFC file format generated by, e.g. ArchiCAD, Revit and AutoCAD. This allows for a faster and more productive workflow.
- **Flexibility.** Equation-based modelling approach allows to setup the systems with extreme precision and, as a result, get better results.
- **Transparency.** IDA provides a detailed overview of its working process and the algorithm that it uses.
- **Quality.** Unlike with hand-based calculations, spotting a mistake is much easier in IDA, as the input can be changed at any point. This allows to see how a particular parameter affects the results.

### 5.2 Energy simulation process

The workflow in IDA can be described as follows:

- **Step 1: Setting up 'General' tab.** This is the front page of any project in IDA. All the necessary information regarding the weather, location, HVAC systems, building materials, thermal bridges, infiltration rates etc. can be set up here.
- **Step 2: Setting up 3D model and zones.** 3D model can be made with the help of an inbuilt graphic engine. It allows to set up both the general geometry and the geometry of particular zones. Zones must be supplied with the necessary equipment for correct readings.

- **Step 3: Simulation.** The results can be simulated through a ‘Simulation’ tab. IDA allows to perform multiple simulations, yet, for the purposes of this study, only energy simulation was performed.

### 5.2.1 Setting up ‘General’ tab

‘General’ tab allows to define settings for the whole project. By default, these settings affect the whole building, but they can be manually changed for each zone separately later in the process.

#### Global data

A climate file for Joensuu region was downloaded from IDA database. The climate file was chosen on the basis of having recorded temperatures for the year 2017 during the monitoring period. With this file, IDA automatically defined the project’s location. Unlike GBS, IDA did not require to place the exact location on the map. A suburban wind profile was selected on the basis that the reference object was built in a privately owned residential area out of the city centre. Two weeks of vacation time were added in August in ‘Holidays’ tab.

#### Building defaults

Building defaults tab allows to define construction elements, their thicknesses, material composition and U-values. All of these can be later changed in zones. Construction elements were setup according to blueprints available for the reference object. Figure 14 shows building defaults settings in IDA.

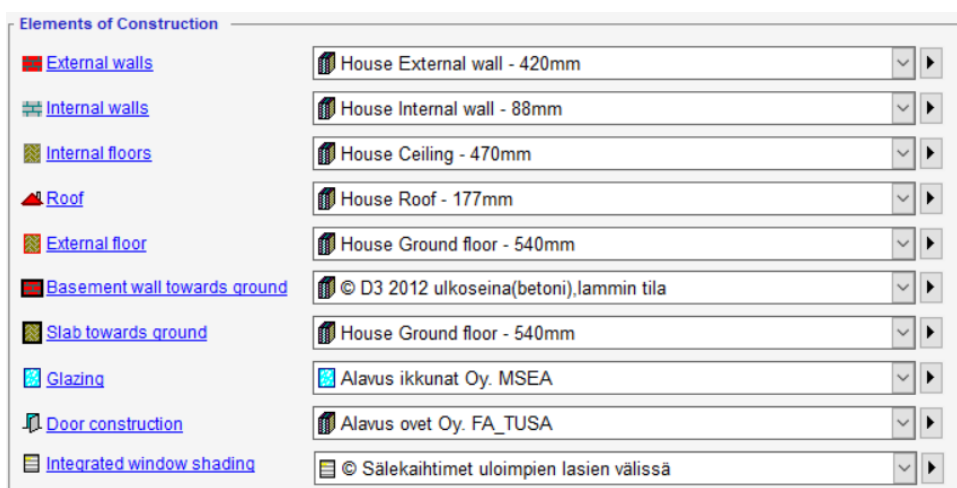


Figure 14. Building defaults settings in IDA

Unlike GBS, IDA had no problem recognizing ceiling as an upper heat barrier for the house and both the ceiling and the roof were set up according to their original designs.

## Site shading and orientation

The project was oriented 15° degrees eastwards from the true north (see Figure 15), according to blueprints. Due to IDA's limitations, the covered area between the house and storage had to be added as horizontal shading surface. This surface was added instead of an extended roof overhang where the owners keep their cars. No vertical shading surfaces were added, because as was stated in Chapter 2.1 'Object description' – "The plot is surrounded with other privately-owned homes of similar size and height, that do not cause any shading effect on the property. "

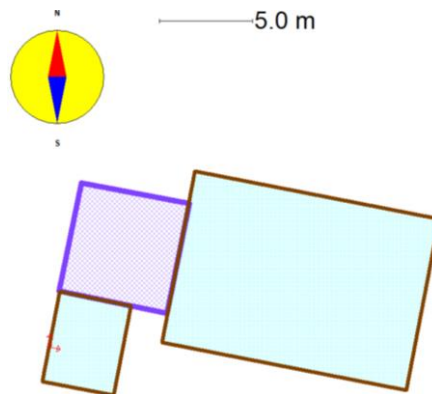


Figure 15. Horizontal shading (purple area) and rotation in IDA

## Thermal bridges

Thermal bridges were given in watts per Kelvin per meter of length. Known values were taken from FBC Part C4. Other values were kept at 'Typical' condition. However, that might prove to be a conservative approach since all the known values were put at 'Good' condition (see Figure 16) and it is entirely possible that the whole house has 'Good' thermal bridge protection.



Figure 16. Thermal bridge conductivity values in IDA

## Ground properties

As no information was available for ground composition, a mixture of sand and soil was selected based on FBC Part C4 standard.

## Infiltration

IDA allows to select either 'Wind driven flow' or 'Fixed infiltration'. For better and more accurate results, the former option was chosen. Air tightness was defined at 2 m<sup>3</sup>/(h\*m<sup>2</sup>) at 50 Pa, following FBC Part D5 standards. Pressure coefficients were auto filled for 'Semi-exposed' area, as while it was established before that the house experiences no shading, it is still protected from winds by tall coniferous trees in its vicinity. Figure 17 shows the infiltration tab in IDA.

Figure 17. Infiltration tab in IDA

## Extra energy and losses

Domestic hot water use can be defined here. Hot water use was setup to 50 L per occupant per day. Two occupants were selected for the project. Water distribution schedule followed the schedule from FBC D3 for a single-family house. Figure 18 shows the water use settings in IDA.

Figure 18. Domestic hot water use in IDA

## System parameters

System parameters tab was left by its default settings as these are internal settings that affect how IDA processes its simulation. Nevertheless, since these parameters may influence the results, the decision was made to include them in Appendix 4: 'IDA system parameters' for full transparency.

## 5.2.2 Setting up HVAC systems

Both the air handling units (later in text referred to as AHU) and heating plant (heat pump) were set up in 'HVAC systems' tab.

### AHU in the House

IDA allows to choose from a selection of premade AHU systems or, alternatively, the system can be set up by the user either from scratch or on the basis of a premade AHU unit. AHU units for the project were based on a 'Standard AHU unit' from IDA selection. They were further modified to resemble the actual AHU units used in the house and storage. A graphic representation of a House AHU unit can be seen in Figures 19 and 20 below.

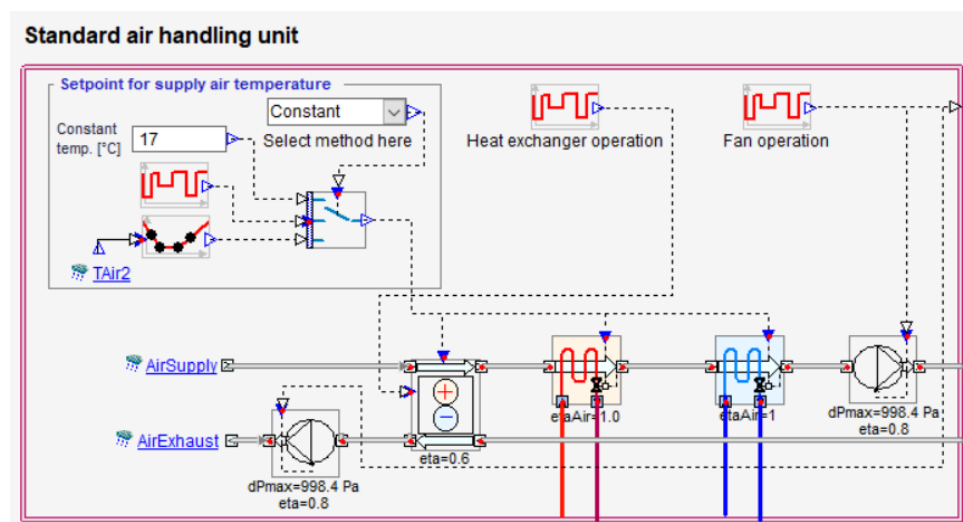


Figure 19. House AHU unit in IDA

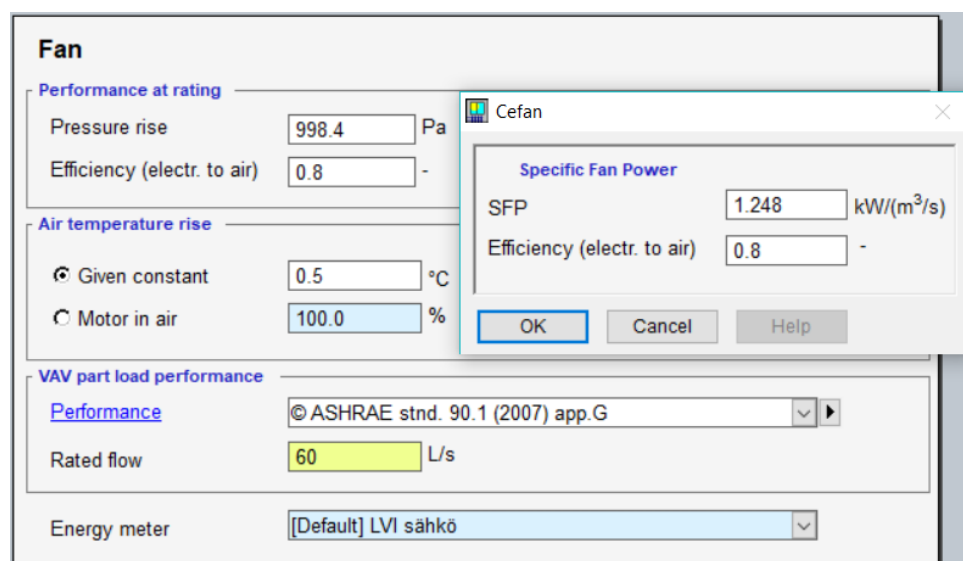


Figure 20. Fan properties for House AHU in IDA

Parameters set up for House AHU unit can be found in Table 23 below.

Table 23. Set parameters for House AHU unit in IDA

Parameter	Value	Taken from
Supply air	17 oC	Educated assumption
Heat exchanger efficiency	0.6	FBC Part D5 (for counter-flow heat exchanger)
Operation Schedule	Always on	-
Fan pressure	998.4 Pa	Automatically defined by IDA
SFP (Specific Fan Power)	1.248 kW/(m <sup>3</sup> /s)	Defined back in Chapter 3
Fan efficiency (electricity to air)	0.8	IDA default
Fan operation schedule	Always on	-
Air flow	60 L/s	Given by the owner
Cooling coil	Yes	Given by the owner
Cooling coil (liquid temperature rise)	5 oC	IDA default
Heating coil	Yes	Given by the owner
Heating coil (liquid temperature drop)	20 oC	IDA default

### AHU in the Storage

The storage AHU was setup in a similar fashion. The supply temperature was set at +10 °C for a period from October 15<sup>th</sup> to April 15<sup>th</sup>. The rest of the year AHU just circulates the air without any cooling or heating. The heat exchanger efficiency was estimated at 0.4. Keep in mind that this is not an actual number, but rather an educated guess, as no real number was given for AHU in the Storage. The cooling coil was disabled by switching its parameter to zero. The heating coil was on for a period from October 15<sup>th</sup> to April 15<sup>th</sup>. Fan pressure, fan efficiency and SFP index were left unchanged as no numbers were provided for them. Air flow was set at 20 L/s. A graphic representation of a Storage AHU unit can be seen in Figure 21.

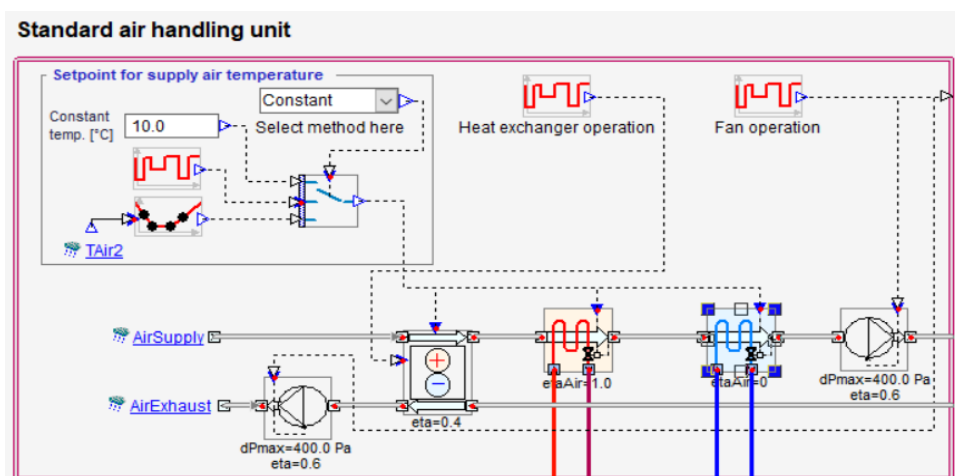


Figure 21. Storage AHU in IDA

## Heating plant

The standard heating plant available in IDA was not suitable for the study. Thus, a plant resembling the real system was manually set up (see Figure 22).

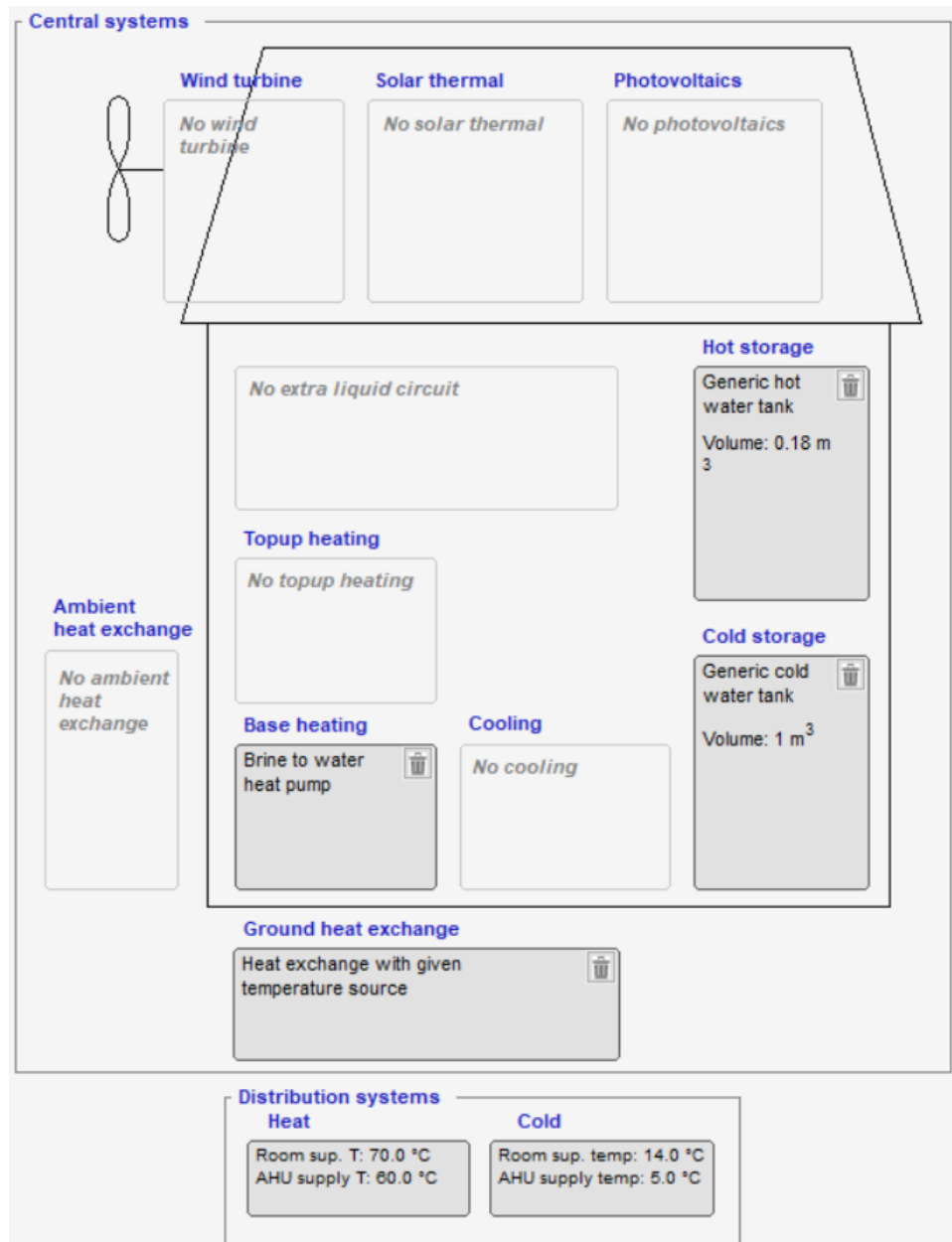


Figure 22. Heating plant arrangement in IDA

The heat pump ground circuit was setup as a heat exchanger with the given temperature source. Power was set at 10 kW and pressure drop was set at 94000 Pa. These numbers come from a heat pump manufacturer (model NIBE F1245-6). Other parameters were left by default (see Figure 23).

**Heat exchange with given temperature source**

Given temperature

Constant  °C

Schedule

Heat exchanger

Power  kW

$t_{\text{given}} - t_{\text{brine}}^*$   °C

Pressure drop  Pa

\*Logarithmic temp. diff.

Figure 23. Ground circuit settings in IDA

The heat pump itself was chosen from a selection of premade heat pumps in IDA that most resembled the one used in the house. The total heating capacity was set at 6 kW, and COP index was set at 5.03 (see Figure 24). Both numbers came from the manufacturer. Although, as it was later learned the actual performance of a heat pump was better.

Heat pump model

Energy meter

Main parameters at rated conditions

Total heating capacity  kW

COP  0-10

Figure 24. Heat pump settings in IDA

The hot water tank that was originally supplied with the heat pump, due to IDA limitations had to be placed as a separate object. Its capacity was defined as 0.18 m<sup>3</sup>, according to the owner. The shape factor was set at 3, to closely resemble the actual shape of the water tank. U-value and number of layers were left by default. The settings for a water tank can be seen in Figure 25.

**Generic hot water tank**

Water volume  m<sup>3</sup>

Shape factor (height/diameter)  -

Insulation U-value  W/(m<sup>2</sup>·°C)

No. layers in model  1 - 50

Figure 25. Hot water tank settings in IDA

It is a requirement in IDA to have a cold water tank in the system even if in reality the house relies on district water supply. The cold water tank capacity was set at  $1\text{m}^3$ , although it should not affect the results.

The hot water circuit was connected to the AHU unit for air heating. The temperature of the supplied water was left by default at  $60\text{ }^\circ\text{C}$ . The setpoint was added so as to stop the supply when the room temperature reaches  $23\text{ }^\circ\text{C}$  (see Figure 26).

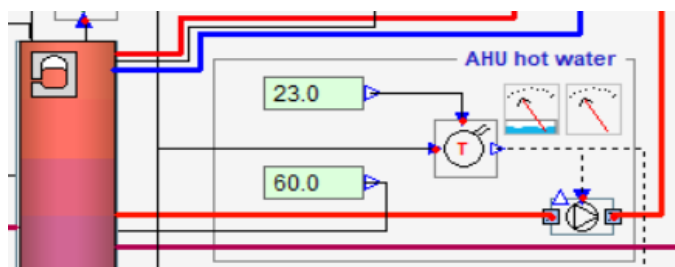


Figure 26. AHU hot water settings in IDA

The same was done for the cold water circuit connected to the AHU unit. Its supply temperature was set at  $5\text{ }^\circ\text{C}$  (see Figure 27).

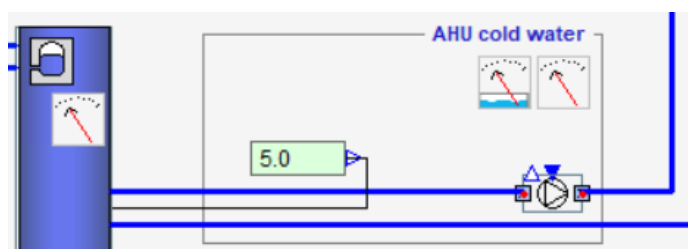


Figure 27. AHU cold water settings in IDA

Hot water for domestic use was set at  $55\text{ }^\circ\text{C}$ , according to FBC Part D5. Supply losses were estimated to be insignificant, since the house had no hot water circulation instead supplying hot water directly from the tank. Other parameters were left by default (see Figure 28).

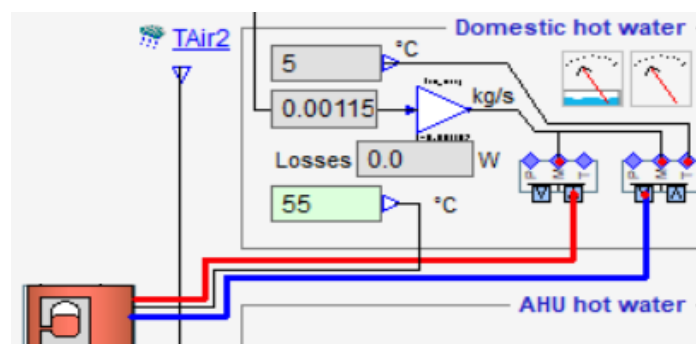


Figure 28. Domestic hot water settings in IDA

Hot water for underfloor heating was turned on and set at  $34\text{ }^\circ\text{C}$ , according to the owner.

### 5.2.3 Making 3D model

#### General geometry

Zones were setup according to the blueprints. Similar to Chapter 4 ‘Energy Analysis via Autodesk Green Building Studio’, faux partition walls in Kitchen and in bedroom were taken away for simplicity. The general zone arrangement is shown in a Figure 29. The 3D view of the model is shown in Figure 30.

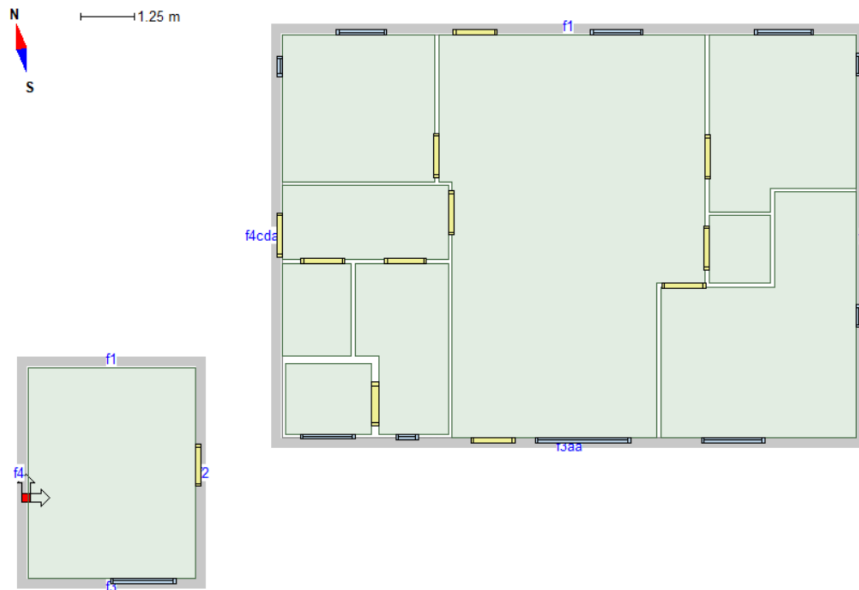


Figure 29. Floor plan with zone arrangement in IDA

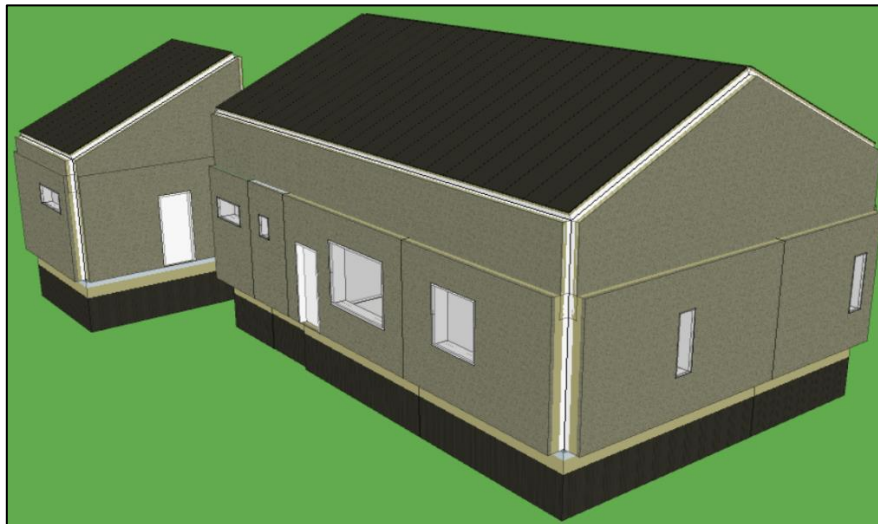


Figure 30. 3D view of the model in IDA

Walls, windows and doors were already defined in ‘General’ tab. Although in some areas, for example in sauna and in storage, walls had to be manually defined as their structure differed from other walls in the house.

## Zone specific settings

Zones were further individually modified, based on zone specific needs and requirements. Those modifications include setting up controller setpoints, a ventilation unit, room specific heating solution and internal gains. Figure 31 below presents a general setup for a zone.

Figure 31. Zone specific settings in IDA

For all zones in the house, 'House AHU' was selected. For a zone in the storage, 'Storage AHU' was selected. The supply and return airflow was set at 0.496 L/(s\*m<sup>2</sup>) as was calculated in Chapter 3. Other values were automatically defined by IDA, based on prior information received from 'General' tab.

Two controller setpoints were defined in the project (one for the house, one for the storage). The minimum and maximum temperatures inside the house were set at 21 °C and 23 °C respectively. The temperature in the storage was set at 10 °C. Other values were left unchanged, as no such information was available. The controller setpoint settings can be seen in Figure 32 below.

	Min	Max	Unit
Temperature	21	23	°C
Mech. supply air flow	0.496	0.496	L/(s.m2)
Mech. return air flow	0.496	0.496	L/(s.m2)
Relative humidity	20	80	%
Level of CO2	700	1100	ppm (vol)
Daylight at workplace	100	10000	Lux
Pressure diff. envelope	-20	-10	Pa

The control action of heating and cooling depends on the controller used in the actual device. Defaults are P control for radiators and PI for most other room units.  
\* when both VAV and other means of cooling have been defined, VAV is used first and setpoints of other room units are offset by 2.0 °C. (Change globally in System Parameters)

Figure 32. Controller setpoints settings in IDA

Zones were equipped with heating/cooling floor systems that run parallel tubes for hot and cold water. These tubes were set 2 cm below the floor. Other settings were left by default (see Figure 33).

Floor heating and cooling (temperature control)			
	Cooling	Heating	
Design power	40.0	40.0	W/m <sup>2</sup>
	365.9	365.9	W
dT(water) at design power	5.0	5.0	°C
Controller	PI		
Sensor	Air temperature		
Coil massflow			
<input type="radio"/> Flow control (2 way valve)			
<input checked="" type="radio"/> Temperature control (3 way valve). Flow given by Design power and this DeltaT:			
		3	°C
Location in slab			
Depth under surface	0.02		m
Heat transfer coefficient			
H-water-pipe-fin*	30		W/(m <sup>2</sup> ·K)

Figure 33. Heating and cooling floor settings in IDA

Internal heat gains (heat loads) were defined for each zone individually based on specific needs of each zone. For example, occupational heat gains (heat load from people) were not defined for storage and technical facility as people rarely occupy these spaces. The same applied to lighting. Heat gain from electrical equipment was placed in each zone. All heat gains were setup in accordance with FBC D3 Table 3. Heat gains from lighting and electrical equipment were given 'Laitteet, kiinteistö' energy meter.

In addition to these standard heat gains, an object resembling the fireplace was installed in the Living room. The idea was that IDA would treat this object as a heat load and automatically adjust heating needs of the house. Its emitted heat per unit was estimated at 850 W, based on its known total energy production. Calculations for the fireplace were done in Chapter 3.2.3 'Heat loads'. Fuel was selected as the energy carrier for the fireplace. 'Uusiutuva polttoaine' was selected as its energy meter. Figure 34 shows the settings for the fireplace in IDA.

Number of units	<input type="text" value="1"/>	
<a href="#">Schedule</a>	Fireplace usage	<input type="button" value="v"/> <input type="button" value="▶"/> *
Emitted heat per unit Only this consumes energy	<input type="text" value="850"/> W	[* Schedule smoothing applied. Change in <a href="#">System parameters</a> ]
Energy carrier	Fuel	<input type="button" value="v"/>
<a href="#">Energy meter</a>	Uusiutuva polttoaine	<input type="button" value="v"/>
<b>Advanced</b>		
Long wave radiation fraction	<input type="text" value="0.0"/> 0-1	
Liquid water emission per unit	<input type="text" value="0.0"/> kg/s	Emitted as water droplets, i.e. the evaporation heat is removed from the air
Dry steam emission per unit	<input type="text" value="0.0"/> kg/s	Emitted as water vapor, i.e. the evaporation heat is not removed from the air
CO2 per unit	<input type="text" value="0.0"/> mg/s	
Utilization factor	<input type="text" value="0.8"/> 0-1	Share of heat and other emissions that are deposited in zone

Figure 34. Fireplace settings in IDA

Fireplace usage was extended for a period from October 15<sup>th</sup> until April 15<sup>th</sup>. Fireplace usage was extended so as to avoid those spikes in energy usage that were recorded in Chapter 3.3 'Results'.

The fireplace energy production rate was based on a reference fireplace model from Tulikivi manufacturer. According to the manufacturer, their typical Jalanti model has the following characteristics (Tulikivi, n.d.):

- 80 % fireplace efficiency
- 4.2 h 100 % of energy emitted
- 15.6 h 50 % of energy emitted
- 27.8 h 25 % of energy emitted

The fireplace was assumed to be used on a regular basis. The fire would be started in the evening when everyone is at home and the temperature outside starts to drop. Its core heating energy would be released during the night so as to keep the house warm. Heating energy would be at about 50 % in the morning and would continue to slowly decline throughout the day when the owners are away at work. Then, the fireplace would be reignited the following evening. It should be noted that this is only an assumption. In reality, lighting of fire could have taken place in different times. Daily schedule for a fireplace can be seen in Figure 35 below.

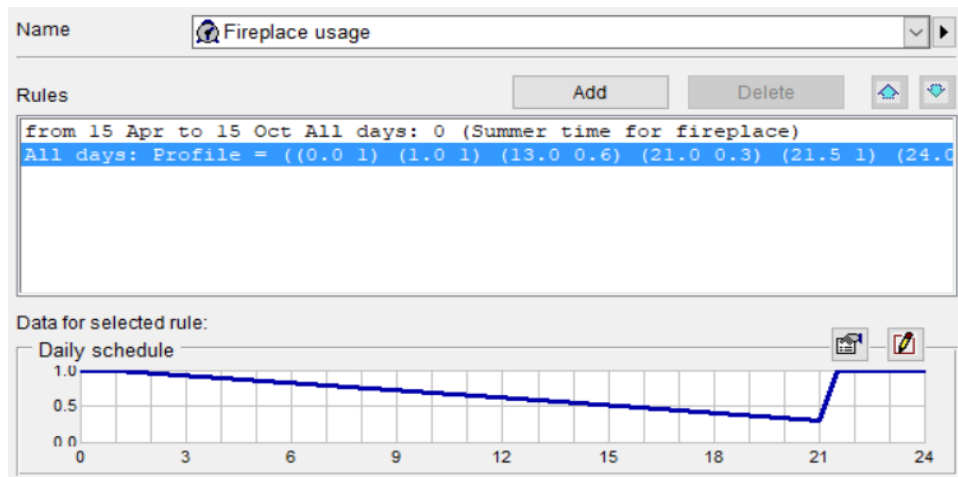


Figure 35. Fireplace usage schedule in IDA

### 5.2.4 Energy consumption simulation

Custom energy simulation was initiated for the period from January 1<sup>st</sup> 2017 to December 31<sup>st</sup> 2017.

### 5.3 Results via IDA ICE

While IDA performed a full energy analysis of the entire house and all of its systems, this study was only concerned with purchased energy results. These results are presented in Figures 36, 37, 38 below.

#### Purchased energy by Energy meter

		Purchased energy		Peak demand	Primary energy	
		kWh	kWh/m <sup>2</sup>	kW	kWh	kWh/m <sup>2</sup>
■	Valaistus, kiinteistö	548	3.9	0.06	658	4.7
■	Laitteet, kiinteistö	1883	13.5	0.21	2259	16.1
■	LVI sähkö	1172	8.4	0.16	1406	10.0
■	Sähkölämmitys, kiinteistö	0	0.0	0.0	0	0.0
	Total, Facility electric	3603	25.7		4323	30.9
■	Uusiutuva polttoaine	2589	18.5	0.85	1294	9.2
	Total, Facility fuel*	2589	18.5		1294	9.2
	Total	6192	44.2		5617	40.1
□	Lämmitys, asukas	2590	18.5	1.5	3108	22.2
	Total, Tenant electric	2590	18.5		3108	22.2
	Grand total	8782	62.7		8725	62.3

\*heating value

Figure 36. Table depicting purchased energy results by energy meter in IDA

### Monthly Purchased/Sold Energy

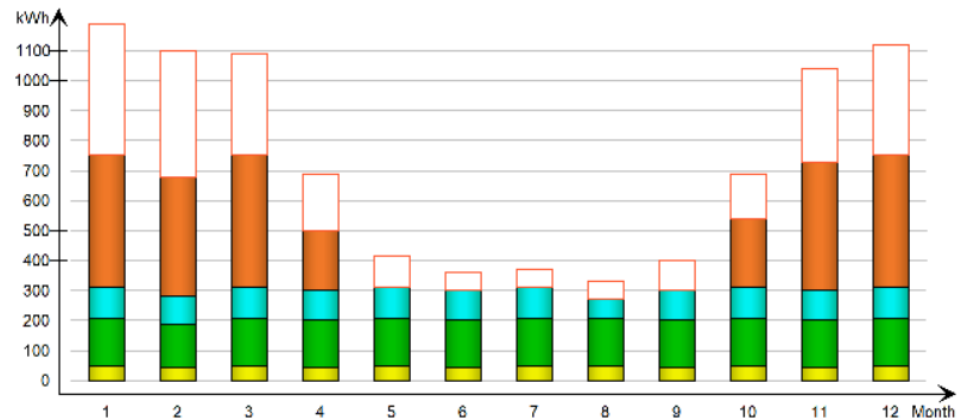


Figure 37. Graph depicting purchased energy spent by month in IDA

As can be seen in the results, IDA counted energy needed for the fireplace in kWh (Uusiutuva polttoaine). In the monitoring data this number is represented by 1.5 stacked m<sup>3</sup> of burned birch tree logs. If fireplace consumption is deducted, the total purchased energy according to IDA will be one fifth (1/5) higher than the monitoring data. This discrepancy mainly comes from other energy needs, as the energy consumption of a heat pump (Lämmitys, asukas) is actually a little lower than in the monitoring data (2590 kWh against 2784 kWh). In order to more carefully study this discrepancy, a graph was produced that compares side by side other energy needs according to IDA and other energy needs according to the monitoring data.

### Purchased energy for other needs

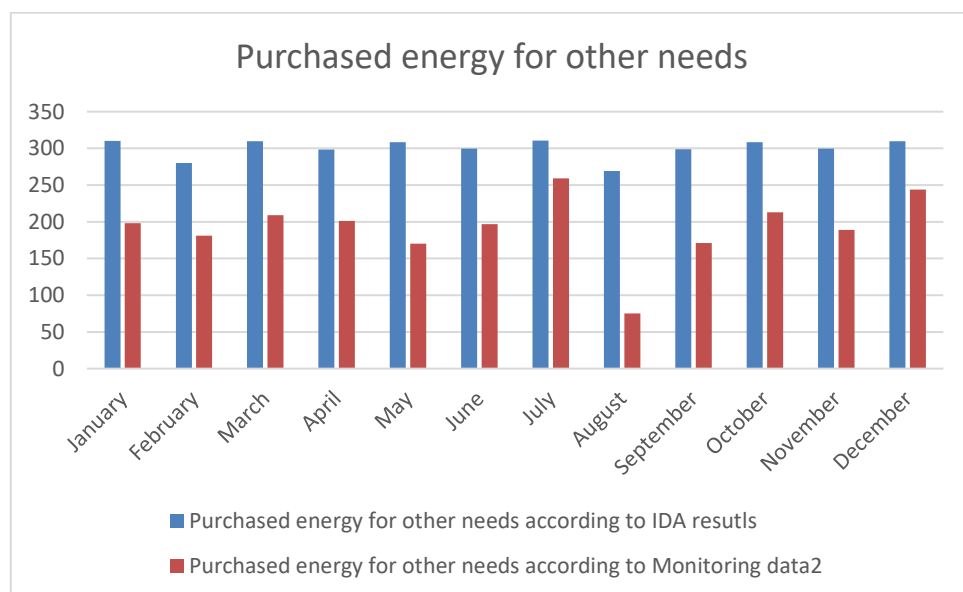


Figure 38. Graph depicting purchased energy for other needs by month

The results are strikingly similar to the ones recorded in Chapter 3.3 'Results'. Those results were also based on FBC standards. This consistency

proves the legitimacy of the results. Thus, this difference can be explained either by outdated standards or that the house wasn't simply fully equipped yet during the monitoring period. Looking at how other energy needs were allocated makes this clearer (see Figure 39).

Month	Facility electric							
	Valaistus, kiinteistö		Laitteet, kiinteistö		LVI sähkö		Sähkölämmitys, kiinteistö	
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)
1	46.6	55.9	159.9	191.9	104.0	124.8	0.0	0.0
2	42.1	50.5	144.4	173.3	94.2	113.0	0.0	0.0
3	46.6	55.9	159.9	191.9	103.1	123.7	0.0	0.0
4	45.1	54.1	154.8	185.8	98.5	118.3	0.0	0.0
5	46.6	55.9	159.9	191.9	101.8	122.2	0.0	0.0
6	45.1	54.1	154.8	185.8	99.9	119.8	0.0	0.0
7	46.6	55.9	159.9	191.9	103.9	124.7	0.0	0.0
8	46.6	55.9	159.9	191.9	62.5	74.9	0.0	0.0
9	45.1	54.1	154.8	185.8	98.8	118.6	0.0	0.0
10	46.6	55.9	159.9	191.9	102.1	122.5	0.0	0.0
11	45.1	54.1	154.8	185.8	99.6	119.5	0.0	0.0
12	46.6	55.9	159.9	191.9	103.4	124.1	0.0	0.0
Total	548.5	658.2	1882.9	2259.5	1171.7	1406.1	0.0	0.0

Figure 39. Other energy needs per need per month in IDA

In Figure 39, energy meters are as follows:

- ‘Valaistus, kiinteistö’ Lighting
- ‘Laitteet, kinteistö’ Electrical equipment
- ‘LVI sähkö’ Energy spent on Fan operation

Figure 39 shows that the bulk of purchased energy went to powering electrical equipment and powering fans in AHU units. Fan energy to electricity efficiency was left by default at 0.8. The results suggest that the actual efficiency of fans was much higher.

As for electrical equipment, it is believed that house, being newly built and only occupied by a family of two, was not fully equipped at the time monitoring took place.

## 6 COMPARATIVE ANALYSIS

Three energy simulation methods discussed in detail in Chapters 3, 4, and 5, were compared and analyzed based on their result accuracy, time consumption, user friendly interface, freedom of input and conformity with the Finnish standards.

### Result accuracy

Results produced by GBS were excluded from comparison due to them being at least six times higher than the monitoring data. For an in-depth analysis of GBS results and its comparison with monitoring data, see Chapter 4.3 'Results via Autodesk Green Building Studio'.

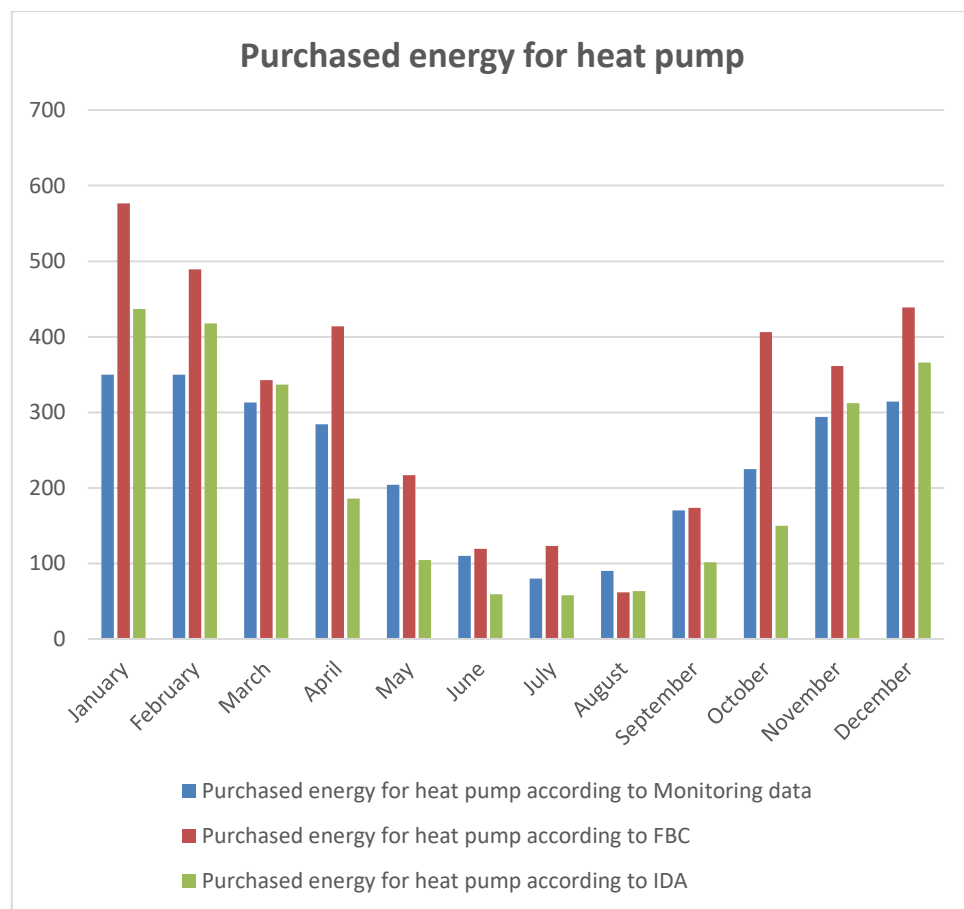


Figure 40. Comparative graph depicting purchased energy for heat pump according to studied methods

The graph in Figure 40 clearly shows that IDA results were much closer to the monitoring data. IDA showed better results only being off by 7%, whereas FBC results were off by 34%. IDA consistently performed better in the winter months than FBC method, showing on average 20% difference whereas FBC showed 48% difference. Though, it should be noted that IDA showed much smaller results for May and September, when FBC results were much closer to the monitoring data in these months.

When it comes to heating solutions, IDA takes more information into account which allows it produce weighted reliable results, such as weather conditions, exact placement of heating solution, room environment, soil conditions etc. FBC method relies solely on mathematical equations and thus, cannot fully assess all the factors that are at play.

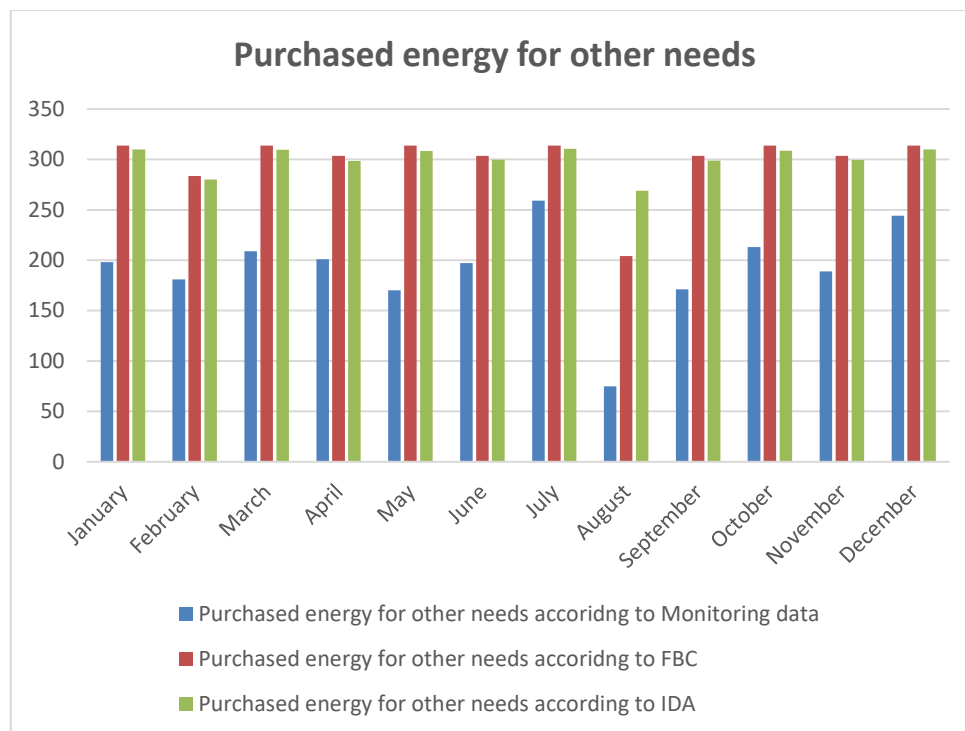


Figure 41. Comparative graph depicting purchased energy for other needs according to studied methods

According to the graph in Figure 41, IDA and FBC showed strikingly similar results. In fact, FBC performed slightly better, because IDA failed to recognize two weeks of August vacation. Later the issue was resolved. It turned out that IDA treated Holidays as Sundays, which in FBC schedules were identical to any working day.

It is believed that the reason why both methods could not accurately assess energy spent on other needs is either related to the fact that the house, being newly built and only occupied by a family of two, was not fully equipped at the time when monitoring took place or is due to outdated energy standards. In the Finnish Ministry of Environment latest version of decree on the Energy Performance of New Buildings (Ympäristöministeriö, 2017), standards for lighting were reduced, which means that the ministry is aware of this issue and is working on improving it in later versions of standards. Yet, from the same decree it follows that the standard for electrical equipment were left unchanged, which leaves room for improvement in future versions.

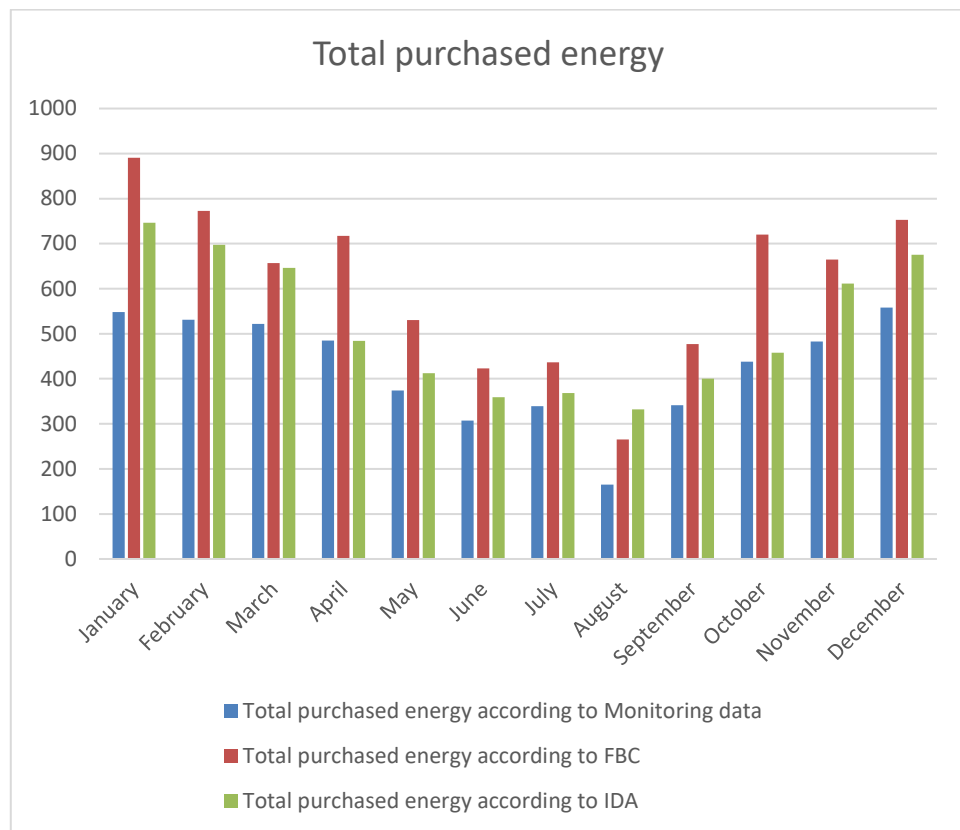


Figure 42. Comparative graph depicting total purchased energy according to studied methods

When the total purchased energy is compared (see Figure 42), IDA again shows more consistent results that follow the general trend presented in the monitoring data.

### Time consumption

FBC method proved to be the most time-consuming of all. Everything had to be calculated manually. Even though the process was greatly sped up by using Excel, in the end it took about a month of daily work (about 7 hours per day) in Excel to get correct readings. FBC method is based on a step-by-step calculation where the user cannot progress without finishing the previous step.

The time spent on GBS method can be divided into two categories: time spent on modelling in Revit and time spent on running energy analysis. Work in Revit would not consume much time for a person with a professional background in engineering and architecture. Conservative estimations would put the time author spent on work in Revit at one week of daily work. Setting up the project in GBS took no time as everything was setup and defined in Revit. GBS runs its simulations in the cloud thus taking no time from the user. Yet, as was mentioned back in Chapter 4, on multiple occasions GBS simulations would fail without any definitive

reason or explanation why this happened. Therefore, trying to manually solve the problem took the author additional two weeks of daily work.

The author was not familiar with IDA interface, thus it had to be learnt in the process. Learning how to operate IDA took the author a week. Working in IDA itself took extra one and a half weeks of daily work.

### **User interface**

Originally it was expected from GBS to perform the best in this category, but this turned out to be wrong due to multiple simulation failures in GBS and no guidance from GBS that would help to resolve these issues. Despite a user friendly interface of Revit and straightforwardness of GBS settings, GBS needs to improve its troubleshooting mechanism.

Being a fully written on paper with guiding information explaining each step of the process, FBC method proved to be very informative and helped the author to better understand the whole process behind simulating energy consumption. However, due to its linear structure tracking mistakes and solving problems was time consuming. FBC method's algorithm is based on a system of interdependent equations; thus if a mistake was made early in the process, every following equation had to be accounted for it. This was avoided to a certain degree by using Excel table format.

Upon learning how to operate IDA, IDA interface proved to be user friendly and working in it was comfortable. What made IDA interface the best for the author, was the ability to always go back and change any parameter. IDA would still run the simulation. This allowed to better monitor input mistakes.

### **Freedom of input**

GBS offered very little freedom of input. GBS interface was found limiting and troublesome to set up the project in the way that it would suit GBS standards. Problems with GBS interface were listed in Chapter 4.

FBC method is mainly based on mean table values. Occasionally they can be changed if better numbers are available. For example, the monthly temperature recordings were changed from the ones available in FBC Part D3 to the weather data from the Finnish Meteorological Institute for the year 2017. Airflow, inside temperature etc. were changed from FBC standard values to better resemble the reference object.

There were no software limitations in IDA. IDA allowed to set up the house geometry, heating plant, AHU units and other parameters in the way that most resembled the reference object. This freedom of input can be

attributed to IDA equation-based modelling approach and its graphic interface.

### Conformity with Finnish standards

GBS understandably did not conform with the Finnish standards as it follows the American ASHRAE standards. In fact, even weather conditions could not be properly set up in GBS, as its weather station coverage does not go that far into the north.

Both FBC and IDA methods conformed with Finnish standards. IDA had an option of a special extension that sets all the default values according to the Finnish standards. The author used this extension so that when values are unknown, they would at least be within the Finnish standards.

### Summary

To summarize all points Table 24 was devised. The results presented in Table 24 are true for a specific reference object studied in this thesis in the Finnish environment. The results might not be similar for other projects in other climatic conditions.

Table 24. Summary of all points made in Chapter 6 ‘Comparative analysis’

Point of comparison	FBC method	GBS	IDA ICE
Result accuracy (heat pump consumption)	34 % difference	681 % difference	7 % difference
Result accuracy (energy spent on other needs)	55 % difference	513 % difference	56 % difference
Result accuracy (total energy spent)	44 % difference	560 % difference	27 % difference
Time consumption	140 h	35 h (Revit); 3 h (GBS) +70 h (solving issues with troubleshooting)	56 h + 35 h (learning)
User interface	Very Good (requires little prior knowledge)	Bad (little guidance with troubleshooting)	Good (requires prior knowledge)
Freedom of input	Limited	Very limited	Good
Conformity with Finnish standards	Yes	No	Yes

## 7 CONCLUSION

This thesis was aimed at studying three energy simulation methods individually and comparing them against each other with an intent to find out what the key factors are that affect the method's result accuracy. The chosen methods were tested on a reference object provided by the commissioning party. In the end, the following key findings can be reported.

The ability to simulate house indoor environment in its intricate details, such as the airflow and heat passing from one room to another is an important factor that should not be underestimated. This was best exemplified with the study of an analogue method described in the Finnish Building Code. FBC method, having no means to simulate house environment with regards to its layout, position and shape performed worse when accounting for heating needs of the house.

The method's conformity with the Finnish standards is perhaps the most important factor when working on a project in Finland. This was best exemplified with the results received from Green Building Studio. One of the biggest flaws in GBS was its complete incompatibility with the Finnish energy standards and Finnish building practices. This wasn't the only issue encountered with GBS. The rest were covered in detail in Chapter 4.

Limited data about the project can also significantly impact the results. This was best exemplified with the results received from IDA ICE. While IDA performed much better than other two methods when simulating energy needs for heating, it failed to accurately simulate energy consumption for lighting and powering electrical equipment in the house. Its results were identical to the ones received with the FBC method. Both methods relied on standard values that for one reason or another were not representative of the actual consumption of the house.

In short, all these factors are important, and should be taken into consideration. The hope is that this thesis will be of any help to those who are torn by the amount of energy simulation methods and tools available on the market.

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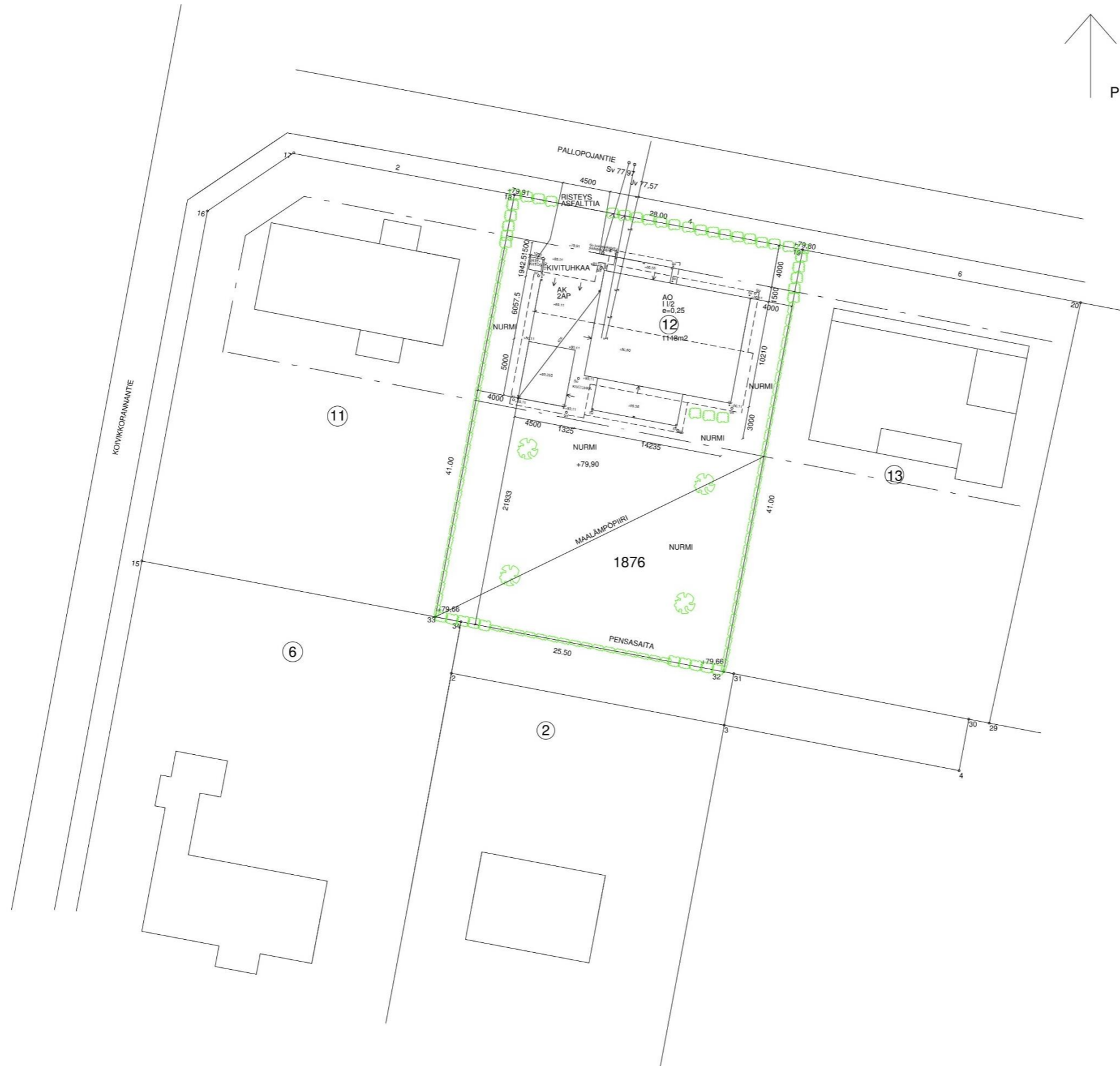
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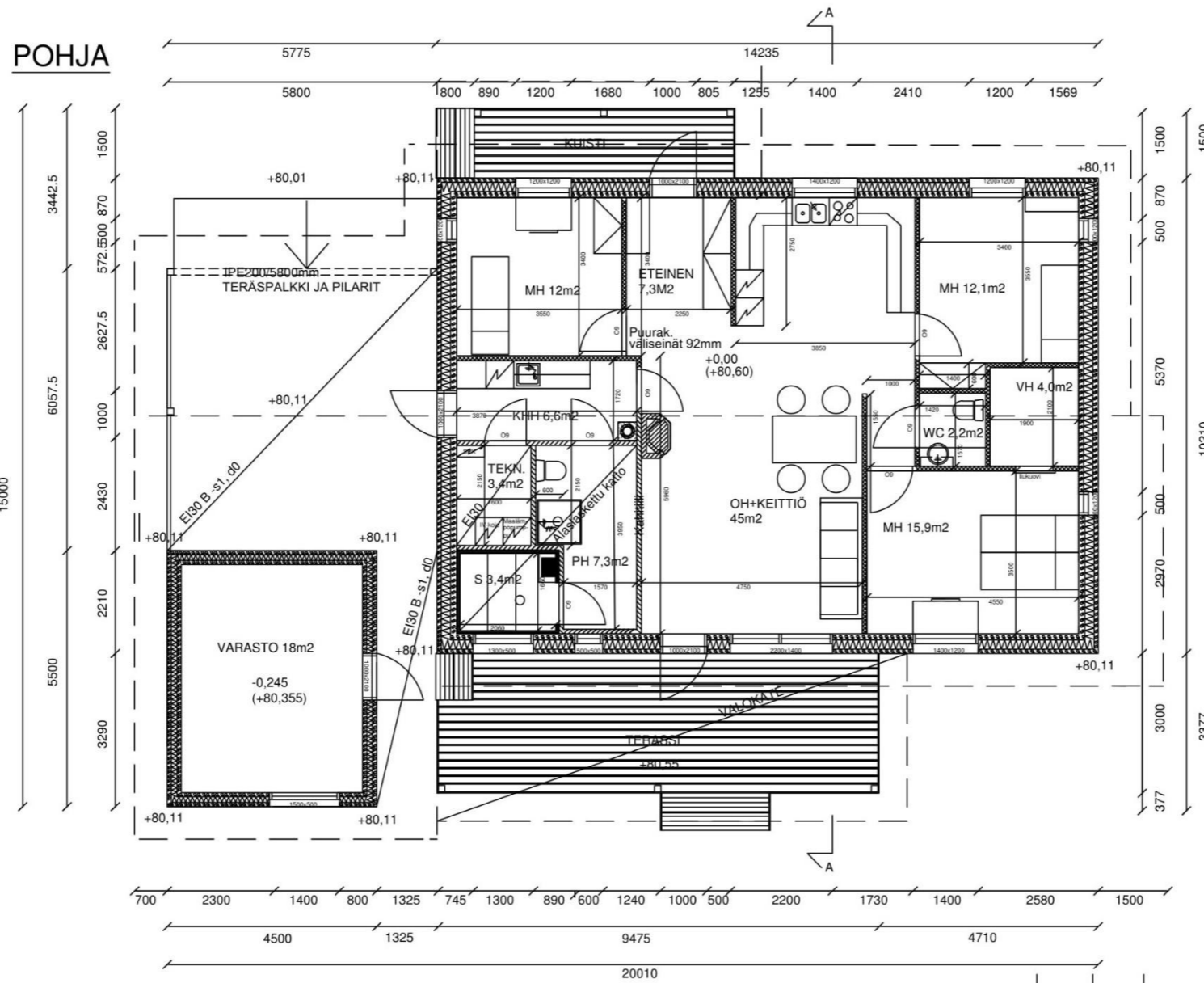
Appendix 1: Blueprints for the reference object (Site plan)



RAKENNUSOIKEUTTA TONTILLA 287m<sup>2</sup>  
 RAKENNETAAN:  
 PINTA-ALA TALO 145m<sup>2</sup>, VARASTO 25m<sup>2</sup>, YHT. 170m<sup>2</sup>  
 KERROSALA TALO 120m<sup>2</sup>, VARASTO 18m<sup>2</sup>, YHT. 138m<sup>2</sup>  
 TILAVUUS TALO 360m<sup>3</sup>, VARASTO 47m<sup>3</sup>, YHT. 407m<sup>3</sup>.  
 RAKENNUSOIKEUTTA JÄÄ 142m<sup>2</sup>

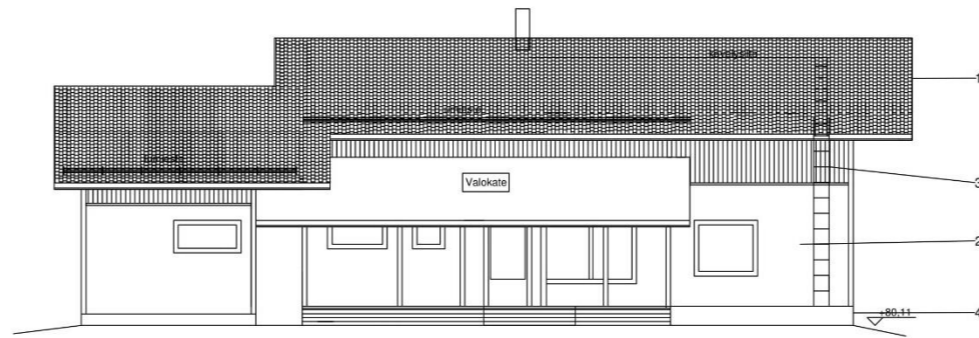
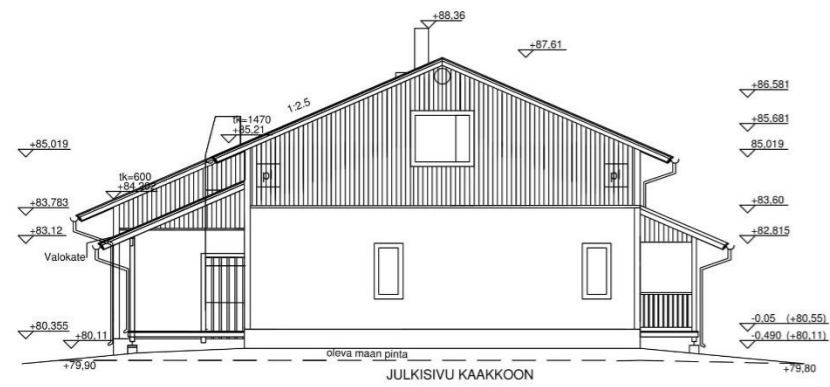
TUNN. LUKU. MUUTOS		NIMI. PVY	
Kaupunginosa	Kortteli	Tontti	Vierasmäen merkintä
Naljakka	1876	12	
Rakennuslupa	UUDISRAKENNUS	Pääpiirustus	Jalka no
Rakennuskooste		Pääpiirustus	Mittakaava: 1:200
Suunnittelija, työnro ja projektin numero		Muuta	
ARK /			
Päädys, suunnitelma, oheen selvennys ja koulutus		Yhteyshenkilö	
		Tiedosto	

Appendix 1: Blueprints for the reference object (Floor plan)



TUNN.	LUKUM.	MUUTOS	NIMIM. PVM	
Kaupunginosa	Korttelitila	Tontti/nro	Viranomaisten merkintöjä	
Noljakka	1876	12	Piirustuslaji	Juoks.no
Rakennustoimenpide	UUDISRAKENNUS		Pääpiirustus	
Rakennuskohde	[REDACTED]		Piirustuksen sisältö	Mittakaavat
			Pohjapiirustus	1:100
			Suunnitteluala, työnnumero ja piirustuksen numero	Muutos
			ARK /	
Päiväys, suunnittelija, nimen selvitys ja koulutus	[REDACTED]		Yhteyshenkilö	Tiedosto
			[REDACTED]	[REDACTED]

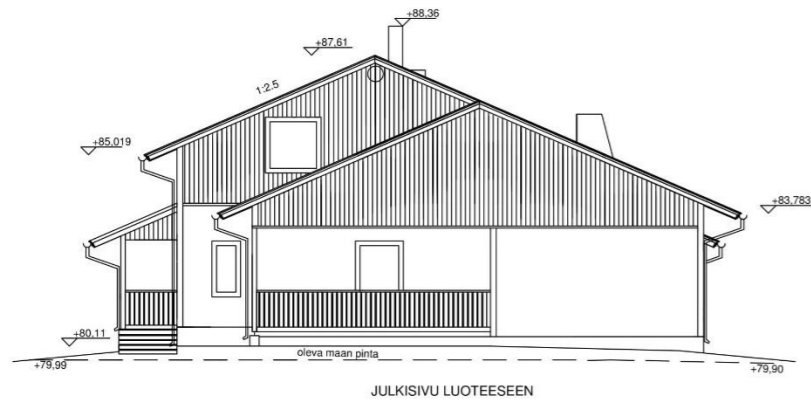
JULKISIVUT



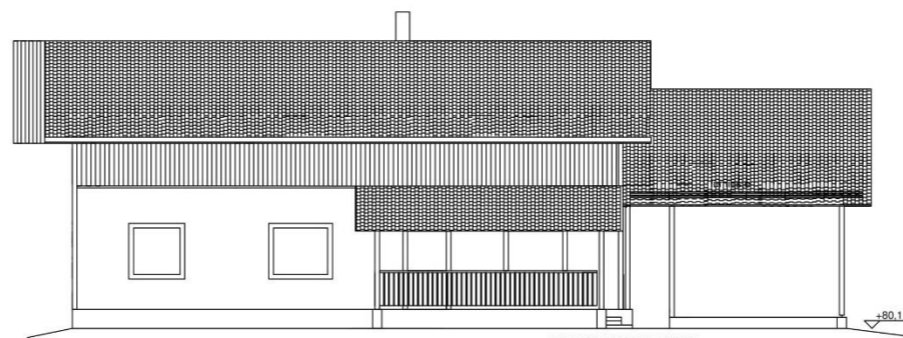
JULKISIVU LOUNAASEEN

JULKISIVUMATERIAALIT	
1. Tiilikate : savitiilenpunainen	Ikkunat: valkoinen
2. Rapattu betseinä : valkoinen	Ulko-ovet: valkoinen
3. Pystypaneeli 145 : harmaa	Räystään otsa- ja aluslaudat: valkoinen
4. Sokkeli : tumman harmaa	Nurkka- ja piililaudat, listat : valkoinen
	Värit: värytysuunnitelman mukaan.

VESIKATTOVARUSTEET RAK.MK F2:n MUKAAN.



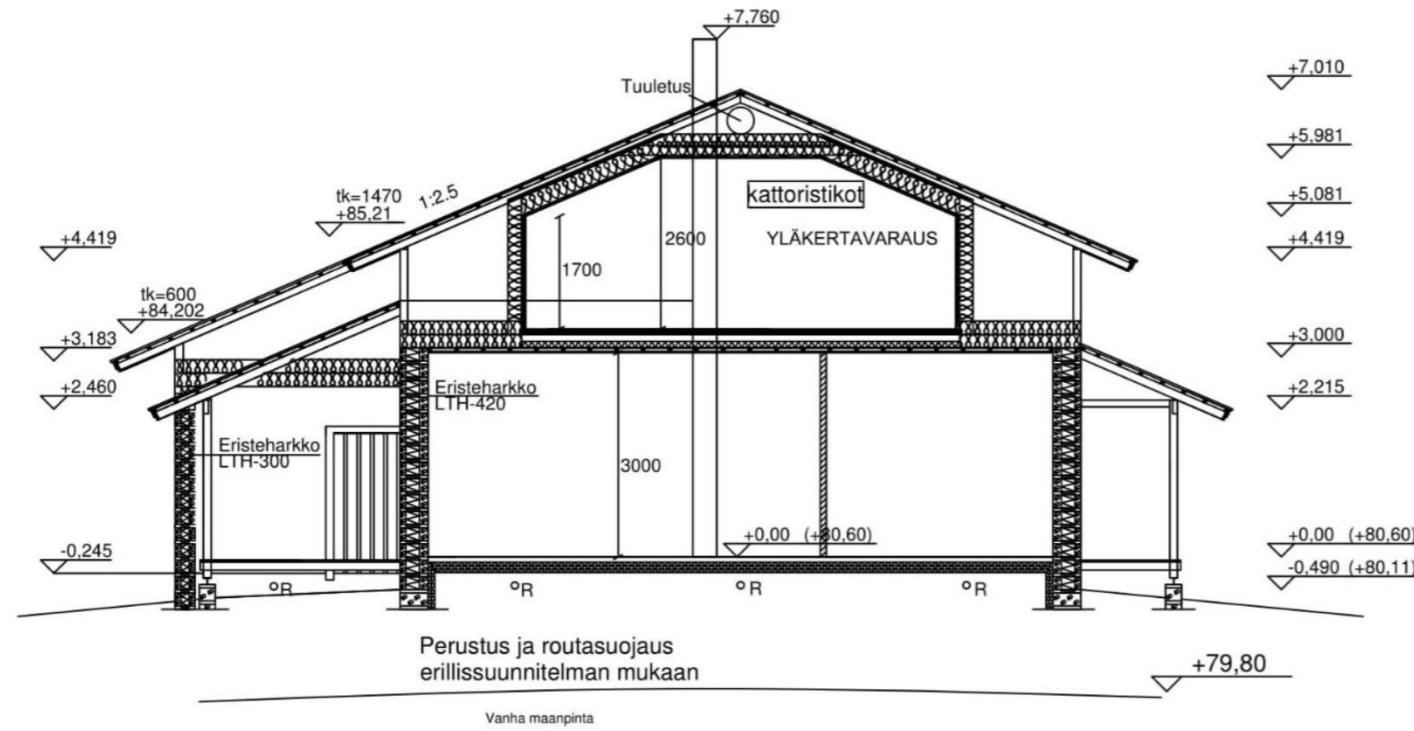
JULKISIVU LUOTEeseen



JULKISIVU KOILLISEEN

TUNN.	LUKUM.	MUUTOS	NIMM. PVM	
Kaupunginosa	Korttelin	Tontin	Vieromaisen merkintä	
Naljakka	1876	12	Juoks.no	
Rakennusluokitus	UUDISRAKENNUS		Pääpiirustus	
Rakennuskohde			Julkisivut	1:100
			Suunnittelun, työnnumero ja piirustuksen numero	Muutos
			ARK /	
Päiväys, suunnittelija, nimen selvennys ja koukutus			Yhteyshenkilö	Tiedosto

## LEIKKAUS A-A



## RAKENTEET

### YLÄPOHJA

U=0,08 W/m²K  
 Vesikate tiili  
 Ruodelauditus  
 Tuuletusrimat  
 Aluskate  
 Kattoristikot  
 Mineraalivilla 500 mm  
 (levyillä 100 mm +  
 puhallusvilla 400 mm)  
 Muovikalvo  
 Harvarimoitus  
 Sisäkattolevy

### ULKOSEINÄ ASUNTO

U=0,12 W/m²K  
 Rappaus  
 Tasoite/vahvikkeet  
 Harkko LTH-420 420 mm  
 -tasoite  
**ULKOSEINÄ VARASTO**  
 U=0,23 W/m²K  
 Rappaus  
 Tasoite/vahvikkeet  
 Harkko LTH-300 300 mm  
 -tasoite

### ALAPOHJA

(MAANV. TB-LAATTA)

U=0,15 W/m²K  
 (1 m:n reunakaistalla)  
 U=0,11 W/m²K  
 (keskialueella)  
 Lattianpinnoite+  
 tasoitekerros 10 mm  
 Teräsbetoni-laatta 80 mm  
 Lämmöneriste EPS 200 150 mm  
 Kapillaarisen kosteu-  
 den estävä sorastus 300 mm

### LÄMMÖNERISTYSVAATIMUKSET

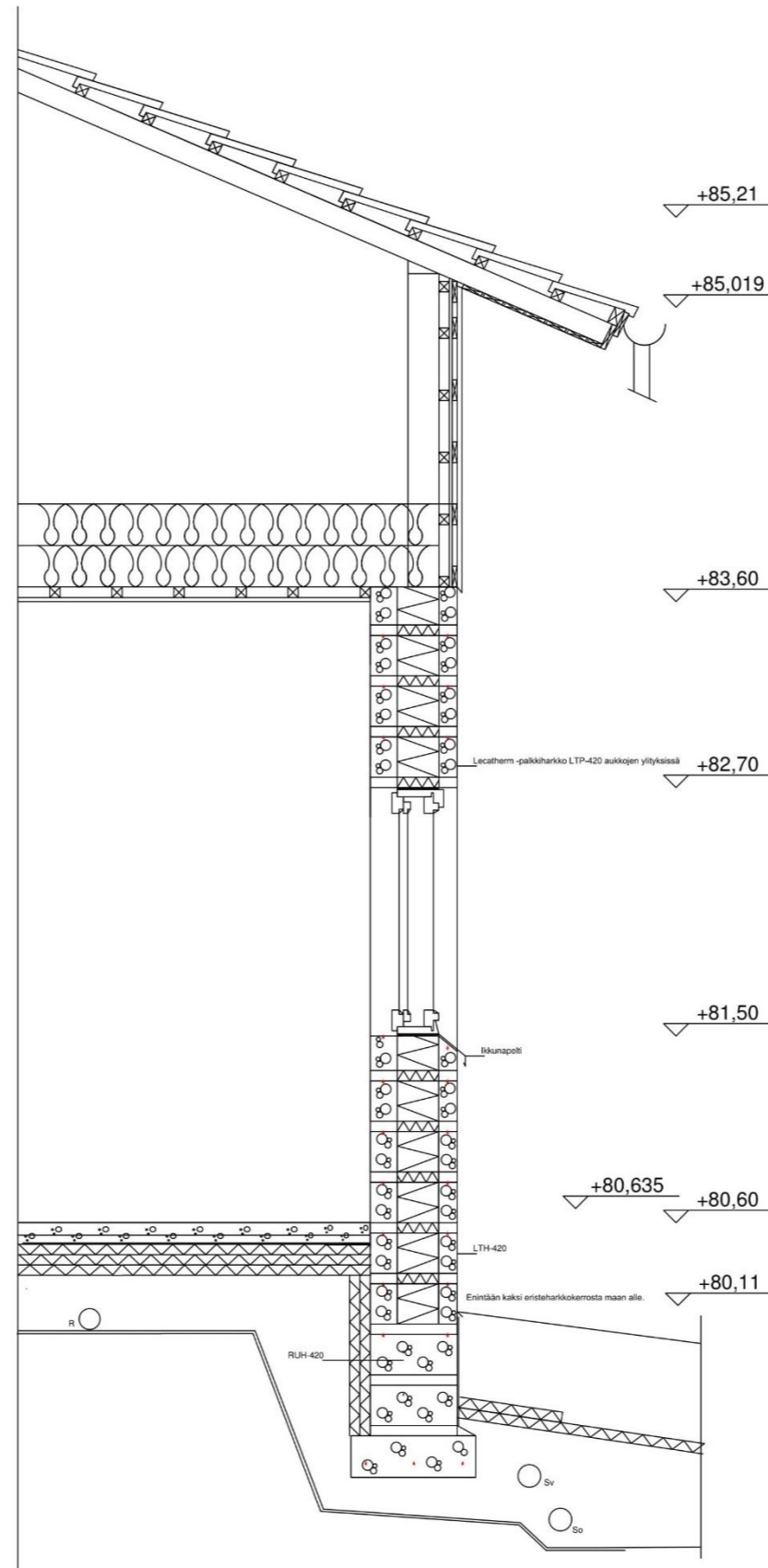
RAKENNUSOSAT	Perusratkaisu	Suunnitteluratkaisu
-ASUNTO LTH-420	U-arvot W/m²K	U-arvot W/m²K
Ulkoseinä	0,17	0,12
Yläpohja	0,09	0,08
Alapohja (reunakaista)	0,16	0,15
Alapohja (keskialue)	0,16	0,11
Ikkunat	1,00	0,85
Ulko-ovet	1,00	1,00

### LÄMMÖNERISTYSVAATIMUKSET

RAKENNUSOSAT	Perusratkaisu	Suunnitteluratkaisu
-VARASTO LTH-300	U-arvot W/m²K	U-arvot W/m²K
Ulkoseinä	0,26	0,23
Yläpohja	0,14	0,08
Alapohja (reunakaista)	0,24	0,15
Alapohja (keskialue)	0,24	0,11
Ikkunat	1,40	0,85
Ulko-ovet	1,40	1,00

TUNN.	LUKUM.	MUUTOS	NIMIM.	PVM
Kaupunginosa	Korttelitila	Tontti/nro	Viranomaisten merkintöjä	
Nol jakka	1876	12		
Rakennustoimenpide			Piirustuslaji	Juoks.no
UUDISRAKENNUS			Pääpiirustus	
Rakennuskohde			Piirustuksen sisältö	Mittakaavat
			Leikkaus Rakenteet	1:100
			Suunnitteluala, työnnumero ja piirustuksen numero	Muutos
			ARK	/

Appendix 1: Blueprints for the reference object (Detail view of the wall)



YLÄPOHJA

U=0,08W/m<sup>2</sup>K  
 Vesikate tiili  
 Ruodelaudoitus  
 Tuuletusrimat  
 Aluskate  
 Kattoristikot  
 Mineraalivilla 500mm  
 (levyvillä 100mm+  
 puhallusvilla 400mm)  
 Muovikalvo  
 Harvarimoitus  
 Sisäkattolevy/panelointi

ULKOSEINÄ ASUNTO

U=0,12W/m<sup>2</sup>K  
 Rappaus  
 Tasoite/vahvikkeet  
 Harkko LTH-420 420mm  
 -tasoite

ULKOSEINÄ VARASTO

U=0,23W/m<sup>2</sup>K  
 Rappaus  
 Tasoite/vahvikkeet  
 Harkko LTH-300 300mm  
 -tasoite

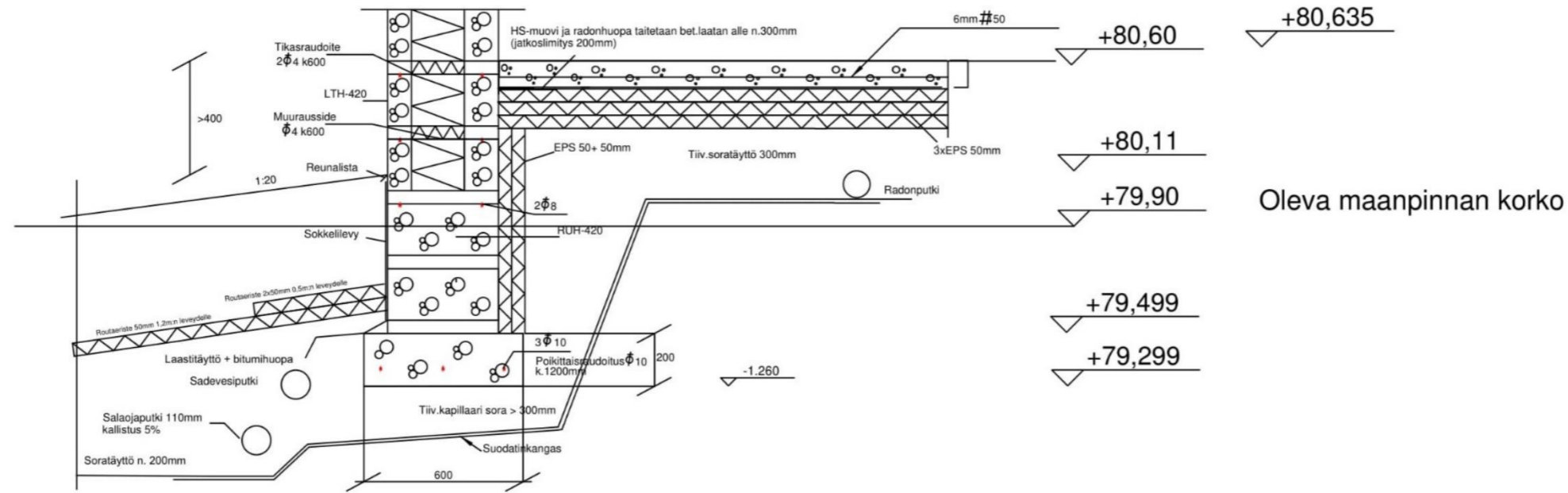
ALAPOHJA

(MAANV. TB-LAATTA)

U=0,15W/m<sup>2</sup>K  
 1m:n reunakaistalla  
 U=0,11W/m<sup>2</sup>K  
 keskialueella  
 Lattiapinnoite+  
 tasoitekerros 10mm  
 TB-laatta 80mm  
 Lämmöneriste EPS 200 150mm  
 Kapillaarisen kosteu-  
 den estävä sorastus 300mm

TUNN.	LUKUM.	MUUTOS	NMIM. PVM	
Kaupunginosa	Korttelitila	Tonttinen	Viranomaisen merkintä	
Noljakka	1876	12	Piirustaja	Juoks.no
Rakennuslupamenetelmä	UUDISRAKENNUS		PÄÄPIIRUSTUS	
Rakennuskohde	[REDACTED]		Piirustuksen sisältö	Mittakaavat
			ULKOSEINÄLEIKKAUS	1:20
			Suunnitteluala, työnnumero ja piirustuksen numero	Muutos
			RAK	/
Päätyä, suunnittelija, nimen soveltaminen ja koulutus			Yhteyshenkilö	Tiedosto
[REDACTED]			[REDACTED]	[REDACTED]

Appendix 1: Blueprints for the reference object (Detail view of the foundation)



TUNN. LUKUM. MUUTOS			NIMIM. PVM	
Kaupunginosa Noljakka	Kortteli/tila 1876	Tontti/nro 12	Viranomaisten merkintöjä	
Rakennustoimenpide UUDISRAKENNUS			Piirustuslaji PÄÄPIIRUSTUS	Juoks.no
Rakennuskohde [REDACTED]			Piirustuksen sisältö PERUSTUSLEIKKAUS	Mittakaavat 1: 20
			Suunnitteluala, työnnumero ja piirustuksen numero	Muutos
			RAK	/
Päiväys, suunnittelija, nimen selvennys ja koulutus [REDACTED]			Yhteyshenkilö [REDACTED]	Tiedosto [REDACTED]

### Heat lost through a building component

$$Q_{component} = \sum U_i A_i (T_{in} - T_{out}) \Delta t / 1000 \quad (3.4)$$

Where:

- $U_i$  thermal transmittance factor, W/(m<sup>2</sup>K)
- $A_i$  floor area of a building component, m<sup>2</sup>
- $T_{in}$  indoor air temperature, °C
- $T_{out}$  outdoor air temperature, °C
- $\Delta t$  time period, h
- 1000 factor for converting to kilowatt hours

### Air leakage heat loss

$$Q_{air\ leakage} = \rho_i c_{pi} q_{air\ leakage\ flow} (T_{in} - T_{out}) \Delta t / 1000 \quad (3.8)$$

$$q_{air\ leakage\ flow} = \frac{q_{50}}{3600 * x} A \quad (3.9)$$

$$q_{50} = \frac{n_{50}}{A} V \quad (3.10)$$

Where:

- $\rho_i$  air density, 1.2 kg/m<sup>3</sup>
- $c_{pi}$  specific heat capacity of air, 1000 W s/(kg K)
- $q_{air\ leakage\ flow}$  air leakage flow, m<sup>3</sup>/s
- $q_{50}$  air leakage number of the envelope, m<sup>3</sup>/(h m<sup>2</sup>)
- $n_{50}$  air leakage number with 50 Pa pressure difference, 1/h
- $A$  surface area of the building envelope, m<sup>2</sup>
- $V$  air volume of a building, m<sup>3</sup>
- $x$  factor
- 3600 conversion factor

### Heating of supply air

$$Q_{iv, supply} = t_d t_v \rho_i c_{pi} q_{supply} (T_{in} - T_{inb}) \Delta t / 1000 \quad (3.14)$$

Where:

- $t_d$  average daily running time of ventilation, h/24
- $t_v$  average weekly running time of ventilation, h/24
- $q_{supply}$  supply air flow, m<sup>3</sup>/s
- $T_{inb}$  inblown air temperature, °C

### Net heating energy need for ventilation

$$Q_{iv} = t_d t_v \rho_i c_{pi} q_{supply} \left( (T_{inb} - \Delta T_{fan}) - T_{recov} \right) \Delta t / 1000 \quad (3.11)$$

$$T_{recov} = T_{out} + \frac{\phi_{recov}}{t_d t_v \rho_i c_{pi} q_{supply}} \quad (3.12)$$

$$\phi_{recov} = \eta_{exchanger} t_d t_v \rho_i c_{pi} q_{exhaust} (T_{in} - T_{out}) \quad (3.13)$$

Where:

- $q_{supply}$  supply air flow, m<sup>3</sup>/s
- $q_{exhaust}$  exhaust air flow, m<sup>3</sup>/s
- $\Delta T_{fan}$  temperature rise in the fan, °C
- $T_{recov}$  temperature after heat recovery, °C
- $\phi_{recov}$  average monthly power needed for heat recovery, W
- $\eta_{exchanger}$  temperature ratio in a heat exchanger

### Energy need for domestic hot water

$$Q_{dhw,net} = \rho_v c_{pv} V_{dhw} (T_{dhw} - T_{dcw}) / 3600 \quad (3.18)$$

$$V_{dhw} = n V_{dhw,spec,person} \Delta t / 1000 \quad (3.19)$$

Where:

- $\rho_v$  water density, 1000 kg/m<sup>3</sup>
- $c_{pv}$  specific heat capacity of water, 4.2 kJ/kg K
- $V_{dhw}$  domestic hot water consumption, m<sup>3</sup>
- $T_{dhw}$  domestic hot water temperature, °C
- $T_{dcw}$  domestic cold water temperature, °C
- 3600 factor for converting to kilowatt hours
- $n$  number of people
- $V_{dhw,spec,person}$  specific hot water consumption per person per day, dm<sup>3</sup>
- $\Delta t$  time period, days
- 1000 factor for converting to cubic meters

### Energy needs for lighting and electrical appliances

$$E_{lighting} = k \Sigma P_{light} A_{house} \Delta t f / 1000 \quad (4.1)$$

$$E_{appliances} = k \Sigma P_{app} A_{house} \Delta t / 1000 \quad (4.1^*)$$

Where:

- $k$  degree of use
- $P_{light}$  electrical power of lighting per square meter, W/m<sup>2</sup>

- $P_{app}$  electrical power of appliances per square meter, W/m<sup>2</sup>
- $A_{house}$  illuminated area of the house, m<sup>2</sup>
- $f$  factor depending on the lighting control type

### Heat load from people

$$Q_{people} = k n \phi_{person} \Delta t / 1000 \quad (5.1)$$

Where:

- $k$  degree of use
- $n$  number of people
- $\phi_{person}$  heat output of one person, W
- $\Delta t$  length of stay, h
- 1000 conversion factor

### Solar radiant energy

$$Q_{sol} = \Sigma G_{rad,hor} F_{dir} F_{trans} A_{win} g \quad (5.4)$$

$$g = 0.9 g_{permeation} \quad (5.5)$$

Where:

- $G_{rad,hor}$  total solar radiant energy on horizontal surface, kWh/m<sup>2</sup>
- $F_{dir}$  factor converting radiant energy on a horizontal surface to radiant energy on a vertical surface by compass direction
- $F_{trans}$  correction factor for radiation transmittance
- $A_{win}$  surface area of the window, m<sup>2</sup>
- $g$  transmittance factor for solar radiation through daylight opening
- $g_{permeation}$  total permeation factor of the solar radiation perpendicular to the window

### Hot water storage heat loss

$$Q_{dhw,storage,load} = \frac{Q_{dhw,storage,loss}}{2} \quad (2)$$

$$Q_{dhw,storage,loss} = \frac{Q_{dhw,storage,loss,year}}{365} \Delta t \quad (3)$$

Where:

- $Q_{dhw,storage,loss,year}$  heat loss from a domestic hot water storage in a year, kWh
- $\Delta t$  number of days in a month, days
- 365 number of days in a year, days

## Heat load from a fireplace

$$Q_{firepalce} = \frac{Q_{fireplace,total}}{\Delta t_{heating\ season}} \Delta t_{month} \quad (4)$$

Where:

- $Q_{firepalce,total}$  total heating energy released by a fireplace, 2550 kWh
- $\Delta t_{heating\ season}$  time period during which the fireplace was slowly releasing heat into the house, h
- $\Delta t_{month}$  hours in a month, h

## Heat load energy recovered for heating

$$Q_{int.heat} = \eta_{heat} Q_{heat\ load} \quad (5.10)$$

$$\eta_{heat} = \frac{1-\gamma^a}{1-\gamma^{a+1}} \quad (5.11)$$

$$\gamma = \frac{Q_{heat\ load}}{Q_{space}} \quad (5.14)$$

$$a = 1 + \frac{\tau}{15} \quad (5.13)$$

$$\tau = \frac{C_{building}}{H} \quad (5.15)$$

$$H = \frac{Q_{space}}{(T_{in}-T_{out})\Delta t} 1000 \quad (5.16)$$

Where:

- $\eta_{heat}$  degree of heat loads recovered by month
- $Q_{heat\ load}$  heat loads received by month
- $\gamma$  heat load to heat loss ratio
- $a$  numerical parameter
- $\tau$  building's time constant
- $C_{building}$  building's interior effective thermal capacity, Wh/K
- $H$  building's specific heat loss, W/K

## Energy consumption

$$Q_{heating,space} = \frac{Q_{space,net}}{\eta_{space}} \quad (6.1)$$

$$Q_{space,net} = Q_{space} - Q_{int.heat} \quad (3.1)$$

$$Q_{heating,iv} = Q_{iv} \quad (6.1^*)$$

$$Q_{heating,dhw} = \frac{Q_{dhw}}{\eta_{dhw}} \quad (6.4)$$

Where:

- $Q_{space,net}$  net energy need for space heating, kWh
- $Q_{iv}$  net energy need for ventilation, kWh
- $Q_{dhw}$  net energy need for domestic hot water, kWh
- $\eta$  heating system's efficiency factor

### Electric energy consumption

$$E_{HP} = \frac{Q_{heating,space}}{SPF_{space}} + \frac{Q_{heating,dhw}}{SPF_{dhw}} \quad (6.17)$$

$$E_{iv} = SFP_{iv} q_{supply} \Delta t \quad (7.1)$$

$$SFP_{iv} = \frac{P_{iv}}{q_{supply}} \quad (7.2)$$

Where:

- $SPF_{space}$  annual mean production index for heating spaces
- $SPF_{dhw}$  annual mean production index for heating water
- $SFP_{iv}$  specific electric power of a ventilation unit, kW/(m<sup>3</sup>/s)
- $q_{supply}$  air flow in the machine, m<sup>3</sup>/s
- $\Delta t$  running time period, h
- $P_{iv}$  electric power of the ventilation machine, kW

### U-value conversion


$$U = \frac{1}{R} \quad R = \frac{t}{\lambda} \quad \lambda = \frac{t}{R} \quad (5)$$

Where:

- $U$  thermal transmittance value, W/m<sup>2</sup>K
- $R$  thermal resistance, m<sup>2</sup>K/W
- $\lambda$  thermal conductivity, W/m K
- $t$  thickness of an element, m

## Appendix 3: Energy consumption results via Green Building Studio

### Model 1: Service type – Water loop heat pump

Energy, Carbon and Cost Summary	
Annual Energy Cost €2,944	
Lifecycle Cost €40,093	
Annual CO <sub>2</sub> Emissions	
Electric 0.0 Mg	
Onsite Fuel 3.9 Mg	
Large SUV Equivalent 0.4 SUVs / Year	
Annual Energy	
Energy Use Intensity (EUI) 863 MJ / m <sup>2</sup> / year	
Electric 11,841 kWh	
Fuel 78,262 MJ	
Annual Peak Demand 4.6 kW	
Lifecycle Energy	
Electric 355,241 kWh	
Fuel 2,347,868 MJ	
Assumptions 	

Weather Station: [GBS\\_06M12\\_02\\_228240](#)



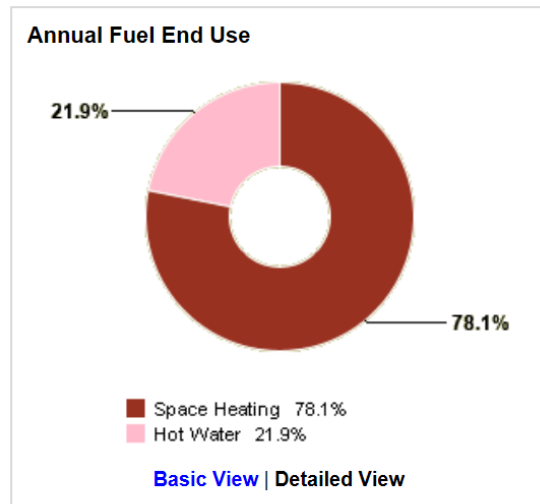
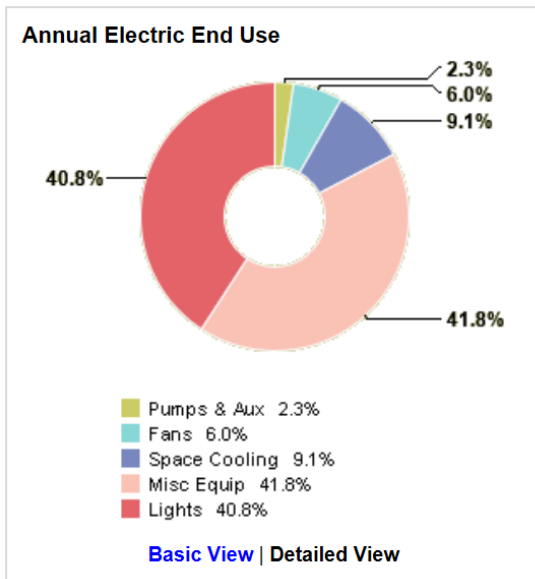
Distance to your project 135.1 mi (217.4 km)

Latitude = 60.7000 , Longitude = 28.8500

Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
65 °F	95	65 °F	8601
70 °F	19	60 °F	7026
75 °F	0	55 °F	5636
80 °F	0	50 °F	4429

IP  SI

Annual Design Conditions				
Threshold	Cooling		Heating	
	Dry Bulb(°F)	MCWB(°F)	Dry Bulb(°F)	MCWB(°F)
0.1 %	83.8	72.0	-7.8	-7.9
0.2 %	82.4	71.8	-7.1	-7.2
0.4 %	81.3	70.5	-6.2	-6.3
0.5 %	80.6	70.5	-5.8	-6.0
1 %	77.9	66.0	-4.5	-4.8
2 %	75.7	65.5	-1.3	-1.5
2.5 %	74.7	64.7	0.3	0.1
5 %	71.1	62.1	9.7	9.4



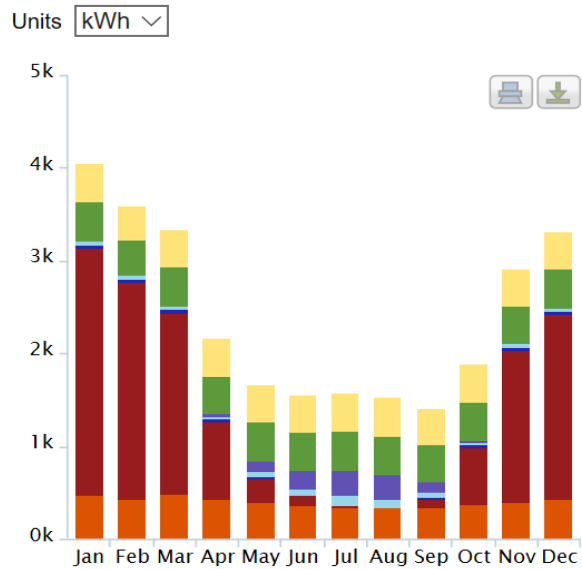
### Total Energy

**Chart Sort:**

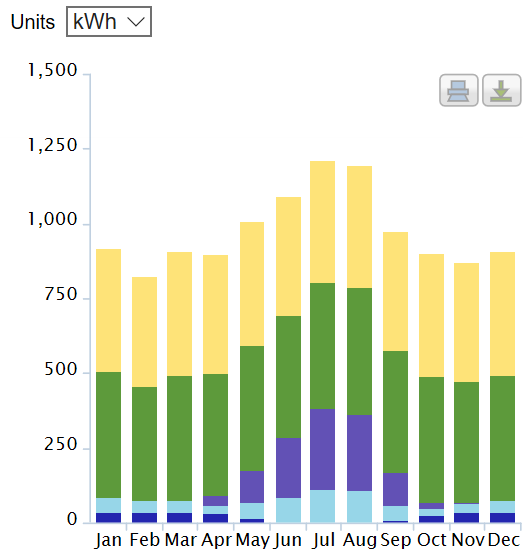
- Chronological
- Alphabetical
- Run Total

**Legend:**

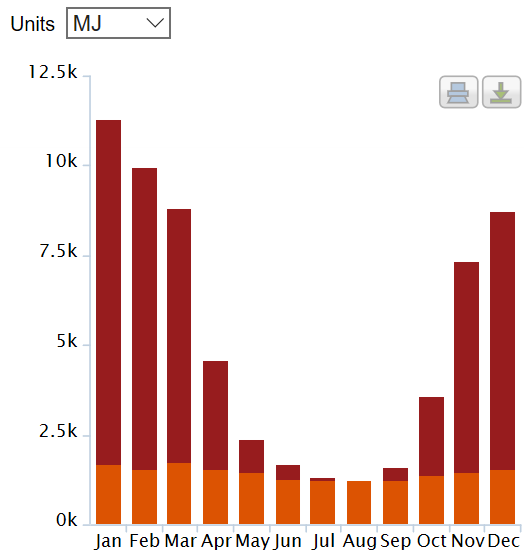
- Area Lights
- Misc Equip
- Hp Supp
- Space Cooling
- Vent Fans
- Pumps Aux
- Space Heat
- Hot Water




### Electricity



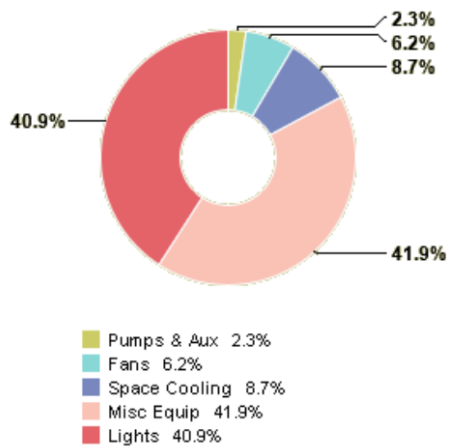
### Fuel (Natural Gas)



## Model 2: Radiant floor central heating

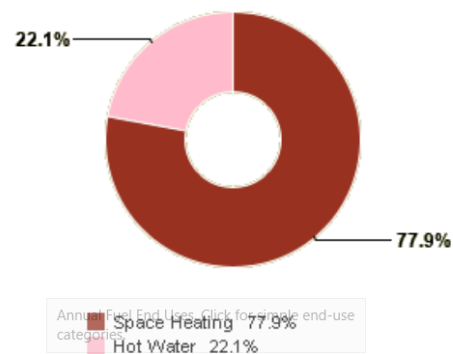
Energy, Carbon and Cost Summary	
Annual Energy Cost	€2,931
Lifecycle Cost	€39,915
Annual CO <sub>2</sub> Emissions	
Electric	0.0 Mg
Onsite Fuel	3.9 Mg
Large SUV Equivalent	0.4 SUVs / Year
Annual Energy	
Energy Use Intensity (EUI)	857 MJ / m <sup>2</sup> / year
Electric	11,818 kWh
Fuel	77,466 MJ
Annual Peak Demand	4.6 kW
Lifecycle Energy	
Electric	354,542 kWh
Fuel	2,323,971 MJ
Assumptions 	

Annual Electric End Use



[Basic View](#) | [Detailed View](#)

Annual Fuel End Use

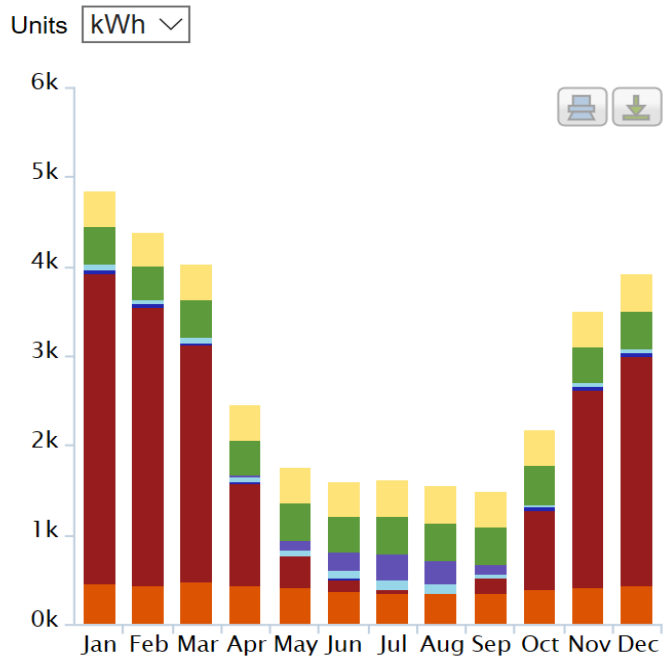


[Basic View](#) | [Detailed View](#)

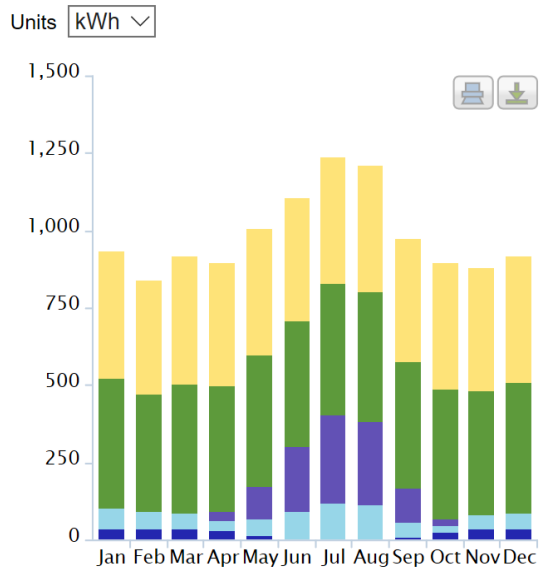
### Total Energy

**Chart Sort:**

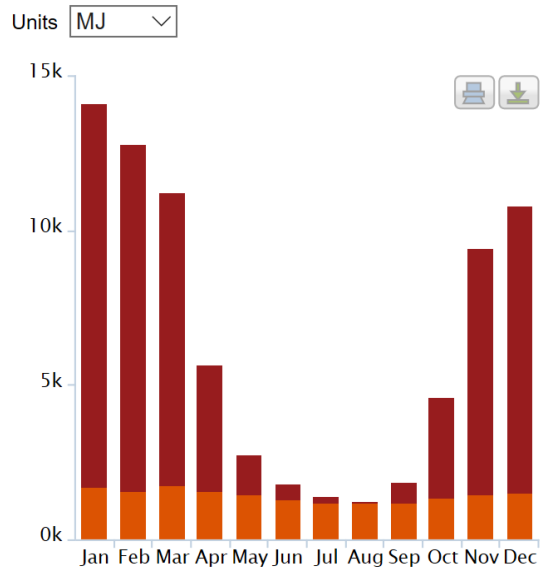
- Chronological
- Alphabetical
- Run Total
- Area Lights
- Misc Equip
- Hp Supp
- Space Cooling
- Vent Fans
- Pumps Aux
- Space Heat
- Hot Water




### Electricity

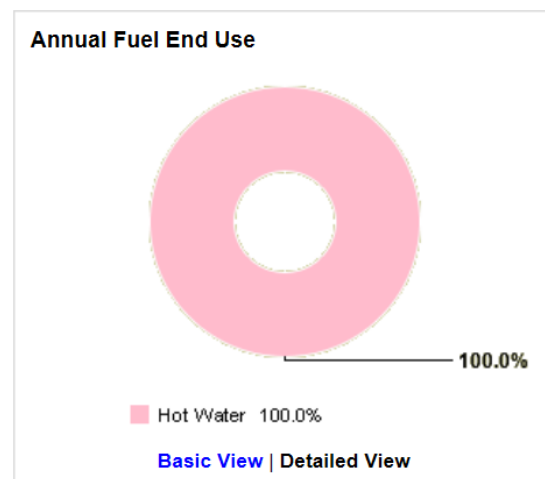
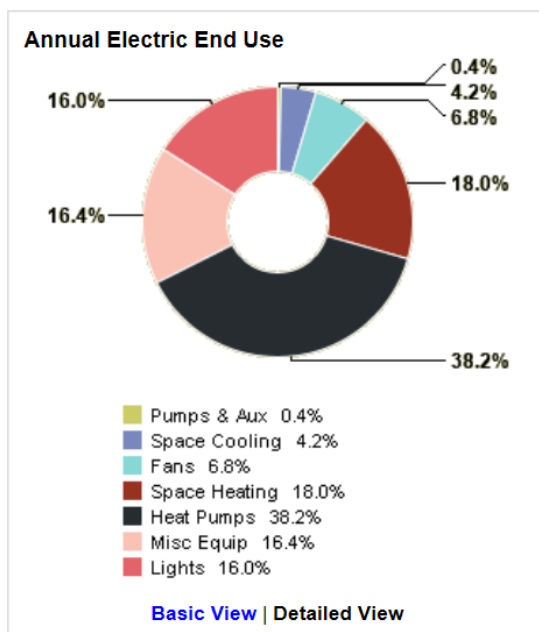


### Fuel (Natural Gas)

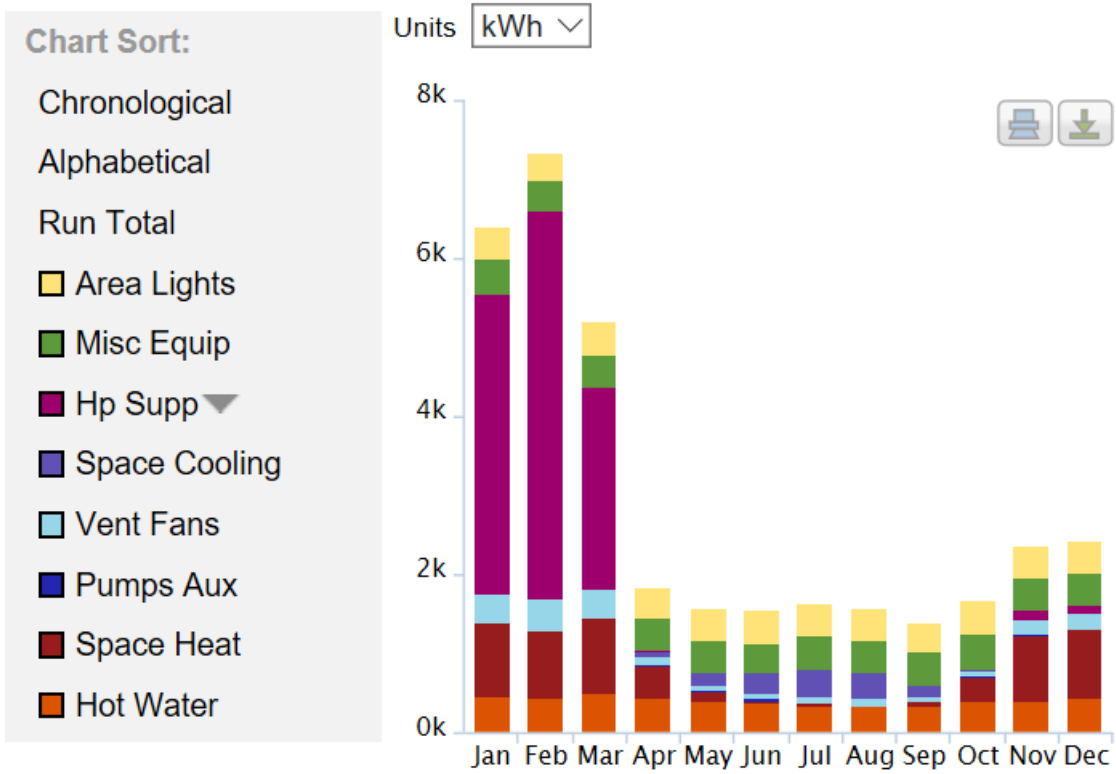


### Model 3: Fully electric service

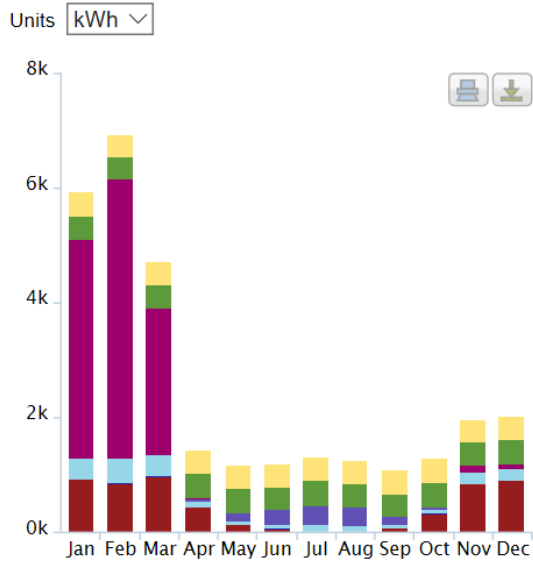
Estimated Energy & Cost Summary	
Annual Energy Cost	€5,437
Lifecycle Cost	€74,046
Annual CO <sub>2</sub> Emissions	
Electric	0.0 Mg
Onsite Fuel	0.9 Mg
Large SUV Equivalent	0.1 SUVs / Year
Annual Energy	
Energy Use Intensity (EUI)	898 MJ / m <sup>2</sup> / year
Electric	30,182 kWh
Fuel	17,121 MJ
Annual Peak Demand	27.6 kW
Lifecycle Energy	
Electric	905,449 kWh
Fuel	513,628 MJ
Assumptions 	



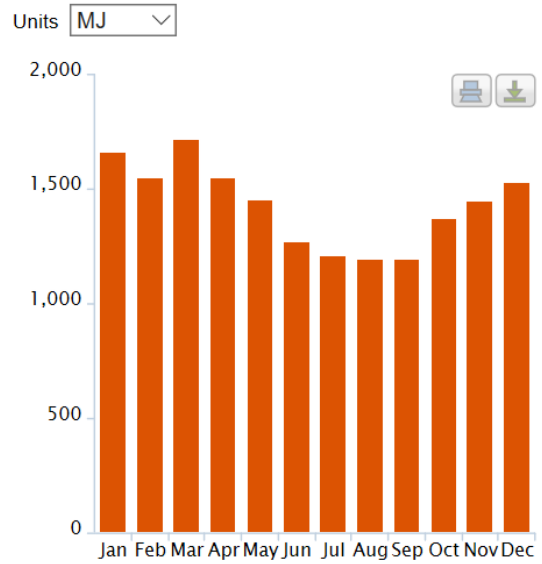
### Total Energy



### Electricity




### Fuel (Natural Gas)



## Appendix 4: IDA system parameters

Degree of automatic schedule smoothing	<input type="text" value="5"/>	-	(0 = no smoothing 5 = ± 1 h)
P-band for proportional temperature controllers; deadband for on-off controllers	<input type="text" value="2.0"/>	°C	(a small number may cause numerical problems)
Setpoint offset for water based cooling room units when there is temperature controlled VAV	<input type="text" value="2.0"/>	°C	(positive value means air is used before water)
Solar radiation level at which integrated shadings are drawn	<input type="text" value="100"/>	W/m <sup>2</sup>	(measured when the shading device is not drawn)
Side on window where the solar radiation level for shading control is measured	<input type="text" value="Inside"/>		
Solar radiation incident angle, below which solar shading may be automatically drawn	<input type="text" value="90"/>	°	
PMV (Fanger) level at which occupant wears maximum clothing	<input type="text" value="-1"/>	[-3, -0.1]	(a proportional controller is used to 'dress' occupants; controller offset error is used to represent the fact that occupants will not immediately change dress)
PMV (Fanger) level at which occupant wears minimum clothing	<input type="text" value="1"/>	[0.1, 3]	
Method for measurement of daylight level	<input type="text" value="At first occupant"/>		(Average over floor or point measurement at first occupant)
Ambient air CO <sub>2</sub> level	<input type="text" value="400.0"/>	ppm (vol)	
Window frame absorptance	<input type="text" value="0.5"/>	0 - 1	
Exponent in leak power law when ELA is given	<input type="text" value="0.6"/>	-	
Cd factor in flow(pressure) for large openings.	<input type="text" value="0.65"/>	-	
Building time constant for determining "memory" for when a casual gain or loss is useful or harmful	<input type="text" value="24"/>	h	(used for "during heating/cooling" reporting; ideally, make a simulation experiment to estimate)
Sliding average length for calculation of result table scalars	<input type="text" value="15"/>	min	(measures of, e.g., max and min temperatures are not instantaneous)

## Appendix 5: Delivered energy report from IDA ICE

		Delivered Energy Report	
Project		Building	
FIN YMa1010/2017Erillinen_pientalo Mallinnus perustuu vesiradiaattorijärjestelmään 70/40 lämpötiloilla, joka liitetty kaukolämmön alakeskukseen. Mallinnus YMa1010/2017 mukainen. -Vuotoilma YMa1010/2017 kohta 4.3.3 ja 2.3.2 (tasauslaskennan mukainen vuoto, 1-kerroksinen rakennus) Mallinnusta täydennetty "YMohje ("D5") 2018" arvoilla seuraavasti: -"YMohje ("D5") 2018" taulukko 3.1-3.3, rakenteiden väliset kylmäsilat (betonisat rakenteet) -KL-alakeskuksen vuosihyötysuhde ja sähkönkäyttö, "YMohje ("D5") 2018" taulukko 7.1 (ja 7.2) -Lämmitysjärjestelmien lämmönjaon ja -luovutuksen vuosihyötysuhde, "YMohje ("D5") 2018" taulukko 6.1 -Lämmitysjärjestelmän apulaitteiden sähkönkulutus, "YMohje ("D5") 2018" taulukko 6.1 -Lämpimän käyttöveden häviöt "YMohje ("D5") 2018" kohta 6.3 (ei varaajaa). Kiertojohdon ominaispituus 0,20 m/m <sup>2</sup> . Kierron ja varastoinnin häviöistä 50 % lasketaan hyödyksi tilojen lämmityksessä. LKV kokonaishäviöistä 44 % lasketaan hyödyksi tilojen lämmityksessä.(Jakojohton häviöistä ei lämpöä hyödyksi) -Lämpimän käyttöveden lämmitysenergian nettotarpeelle ei ole käytetty YM asetuksen 5/13 mukaista asuntojen lukumäärään sidottua rajoitetta. -Lämpimän käyttöveden pumpun sähkönkulutus "YMohje ("D5") 2018" kohdan 6.3.4 mukaisesti (kiertojohdon eristystaso 1,5*D) -Tasauslaskimeen(IDA-tuloste) kaikki lähtötiedot syötetään lämpimien tilojen mukaisilla arvoilla. Käyttäjän tulee itse täydentää ja tarvittaessa myös muuttaa tietoja tasauslaskentatulostukseen. -Halutessaan energiatodistustulosteen(IDA-tuloste) luokan 9 rakennukseen käyttäjä voi valita rakennuksen mallipohjaksi jonkun luokan 1-8 rakennuksista ja muuttaa sitä suunnittelutapausta vastaavaksi. Simuloinnin jälkeen käyttäjä voi sitten muuttaa rakennuksen käyttötarkoituksen luokan IDA-energiatodistustulosteen sivulle 1.		Model floor area	140.0 m <sup>2</sup>
Customer		Model volume	769.7 m <sup>3</sup>
Created by	Semion Iudin	Model ground area	144.1 m <sup>2</sup>
Location	Joensuu_029290 (ASHRAE 2013)	Model envelope area	635.1 m <sup>2</sup>
Climate file	FIN_JOENSUU_029290(IW2)	Window/Envelope	2.2 %
Case	IDA THESIS PROJECT 1	Average U-value	0.2915 W/(m <sup>2</sup> K)
Simulated	10.10.2018 16:35:35	Envelope area per Volume	0.8251 m <sup>2</sup> /m <sup>3</sup>

## Building Comfort Reference

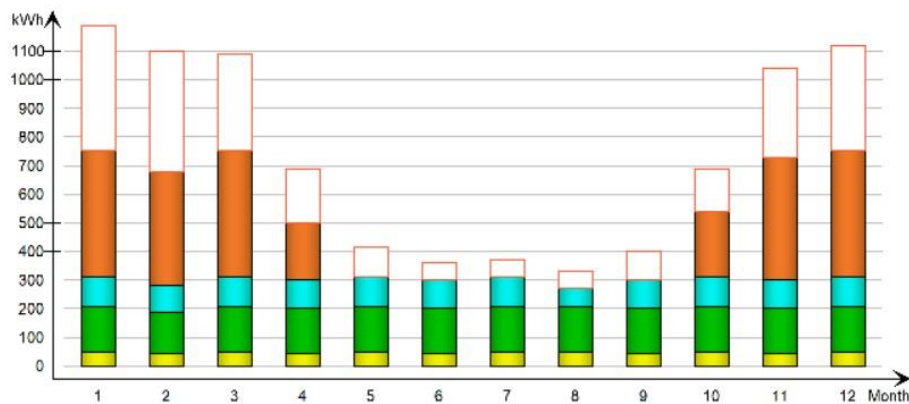
Percentage of hours when operative temperature is above 27°C in worst zone	0 %
Percentage of hours when operative temperature is above 27°C in average zone	0 %
Percentage of total occupant hours with thermal dissatisfaction	6 %

## Delivered Energy Overview

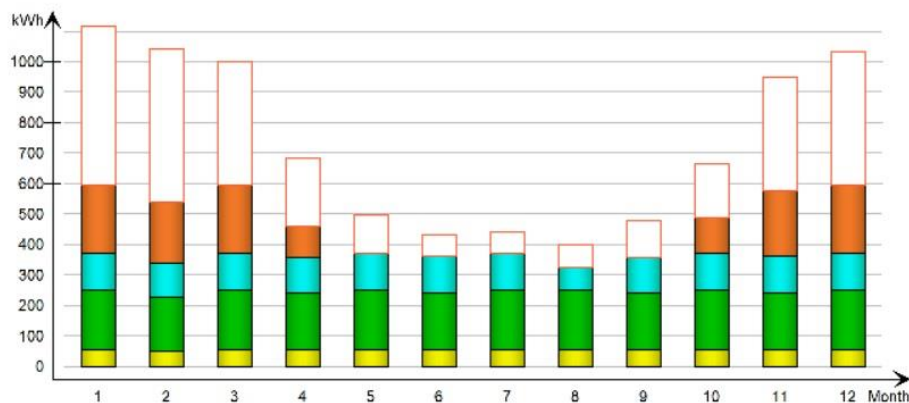
	Purchased energy		Peak demand	Primary energy	
	kWh	kWh/m <sup>2</sup>	kW	kWh	kWh/m <sup>2</sup>
Valaistus, kiinteistö	548	3.9	0.06	658	4.7
Laitteet, kiinteistö	1883	13.5	0.21	2259	16.1
LVI sähkö	1172	8.4	0.16	1406	10.0
Sähkölämmitys, kiinteistö	0	0.0	0.0	0	0.0
<b>Total, Facility electric</b>	<b>3603</b>	<b>25.7</b>		<b>4323</b>	<b>30.9</b>
Uusiutuva polttoaine	2589	18.5	0.85	1294	9.2
<b>Total, Facility fuel*</b>	<b>2589</b>	<b>18.5</b>		<b>1294</b>	<b>9.2</b>
<b>Total</b>	<b>6192</b>	<b>44.2</b>		<b>5617</b>	<b>40.1</b>
Lämmitys, asukas	2590	18.5	1.5	3108	22.2
<b>Total, Tenant electric</b>	<b>2590</b>	<b>18.5</b>		<b>3108</b>	<b>22.2</b>
<b>Grand total</b>	<b>8782</b>	<b>62.7</b>		<b>8725</b>	<b>62.3</b>

\*heating value

## Monthly Purchased/Sold Energy



## Monthly Primary Energy



Month	Facility electric								Facility fuel (heating value)		Tenant electric	
	Valaistus, kiinteistö		Laitteet, kiinteistö		LVI sähkö	Sähkölämmitys, kiinteistö		Uusiutuva polttoaine	Lämmitys, asukas			
	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)	(kWh)	Prim. (kWh)		
1	46.6	55.9	159.9	191.9	104.0	124.8	0.0	0.0	443.4	221.7	436.5	523.8
2	42.1	50.5	144.4	173.3	94.2	113.0	0.0	0.0	400.5	200.3	417.7	501.2
3	46.6	55.9	159.9	191.9	103.1	123.7	0.0	0.0	443.4	221.7	336.6	403.9
4	45.1	54.1	154.8	185.8	98.5	118.3	0.0	0.0	199.4	99.7	186.0	223.2
5	46.6	55.9	159.9	191.9	101.8	122.2	0.0	0.0	0.0	0.0	104.3	125.2
6	45.1	54.1	154.8	185.8	99.9	119.8	0.0	0.0	0.0	0.0	59.0	70.9
7	46.6	55.9	159.9	191.9	103.9	124.7	0.0	0.0	0.0	0.0	58.0	69.6
8	46.6	55.9	159.9	191.9	62.5	74.9	0.0	0.0	0.0	0.0	63.3	75.9
9	45.1	54.1	154.8	185.8	98.8	118.6	0.0	0.0	0.0	0.0	101.3	121.6
10	46.6	55.9	159.9	191.9	102.1	122.5	0.0	0.0	229.6	114.8	149.6	179.5
11	45.1	54.1	154.8	185.8	99.6	119.5	0.0	0.0	429.1	214.6	312.0	374.4
12	46.6	55.9	159.9	191.9	103.4	124.1	0.0	0.0	443.4	221.7	365.8	439.0
<b>Total</b>	<b>548.5</b>	<b>658.2</b>	<b>1882.9</b>	<b>2259.5</b>	<b>1171.7</b>	<b>1406.1</b>	<b>0.0</b>	<b>0.0</b>	<b>2588.8</b>	<b>1294.4</b>	<b>2590.1</b>	<b>3108.2</b>