Evaluation of energy demand and energy use of an existing single family building, with special emphasis on energy efficiency of heat exchanger in ventilation

Daniel C. Axelsen

Thesis of 60 ECTS credits
Master of Science (M.Sc.) in Sustainable Energy Science – Iceland School of Energy

April 2016

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Thesis of 60 ECTS credits submitted to Iceland School of Energy at Reykjavík University in partial fulfillment of the requirements for the degree of

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Supervisors:

Björn Marteinsson,
Associate professor, University of Iceland
Engineer/architect, Innovation Center Iceland

Jónas Þór Snæbjörnsson,
Professor, Reykjavík University, Iceland

Examiner:

Guðni Ingi Pálsson, MSc,
Civil Engineer at Mannvit Consulting Engineers

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Abstract

Energy modelling of houses and other buildings helps the designers to determine the energy performance of the building at an early stage. It furthermore gives the advantage of altering the building's design early in the planning phase to ensure that it fulfils requirements of increasing energy demands. Energy models also serve as a tool to predict the energy consumption and thereby energy cost of running the building. Energy modelling is becoming widely used but there are many uncertain parameters associated with any energy model that should be validated for accuracy. In this study a house was equipped with measuring equipment to verify the results from two different energy models, an excel model developed by Iceland Innovation Center and a 3D-model from Autodesk Revit using Autodesk Green Building Studio for Revit. It furthermore serves the purpose of testing the quality and usability of the measuring equipment used.

The report is conducted with a non-engineering approach which serves the purpose of considering the energy models and their complexity from a non-engineering angle. This is important, with lawmakers dictating the use of energy calculations and simulation to some extent within the architecture profession.

Mat á orkuþörf og orkunotkun í einbýlishúsi, með sérstaka áherslu á orkunýtingu varmaskiptis í lofræstikerfi

Daniel C. Axelsen
April 2016

Útdráttur

Orkulíkön af húsum og öðrum mannvirkjum geta stutt hönnuði við mat á orkunýtni á fyrstu stigum verkefna. Að auki geta slík líkön gert hönnuðum mögulegt að gera breytingar á fyrstu stigum framkvæmdar með það markmið að uppfylla kröfur varðandi orkunýtni. Einnig má nýta orkulíkön til þess að spá fyrir um orkuþörf bygginga og áætla út frá því rekstrarkostnað. Orkulíkön eru nýtt í auknum mæli við byggingarframkvæmdir en þó eru enn óvissuþættir sem varpa þarf frekara ljósi á, og þar með auka áreiðanleika. Í þessu verkefni voru gögn frá mælingum í húsi borin saman við tvenns konar orkulíkön, annars vegar Excel líkan þróað af Nýsköpunarmiðstöð Íslands og hins vegar þrívítt líkan úr Autodesk Revit, hermt með Green Building Studio for Revit. Einnig þjónar það þeim tilgangi að prófa gæði og notagildi þess mælitækis sem notað er.
Í þessari ritgerð nálgast höfundur viðfangsefnið á almennan hátt. Almenn nálgun felur í sér að sneitt er hjá flóknum tæknilegum atriðum. Slík nálgun á viðfangsefnið er mikilvæg svo að sem breiðastur hópur hafi gagn af niðurstöðunum m.a. þeir sem setja lög og stjórna því að hvaða marki líkanagerð og hermun líkana getur nýst arkitektum og öðru fagfólki

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Chapter 1 Introduction & background

This thesis comprises energy auditing of a recently built house in the town of Eyrarbakki. The energy use of the building is estimated through modelling and monitoring. The monitoring system is comprised of sensors installed both inside the house and on the outside, monitoring both the indoor climate and key meteorological parameters. The recorded data are intended to be used to verify the modelling results.

The thesis is part of a research project carried out by Innovation Center Iceland (NMI) led by professor Björn Marteinsson (BM). The project initially started out as an internship between NMI and Daniel Axelsen. The Internship comprised augmentation of an energy model developed by BM on the project house. This model will be referred to as the BM-Excel model and will be used as the main model in this thesis.

The main objective of the research was to finalize augmentation of the energy model developed by BM and to some extent compare the results of the model with real life data collected from the house. The house was equipped with censoring equipment as part of this thesis as well. It will also serve as a test of the chosen sensor types and the equipment that comes with it. This test will show whether this type of monitoring system should be used in the future and also the complexity of it both in terms of installation and usage.

Within the scope of the objective is a benchmark to compare the BM-Excel model's results against an energy analysis using a commercially available energy modelling software. A number of different models exist. For this thesis a simulation of the project will be carried out in a 3D BIM model using Revit Architecture and Green Building Studio developed by one of the leading companies in the industry, Autodesk. This benchmark test serves both as a comparison for results but also to determine the complexity and usability of this exact software package and its importance when designing houses with 3D-models and BIM software.

The Revit energy model is assumed to be a more sophisticated model as it has more possible input parameters that can be adjusted, depending on building type, usage and location. I will be using the standard inputs on small dwellings defined by Autodesk to compare the result with the BM-Excel model's results.

The project house is equipped with a heat exchanger located in a ventilation system in the house. The Energy models include an assumed efficiency of the heat exchanger. In this thesis a heat transfer efficiency estimate will be carried out based on the data collected by sensors installed in the ventilation ducts of the ventilation system to see if the assumed efficiency corresponds to the calculated.

1.1 Thesis structure

Chapters 1 and 2 start with a general description on the matter of energy use in buildings including a more specific view on energy use in buildings in Iceland.

After this introduction, chapter 3 describes energy models in general and their purpose. This chapter includes an introduction and description of the basics on key parameters for energy modelling – parameters that are used later in this thesis for the two energy models. The chapter furthermore looks at possible inaccuracies due to input assumptions or other factors regarding the usage of the house.

Chapter 4 is a presentation of the project house this entire thesis is based on. It describes the house both in terms of location and construction. The installed heat exchanger in ventilation is also described here. The chapter furthermore looks into the legislation on energy through the Icelandic building regulations. At the end of the chapter the energy loss through the building envelope is evaluated.

Chapter 5 is a description of the two energy models used in this thesis. This chapter also presents the results of the models. Chapter 5 furthermore looks into a method using probability analysis on the result of the BM-model to correct for uncertainties within the model.

The chapter starts with a description of the main model; the BM-Excel model and its results. Then the probability analysis is applied and its result presented.
Next, the Autodesk Revit and Green Building Studio model is described and its results presented.

Chapter 6 focuses on the monitoring systems installed in the project house. Here the physical equipment and its placement are described. The chapter furthermore looks at how the data is collected from the monitoring systems. At the end of the chapter the challenges and problems that occurred throughout this installation and monitoring period are discussed.

Chapter 7 is a presentation of the acquired data collected by the monitoring systems. The data in this chapter is presented through figures based on collected data.

Chapter 8 is the part that compares the results of the acquired data as well as the result from the modelling. The comparisons are carried out to the extent possible based on the acquired data.

Chapter 9 sums up the discussions and draws conclusions on the results of the research.

Chapter 2 Energy use in buildings

Historically, the energy use in buildings has changed. Before the 1970s the focus on energy use in buildings wasn't of big concern. With the oil crisis in the 1970s and 1980s energy consumption suddenly became a topic concerning most people. With America's support of Israel in its war against Egypt, Arabic oil producing countries decided to boycott the west and especially America. The boycott caused the price of 1 barrel of crude oil to rise by 400% in 1974 [1].
Back then, private oil burners were widely used and many power plants were running on oil as well. This meant that the incentive for lowering energy consumption in buildings became important.

Throughout the last 30 years the focus on improving insulation and optimizing energy use in buildings has resulted in a great reduction in energy consumption in terms of heating energy for buildings. In recent years the incentive has changed towards a focus on the emission of greenhouse gasses in order to minimize global warming and provide a sustainable environment [2].
Rising temperatures caused by global warming may contribute to changes in the way energy is consumed in buildings. In areas were heating used to be the main demand, the demand for cooling is now growing [2]. If this global phenomena is to continue it is important to adjust to this change and make provision for the cooling demand in buildings so that the design can adapt to users' requirements.

Another focus area affecting the energy consumption in buildings comes from the demand of creating a good indoor climate. A good indoor climate helps the users of a building to maintain good health. With new buildings becoming almost hermetically airtight, the need for good ventilation systems is increasing. This is due to the need for fresh air as well as the increased risk of fungus growth caused by the high moisture content of the air within airtight buildings. In order to meet the increased demand for a good indoor climate with a minimal use of energy, there is a need for a smart solution in implementing a ventilation system, especially in small dwellings.

With today's regulation requirements for increased insulation and airtightness of buildings, the primary energy consumption generally has shifted towards a decreasing heating usage. The energy consumption from electrical appliances, however, is following an increasing trend. This change in energy consumption is not only explained by changes in the design of buildings. It is also the result of a change in the way we live. Today most people in the western world have a multitude of appliances and other electrical equipment, such as dishwashers, dryers, PCs, tablets, TVs, cell phones etc., all of which contribute to an increased electrical energy consumption. In fact, according to a Danish study conducted by Statens Byggeforskningsinstitut, (SBI), about 70% of the total energy consumption in buildings in Denmark in 2008 was electrical consumption [2].

In order to be able to minimize the energy usage of a building cost-effectively, a strategy must be implemented at the design stage. Here, the focus must be on both the heating, ventilation and air conditioning systems (HVAC), as well as the building envelope (external walls, ground floor slab, windows/doors and roof). The building envelope comprises elements such as the type of insulation and thicknesses as well as types, areas and placement of glazed areas. In fact a 50-75% reduction in energy consumption compared to buildings designed in 2000 is achievable if a clever design is carried out [3].
The changed energy profile dictates a change in paradigm in terms of where the energy is used and thereby not only focuses on the energy in terms of heating, as the main energy consumption no longer comes from there. The focus on energy efficient buildings should maintain but adapt accordingly to how the energy is used. One example of a good energy efficiency standard is the German passive house standard [4]. The requirements for a building built according to the German standard are as follows:

"1.*The* ***Space Heating Energy Demand*** *is not to exceed 15 kWh per square meter of net living space (treated floor area) per year or 10 W per square meter peak demand.*

In climates where active cooling is needed, the ***Space Cooling Energy Demand*** *requirement roughly matches the heat demand requirements above, with a slight additional allowance for dehumidification.*

2. *The* ***Primary Energy Demand,*** *the total energy to be used for all domestic applications (heating, hot water and domestic electricity) must not exceed 120 kWh per square meter of treated floor area per year.*

3. *In terms of* ***Airtightness****, a maximum of 0.6 air changes per hour at 50 Pascals pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states).*

4. *Thermal* ***comfort*** *must be met for all living areas during winter as well as in summer, with not more than 10 % of the hours in a given year over 25 °C. For a complete overview of general quality requirements (soft criteria) see Passipedia[5].*

All of the above criteria are achieved through intelligent design and implementation of the 5 Passive House principles: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation and airtight construction."

As quoted above, the standard focuses on decreasing a building's energy usage in terms of heating but completely leaves out the electrical consumption. In order for a standard like this to work and keep its importance, it must be adapted according to today's energy profile.

2.1 – Energy use in buildings in Iceland

Iceland is a country enjoying the benefits of having vast amounts of energy running right under its feet due to the country's geographical location. The country is situated right above the mid-Atlantic ridge, which connects the European and North American tectonic plates. The ridge between the two plates is a divergent plate margin, meaning that the two lithospheric plates are moving apart causing a rift through Iceland. This process creates movement in the underlying asthenosphere allowing magma to rise up and out through the lithosphere. This process produces the great geothermal energy that Iceland is experiencing [6].

Iceland utilizes its geothermal energy in the form of geothermal power, and in fact about 90% of Iceland's hot water, both in terms of space heating and tap water, comes from geothermal energy provided by the world's largest geothermal district heating system [7]. The development of the use of geothermal energy for space heating between 1970 and 2013 is shown in figure 2.1. Iceland does not only benefit from its geothermal resources; hydropower also plays a substantial role in Iceland. In fact, 72% of Iceland's electricity production in 2014 came from hydropower[8]. Of the remaining electricity generation, 25% came from geothermal electricity generation[9] and the rest from wind turbines and imported fuels (petroleum derived) [10].

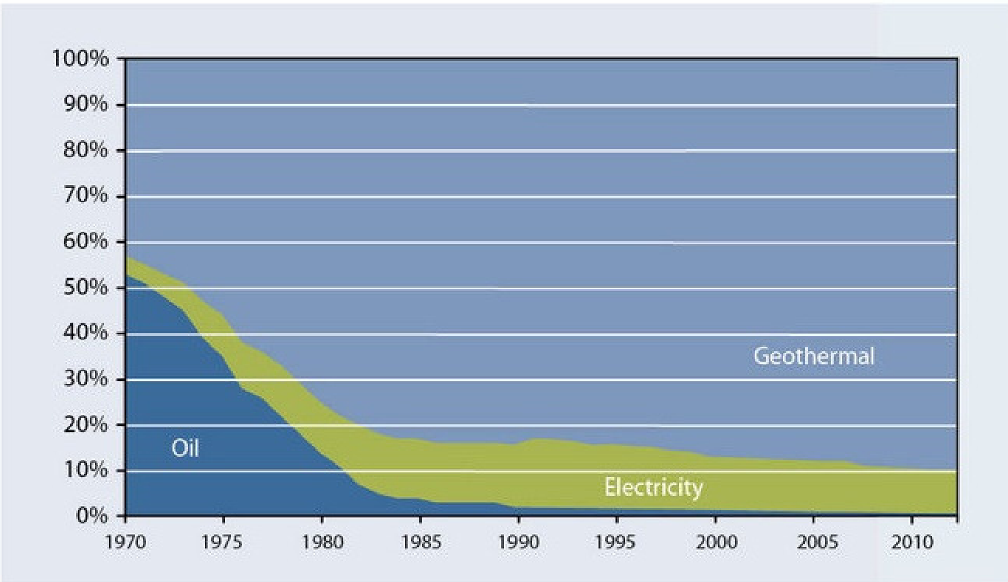


Figure 2.1 - Source of energy for space heating in Iceland the past 43 years [11]

The geothermal energy is a sustainable energy source and Icelanders benefit from this by achieving low space heating and hot water prices. Icelanders living in the greater Reykjavik area pay about 3,2 ISK pr. kWh [12] (number from 2013) and Icelanders living in areas with more expensive geothermal district heating pay about 4,8 ISK pr. kWh [12]. This is substantially less than neighbouring Scandinavian countries like Denmark pay. In Denmark the price of hot water is about 13,8 ISK pr. kWh [13] for district heating (water carried, not steam. 2013 prices).

As mentioned in the previous chapter, factors such as rising energy prices and emission of greenhouse gasses are the main global reasons for reducing energy consumption. The main incentive for Iceland to lower its energy consumption is the price of energy and, more precisely, the price of energy in areas where energy prices are higher. These areas are categorized as geothermally cold areas. Some towns and many rural farms in Iceland are in fact not even connected to a central heating grid and are therefore 100% reliable on electricity for heating. People living in these areas have to pay close to 8 ISK pr. KWh (2013 prices) as illustrated in figure 2.2.
This is where the real incentive for saving energy kicks in. It is furthermore not only a great incentive for the people living in these areas but also for the state, as electricity prices for space heating are subsidized with around 4 to 5 ISK per. kWh by the government [12].

Figure 2.2 – Energy prices compared for residential heating in 2013[12]

Icelanders have the possibility of receiving subsidies from the government if they fulfil one or more of the following three points according to Icelandic legislation [14]:

1. *"Niðurgreiðslu kostnaðar við hitun íbúðarhúsnæðis hjá þeim sem ekki eiga kost á fullri hitun með jarðvarma.*
2. *Greiðslu styrkja vegna stofnunar nýrra hitaveitna og yfirtöku starfandi einkaleyfishitaveitna á einkahitaveitum.*
3. *Greiðslu styrkja vegna umhverfisvænnar orkuöflunar og/eða aðgerða sem leiða til bættrar orkunýtingar við húshitun."*

Number 1 states the possibility of amortisation of heating expenses when a house is not fully heated with geothermal energy. This only applies for permanent residents, and houses with full-time occupancy.

Number 2 states the possibility of receiving payment of subsidies for establishing new, or taking over existing, private central heating companies.

Number 3 states the possibility of receiving payment of subsidies for using what is considered green electricity for heating or by establishing energy efficient heating in your house.

The subsidies described above are split in to two different categories; feed-in tariffs and up-front tariffs: The subsidised amount depends on where in the country a person is situated. There is one rate for rural areas and one for urban areas. In urban areas the possibility of subsidies as a feed-in tariff are 3,93 ISK/kWh of electric consumption for space heating up to 40.000kWh per year [14]. In rural areas the subsidies are somewhat higher and the possible subsidy here is 5,31 ISK/kWh of electric consumption for space heating of up to 70.000kWh per building per year [14].
These subsidies can also be received as an upfront tariff for establishing or changing to an energy efficient heating system; for example, if one were to install an air-air/ground-air heat pump or a heat exchanger in his/her house. The user would then receive an upfront subsidy scaled according to average annual energy use in kWh, instead of receiving annual subsidies. This upfront subsidy can equate to a maximum annual energy use of 40.000kWh for urban areas and 70.000 for rural areas. The maximum upfront subsidy possible in urban areas equates to 8 years multiplied by the average electricity usage for space heating up to 40.000kWh per year [11]. The user then does not receive any subsidies in the first 8 years after receiving this upfront subsidy and is obligated to pay the full price per kWh of electricity used for space heating in that period of time.

Chapter 3 Energy modelling background

3.1 The purpose of energy modelling

The previous chapters discuss the energy use within buildings as well as the importance of implementing the correct solutions at an early stage of the design phase when planning a new house. An efficient way to do this in terms of energy use and losses is to run an energy model on the proposed project.
Energy modelling consists of an analysis of the building design in terms of its predicted energy use for the respective location. The results can be used to make changes at an early stage of the design to optimize and fulfil requirements set by building authorities and the building owner regarding energy use and indoor climate. There are a number of different energy models available on the market, which require different levels of details regarding the building information. The more information needed the more assumptions and possible errors are present. Each individual model therefore can provide a different result but it cannot be said that one is necessarily more accurate than another as there are no known models that give a precise result. This is important to bear in mind when working with these kinds of models.

Energy models can be created based on complicated 3D models equipped with detailed information on all building parts as well as location and climate data for the given area. The information provided is then processed in a simulation providing a variety of results. The results can be useful for the designer/planner to make sure that the energy losses and overall energy consumption are within the limits set by local building regulations. The results can furthermore be useful for the building's owner or end user, as they can provide guideline information on the building's monthly or annual energy consumption, indicating the costs of running the building. This is especially useful for larger commercial buildings where either private investors or municipalities have to budget for the energy costs. It also a useful tool to benchmark different options against each other in order to pick the most beneficial solution. By benchmarking different options, the owner also gets more clarity on the investment, as the capital expenses might not be as important as the lifecycle costs. In this case, the owner might choose a more expensive system in terms of installation costs if the running costs are less and therefore provide a cheaper and more trouble-free solution over a life cycle of, for example, 10, 20 or 30 years. Furthermore, the results can be used to clarify CO2 emissions, an issue that larger commercial buildings especially commonly focus on.

Simpler energy models can also be created using programs such as Excel, MATLAB etc. Here, the information on building parts is described and used together with other parameters such as climate data, sun radiation, ventilation systems (if present), number of habitants, tap water etc. The precision of the end result very much depends on the precision of the parameters included and these parameters are all much affected by the number of inhabitants, which is extremely difficult to account for.

It is important to consider energy modelling as a guideline and not as an exact predictor, as many parameters can influence the result. The key parameters used in energy modelling are described in the following sections.

Energy modelling is an important tool in preliminary planning when designing a building. It is, however, important to mention that the focus in energy modelling should be adapted to include a stronger focus on electricity use due to the changed energy profile in dwellings. It is a difficult procedure as it can be difficult to predict users' electricity use as well as the number and type of electrical appliances. Also, such information is likely to vary between countries. The difference in energy prices could, for example, affect the behaviour of the user and the way in which he or she thinks about turning off appliances, as well as the incentive to buy energy efficient appliances. A way to deal with this could be by adding assumptions in the model based on country or regional data concerning typical electricity use per user.

3.2 Key parameters in energy modelling

When working with an energy model, a number of parameters must be defined, or to some extent assumed, in order to get a reliable result. These parameters vary in terms of detailing from the complexity level of the used energy model. The following parameters must however be defined to some extent in order to obtain a useful result[15]. The key parameters are:

- Building type
- Building location
- Weather data
- Internal temperature
- Usage type
- Number of occupants
- Installations
- Internal heat gain
- Other electric usage
- Cold bridges
- Infiltration
- Ventilation losses
- Heat transfer and the building envelope

3.2.1 Building type and location

The type of building must be defined; is it a one-storey single family house, an apartment building or perhaps a school or hospital? This is especially important when using complex models with predefined data inputs depending on building types. Where the building is geographically located and what directions the façades face must also be determined. The presence of any significant shading must also be determined. This can be from trees, mountains, roof overhangs or other objects blocking the incoming solar and sky radiance.

3.2.2 Weather data

Based on the previous point, this defines the mean temperatures, solar and sky radiation humidity and wind velocity. Typically, monthly mean values from a reference year are utilized in simpler models like the BM-Excel model, whereas more complex models can utilize forecasts based on historic weather data for dating many years back. Others use data recorded in given years and the model calculates for that chosen year.
Once again, depending on the complexity of the used model, the mean temperature values can simply be the average temperature, also known as dry bulb temperature, during each month based on the previous year. They can, however, also be a combination of dry bulb and wet bulb temperatures.

The dry bulb temperature is the ambient air temperature, which means the temperature measured by a thermometer.

The wet bulb temperature is the adiabatic saturation temperature. When adiabatic evaporation of water and the cooling effect of it is measured, it is called the wet bulb temperature. The wet bulb temperature is always lower than the dry bulb temperature and above the dew point temperature where the moisture in the air condensates. The differences between wet and dry bulb temperatures are defined by the humidity of the air present.

The sun and sky radiation has a significant importance to the overall result. It is energy that is received primarily through glazed areas and it accounts for a large amount of energy. It is energy that is not consumed in a traditional way, but simply is present, and it therefore accounts on the positive side of the energy calculation as it can be subtracted from the primary energy consumption.

Wind velocity is also a parameter within the weather data parameter that should be considered. The wind velocity affects the infiltration of outside air into the building and affects the air change losses in the house.

3.2.3 Internal temperature

The internal temperature has a great effect on the energy performance of a building. Simpler energy models, like, for instance the BM-Excel model, which work with one parameter concerning the indoor temperatures, simplify the actual 24-hour heating profile. This is typically assumed to be to 21°C. This temperature is an average temperature of the assumed 24-hour heating profile of the house. More complicated models define a set point temperature for both heating and cooling (if present).
The set point for heating ensures that the internal temperature never goes below this value, while the set point for cooling will not be exceeded. The internal temperature can fluctuate between these set points. The set points are commonly set at 20°C for heating and 26°C for cooling. These model types typically also let the user define zones within the building where set points can differ.

In Denmark rooms heated between 5°C and 15°C can be left out of the energy calculation. If the room is chosen to be left out, all energy from light, ventilation and heating is left out of the calculation. If, however, the room is chosen to be included, it must be calculated as having a temperature of 20°C[15]. In the Icelandic building regulations there are no definitions regarding energy modelling. The definition only describes the maximum U-values for the building envelope encompassing rooms heated from 10°C to 18°C and 18°C and above. These temperature ranges vary from country to country with the respective building regulations. The heated floor area also differs, being either gross or net area depending on the country's definition.

3.2.4 Usage type and number of occupants

This parameter defines how many people use the building and for how many hours a day/week/month. It also defines for what purpose the building is used. The parameter influences the amount of hot water, electricity and heating, and how they are used. It is also the most difficult parameter to define as it often varies even within short timelines.

3.2.5 Installations

This includes the energy spend on hot water, electricity, mechanical ventilation and heat exchangers, if present. Installations are very much connected to the usage type and number of users, and there are big uncertainties among the parameters of this category.

3.2.6 Internal heat gain

This is the heat energy received from warm bodies (people) and excess heat from electrical appliances. This parameter is closely connected to the usage type and number of occupants, and is therefore very difficult to determine precisely. In Denmark there is a standard definition which stipulates using 4 W/m^2 for people and 6 W/m^2 for appliances[15]. The actual usage, however, is expected to deviate much from this standard definition.

3.2.7 Other electric usage

This includes external lighting and heating. This parameter depends on the building regulations but is normally not a part of an energy calculation. However, it is good to be aware of the fact that it is present.

3.2.8 Cold bridges

This refers to areas where materials with high thermal conductivity penetrate the building envelope through the insulation material. This can be, for example, a concrete balcony attached to the loadbearing inner wall or floor.

3.2.9 Infiltration

This parameter deals with the airtightness of the building envelope. The infiltration is defined by Danish standards from the following:

Table 3.1 - Calculation principle for infiltration[15]

	Infiltration, qinf (l/s/m²)
Within usage time	0,06 x q50 + 0,04
Outside usage time	0,06 x q50

Here, q50 is the airflow through the building in l/s/m² measured at 50 Pa pressure difference in both under and over pressure. The factor used to translate the building envelope's air leakage at a pressure difference of 50 Pa when performing a blowerdoor test is taken as 0,06. In realistic conditions the infiltration will vary depending on the amount of wind blowing at the different surfaces of the building. The value of 0,06 is defined by SBI to match a typical Danish dwelling with no ventilation channels. The location is in an open landscape surrounded by other houses and vegetation half the height of the calculated house. The house is situated in a typical Danish climate with wind speeds of 4,5m/s and external dry bulb temperatures of 1,5°C[15].

The 0,06 factor must be considered when using in other climates, such as the Icelandic, with wind speeds, landscape and temperatures being quite different.

Icelandic building regulations describe a maximum infiltration of $3m^3/m^2$ per hour.

3.2.10 Ventilation losses

Ventilation losses covers energy losses through both natural and mechanical ventilation.

In general, ventilation losses are calculated by the definition in DS418:2011 Beregning af bygningers varmetab. The following is a translation, the original Danish text can be found in appendix 16.

$$\Phi_v = \rho\, c\, q\, (\Theta_i - \Theta_e)$$

"Where:

Φ_v, *ventilation loss in W*

ρ, *the air density in* kg/m^3

C, specific heat in J/kg K

Q, airstream from external air added to the room in m^3/s

Θ_i, *dimensioned internal temp in ℃*

Θ_e, *dimensioned external temp in ℃*

At 20 ℃ and 1013mbar is c = 1005 J/kg K, and $\rho = 1{,}205\ kg/m^3$ *(dry air)*

For normal rooms the difference in air temperature and internal temperature is not accounted for[16]."

Losses through natural ventilation covers leaks in joints around windows and doors located in outer walls or the roof. The calculation of natural ventilation is defined in DS418:2011 by the following:

"Here the airstream q is calculated from the amount of outside air in l/s per heated floor area in m². The calculation looks as the following.

$$\Phi_v = \rho c \frac{q_a}{1000} A\ (\Theta_i - \Theta_e) \approx 1{,}21\ q\ A\ (\Theta_i - \Theta_e)$$

q_a is the amount of outside air in l/s
A is the heated floor area in m^2
For q_a the value 0,3 l/s per m^2 is used for rooms like living rooms, toilets and kitchens. For larger rooms like storages etc. the value used is lower and typically 0,18 l/s per m^2 is used.

These values are difficult to verify and therefore carry great uncertainty. If it is expected that the air leaks are greater and thereby causing an air stream higher than 0,3 l/s per m^2 then the loss instead can be calculated by knowing the length of all joints around the calculated room, the air penetration of that room and the location of the building. The airtightness on joining elements in windows and doors are typically specified by the manufacture. If not however the definition suggests 0,5 · 10-3 m3/s per joint between fixed frame and opening mullions at a normal location and 0,8 · 10-3 m3/s in exposed location – meaning by the sea or other open and windy areas[16]."

For mechanical ventilation systems, such as the heat exchanger present in the calculated house in this thesis, the ventilation losses are calculated differently.
Here the energy loss calculations are based on the specifications of the system and it is accounted for that infiltration through ventilation ducts are present. The infiltration and exfiltration through the system pipes are affected by external conditions such as wind velocity and temperature. The calculation differs depending on the type of system. For a ventilation system with a heat exchanger like the one present in this project, it is defined by the following:

" $\Phi_v = \rho\ c\ (q_2 + q_3)(\Theta_i - \Theta_e) - \rho\ c\ \ q_1\ (\Theta_l - \Theta_e)$

Where:
q1, airstream from outside through system in m^3/s
q2, exhaust air in m^3/s
q3, airstream of exfiltration in m^3/s
q4, airstream of infiltration in m^3/s
ρ, the air density in kg/m^3
c, specific heat in J/kg K
Θ_i, dimensioned internal temp in ℃
Θ_e, dimensioned external temp in ℃
Θ_l, external air temperature after heat exchanger unit in ℃

The same air conditions for q is a requirement e.g. 20°C and 1013mbar and that ρ is in the same condition. Furthermore the temperature increase Θ_l −

Θ_e through the system must only come from the heat exchanger. Θ_l is defined by the data on the heat exchanger unit.

q_1 and q_2 is determined under normal operation. Normally q_1 is slightly lower than q_2. q_3 is determined with consideration to the airtightness of the building, usage and location. In buildings where the airtightness of the building envelope is examined under pressure test with 50Pa (q_{50}) exfiltration is within usage time is determined by 0,04 + 0,06 $\cdot$ q_{50} l/s m^2. Outside normal usage time exfiltration is determined as 0,06 $\cdot$ q_{50} l/s m^2.
The ventilation loss can be covered by additional heat from air treatment components, like heat exchangers such as radiators in rooms where external air is added.

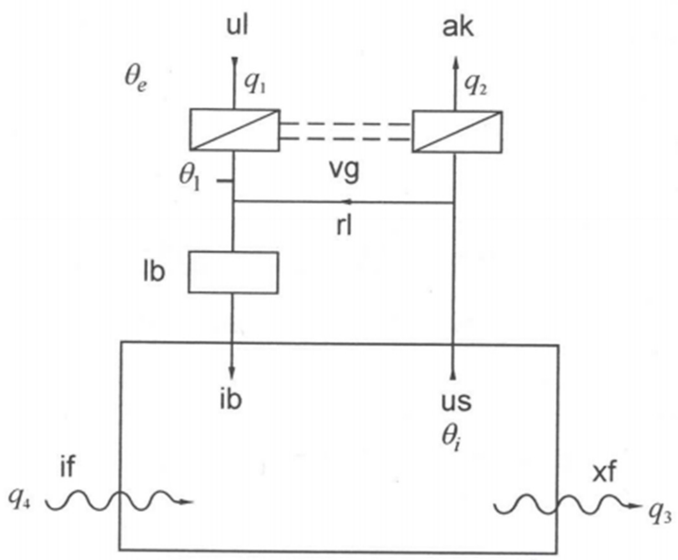


Figure 3.1 – schematic explanation of mechanical ventilation loss calculation[16]

A schematic explanation of the calculation is illustrated in figure 3.1. The large square represents the area that is calculated, this can include more than 1 room."

3.2.11 Heat transfer and the building envelope

With temperature differences comes heat transfer. The greater the temperature difference is, the faster the heat transfer through the building envelope becomes. Heat is always transported from the warmer area towards the colder area, meaning from the inside towards the outside on most days of the year in Iceland. Other countries with warmer climates do experience heat transfer from the outside in. As long as there is a temperature difference, heat is transferred. When temperatures become the same in both areas, heat transfer stops and thermal equilibrium is achieved[17].
Other factors influencing the heat transport through the building's envelope are the thermal resistance (R-value) to heat transport. The thermal resistance of a material located between the hot and cold area dictates the speed of the heat transport and thereby the heat loss as defined over time.

Heat transport is heat energy and is present as three different types; radiation, conduction and convection.
Radiation is present through electromagnetic waves coming from hot surfaces, like the sun for instance.
Conduction heat transport is transferred by direct contact from the molecules of a warm surface to the molecules of a cold surface. It can also happen when a liquid or gas flows and transports the heat of the source media with its flow.
In convection heat transport, molecules in the air colder than any surface absorb the heat. The molecules then expand and rise, taking the heat energy away from the surface. This is the process used by a radiator or convector, which the name also describes.

Thermal conductivity (λ–value) and thermal resistance (R-value) are the properties of a material defining its heat conducting capabilities. It is also from these two values that the thermal transmittance (U-value) is calculated. The U-value is the used value in energy models concerning energy losses through the building envelope. The three values are defined as follows:

λ –value The symbol lambda (λ) in energy terms describes the thermal conductivity of a material. The unit is in either W/mK or mW/mK. The lambda value describes the amount of heat energy with a temperature difference of 1°C on each side, that can pass through $1m^2$ of 1m thick material[18].
The thermal conductivity, λ, is a parameter describing the thermal characteristics of the material. A material with low thermal conductivity has good insulation qualities. The lambda value is essential in estimating the thermal resistance of each material layer (R-value), as well as the thermal transmittance of a whole building element (U-value).

The lambda value is either specified as a declared value or design value. The declared value is the value given by the manufacture. This value is based on measurements carried out in a lab with specific temperatures and moisture content.

The design value is the value that is to be used for calculating the U-value. The idea with the design value is to consider the variability in the lab measurements to the actual variability in the real construction. The difference in the design and declared values comes when average temperature and moisture content differ from each other. It has, however, proven not to be as important as originally thought and it is therefore only relevant for the slab where the declared value must be multiplied by a factor 1,2. In the rest of the building, the design value and declared value are now considered to be equal [18].

R-value is a measurement of a material's thermal resistance. It is an indicator for a material's resistance to conductive heat transport. The R-value is specified through the unit m^2K/W. It describes the heat resistance through 1 m^2 of material [18]. The R-value can be calculated when the λ-value is specified with the following formula:

$$R = \text{material thickness in meter} / \lambda \quad (1)$$

Table 3.2 depicts thermal resistance of different materials. As shown, metals typically have a very low thermal resistance as they transfer heat quickly and efficiently. Wood, on the other hand, has a moderately high thermal resistance.

Table 3.2 – Thermal resistance of certain materials[17]

Material	Thermal Resistance
Metals	Very low
Masonry	Moderately low
Wood	Moderately high
Glass	Low
Air	Best resistor commonly found in buildings

U-value is the thermal transmittance of a whole building element. The unit is W/m^2K. The U-value describes the overall amount of heat energy when the temperature difference is 1°C on each side of the element that is transferred through 1 m^2 in 1 hour [18]. The U-value is calculated by the following formula:

$$U = 1 / \Sigma R \quad (2)$$

This is the reciprocal value of the sum of thermal resistance (R-value). This formula, however, doesn't account for other factors than the materials in an element. In order to account for other factors, ΔU must be added into the equation. These factors can be inconsistency in insulation and therefore air cavities (ΔU_g), mechanical fixing (ΔU_f), which can be long screws for fixing insulation to the loadbearing element, e.g. a concrete wall, and reversed roofs (ΔU_r), where rainwater is running between the insulation layer and the waterproof membrane of the roof.

$$\Delta U = \Delta U_g + (\Delta U_f) + (\Delta U_r). \quad (3)$$

How to calculate ΔU_g,,ΔU_f and ΔU_r is described in Danish standard DS418:2011 – Beregning af bygningers varmetab. An example of such a calculation can be found in section 4.4.1.

Temperature differences and heat flow also affect the flow of humidity and water vapour in the air. Humidity and water vapour is present in air at all times; the difference is the amount of water vapour present at a given time. Warm air contains more water vapour than cold air, and warm air can also hold more water vapour than cold air.
Air has a maximum amount of water that it can contain; the amount of water vapour is typically below that level. At those times when the maximum possible water vapour in the air is reached, condensation begins. The condensation process is present on either cooler surfaces as water, or in the air as fog and rain.
The expression relative humidity refers to the amount of water vapour present in the air divided by the maximum possible amount of water vapour in air at a certain

temperature. This means that at a relative humidity of 50%, the air contains half of the maximum possible vapour at the given temperature.

When the air temperature goes low enough it reaches the dew point. The dew point is when the relative humidity is 100%. When the air cools below the dew point, the water vapour condenses by changing from a gas into solid water droplets. The water vapour, however, only condenses until 100% relative humidity is maintained. The remaining water vapour remains in a gaseous state in the air[17]. The most optimal internal relative humidity for humans is considered to be within a 20-50% range. With higher relative humidity, sweat cannot evaporate off the skin, and it becomes more difficult to cool off. This often occurs during summer time when the warmer air contains more water vapour, which means higher relative humidity.

A family of four produces about 11kg of water vapour per day[17]. This is emitted both from breathing and sweating, as well as cooking and washing. With houses becoming more and more airtight this is a significant add on to the relative humidity inside the house and can cause extra condensation, especially around colder surfaces such as glazed areas. This condensation can eventually lead to moulding if not treated. The moisture, however, doesn't only show in visible areas of the building. It also becomes present within the building envelope. As moisture content in the air rises inside the house, a vapour pressure in the air is created. This makes the water vapour expand into areas where the vapour pressure is lower – for instance, inside the building envelope.

The external walls in a house experience hot, moist air on the internal side and cold, drier air on the external side (Icelandic climate). This makes the water vapour migrate through the wall from the moist internal side towards the drier external side. The humidity thereby follows the heat flow through the building envelope.

With most materials having only some or moderate resistance to water vapour, it can easily migrate into the building envelope if not prevented. The big problem with this is when the temperature reaches below the dew point and water condensation within the building envelope occurs. The condensation creates a lowering of the vapour pressure within the building element and, as a result, more moisture is pushed in from the warmer side. The inside of the building element then becomes more and wet over time.

A wet inside of a building element can cause a number of issues. The insulating material, such as Rockwool, collapses and sink together and loses its insulating capability. A higher heat flow will then be present, resulting in a higher heat loss. If the building element, e.g. a wall, is built of wooden studs, these will become wet and rot over time. If steel studs or other mechanical fixings are present, these can corrode over time, despite non-corrosive treatment. Furthermore, a wet and moist environment close to the warm side is a breeding ground for fungus. This is a serious health concern both for people and animals and if not found in time can lead to hospitalisation and lung and respiratory diseases[17]. In order to prevent the travel of moisture into the building envelope, a vapour barrier must be installed when building the house. This is typically in the form of a thin plastic foil.

It is extremely important that the vapour barrier is located on the warm side of the building element to prevent the moisture from reaching cooled air and creating condensation within the building element.

Figure 3.2 illustrates an external wall and the effects of water vapour in air with and without a vapour barrier.

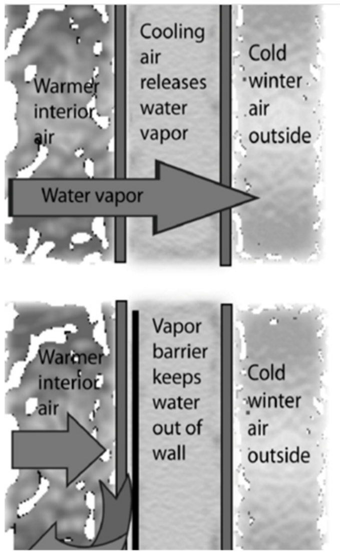


Figure 3.2 – External wall with and without a vapour barrier[16]

3.3 Inaccuracies in energy modelling

As mentioned, energy modelling should be used as a guideline tool as many input parameters are based on assumptions. These assumptions are based on previously gathered data and can therefore be inconsistent. It is always important to be critical of the data used in a model in order to get the most realistic result possible.

Climate data is one assumption in a model that can cause inconsistencies. Climate data used in energy models are, as mentioned earlier in this chapter, based on a reference year or historic weather data over a number of years. These data can vary a lot from year to year and therefore can create inconsistencies; for example, if the assumed data is from a year with either an extremely harsh winter or a very warm and long summer. The temperatures and the incoming solar radiance will be showing a result with either bigger heat losses or less energy used for heating, and are therefore not a reflection of the actual energy profile of the house.

The uncertainty in these factors makes it difficult to estimate the free energy use, also called effective energy use, which is the energy consumption from sources other than traditional use, like hot water.

Another important assumption which affects a number of parameters in an energy model is the behaviour of the users in the building that is being modelled. For instance, if looking at a small dwelling like the one in this report, it is very important to know how the house is used. During night time, some users prefer lower temperatures than others; complicated models account for this with precision whereas simpler models do not. It is however very much up to the user of the more complicated energy model to get these values defined to reflect reality. If the house is equipped with programmable thermostats, it can make sense to have the house run with lower energy consumption during night. Some users might prefer 25°C or even 19°C. The internal temperature assumption is therefore indeed linked to the users and can result in a substantial variance from the model.

The user also determines whether the building is empty for longer periods. This could be due to holidays or perhaps the building simply not being used as a primary residence and therefore left empty for long periods of the year. In that case, an assumption of 21°C could be inappropriate and be quite different from the actual average temperature.
Fluctuations in temperature are also very much affected by the amount of natural ventilation a user requires. If windows and doors are kept open for shorter periods at several times of day, the internal temperature will change during these intervals. However, houses with mechanical ventilation systems might not suffer from these fluctuations in temperature, as natural ventilation is not needed. Mechanical ventilation does, on the other hand, have some electric energy consumption through its electric motors.

The determination of the U-values also contributes to the uncertainty of the model. Theoretical U-values can differ a lot from how a building part is actually built in-situ; for instance, if the insulation is pressed together during installation or does not fill out the entire cavity etc.
The λ-value of the insulating material used is in some cases not detailed in the design specifications or the contractor simply does not pay attention to this value when purchasing the materials. This can lead to higher or lower thermal conductivity than assumed when calculating the U-values.
Determining U-values for windows can be quite difficult, as windows do not only consist of one value, i.e. the glass U-value, but several other parameters that depend on the type of window. These are, for instance, line losses between frames and adjacent building parts, frame material and its width and depth. In addition, if the window is divided into several pieces with glazing bars for aesthetic reasons, this should be taken into account when calculating the U-value for the windows.

Chapter 4 The case studied

4.1 The site

The project house (see figure 4.1) is designed and owned by Icelandic architect Gestur Ólafsson (GÓ), owner of Skipulags- arkitekta- og verkfræðistofan ehf. The house is situated about a 45min drive southeast of Reykjavik in the old fishing town of Eyrarbakki, which is a part of the Árborg municipality that also encompasses the towns of Selfoss and Stokkseyri.

The town is close to the low temperature geothermal reservoirs called Ósabotnar and Thorleifskot-Laugardaelir [19]. These low temperature reservoirs are utilized by the local district heating company Selfossveitur, and provide district heating for the entire Árborg municipality. The reservoirs, however, are encountering numerous problems, and with an increasing heating demand and a dropping energy output, aren't considered as efficient as the high temperature reservoirs providing e.g. Reykjavik with hot water and space heating.

The low temperature system of Thorleifskot-Laugardaelir has experienced a decline in energy outputs, primarily from an excessive inflow of cold groundwater due to fractures in the wells [19]. The other low temperature system of Ósabotnar was initiated in 2000, primarily due to the drop in energy outputs at Thorleifskot-Laugardaelir. The Ósabotnar reservoir has also faced challenges, the main one being a high level of calcite resulting in calcite deposits in the pumps preventing them from operating efficiently [20].

The project house in Eyrarbakki is located in an area with district heating and connected to the district heating system of Selfossveitur. However, there is a possibility that increasing prices, along with the growing challenges associated with the local geo-thermal reservoirs, may affect energy supplies in the future.

The idea and objective for building the house was to explore the possibilities of building an energy efficient, environmentally friendly and low maintenance house in Iceland. Furthermore, the house was built in a somewhat non-traditional way in order to build economically. The goal was to achieve a 20% reduction in construction costs, compared to a more traditional building practice.

One challenge in realizing the building project was to find a location where money could be saved without compromising time plans, typical standard of living, aesthetics and environmental aspects. This required extra careful planning at an early stage of the design period. The location of the house was selected based on the vicinity to good infrastructure and building supply resources, in order to shorten the construction period and lower the building cost.

In 2009 an application for partial funding of the initial planning of the house was submitted to Íbúðarlánasjóður Research Fund. When funding was approved, the project was initiated.

The house is a one-story house with a 127m^2 footprint and must be considered somewhat smaller than the average for the area. Dwellings within the capital region of Iceland have an average size of 114,5m^2 and dwellings outside the capital region are generally larger[21]. The volume of the house is calculated to be 338m3. As illustrated on figure 4.1 and 4.2, the cladding on the house is the traditional sinus plates often used in Iceland.

Figure 4.1 - The house in Tungata 9 Eyrarbakki

Figure 4.2 - The house in Tungata 9 Eyrarbakki

The initial design of the structural elements of the house suggested to use light load bearing steel studs in external walls and light load bearing steel trusses in the roof [22]. The energy authority in Sweden developed this system, which has been used with great success [22]. However, manufacturing and shipping time, cost and environmental aspects concerning the shipping of the profiles from Sweden were against their use. The first reaction was to initiate a plan to build a factory in Iceland, producing these profiles. This however, was not realized, and the house ended up being constructed with wooden studs and trusses instead [22].

Figure 4.3 – Picture of the construction process [22]

Figure 4.4 - Picture of the construction process [22]

Figure 4.5 - Picture of the construction process [22]

As shown on the detailed design drawings in Appendix 01, the initial plan of light steel studs is kept in the drawing material in order to keep the original plan within the planning material [22], although these were not used. As built drawings which were later produced describe the use of wooden studs instead. As built drawings are located in appendix 12.

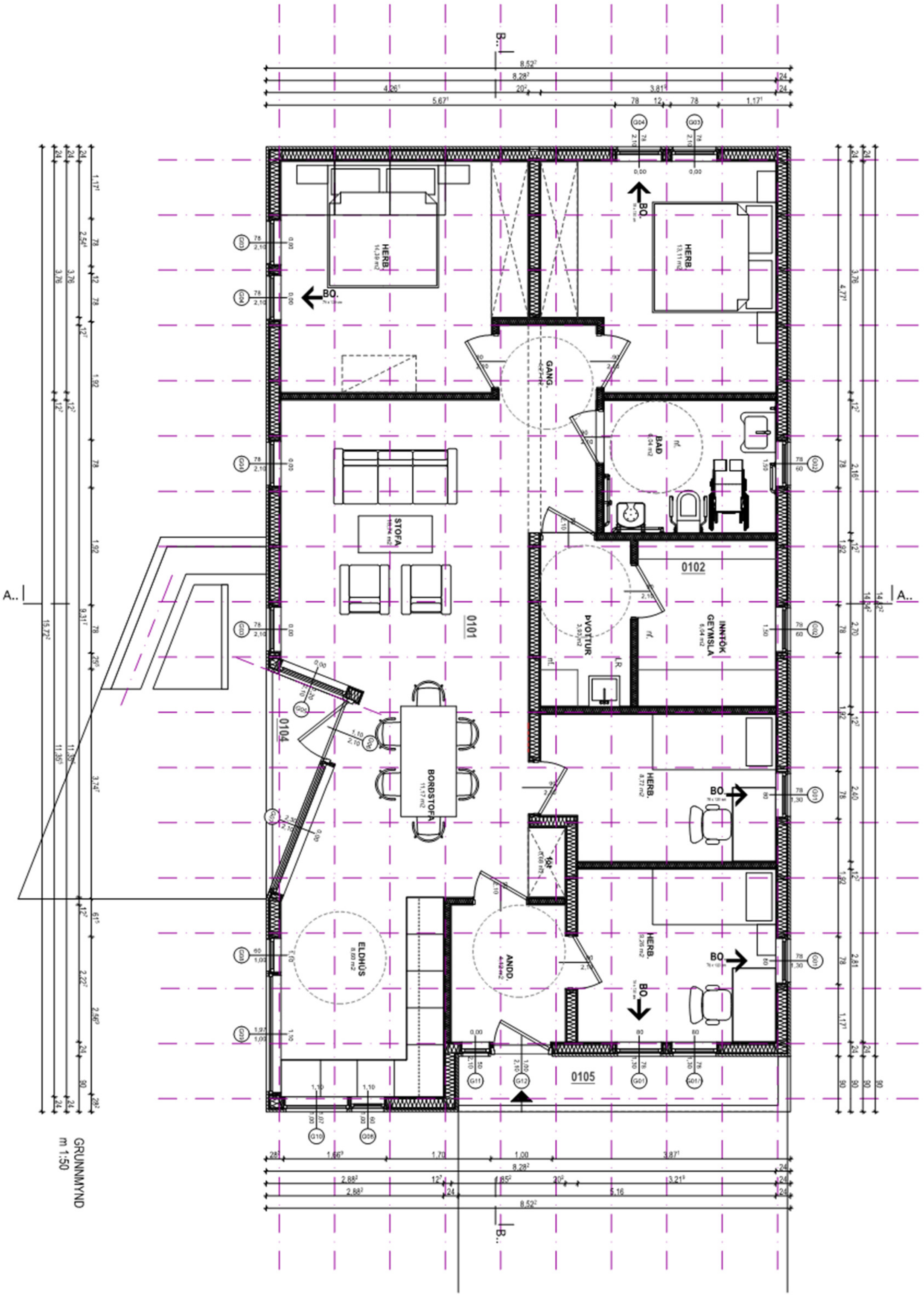


Figure 4.6 – Plan layout of the house (part of original drawing material)

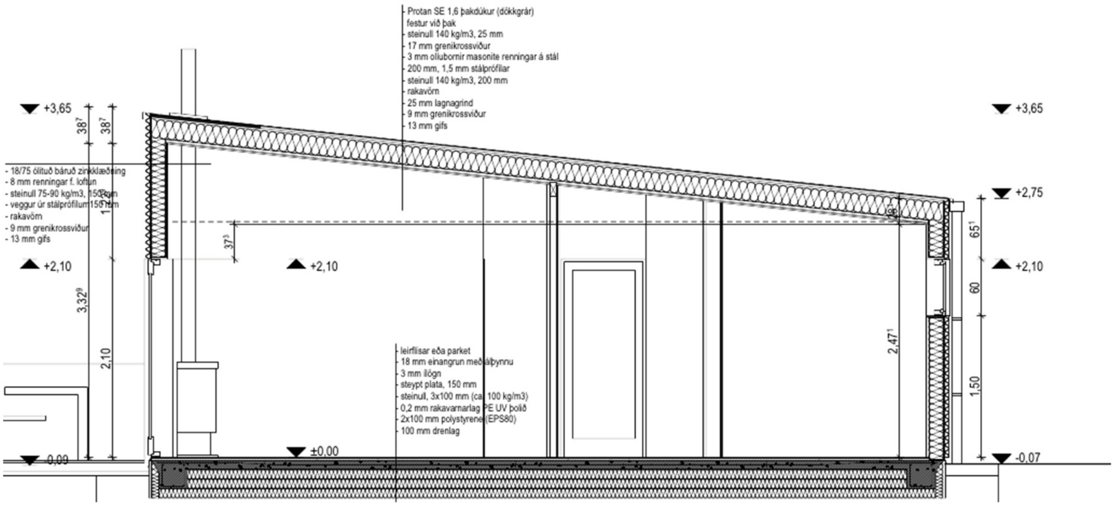


Figure 4.7 – Section layout of the house (part of original drawing material)

Table 4.1. Technical descriptions of main components of the project house

Walls:	Exterior cladding consists of corrugated steel plates attached to 150mm wooden studs insulated with 150mm Steinull HF insulation with a thermal conductivity of 0,038 W/mK. Interior cladding is separated from the insulated layer with a damp proof membrane. The interior cladding consist of 1 x 9mm plywood and 1 x 12.5mm plasterboard.
Roof:	Exterior roof material consists of Protan SE roof felt on 25mm pressure resistant stone wool with a thermal conductivity of 0,037 W/mK. Below is 17mm thick plywood plates. The roof construction is built with 195mm wooden trusses and insulated with 195mm stone wool with a thermal conductivity of 0,037 W/mK. The interior cladding consists of 1 x 9mm plywood and 1 x 12.5mm plasterboard, both separated from the steel trusses with a damp proof membrane.
Floor:	The floor consists of a 150mm reinforced concrete slab on top of 200mm expanded polystyrene with a thermal conductivity of 0,036 W/mK.
Windows:	Double glazed Velfac Clear / Energy (As described in original project material (appendix 01)
Doors:	Double glazed Velfac Clear / Energy (As described in original project material (appendix 01)

The plan and section layout of the house can be seen in figure 4.6 and 4.7. It illustrates the distribution of rooms in the house, which consist of a combined kitchen and living room, a bathroom, a service room, where the heat exchanger is installed and all utility pipes as well as electricity enters the house, a washing room and four bedrooms. It should be noted that the two smaller bedrooms were initially planned as a garage. The technical specifications of the house are described in table 4.1. Table 4.2 summarizes the area of walls and openings (windows and doors) in m^2 and towards which direction these are facing.

Table 4.2 – Amount of walls and windows/doors in m^2 and their direction

Facing direction	**External walls area (m^2)**	**Window/Door type and area (m^2)**
NE	41,7	2 x G01 = 2,02 2 x G02 = 0,47
SE	21,3	2 x G01 = 2,02 G05 = 2,31 G08 = 0,6 G10 = 1,07 G11 = 1,05 G12 = 2,1
SW	37,4	4 x G03 / G04 = 6,56 G06 = 2,31 G07 = 5,26 G08 = 0,6 G09 = 1,97
NW	21,7	2 x G03 / G04 = 3,28
Total	**122.1**	**31.62**

Weather data from the Iceland MET office for the area can be found in appendix 10. These data are graphical illustrations of temperature, dewpoints, wind speed, wind directions and barometric pressure over the past 10 years for Eyrarbakki.

4.2 Current building regulation requirements

In 2012, during the design process, a revision of the Icelandic building regulations was published[23]. This meant more strict requirements relating to insulation values as well as air change in houses. Se table 4.3 on insulation values; note that table 4.3 is a translation of the Icelandic requirements which can be found in appendix 17. table 4.4 provide recommended and required air change values; note that table 4.4 is a translation of the Icelandic requirements which can be found in appendix 17.

The requirements listed in table 4.3 reflect the maximum allowed U-values for different building parts of a house e.g. the roof, walls etc. There are two requirements for each building part. The first one describes the requirement of a building part encompassing a room heated to 18°C or above. The other one describes the requirement of a building part encompassing a room heated from 10°C – 18°C.

Table 4.3 - New structures and extensions for possible maximum U-values of the individual buildings parts[23]

Building components	**Maximum allowed U-value (W/m2K)**	
	Ti ≥ 18°C	**18°C > Ti ≥ 10°C**
Roof	0,20	0,30
Outer walls	0,40	0,40
Light outerwalls	0,30	0,40
Windows (frames, glass weighted average, K-glass)	2,00	3,00
Doors	3,00	No restriktions
Skylights	2,00	3,00
Floor against ground	0,30	0,40
Floors against unheated rooms	0,30	0,40
Floors against outdoor air	0,20	0,40
Exterior walls, the weighted average (wall surfaces, windows and doors)	0,85	No restriktions

Ti = Indoor room temperature

Table 4.4 describes how much ventilation is required to ensure a good indoor climate no matter what type of ventilation system is present.

Table 4.4 Requirements for Residential space ventilation and related rooms[23]

Residential spaces can be ventilated with natural ventilation, mechanical ventilation or a combination of both. *The following shall ensure ventilation in residential houses is possible regardless ventilation type.* a. *All living areas must be ventilated so that the air quantity delivered to the room is at least 0.42 l/s per m^2 floor area while the room is in use and at least 0.2 l/s per m^2 floor area while the room is not in use. Also, ensure that the fresh air quantity delivered to the bedroom is never less so than it corresponds to 7 l/s per bed while the room is in use.* b. *Rooms that are not in constant use must be ventilated so that the amount of fresh air is at least 0.24 l/s per m^2 floor area.* c. *Air extraction from residential kitchens must be at least 30 l/s.* d. *Air extraction from residential bathrooms must be at least 15 l/s.* e. *Air extraction from residential washing rooms must be at least 10 l/s.* f. *Air extraction from residential single storage or basement rooms where there is a constant presence must be at least 0.2 l/s per m^2 floor area* g. *Air extraction from residential laundry rooms of one apartment shall minimum be of 20 l/s.* *Air extraction in apartments for elderly and specialized flats for the disabled should be assumed to be in use 24 hours a day.* *Supply of fresh air to the kitchen, bathroom, toilet, laundry must come through an opening of at least 100 cm^2. when these rooms are not next to an outer wall fresh air can come from adjacent rooms with less pollution or moisture. When these rooms are located next to an outer wall, the fresh air must come from the outside, through a window or special ventilation.*

4.3 The ventilation system

The new requirements discussed in section 4.2 combined with studies conducted by B. Marteinsson regarding indoor climate [22] led to the decision to install an air to air heat exchanging unit providing fresh warm air through a ventilation system in the house. The heat exchanger works both as an air exchange unit as well as a heating device. Nevertheless, the house is fitted with water carried floor heating throughout the entire house, as well as the outside driveway.
Unlike many places in Iceland, the area of Eyrarbakki is very flat and there are no obstacles such as mountains or trees creating any shade. The house receives direct daylight from all directions.

The ventilation system in the house is a combined heat recovery unit (see figure 4.8). The unit is a rotary heat exchanger manufactured by Swedish company Systemair[24]. The model name is VR 400 DCV/B. The unit has 5 inlet and outlet connections located on the top. The connections are illustrated and explained in figure 4.9. The unit is the left hand version in the figure. Furthermore, there is a 2000w electrical heating unit installed in the duct blowing fresh air into the house. This heating unit supports the heating of the incoming air.

Figure 4.8 - Systemair VR 400 DCV/B installed in the house

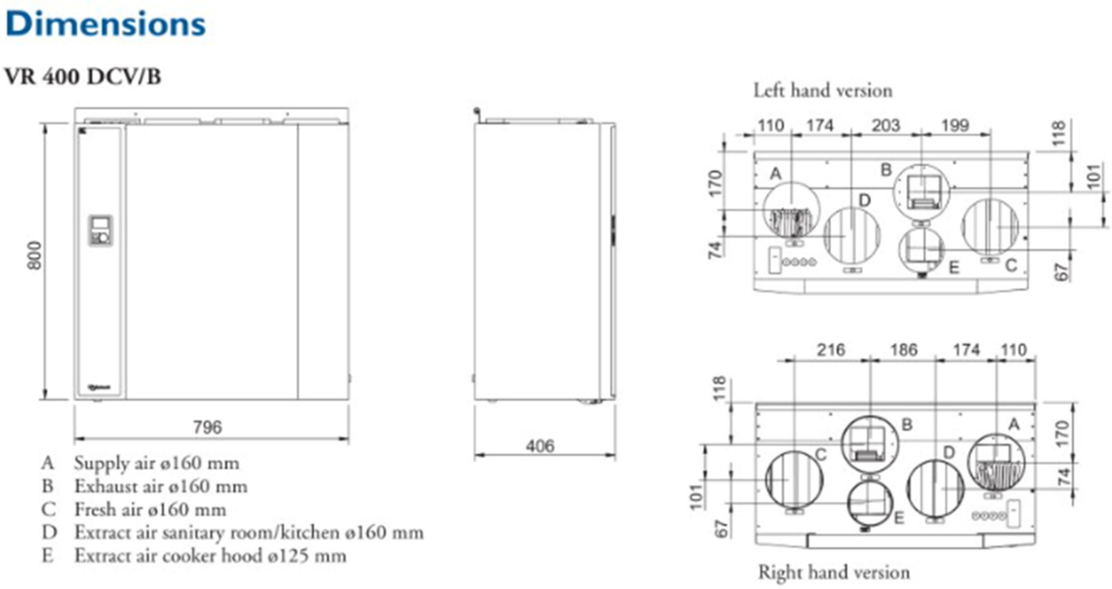


Figure 4.9 – Systemair VR400 DCV/B main unit dimensions and connections[24]

Figure 4.10 illustrates the air flow through the heat exchanger. t_1 is the duct where fresh cold air is dragged into the heat exchanger (C on the left hand version in figure 4.9). t_2 is the duct from which warm fresh air is blown into the house (A on the left hand version in figure 4.9). t_3 is the warm used air dragged out of the house through the heat exchanger and finally outside the house (D on the left hand version in figure 4.9. B on the left hand version in figure 4.9 is the external exhaust pipe and is the arrow with no mark in figure 4.10.

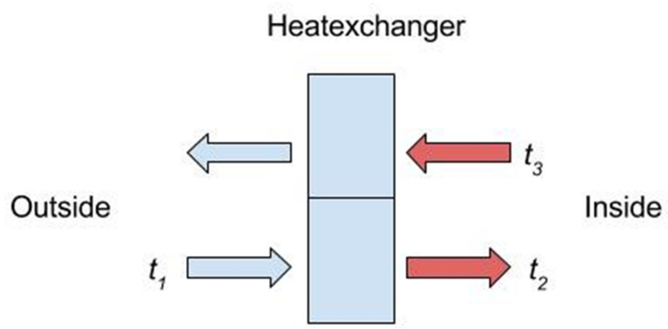


Figure 4.10. – Air circulation through heat exchanger

Table 4.5. The main components of the ventilation system

Component:	Function:
A: Supply air	Fresh temperate air blown through ventilation ducts into the various rooms in the house.
B: Exhaust air	Used air blown to the outside of the house
C: Outdoor air	Fresh air drawn in from the outside.
D: extract air	Used air extracted through ventilation ducts from the various rooms in the house.
E: Cooker hood	Used warm air extracted from cooker hood. This connection is not in use in the house.
Thermal wheel	Heat exchange from hot air to heat up cold fresh air happens through the thermal wheel. The wheel is turning at a constant speed by use of a small electrical motor.
Regeneration section	Where cold fresh are is blown through Thermal wheel
Absorption section	Where warm exhaust air is blown through Thermal wheel
Purge sector	Prevents exhaust air from being carried in the thermal wheel and blown back in the house
Mechanical motor 1 and 2	The motors draws air through the ventilation system.
2000w electrical heating unit	Support heating up the fresh air before it is blown into the house.

Table 4.5 lists the main components in the heat exchanger. Rotary heat exchangers like the unit installed in the house work by a small engine driving a wheel perforated with a matrix of air flow channels. This wheel is called the thermal wheel (see Figure 4.8 and 4.11). The thermal wheel is made out of a material with high thermal conductivity typical aluminium. It is through this wheel that the heat exchange takes place. The wheel rotates through two separated rooms; one in which cold fresh outdoor air is blown into and through the perforated wheel. This is called the regeneration section. In the other room, warm exhaust air from the house is blown into and through the wheel. This section is the adsorption section[25].

Typically, the adsorption and regeneration sections are designed with counter flowing airstreams to achieve higher performance.

There are two types of energy present when looking at the heat exchanger. The first type is called sensible energy and is the heat transferred through the counter flowing airstreams.

The other type is called latent energy and is present where moisture differences in the two airstreams create water condensation. The condensed water will attach to the internal walls in the perforated wheel in the adsorption section. It will then rotate to the regeneration section where it supports the sensible energy heating up the fresh air.

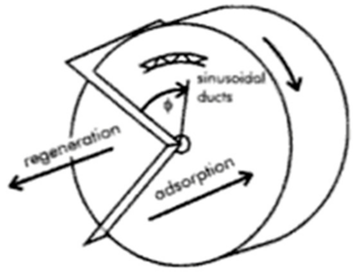


Figure 4.11 - Rotating thermal wheel in heat exchanger. [24]

The two sections are typically not hermetically separated and it is therefore expected that some exhaust air is carried in the rotating wheel and blown into the house with the heated fresh air. This, however, can be prevented if a purge sector is applied. The purge sector prevents exhaust air from being carried in the thermal wheel and blown back in the house. The heat exchanger operates under different thermal efficiencies depending on various factors.

According to figure 4.12 it operates at a thermal efficiency from max η_{th} = 87% efficiency at a flow of 100m^3/h and down to η_{th} = 73% at a flow of 680m^3/h. These efficiencies are based on an air ratio of 1:1 and an air humidity of 50%. In the BM-Excel model discussed in Chapter 6, the thermal efficiency for the heat recovery unit is assumed to be η_{th} = 80%.

Looking at the air change rate we see that at 80% efficiency there is an air change of about 360m^3/h. The air change rate of the house can then be calculated by dividing the air change with the volume of the house. This gives $\frac{360m^3/\text{h}}{338m^3} = 1{,}07\ hours$, meaning that all air inside the house has been changed within a little over an hour.

The supply and extract graphs in figure 4.12 show the air change through the heat exchanger under different air pressure.

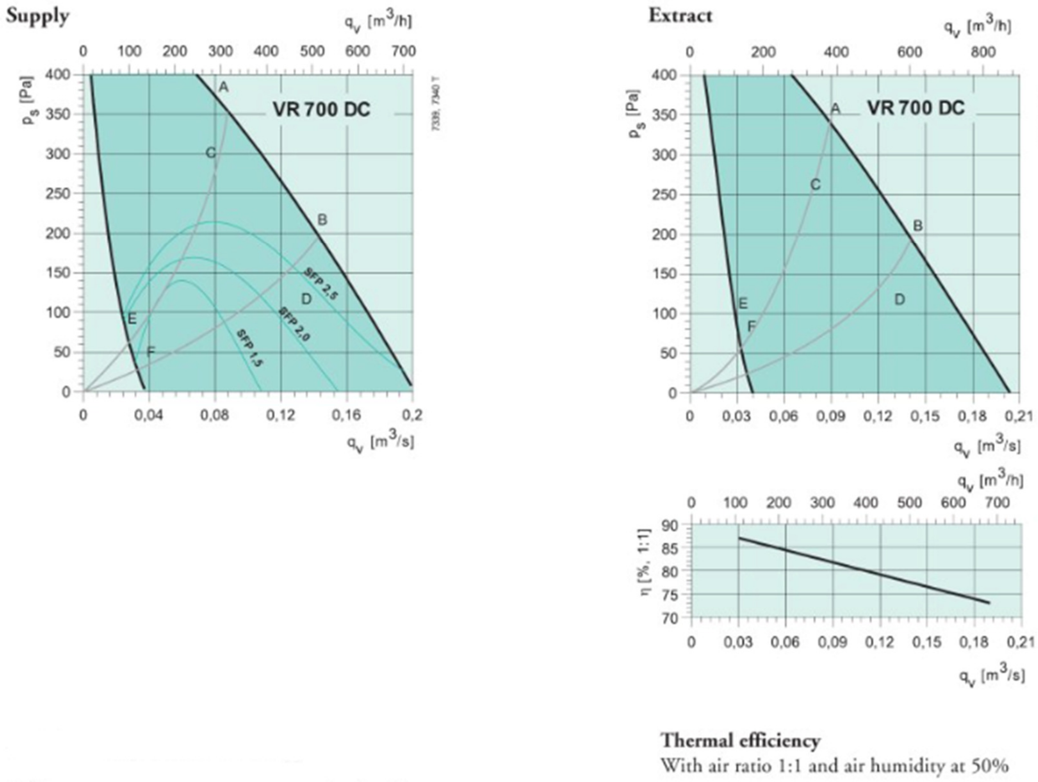


Figure 4.12 – Thermal efficiency for heat exchanger unit.

4.4 Evaluation of U-values for the energy models

4.4.1 External walls, slabs and roof

The U-values for the project house were calculated by using the software Rockwool Energy Design 4.1 [26]. The program is developed by the Danish insulation company Rockwool and is herein used to calculate the U-values for the various building parts. The program calculations are based on the Danish standard DS418:2011 – "Beregning af bygningers varmetab"[27]. The Rockwool Energy Design software does feature other functions such as energy frame calculations and profitability calculations but these are conducted in line with Danish building regulations and Danish building material and labour price books.

When performing a calculation with the program, the user has three options when it comes to λ– and R-value for a material. These options are marked as A, B or C for each material on the final result sheet.

A. is considered reliable information as the material and its specifications are a part of the Rockwool Energy Design material library and therefore verified by Rockwool.
B. is also considered reliable as the information has been submitted by the manufacture or reseller of the material. Rockwool however has not verified the values.

C. is considered less reliable as this option is marked only when the user of Rockwool Energy Design computes the values himself.

All values in this report are option A values, which is also marked in the final result sheet on each building element from the program.
The final result sheets for each building part are specified in appendix 09. Table 4.7 later in this chapter sums up the values from each building element based on the result sheets in appendix 09.

UDE INDE

	Producent	Navn	Tykkelse [m], antal	Lambda [W/(mK)]	Q	R [m²K/W]
	Rse (ude)					0,13
1	Generisk materiale	Stål	0,006	50,000	A	~~0,00~~
2	Generisk materiale	Ventileret lag	0,009	-	A	-
3	Inhomogent materialelag	bestående af:	0,150	0,038		3,92
	ROCKWOOL A/S	Super A-Murbatts	95,00%	0,034	A	-
	Luftspalte	Niveau 1: ΔU" = 0,01 W/(m²K)				
	Generisk materiale	Træ 450kg/m3	5,00%	0,120	A	-
4	Generisk materiale	PE-folie (hæftet fast) 0,15 mm	0,000	0,170	A	0,00
5	Generisk materiale	Krydsfiner, 700 kg/m3	0,009	0,170	A	0,05
6	Generisk materiale	Gips 13 mm	0,013	0,250	A	0,05
	Rsi (inde)					0,13
			0,187			**4,28**

Begrundelse for ændring af overgangsisolanser:

Byggematerialerne er grupperet i 3 klasser. Disse klasser er:
A Data er indtastet og verificeret af ROCKWOOL A/S.
B Data er indtastet og verificeret af andre producenter eller leverandører.
C Egen indtastning af data.

U-værdikorrektion i henhold til DS 418
Korrektion for mekanisk fastgørelse dUf = 0,000 W/(m²K)
Korrektion for luftspalter dUg = 0,008 W/(m²K)

U = 1 / 4,28 + 0,000 + 0,008 = 0,24 W/(m²K)

U_{max} = 0,30 W/(m²K) U = 0,24 W/(m²K)

Figure 4.13 – Result sheet on external wall.

The information stated on each result sheet is described by the following.

On the top is a 3D drawing of the building part. For vertical building parts, e.g. walls, the inside is on the right side of the drawing and outside on the left. For horizontal building parts, inside and outside is marked in the following way. For slabs, inside is marked above and outside is marked below. For roofs, inside is marked below and outside is marked above.

Below the drawing are all building materials within the specified building part listed numerically from top to bottom. Each building material has a description listed horizontally, starting with the manufacture. In most cases, it is marked with generic material as there are several manufactures. After manufacture comes the name of the material, which gives a short description of what it is. Then comes thickness in meters for the material used in the given building part. The λ–value is stated and the reliability of the value is located next to it under the letter Q. Finally, is the calculated R-value, which is summed up in the bottom.

U_{max} is the maximum allowed u-value according to Danish building regulations and is therefore without importance herein.

If looking at the result sheet depicting the result of the outer walls, the U-value is calculated to be 0,24 W/m^{2}K. If doing a manual calculation of this result, the value is somewhat lower.

$$U = 1 / \Sigma R_i \quad \leftrightarrow \quad U = 1 / 4{,}28 \text{ m}^2\text{K/W} \quad \leftrightarrow \quad \underline{U = 0{,}23 \text{ W/m}^2\text{K}}$$

The reason for the inconsistency in the results is due to a correction of the transmission coefficient for either mechanical attachments, air cavities or reversed roofs according to Annex A in the Danish standard DS418:2011 – "Beregning af bygningers varmetab" [27].
Since neither mechanical fixings nor reversed roof are present in this building element, the calculation of the correction looks as follows:

$$\Delta U_g = \Delta U'' \left(\frac{R_i}{R_T}\right)^2 \qquad (4)$$

$\Delta U''$ is listed in a table and divided into levels for air cavities in the insulating material. The DS418:2011 propose three levels; 0, 1, and 2, depending on the estimated size of the correction. Table 4.6 is a translation of the correction. The original table can be found in appendix 02; Table A.1.

Table 4.6 – Translation of correction table A.1 in DS418:2011 Anneks A

Level	$\Delta U''$ W/m^{2}K	Description
0	0,00	No air cavities across the entire insulating layer.
1	0,01	Possibility of air cavities across the insulating layer. No air circulation on the hot side of the insulation.
2	0,04	Possibility of air cavities across the insulating layer. Possibility of air circulation on the hot side of the insulation.

It can be expected that the insulation is not 100% tight in all corners and therefore small air cavities should be expected and accounted for. Therefore, for this building part, Level 1 is selected and $\Delta U"$ = 0,01 W/m^{2}K. Now that $\Delta U"$ is decided, R_i and R_T must be determined. R_i is the R-value of the insulating material, whereas R_T is the total resistance value or the sum of all the in R_i values. Both values are present on the result sheet of the outer wall, i.e.:.

R_i = 3,92 m^{2}K/W

R_T = 4,28 m^{2}K/W

Now the correction can be determined by plotting the numbers into equation 4

$$\Delta U_g = 0{,}01\left(\frac{3{,}92 m^2K/W}{4{,}28\, m^2K/W}\right)^2 \quad \leftrightarrow \quad \Delta U_g = 0{,}008 W/m^2\text{K}$$

since either ΔU_f and ΔU_r are present in the outer wall $\Delta U = \Delta U_g$

On the result sheet for the outer wall ΔU is named dUg and equals 0,008 W/m^2K as the equation above suggests.
The theoretical approach applies to the other result sheet from the Rockwool Energy Design program.

It is furthermore worth mentioning that the praxis of multiplying the declared λ-value by a factor 1,2 to reach the correct design λ-value is accounted for in the slab calculation.

Table 4.7 – Building element values from result sheets.

Building part:	**Total thickness (m)**	**R_T (m^{2}K/W)**	**U-value (W/m^{2}K)**
Outer walls	0,187	4,28	0,24
Roof	0,297	5,40	0,19
Slab	0,456	8,30	0,12

4.4.2 Windows and doors:

The 3D Revit model, which is described in more detailed in section 5.3, can be used for many purposes. In this report, not only did it serve its purpose as an energy model, but it was also used to do a simple extraction for creating a window schedule based on the original drawing material as windows and their sizes are defined herein. The window schedule can be seen in appendix 03. From this schedule it was easy to apply windows to the Velfac energy calculation program[28]. All energy calculations from the Velfac energy calculator can be located in appendix 04. As all doors in the house are glass doors, they are calculated in the same way as the windows. The results on windows and doors are depicted in table 4.8 and 4.9. Table 4.8 is an overview of window types, the number of each window/door type, and the direction in which they face. Window type numbers are similar to the original drawing material found in appendix 01. For instance, are there 2 windows of the type G01 facing south east, which is a 90° angle to the north east facade.

Table 4.9 is the results on energy calculations of each window type from the Velfac result sheets summed up.

Table 4.8 – Description of window and doors

Windows and Doors amount and ID
Windows and Doors towards North East (Angle 0°)
2 x G01
2 x G02
Windows and Doors towards South East (Angle 90°)
G05
G10
G08
G11
G12(door)
2 x G01
Windows and Doors towards South West (Angle 180°)
4 x G03 / G04
G06 (door)
G07
G08
G09
Windows and Doors towards North West (Angle 270°)
2 x G03 / G04

Table 4.9 – Window and door energy calculations

Type	**E_w**	**A_w window area**	**A-rude glazed area**	**F_f glazed area in %**	**U_w**
G01	-40	1,01	0,79	78	1,50
G02	-64	0,47	0,33	70	1,65
G03/G04	-46	1,64	1,25	76	1,53
G05	-21	2,31	1,96	85	1,38
G06	-31	2,31	1,97	85	1,49
G07	-6	5,25	4,75	90	1,29
G08	-57	0,6	0,43	72	1,61
G09	-25	1,97	1,65	84	1,41
G10	-37	1,07	0,85	80	1,48
G11	-54	1,05	0,77	73	1,59
G12	-34	2,1	1,77	84	1,52

Table 4.9 summarizes a number of values from the result sheets. All the parameters from the result sheet are defined as follows [29][30]:

- ***E_w*** is the overall energy performance of the actual window with the desired size, glass type and gas type in the cavity between the glass layers. The unit is like the E_{ref} in kWh/m^2. The value is for the entire window and not only the glazed area. It is the balance between lost energy during cold season and gained free energy from the sun. Values are marked negative as they have an overall positive effect, which means that they receive more energy from the sun and sky than they lose through heat loss.

- ***U_w*** is the U-value without any other factors, such as sunlight, included. U_W is the "dark" U-value and it represents the entire window, both glass and frame.

- ***U_g*** is the U-value of the glass area alone. This value was much used some years ago but today the entire window's U-value is used instead. It is furthermore represented as a "dark" value as explained in U_w.. U_g is not present in table 4.9 as the value is the same for all window types in the project. Ug = 1,11.

- ***LT_g*** represents the light transmittance on the glazed area. It is an indicator of the amount of sunlight passing through the window. A higher value represents a higher percentage of sunlight passing through the glass. LT_g is not present in table 4.9 as the value is the same for all window types in the project. LTg = 0,8.

- ***g_g***, also known as the g-value, is a measure of how much "free" heating is received through sunlight. A higher G-value means a higher amount of heat received from sunlight. g_g is not present in table 4.9 as the value is the same for all window types in the project. gg = 0,62.

- ***E_{ref}*** is an expression of a window's overall energy performance and the unit is in kWh/m^2. A window manufacture within the EU must provide an U_{ref} according to European legislation. The value is based on the "European standard window" This window is described as being 1230mm x 1480mm with standard glass, no glazing bars and a one-sided open/close function. The $U_{\mathbf{ref}}$ is meant as a more precise measuring tool for engineers and architects when choosing the right window. It also shows that the window with the lowest U_w isn't always the best performing window. Typically this value is negative as there mostly are some losses affiliated. However, some triple glazed windows have a positive E_{ref} as they can contribute more energy than they lose. These windows however are often very expensive.
  E_{Ref} is not present in table 4.9 as the value is the same for all window types in the project. Eref = -24 kWh/m^2.

The U_w-values for the windows and doors established in Table 4.9 are used in both the energy models. This value is then combined with solar radiance numbers from the greater Reykjavik area (Data provided by BM) and monthly mean temperatures for Eyrarbakki[31].

Chapter 5 Energy models studied

5.1 The BM-Excel energy model

The BM-Excel energy model was originally developed by BM for Innovation Centre Iceland. BM developed the model to calculate a larger building with a different usage purpose. Besides translating the model into English, a number of factors have been augmented in order to fit the house in Eyrarbakki. The BM-Excel model encompasses the factors and assumptions depicted in table 5.1.

The BM-Excel model consists of two calculation sheets. Sheet one calculates heat losses and given heat. The heat losses are based on calculated U-values. The U-values are multiplied by the area of a specific building part to get the power in w/K. The power is then used to calculate the amount of energy in MJ lost during a given month. This is calculated by multiplying the calculated power with the degree class of the same month. The result is then multiplied by 3,6 in order to get the final result in MJ. The degree classes are calculated by subtracting the assumed indoor temperature of 21°C with the mean temperature of the given month in Eyrarbakki (located in sheet 2). The difference is multiplied by 24 to get the heat loss for one day as the time factor is 60min and then multiplied with the number of days in the specific month to get the monthly heat loss in MJ.
Given heat calculates the “free” heating energy received by the following factors:

- Normal electricity use from inhabitants
- Sun and sky radiation affecting internal temperatures
- Hot tap water usage

Since not all the given heat is utilized effectively as it is ventilated out of the house, the result of the given heat is multiplied with an efficiency coefficient. Figure 5.1 illustrates the result in the model of the given free heat and the result after it has been corrected by the efficiency coefficient

Table 5.1 – Explanatory factors and assumptions used in the BM-excel model

Explanatory factors and assumptions in the BM-excel model			
Parameter	Value	Source	Level of knowledge.
Time factor	60min (1h)		100%
Specific heat capacity of water	4200 J/kgK		100%
Air density	1,2kg/m3		Assumption as this value is temperature dependent.
Specific heat capacity of air	1000 J/kgK		100%
Mean monthly temperatures of Eyrarbakki based on previous year's temperatures	2°C, 0.6°C, 2°C, 4.9°C, 7.5°C, 11.1°C, 11.1°C, 11.1°C, 9.5°C, 3.1°C, 5.3°C, -1,4°C	[31]	This is an assumption based on 2014 data.
Constant indoor temperature	21°C		This is an assumption.
Ventilation recovery efficiency	0,8		This is an assumption.
Efficiency coefficient of supplied energy staring with January.	1.00, 0.99, 0.84, 0.65, 0.48, 0.41, 0.39, 0.43, 0.64, 0.97, 0.99, 1.00		This is an assumption.
Calculated air change starting with January. This is a ratio.	0.6, 0.6, 0.6, 0.7, 0.8, 1, 1, 1, 0.8, 0.7, 0.6, 0.6		This is an assumption with big uncertainty.
Number of inhabitants	4		This is an assumption.
Free heating from electrical usage	5kwh/inhabitant/day	Mypages at on.is	Based on annual mean electricity use.
Tap water usage	60 litres/occupant, per day	(BM)	This is an assumption.
Hot water temperature	55°C	X	This is an assumption.
Incoming energy MJ/m2 @ 64°north from sun and sky radiation		Data on greater Reykjavik from Iceland inn. center	Average historic values based on average cloudiness.

Tap water total	**1718,6**	**1552,3**	**1718,6**	**1663,2**	**1718,6**	**1663,2**	**1**
TOTAL THERMAL USE (MJ)	**8308,5**	**7717,6**	**7929,9**	**6781,4**	**6232,7**	**5096,0**	**5**
GIVEN HEAT							
..Normal electricity usage	2232,0	2016,0	2232,0	2160,0	2232,0	2160,0	
.. Sun and sky-radiation	373,7	1439,6	4363,0	5538,1	7196,0	6166,8	
.. Hot tapwater	171,9	155,2	171,9	166,3	171,9	166,3	
.. Total	2605,7	3455,6	6595,0	7698,1	9428,0	8326,8	
Effective energy from sources (Inhabitants, general electricity, sun etc.	**2777,0**	**3596,4**	**6070,2**	**5919,6**	**5834,9**	**4864,2**	**5**
.. % of total heat consumption	33,4	46,6	76,5	87,3	93,6	95,5	
TOTAL THERMAL NEED	**5531,4**	**4121,1**	**1859,7**	**861,9**	**397,8**	**231,8**	

Figure 5.1 – Result on Effective energy from sources (Inhabitants, general electricity, sun etc.) multiplied the efficiency coefficient of supplied energy.

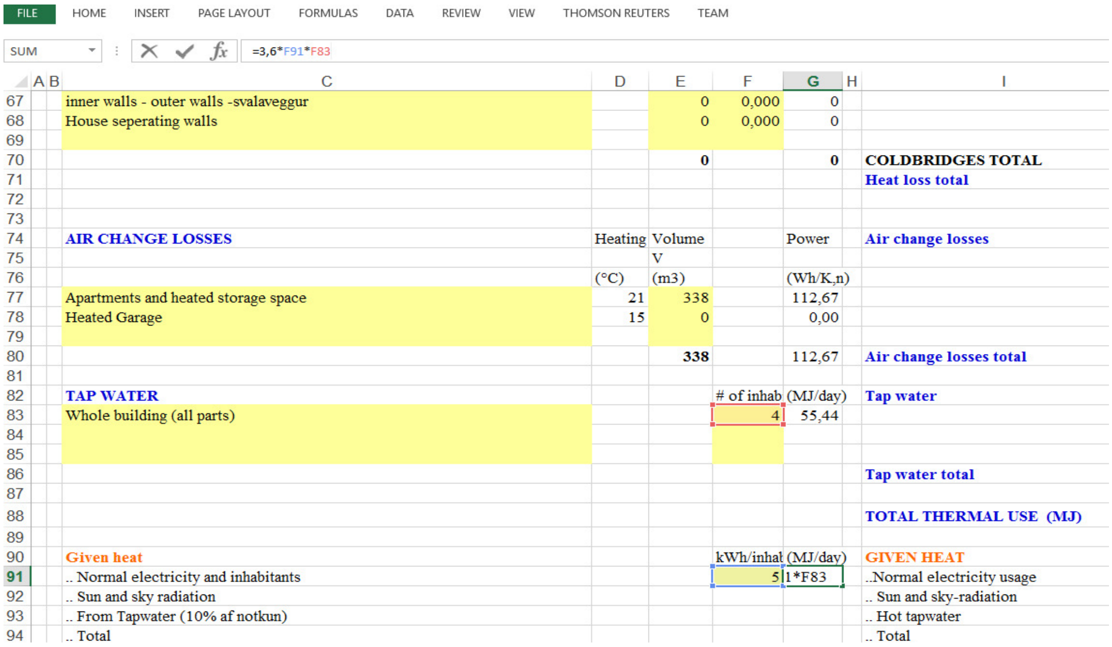
Figure 5.2 shows the efficiency coefficient throughout all months of the year. In January and December, it is 1 as doors and windows are assumed to be held closed, combined with less sun and sky radiation. Therefore, the assumption is that all free energy in those two months is utilized. Moving towards the warmer months the coefficient is becoming lower as much more energy is received from sun and sky combined with windows and doors being held open much more and therefore a lower utilization of the free energy received.

=K91+K93+K92*K11

I	J	K	L	M	N	O	P	Q	R	S	T	U	V
REIKNUÐ ORKUNOTKUN OG VARMAÞÖRF(DEFERRED ENERGY USE AND THERMAL NEED)													
					ENERGY (MJ)								
	Jan	Feb	Mar	Apr	Mai	Jún	Júl	Ág	Sep	Okt	Nóv	Des	Whole year
# days in the month	31	28	31	30	31	30	31	31	30	31	30	31	365
Degree classes (þús °Ch)	14,1	13,7	14,1	11,6	10,0	7,1	7,1	7,4	8,3	13,3	11,3	16,7	134,7
Coeffecient Qg/Ql	0,4	0,6	1,1	1,5	2,1	2,4	2,6	2,3	1,5	0,7	0,5	0,3	
Ventilation recovery efficiency	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	
Efficiency coefficient of supplied energy	1,00	0,99	0,84	0,65	0,48	0,41	0,39	0,43	0,64	0,97	0,99	1,00	
Calculated air change (1/h)	0,6	0,6	0,6	0,7	0,8	1	1	1	0,8	0,7	0,6	0,6	

Figure 5.2 – Efficiency coefficient of supplied energy throughout the months of the year

Given heat from normal electricity use from inhabitants adds the estimated amount of heating energy received from electrical appliances to the model. These appliances are factors such as TVs, refrigerators, computers, light bulbs etc. The model assumes an addition of 72MJ per day based on the assumption for number of inhabitants and kWh/inhabitant/day listed in table 5.1. Figure 5.3 illustrates this calculation in the BM-Excel model.



FILE HOME INSERT PAGE LAYOUT FORMULAS DATA REVIEW VIEW THOMSON REUTERS TEAM

SUM =3,6*F91*F83

	C	D	E	F	G	H	I
67	inner walls - outer walls -svalaveggur		0	0,000	0		
68	House seperating walls		0	0,000	0		
69							
70			0		0		COLDBRIDGES TOTAL
71							Heat loss total
72							
73							
74	AIR CHANGE LOSSES	Heating	Volume		Power		Air change losses
75			V				
76		(°C)	(m3)		(Wh/K,n)		
77	Apartments and heated storage space	21	338		112,67		
78	Heated Garage	15	0		0,00		
79							
80			338		112,67		Air change losses total
81							
82	TAP WATER			# of inhab	(MJ/day)		Tap water
83	Whole building (all parts)			4	55,44		
84							
85							
86							Tap water total
87							
88							TOTAL THERMAL USE (MJ)
89							
90	Given heat			kWh/inhal	(MJ/day)		GIVEN HEAT
91	.. Normal electricity and inhabitants			5	1*F83		..Normal electricity usage
92	.. Sun and sky radiation						.. Sun and sky-radiation
93	.. From Tapwater (10% af notkun)						.. Hot tapwater
94	.. Total						.. Total

Figure 5.3 – Screenshot from excel energy model

Given heat from sun and sky radiation is the amount of heat energy received through glazed areas depending on the on angle; North, South, East and West of a glazed area. The calculation is located on sheet 2 in the model. The amount of energy in MJ is calculated per month and is based on Eq (5.1) as:

$$MJ\ per.month = A * B * C * D * E \qquad (5.1)$$

The parameters in Eq. 5.1 are the following:

- A is the glazed area on a specific angle e.g. north east
- B is the ratio of glass area
- C is the sun factor (solar factor)
- D is the screening area
- E is the incoming energy MJ/m2 @ 64°north at the angle (0, 45; 315, 90; 270, 135; 180, 225) for the specific month

Calculations for each angle of sunlight are summed up for each month. Figure 5.4 shows this calculation in the BM-Excel model.

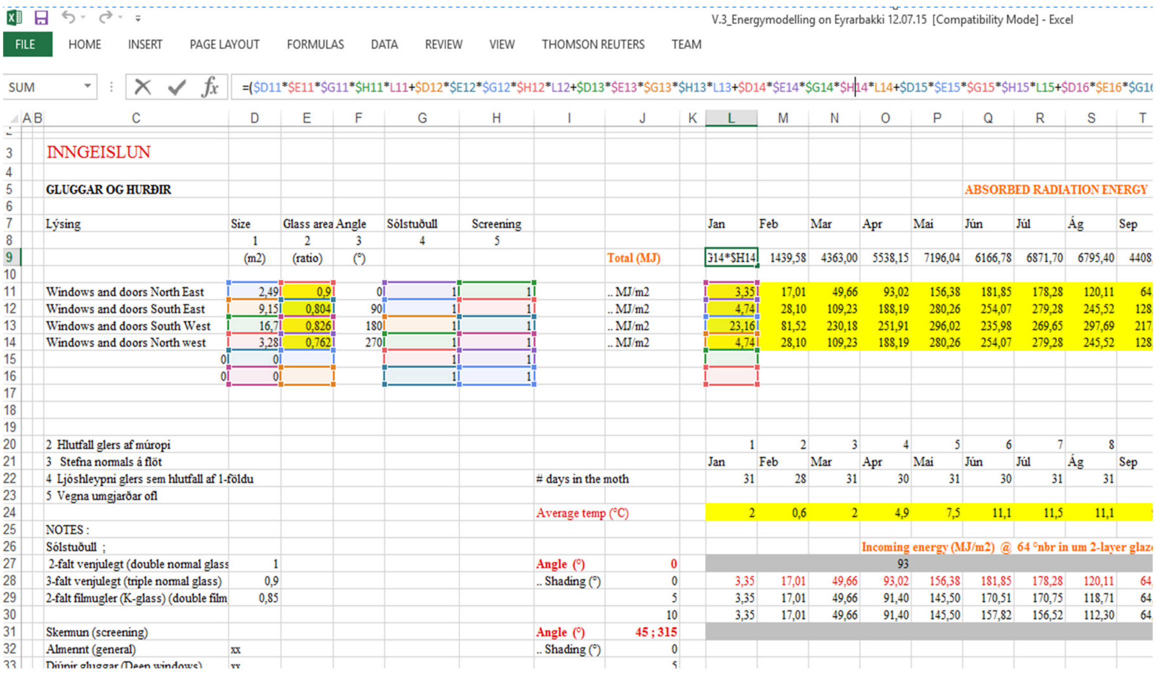


Figure 5.4 – Screenshot from excel energy model.

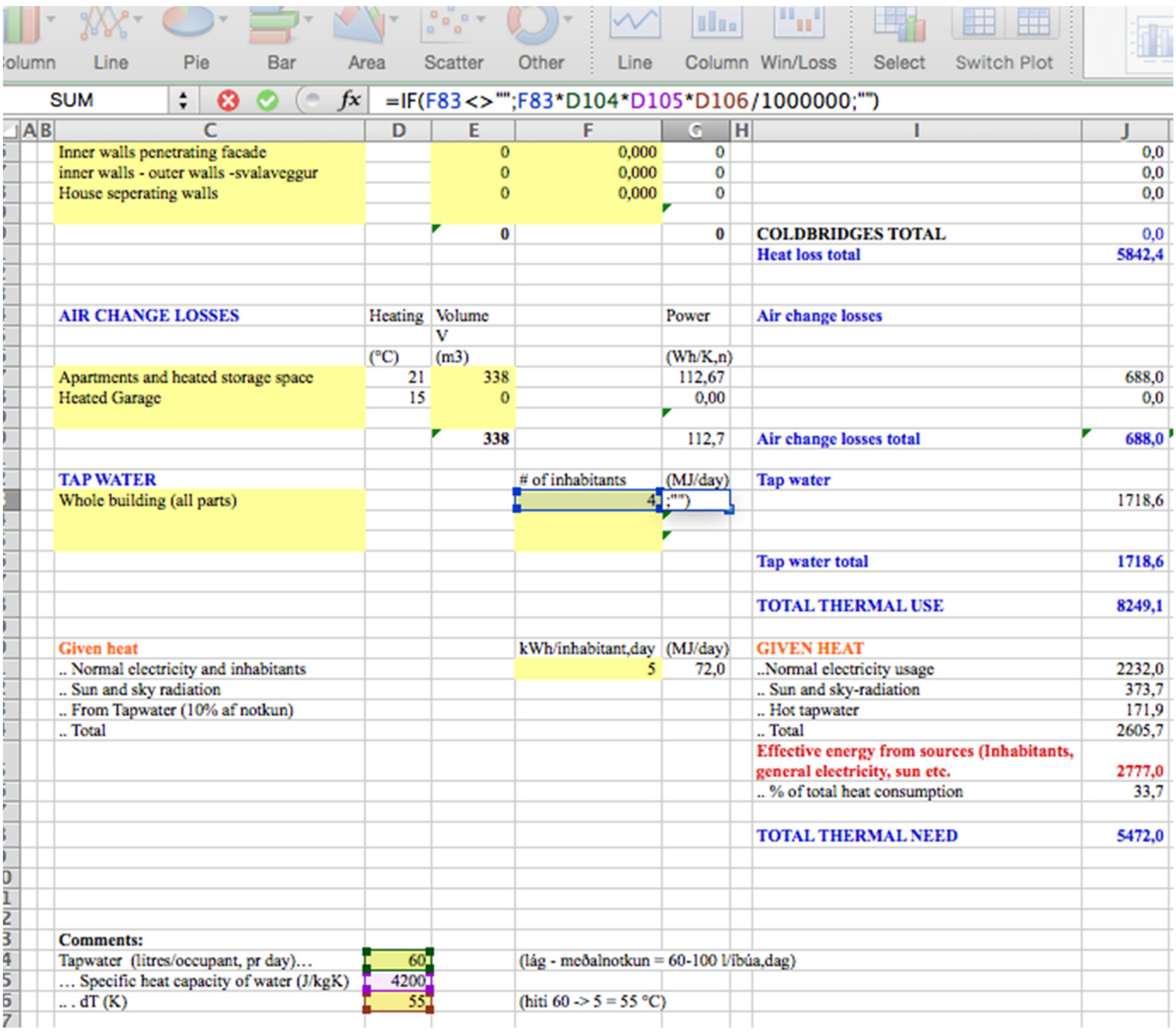
Given heat from tap water is assumed to be 55,44MJ per day. This assumption is based on the following equation:

$$Given\ heat = \frac{F * G * H * I}{J} \qquad (5.2)$$

The parameters used in Eq.5.2 are the following:

- F is the number of inhabitants
- G is the amount of tap water used per day in m^3
- H is effective cooling of hot tap water while used in °C
- I is the specific heat capacity of water measured in J/kgK
- J is the Conversion factor from Joules to MJ is 1.000.000.

On figure 5.5 this calculation is shown in the BM-Excel model.



C	D	E	F	G	I	J
Inner walls penetrating facade		0	0,000	0		0,0
inner walls - outer walls -svalaveggur		0	0,000	0		0,0
House seperating walls		0	0,000	0		0,0
		0		0	COLDBRIDGES TOTAL	0,0
					Heat loss total	5842,4
AIR CHANGE LOSSES	Heating	Volume		Power	Air change losses	
		V				
	(°C)	(m3)		(Wh/K,n)		
Apartments and heated storage space	21	338		112,67		688,0
Heated Garage	15	0		0,00		0,0
		338		112,7	Air change losses total	688,0
TAP WATER			# of inhabitants	(MJ/day)	Tap water	
Whole building (all parts)			4	;"")		1718,6
					Tap water total	1718,6
					TOTAL THERMAL USE	8249,1
Given heat			kWh/inhabitant,day	(MJ/day)	GIVEN HEAT	
.. Normal electricity and inhabitants			5	72,0	..Normal electricity usage	2232,0
.. Sun and sky radiation					.. Sun and sky-radiation	373,7
.. From Tapwater (10% af notkun)					.. Hot tapwater	171,9
.. Total					.. Total	2605,7
					Effective energy from sources (Inhabitants, general electricity, sun etc.	2777,0
					.. % of total heat consumption	33,7
					TOTAL THERMAL NEED	5472,0
Comments:						
Tapwater (litres/occupant, pr day)...	60		(lág - meðalnotkun = 60-100 l/íbúa,dag)			
... Specific heat capacity of water (J/kgK)	4200					
... dT (K)	55		(hiti 60 -> 5 = 55 °C)			

Figure 5.5 – Screenshot from excel energy model.

5.2 Results from the BM-Excel model

Total primary energy demand, which includes heat losses through building elements, hot water usage and air change losses in kWh pr. year is 23293,7kWh or 183,4kWh/m^2 pr. year.

The total energy need for heating the house equates to 8065,0kWh or 63,5kWh/m^2 pr. year. This is the total primary energy demand subtracted by the given "free" heat in terms of normal electricity usage, sun and sky radiation, and hot tap water. Also, a correction of the "free" energy is performed here with the efficiency coefficient of supplied energy. This coefficient accounts for energy lost through natural ventilation, such as open doors and windows, meaning that in the summer more free energy is lost through open windows and doors than in the winter.
These two results will be discussed further in chapter 8 where they are compared to other results.

It is important to mention that these results are based on gross floor area and gross volume. According to requirements used by the Danish regulator Energistyrelsen for defining heated floor areas in energy calculations, the following guideline should be considered:

> *"En bygnings opvarmede etageareal beregnes ved sammenlægning af bruttoarealerne af samtlige opvarmede etager, herunder opvarmede kældre og tagetager. Bruttoarealet måles i et plan bestemt af oversiden af færdigt gulv og til ydersiden af ydervæggene"*[32].

This definition can be translated to:

> *A building's heated floor area must be calculated by the gross area of all heated floors, including heated basements and roof floors. Gross area is measured in a plane specified by the upper side of the finish floor to the outer side of the external walls.*

Heated areas are here defined as rooms heated to 15°C or more[32]. This definition varies from country to country and it must therefore be considered when looking at how other models interpret volumes and areas.

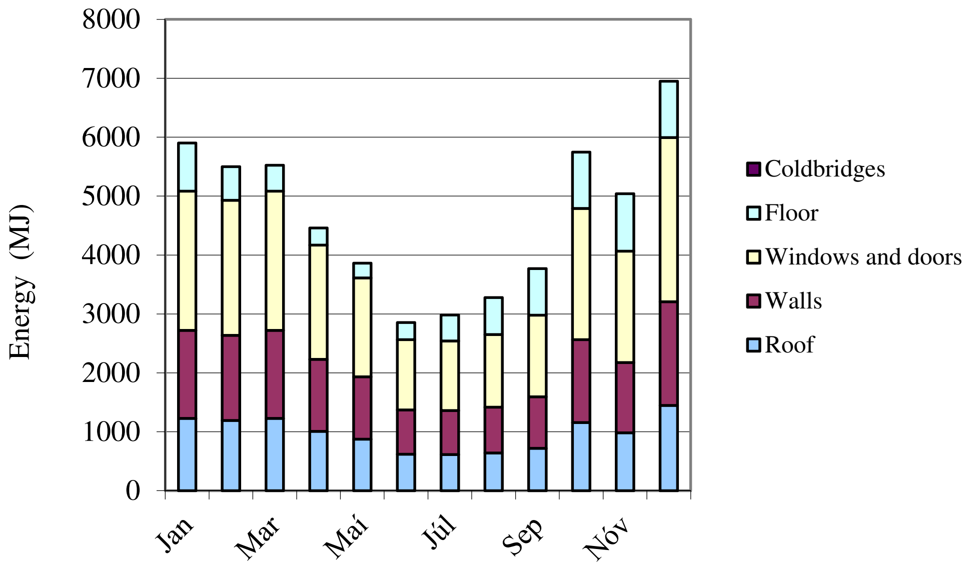


Figure 5.6 – Monthly energy losses for the various building parts.

From the BM-Excel model, we also get figures illustrating losses, additions and requirements for the house. Figure 5.6 depicts the amount of energy lost through building parts month by month. It is clear that the highest losses occur through the glazed areas, which is to be expected. The second highest loss occurs through walls, and then the roof. The losses peak in December, which can be explained by the fact that December is the only month with a negative external mean temperature of -1.4°C, (see Table 5.1 for mean temperature values).

Figure 5.7 depicts the “free” energy received by hot water, electricity and sun and sky radiation. The figure illustrates what was expected: that the free energy from sun and sky radiation is by far the largest factor. However, in the winter months with almost no light, the energy received from sun and sky radiation is very little. Tap water and electricity usage is illustrated by being almost constant.
Here it must be considered that due to the usage pattern and the change in number of people visiting the house illustrated in appendix 07, the figure would look different as the house is completely empty for some periods. The results from the BM-Excel model are based on a constant usage of 4 people throughout the whole year.

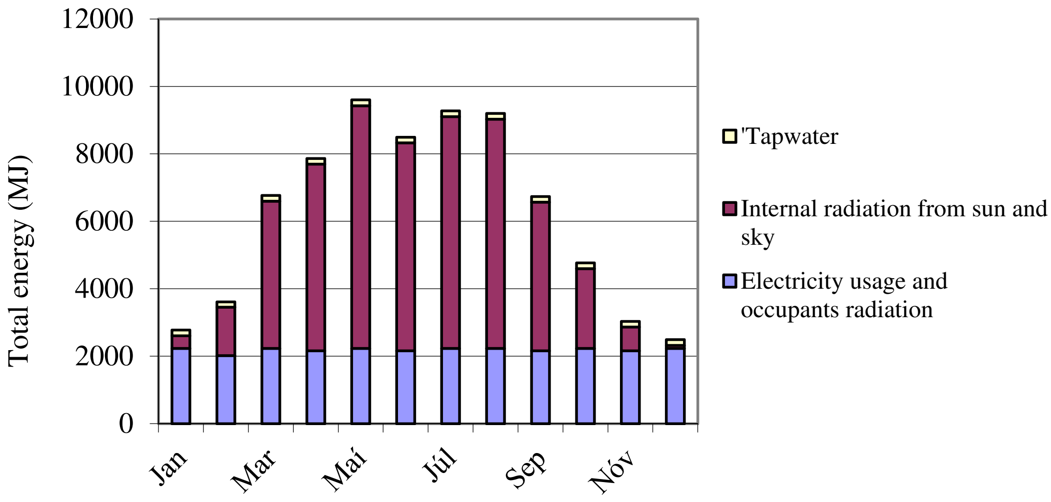


Figure 5.7 – Monthly “free” energy additions from various sources

Figure 5.8 shows the monthly energy losses from hot water and air change losses and total building part losses. The figure clearly illustrates how the building part losses rise in the winter months, with a colder and darker climate resulting in a higher internal and external temperature difference. Losses due to air change and tap water are close to constant.

Figure 5.9 illustrates how the building’s energy demand changes month by month throughout the year. The building is almost completely without heating energy need in the summer months of May, June and July. Here, the effective or “free” energy from inhabitants, heat generated by electric components, and especially the incoming solar and sky radiation through glazed areas, are contributing far more heating energy. From October to March, however, the picture is substantially different. This indicates the long days with light through the summer months changing into almost no light throughout the winter months. Especially in December and January, with very little solar energy present, the heating demand rises substantially.

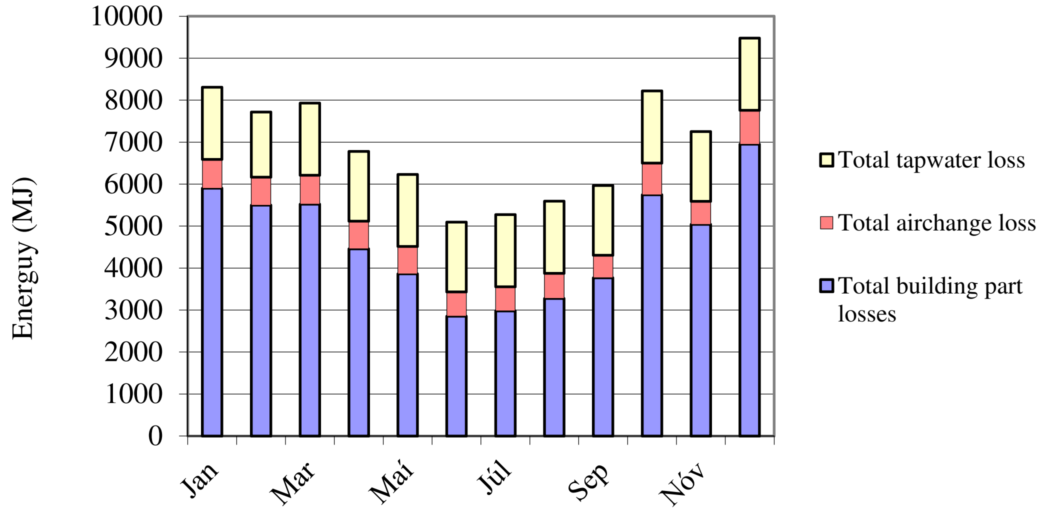


Figure 5.8 – Monthly energy losses from building parts, hot water and air changes

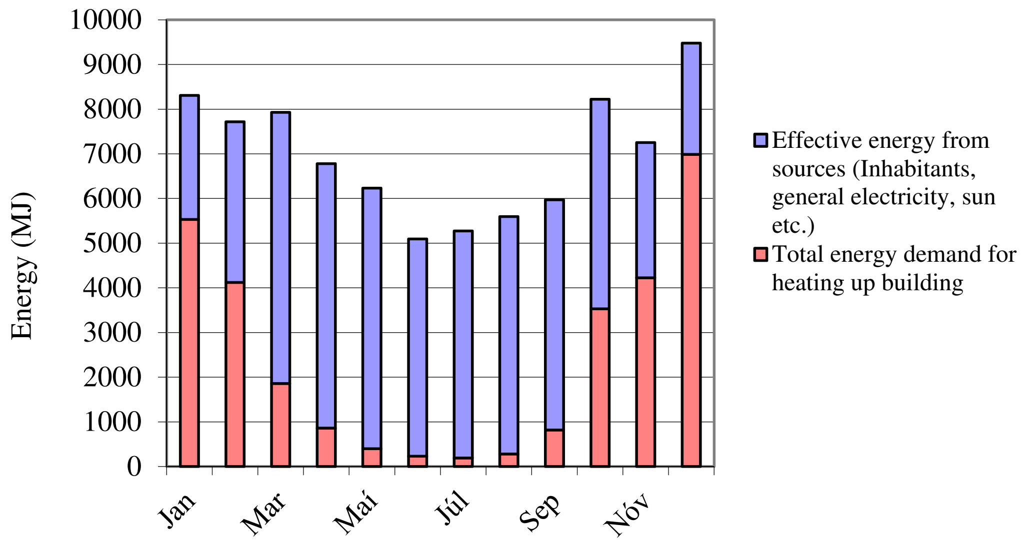


Figure 5.9 – Total monthly energy requirements

5.2 Probability estimate of BM-Excel model using a 3-point estimation method

The Elforsk project 345-002: Energisyndere I lavenergibyggeri[33] describes a method normally used in project management (PM), so-called PERT analysis, which can give a more realistic outcome of a building's energy performance in the design phase as it accounts to some extend for several uncertainties.

Energy modelling has a number of uncertainties due to the many parameters, as discussed previously, which influence the results greatly. Among these uncertainties, to name a few, are weather data. It is impossible to predict the weather. The usage pattern in a building can also have high uncertainties and the usage purpose of a building can completely change, causing the energy profile to change drastically. The method applies successive calculation of the various energy modelling parameters, accounting within a defined uncertainty for their variability. A total of 269 parameters, each with a defined deviation in %, has been developed in an Excel sheet for Project 345-002. It can be located in appendix 05. All parameters have been divided into 3 groups describing their importance. These groups are called 1 – Critical parameters that must be included, 2 – Important parameters that should be investigated, 3 – less important parameters which can be left out. Project 345-002 concludes that the method is useful and provides evidence of the applied method by comparing results with measurements from actual buildings.

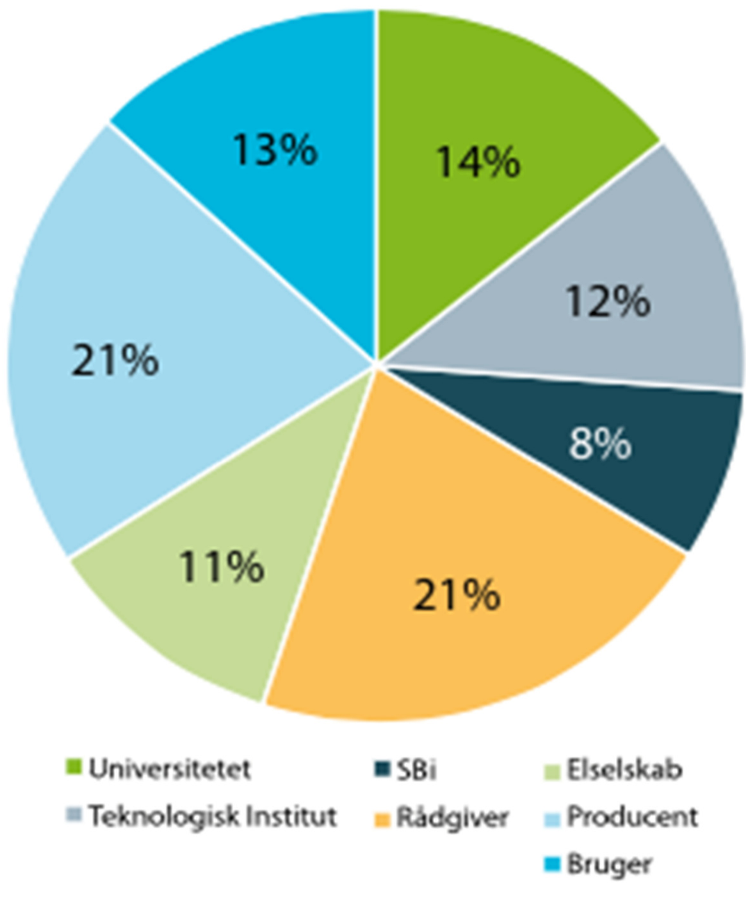


Figure 5.10 – Distribution of involved parties on research projects in %. [32]

Elforsk is a Danish organisation that grants 25million DKK every year in research and development projects with a special focus on a reduction in electrical consumption. Figure 5.10 represents the typical distribution of parties involved in research projects funded by Elforsk. The figure is based on a total of 204 research projects spanning from 2002 – 2011 [34]. As figure 5.10 showed, there was a healthy mix of universities, different Danish research institutes, private consultants, producers and end-users involved in Elforsks research projects.

Project 345-002 has been developed to be used with the Danish energy modelling software Be10, developed by SBI[33]. In this chapter, I will be using the theories described in the project report [33] on successive calculation and apply them to fit the BM-Excel energy model.

Since it is not possible to calculate an exact value on energy consumption of a building, the method described here uses a probability analysis to archive an estimate on energy consumption as a less static result. The method uses a 3-point estimation also known from PERT analysis [33], which is very popular within PM. PERT analysis method uses a Beta distribution for uncertain parameters. Project 345-002, however, suggests use of a Gamma distribution instead, where the distribution curve often is shifted, so that the mean value is on the right side of the top of the curve. Figure 5.11 illustrates the Gamma distribution curve. M is the mean value, A is the optimistic estimate, B is the pessimistic estimate and C is the most likely estimate.

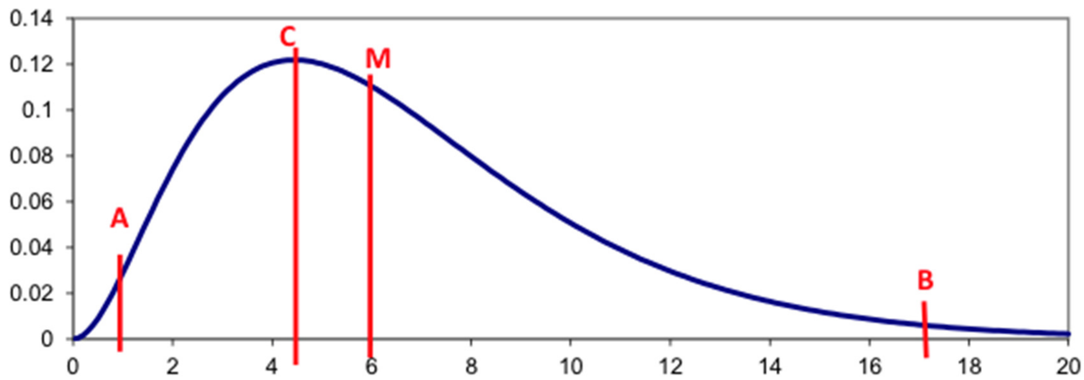


Figure 5.11 – Gamma distribution curve used for uncertain parameters in 3-point estimate [31]

5.2.1 Sensitivity analysis for a 3-point estimation

As mentioned, the sensitivity analysis along with the 3-point estimation are tools typically used within the PM discipline with a specific goal of estimating duration of projects, needed resources and, by that, the specific economy of a project. Here, the tools are applied by breaking down project requirements into smaller work packages. This discipline is called WBS (Work Breakdown Structure) [35]. This structure makes it much easier to understand and estimate the length of each work package. It is from the WBS that the estimation of pessimistic, optimistic and most likely values are determined. If no exact similar recorded value is already available to a work package, the project manager will typically ask a professional with experience within the specific field. The professional will then give an estimate of the three values. This is called a sensitivity analysis. This method, however, is not applicable for this project as it does not deal with time, but specific calculated values e.g. U-values, areas etc.
The method applied for this type of sensitivity analysis for 3-point estimation is based on regulatory decided deviations such as EU standards (EN). It also uses uncertainties

described in the Be10 handbook developed by SBI [33]. Furthermore, Trine Dyrstad Pettersen, research manager at Sintef Bygforsk, has contributed with deviations based on Norwegian experience.

The 269 parameters for the sensitivity analysis (appendix 05.) are in accordance with the input parameters of Be10. In this thesis, the parameters applicable to the BM-Excel model will be used to create a 3-point analysis. Appendix 06 is a brief version of the 269 parameter version altered to fit the BM-Excel model introduced in section 5.1. Sensitivity for each parameter can be located in appendix 06.

The sensitivity analysis in Appendix 06 calculates a minimum and a maximum value, also called optimistic and pessimistic values, for the 3-point method. The values from the sensitivity analysis are then added into the BM-Excel energy model. For this purpose the BM-Excel model has been copied into three complementary versions. One model, containing the original values evaluated, is considered the most likely set of values. The second contains the minimum, also referred to as optimistic values, and the last one contains the maximum, also called pessimistic values. The results of the three models are then used in the probability calculation applying the 3-point method.

The results that I will compare here are the total energy needs for heating in kWh/m2 pr. year.

5.2.2 The impact of the sensitivity analysis on the energy model

The deviation in the sensitivity analysis of 1% in area and 5% u-values on building envelope constructions are quite low and do not affect the total energy need for the building very much according the BM-Excel model. This is supported by Project 345-002, which classifies areas on building envelope constructions as having little influence and are possibly able to be left out of the model. U-values are described as having some importance and should be investigated[33]. Table 5.2 illustrates the difference before and after minimum values from the sensitivity analysis in appendix 6 are added to the BM-Excel model. The opposite effect occurs for the maximum values from the sensitivity analysis. The table illustrates the new result in the BM-Excel model for every parameter category changed. This method can be referred to as an OAT-analysis (One-At-the-Time), which is a local sensitivity analysis that provides clarity on the effect of each parameter changed[33]. Table 5.2 represents steps 1 through 8 in the OAT-analysis; step 1 being no parameters changed, step 2 being 1 parameter category changed, and for each step the next changed parameter category is changed, with step 8 being all parameter categories changed. Total primary energy demand is the energy demand of the house before given “free” energy is subtracted. Total energy need for heating the building is energy demand after given free energy is subtracted.

Table 5.2 – Influence from sensitivity analysis (appendix 6) minimum values on the excel energy model

Effects of sensitivity analysis step by step	Total primary energy demand kWh/m^2 per year	Total energy need for heating the building kWh/m^2 per year
1. Original result from BM-Excel (Most likely)	183,4	63,5
2. U-values and area changed	177,9	59,4
3. Glass area ratio changed	177,9	60,7
4. Ventilation recovery efficiency changed	184,7	65,2
5. Hot water temp and consumption changed	168,3	50,4
6. Normal electricity and inhabitants changed	168,3	55,5
7. Calculated air change changed	165,7	53,8
8. Final minimum values	**165,7**	**53,8**

It's interesting to see how the numbers are affected when the glazed area ratio is minimized so that the building receives less "free energy". The total energy need for heating the building is the result of total primary energy demand minus the free energy received. This affects the building in such a way that more "bought" energy is needed to heat the building. The same thing is happening when normal electricity and inhabitants are changed, as this also is "free energy" and therefore the total energy need for heating the building goes up.

The ventilation recovery efficiency has quite an effect as depicted in Table 5.2. With an efficiency lowered by 10% the total energy for heating the building goes up by 4,5 kWh/m2 per year.

The sensitivity analysis uses 15% deviation for inhabitants and 10% for electricity. The 10% are based on general lighting deviations. One could argue that this number should be higher, especially for this house as the day-to-day usage pattern is so inconsistent, as appendix 07, covering the energy use of the house, demonstrates. The lighting deviation factor should therefore perhaps be higher.

Tap water temperature and especially tap water usage have a very big influence on the total energy need for the building. This becomes obvious, when these numbers are altered in the model when determining min and max for the 3-point estimation. This item is also highlighted as a very critical factor in Project 345-002. In Appendix 06, the sensitivity analysis suggests use of a 1/3 deviation in min and max estimation for the 3-point analysis. A 33% deviation is quite high, but as the house in Eyrarbakki also has a very inconsistent day-to-day usage, this high difference must be considered plausible and perhaps even not high enough. For other buildings with more consistent day-to-day usage, this number should be somewhat lower.

Calculated air change is described with 10% deviation in the sensitivity analysis for both winter and summer. Once again, it's difficult to determine whether this estimate is realistic, especially due to the day-to-day usage. Nevertheless, the mechanical ventilation located in the house can make this assumption more reliable as the system runs continuously, whether there are people in the house or not. It also means that when people are in the house they are less likely to open windows as the house is constantly replenished with fresh air. Furthermore, the model itself accounts for winter and summer months where people are more or less likely to have open doors and windows due to the outside weather.

Air change losses in the BM-Excel model are based on the building's volume. This is not a parameter in the sensitivity analysis in appendix 06. The deviation is therefore assumed to be 1%, which is also what the sensitivity analysis uses for air change loss based on areas.

Mean temperatures and radiation values from sky and sun are not altered. Therefore, the model is based on the reference year for these inputs. In this case 2014 monthly mean values.

The results produced by the sensitivity analysis in the three BM-Excel energy models gives the following values for the total energy need for heating the building per year:

- Most likely estimation is 63,5 kWh/m2 per year.
- Optimistic estimation is 53,8 kWh/m2 per year.
- Pessimistic estimation is 73,1 kWh/m2 per year.

These values are used in the following chapter.

5.2.3 The 3-point method

After having calculated and applied the values from the sensitivity analysis into the BM-Excel energy models, the 3-point estimation can be applied. The formula contains the letters O, ML and P. O is the Optimistic values from the sensitivity analysis, which are the 1% quantile. ML is the Most Likely values and these are the values from the initial energy model. P is the Pessimistic values from the sensitivity analysis, and the 99% quantile. The values are computed into Eq. 5.1 and the result is M, which is the mean value.

$$M = \frac{O+2{,}9ML+P}{4{,}9} \sim \frac{O+3ML+P}{5} \qquad (5.1)$$

Then, the standard deviation is calculated by Eq. 5.2 and the variance by Eq. 5.3. The standard deviation is used for the result depending on the confidence interval that the calculation is based on. The confidence interval and probability are depicted in Table 5.3.

$$S = \frac{P-O}{4{,}6} \sim \frac{P-O}{5} \qquad (5.2)$$

$$V = S^2 \quad (5.3)$$

Eq. 5.4 is the sum of all mean values. Eq. 5.5 is the standard deviation of the entire BM-Excel energy model.

$$M_{Total} = \sum M \quad (5.4)$$

$$S_{Total} = \sqrt{\sum V} \quad (5.5)$$

Table 5.3 – Confidence interval and probabilities[36]

Interval	Probability
$M_{Total} \pm S_{Total}$	68%
$< M_{Total}+2\ S_{Total}$	84%
$M_{Total} \pm 2S_{Total}$	95%
$M_{Total} + 2S_{Total}$	97%
$M_{Total} \pm 3S_{Total}$	99%
$< M_{Total}+3S_{Total}$	99,5%

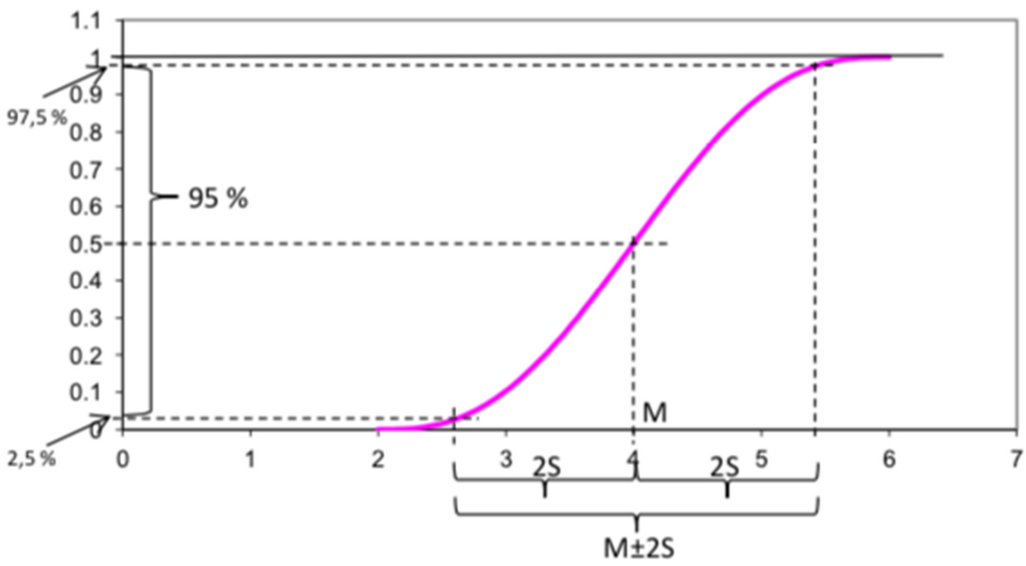


Figure 5.12 – Graphical illustration on the coherence of confidence interval and probabilities in the 3-point method. Source [33].

The calculation of Eq. 5.4 and 5.5 can be carried out by adding together all values from the sensitivity calculation in the energy models[33] and therefore $M = M_{Total}$ and $S = S_{Total}$ in this calculation. The values used for O, ML and P are therefore the three end results in the previous section. With these parameters determined, the calculation looks as the following:

$$M_{Total} = \frac{53{,}8+(3x63{,}5)+73{,}1}{5} \qquad = 63{,}48 \text{ kWh/m2 per year.}$$

$$S_{Total} = \frac{73{,}1-53{,}8}{5} \qquad = \underline{3{,}86 \text{ kWh/m2 per year.}}$$

$$V_{Total} \qquad = \underline{14{,}9 \text{ kWh/m2 per year.}}$$

Project 345-002 uses a probability of 97% in its estimate, which means when looking at table 5.3 that the confidence interval is within M_{Total} + $2S_{Total}$. It is therefore reasonable to use the same probability and therefore confidence interval in this report. When doing so, the result looks as the following:

63,48 kWh/m2 per year + (2 x 3,86 kWh/m2 per year) = 71,2 kWh/m2 per year

This result can be translated into saying that with the 3-point method based on the sensitivity analysis there is a 97% probability that the primary energy consumption in the house will be below 71,2 kWh/m2 per year. This number is about 11% higher than the original BM-Excel energy model, in which the result of primary energy consumption was 63,5 kWh/m2 per year.

Not only does this method take deviations into account through the sensitivity analysis, it furthermore gives a less static result. This is both good and bad. In terms of benchmarking for legislation and archive requirements given in the building regulations, an absolute result is needed, to make it easier for designers to evaluate a common requirement.
With that said, however, the method is very good tool when presenting the building's energy performance to a client. Here, there is room for more uncertainty, and the designer is able to predict and present a result that spans over an interval instead of a static result. This could be presented by saying that it is believed there is statistically a 95% probability that the house will have a total primary energy consumption within 55,76 - 71,2kWh/m2 per year. This should always, however, be presented with emphasis on the importance of the inaccuracies related to estimating the parameters used in the model.

5.3 The Revit and Green Building Studio energy model

Autodesk Revit is a 3D based design software for architectural design, structural engineering and Mechanical, Electrical, Plumbing (MEP) professionals. The software is specific for Building Information Modelling (BIM). The US National Building Information Model Standard Project Committee defines BIM by the following:

"Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" [37].

The key letter in BIM is the letter I, which stands for information, and information is exactly what it is all about. The 3D-model makes it possible to extract numerous types of information about a project, e.g. quantities, amounts and collision checking between structural, MEP and architectural models. This information can be transferred directly into other software that deals with prices, time scheduling, labour and energy performance. The really interesting characteristic here is when the software working with Revit allows the user to track changes back into Revit so that the project is always up to date, regardless of where a change has been made. This allows a person working with project economy to make changes and let these changes be saved back into the model, so that the designer is aware of changes and updates.

In this report I will look into the Green Building Studio (GBS) for Revit which is a cloud-based software by Autodesk. The software allows the user of Revit to fill in information in a BIM-model, regarding building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and weather data by location. There are many parameters that can be altered within Revit, but for this report the simulation will be done from a predefined data set in Revit called Single Family. The software also features pre-set parameters for offices, schools and so on. Figure 5.13 represents the Revit model which is the basis of the GBS simulation.

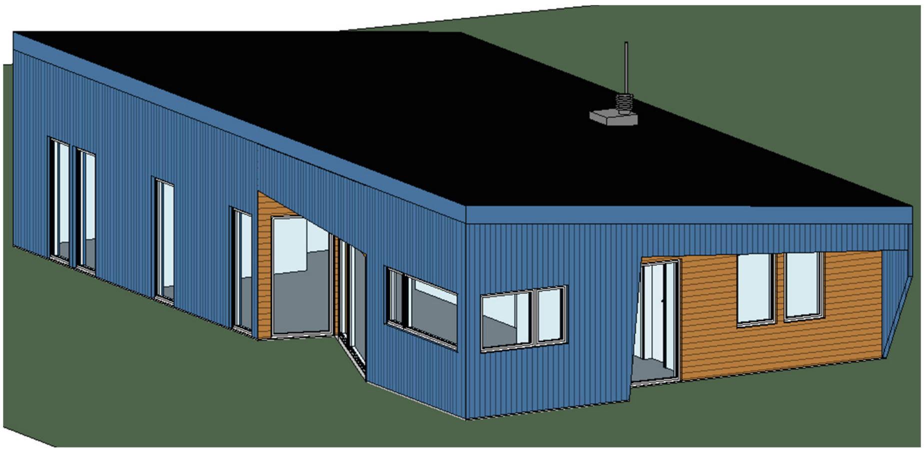


Figure 5.13 – An axonometric view of the Revit 3d model

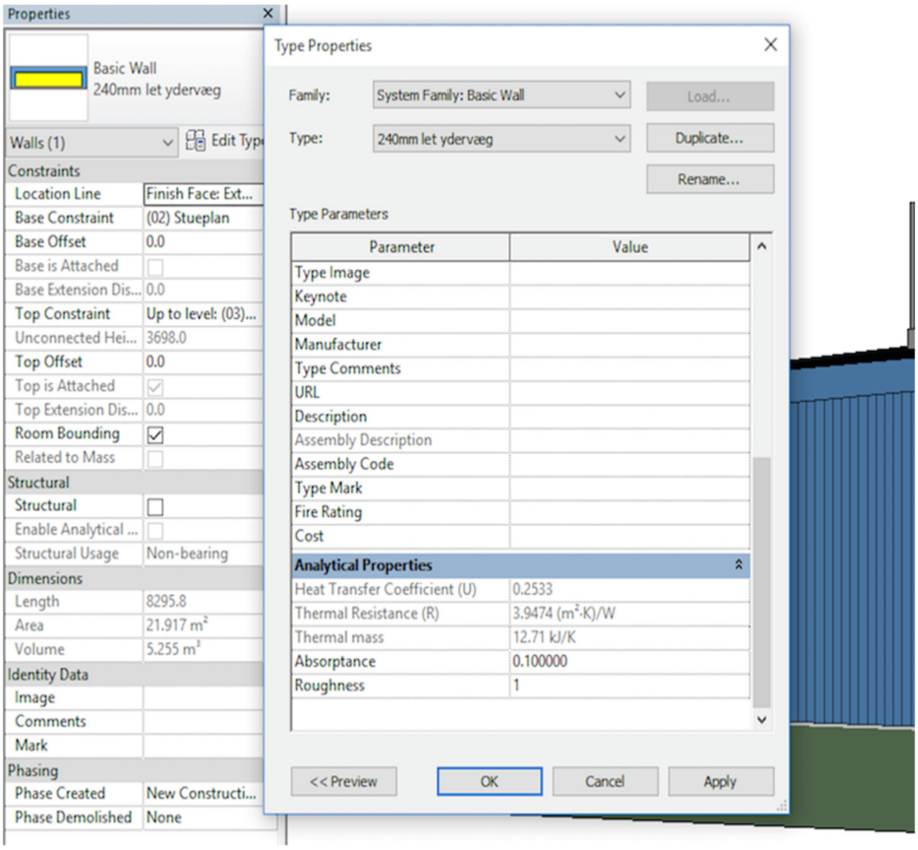


Figure 5.14 – U-value calculation of a building element (external wall) from Revit

Revit has two options when performing an energy simulation: one called building simulation, and the other analytic simulation. Building simulation is the detailed simulation where all building elements are defined in the BIM-model. This means u-value determination, location of building, position of building, number of inhabitants, heating/cooling systems, electric consumption and many more. This is the type of simulation that is used herein. The analytic type simulation is a much less detailed simulation which can be performed in the beginning of the design stage where very little is known. Then, the simulation utilizes a conceptual model where no information is yet defined and the key parameters used are location and placement of house plus climate data for that site.

Revit features its own U-value calculator for building elements. It calculates by processing previously described parameters for determining U-values. The results of the calculations here are close, but with small deviations from the ones performed in Rockwool Energy Design 4.1. Figure 5.14 shows such a calculation example in Revit on an outer wall. In this case, the U-value is about 4% higher in Revit than in the one performed in Rockwool Energy Design 4.1. The reason for this discrepancy is found within Revit. When a building element like the outer wall is defined, all the materials are defined either as being thermal, structural, substrate, membrane layer or finish layer. Only in the thermal layer it is possible to calculate a U-value. This means that for this wall calculation in Revit, the U-value is calculated only from the properties of the insulation layer, whereas in the Rockwool Energy Design calculation properties of all layers in the building element are accounted for. Therefore, the Rockwool calculation must be considered more precise.

Revit has about 30 different window types to choose from. These types deviate some from the Velfac calculator and give each window the same u-value no matter the size. Therefore, I have chosen to overwrite the built in Revit types and instead create my own type using the values from the Velfac calculator. This is the only place in the Revit model where I will be using previously calculated values to overwrite Revit pre-set values. The U-value calculation on windows can be seen on figure 5.15.

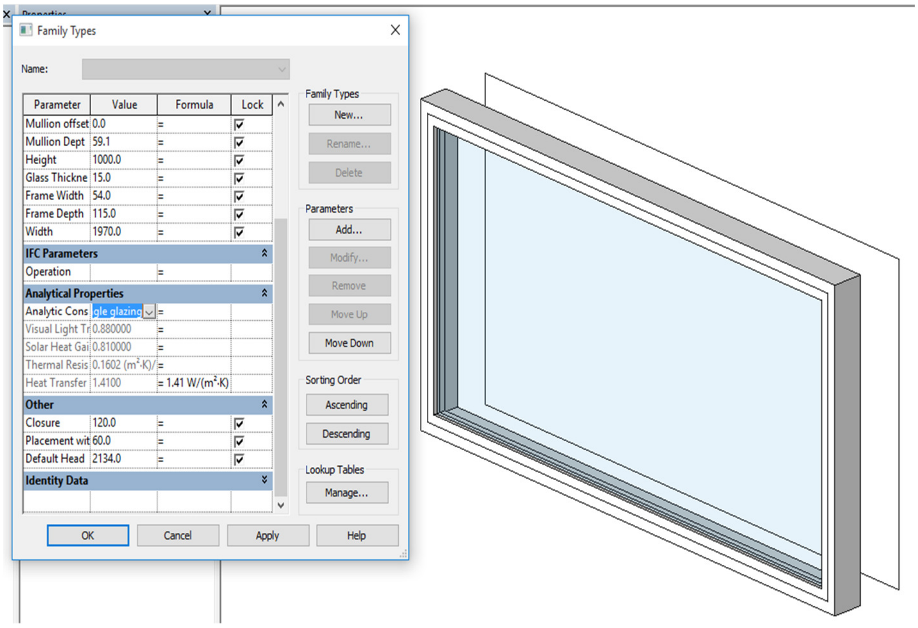


Figure 5.15 - U-value calculation of a window from Revit

When drawing a model in Revit, the model faces north on the top of the screen in plan view. This, however, is not true north, and it is therefore important to rotate the model towards true north so that the energy simulation accounts for correct shading and incoming sun and sky radiation.

When the Revit model has been drawn and all information on building elements, location settings, heating systems and pre-set parameters are chosen, the user must define a set of spaces. The model utilizes the spaces to define the interior of the house as well as rooms. The spaces calculates net volume and net area of the house. It is important to notice this as the parameters on area and volume in the BM-Excel are based on gross values. Figure 5.16 illustrates the spaces defined within the building. Spaces are shown with a green colour.

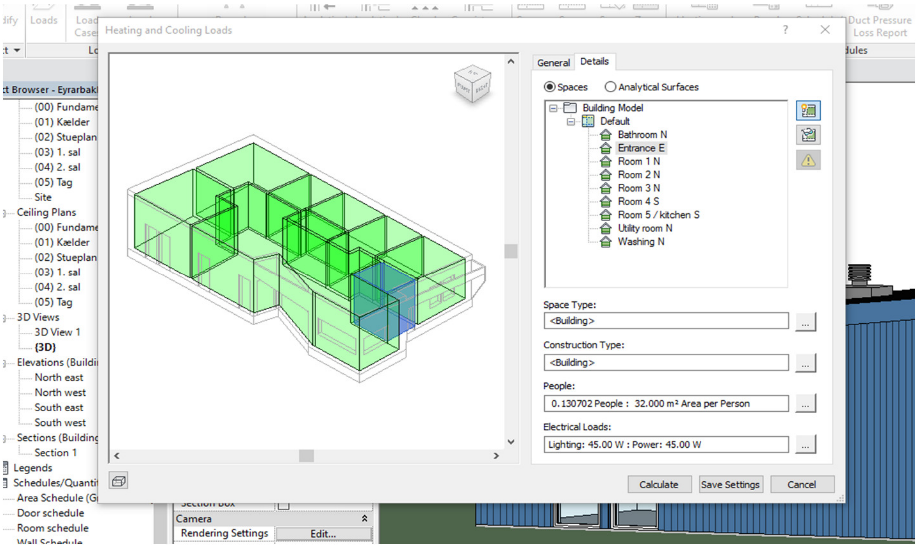


Figure 5.16 – Rooms and spaces within the Revit model

Now the model is ready to be submitted to the Autodesk Green Building Studio. Revit has a built in button that when pushed submits the data from the model to the GBS cloud based energy software. The results of the model I will get back to, but first a bit on GBS.

GBS runs on a software type called DOE2.2, developed by James J. Hirsch & Associates in collaboration with Lawrence Berkeley National Laboratory. DOE is a freeware building analysis software that is intended to predict energy use and its costs[38].

When entering the GBS cloud service, there is the initial run based in the parameters defined in Revit. GBS furthermore creates a number of other runs based on different settings in the house, such as other heating systems, window types, inhabitants and more. In this case, GBS created 106 other runs with different setups.

The software then compares energy use and costs and potential savings between the different setups. Figure 5.17 shows the initial run written in purple and five other runs with different setups. These are written in blue.

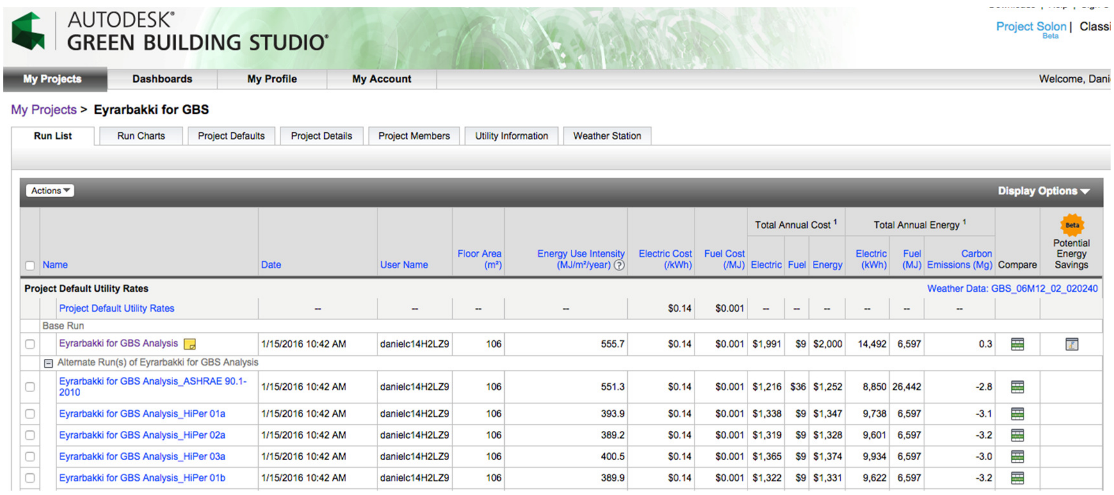


Figure 5.17 – GBS cloud service on Eyrarbakki

One would now expect that all the parameters defined in Revit are included in the first run. This, however, is not the case. When examining the first run more thoroughly, it is clear that only some information from the Revit model has been exported. Data on U-values for building elements are successfully exported. Information on inhabitants and heating systems, however, are not the same and GBS has changed these parameters. These parameters can be changed in the cloud software but when doing so, the system suffers from constant crashes.

At first look, GBS seems to be implemented into Revit in such a way that it seems to be a part of the Revit software package. When running a simulation, though, it quickly shows that this is not the case and that the software is clearly still under development. When the model parameters are uploaded to the GBS cloud server, all alterations are to be made through the cloud service and not in Revit. This is very unfortunate as all parameters that might be altered do not go back to Revit and the model simply becomes out-dated in terms of energy calculations. This makes the time spent within the Revit model seem lost as the data can be typed into GBS directly without a present 3D-model.

5.3.1 Result from the Revit and Green Building Studio model

Autodesk Revit and GBS are American software and the results therefore are very much in line with US standards, units, currency etc. The US Environmental Protection Agency (EPA) works with two types of energy consumption; source and site energy consumption. Site energy describes the amount of heat and electricity consumed by the building. Source energy is the total amount of energy consumed. It includes not only the heat and electrical energy consumed by the building, but also the amount of raw fuel (natural gas) consumed at the power plant as well as transmission and delivery of energy[39].

EPA has determined source energy as being the best suited result for evaluation of building energy losses and as an equal benchmarking standard. The result from GBS reflects this standard and thereby isn't of much use in Iceland and this report.

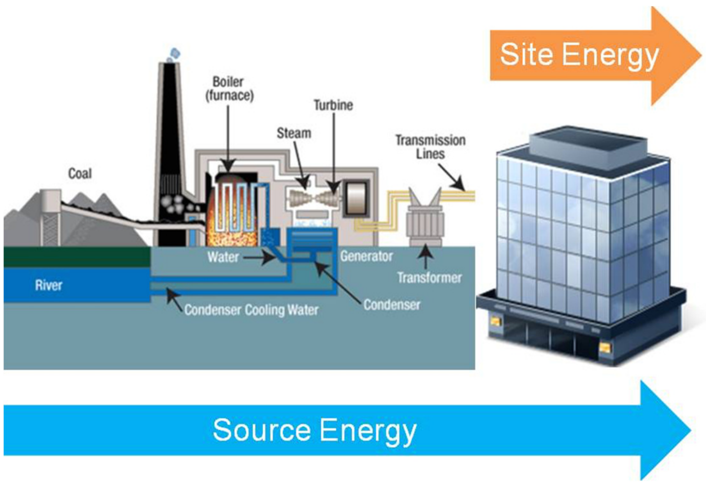


Figure 5.18 – Site and source energy defined by EPA[39]

Based on the EPA definition, GBS produces results based on the amount of natural gas burnt at a power plant. This is a result that unfortunately isn't of much use here in Iceland, where all energy is sustainable and either comes from geo-thermal or hydropower generation. Furthermore, the results are incomparable with the BM-Excel model. The result sheet from GBS can be found in appendix 11.
At first glance, the only result that could be used to some extent is the monthly heating loads. However, when looking more closely at this, it shows that hot water is not included in the chart.

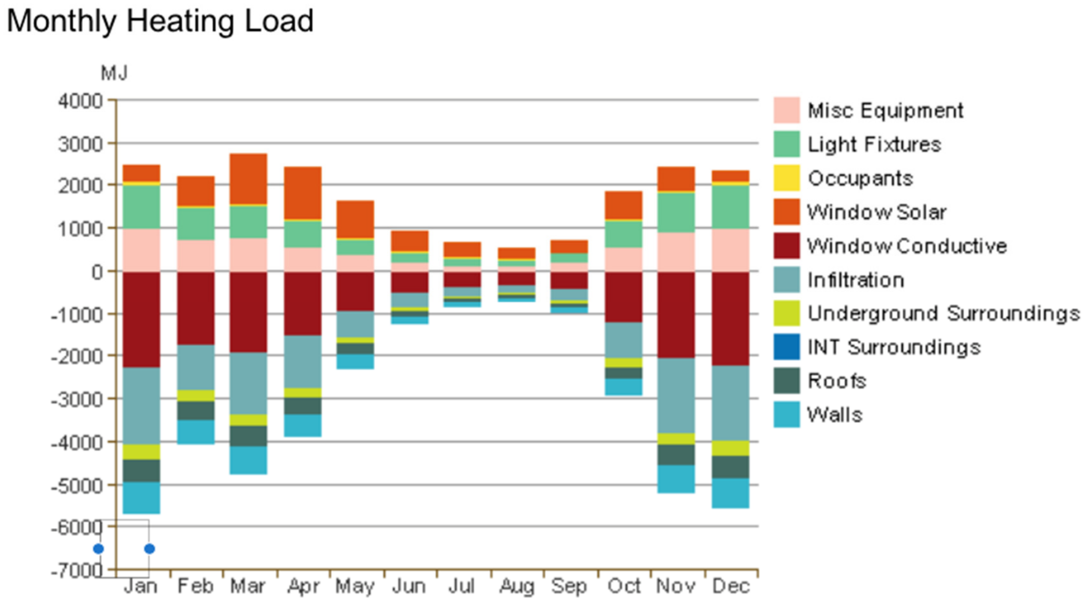


Figure 5.19 – Monthly heating loads from GBS on Eyrarbakki

The monthly heating loads are very much based on climate data and GBS also includes a number of figures on climate data in the result sheet. When comparing these data with MET office climate data, it is clear the data is inconsistent. Mean temperatures are too high and the wind rose indicates a different picture than the data from the MET office.
When looking further into this matter, it becomes clear that even though the building location has been defined by GPS coordinates, the weather station being used in GBS is located far from the actual site. Figure 5.20 is a screen shot from GBS of this.

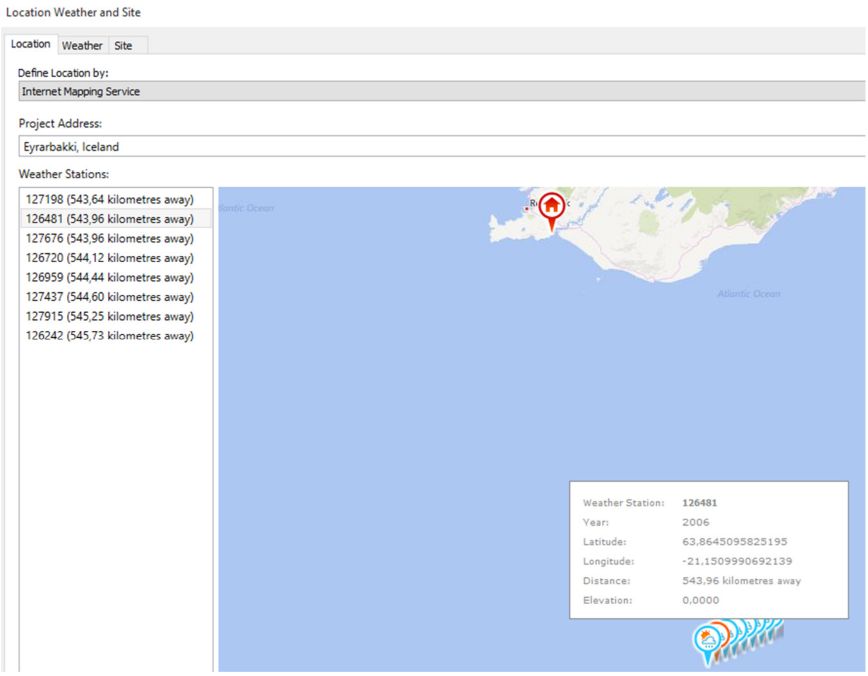


Figure 5.20 closest weather station Iceland from GBS

As illustrated, the nearest weather station is located about 550km south of Iceland in the middle of the ocean. If it is not possible to change the weather data within GBS and use data from the Icelandic MET office, then the basis for energy calculations for Icelandic buildings is not present within the Revit framework.
Further investigation into this dilemma revealed that it is possible to change the weather data when defining the location of the building within Revit. However, when the model is exported, GBS automatically overrides this manual data and defines the closet weather station within the software and the result is therefore the same.

With these challenges, it was decided to contact the consulting firms in Iceland and see if any of their professionals had experience with the software and perhaps similar issues.
We started out by contacting Sigurður Harðarson, Architect, Design Manager, CEO and Partner at Batteríið architects. He had some experience with the software from a few years ago but advised us to contact Davíð Friðgeirsson (DF), BIM manager at Verkis engineers.
DF had some experience of the software on a project in Norway a few years back. They had encountered the same issues as we and had contacted Autodesk regarding the weather data. Autodesk, however, never responded to their inquiry.
DF also had a similar experience with difficulties processing a detailed building simulation like the one in this report and we concluded that the software simply is not ready to handle detailed BIM-models. DF also mentioned that the constant development and changes made in the software's user interface posed a challenge to the user and made the software difficult to master. This generally supports the conclusion that the software still undergoes heavy development and is still not practical to use.

DF had also used the less detailed analytic simulation by analysing a very simple conceptual mass from Revit. This experience had shown some useful results. The conceptual model makes it simpler to use and even though the actual results are not useful, the change in the result when the conceptual mass is, for example, rotated or a window is moved from north to south, shows some impact in the energy use and indicates whether a conceptual change to the building is likely to be positive or negative for the building's energy consumption.

Overall, the conclusion is that it is too soon to use GBS with Revit as a trustworthy energy model, especially when the building is located in Iceland. Furthermore, the gap between Revit and GBS makes the time spent on a detailed BIM-model in energy terms not wisely used. In addition, the fact that the software is developed with such a strong connection to the US standards will most likely make it difficult to use in other places. It can, however, be used in the beginning of the planning phase with a simple and less time consuming conceptual model to evaluate the energy related implications of specific design decisions.

Chapter 6 The monitoring systems and data

6.1 Installation and location of monitoring equipment

The house was instrumented to allow for a true estimation of the actual energy use, in order to be able to verify the energy modelling introduced in chapter 5. The following monitoring equipment was installed in the house:

1. An external weather station, monitoring wind direction, wind velocity, barometric pressure, humidity and precipitation.
2. Two sensors measuring the temperature and humidity of the outside air on the south and north walls of the house.
3. Two sensors measuring both temperature and humidity of the indoor air on the south and north side of the house.
4. One flow sensor on the incoming hot water flow meter.
5. Two temperature sensors monitoring the temperature of the hot water coming in to the house and the temperature of the hot water going out of the house.
6. Four temperature sensors, one in each of the four air ducts of the heat exchanger unit.
7. One electric sensor monitoring the current driving the heat exchanger unit.

Figure 6.1 and 6.2 show the location of the sensors. All data channels are coded with a unique ID related to the location of the sensor in the house so that the data received can be easily recognised. The external temperature and humidity sensor on the north and south façade was unfortunately broken due to weather damage and therefore did not record any data. Sensor ID 245 measuring the hot water flow detected measurements from 8th of November till 29th of November, when it unfortunately broke down.

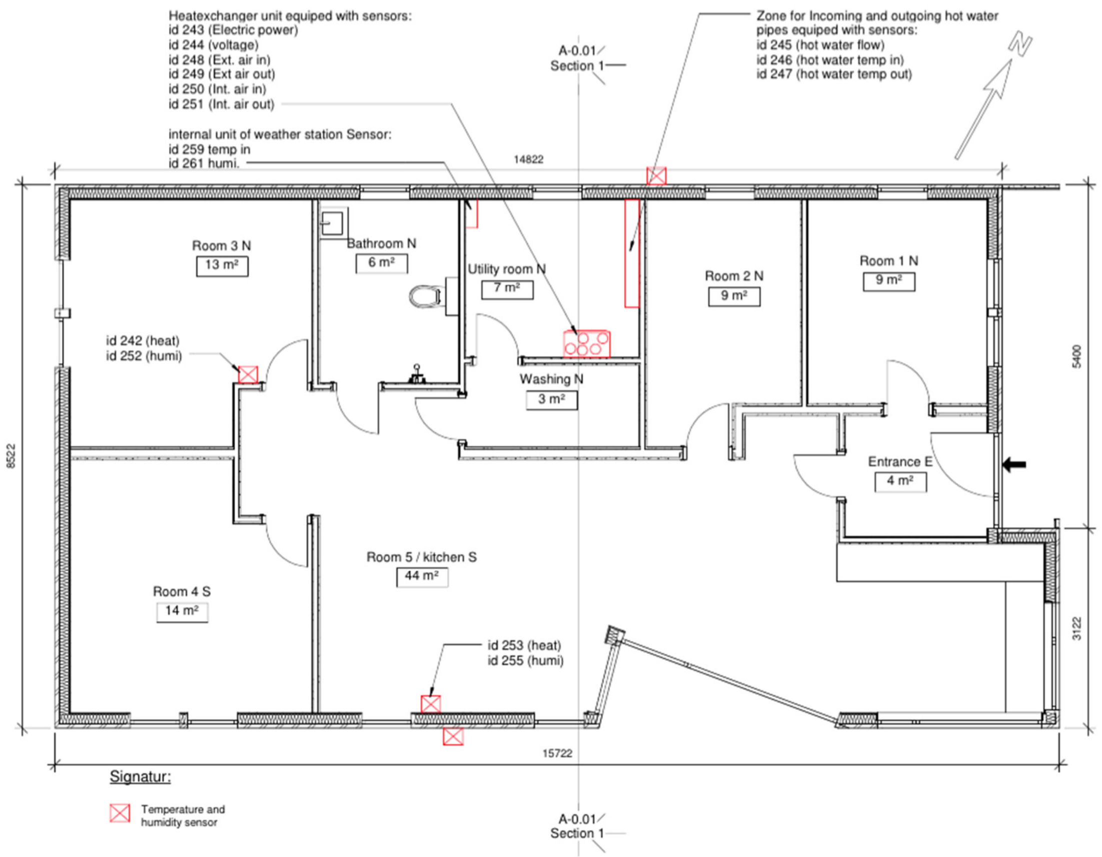


Figure 6.1 – Plan layout from the Revit 3D model illustrating sensor placing

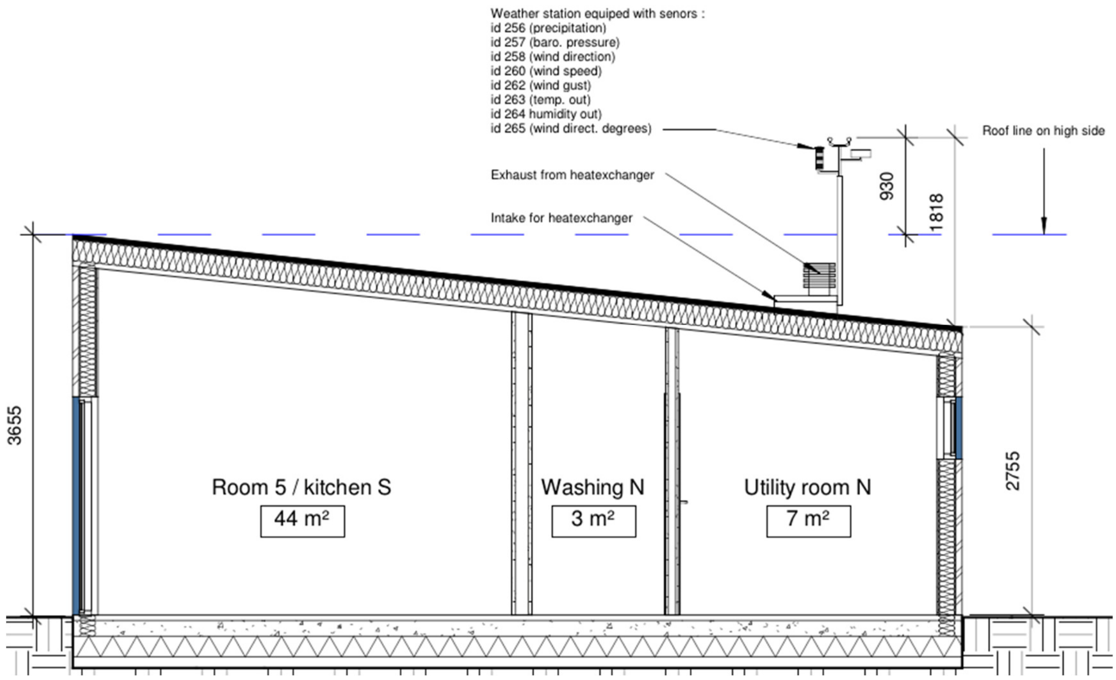


Figure 6.2 – Section in Revit 3D model illustrating weather station placement.

6.1.1 The external weather station.

Figure 6.3 – The weather station unit

The weather station is a Velleman WS1080. The specifications for the weather station can be found in Appendix 15.
The weather station is composed of an external unit shown in Figure 6.3 and an internal unit located inside the building shown in Figure 6.4. Both units measure barometric pressure, temperature and humidity. Therefore, the station supplies information about both the indoor and the outdoor climate. The external unit features a rain collector measuring the amount of precipitation in intervals of 1 hour, 24 hours, 1 week or 1 month. It is furthermore equipped with a wind speed and wind direction detector. The wind vane and velocity sensor is located about 0,9m above the high side of the roof, as shown in figure 6.2.
The internal unit is mounted in the utility room of the house more or less right beneath the external unit shown on Figure 6.1.
All data collected by the external weather station unit is submitted wirelessly from the roof to the internal weather station. The internal unit then communicates wirelessly with the local data acquisition unit.

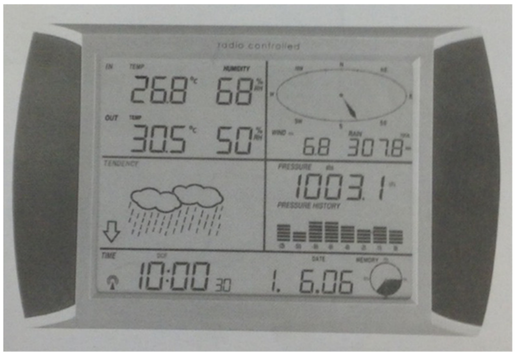


Figure 6.4 – The weather station internal unit

The installation of the external unit was partially prepared at the university lab where the vertical pole included in the package was extended in an attempt to reduce the influence of the roof on the wind flow monitored. The roof of the house has a slope in one direction (positioning of monitoring systems are shown later in this chapter) and the position of the external unit is in the lower end of the roof. In order to get especially the wind speed and wind direction detector high enough and completely clear of the higher end of the roof, some augmentation of the pole was made. The included pole was extended by 1.3m by gluing it into a galvanized 1” steel pipe. The pipe was mounted in an unused TV-antenna fixture located on the roof.

6.1.2 The temperature and humidity sensors.

All in all, four sensors measuring temperature and humidity were installed in pairs on the outside and inside of the house. One sensor was installed outdoors on the south side and another one on the inside of the same wall, and the same was done for the north wall. All the sensors are of the same type (see figure 6.5). Their specifications can be found in Appendix 15

Figure 6.5 – External and internal temperature and humidity sensor.

Figure 6.6 – The box housing the external temperature and humidity

Figure 6.7 – Internal temperature and humidity sensor installed.

Figure 6.8 – Ext. south façade temp, and humidity sensor.

Figure 6.9 – Internal north façade temperature and humidity sensor.

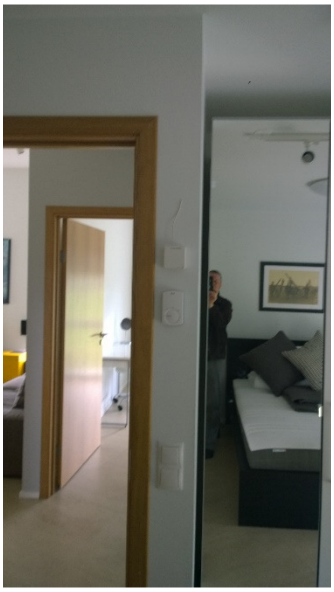


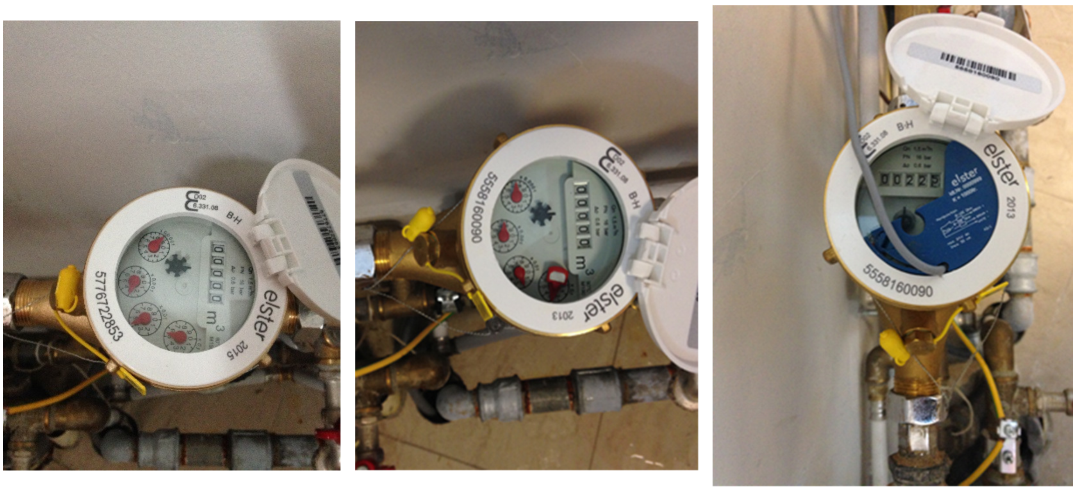
Figure 6.10 - New external box with hole for sensor contact to outside air.

The sensors are installed on the façades at a height of about 2,2m. The one on the south façade will be in direct sunlight most of the day when the sun is shining, whereas the ones installed on the north façade will be in the shade and therefore less affected by the sunlight. These different locations are chosen as the temperature and humidity levels can vary due to the amount of exposure to direct sunlight.

The temperature/humidity sensors are, like the weather station, connected wirelessly to a gateway positioned in the utility room of the house. The sensors located outdoors are placed in standard watertight plastic boxes normally used for electrical connections that are fixed to the cladding (see figure 6.6 and 6.8). Due to problems with the external sensors, a new box was created (see figure 6.9). The problems are described in section 7.3. The indoor sensors are glued directly to the wall (see figure 6.7 and 6.10). The internal sensors are wirelessly connected to the same gateway as the external ones.

6.1.3. Flow meter sensor.

In order to measure the amount of incoming hot water to the house, a flow sensor was installed. The original flow meter installed in the house did not have the required fittings for mounting a sensor and was therefore switched with a new flow meter. The new flow meter is equipped with a magnet on the needle to allow the monitoring of its rotation. On top of the new flow meter, an electromagnetic sensor (Figure 6.11) was fitted that measures the amount in m^3 of water running through. The sensor measures the rotation of the needle; one rotation equals 0.1 m^3 of hot water. The sensor is connected to a data acquisition unit sending wireless data to the gateway located in the same room (the utility room).



(a) (b) (c)

Figure 6.11 – The flow meter. (a) Old flow meter, (b) New flow meter, (c) New flow meter with a flow sensor installed.

6.1.4 Temperature of incoming and outgoing hot water.

The main hot water pipes, both in and out of the house, were equipped with a temperature sensor (see specification on Dallas 18B20 sensor in appendix 15). The sensors were fixed with steel clamps to the copper union-T fitting of the pipe system, both the in-flow and the back-flow. After installation the sensors were wrapped in insulation and duct tape to minimize the influence of external temperature fluctuations. The sensors are both connected to the same data acquisition unit as the flow meter sensor and the data is transmitted wirelessly to the gateway.

Figure 6.12 – not insulated temperature sensor

Figure 6.13 –Insulated temperature sensor

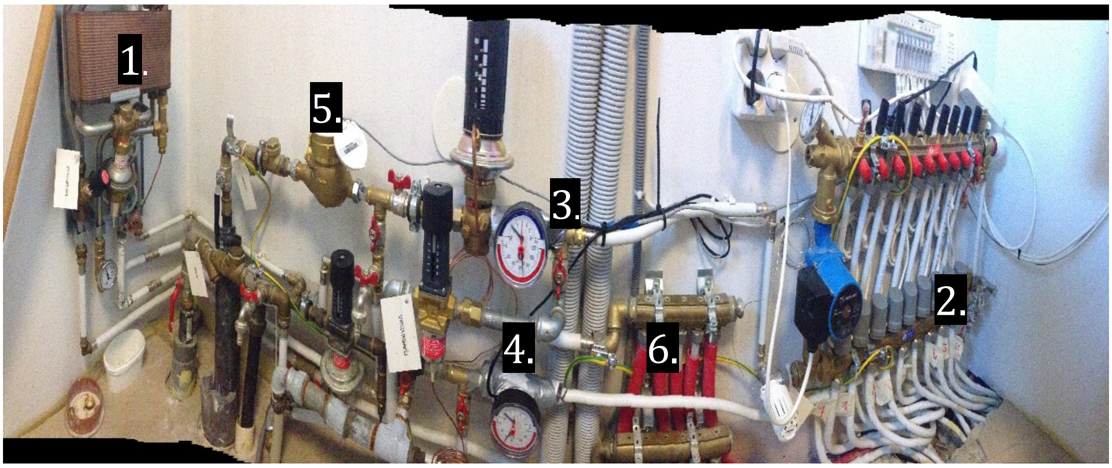


Figure 6.14 – the whole water system in the house. 1: Heat exchanger, 2. Floor heating distribution pipes, 3. Incoming hot water, 4. Outgoing hot water, 5. Flow meter, 6. Hot water.

Figure 6.14 shows the entire cold and hot water system in the house. To the left, marked with 1., is a heat exchanger for the hot tap water. This is a closed system heating up the incoming cold water, as the hot water in the area contains unwanted sediments. All the way to the right marked with 2. are the hot water distribution pipes for the floor heating system. At 3., the incoming hot water is measured and at 4., the outgoing hot water is measured. At 5., the flow meter is located. 6. is where the hot tap and shower water distribution pipes are located, and just below are the cold water distribution pipes.

6.1.5. Temperature sensors in the heat exchanger unit.

The heat exchanger was fitted with four temperature sensors of the same type as were installed on the hot water pipes. One sensor was installed in each of the four ducts of the heat exchanger; i.e. the internal supply air duct, the internal exhaust air duct, the external supply air duct and the external exhaust air duct. The sensors were fitted tightly in a 10 mm hole that was drilled in each duct. They were then glued using silicone and duct tape to ensure airtightness of the ducts and to prevent the pressure within the duct from pushing the sensors out of position (see figure 6.15). All four sensors were connected to the same data acquisition unit, which then transmitted the data to the gateway.

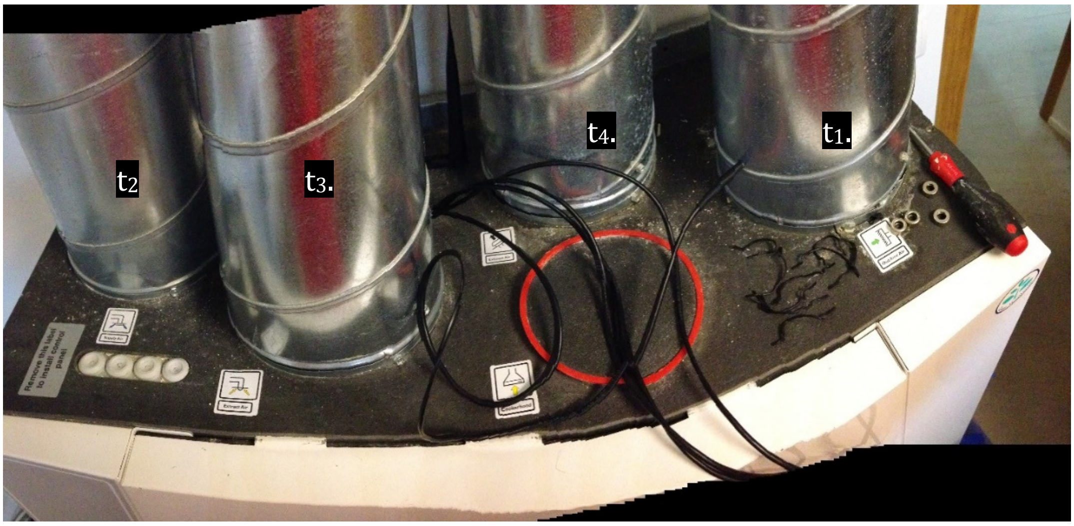


Figure 6.15 – Temperature sensors in the heat exchanger. t_1: Fresh air intake, t_2: warm supply air. t_3: Warm extract air. t_4: External exhaust air.

Figure 6.16 – Heat exchanger unit opened.

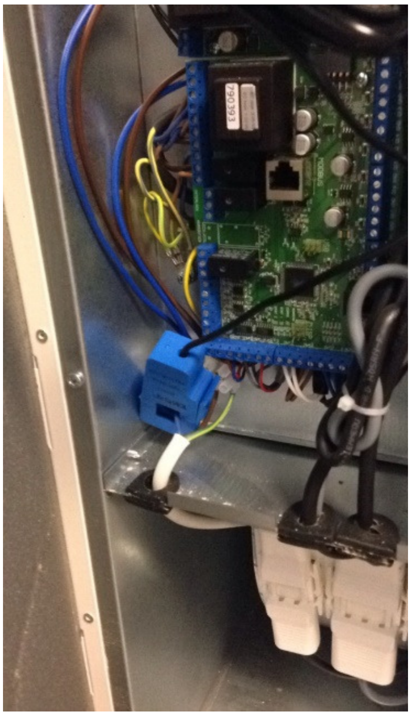


Figure 6.17 – CT fitted in heat exchanger

6.1.6. Electricity sensor on heat exchanger

The heat exchanger is driven by an electrical motor. In order to measure its efficiency, a current transducer (CT) was fitted within the engine's main 230V connection. The CT is a blue clip, shown in figure 6.17, which is attached directly onto the neutral electricity wire. The CT then measures the alternating electric current in the wire by measuring a magnetic field created by electrons running through the wire. The CT is connected to the same data acquisition box as the temperature sensors mounted in the ducts.

6.2 The monitoring connection and data acquisition

As mentioned in the previous chapter, all are sensors connected to a gateway located in the installation room of the house. The gateway has a wireless 3G connection through a sim card of the same type as in cell phones. The connection diagram below (figure 6.18) illustrates schematically the connection setup of the whole system.

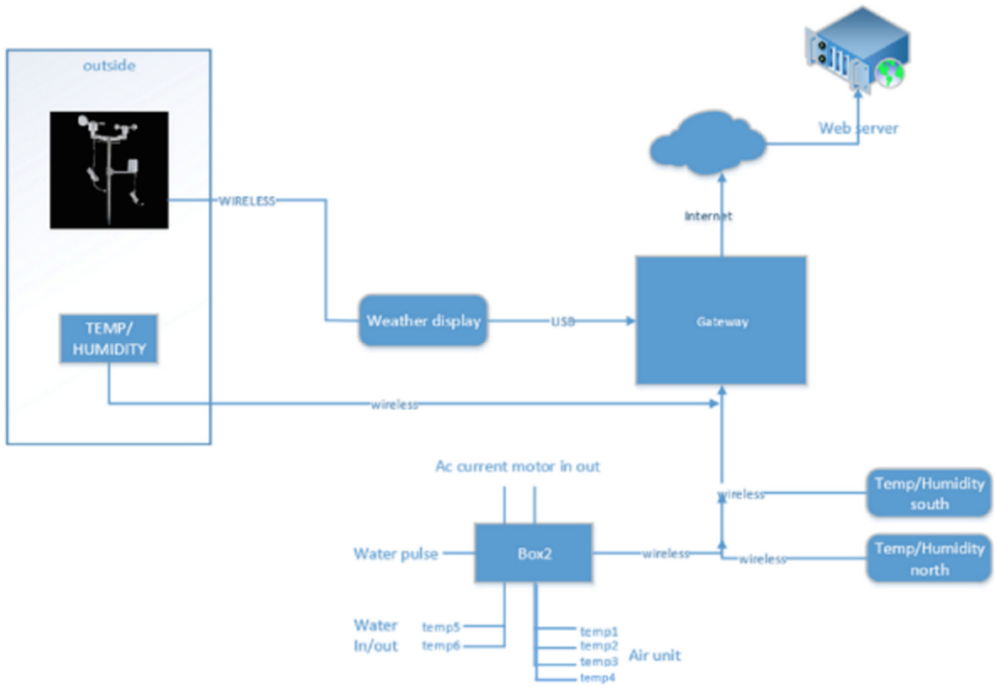


Figure 6.18 – The connection setup of the monitoring system.

All data is submitted to a webserver accessible from the internet. The layout of the online data feed is illustrated in figure 6.19. Each row represents a sensor and is described with a short name and an ID number. The data feed constantly updates and indicates how long ago data from each sensor has been received. For instance, ID 247 on the hot water out of the building indicates that the last update on received data was 28 seconds ago, and the value received was 37,7. The four icons to the far right in each row let the user edit the name of a sensor, delete a sensor, and create a graph from all data received, and the last icon lets the user export the data to a .CSV file (comma separated values) compatible with Excel.

Node:10

Id	Name	Tag	Datatype	Engine	Public	Size	Updated	Value
244	voltage	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	240
245	hot_water_m3	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	0.00
246	water_temp_in	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	59.7
247	water_temp_out	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	37.7
248	Ext_air_in	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	4.60
249	Ext_air_out	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	8.00
250	Int_air_in	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	20.1
251	Int_air_out	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	22.0
243	electric_power	Node:10	REALTIME	PHPTIMESERIES		2Mb	28s ago	14.0

Node:0

Id	Name	Tag	Datatype	Engine	Public	Size	Updated	Value
256	rain_mm	Node:0	REALTIME	PHPTIMESERIES		93.3kb	50 mins ago	0.00
257	rel_pressure	Node:0	REALTIME	PHPTIMESERIES		93.9kb	50 mins ago	991
258	wind_dir_txt	Node:0	REALTIME	PHPTIMESERIES		93.7kb	50 mins ago	0.00
259	temp_in_c	Node:0	REALTIME	PHPTIMESERIES		93.7kb	50 mins ago	21.5
260	wind_speed	Node:0	REALTIME	PHPTIMESERIES		93.9kb	50 mins ago	4.80
261	hum_in_perc	Node:0	REALTIME	PHPTIMESERIES		93.8kb	50 mins ago	20.0
262	wind_gust	Node:0	REALTIME	PHPTIMESERIES		93.7kb	50 mins ago	6.10
263	temp_out_c	Node:0	REALTIME	PHPTIMESERIES		93.8kb	50 mins ago	1.40
264	hum_out_perc	Node:0	REALTIME	PHPTIMESERIES		93.8kb	50 mins ago	60.0
265	wind_dir_deg	Node:0	REALTIME	PHPTIMESERIES		93.8kb	50 mins ago	0.00

Figure 6.19 – Layout of online datafeed from sensors expect the two external sensors.

6.3 Issues and challenges with the monitoring equipment.

Several issues defied the start-up of the monitoring equipment. These issues were luckily solved along the way. In that context, it is important to point out that thorough planning is crucial for a project like this to become successful.

The house in Eyrarbakki is located about 60km from central Reykjavik and it is therefore not a quick fix when problems occur. The long distance combined with the fact that the house is rented out to tourists and therefore not accessible at all times makes it even more challenging to fix any problems fast.

The first problem experienced was the sudden loss of internet connection, when the owner of the house turned off the wireless 3G connection, due to excessive data usage. It is most likely that the excessive data usage comes from some of the visitors to the house, as the data acquisition units submit only a small amount of data bytes and it was within the first days after the system came online that the connection was closed. This issue was solved by installing another independent wireless 3G connection sponsored by the Innovation Centre.

The next issue occurred due to missing data points during intervals of several hours. The missing data points were the weather data from the weather station on the roof. It turned out that even though the internal part of the weather station was situated in the utility room right below the external weather station, the signal strength was not strong enough. This was solved by moving the internal weather station closer to the window in the north façade in the utility room.

Data acquisition unit no. 2, indicated on the diagram in figure 6.18 (Named box 2 on diagram), which gathers data from the heat recovery unit, hot water temperatures in

and out and the in-flow of hot water sensor, also caused some problems. The unit was initially connected to a 230V socket located next to the entrance to the utility room. This socket, however, turned out to be used for different purposes by the cleaning staff and the unit was therefore unplugged occasionally and sometimes not re-plugged. This resulted in long periods without data from the sensors attached to this unit. The power connection was moved to another outlet using an extension cord.
The extension cord, however, did not solve the problem completely as data points were still missing from the sensors in the heat recovery unit. This turned out to be caused by the extension cord, which was badly grounded. After the cord was properly grounded, the data acquisition was as desired.

A quality assurance measure was initiated to see the precision of some of the data. In particular, the weather station on the roof was studied, as the build quality of the external unit in many ways seemed to be somewhat cheap.
Figure 6.20 and 6.21 show the barometric pressure in hPa from the same week in December. One represents measurements by the Icelandic MET office at their station in Eyrarbakki, whereas the other shows the measurements at the house. The two figures can be considered to be almost identical and are a good indication of the data quality from the weather station. Figure 6.21 has two areas with data points missing over a larger period. These two areas are indicated with red circles on the graph. This is due to the issues related to limited signal strength between the internal and external weather station unit, as previously discussed.

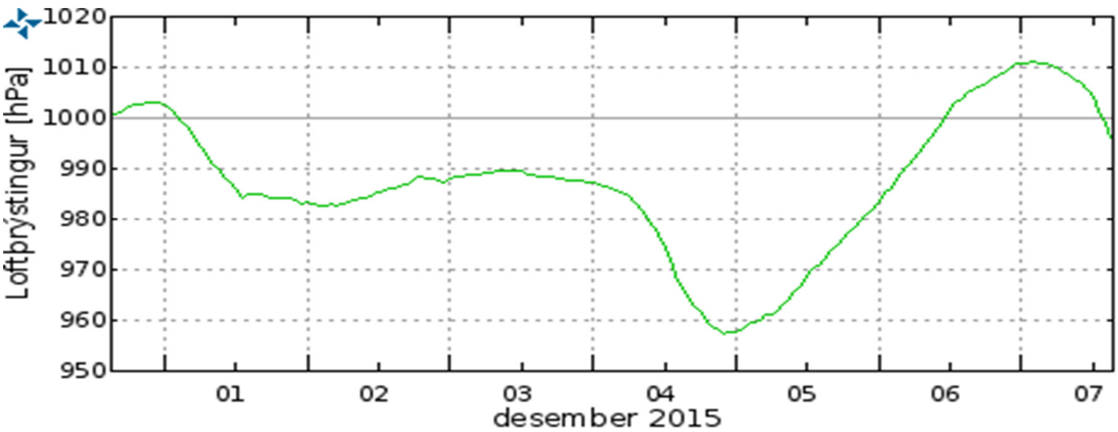


Figure 6.20 – Iceland MET-office graph illustrating barometric pressure in hPa from 1st of December – 07th of December.

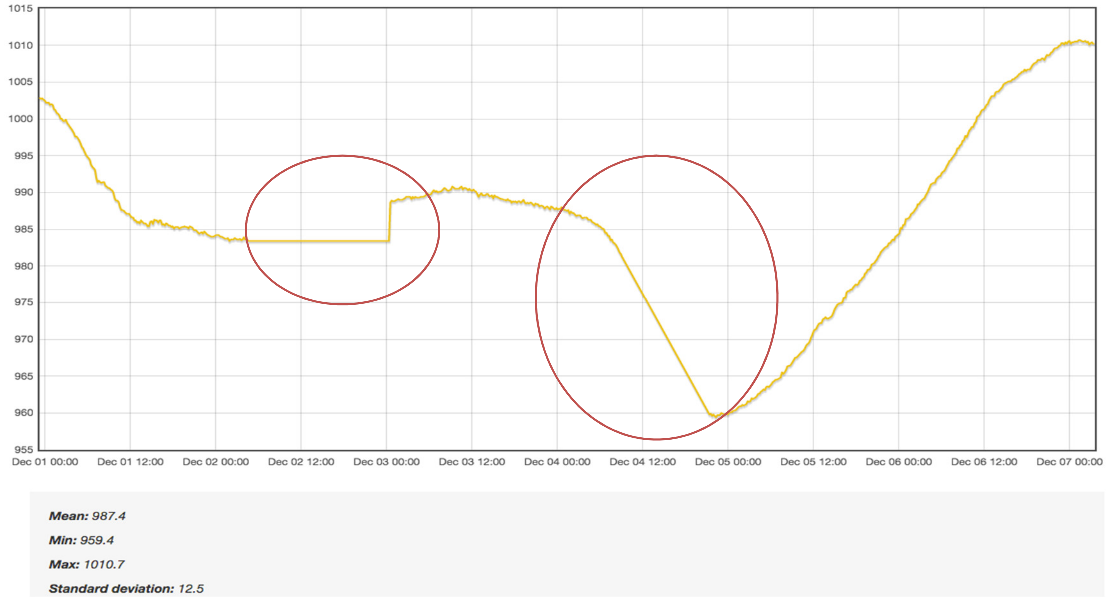


Figure 6.21 – Weather station data on Barometric pressure in hPa from 1st of December to 7th of December

Figure 6.22 and 6.23 show the time history of the outside air humidity. On one hand data collected by the weather station and on the other data published by the Icelandic MET office. Again the signal strength issue is visible on the figure 6.23 and is indicated with two red circles. The two graphs show a similar looking pattern with time, however the humidity scales are very different. The data from the weather station illustrated in figure 6.23 shows consistently much lower air humidity compared the data from the MET office. This inconsistency in the data from the weather station and the MET office may perhaps be explained by the location of the weather station on the roof. As shown on figure 6.2 and figure 6.3, the weather station is mounted directly above the exhaust tube from the heat exchanger. The air blown out from the exhaust may possibly affect the humidity measured by the sensor in the weather station. Therefore, the data collected may be an underestimation of the true humidity.

The same inconsistencies can be seen in the data from the outside temperature sensor in the weather station. Here, the pattern once again is the same, but now the temperature is somewhat higher in the weather station data than the MET office data. Again, this is very likely due to the hot air coming from the heat exchanger exhaust tube, which may affect the temperature measured by the sensor in the weather station.

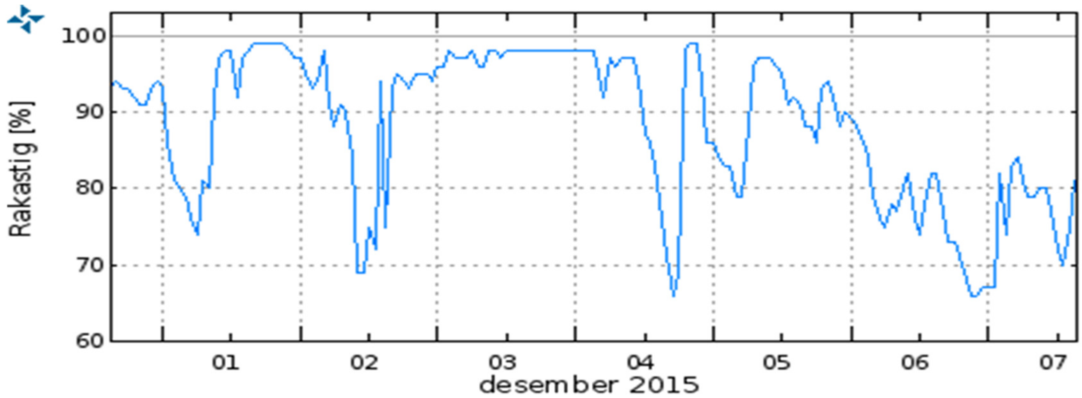


Figure 6.22 - Iceland MET-office graph illustrating outside air humidity in % from 1st of December – 07th of December.

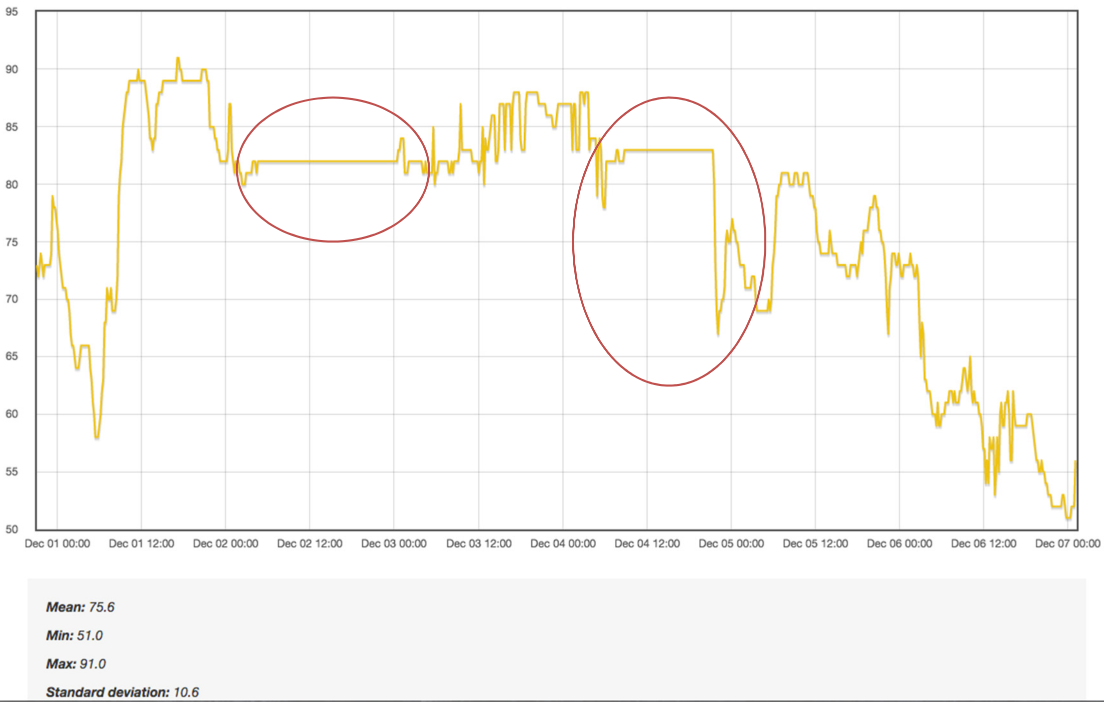


Figure 6.23 - Weather station data on outside air humidity in % from 1st of December – 07th of December

In Appendix 08 a comparison between other variables collected by the weather station and data from the MET office station at Eyrarbakki is shown. Those include wind speed, wind direction, temperatures and dew-point temperatures.

The data collected from the weather station on these are fairly accurate when compared with the MET office data located in the same appendix.

Chapter 7 Acquired data presented

The following chapter is a description of the data that was collected from the sensor equipment installed on the house in Eyrarbakki. The chapter also serves as a description of further implications and changes that were encountered and carried out later on in the progress of this thesis.

The data that has been recorded in the house has in many ways turned out to be problematic.
First of all, the sampling rate, which is the amount of data recorded pr. time interval, is not constant and the individual sensors don't have the same sampling rate.
The sensors are of a type with a unique ID and timestamp, and this means that the measurement period isn't the same for each sensor.
The data collected from the sensors also contain many outlier values illustrated by either zeros (where not expected) or extremely high values which are false as they do not correspond to a physical possible reality.

The data has been plotted into the following figures with the most obvious outlier values removed. The data has furthermore been resampled allowing a correlated timestamp with reasonable accuracy.

Due to the problematic data, the general illustrations are drawn to illustrate a not too detailed picture as the data doesn't justify going into too much detail. There are, however, examples with more detailed graphs in order to explain some of the more general illustrations.

7.1 The hot water in and out.

Figure 7.1 depicts the incoming and outgoing hot water temperatures in the house. As the figure shows, the sensor for incoming hot water started measuring about one month prior to the outgoing water sensor. As illustrated in the figure, the data contains some major fluctuations in both incoming and outgoing water temperatures. Furthermore, the outgoing temperature is often unusually high. This temperature was expected to be near 20 - 25°C and not as measured, where it most of the time is between 30 - 40°C and in some cases even higher.
From a second visit to the house it was discovered when the fluctuations in the hot water temperature occurs as well as why.
When no hot water is used in the house, the incoming hot water temperature is measured at the sensor to be about 60°C, and the outgoing about 40°C.
When the house is in use and the heating systems are operating, the temperatures change rapidly. When the floor heating is turned on the outgoing temperature drops within 10 minutes down to around 22 - 25°C. This was discovered by changing the heat settings of the house at the second visit.
The big fluctuations in figure 7.1 illustrate the changes in the hot water temperature when the floor heating is turned on and off. This discovery furthermore corresponds with the usage schedule in appendix 07. Here it can be seen that for a period from

mid-November to the end of December the house simply did not have any visitors and the heating system therefore was not activated. When looking at that same period on figure 7.1, the fluctuations in temperature are minimal and a more constant temperature of 35 – 40°C is maintained, supporting this discovery.
With the reason for fluctuations in temperature sorted out, we still needed to find out why the temperatures were measured to be so much higher than anticipated. The theory on why this is, is that the floor heating has a circulation through the main distribution pipes when no hot water is in use and they are therefore are at a low flow rate. This means that when the flow is low the hot water never enters the floor heating pipes but instead is circulated through the distribution pipes and then directly out of the house. This results in an outgoing temperature that is around 20°C lower than the incoming temperature. This explains the high outgoing temperature as the heat is never utilized fully through the floor pipes.
When the system is activated, the flow rate increases and the water runs into the floor heating pipes. Now the energy is utilized as intended through the floor heating and the outgoing temperature reflects this with a much lower temperature of around 22 - 25°C.

The fluctuations in incoming hot water were initially assumed to be coming from the water supply in Selfoss. This, however, is not the case. These fluctuations also occur from the usage of the house.
A combination of two factors result in this fluctuation. 1. The flow of incoming hot water varies depending on whether the house is in use or not. When the house is in use, the hot water flow rate increases due to a higher water consumption. When the house is not in use, the flow rate drops again.
2. The thickness of insulation covering the sensor mounted to the pipe is too thin, resulting in measurements being affected by external temperatures from the room it is located in.
In the period mid-November to the end of December, when the house did not have any visitors, the temperature was rather stable. According to the hot water supply company Selfossveitur, the incoming hot water temperature is about 65-70°C in houses located in Eyrarbakki. The temperature measurements during the stable period was about 60 - 65°C. The sensor must therefore be considered to be affected by the room temperature in such a way that the measured temperature is about 5-10°C lower than the actual temperature of the incoming hot water.

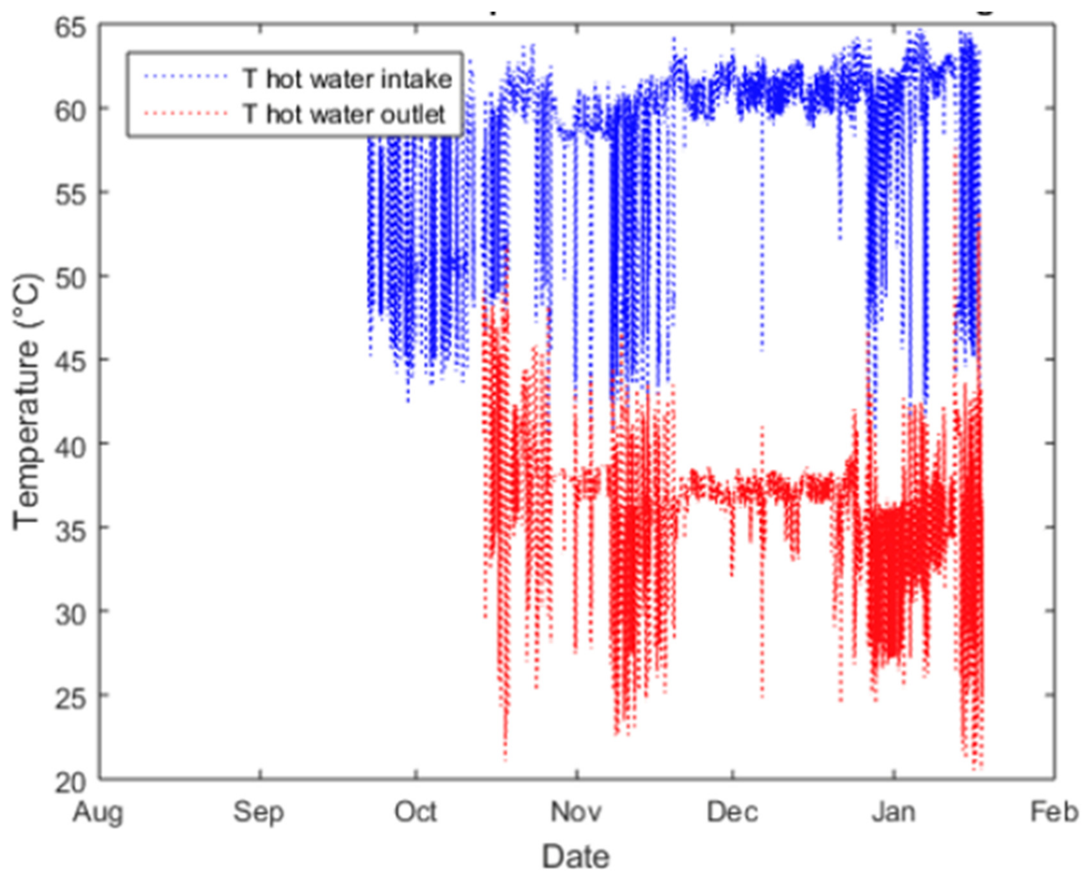


Figure 7.1 – Hot water incoming and outgoing temp.

Figure 7.2 illustrates the temperature difference between the incoming and outgoing hot water. The figure illustrates a subtraction of the hot water in with the hot water out temperature. Like figure 7.1, it illustrates high fluctuations when the house is in use and a more stable temperature when the house is empty.

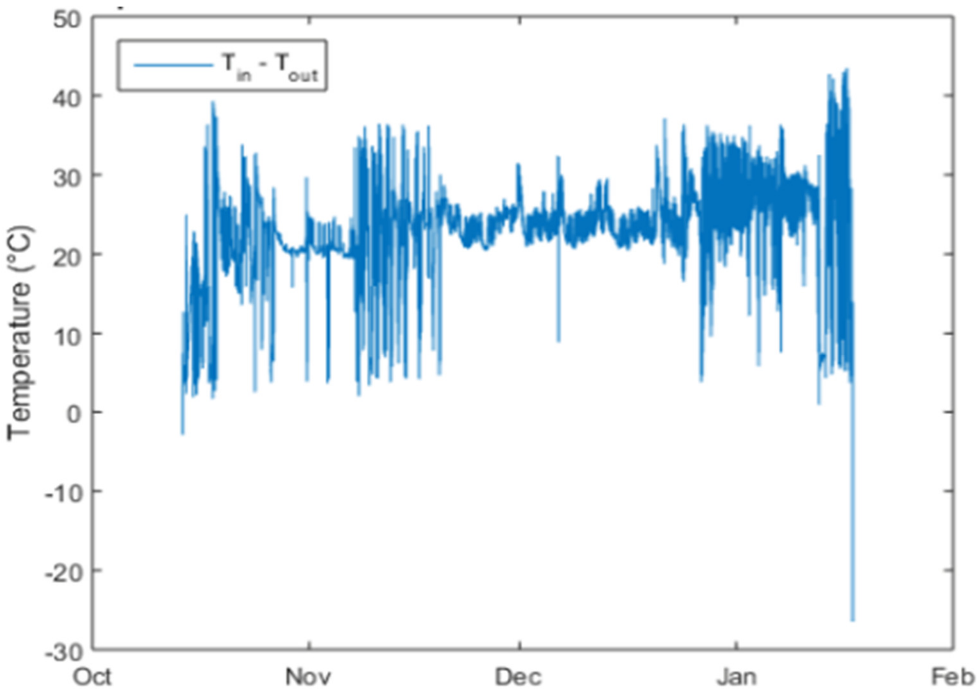


Figure 7.2 – Temperature difference hot water in and out of the house.

7.2 The flow meter

The flow meter measuring the amount of hot water being used stopped functioning shortly after installation and the data that was actually collected was invalid. The sensor is the blue disk installed on top of the flow meter, illustrated in figure 6.11. Under the disk is a magnet measuring the spinning of the needle below. The disk can be hard to place correctly above the needle and the needle being measured is indicating 0,1m^3 / 100liters of usage per. spin. This means that when the disk is placed correctly above the needle, 100litres of hot water must be used in order to get a reading. At a visit in February 2016 the sensors were rotated to a new position and hot water taps and the shower in the house were turned on to determine if the sensor was still working. It did not pick up a reading from this action, however. It then turned out that by swiping a magnetised screwdriver over the sensor an immediate reading happened. This meant that the sensor in fact was intact. It was then discovered that the sensor was affected by the temperature sensors connected to the same gateway and that data therefore wasn't submitted to the cloud. The flow meter sensor was therefore disconnected and a separate wireless connection for this sensor was installed to prevent any interference from other sensors. It was confirmed that there now was a connection and that data could be received correctly by once again swiping a magnetised screwdriver over the sensor.

As depicted in the usage schedule in appendix 07 the house is empty most days at this time of the year. With the sensor only measuring 0,1m^3 of hot water usage, it is difficult to get any readings. In any future project it is advised to use a flow meter with a magnet placed on one of the more sensitive needles measuring either 0,01 or 0,001m^3. This would assist with obtaining readings even though little hot water is being used.

7.3 The external sensors

The two external heat and moisture sensors on the northern and southern façades only recorded data for a short period and the data collected was invalid. The reason for this was due to moisture. For one, the sensors are designed for internal usage and the waterproof box they were put in got filled with moisture and the electrical circuits did not survive this. Secondly, the data that was measured was within the closed box and the moisture content was not similar to the outside air moisture content. The sensors therefore where replaced with two new ones. In the new boxes the electrical circuits are isolated from the sensor and the sensor has connection to the outside air through a hole in the underside of the waterproof box. The new box was attached on top of the old box as shown in figure 6.10.

With the new external temperature sensors were installed, the previous theory regarding the temperature measurements from the roof being too high was confirmed. This is depicted in figure 7.3. Here, it is illustrated that the temperature measured by the weather station on the roof next to the ventilation exhaust is about 2°C higher (yellow line) than the temperature measured by the new sensors on the south façade (blue line) and north façade (red line). Each day at noon the south wall receives direct energy from the sun, resulting in a higher temperature on the south façade during daytime. This is shown with big peaks in the south wall temperature measurement. Outside peak time, which is at night, the temperature is generally a bit higher on the north façade than on the south façade. There is, however, uncertainty regarding whether this is due to inaccuracy in the sensors or some small effects from the house; this is shown here.

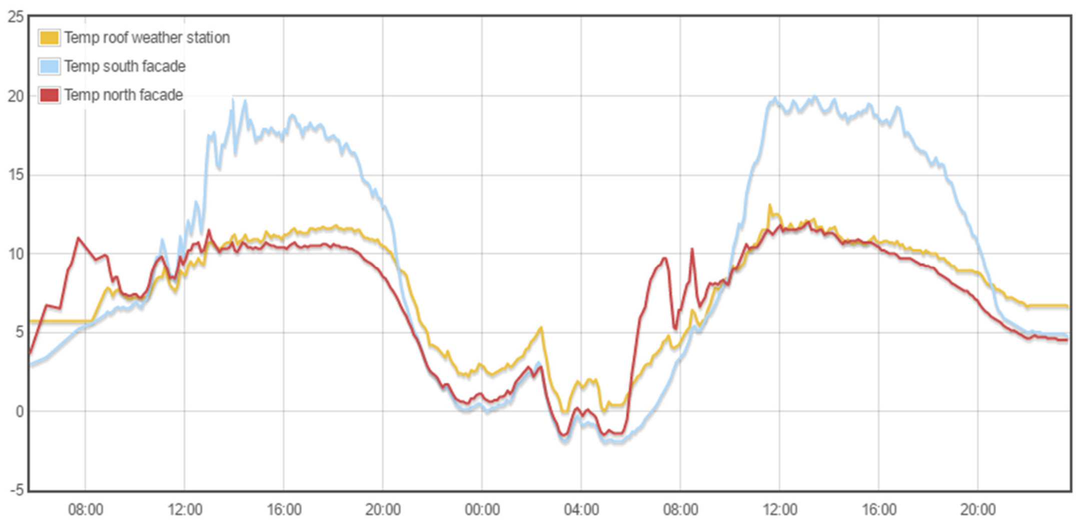


Figure 7.3 – External temperature readings.

7.4 The Heat exchanger

Figure 7.4 shows the electric power usage recorded by the current clip in the heat exchanger. The figure shows an almost constant usage between 0w and a little above 2000w. The figure looks somewhat strange. However, if the time interval is changed into a shorter period, the readings make more sense. (See figure 7.5). Here, the electric power indicated with a blue line draws a special pattern on the heat exchanger. It shows how the heat exchanger turns on the heating element at a programmed time interval. In this case, every 5th minute the heating element is turned on and the power consumption rises. The element is on for about 2 minutes and then shuts down again.

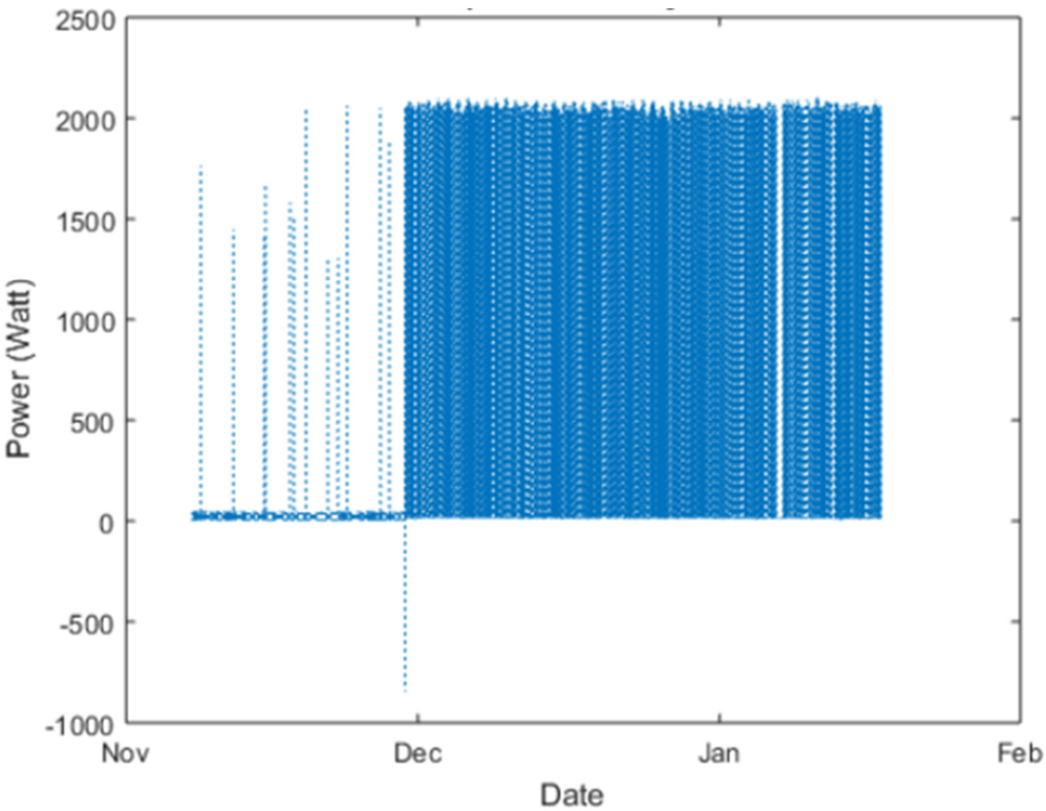


Figure 7.4 Electric power from the heat exchanger including the 2000w AC heating element.

Figure 7.5 furthermore shows the internal air outlet temperature (t_2), internal air inlet temperature (t_3) and the temperature on the internal north and south walls.
For this project we wanted to see the electric consumption without the 2000w heating element as this is not an optimal solution in Iceland. A water heating unit would be much preferred. Originally we thought that the 2000w electric heating element was not connected and therefore the measuring clip was attached where it is. Because of the 2000w heating element the measurement of the electricity cannot be used as we only wanted to know the electricity use for the electric motors and then calculate the air flow from this information. This was intended then to be plotted with an efficiency calculation of the heat exchanger. Therefore, this measurement cannot be used. Instead, a temperature transfer efficiency calculation will be carried out in chapter 8. This will be based on the temperature sensors located in the ventilation ducts above the heat exchanger and plotted with the internal and external temperatures.

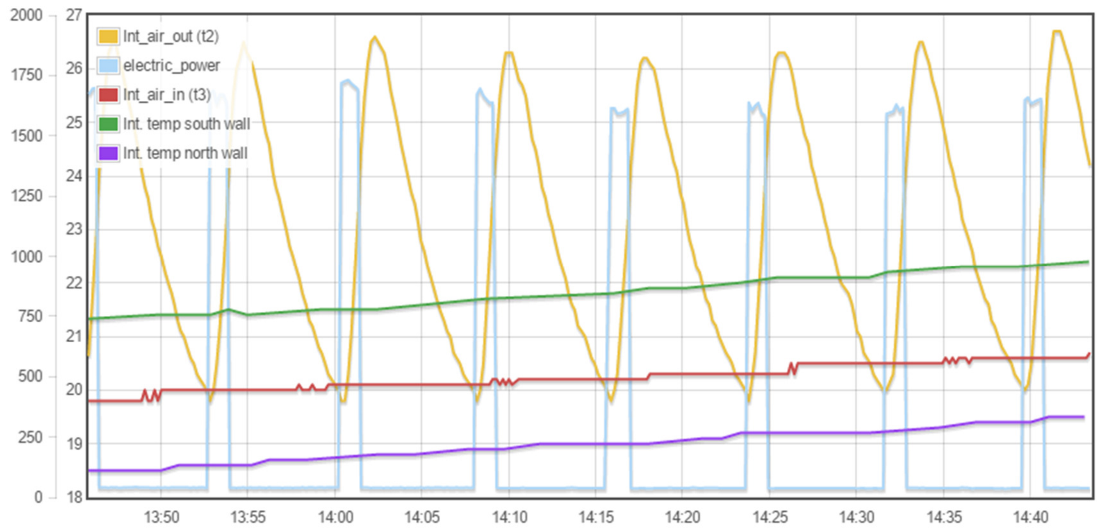


Figure 7.5 – Data plot in data from heat exchanger and internal temperature sensors on north and south façade.

Figure 7.6 depicts the air temperature within the ventilation ducts just above the heat exchanger. The figure illustrates the air temperature coming from the outside (t_1) as well as the air temperature coming from within the house(t_3). The recording of data started about 2 months earlier for the intake air temperature of air coming from inside of the house.

The figure corresponds with the usage schedule in appendix 07. It shows a higher internal intake temperature(t_3) when the house is in use. The external intake temperature (t_1) follows the outside temperature and gradually falls the closer we get to winter. It is, however, anticipated that the external intake temperature(t_1) is somewhat higher than the external air temperature as the sensors are placed well inside the house and the air must be expected to gain some temperature before it hits the sensor. Figure 7.7 illustrates the external intake temperature (t_1, green line) VS. the external south and north temperature (blue and yellow). Here, it is clear that the intake temperature is about 7°C higher.

Figure 7.7 furthermore shows the internal intake temperature (t_3, red line) VS. the internal south and north temperature (brown and purple line). The internal intake temperature follows the south and north temperature as expected.

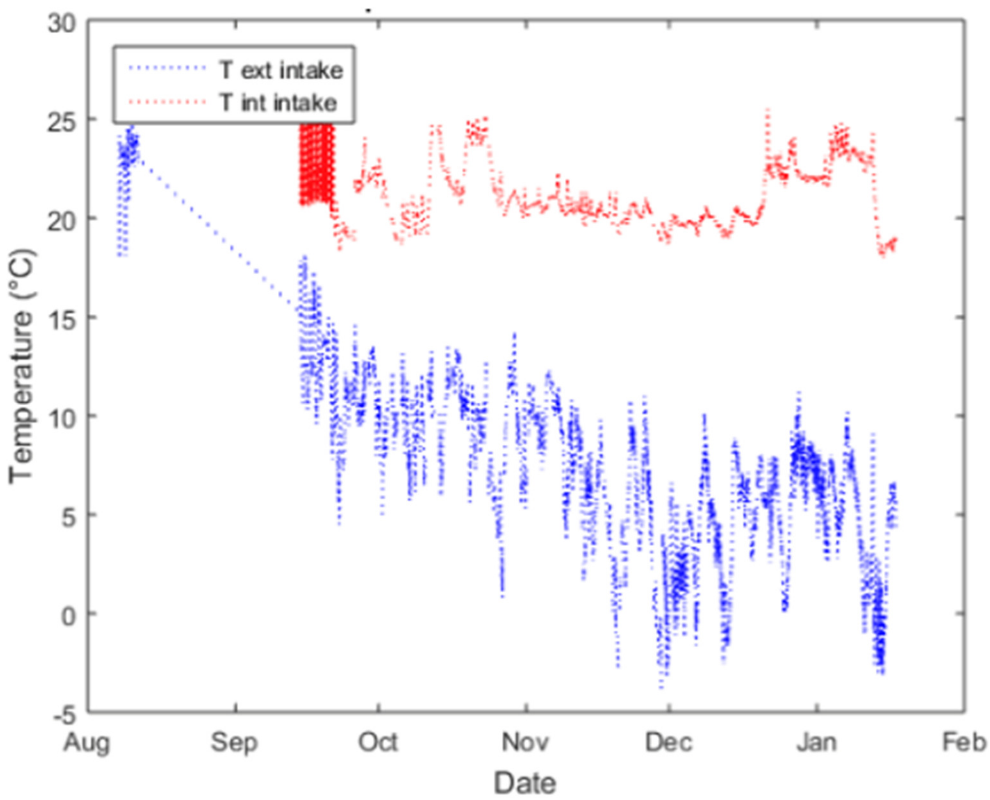


Figure 7.6 – Air Intake temperature for heat exchanger from outside and inside the house.

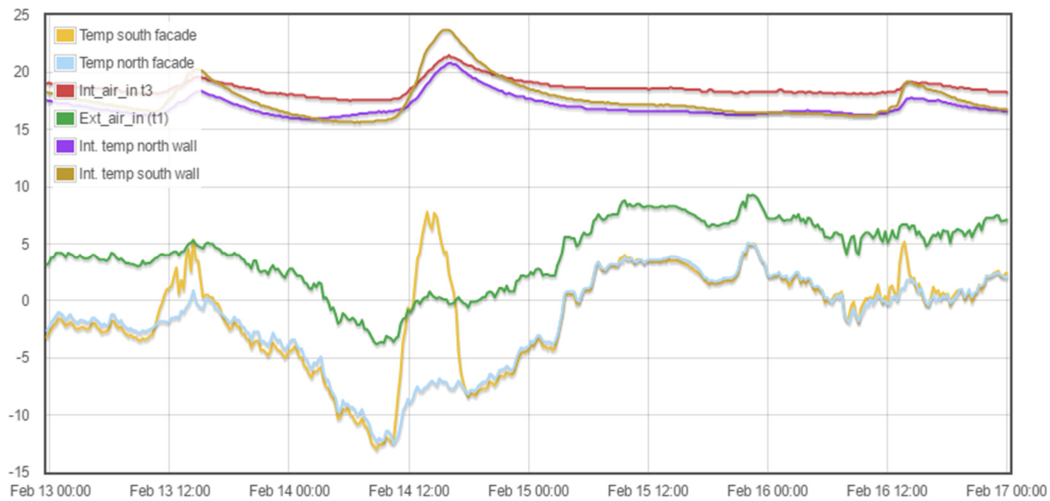


Figure 7.7 – Internal and external north and south wall temperatures V.S. Internal and external air intake temperatures in heat exchanger.

Figure 7.8 depicts the air temperature blown into the house as well as blown out of the house. At first glance, the internal output temperature (t_2) has some funny looking fluctuations. However, if the data is correlated with the heating elements data at a shorter time interval the fluctuations make much more sense. This is illustrated in figure 7.9 and it is clear that the temperature profile follows the heating element profile. When the heating element is turned on, the internal output temperature immediately rises from about 19.5°C to 26°C then goes down as the heating element turns off.

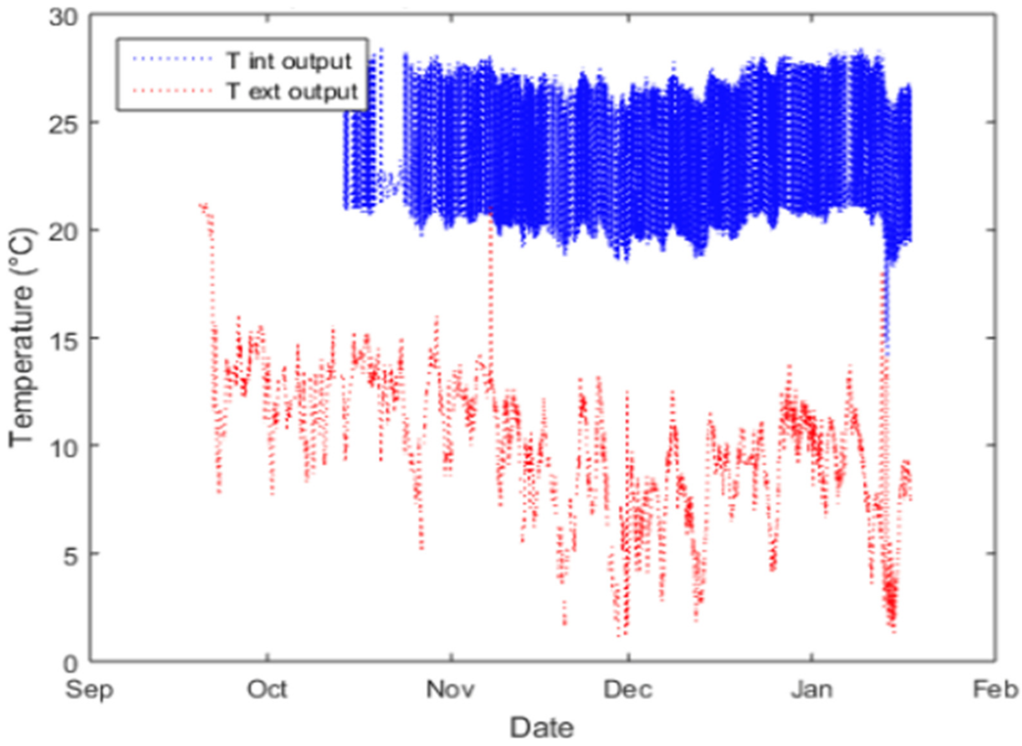


Figure 7.8 – Output air temperature to inside and outside.

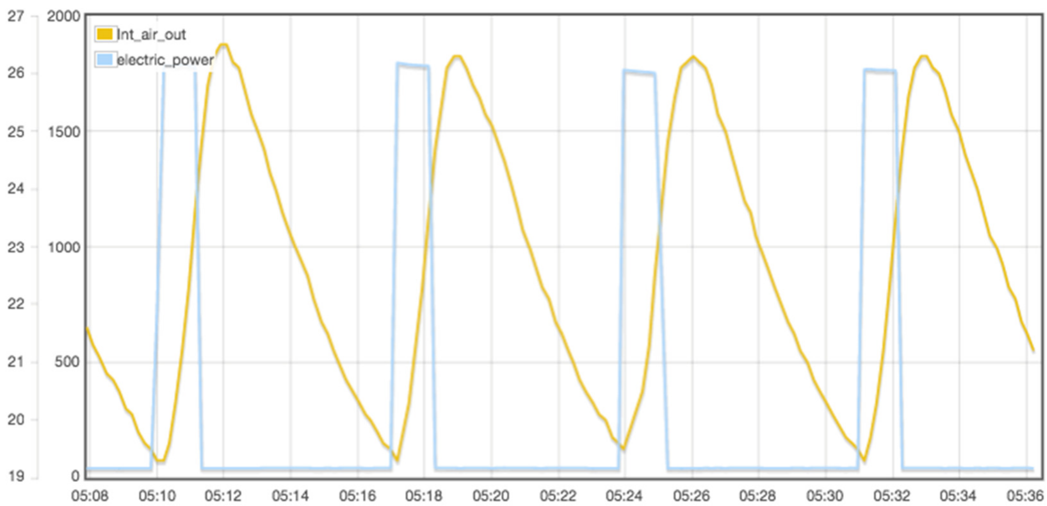


Figure 7.9 – Internal output air VS. electric heating element usage.

The external output temperature in figure 7.8 is the air temperature of used air coming from within the house after it has gone through the heat exchanger. It shows that the output temperature varies within about 10°C. If the data of the external output temperature is compared with the internal intake temperature (figure 7.10), we can see that the heat exchanger utilizes the intake air in such a way that the output air is about 10°C lower.

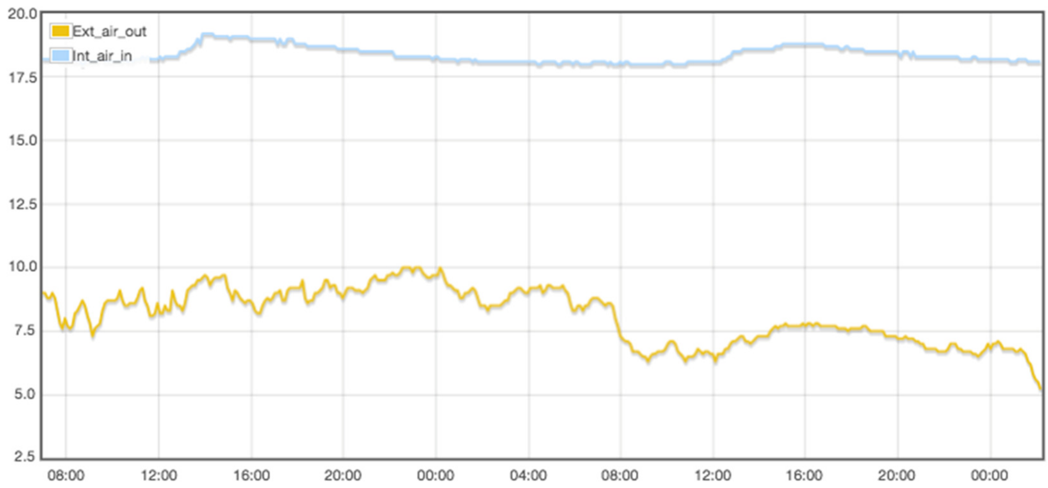


Figure 7.10 – Internal air input VS. external air output.

7.5 Internal north and south temperature and moisture sensors

Figure 7.11 represents the recorded temperatures within the house at the north and south façades. It reveals as expected a higher temperature on the south wall than the north wall.

Figure 7.13 illustrates the size of the temperature difference by subtracting the south wall temperature from the north wall temperature. In general, the temperature difference is within 4°C. November through December there are some longer periods with bigger temperature differences; this is very clear on figure 7.11. These bigger differences are assumed to be due to incoming sun through the big glazed areas on the south façade. Figure 7.12 illustrates the temperature differences over a shorter time period and here we can see that before 12:00 the temperature difference is about 4°C and after 12:00, when the sun is up in the sky, the temperature spikes up and falls again a few hours later as the sun goes down.

The times when the temperature difference goes negative in figure 7.13 are assumed to be when windows on the south façade have been opened and the south wall sensors therefore have picked up colder temperatures.

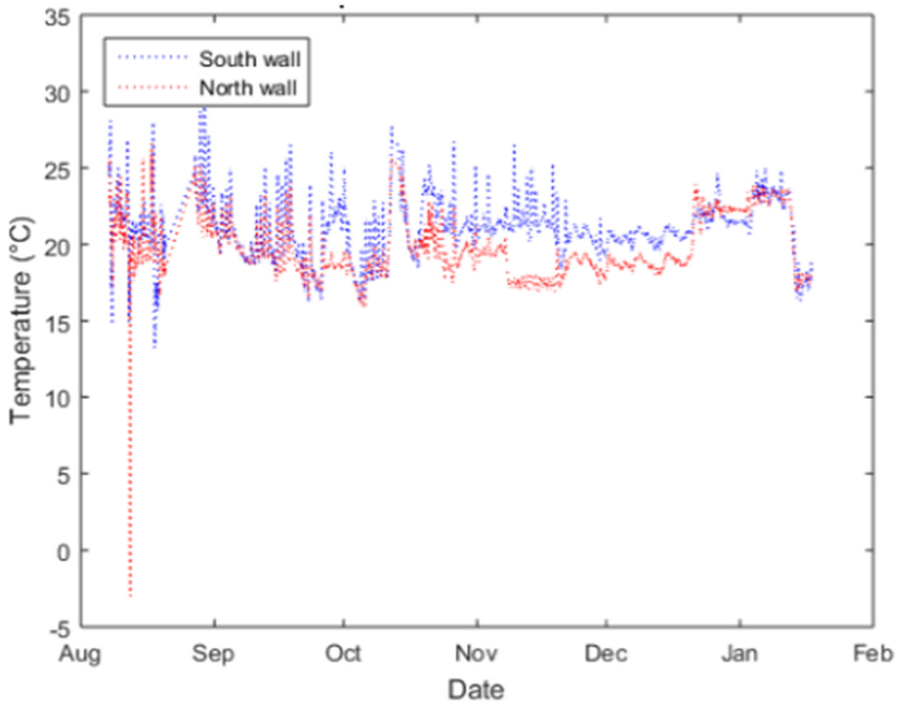


Figure 7.11 – Internal temperatures on north and south wall

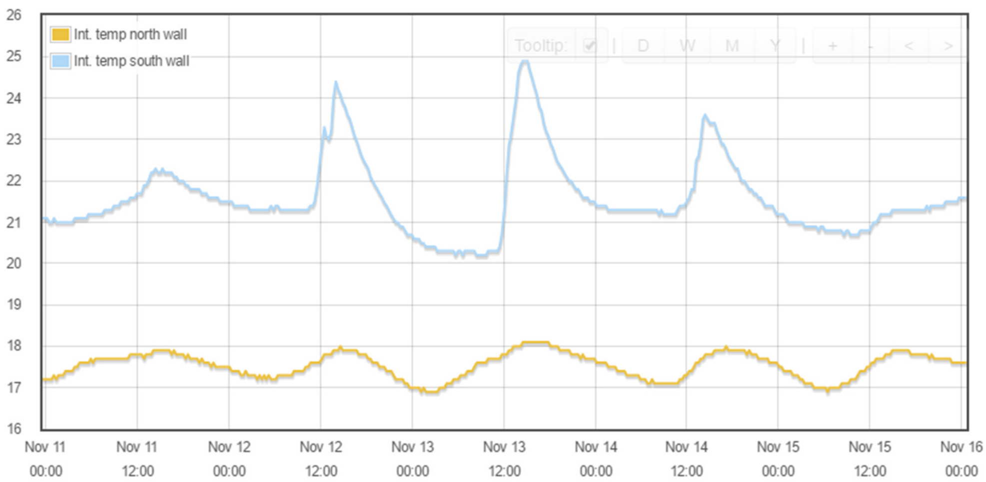


Figure 7.12 – Inside temperatures on north and south wall

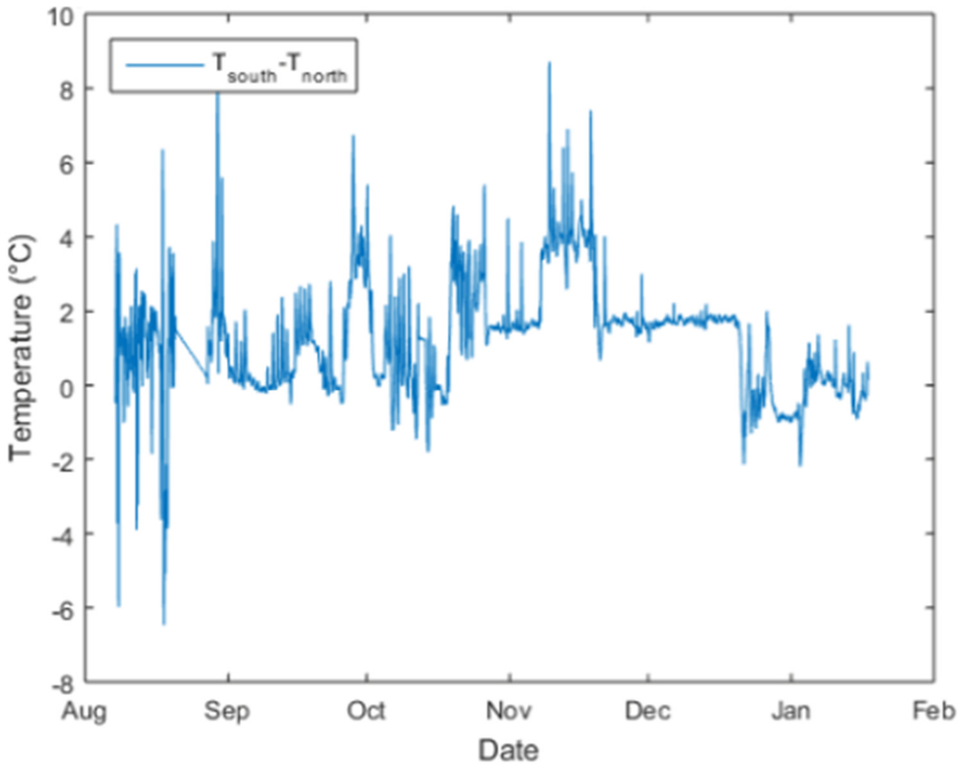


Figure 7.13 – Temperature differences within the house

The north and south wall sensors also measure the relative humidity and figure 7.14 and 7.15 depict these data. Also, here the data is, as expected, showing a higher relative humidity on the north wall than the south wall. This is mainly due to the colder air temperature in the northern part of the house, explained primarily by less incoming sunlight through the windows.

It also shows that the difference in relative humidity changes according to changes in temperature, which was expected. This is illustrated by figure 7.16 with a shorter time interval.

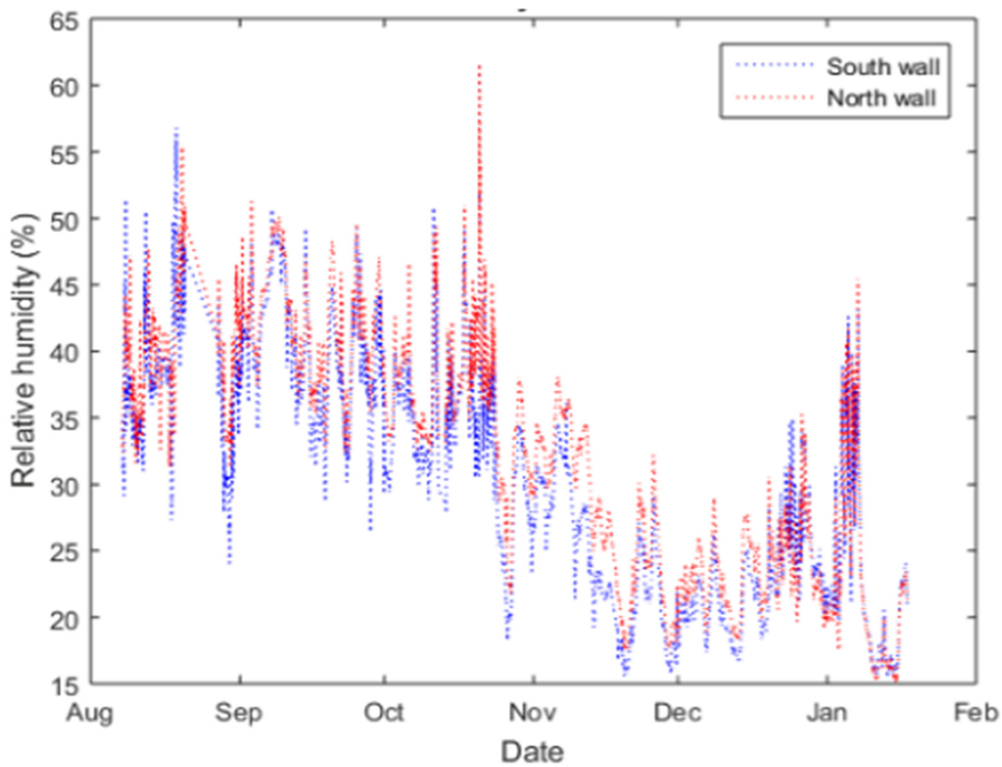


Figure 7.14 – Relative humidity on north and south wall inside the house

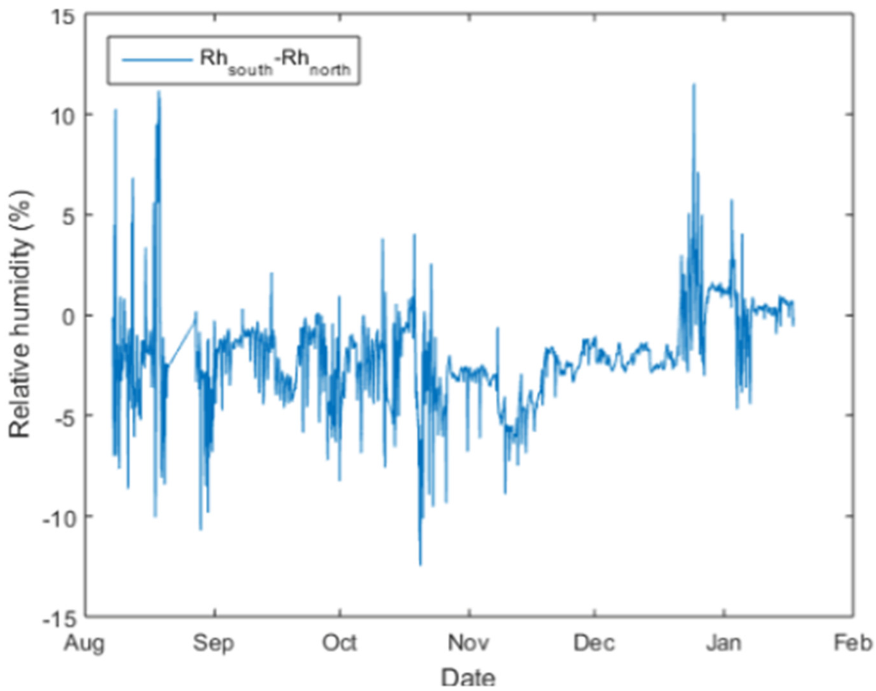


Figure 7.15 – difference in relative humidity on north and south wall

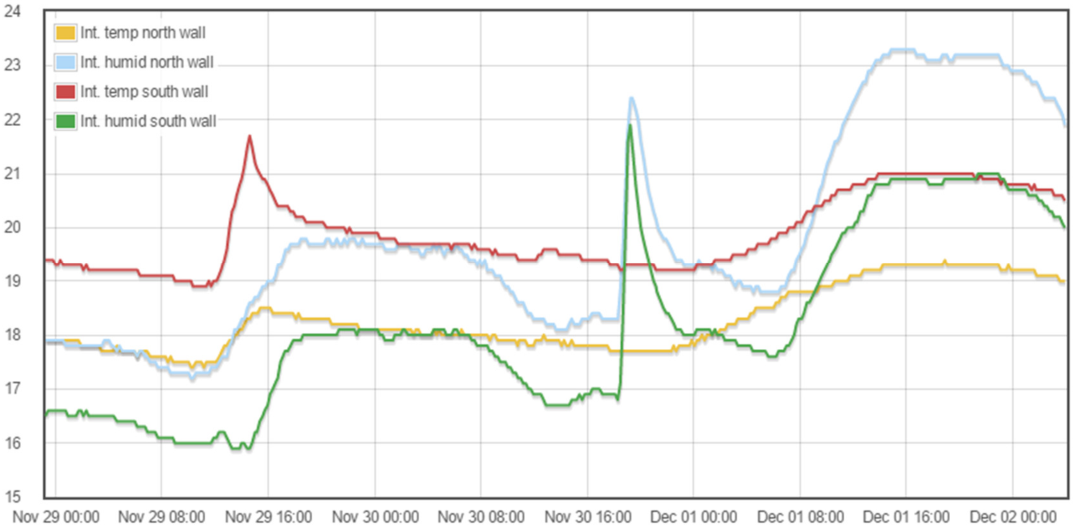


Figure 7.16 – Internal Temperature vs. internal humidity on north and south wall

Chapter 8 Comparison of acquired data

The original intention of this chapter was to make comparisons of main results in the report. First, the results of the BM-Excel energy model and the Autodesk Green Building studio were to be compared. The result of the Green Building studio model, however, turned out to be inconclusive and a comparison of the two models therefore is not possible. The comparison of the actual energy use measured in the house and the calculated result from the BM-Excel model also was a desired result; this, however, also turned out not to be possible due to problems with the flow meter sensor. This chapter therefore instead focuses on comparing other data acquired from the project. I will be comparing external data on temperatures and wind velocity. I will do a temperature transfer efficiency calculation on the heat exchanger and also a comparison of the BM-Excel model result with statistics from OR (Reykjavik Energy Authority).

For comparing the external temperature and wind measured, data from the IMO will be used. This gives an indication of the quality of the acquired data. By looking at this, it can be determined whether the sensors ought to be used for other projects, or if other types of sensor equipment should be chosen for more precise results. It can also be used to optimize installation of sensors for future projects.
In order to compare the data, the IMO has provided hourly mean climatological data from weather station 1395 located in Eyrarbakki. The data available from the IMO is represented in table 8.1.

Table 8.1 – Data from IMO weather station 1395

T	Mean temperature °C
TX	Average daily maximum temperature °C
TN	Average daily minimum temperature°C
TD	Dew point temperature°C
RH	Relative humidity
D	Wind direction
F	Mean wind m/s
FX	Max mean wind m/s
FG	Gust wind m/s
P	Mean sea level pressure

The data is available for the period 06/10/2005 - 14/3/2016. In this chapter, I will be using mean temperatures and mean wind from the IMO data for the comparison.
I will compare the wind velocity data collected by the weather station located on the roof of the house. Also the external temperatures measured at the north and south façades will be compared with the IMO temperature data in order to see if the microclimate located around the house deviates much from the data collected by the IMO. I will be using the data set on a period that fits the running time for the given sensor. The exact interval is described in later parts of this chapter.

The efficiency of the heat exchanger was furthermore a desired result to compare with the assumed efficiency in the model. The unwanted intervention of the 2000w heating element, however, made this comparison more difficult to do precisely. Even so, this chapter will be looking at comparing the efficiency by calculating the temperature transfer efficiency. This will be carried out by using the measured temperatures in the four ventilation ducts entering the heat exchanger unit.

The intention of calculating the actual energy use of the house with the result of the BM-Excel turned out not to be possible as the flow meter sensor measuring the amount of hot water used simply never started functioning correctly. This meant that no data on hot water usage was ever collected. In this chapter, I will therefore instead compare the result from the BM-Excel model by plotting numbers with average consumption statistics from OR into the model.
Given a larger timeframe, it should be possible to acquire data on energy consumption in the house. It all depends on getting the flow sensor up and running.

8.1 Comparison of available wind velocity data.

For this comparison, I will be using the collected data on wind velocity acquired by the weather station located on the roof of the house. For the comparison, hourly mean data will be used. This means 24 data points per day. The reason for this time interval is primarily due to the comparable data from the IMO, which is in mean hourly values. Furthermore, the amount of data when extracting shorter time intervals from the cloud drive has proven to be very difficult to handle.
The data from the IMO is constant for each hour in the day. The data acquired from the weather station is not as consistent and therefore can result in some inconsistency in the result.

The wind blows with different velocities depending on the height and location at which it is measured. Wind velocities at different heights can be compared by the use of logarithmic wind profiling. Here, wind velocity is calculated at different heights based on a reference height and the wind velocity at this height.
Logarithmic wind profiling can be imprecise where hills, ridges large trees and other big obstacles surround the site. In a flat terrain, however, the logarithmic wind profile can be used as a good estimate to compare wind velocities at different heights.
For the location in Eyrarbakki, this method fits very well. In areas with more obstacles in the terrain, one could argue about how precise this calculation would be.
The equation for determining the logarithmic wind profile is depicted in e.q. 8.1

$$V_2 = V_1 \frac{ln\frac{h_2}{Z_0}}{ln\frac{h_1}{Z_0}} \qquad (8.1)$$

Eq. 8.1 consists of the following factors:

- h_1 is the reference height above the ground; in this case 10m as the IMO wind anemometer is located at 10m height[40].
- h_2 is the height desired to compare; in this case 5m as the weather station is located about 5m above ground.
- V_1 is the wind velocity at height h_1
- V_2 is the calculated wind velocity at height h_2
- Z_0 is the surface roughness length.

The surface roughness length, Z_0 , describes the roughness induced by obstacles located in the landscape that affect the shear layer at the surface which controls the shape of the wind profile. All of Iceland used to be classified by having a surface roughness, $Z_0 = 3$ cm [40]. This is equal to a roughness class between class I and II in the Eurocode. The classes are described in European standard EN 1991-1-4:2005+A1 - Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. The classes as described are shown in table 8.2.

Table 8.2 Terrain categories and terrain parameters[41]

Terrain category	Z_0 *m*	Z_{min} *m*
0. Sea or coastal area exposed to the open sea	*0,003*	*1*
I. Lakes or flat and horizontal area with negligible vegetation and □*without obstacles*	*0,01*	*1*
II. Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	*0,05*	*2*
III. Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such 0,3 5 as villages, suburban terrain, permanent forest)	*0,3*	*5*
IV. Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m	*1,0*	*10*
NOTE: The terrain categories are illustrated in A.1.		

Today, the surface roughness class can be chosen freely by a designer from the EN 1991-1-4:2005+A1 - Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. For this calculation, I will be using a surface roughness of $Z_0 = 3$ cm as the Eyrarbakki area is located at the sea and without larger obstacles in or around the area.

E.q. 8.1 was adapted into a spreadsheet containing hourly mean wind data from the IMO in the time interval 09/11/15 – 12/01/16. An export of mean hourly wind data of the house was performed and added to the same spread sheet. The two data sets were then plotted into the same graph and the result can be seen in figure 8.1. The x-axis represents the time interval of the collected data. The y-axis represents the wind velocity in m/s. The orange dots indicate the data set from the weather station located on the roof of the house. The blue dots indicate the data set from IMO profiled to wind velocity at 5m height, i.e. the same height as the anemometer on the roof of the study building.

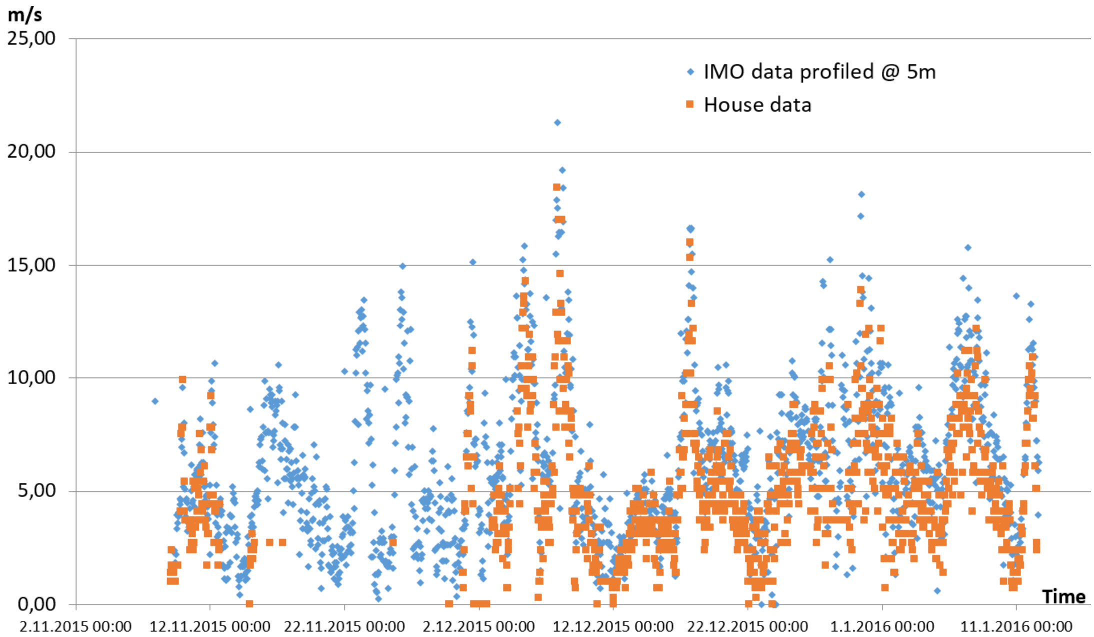


Figure 8.1 – Comparison of wind data recorded above the roof of the house in Eyrarbakki and IMO data adjusted to represent wind velocity at 5m above terrain.

There is a gap in the house data from around 17/11/15 – 01/12/15 due to technical problems mentioned earlier in this report. Besides this missing time interval, the data comparison looks good and fairly similar. The precision of the weather station can therefore be considered as relatively precise and indeed useful. With relative high wind velocities in Iceland, these data can be used when determining a building's resistance to wind pressure, as well as being used as a factor to determine if the choice of cladding is suitable for the building in a given area. Cladding includes finish material on both walls, roofs and roof terraces.

8.2 External temperatures compared

The comparison of monitored external temperatures with IMO data can be useful to see if the sensors seem to be functioning properly and to determine if the climate around the house deviates much from the IMO data. For this comparison, I will be using the collected data from the external temperature sensors installed on the house's north and south façades. The temperature data collected by the weather station on the roof will not be included in this. The sensors on the facades are installed at about 2m height, as can be seen on figure 6.8. The data available from the IMO comes from weather station 1395 located in Eyrarbakki close to the house. This data is also measured at 2m height. The data sets should therefore be comparable. The comparison is once again carried out by comparing mean hourly data for the same reasons mentioned in chapter 8.1.

Figure 8.2 represents a comparison between the mean hourly temperatures from the IMO weather station in Eyrarbakki and the recorded data obtained at the house's north and south façades. The y-axis marks the external temperature and the x-axis marks the time interval. The time interval of the data set goes from 12/02/16 – 14/03/16. The reason for the rather short time interval is the new temperature sensors that had to be installed on the house. These simply were not up and running before the 12th of February.

The comparison of the three data sets depicted in figure 8.2 shows a good connection with a very similar pattern between the three.

The record data from the temperature sensor located at the north façade has some outlying values which are shown as being much higher than either of the two other data sets. The explanation for why these values deviate so much is assumed to be due to the window in the utility room being located next to the temperature sensor (see figure 6.8). When the window is opened, the hot air from the inside of the utility room flows out past the sensor, affecting the measured temperature. This could have been prevented by placing the sensor further away from the window.

The temperature difference between the north and south was expected to be more visible, with south temperatures being higher due to solar radiation. The explanation for why these differences aren't greater is that the measured period was during the winter months with a relatively low position of the sun and thereby less daylight. Had the measured period been during the summer months, the difference must be expected to be higher.

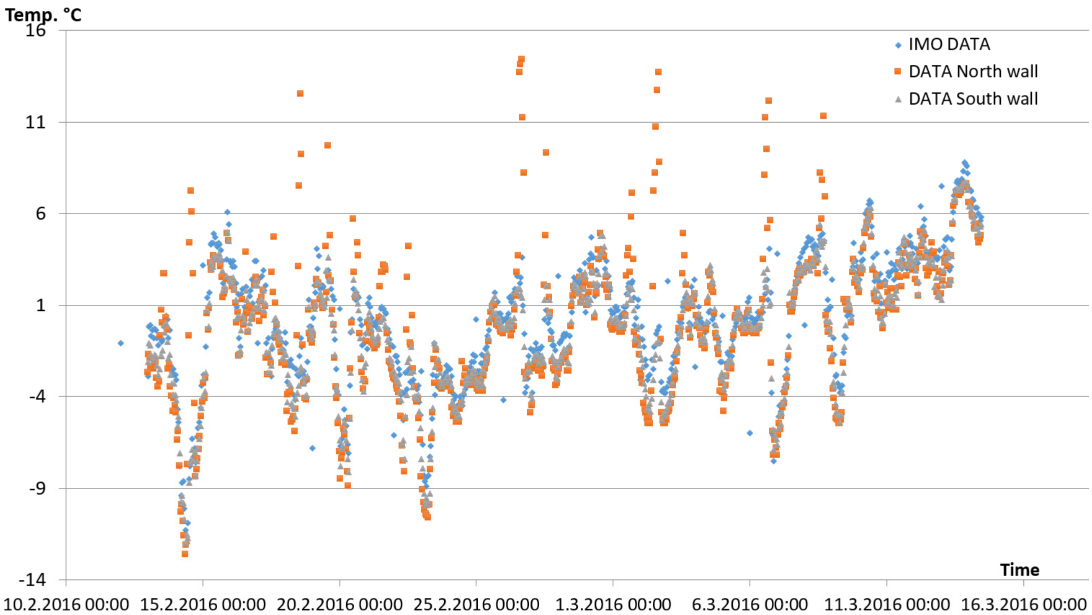


Figure 8.2 - Mean hourly external temperatures in Eyrarbakki compared

8.3 Heat exchanger efficiency

For calculating the temperature transfer efficiency, data from three of the four temperature sensors installed in the ventilation pipes are used. Figure 4.10 shows the location of the three sensors used for the calculation.

Before starting the calculation it is important to mention the 2000w electric heating element. We know that the heating element might affect the result of the calculation as it is positioned in the internal air out (t_2) duct. Since it is not know exactly how far from the temperature sensor it is located, it is unknown how the heating element will affect the result of the calculation.
Eq. 8.2 calculates the temperature transfer efficiency based on the acquired data from the temperature sensors. The equation was applied in an Excel spread sheet containing measurements for the three temperatures for each minute over the measured time interval.

$$\mu_t = \frac{(t_2 - t_1)}{(t_3 - t_1)} \tag{8.2}$$

The result of the temperature transfer efficiency is depicted in figure 8.3. The x-axis of the figure indicates the time interval. On the y-axis both internal temperatures and efficiency of heat exchanger are illustrated.

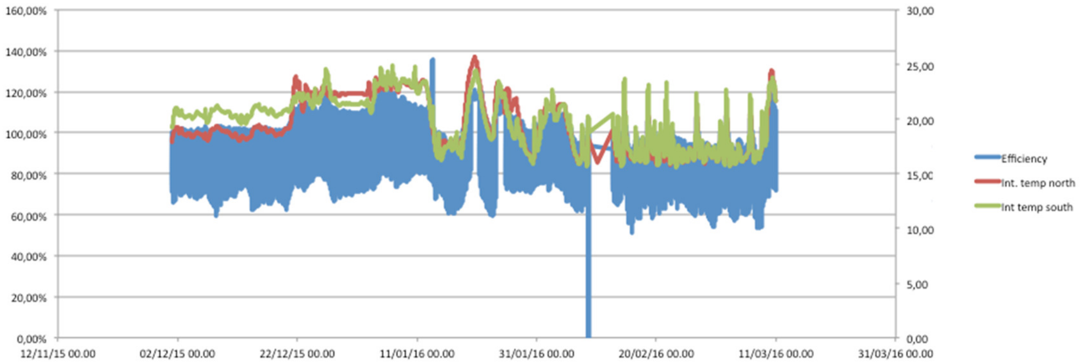


Figure 8.3 – Efficiency calculation of heat exchanger.

The result of the calculation indicates an efficiency estimate that roughly spans between 60% and 120%. This result shows an efficiency that in many cases is well is above what is physically possible, as the upper limit of efficiency on this type of heat exchanger unit is 87% as shown in figure 4.12. This tells us that the heating element is causing great interference with the result and that Figure 8.3 therefore does not show a correct picture of the reality.

When looking into some of the data, it shows various discrepancies. One of these being the external temperature used for the calculation. Table 8.3 illustrates the measured temperature at sensor t_1 compared with the IMO data in the same time and day.

Table 8.3 – External temperature difference and effects on efficiency results compared.

Time and date	Calculated efficiency	Measured external temperature at t_1	External temperature from IMO	Temperature difference (t_1 - IMO)
13:00 25/01/2016	116%	9°C	3,8°C	5,2°C
13:00 16/01/2016	72%	6,5°C	2,4°C	4,1°C

As shown in table 8.3, on the 25th of January 2016 at 13:00, where the calculated efficiency is at 116%, the measured external temperature in the heat exchanger pipe (t_1) is 9°C. At the same time and date, the IMO data shows an external temperature of 3,8°C. This suggests that either something has affected the sensor on the house or that the air is heated by 5,2°C by going through the roof construction and through about 1.5m of non-insulated pipe from the ceiling to the sensor's location. On the 16th of January 2016 at 13:00 where the efficiency was 72%, the measured external temperature (t_1) was 6,5°C. At the same time, the IMO data depicts an external temperature of 2,4°C, a difference of 4,1°C.
This finding shows that the external air temperature measured in the pipe (t_1) just before entering the heat exchanger is subject to an increased temperature from receiving heat from the surroundings within the house.

If we go further and look into t_2 and t_3, we see the following:

Table 8.4 – t_2 and t_3 compared

Time and date	Calculated efficiency	t_2	t_3
13:00 25/01/2016	116%	23,7°C	21,72°C
13:00 16/01/2016	72%	18,71°C	23,56°C

When the temperature of the air that is blown into the house after going through the heat exchanger (t_2) is above the temperature of the dirty hot air that is sucked out of the house before entering the heat exchanger (t_3) the temperature transfer efficiency goes above 100%. This suggests that there are other factors affecting the sensors. The main element here would be the 2000w heating element that affects the sensor and, when turned on, applies additional energy and, by that, heat which affects this calculation. Figure 7.9 depicted the heating element's cycle and showed that the heating element is on for about 1,5 minutes and off for about 5,5 minutes. With this information, we can look at the data in a more simplistic manner as the amount of data used for the previous figure was too heavy to work with. The efficiency calculation is once again done by use of eq. 8.2, but this time without getting the interference of the heating element, or at least little of it. For the calculation, it is assumed that the ventilation flow rate is the same at all times. We know from inspecting the system that the ventilation rate can be changed, but this only can be done manually and we therefore assume that no one has been changing it in the measured period. By looking at the data as it is depicted in figure 7.5, the data readings are done for t_3, t_2 and t_1 at the time that t_2 is at its lowest. It is here that the interference from the electric heating element in the heat exchanger is off, or at least at its lowest.

For this calculation, I have chosen three different data readings for two different dates. Furthermore, the temperature measured at the roof is included: The readings and calculation look as the following:

Table 8.5 – data readings directly from graph on 2nd of March and 1st of May

Date and time	T_1 in °C	T_2 in °C	T_3 in °C	Outdoor temp on roof in °C	Efficiency
March 2nd 15:50	1	18	21,5	2	83%
March 2nd 16:10	-1	18	21,5	2	84%
March 2nd 16:30	0	17,5	21,5	2	81%
May 1st 11:00	11	20,5	22	9	86%
May 1st 11:20	12	20	22	9	80%
May 1st 11:40	13	19,5	22	9	72%

The data readings from table 8.5 were then plotted into figure 8.4 below.

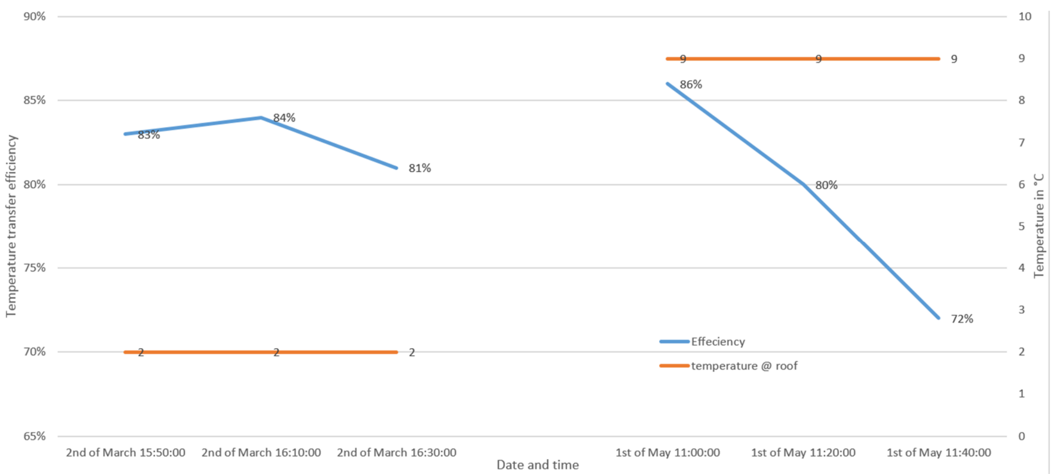


Figure 8.4 – Efficiency calculation on heat exchanger from readings of graph like the one in figure 7.7

The result of this shows a more correct picture of the reality of the heat exchanger. The six efficiency figures plotted on the graph are, however, still a bit high, as 5 of 6 are between 1% and 5% from maximum possible efficiency of 87%. There is no doubt that there are inaccuracies when reading directly off the graph, which could be one reason for the slightly high efficiency. Furthermore, we know that the incoming temperature t_1 is affected by the house before entering the heat exchanger and therefore also affecting the result. Finally, there might still be some heat left in the heating element, even though it is off at the measured time. This would affect the efficiency result.

8.4 Energy usage compared

Because the result of the BM-Excel model could not be compared with the actual use in the house due to lack of data, a comparison of average numbers will be performed instead. Orkuveitan (OR), the Reykjavik city utility company, does not have available an estimate or information regarding the overall average heating energy for new houses. Instead, they have provided average data on electricity usage and hot water usage. It is unclear whether this data is solely on single family houses or in fact also includes multifamily houses with two or three families living in it. If this is the case then the results based on the OR numbers must be expected to be significantly higher than the BM-Excel model, as the consumption in a house with three families must be considered higher than in a single family house with 4 inhabitants.
In this chapter, the energy use based on the data from OR will be calculated and compared to the result from the BM-Excel model.
OR provided the following data:

- 4-people family uses 4000 to 6000 kWh/year in electricity
- Experience on hot water usage in m^3/year spans from 1,2 to 1,5 times size of the house in m^3.
- Incoming hot water temperature in Reykjavik is 75° to 80°C

The hot water usage is the actual usage in houses in Reykjavik based on experience from OR. The result of the energy use calculation based on the OR numbers should therefore not be compared with the total energy demand in the BM-excel model. Instead it should be compared with the total energy need, which is the energy demand after received “free” energy is accounted for.

The BM-Excel model looks at the energy use from heat energy consumption mainly from hot water and not electricity consumption. Since the received “free” energy is accounted for, the electricity usage of 4000 – 6000kWh/year from OR will not be included in this energy calculation.
I will however based on assumptions calculate the amount of free energy received from electricity usage based on the numbers from OR and compare result with the free energy from electricity that was used in the BM-Excel model.

As described earlier, the incoming hot water temperature in Eyrarbakki is between 65°C and 70°C. Since the energy content in hot water in Eyrarbakki is lower due to the lower incoming hot water temperature, the amount of hot water used in Eyrarbakki to achieve the same energy usage is higher.

I will start by conducting the calculation for Reykjavik based on the numbers from OR. Then, I will use the result to compare with the BM-Excel model. I will furthermore use the result to calculate the energy content of hot water in kWh/m^3 for both Eyrarbakki and Reykjavik as these values are different due to the incoming hot water temperature. With these results, I will furthermore calculate how much more hot water must be consumed in Eyrarbakki to comply with a similar energy use as calculated for Reykjavik.
For the calculation of the energy content in hot water, Eq. (8.3) is applied.

$$E = c_p \times d_t \times m \tag{8.3}$$

Where:

- E = Energy in kJ
- c_p = specific heat of water taken as 4.2 kJ/kg°C
- d_t = temperature difference between incoming and outgoing hot water in °C
- m = mass of water in kg is calculated on the basis of the amount of hot water consumed

OR stated a use of between 1,2 – 1,5 m^{3}times the size of house in m^3. For this calculation, I have chosen to use the lower bound value of 1,2 m^3, as I am assuming that the house in Eyrarbakki is rather energy efficient.

In the calculation of the temperature difference, I will be using the same outgoing temperature for both Reykjavik and Eyrarbakki. For this I will use the measured temperature from the house for when the house is in use and the water is in circulation through the floor heating pipes. The measured temperature at the sensor was 22°C - 25°C; however, the sensor is located about 1,5m from the outgoing hot water distribution pipes. At these 1,5m the pipes are uninsulated. Therefore, a certain loss must be expected. I will therefore use 30°C for the hot water out temperature for this calculation.
For the incoming temperature, I will be using 65°C for Eyrarbakki and 75°C for Reykjavik. The calculation on Reykjavik looks as follows.

Energy content in water in Reykjavik:

$$E = \frac{\left(4.2\,\frac{\mathrm{kJ}}{\mathrm{kg}}\,°\mathrm{C}\right) \times \ (75°\mathrm{C} - 30°\mathrm{C})}{3{,}6} = 52{,}5\,\frac{kWh}{m^3} \leftrightarrow$$

The energy use for Reykjavik is $52{,}5\,\frac{kWh}{m^3} \times\ 1{,}2\ = 63\,\frac{kWh}{m^3}\ per\ year$

The estimated annual hot water usage in Reykjavik for a house with a similar size as the house in Eyrarbakki is 338m^3 x 1,2 = 405,6m^3 pr. year.
Total energy need for a similar size house in the Reykjavik area is therefore according to this calculation:

$$\frac{52{,}5\frac{kWh}{m^3} \times 405{,}6m^3}{127m^2} = 167{,}7\frac{kWh}{m^2}\ pr.year$$

Table 8.6 – Results of total energy need from BM-excel model and calculation on Reykjavik based on OR numbers

Reykjavik	**Eyrarbakki**
$167{,}7\frac{kWh}{m^2}\ pr.year$	$63{,}5\frac{kWh}{m^2}\ pr.year$

Table 8.6 shows a difference of $104{,}2\frac{kWh}{m^2}\ pr.year$ in the two calculations. The difference in the two results are big. It is impossible to say that one is correct and that another is not, as assumptions and uncertainties simply are too big. It is however possible to mention what is believed to be the primary reasons for the big differences and where they are located.

First of all the big difference indicates that the numbers from OR includes multifamily houses which causes a higher energy consumption and partly explains the big difference.
The second indication is believed to come from air change losses in the BM-excel model. This includes ventilation recovery efficiency and calculated air change. These assumptions come with great uncertainty and small changes could easily affect the result of the BM-excel model in a way so that the result would increase much.
The two above mentioned uncertainties has such an impact that these alone are believed to be the main reason for the difference in the two results.

After having estimated the energy use in Reykjavik based on OR numbers and compared the result with the BM-excel model, the energy content in water in Eyrarbakki is calculated. It looks as follows:

$$E = \frac{\left(4.2\frac{\text{kJ}}{\text{kg}}\text{°C}\right) \times (65\text{°C} - 30\text{°C})}{3{,}6} = 40{,}8\frac{kWh}{m^3}$$

Table 8.7 – Calculated energy content in hot water compared.

Reykjavik	**Eyrarbakki**
$52{,}5\frac{kWh}{m^3}$	$40{,}8\frac{kWh}{m^3}$

Table 8.7 is a comparison of the calculated energy content in hot water for Reykjavik and Eyrarbakki. The result shows as expected a lower energy content in the hot water in Eyrarbakki compared to Reykjavik. Since the same energy use is expected for a similar house in Reykjavik and Eyrarbakki, we can calculate the difference in hot water usage based on its energy content. With the calculated values above, the needed amount of hot water usage to get to the same energy use in Eyrarbakki can be calculated by the following:

$$\frac{167{,}7\frac{kWh}{m^2}\ pr.year \times 127m^2}{40{,}8\frac{kWh}{m^3}} = 522m^3$$

As table 8.8 illustrates, the estimated hot water usage in Eyrarbakki is much higher than in Reykjavik. This means that in order to reach the same amount of energy use from the hot water in Eyrarbakki, the user has to use 522m^3 of hot water compared to the 405,6m3 in Reykjavik.

Table 8.8 – Estimated annual hot water usage compared.

Reykjavik	**Eyrarbakki**
405,6m^3 pr. year.	$522m^3$ pr. year.

Electricity usage is variable and much dependent on the number of inhabitants as well as the number of appliances and how and when these are in use. According to OR it is common that a 4-people family uses 4000 to 6000 kWh/year in electricity. The amount of electricity that is transformed into heat energy varies much. For instance, with an old type incandescent bulb only about 8% becomes light and the remaining 92% becomes heat energy in the form of radiant energy as infrared and ultraviolet radiation combined with conduction and convection heat[42]. For this reason, incandescent bulbs are no longer sold in Europe and Iceland. The house in Eyrarbakki is equipped with a combination of metal halide and fluorescent light. Both types are more efficient. In metal halide 27% of electric energy becomes light and the remainder is converted to heat energy[42]. Fluorescent light are less efficient but still converts 21% electric energy to light[42]. Like light bulbs, TVs and kitchen appliances etc. also convert different amounts of electric energy into heat energy; these are very difficult to estimate though.
For this calculation, I assume that 80% of the total electric energy consumed becomes heat energy. Furthermore, I will be using the higher value of 6000kWh as it still is uncertain if this number is a family of 4 in a single family house or in a multifamily house. With much of Reykjavik being multifamily houses this could mean a lower electricity consumption as some electrical usage such as outdoor lighting, washing and drying could be shared in the building.
80% of 6000kWh is 4800kWh in "free" heating energy per year. Table 8.9 compares this result with the assumption used in the BM-Excel model.

Table 8.9 – Annual free heating energy received from electric appliances and lighting Compared.

Result based on OR numbers for Reykjavik	**BM-Excel model assumption for Eyrarbakki**
4800kWh pr. year	7300kWh pr. year

The assumption used in the BM-Excel model is 52% higher than the calculated 4800kWh/year based on OR numbers.

Once again it is not possible to say which is more correct as assumptions are too big. Does the number from OR in fact include multifamily housing it makes sense that the result is somewhat lower than the assumed value in the BM-excel model. Since the BM-Excel model represents a single family house where no electric expenses are shared with others.

Chapter 9 Summary & Conclusions

9.1 Energy models

Energy modelling is a useful tool and can be applied for reasonable estimates under predefined conditions. It must, however, always be in the back of one's head that the result of an energy model is not a result depicting the building's energy performance in reality.
It is as a benchmarking tool to make sure designers factor energy into the design at an early stage, as well as a quantifying tool for legislating the building regulations and it provides a common principle on how to assess a building to ensure it is designed according to the regulations.

With numerous energy models available on the market it can be very difficult to find a suitable and reliable model as these have been found to be geographically specific, and the standards used in specific regions vary. Even when working with the biggest developers in the CAD and BIM industry, there is no assurance that their software can be utilized with a satisfying result.

The main results of the BM-Excel model consist of the total primary energy demand, which was 183,4kWh/m^2 pr. year, and the total energy need of 63,5kWh/m^2 pr. year. The result of the total energy need was remarkably low and further investigation on especially the efficiency coefficient of supplied energy is needed as there are no known guidelines on how these values represent a correct picture. The values of this coefficient representing the conditions for each month have a very big effect on the resulting total energy need as slight changes in the efficiency coefficients will result in dramatic changes in the total energy need.

The predefined assumptions and inputs in an energy model will have a big effect on the end result. For instance, the number of inhabitants in the models tested in this thesis are set to four. This number varies considerably due to the day to day usage pattern of the project house, but this also applies to buildings in general. The number of inhabitants has a very high effect on e.g. hot water usage, which as mentioned earlier, has a very high influence on the overall energy consumption of the building. It must therefore be clarified for building owners that the end result of any energy model is NOT an exact result that should be expected to show how the building actually performs. Many factors are influencing the model and the result should be observed as a static result under very specific conditions.
The 3-point method described in this thesis adds some room for fluctuating input values and specifies the result with within a specific margin. It is a better format for presentation to a building owner, which should then have some idea of the possible variability of the energy requirements. However, as previously mentioned, it should always be specified to the building owner that the results from an energy model is not to be considered an exact result, but observed as a guideline under very specific circumstances. Project 345-002[43] supports this conclusion and it describes the

importance of keeping the building owner informed. Be10 [ref no.], which the Project 345-002 is based on[43], was originally developed by SBI for professionals to be able to define a benchmark for the municipalities and building authorities to compare the energy performance of different buildings. The method was developed to provide benchmarking numbers and not to evaluate the actual energy performance of buildings[33]. Due to a lack of communication and precise description, the model, however, was very quickly adapted in the planning industry by both engineers and architects to determine certain designs on e.g. window sizes and insulation thicknesses at an early stage of a design. The problem with this adaption is that Be10 now determines the geometry of buildings. As Be10 does not account for factors such as daylight, air quality etc.; design decisions based only on Be10 may result in a building that does not fulfil the expectations of its owners and end users.
Project 345-002 proposes revisions of Be10 to better address the needs of engineers and architects for a tool to use for building design as it is already so strongly implemented in the planning industry in Denmark.
It is important to keep this example in mind when looking at energy modelling in Iceland in order to prevent similar problems from occurring. The Icelandic planning sector is still not using energy modelling tools to the same extent as is traditional in Denmark, but with tighter climate goals in the future and increased pressure from the international community on lowering emissions, energy modelling tools will be used to a much wider extent in the near future.

9.2 Sensors, equipment and data

For this project, it is important to discuss the crucial importance of the equipment being used. In this project, both the physical equipment as well as software for controlling the equipment has caused many problems, and the time spend has turned out to be much more than anticipated for this project. It furthermore illustrates the importance of using equipment with known strengths and weaknesses if any knowledge base is to be created.
The placement of monitoring equipment, such as the sensors placed in the house, is of extreme importance for the accuracy and relevancy of the results. As seen from both the weather station’s temperature sensor and the external north wall temperature sensor, their placement causes them to be affected by hot air coming from the inside of the house. Therefore, good planning before execution is crucial.

The software used for collecting the data has been found to be quite difficult to get up and running correctly. The export method in order to acquire collected data is an export into .CSV (comma separated text values) files that can be imported into various data analysis programs, such as for instance Excel. The export itself did not work in the beginning but was fixed. When the export function was running, an export was easily done. However, the amount of data collected creates problems in Excel, even over the relatively short time period of this project and Excel is not an ideal analysis environment for large data sets.

The data can also be used without export as the cloud service has a graph function, among others, which lets the user combine graphs over desired time intervals. This function is easy to use and provides good illustrations of the collected data. The user interface of the cloud-based system is furthermore very simple and easy to use and it is possible to become familiar with it quickly. Unfortunately, this function can only be used with data collected to the cloud service. When comparisons are to be made with external data, such as data from IMO, an export must be performed and the data processed through Excel, MATLAB or other data analysis software.

The overall amount of data which was collected in the time interval of this thesis has turned out to be a big challenge for the author to handle, with data for only a few months already pushing normal computers to the limit. Excel has not turned out to be very suitable for this amount of data, and for future data analysis where hopefully a full year of recorded data will be available, other software for handling the data should be addressed, e.g. MATLAB could be an option.

9.3 Future recommendations

The monitoring equipment can partially be used. The cloud service is definitely recommended for its intuitive and easy online usability. After all, the main problems have now been fixed; all sensors except the external north humidity sensor and the flow meter sensors have been running without problems. In a future project, it would be sensible to look into what other types of flow meter sensors exist as the current one is difficult to mount correctly. Furthermore, one should look into the flow meter itself to see if a more sensitive model is available. Regarding the external humidity sensor, it appears that water has once again entered the box in which the sensor is mounted, as readings briefly after installation of the new box rose to an almost constant 100% humidity. It is therefore my recommendation in the future to find and use sensors developed for external use as it simply is too difficult to construct a casing that can withstand the Icelandic climate.

The weather station, which originally was noted as being of rather cheap quality, has performed quite well considering the Icelandic conditions with several storms. The data from it has furthermore looked accurate. This type of weather station could be used in other low budget projects.

It is also crucial to have an experienced expert like Halldór Axelsson to overlook installation connections on monitoring equipment as well as programming the cloud service to work correctly with the monitoring equipment. It is also recommended to investigate the possibility of data acquisition with a sampling rate providing a simultaneous timestamp for all measured data for a more precise data analysis.

Unfortunately, in this thesis project we never got to do a comparison of the BM-Excel model and the actual energy use due to the lack of a functioning flow meter sensor. However, if this sensor can be applied correctly, and new external sensors are installed, there should be a good chance of getting all data for a period from the house to compare with the BM-Excel model. That said, the modelled result would always be different from the reality due to the variability in the usage of the house. For any future projects, it is recommended to find a house with a more stable usage, such as a typical family house, to improve the likelihood of getting comparable results from the model and the full scale observations.

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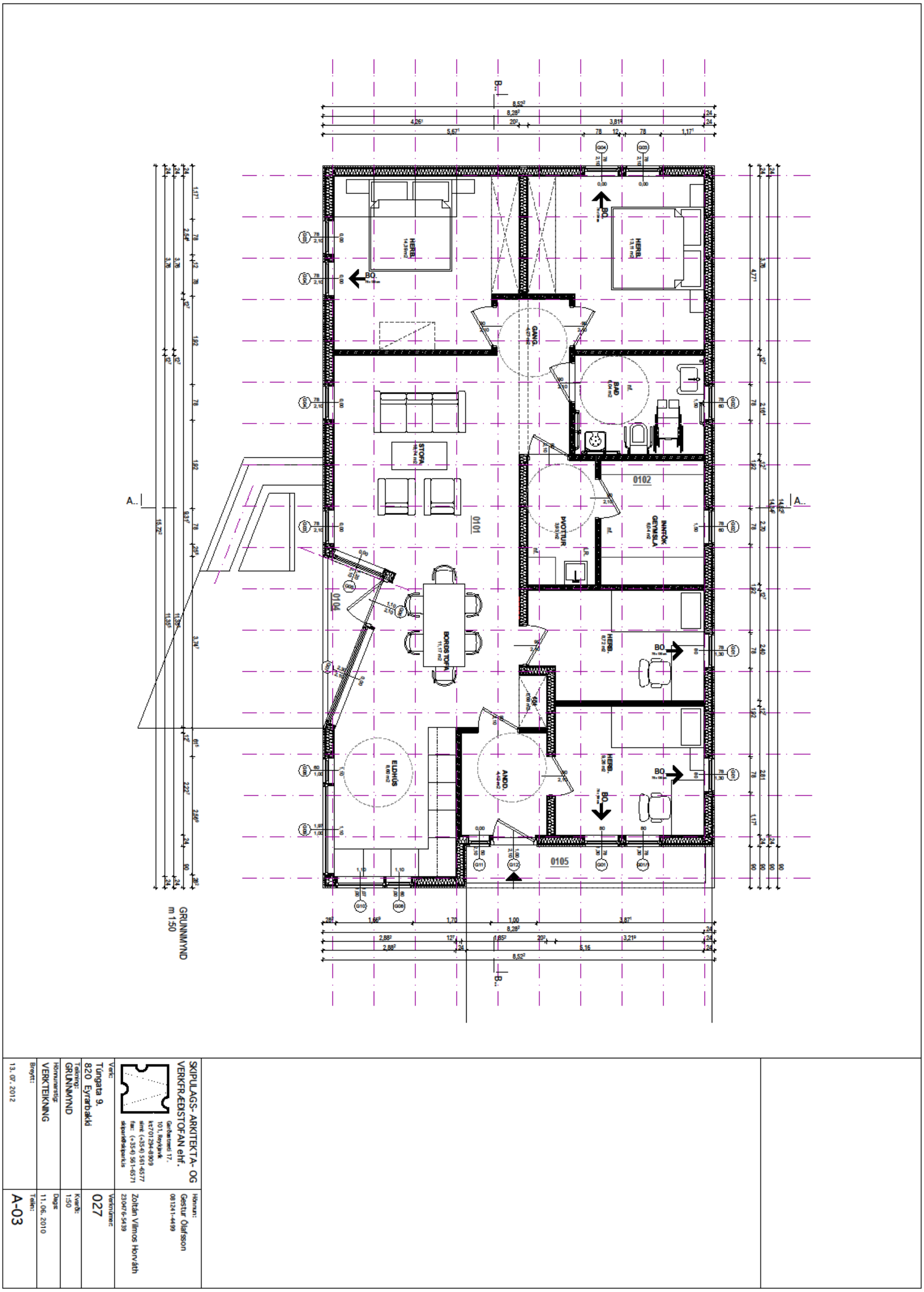
Appendix 1. Original drawings of the house in Eyrarbakki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Zoltán Vilmos Horváth
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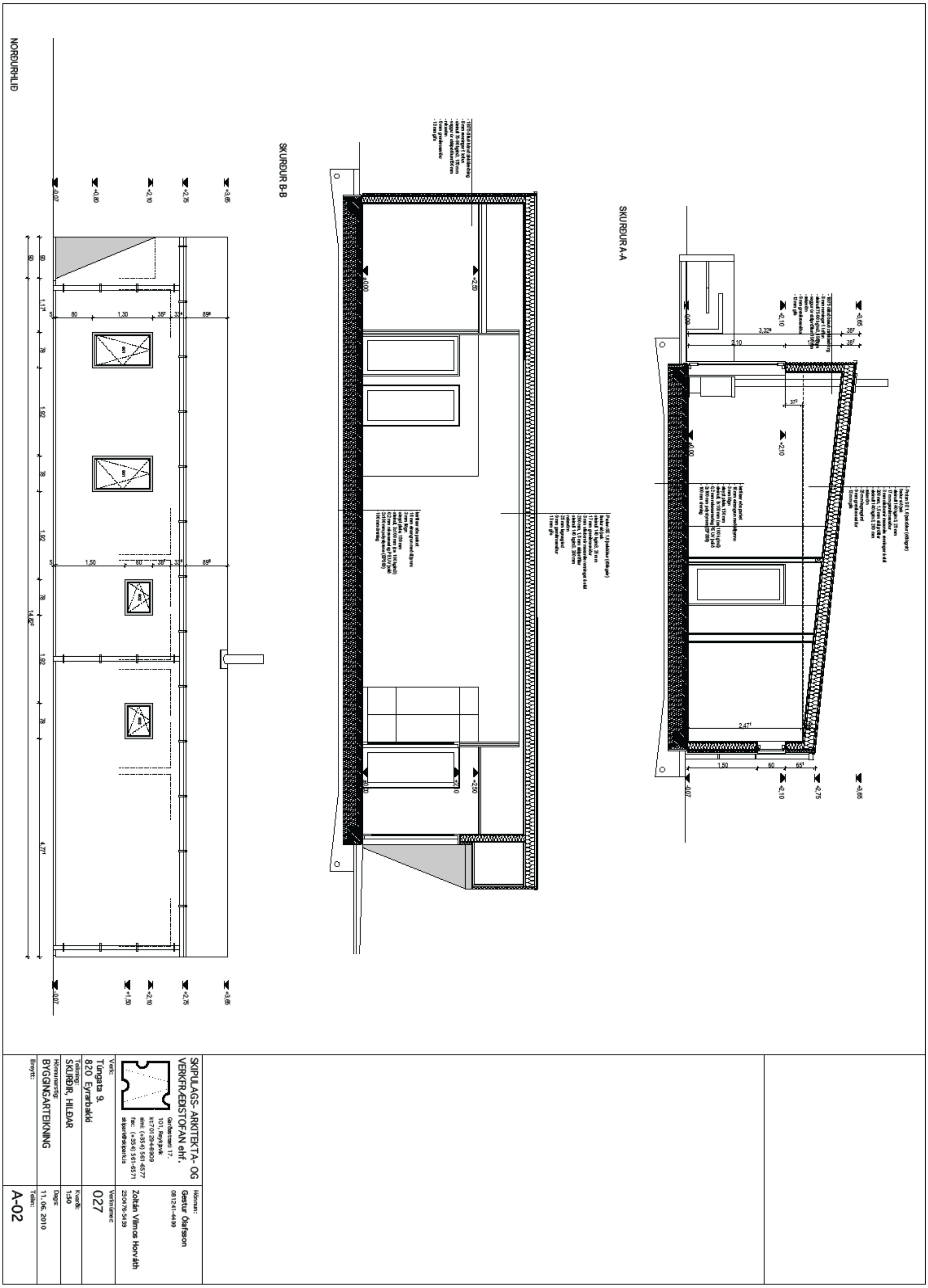
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kt:701294-8909
sími: (+354) 561-6577
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skipark@skipark.is
Hönnun:
Gestur Ólafsson
081241-4499
Zoltán Vilmos Horváth
230476-5439
Verk:
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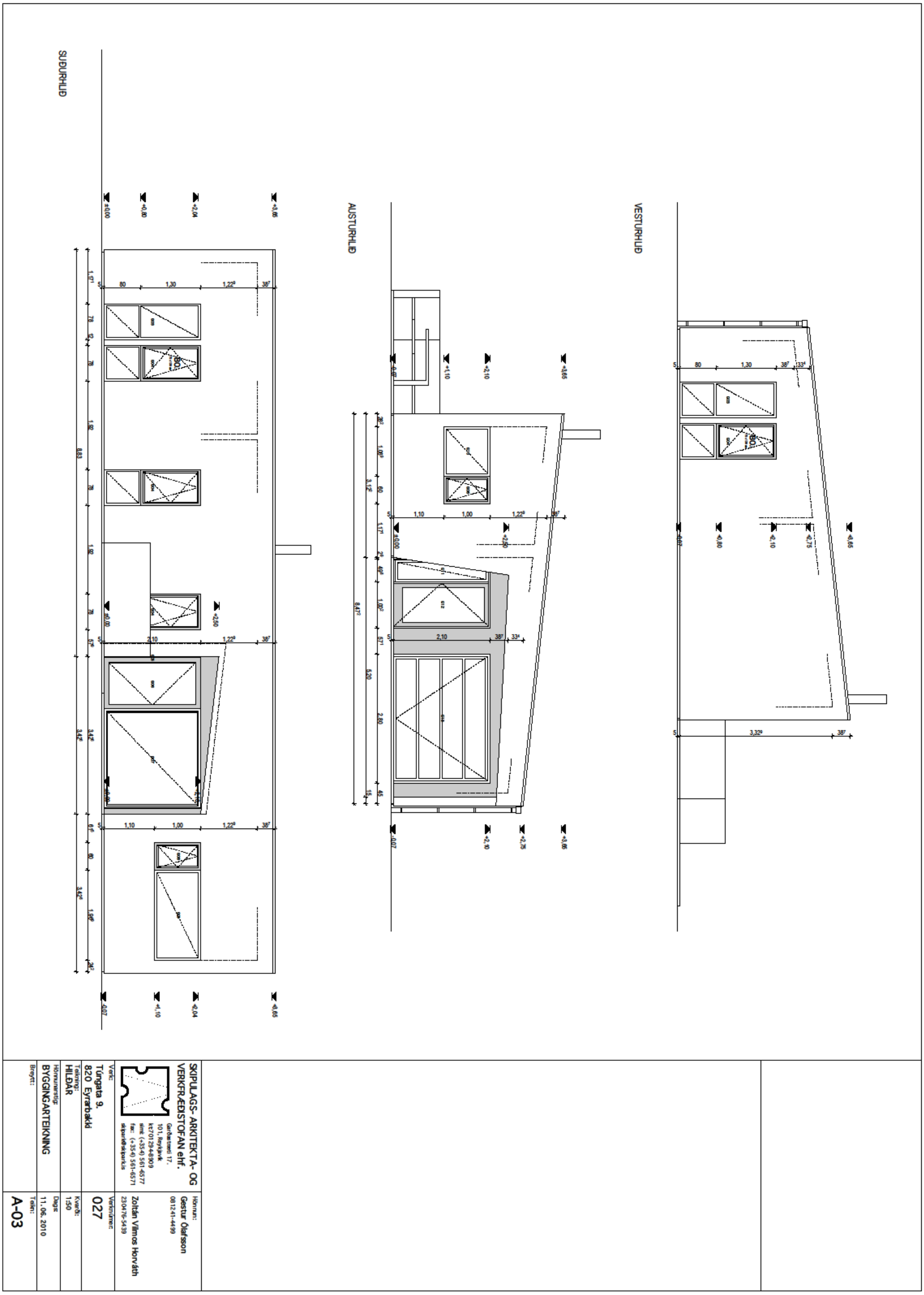
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sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is
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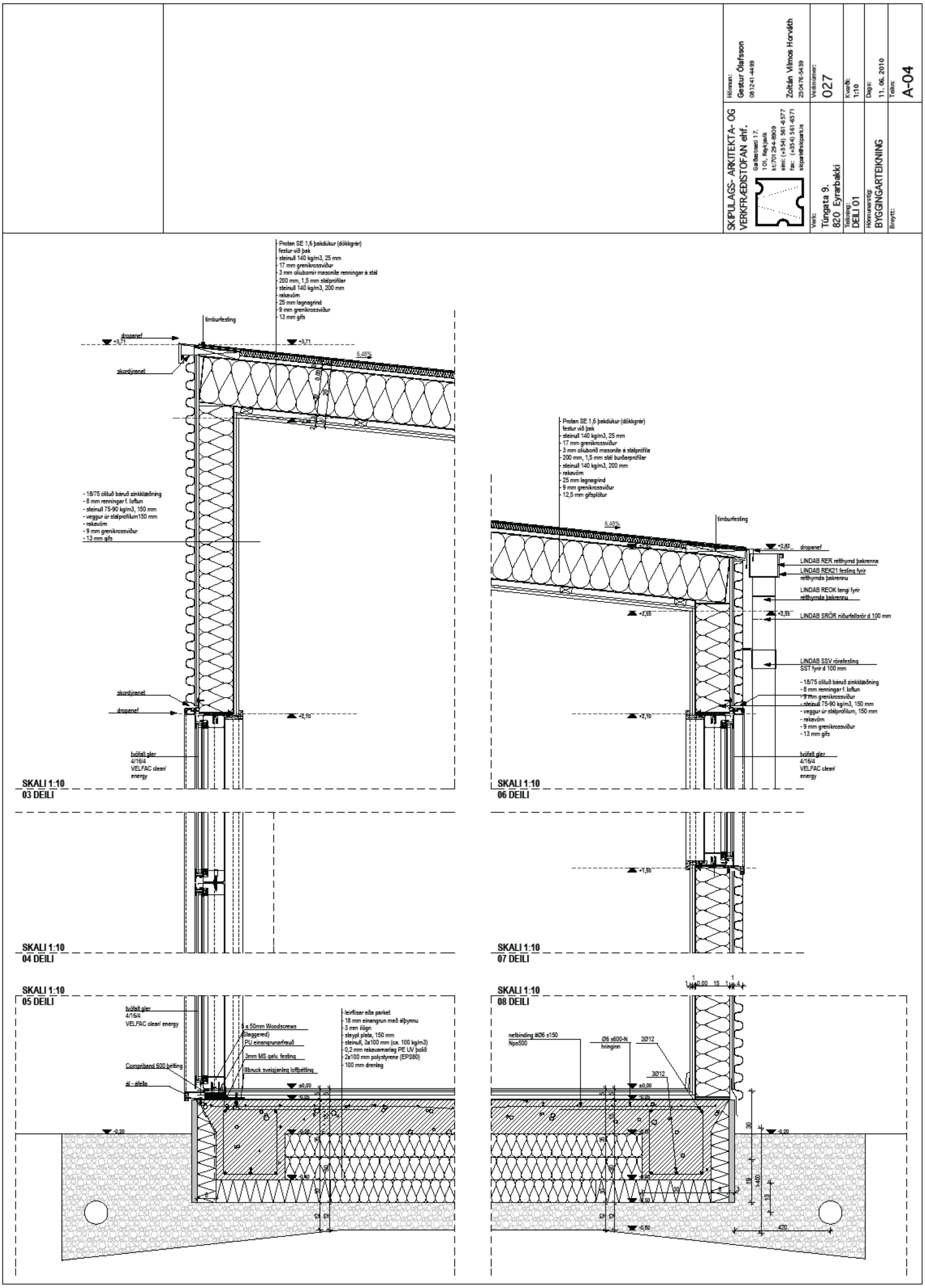
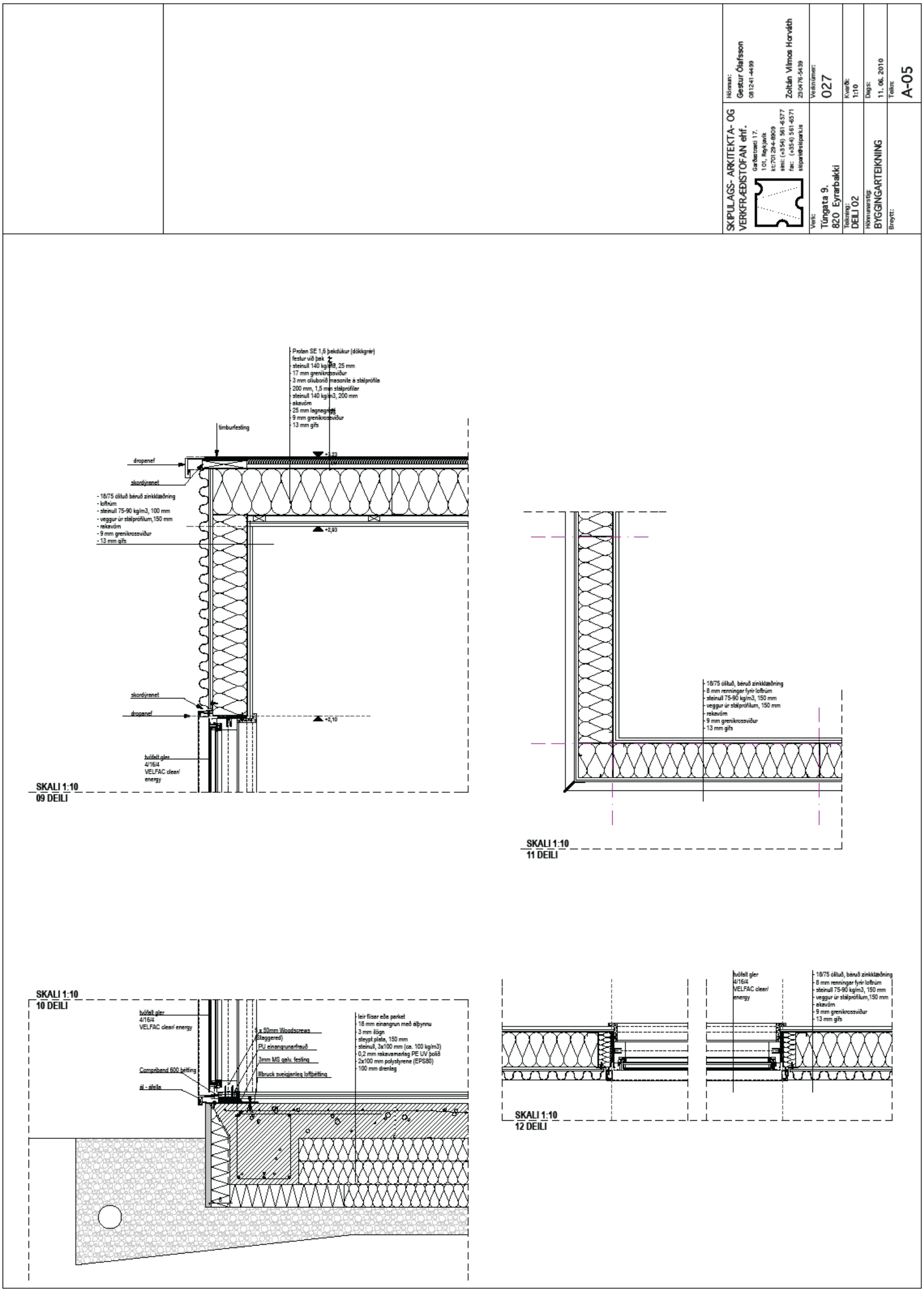
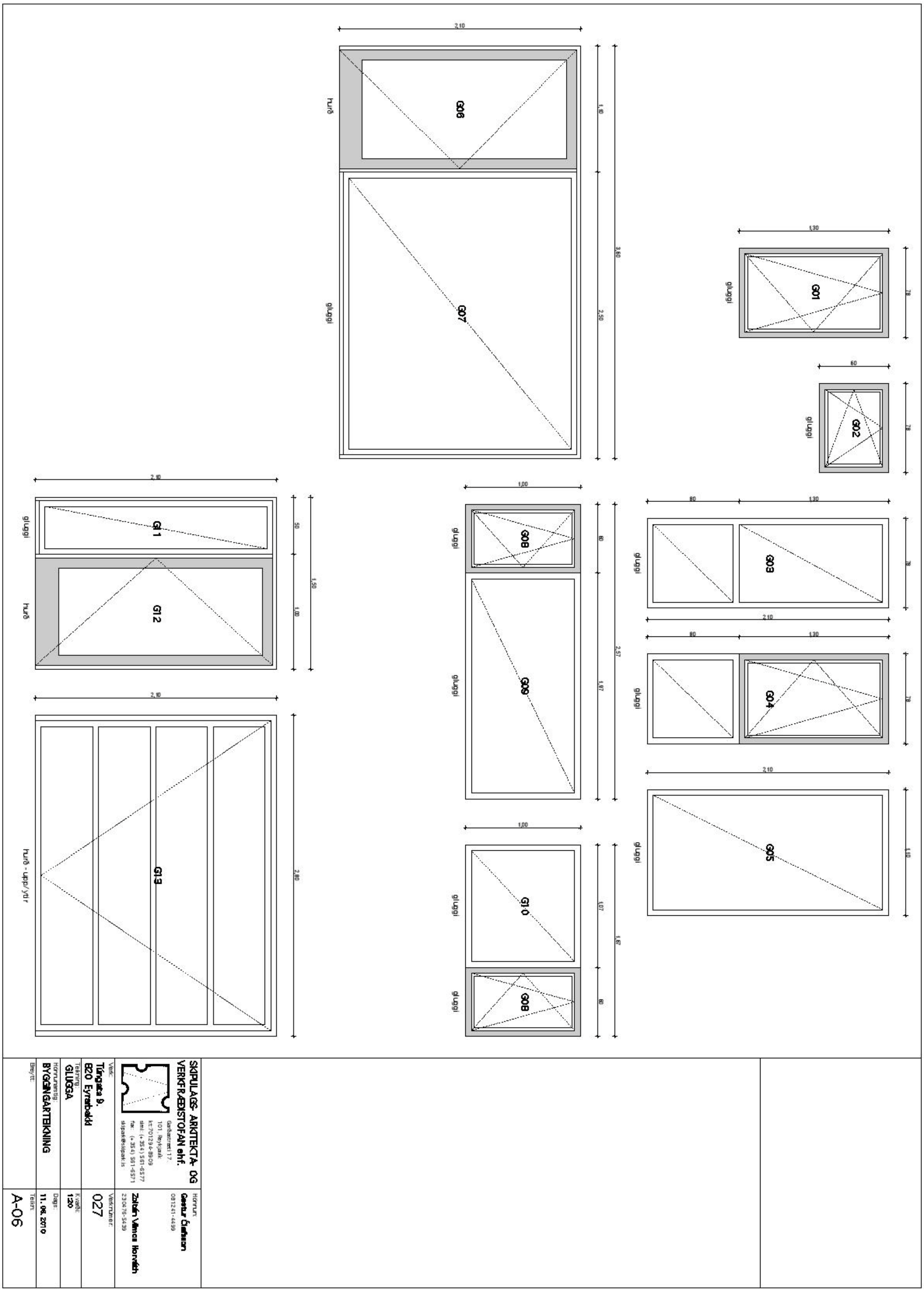
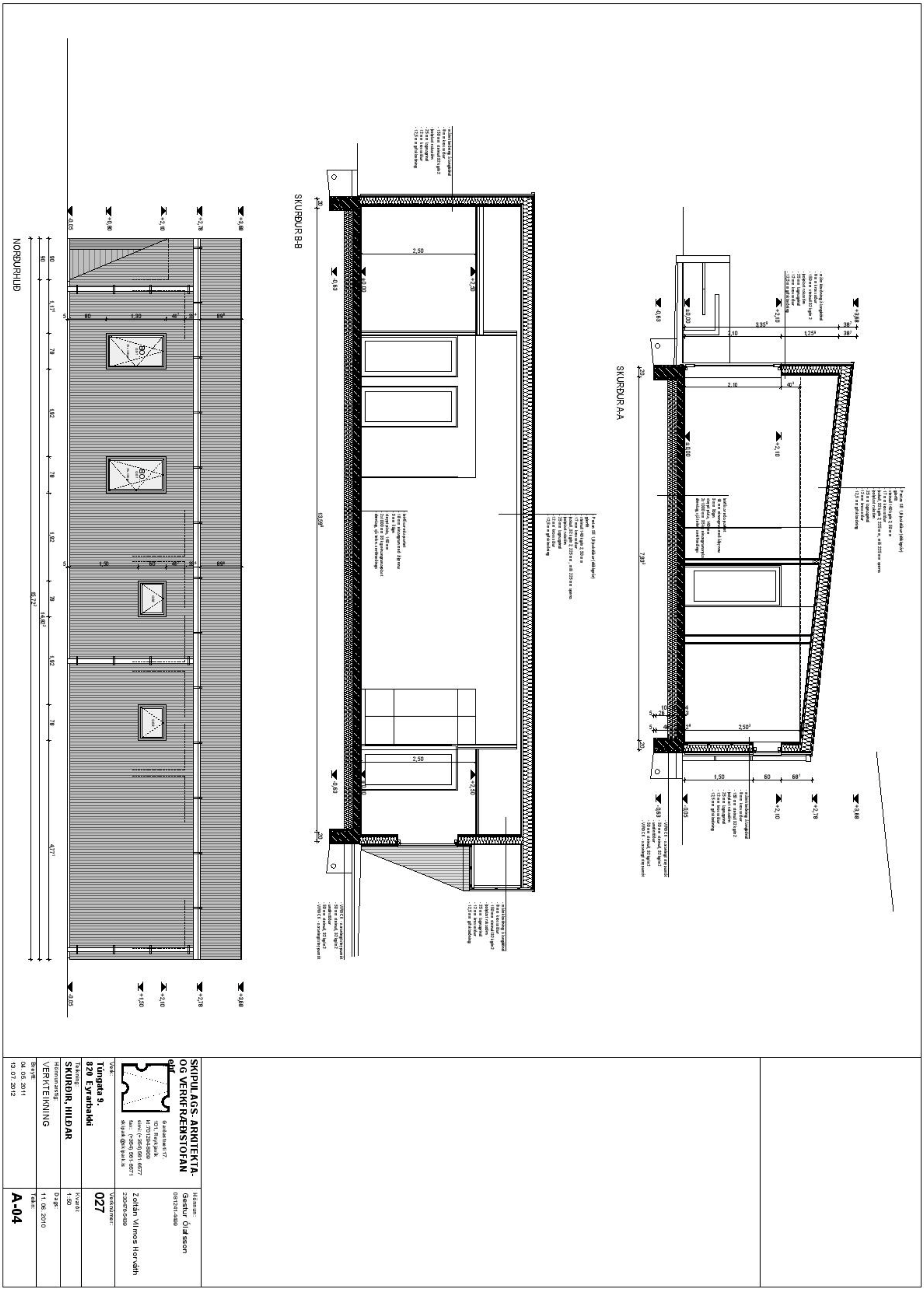
Gestur Ólafsson
081241-4499
Zoltán Vilmos Horváth
230476-5439
Verk:
Túngata 9.
820 Eyrarbakki
Verknúmer:
027
Teikning:
HLIÐAR
Kvarði:
1:50
Hönnunarstig:
BYGGINGARTEIKNING
Dags:
11. 06. 2010
Breytt:
Teikn:
A-03


SKIPULAGS- ARKITEKTA- OG VERKFRÆÐISTOFAN ehf.
Garðastræti 17.
101, Reykjavík
kt:701294-8909
sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is
Hönnun:
Gestur Ólafsson
081241-4499
Zoltán Vilmos Horváth
230476-5439
Verk:
Túngata 9.
820 Eyrarbakki
Verknúmer:
027
Teikning:
DEILI 01
Kvarði:
1:10
Hönnunarstig:
BYGGINGARTEIKNING
Dags:
11. 06. 2010
Breytt:
Teikn:
A-04
Protan SE 1,6 þakdúkur (dökkgrár)
festur við þak
steinull 140 kg/m3, 25 mm
17 mm grenikrossviður
3 mm olíubornir masonite renningar á stál
200 mm, 1,5 mm stálprófílar
steinull 140 kg/m3, 200 mm
rakavörn
25 mm lagnagrind
9 mm grenikrossviður
13 mm gifs
timburfesting
dropanef
skordýranet
6,48%
+3,71
- 18/75 olíuð báruð zinkklæðning
- 8 mm renningar f. loftun
- steinull 75-90 kg/m3, 150 mm
- veggur úr stálprófílum150 mm
- rakavörn
- 9 mm grenikrossviður
- 13 mm gifs
+2,10
tvöfalt gler
4/16/4
VELFAC clean/
energy
SKALI 1:10
03 DEILI
Protan SE 1,6 þakdúkur (dökkgrár)
festur við þak
steinull 140 kg/m3, 25 mm
17 mm grenikrossviður
3 mm olíuborið masonite á stálprófíla
200 mm, 1,5 mm stál burðarprófílar
steinull 140 kg/m3, 200 mm
rakavörn
25 mm lagnagrind
9 mm grenikrossviður
12,5 mm gifsplötur
timburfesting
+2,82
dropanef
LINDAB RER rétthyrnd þakrenna
LINDAB REK21 festing fyrir rétthyrnda þakrennu
LINDAB REOK tengi fyrir rétthyrnda þakrennu
+2,55
LINDAB SRÖR niðurfallsrör d 100 mm
LINDAB SSV rörefesting
SST fyrir d 100 mm
SKALI 1:10
06 DEILI
SKALI 1:10
04 DEILI
SKALI 1:10
07 DEILI
+1,00
SKALI 1:10
05 DEILI
tvöfalt gler
4/16/4
VELFAC clean/ energy
5 x 50mm Woodscrews (Staggered)
PU einangrunarfrauð
3mm MS galv. festing
Illbruck sveigjanleg loftþétting
Compriband 600 þétting
ál - áfella
leirflísar eða parket
- 18 mm einangrun með álþynnu
- 3 mm ílögn
- steypt plata, 150 mm
- steinull, 3x100 mm (ca. 100 kg/m3)
- 0,2 mm rakavarnarlag PE UV þolið
- 2x100 mm polystyrene (EPS80)
- 100 mm drenlag
±0,00
-0,20
SKALI 1:10
08 DEILI
netbinding #Ø6 s150
Nps500
Ø6 s600-N
hringinn
2Ø12
3Ø12
-0,82
420


SKIPULAGS- ARKITEKTA- OG VERKFRÆÐISTOFAN ehf.
Garðastræti 17.
101, Reykjavík
kt:701294-8909
sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is
Hönnun:
Gestur Ólafsson
081241-4499
Zoltán Vilmos Horváth
230476-5439
Verk:
Túngata 9.
820 Eyrarbakki
Verknúmer:
027
Teikning:
DEILI 02
Kvarði:
1:10
Hönnunarstig:
BYGGINGARTEIKNING
Dags:
11. 06. 2010
Breytt:
Teikn:
A-05
Protan SE 1,6 þakdúkur (dökkgrár)
festur við þak
steinull 140 kg/m3, 25 mm
17 mm grenikrossviður
3 mm olíuborið masonite á stálprófila
200 mm, 1,5 mm stálprófilar
steinull 140 kg/m3, 200 mm
akavörn
25 mm lagnagrind
9 mm grenikrossviður
13 mm gifs
timburfesting
dropanef
skordýranet
- 18/75 olítuð báruð zinkklæðning
- loftrúm
- steinull 75-90 kg/m3, 100 mm
- veggur úr stálprófílum,150 mm
- rakavörn
- 9 mm grenikrossviður
- 13 mm gifs
+2,93
skordýranet
dropanef
+2,10
tvöfalt gler
4/16/4
VELFAC clean/ energy
SKALI 1:10
09 DEILI
18/75 olítuð, báruð zinkklæðning
8 mm renningar fyrir loftrúm
steinull 75-90 kg/m3, 150 mm
veggur úr stálprófílum, 150 mm
rakavörn
9 mm grenikrossviður
13 mm gifs
SKALI 1:10
11 DEILI
SKALI 1:10
10 DEILI
tvöfalt gler
4/16/4
VELFAC clean/ energy
5 x 50mm Woodscrews (Staggered)
PU einangrunarfrauð
3mm MS galv. festing
Illbruck sveigjanleg loftþétting
Compriband 600 þétting
ál - áfella
leir flísar eða parket
18 mm einangrun með álþynnu
3 mm ílögn
steypt plata, 150 mm
steinull, 3x100 mm (ca. 100 kg/m3)
0,2 mm rakavarnarlag PE UV þolið
2x100 mm polystyrene (EPS80)
100 mm drenlag
tvöfalt gler
4/16/4
VELFAC clean/
energy
18/75 olítuð, báruð zinkklæðning
8 mm renningar fyrir loftrúm
steinull 75-90 kg/m3, 150 mm
veggur úr stálprófílum,150 mm
akavörn
9 mm grenikrossviður
13 mm gifs
SKALI 1:10
12 DEILI


G01
G02
G03
G04
G05
G06
G07
G08
G09
G10
G11
G12
G13
gluggi
hurð
hurð - upp/ytr
SKIPULAGS- ARKITEKTA- OG VERKFRÆÐISTOFAN ehf.
Garðastræti 17.
101. Reykjavík
kt: 701294-8909
sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is
Hönnun:
Gestur Ólafsson
081241-4499
Zoltán Vilmos Horváth
230476-5439
Verk:
Túngata 9.
820 Eyrarbakki
Verknúmer:
027
Teikning:
GLUGGA
Kvarði:
120
Hönnunarstig:
BYGGINGARTEIKNING
Dags:
11. 06. 2010
Breytt:
Teikn:
A-06



NORÐURHLIÐ
SKURÐUR B-B
SKURÐUR A-A
SKIPULAGS- ARKITEKTA- OG VERKFRÆÐISTOFAN ehf
Garðastræti 17.
101, Reykjavík
kt.701204-8000
sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is
Verk:
Túngata 9.
820 Eyrarbakki
Teikning:
SKURÐIR, HLIÐAR
Hönnunarstig:
VERKTEIKNING
Breytt:
04. 05. 2011
13. 07. 2012
Hönnun:
Gestur Ólafsson
081241-4490
Zoltán Vilmos Horváth
230476-5459
Verknúmer:
027
Kvarði:
1:50
Dags:
11. 06. 2010
Tekn:
A-04

Appendix 2. Correction for air cavities anneks A DS 418:2011

Anneks A
(normativt)

Korrektion af transmissionskoefficienten

A.1 Generelt

Transmissionskoefficienter beregnet i henhold til DS 418 skal korrigeres for virkningerne af:

- sprækker og spalter i isoleringen
- bindere og tilsvarende mekaniske fastgørelser
- nedbør på omvendt tag.

Den resulterende transmissionskoefficient U fås ved at addere korrektionen ΔU:

$$U = U' + \Delta U$$

hvor

$$\Delta U = \Delta U_g + \Delta U_f + \Delta U_r$$

og hvor

ΔU_g er korrektion for luftspalter i isoleringen

ΔU_f er korrektion for bindere og tilsvarende mekaniske fastgørelser

ΔU_r er korrektion for nedbør på omvendt tag.

A.2 Korrektion for luftspalter i isoleringen

Korrektionen ΔU_g skal justeres for isoleringens isolans i forhold til konstruktionens totale isolans:

$$\Delta U_g = \Delta U'' \left(\frac{R_i}{R_T}\right)^2$$

hvor

$\Delta U''$ er korrektionen for luftspalter i isoleringslaget. $\Delta U''$ findes i tabel A.1.

R_i er isolansen af isoleringen.

R_T er den totale isolans af konstruktionen.

Tabel A.1 – Korrektion for luftspalter i isoleringslaget

Niveau	$\Delta U''$ W/m²K	Beskrivelse
0	0,00	Ingen luftspalter på tværs af hele isoleringslaget
1	0,01	Mulighed for luftspalter på tværs af isoleringen Ingen luftcirkulation på den varme side af isoleringen
2	0,04	Mulighed for luftspalter på tværs af isoleringen Mulighed for luftcirkulation på den varme side af isoleringen

A.2.1 Luftspalter på tværs af hele isoleringslaget

Det antages, at der ikke er forøget varmetab pga. luftspalter vinkelret på isoleringens plan, hvis isoleringen er udført i to eller flere ubrudte lag med forskudte samlinger, eller hvis isoleringen er udført med løsfyld, og hulrummet er helt udfyldt.

Appendix 3. Window schedule from Revit BIM-model

Window schedule

Vinduestype betegnelse	Højde	Bredde	Brystnings højde	Etage	Revit Family
G03 / G04	2100	780	-12	(02) Stueplan	DAN_Fast Karm
G03 / G04	2100	780	-12	(02) Stueplan	DAN_Fast Karm
G03 / G04	2100	780	-12	(02) Stueplan	DAN_Fast Karm
G03 / G04	2100	780	-12	(02) Stueplan	DAN_Fast Karm
G03 / G04	2100	780	-12	(02) Stueplan	DAN_Fast Karm
G03 / G04	2100	780	-12	(02) Stueplan	DAN_Fast Karm
G01	1300	780	788	(02) Stueplan	DAN_Fast Karm
G02	600	780	1488	(02) Stueplan	DAN_Fast Karm
G02	600	780	1488	(02) Stueplan	DAN_Fast Karm
G01	1300	780	788	(02) Stueplan	DAN_Fast Karm
G05	2100	1100	-12	(02) Stueplan	DAN_Fast Karm
G07	2100	2500	-12	(02) Stueplan	DAN_Fast Karm
G06	2100	1100	-12	(02) Stueplan	DAN_Fast Karm
G08	1000	600	1088	(02) Stueplan	DAN_Fast Karm
G09	1000	1970	1088	(02) Stueplan	DAN_Fast Karm
G10	1000	1070	1088	(02) Stueplan	DAN_Fast Karm
G08	1000	600	1088	(02) Stueplan	DAN_Fast Karm
G11	2100	500	-12	(02) Stueplan	DAN_Fast Karm
G12	2100	1000	-12	(02) Stueplan	DAN_Fast Karm
G01	1300	780	788	(02) Stueplan	DAN_Fast Karm
G01	1300	780	788	(02) Stueplan	DAN_Fast Karm

09-04-2015 12:18:15

Appendix 4. Window U-value calculation results

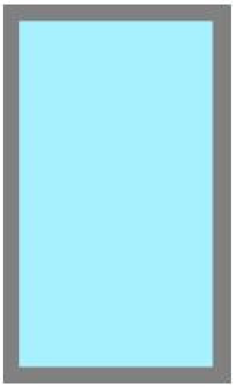
G01

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 780 mm
Højde: 1300 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8



Værdier

U-vindue, U_w	1.50W/m²K
Energitilskud, E_w	-40 kWh/m² pr. år
Glasandel, F_f	78%
Glasareal, A-rude	0.79 m²
Elementareal, A_w	1.01 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

G02

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 780 mm
Højde: 600 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8

Værdier	
U-vindue, U_w	1.65W/m²K
Energitilskud, E_w	-64 kWh/m² pr. år
Glasandel, F_f	70%
Glasareal, A-rude	0.33 m²
Elementareal, A_w	0.47 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

G03

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K7
Dato: 4/9/2015

Bredde:	780 mm
Højde:	2100 mm
H1:	1300 mm
H2:	800 mm

Vægtet gennemsnit glasværdier:
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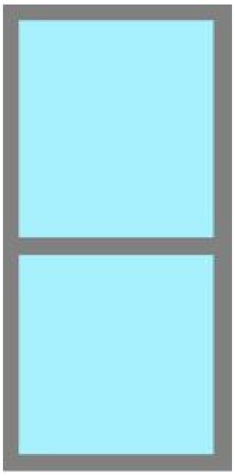


Værdier	
U-vindue, U_w	1.53W/m^2K
Energitilskud, E_w	-46 kWh/m^2 pr. år
Glasandel, F_f	76%
Glasareal, A-rude	1.25 m^2
Elementareal, A_w	1.64 m^2

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

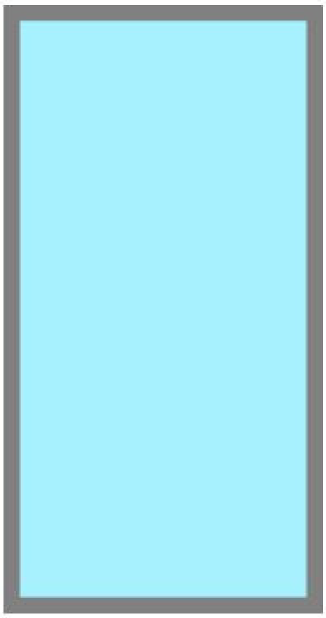
Navngiv_dit_dokument

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 1100 mm
Højde: 2100 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8



Værdier	
U-vindue, U_w	1.38W/m^2K
Energitilskud, E_w	-21 kWh/m^2 pr. år
Glasandel, F_f	85%
Glasareal, A-rude	1.96 m^2
Elementareal, A_w	2.31 m^2

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

G06

VELFAC 200i Terrassedør, 24mm rude

Karmopstalt: Enkelt
Dato: 4/9/2015

Bredde: 1100 mm
Højde: 2100 mm

Vægtet gennemsnit glasværdier:
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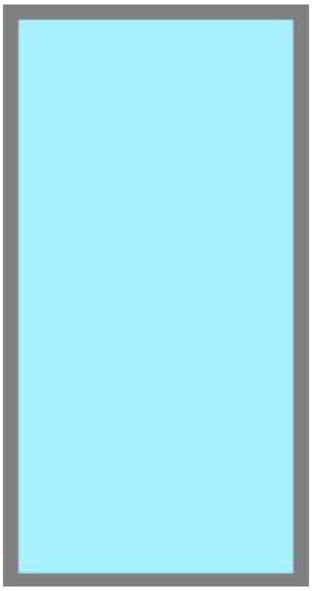


Værdier	
U-vindue, U_w	1.49W/m^2K
Energitilskud, E_w	-31 kWh/m^2 pr. år
Glasandel, F_f	85%
Glasareal, A-rude	1.97 m^2
Elementareal, A_w	2.31 m^2

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

G07

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 2500 mm
Højde: 2100 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8

Værdier	
U-vindue, U_w	1.29W/m²K
Energitilskud, E_w	-6 kWh/m² pr. år
Glasandel, F_f	90%
Glasareal, A-rude	4.75 m²
Elementareal, A_w	5.25 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

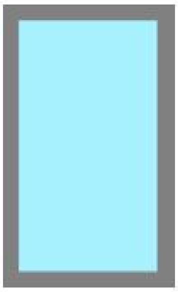
G08

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 600 mm
Højde: 1000 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8



Værdier	
U-vindue, U_w	1.61W/m²K
Energitilskud, E_w	-57 kWh/m² pr. år
Glasandel, F_f	72%
Glasareal, A-rude	0.43 m²
Elementareal, A_w	0.6 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

G09

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 1970 mm
Højde: 1000 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8

Værdier	
U-vindue, U_w	1.41W/m²K
Energitilskud, E_w	-25 kWh/m² pr. år
Glasandel, F_f	84%
Glasareal, A-rude	1.65 m²
Elementareal, A_w	1.97 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

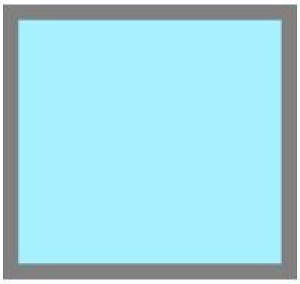
G10

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 1070 mm
Højde: 1000 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8



Værdier	
U-vindue, U_w	1.48W/m²K
Energitilskud, E_w	-37 kWh/m² pr. år
Glasandel, F_f	80%
Glasareal, A-rude	0.85 m²
Elementareal, A_w	1.07 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

VELFAC® **Energiberegner**

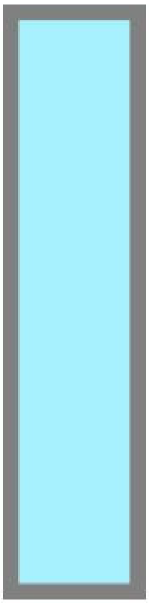
G11

VELFAC 200i Vindue, 24mm rude

Karmopstalt: K1
Dato: 4/9/2015

Bredde: 500 mm
Højde: 2100 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8



Værdier

U-vindue, U_w	1.59W/m²K
Energitilskud, E_w	-54 kWh/m² pr. år
Glasandel, F_f	73%
Glasareal, A-rude	0.77 m²
Elementareal, A_w	1.05 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

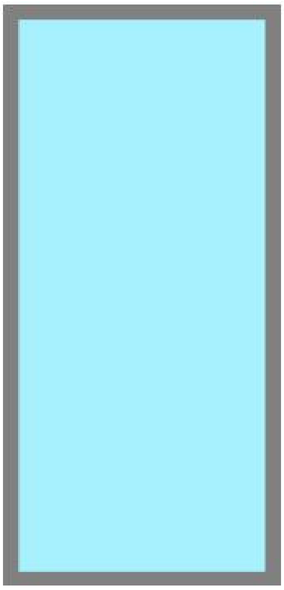
G12

VELFAC 200i Terrassedør, 24mm rude

Karmopstalt: Enkelt
Dato: 4/9/2015

Bredde: 1000 mm
Højde: 2100 mm

Vægtet gennemsnit glasværdier:
Ug=1.11 gg=0.62 LTg=0.8



Værdier	
U-vindue, U_w	1.52W/m²K
Energitilskud, E_w	-34 kWh/m² pr. år
Glasandel, F_f	84%
Glasareal, A-rude	1.77 m²
Elementareal, A_w	2.1 m²

Krav i henhold til Bygningsreglement 2010 for nybyggeri
Vinduessystemets Eref værdi er -24
OBS: Energiberegneren validerer ikke i forhold til begrænsninger ifm. glasvægt, åbnefunktioners min/max-mål, poste-/sprosse-opdeling osv.

Appendix 5. Original sensitivity analysis summed up by 269 parameters

		Parameter	Enhed	Min	Maks	"Gæt"	Begrundelse for min og maks	Kilde
G1	Generel bygnings-beskrivelse	Opvarmet etageareal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
G2		Varmekapacitet	Wh/K m2	-20	20		Intervallets størrelse i vejledningen til Be10 er 40, hvilket betyder at +/- 50 % svarer til +/- 20, altså et interval midt i det oprindelige interval	SBI 213
G3		Normal brugstid, timer/uge	timer/uge	-5	5		Der vurderes en usikkerhed på +/- 5 timer	
G4		Rotation	°	355	5		Der vurderes en usikkerhed på +/- 5 grader	
K1	Ydervæg	Areal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K2		U-værdi ydervæg	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%	Trine D Pettersen
K3	Tag	Areal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K4		U-værdi tag	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for en tagkonstruktion er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K5	Loft	Areal	m2				I denne bygning er loft og tag indtastet som én samlet enhed.	
K6		U-værdi tag	W/m2K				I denne bygning er loft og tag indtastet som én samlet enhed.	
K7	Terrændæk	Areal terrændæk u/ gulvvarme	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K8		U-værdi terrændæk u/ gulvvarme	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for et terrændæk er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K9		Længde af fundament u/ gulvvarme [m]	m	0	0		Der vurderes en usikkerhed på +/- 1 %	
K10		Linjetab, fundament u/gulvarme [W/mK]	W/mK	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for linjetab i konstruktionen er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K11		Areal terrændæk m/ gulvvarme	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K12		U-værdi terrændæk m/ gulvvarme	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for et terrændæk er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K13		Længde af fundament m/ gulvvarme	m	0	0		Der vurderes en usikkerhed på +/- 1 %	
K14		Linjetab terrændæk m/ gulvvarme [W/mK]	W/mK	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for linjetab i konstruktionen er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K15	Kælderværg	Areal kælderværg under bygning	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K16		U-værdi kælderværg under bygningen	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at denne usikkerhed er analog med usikkerheder for kældervægge	Trine D Pettersen
K17		Areal, kælderværg mod det fri	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K18		U-værdi kælderværg mod det fri	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at denne usikkerhed er analog med usikkerheder for kældervægge	Trine D Pettersen
K19		Længde af linjetab, kælder	m	0	0		Der vurderes en usikkerhed på +/- 1 %	
K20		Linjetab, kælder [W/mK]	W/mK	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for linjetab i konstruktionen er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K21	Vinduer	Samlet areal vinduer	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K22		U-værdi	W/m2K	0	0		Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K23		Glasandel	-	0	0		Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	SBI 213
K24		G-værdi, indvendigt vindue 1,2 &3	-	-0,03	0,03		Jf. EN410-2011 samt EN673-2011 er afvigelsen +/- 0,03	EN410-2011, EN673-2011
K25		G-værdi rest	-	-0,03	0,03		Jf. EN410-2011 samt EN673-2011 er afvigelsen +/- 0,03	EN410-2011, EN673-2011
K26	Ovenlys vindue	Areal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K27		U-værdi	W/m2K	0	0		Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K28		Glasandel	-	0	0		Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	Trine D Pettersen
K29		G-værdi	-	-0,03	0,03		Jf. EN410-2011 samt EN673-2011 er afvigelsen +/- 0,03	EN410-2011, EN673-2011
K30	Døre	Samlet areal døre	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K31		U-værdi dør	W/m2K	0	0		Der vurderes en usikkerhed på +/- 5 %	
K32		Glasandel	-	0	0		I følge Be10 er der ingen rude i døren	
K33		G-værdi	-	0	0		I følge Be10 er der ingen rude i døren	
K34	Skygger indvendigt	Venstre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K35		Højre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K36		Udhæng	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K37		Horisont	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K38		Vindueshul [%]	%	0	0		Der vurderes en usikkerhed på +/- 5 %	
K39	Skygger udvendigt	Venstre	°	0	0		Den udvendige ydervæg er konkav, hvorfor der ikke kan dannes skygger fra venstre og højre	
K40		Højre	°	0	0		Den udvendige ydervæg er konkav, hvorfor der ikke kan dannes skygger fra venstre og højre	
K41		Udhæng	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K42		Horisont	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K43		Vindueshul [%]	%	0	0		Der vurderes en usikkerhed på +/- 5 %	
C1	Ventilation	Mekanisk, vinter	l/s/m2	0	0		Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0	0		Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C3		Mekanisk, sommer nat	l/s/m2	0	0		Der er ikke dimensioneret natventilation	
C4		SEL, køkken	kJ/m3	0	0		Be10's værdi er lig den maksimale værdi jf. Be10, hvorfor maks "kun" er vurderet + 5 %. Min er vurderet til - 10 %	
C5		SEL, rest	kJ/m3	0	0		Der vurderes en usikkerhed på +/- 10 %	
C6		Indblæsningstemp	°C	0	0		Indblæsningstemp på 18 er en prædefineret værdi fra Be10	
C7		Driftstid	-	1	1		Det forventes ikke at denne værdi vil variere fra BE10's input	

		Parameter	Enhed	Min	Maks	"Gæt"	Begrundelse for min og maks	Kilde
G1	Generel bygnings-beskrivelse	Opvarmet etageareal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
G2		Varmekapacitet	Wh/K m2	-20	20		Intervallets størrelse i vejledningen til Be10 er 40, hvilket betyder at +/- 50 % svarer til +/- 20, altså et interval midt i det oprindelige interval	SBI 213
G3		Normal brugstid, timer/uge	timer/uge	-5	5		Der vurderes en usikkerhed på +/- 5 timer	
G4		Rotation	°	355	5		Der vurderes en usikkerhed på +/- 5 grader	
K1	Ydervæg	Areal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K2		U-værdi ydervæg	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%	Trine D Pettersen
K3	Tag	Areal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K4		U-værdi tag	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for en tagkonstruktion er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K5	Loft	Areal	m2				I denne bygning er loft og tag indtastet som én samlet enhed.	
K6		U-værdi tag	W/m2K				I denne bygning er loft og tag indtastet som én samlet enhed.	
K7	Terrændæk	Areal terrændæk u/ gulvvarme	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K8		U-værdi terrændæk u/ gulvvarme	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for et terrændæk er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K9		Længde af fundament u/ gulvvarme [m]	m	0	0		Der vurderes en usikkerhed på +/- 1 %	
K10		Linjetab, fundament u/gulvarme [W/mK]	W/mK	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for linjetab i konstruktionen er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K11		Areal terrændæk m/ gulvvarme	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K12		U-værdi terrændæk m/ gulvvarme	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for et terrændæk er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K13		Længde af fundament m/ gulvvarme	m	0	0		Der vurderes en usikkerhed på +/- 1 %	
K14		Linjetab terrændæk m/ gulvvarme [W/mK]	W/mK	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for linjetab i konstruktionen er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K15	Kældervæg	Areal kældervæg under bygning	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K16		U-værdi kældervæg under bygningen	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at denne usikkerhed er analog med usikkerheder for kældervægge	Trine D Pettersen
K17		Areal, kældervæg mod det fri	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K18		U-værdi kældervæg mod det fri	W/m2K	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at denne usikkerhed er analog med usikkerheder for kældervægge	Trine D Pettersen
K19		Længde af linjetab, kælder	m	0	0		Der vurderes en usikkerhed på +/- 1 %	
K20		Linjetab, kælder [W/mK]	W/mK	0	0		Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for linjetab i konstruktionen er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K21	Vinduer	Samlet areal vinduer	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K22		U-værdi	W/m2K	0	0		Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K23		Glasandel	-	0	0		Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	SBI 213
K24		G-værdi, indvendigt vindue 1,2 &3	-	-0,03	0,03		Jf. EN410-2011 samt EN673-2011 er afvigelsen +/- 0,03	EN410-2011, EN673-2011
K25		G-værdi rest	-	-0,03	0,03		Jf. EN410-2011 samt EN673-2011 er afvigelsen +/- 0,03	EN410-2011, EN673-2011
K26	Ovenlys vindue	Areal	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K27		U-værdi	W/m2K	0	0		Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K28		Glasandel	-	0	0		Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	Trine D Pettersen
K29		G-værdi	-	-0,03	0,03		Jf. EN410-2011 samt EN673-2011 er afvigelsen +/- 0,03	EN410-2011, EN673-2011
K30	Døre	Samlet areal døre	m2	0	0		Der vurderes en usikkerhed på +/- 1 %	
K31		U-værdi dør	W/m2K	0	0		Der vurderes en usikkerhed på +/- 5 %	
K32		Glasandel	-	0	0		I følge Be10 er der ingen rude i døren	
K33		G-værdi	-	0	0		I følge Be10 er der ingen rude i døren	
K34	Skygger indvendigt	Venstre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K35		Højre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K36		Udhæng	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K37		Horisont	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K38		Vindueshul [%]	%	0	0		Der vurderes en usikkerhed på +/- 5 %	
K39	Skygger udvendigt	Venstre	°	0	0		Den udvendige ydervæg er konkav, hvorfor der ikke kan dannes skygger fra venstre og højre	
K40		Højre	°	0	0		Den udvendige ydervæg er konkav, hvorfor der ikke kan dannes skygger fra venstre og højre	
K41		Udhæng	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K42		Horisont	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
K43		Vindueshul [%]	%	0	0		Der vurderes en usikkerhed på +/- 5 %	
C1	Ventilation	Mekanisk, vinter	l/s/m2	0	0		Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0	0		Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C3		Mekanisk, sommer nat	l/s/m2	0	0		Der er ikke dimensioneret natventilation	
C4		SEL, køkken	kJ/m3	0	0		Be10's værdi er lig den maksimale værdi jf. Be10, hvorfor maks "kun" er vurderet + 5 %. Min er vurderet til - 10 %	
C5		SEL, rest	kJ/m3	0	0		Der vurderes en usikkerhed på +/- 10 %	
C6		Indblæsningstemp	°C	0	0		Indblæsningstemp på 18 er en prædefineret værdi fra Be10	
C7		Driftstid	-	1	1		Det forventes ikke at denne værdi vil variere fra BE10's input	

C69		Temperaturfaktor (elvandvarmer)	-	0	0		Der vurderes ingen usikkerhed på denne parameter	
C70		Antal af VVB i separate gasvarmere	-	0	0		Der vurderes ingen usikkerhed på denne parameter	
C71		Varmetab fra VVB (gasvandvarmer)	W/K	0	0		Der vurderes en usikkerhed på +/-5 %	
C72		Virkningsgrad	-	0	0		Der vurderes en usikkerhed på +/- 5 %	
C73		Pilotflamme	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C74		Temperaturfaktor (gasvandvarmer)	-	1	1		Kedlen forventes at være i et opvarmet rum	
C75		Antal kedler	-	0	0		Der vurderes ingen usikkerhed på denne parameter	
C76		Nominel effekt, kW	kW	0	0		Der vurderes en usikkerhed på +/- 5 %	
C77		Andel af nom effekt til VBV produktion	-	0	0		Der vurderes en usikkerhed på +/- 5 %	
C78		Belastning (fuldlast)	%	0	0		Der vurderes ingen usikkerhed	
C79		Virkningsgrad (fuldlast)	-	0	0		Bestemt ud fra testforsøg - dem tror vi på	
C80		Kedeltemp (fuldlast)	°C	0	0		Der vurderes ingen usikkerhed	
C81		Korrektion (fuldlast)	-/°C	0	0		Der vurderes en usikkerhed på +/- 10 %	
C82		Belastning (dellast)	-	0	0		Der vurderes ingen usikkerhed	
C83		Virkningsgrad (dellast)	-	0	0		Bestemt ud fra testforsøg - dem tror vi på	
C84	Kedler	Kedeltemp (dellast)	°C	0	0		Der vurderes ingen usikkerhed	
C85		Korrektion (dellast)	-/°C	0	0		+/- 10%, skønnet - manglende dokumentation	
C86		Belastning (tomgangstab)	-	0	0		Der vurderes ingen usikkerhed	
C87		Tabsfaktor (tomgangstab)	-	0	0		Bestemt ud fra testforsøg - dem tror vi på	
C88		Andel til rum	-	0	0		+/- 15%, skønnet - manglende dokumentation	
C89		Temp. Diff		0	0		Der vurderes ingen usikkerhed	
C90		Kedeltemp (min)	°C	0	0		Der vurderes ingen usikkerhed	
C91		Temperaturfaktor for omstillingsrum, b	-	0	0		Der vurderes ingen usikkerhed	
C92		Blæser mv, W	W	0	0		Mærkeeffekt for enhederne	
C93		El til automatik, W	W	0	0		Mærkeeffekt	
C94		Nominel effekt, kW	-	0	0		Der vurderes en usikkerhed på +/- 10 %	
C95		Varmetab fra veksler	-	0	0		Der vurderes en usikkerhed på +/- 5 %	
C96	Fjernvarme-veksler	VBV opvarmning gennem veksler	-	J/N	J/N		Ingen usikkerhed	
C97		Veksler temperature, minimum	°C	0	0		Ingen usikkerhed	
C98		Tempfaktor for opstillingsrum	-	0	0		Ingen usikkerhed	
C99		Automatik, standby effekt	W	0	0		Der vurderes en usikkerhed på +/- 10 %	
C100		Andel af etageareal (direkte el til rum opv)	-				Der vurderes en usikkerhed på +/- 5 %	
C101	Anden rumopvarmning	Andel af etageareal (brændeovne, gasstrålevarme etc.)	-				Der vurderes en usikkerhed på +/- 5 %	
C102		Virkningsgrad	-				Der vurderes en usikkerhed på +/- 10 %	
C103		Luftstrømsbehov	m^3/s				Der vurderes en usikkerhed på +/- 10 %	
C104		Samlet solfangerareal	m2	0	0		Der vurderes en usikkerhed på +/- 1%	
C105		Starteffektivitet	-	0	0		Der vurderes en usikkerhed på +/- 5 %	
C106		1. ordens varmetabskoefficient	W/m2*K	0	0		Der vurderes en usikkerhed på +/- 5 %	
C107		2. ordens varmetabskoefficient	W/m2*K2	0	0		Der vurderes en usikkerhed på +/- 5 %	
C108		Vinkelafhængighed		0	0		Der vurderes ingen usikkerhed på denne parameter	
C109		Samlet rørlængde	m	0	0		Der vurderes en usikkerhed på +/- 5 %	
C110		Varmetab, rør	W/m2*K	0	0		Der vurderes en usikkerhed på +/- 5 %	
C111	Solvarmeanlæg	Varmeveksler effektivitetsfaktor	-	0	0		Der vurderes en usikkerhed på +/- 5 %	
C112		Pumpeeffekt	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C113		Automatik, standby effekt	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C114		Orientering		0	0		Der varieres ikke på denne parameter. Dette gøres ved orientering af bygningen	
C115		Hældning	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C116		Horisont afskæring	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C117		Skygge, venstre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C118		Skygge, højre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C119		Brugsvand/rumopvarmning, kombineret el duo	-	J/N	J/N		Enten/eller - ingen usikkerhed	
C120		Nominel effekt, kW (opv)	kW	0	0		Der vurderes en usikkerhed på +/- 10 %	
C121		Nominel COP (opv)	-	0	0		Der vurderes en usikkerhed på +/- 40 %	
C122		Rel COP ved 50% last (opv)	-	0	0		Der vurderes en usikkerhed på +/- 20 %	
C123		Testtemp (kold side) (opv)	°C	0	0		Fast værdi - ingen usikkerhed	
C124		Testtemp (varm side) (opv)	°C	0	0		Fast værdi - ingen usikkerhed	
C125		Kold side: Jordslange, antræk, udeluft, anden kilde) Opv	-	0	0		Ingen usikkerhed	
C126		Varm side: Rumluft, indblæsning, varmeanlæg	-	0	0		Ingen usikkerhed	
C127		Særligt hjælpeudstyr, W (opv)	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C128		Stand-by effekt, W (opv)	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C129		Temp virknings grad for vgv før VP (opv)	-	0	0		Der vurderes en usikkerhed på +/- 10 %	
C130	Varmepumpe	Dim indblæsning temp (opv)	°C	0	0		Fast værdi - ingen usikkerhed	
C131		Luftstrøm (opv)	m^3/s	0	0		Der vurderes en usikkerhed på +/- 10 %	
C132		Nominel effekt, kW (bv)	kW	0	0		Der vurderes en usikkerhed på +/- 10 %	
C133		Nominel COP (bv)	-	0	0		Der vurderes en usikkerhed på +/- 40 %	

C134		Testtemp (kold side) (bv)	°C	0	0		Fast værdi - ingen usikkerhed	
C135		Testtemp (varm side) (bv)	°C	0	0		Fast værdi - ingen usikkerhed	
C136		Kold side: Jordslange, antræk, udeluft, anden kilde) bv	-	0	0		Fast værdi - ingen usikkerhed	
C137		Særligt hjælpeudstyr, W (bv)	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C138		Stand-by effekt, W (bv)	W	0	0		Der vurderes en usikkerhed på +/- 5 %	
C139		Temp virknings grad for vgv før VP (bv)	-	0	0		Der vurderes en usikkerhed på +/- 10 %	
C140		Luftstrøm (bv)	m^3/s	0	0		Der vurderes en usikkerhed på +/- 10 %	
C141	Solceller	Panelareal	m^2	0	0		Der vurderes en usikkerhed på +/- 1 %	
C142		Peak power	kW/m^2	0	0		Defineret værdi ved solindstråling på 1000 W/m2. Der vurderes en usikkerhed på +/- 5 %	
C143		Systemvirkningsgrad	-	0	0		Jf. Viby elværk, falder virkningsgraden maksimalt med 20 % efter 20 år. Den maksimale værdi er derfor lig input til Be10 og minimum er - 20 %	
C144		Orientering	°	0	0		Ingen usikkerhed	
C145		Hældning	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C146		Horisont afskæring	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C147		Skygge venstre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C148		Skygge højre	°	0	0		Der vurderes en usikkerhed på +/- 5 %	
C149	Belysning	Indstilling A						
C150		Almen min, Vindfang	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
C151		Almin inst., Vindfang	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
C152		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
C153		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
C154		Benyttelsesfaktor	-	0,7	1		Dette er et skøn	
C155		Standby, belysning	W/m2	0	0		Der vurderes en usikkerhed på +/- 10 %	
C156		Nat, belysning	W/m2	0	0		Der vurderes en usikkerhed på +/- 10 %	
C157		Andet, belysning	W/m2	0	0		Der vurderes en usikkerhed på +/- 10 %	
C158		Arbejdsbelysning	W/m2	0	0		Der vurderes en usikkerhed på +/- 30 %	
C159		Indstilling A						
C160		Almen min, toilet	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
C161		Almin inst., toilet	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
C162		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
C163		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
C164		Benyttelsesfaktor	-	0,4	0,6		Dette er et skøn	
C165		Indstilling K						
C166		Almen min, kontor	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
C167		Almin inst., kontor	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
C168		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
C169		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
C170		Benyttelsesfaktor	-	0,7	0,9		Dette er et skøn	
C171		Arbejdsbelysning	W/m2	0	3		Der vurderes en usikkerhed på +/- 30 %	
C172		Indstilling K						
C173		Almen min, møderum	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
C174		Almin inst., møderum	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
C175		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
C176		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
C177		Benyttelsesfaktor	-	0,4	0,6		Dette er et skøn	
C178		Indstilling K						
C179		Almen min, opholdsrum	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
C180		Almin inst., opholdsrum	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
C181		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
C182		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
C183		Benyttelsesfaktor	-	1	1		Antages at være i brug konstant - legende børn konstant	
C184	Setpunkter	Opvarmning	°C	20	22		Antages at være lidt højere	
C185		Ønsket temp	°C	22	24		Dette er et skøn	
C186		Nat vent	°C	24	24		Ingen usikkerhed	
C187		Køling	°C	25	25		Ingen usikkerhed	
C188		Lager opv.	°C	15	15		Ingen usikkerhed	
C189	Dimensioneren de temperaturer	Rumtemperatur	°C	20	20		Ej relevant	
C190		Udetemperatur	°C	-12	-12		Ej relevant	
C191		Lagertemperatur	°C	15	15		Ej relevant	
B1	Naturlig ventilation	Naturlig, vinter	l/s*m2	0	0		Svarende til at alle vinduer osv. er lukkede i vinterhalvåret. Der er lavet et vægtet gennemsnit for alle lokaler. Der vurderes en usikkerhed på +/- 10 %	
B2		Naturlig, sommer	l/s*m2	0	0		Der er lavet et vægtet gennemsnit. Der vurderes en usikkerhed på +/- 10 %	
B3		Naturlig, sommer, nat	l/s*m2	0	0		Der vurderes en usikkerhed på +/- 10 %	
B4		Indstilling M						
B5		Almen min, garderobe	W/m2	0	0		Der vurderes en usikkerhed på +/- 20 %	
B6		Almin inst., garderobe	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
B7		Belysningsstyrke	Lux	0	0		Et reguleringsmæssigt setpunkt	

B8	Belysning	DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
B9		Benyttelsesfaktor	-	0	0		Dette er et skøn	
B10		Indstilling M						
B11		Almen min, depot	W/m2	0	0		Der vurderes en usikkerhed på +/- 20 %	
B12		Almin inst., depot	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
B13		Belysningsstyrke	Lux	0	0		Et reguleringsmæssigt setpunkt	
B14		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
B15		Benyttelsesfaktor	-	0,1	0,4		Dette er et skøn	
B16		Indstilling M						
B17		Almen min, div andre rum	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
B18		Almin inst., div andre rum	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
B19		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
B20		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
B21		Benyttelsesfaktor	-	0,1	0,4		Dette er et skøn	
B22		Indstilling M						
B23		Almen min, køkken	W/m2	0,015	0		Der vurderes en usikkerhed på +/- 20 %	
B24		Almin inst., køkken	W/m2	0	0		Der vurderes en usikkerhed på +/- 40 %	
B25		Belysningsstyrke	Lux	200	200		Et reguleringsmæssigt setpunkt	
B26		DF %	%	0	0		Der vurderes en usikkerhed på +/- 75 %. Det vurderes at gardiner/persienner kan anvendes af brugerne	
B27		Benyttelsesfaktor	-	0,8	1		Dette er et skøn	
B28	Internt varmetilskud	Areal	m^2				Dette er et skøn	
B29		Personer	W/m2	4	5,6		Der vurderes en usikkerhed på +/- 15 %	
B30		App	W/m2	4	6		Der vurderes en usikkerhed på +/- 15 %	
B31		App, nat	W/m2	0	0		Der vurderes en usikkerhed på +/- 15 %	

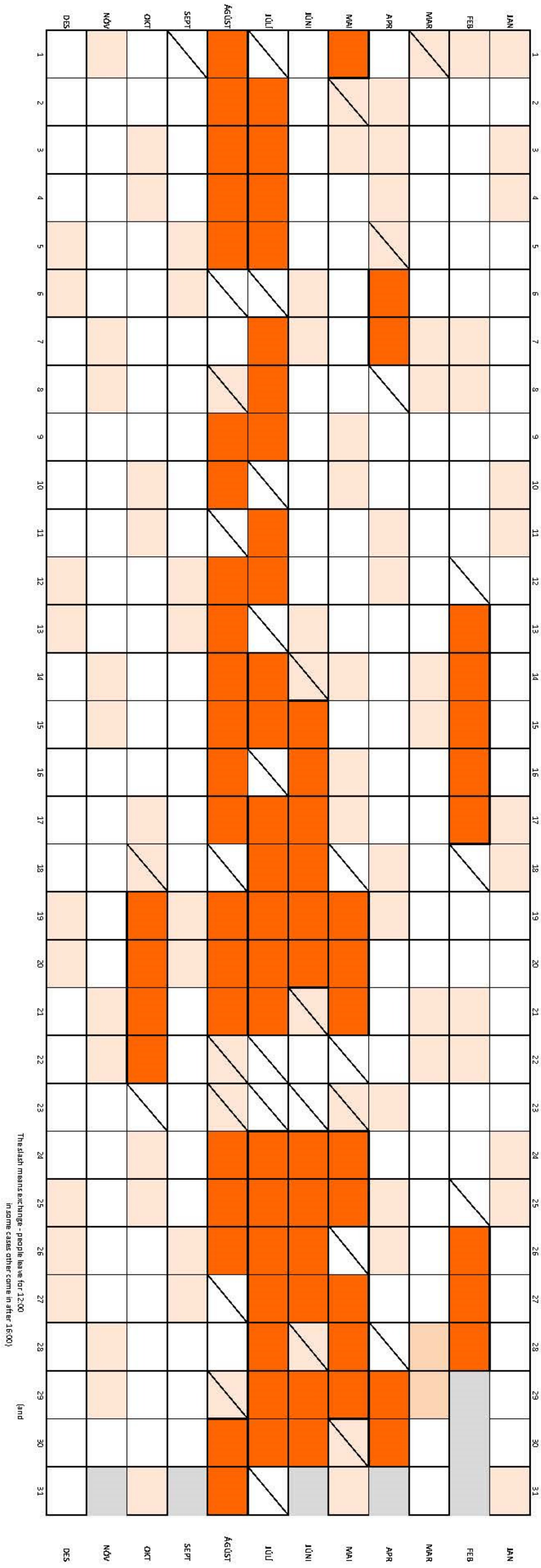
Appendix 6. Altered version of sensitivity analysis fitting the BM-excel model and used for 3-point estimation.

		Parameter	Unit	Min (O)	Maks (P)	Most likely" (ML	Begrundelse for min og maks	Kilde
G1	bygnings-	Opvarmet etageareal	m2	125,73	128,27	127	Der vurderes en usikkerhed på +/- 1 %	
K1		Areal	m2	41,283	42,117	41,7	Der vurderes en usikkerhed på +/- 1 %	
K1	Outerwalls	Areal	m2	21,087	21,513	21,3	Der vurderes en usikkerhed på +/- 1 %	
K1		Areal	m2	37,026	37,774	37,4	Der vurderes en usikkerhed på +/- 1 %	
K1		Areal	m2	21,483	21,917	21,7	Der vurderes en usikkerhed på +/- 1 %	
K2		U-værdi ydervæg	W/m2K	0,228	0,252	0,24	Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%.	Trine D Pettersen
K3	Roof	Areal	m2	125,7597	128,3003	127,03	Der vurderes en usikkerhed på +/- 1 %	
K4		U-værdi tag	W/m2K	0,1805	0,1995	0,19	Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for en tagkonstruktion er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K11	Floor	Areal terrændæk m/ gulvvarme	m2	125,73	128,27	127	Der vurderes en usikkerhed på +/- 1 %	
K12		U-værdi terrændæk m/ gulvvarme	W/m2K	0,114	0,126	0,12	Jf. Trine Dyrstad tillægges i Norge 5 % som sikkerhed for ydervægge. Denne værdi anvendes ligeledes i dette projekt således maks/min svarer til +/- 5%. Det antages således, at usikkerheden på u-værdien for et terrændæk er analog med usikkerheden for en ydervæg.	Trine D Pettersen
K21		Area 2xG01	m2	1,9998	2,0402	2,02	Der vurderes en usikkerhed på +/- 1 %	
K21		Area 2xG02	m2	0,4653	0,4747	0,47	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G05	m2	2,2869	2,3331	2,31	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G10	m2	1,0593	1,0807	1,07	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G08	m2	0,594	0,606	0,6	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G11	m2	1,0395	1,0605	1,05	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G12(door)	m2	2,079	2,121	2,1	Der vurderes en usikkerhed på +/- 1 %	
K21		Area 2xG01	m2	1,9998	2,0402	2,02	Der vurderes en usikkerhed på +/- 1 %	
K21		Area 4xG03 / G04	m2	6,4944	6,6256	6,56	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G06 (door)	m2	2,2869	2,3331	2,31	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G07	m2	5,2074	5,3126	5,26	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G08	m2	0,594	0,606	0,6	Der vurderes en usikkerhed på +/- 1 %	
K21		Area G09	m2	1,9503	1,9897	1,97	Der vurderes en usikkerhed på +/- 1 %	
K21		Area 2xG03 / G04	m2	3,2472	3,3128	3,28	Der vurderes en usikkerhed på +/- 1 %	
K22		U-Value 2xG01	W/m2K	1,425	1,575	1,5	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value 2xG02	W/m2K	1,5675	1,7325	1,65	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G05	W/m2K	1,311	1,449	1,38	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22	Windows and doors	U-Value G10	W/m2K	1,406	1,554	1,48	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G08	W/m2K	1,5295	1,6905	1,61	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G11	W/m2K	1,5105	1,6695	1,59	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G12(door)	W/m2K	1,444	1,596	1,52	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value 2xG01	W/m2K	1,425	1,575	1,5	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value 4xG03 / G04	W/m2K	1,4535	1,6065	1,53	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G06 (door)	W/m2K	1,4155	1,5645	1,49	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G07	W/m2K	1,2255	1,3545	1,29	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G08	W/m2K	1,5295	1,6905	1,61	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value G09	W/m2K	1,3395	1,4805	1,41	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K22		U-Value 2xG03 / G04	W/m2K	1,4535	1,6065	1,53	Jf. Trine Dyrstad er usikkerheden for et vindues u-værdi med kendt geometri 2-7 %. Derfor anvendes middelusikkerheden på +/- 4,5 % ≈ 5%	Trine D Pettersen
K23		Glass area North east	-	0,855	0,945	0,9	Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	SBI 213
K23		Glass area south east	-	0,7638	0,8442	0,804	Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	SBI 213
K23		Glass area south west	-	0,7847	0,8673	0,826	Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	SBI 213
K23		Glass area north west	-	0,7239	0,8001	0,762	Jf. Hjælpevejledning til Be10 ligger værdien typisk indenfor 0,5-0,8. Da vinduesarealerne er forholdsvist store, vurderes der en blot en afvigelse på +/- 5 %	SBI 213
C1		Mekanisk, vinter	l/s/m2	0,63	0,77	0,7	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C1		Mekanisk, vinter	l/s/m2	0,54	0,66	0,6	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C1		Mekanisk, vinter	l/s/m2	0,54	0,66	0,6	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C1		Mekanisk, vinter	l/s/m2	0,54	0,66	0,6	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C1		Mekanisk, vinter	l/s/m2	0,54	0,66	0,6	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C1		Mekanisk, vinter	l/s/m2	0,54	0,66	0,6	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2	Ventilation	Mekanisk, sommer	l/s/m2	0,63	0,77	0,7	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0,72	0,88	0,8	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0,9	1,1	1	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0,9	1,1	1	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0,9	1,1	1	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C2		Mekanisk, sommer	l/s/m2	0,72	0,88	0,8	Der laves et vægtet gennemsnit af ventilationsraterne for de enkelte rum, hvilket bruges som "gæt". Min og maks er skønnet +/- 10 %	
C9		VGV, rest	-	0,72	0,88	0,8	Min og maks er vurderet +/- 10 %. Dette til trods for, at BR10 dikterer en varmegenvinding på minimum 0,7	Vurdering/bR10
C13	Belysning	Almen belysning, installeret		3,15	3,85	3,5	"Gæt" er et vægtet gennemsnit af effekten i de enkelte rum. Min og maks er skønnet +/- 10 %	
C26	Varmefordeling sanlæg	Fremløbstemperatur		52,25	57,75	55	Der vurderes en usikkerhed på +/- 5 %	
C46	Varmt brugsvand	Varmtvandsforbrug	l/ocupant pr day	40	80	60	Eksempel på udregning: 1) 80L/barn/år * 100 børn * 200 dage/år => 975L/m2/år 2) 14 m3/år/pers => 850 l/m2/år. Middel giver ca. 912 l/m2/år. Ca 1/3 går til varmt brugsvand => ca. 300 L	1) HFB notat, 2) Energihåndbogen, (1/3) antagelsen : HFB

B29	Internt varmetilskud	Personer	W/m2	1,292	1,748	1,52	Der vurderes en usikkerhed på +/- 15 %	

Appendix 7. Usage schedule of the Project House

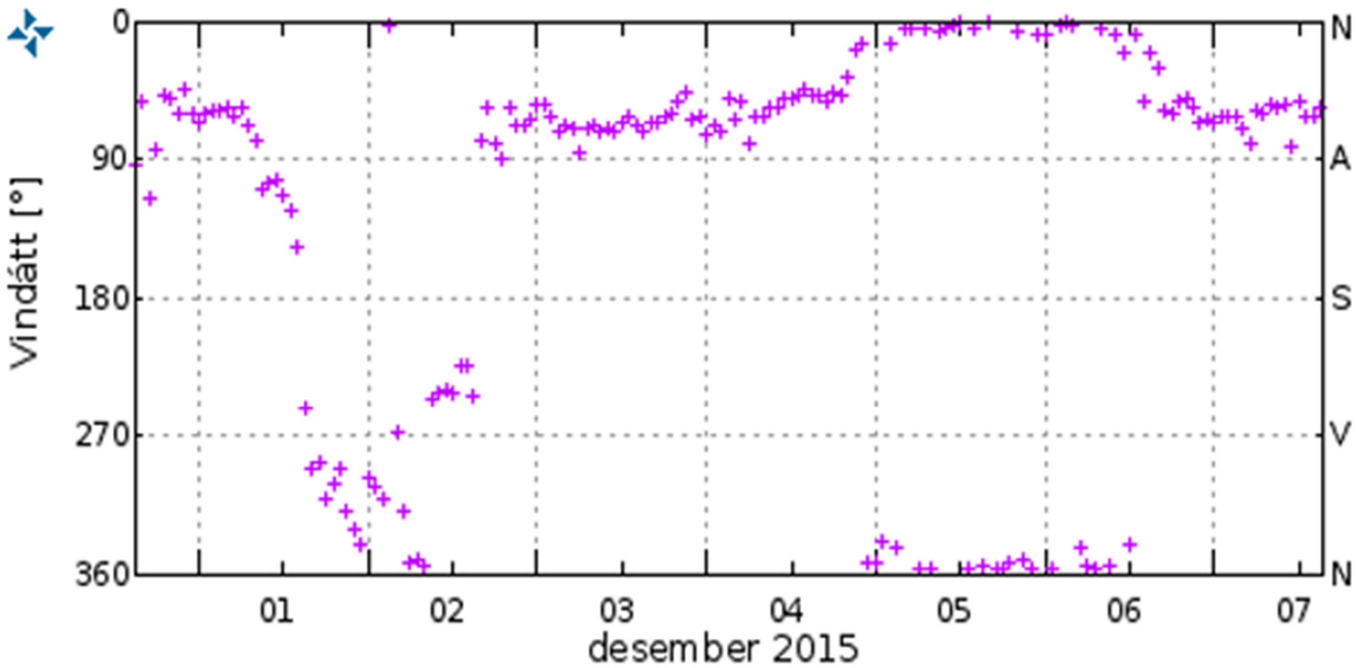
Dark orange fields indicates bookings and therefore when the house is in use. White and light orange indicates that the house has no bookings and therefore is assumed empty.



Appendix 8. First week of December 2015. IMO and weather station data compared

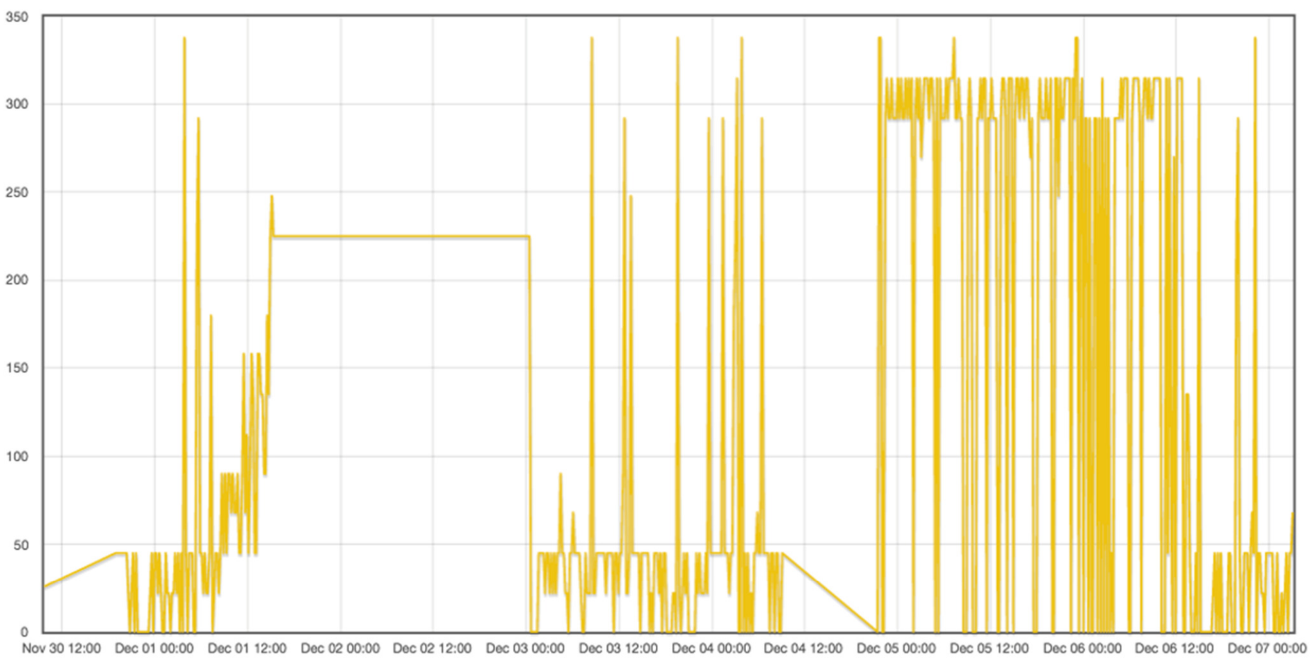
Icland MET office data from Eyrarbakki

Wind direction



Weather station data from the roof of the house

Wind direction



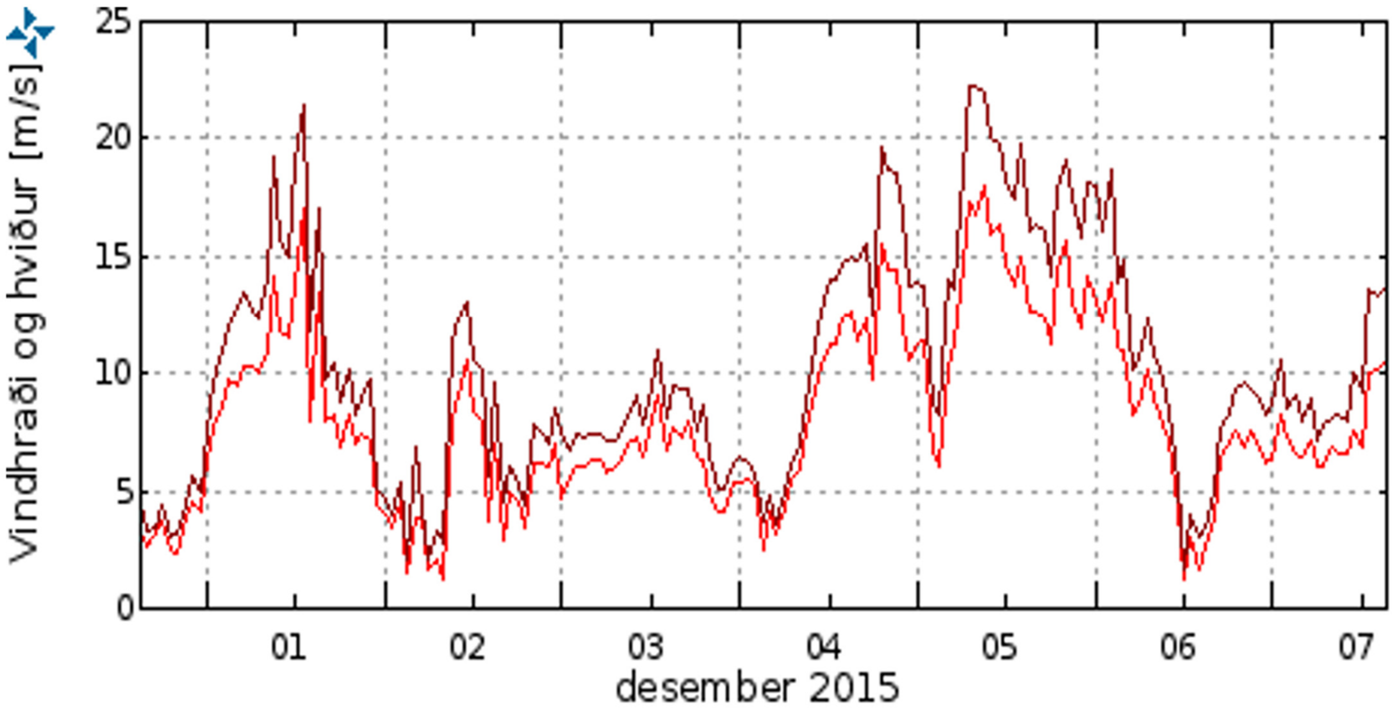
Mean: *131.1*

Min: *0.0*

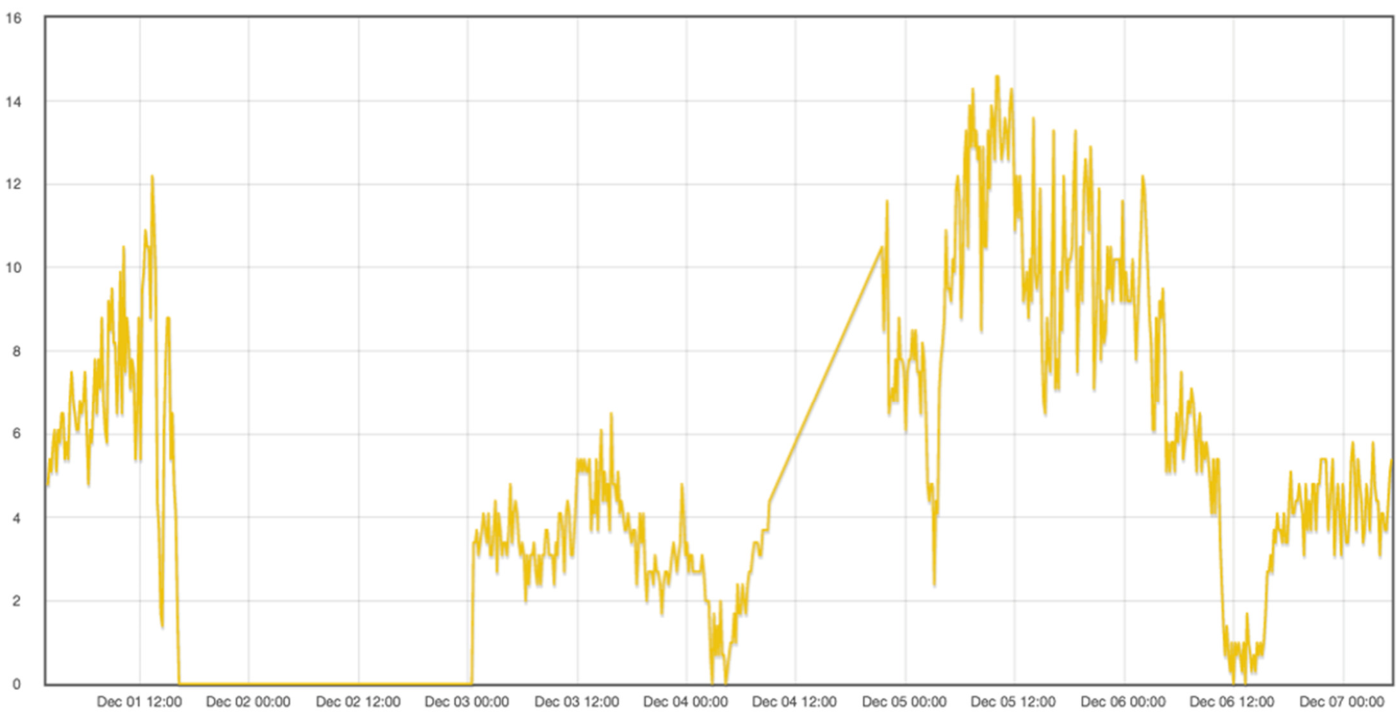
Max: *338.0*

Standard deviation: *126.5*

Windspeed and windgusts



Windspeed



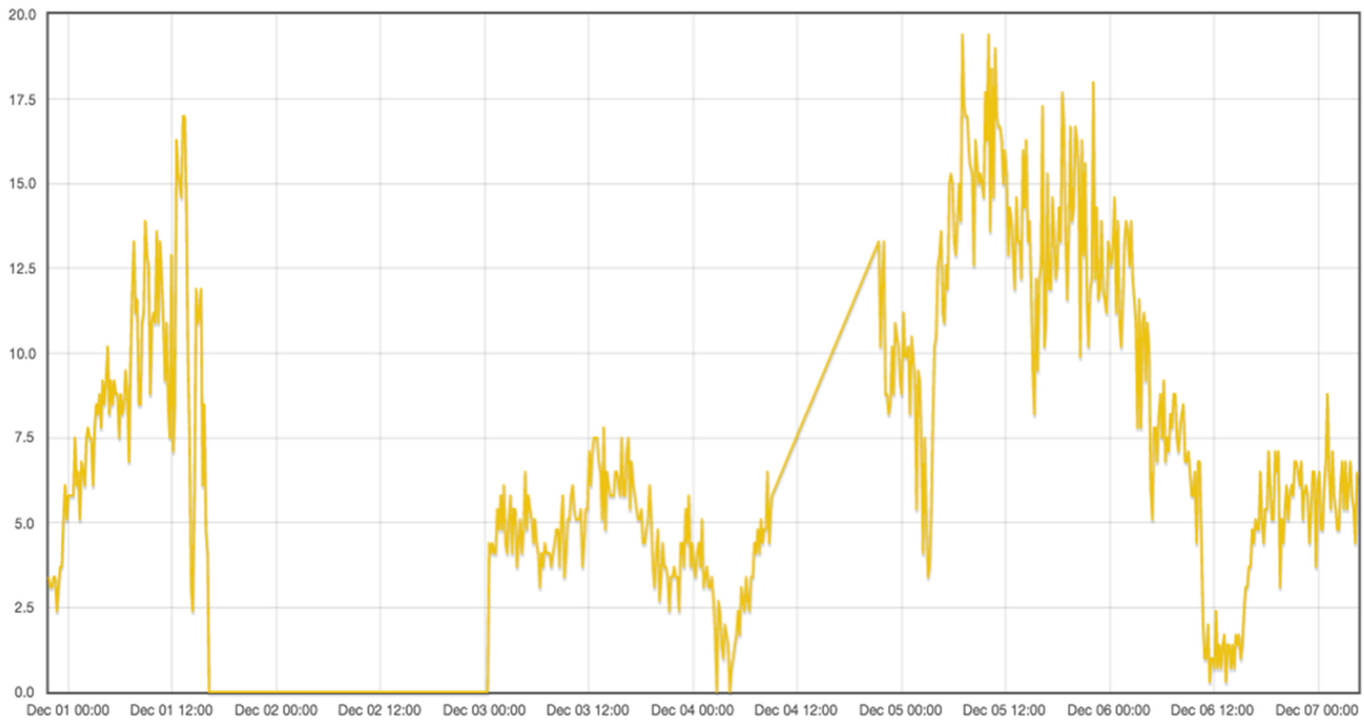
***Mean:** 5.2*

***Min:** 0.0*

***Max:** 14.6*

***Standard deviation:** 3.7*

Windgust



Mean: *6.9*

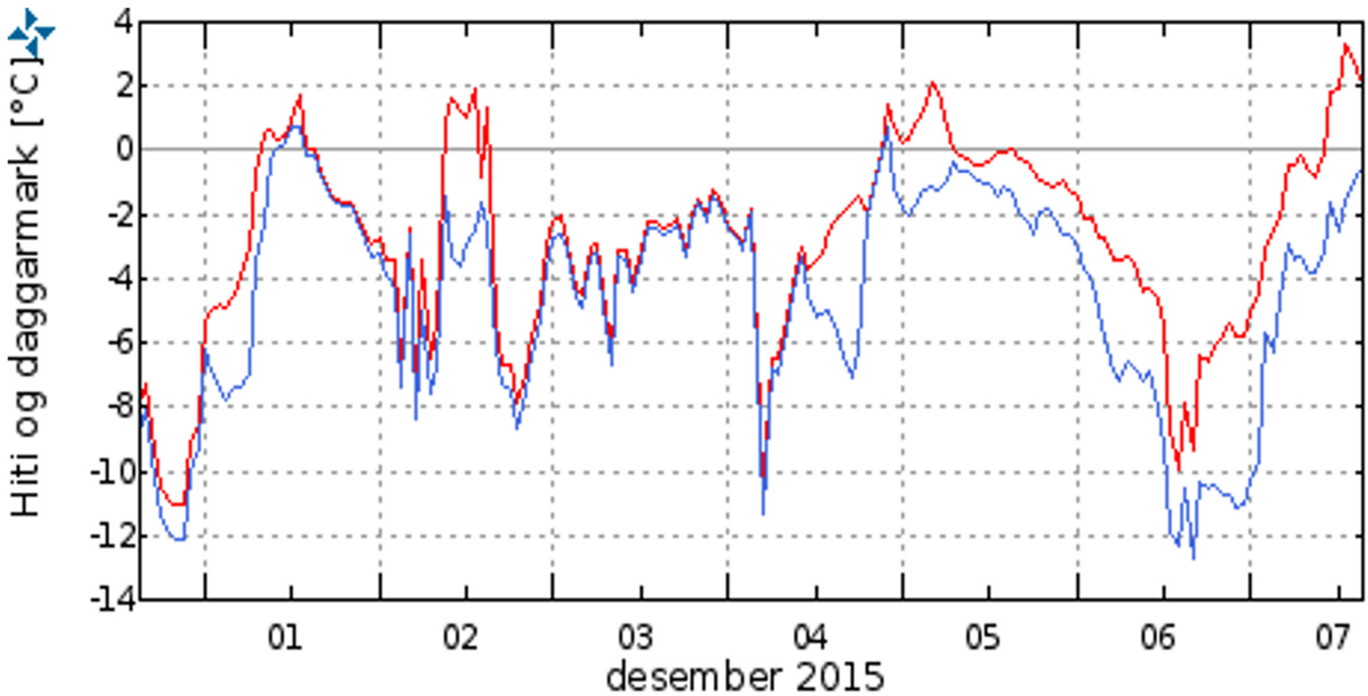
Min: *0.0*

Max: *19.4*

Standard deviation: *4.7*

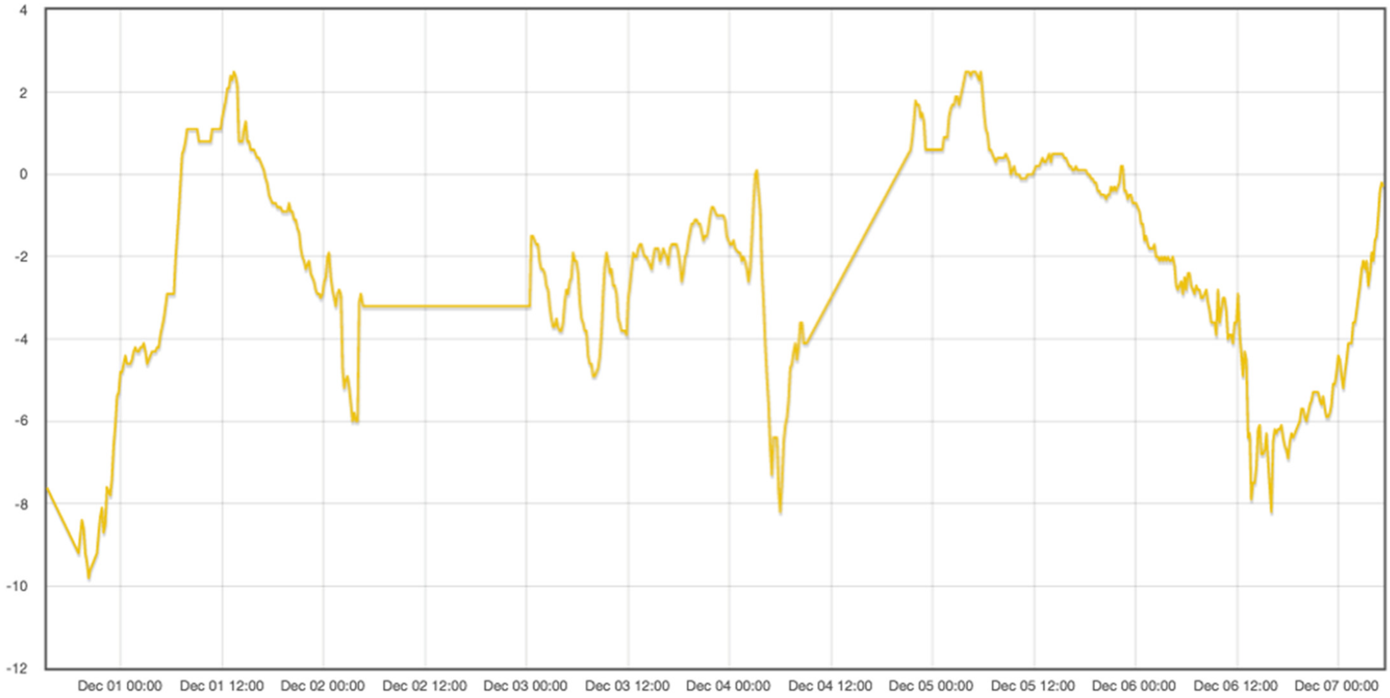
Icland MET office data from Eyrarbakki

Temperature and dewpoints



Weather station data from the roof of the house

Temperature



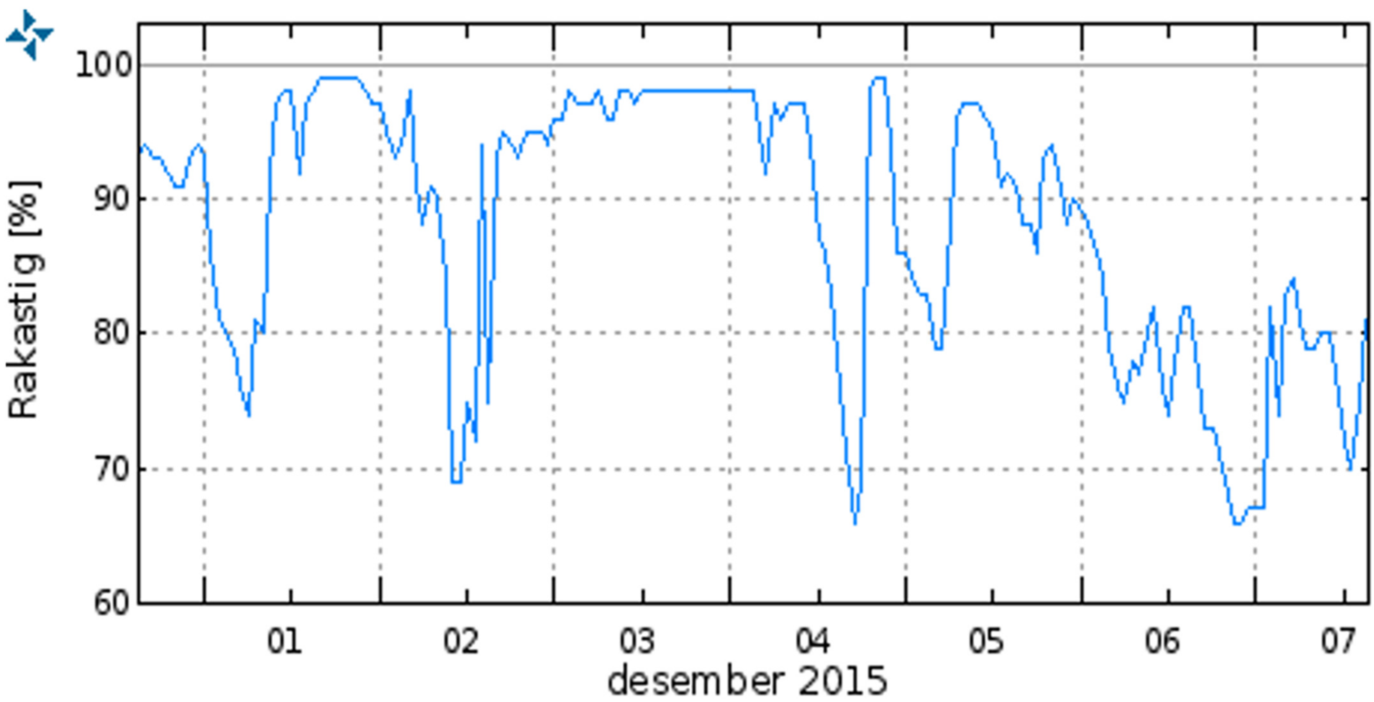
Mean: *-2.3*

Min: *-9.8*

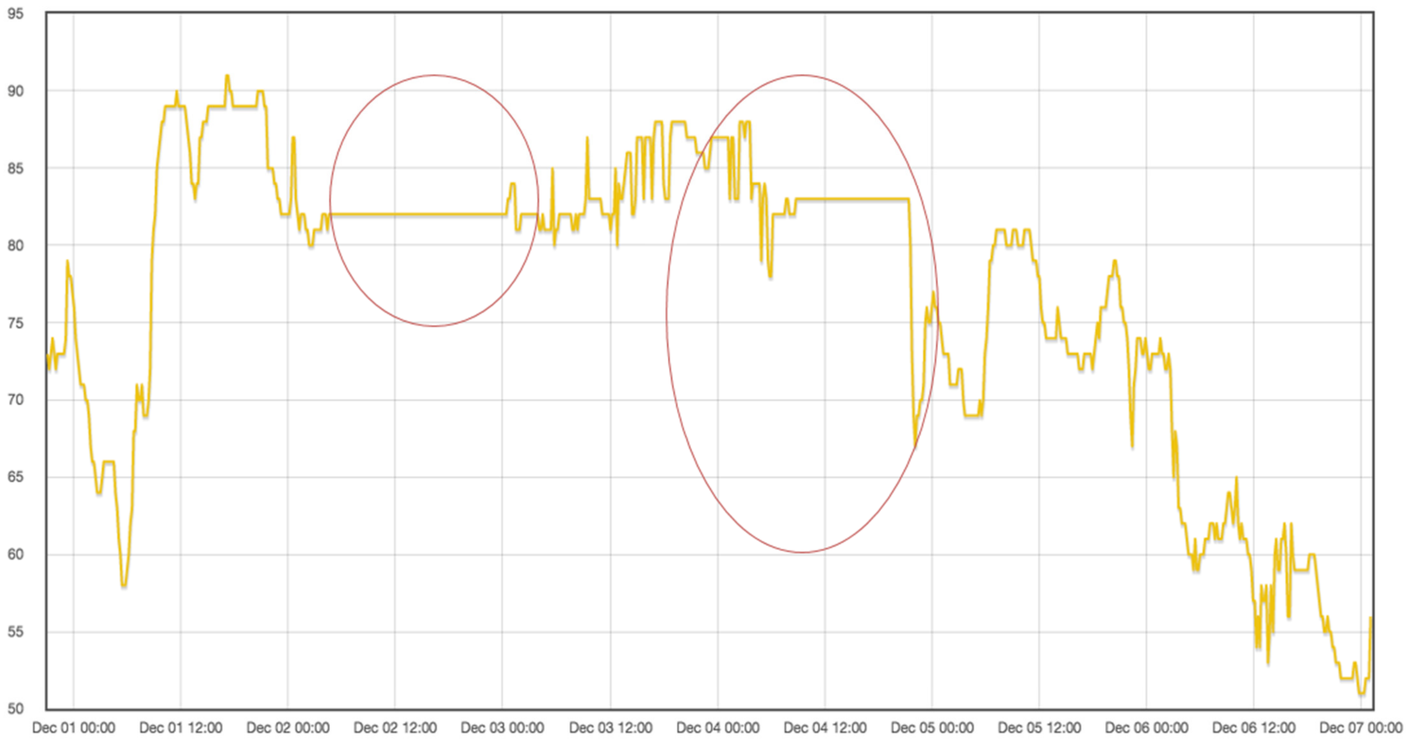
Max: *2.5*

Standard deviation: *2.7*

Outside airhumidity



Outside airhumidity



Mean: *75.6*

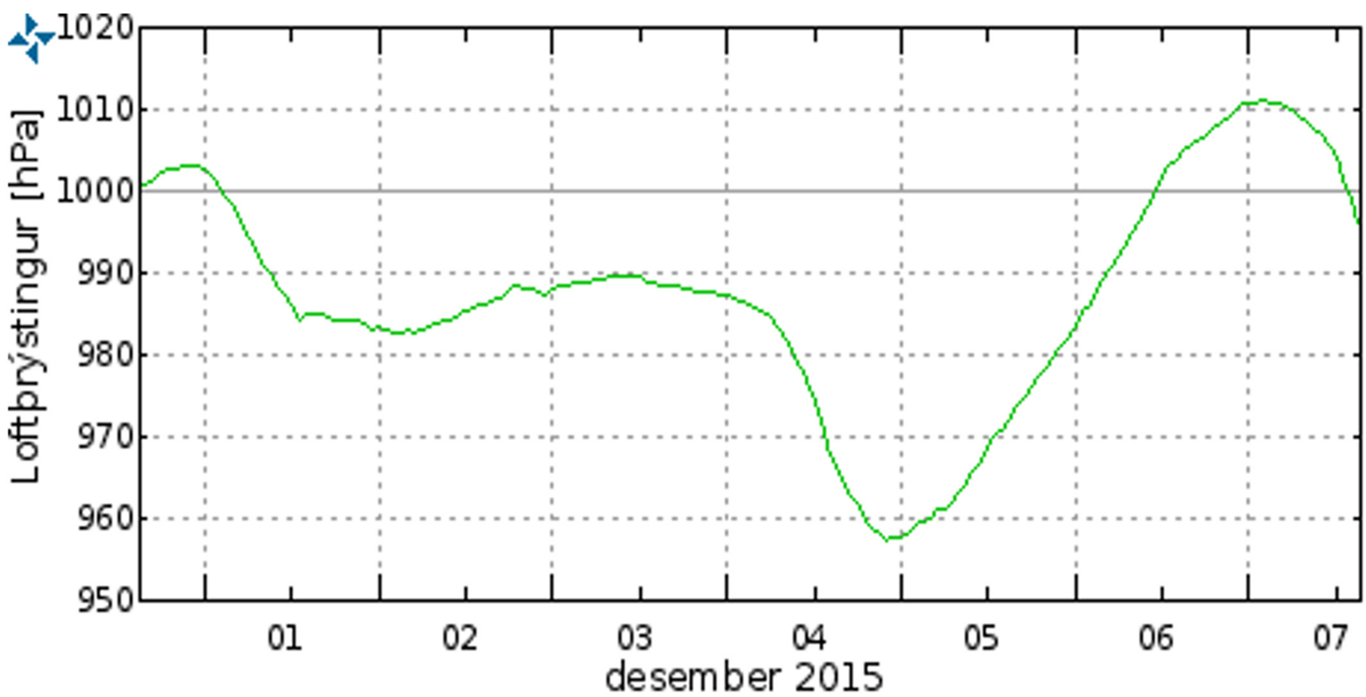
Min: *51.0*

Max: *91.0*

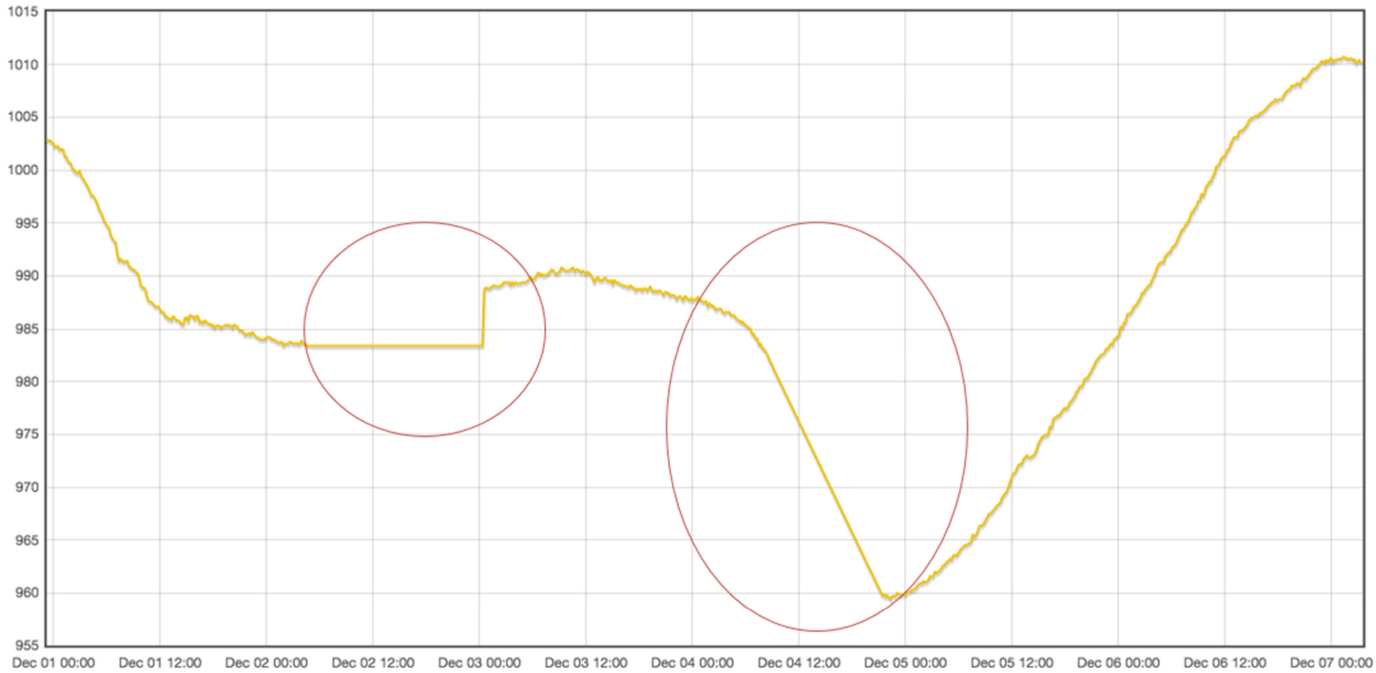
Standard deviation: *10.6*

Icland MET office data from Eyrarbakki

Barometric pressure



Weather station data from the roof of the house
Barometric pressure



Mean: *987.4*

Min: *959.4*

Max: *1010.7*

Standard deviation: *12.5*

Appendix 9. U-value calculation results on building envelope

Rockwool Energy Design 4.1

Dato: 25-11-2015

U-værdiberegning i henhold til DS 418
Konstruktion: **External light wall**
Konstruktionstype: Ydervæg

UDE INDE

	Producent	Navn	Tykkelse [m], antal	Lambda [W/(mK)]	Q	R [m²K/W]
	Rse (ude)					0,13
1	Generisk materiale	Stål	0,006	50,000	A	~~0,00~~
2	Generisk materiale	Ventileret lag	0,009	-	A	-
3	Inhomogent materialelag	bestående af:	0,150	0,038		3,92
	ROCKWOOL A/S	Super A-Murbatts	95,00%	0,034	A	-
	Luftspalte	Niveau 1: ΔU" = 0,01 W/(m²K)				
	Generisk materiale	Træ 450kg/m3	5,00%	0,120	A	-
4	Generisk materiale	PE-folie (hæftet fast) 0,15 mm	0,000	0,170	A	0,00
5	Generisk materiale	Krydsfiner, 700 kg/m3	0,009	0,170	A	0,05
6	Generisk materiale	Gips 13 mm	0,013	0,250	A	0,05
	Rsi (inde)					0,13
			0,187			**4,28**

Begrundelse for ændring af overgangsisolanser:

Byggematerialerne er grupperet i 3 klasser. Disse klasser er:
- A Data er indtastet og verificeret af ROCKWOOL A/S.
- B Data er indtastet og verificeret af andre producenter eller leverandører.
- C Egen indtastning af data.

U-værdikorrektion i henhold til DS 418
Korrektion for mekanisk fastgørelse dUf = 0,000 W/(m²K)
Korrektion for luftspalter dUg = 0,008 W/(m²K)

U = 1 / 4,28 + 0,000 + 0,008 = 0,24 W/(m²K)

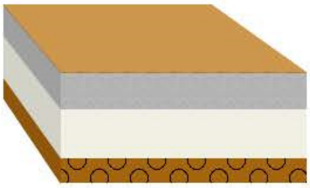
U_{max} = 0,30 W/(m²K) U = 0,24 W/(m²K)

Rockwool Energy Design 4.1

Dato: 25-11-2015

U-værdiberegning i henhold til DS 418
Konstruktion: **Floor slab**
Konstruktionstype: Gulv mod jord (0.5m over - 0.5m under terræn)

INDE



UDE

	Producent	Navn	Tykkelse [m], antal	Lambda [W/(mK)]	Q	R [m²K/W]
	Rsi (inde)					0,17
1	Generisk materiale	1 lag (1/4 tomme) træfiberplade	0,006	0,140	A	0,04
2	Generisk materiale	Armeret Beton (1% stål), 2300 kg/m3	0,150	2,440	A	0,06
3	Generisk materiale	Polystyren, ekspanderet 36	0,200	0,036	A	5,56
	Luftspalte	Niveau 0: ΔU" = 0,00 W/(m²K)				
4	Kapillarbrydende lag	indeholder:	-	-		0,97
	Leca A/S (Saint-Gobain WeberA/S)	Leca 10-20	0,100	~~0,090~~	A	-
	Lambda forøget	faktor 1,2 for 75mm	-	0,103		-
	Luftspalte	Niveau 0: ΔU" = 0,00 W/(m²K)				
	Rj (jord)					1,50
			0,456			**8,30**

Begrundelse for ændring af overgangsisolanser:

Byggematerialerne er grupperet i 3 klasser. Disse klasser er:

- A Data er indtastet og verificeret af ROCKWOOL A/S.
- B Data er indtastet og verificeret af andre producenter eller leverandører.
- C Egen indtastning af data.

U-værdikorrektion i henhold til DS 418
Korrektion for mekanisk fastgørelse — dUf = 0,000 W/(m²K)
Korrektion for luftspalter — dUg = 0,000 W/(m²K)

U = 1 / 8,30 + 0,000 + 0,000 = 0,12 W/(m²K)

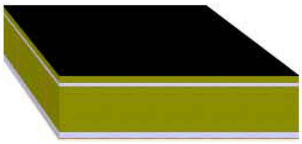
U_{max} = 0,20 W/(m²K) U = 0,12 W/(m²K)

Rockwool Energy Design 4.1

Dato: 25-11-2015

U-værdiberegning i henhold til DS 418
Konstruktion: **Roof construction**
Konstruktionstype: Tag med hældning <= 60

UDE



INDE

	Producent	Navn	Tykkelse [m], antal	Lambda [W/(mK)]	Q	R [m²K/W]
	Rse (ude)					0,04
	Begrænsningen i R-værdien skyldes det svagt ventilerede luftlag					0,15
1	Generisk materiale	Tagpap	0,008	0,230	A	~~0,03~~
2	Rockwool A/S	FlexiBatts	0,030	0,037	A	~~0,81~~
	Luftspalte	Niveau 0: ΔU" = 0,00 W/(m²K)				
3	DS 418	Svagt ventileret, vandret varmestrøm	0,017	-	A	0,09
4	Inhomogent materialelag	bestående af:	0,195	0,041		4,74
	Rockwool A/S	FlexiBatts	95,00%	0,037	A	-
	Luftspalte	Niveau 0: ΔU" = 0,00 W/(m²K)				
	Generisk materiale	Træ 450 kg/m3	5,00%	0,120	A	-
5	Generisk materiale	Polyethylen film 0,15 mm	0,000	0,170	A	0,00
6	DS 418	Ikke ventileret, vandret varmestrøm	0,025	-	A	0,18
7	Generisk materiale	Krydsfiner, 700 kg/m3	0,009	0,170	A	0,05
8	Generisk materiale	Gips 13 mm	0,013	0,250	A	0,05
	Rsi (inde)					0,10
			0,297			**5,40**

Begrundelse for ændring af overgangsisolanser:

Byggematerialerne er grupperet i 3 klasser. Disse klasser er:

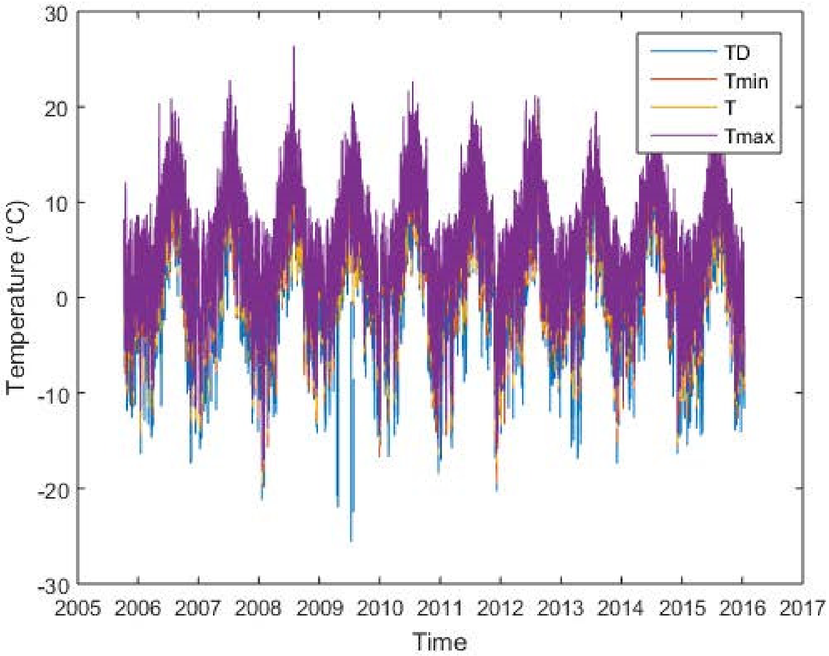
- A Data er indtastet og verificeret af ROCKWOOL A/S.
- B Data er indtastet og verificeret af andre producenter eller leverandører.
- C Egen indtastning af data.

U-værdikorrektion i henhold til DS 418
Korrektion for mekanisk fastgørelse — dUf = 0,000 W/(m²K)
Korrektion for luftspalter — dUg = 0,000 W/(m²K)

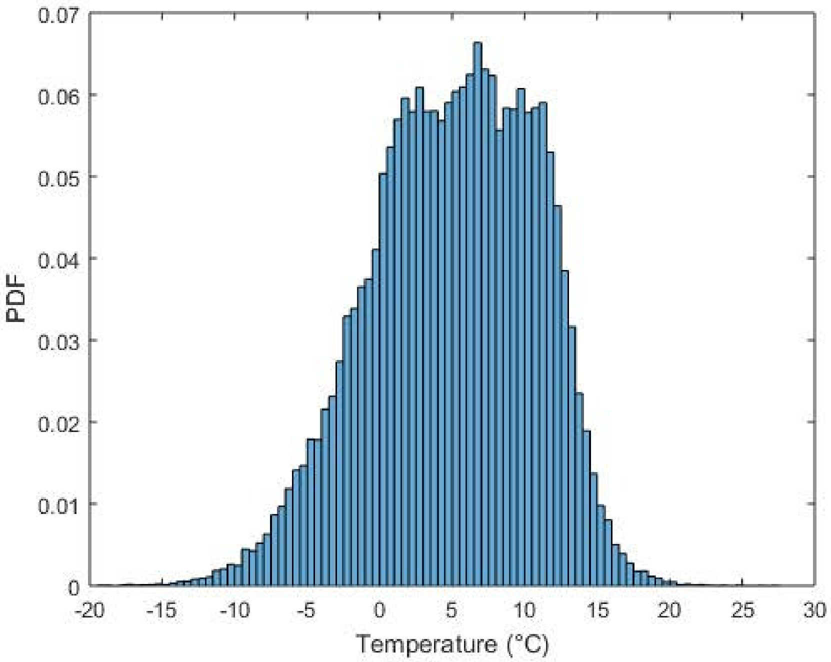
U = 1 / 5,40 + 0,000 + 0,000 = 0,19 W/(m²K)

U_{max} = 0,20 W/(m²K) — U = 0,19 W/(m²K)

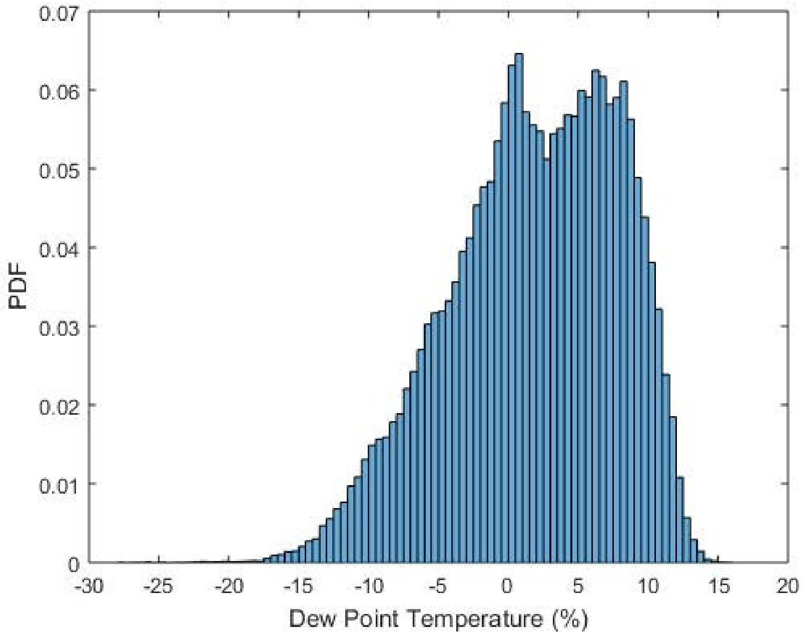
Appendix 10. Weather data from IMO on Eyrarbakki

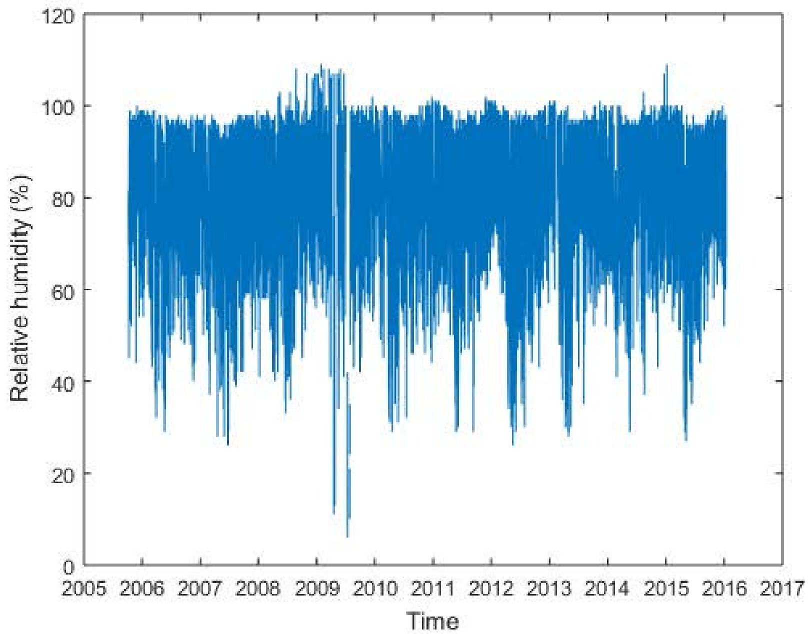


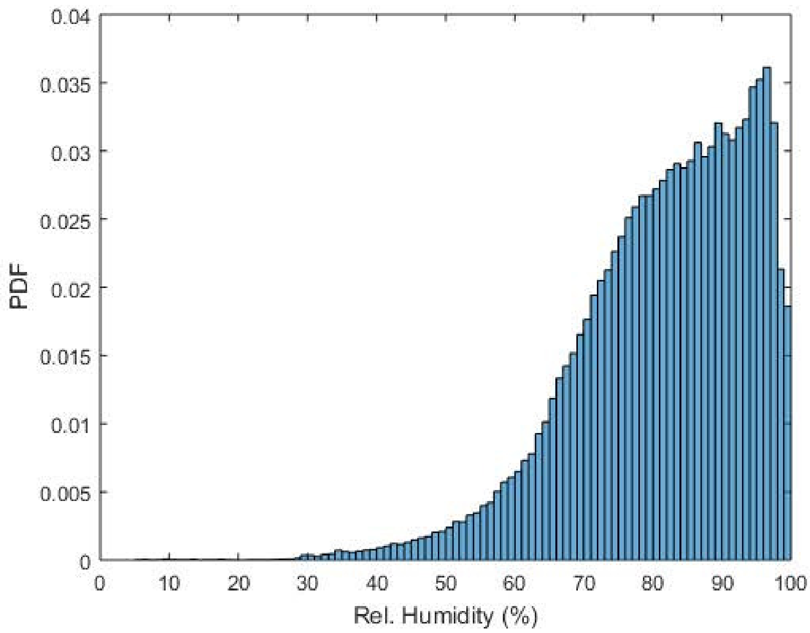
TD
Tmin
T
Tmax
Temperature (°C)
Time



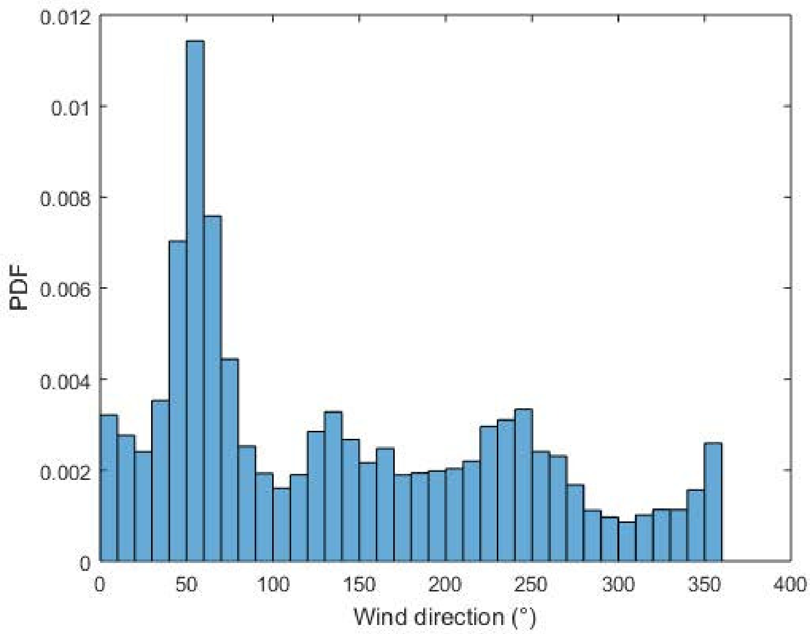
PDF
Temperature (°C)


PDF
Dew Point Temperature (%)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-30
-25
-20
-15
-10
-5
0
5
10
15
20

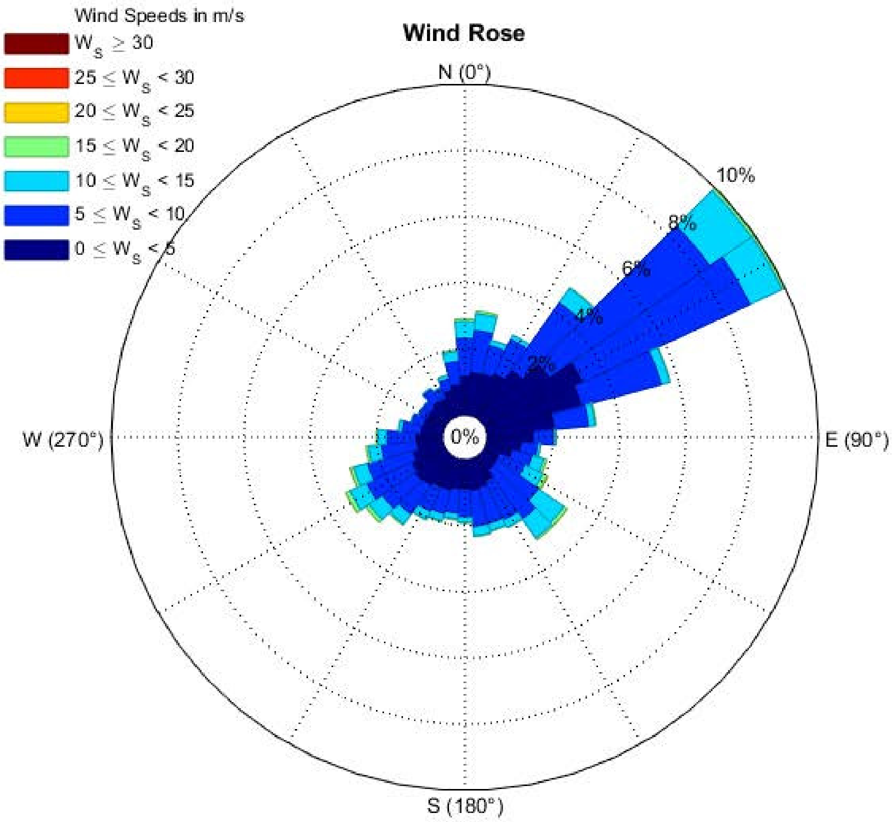

Relative humidity (%)
Time
120
100
80
60
40
20
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

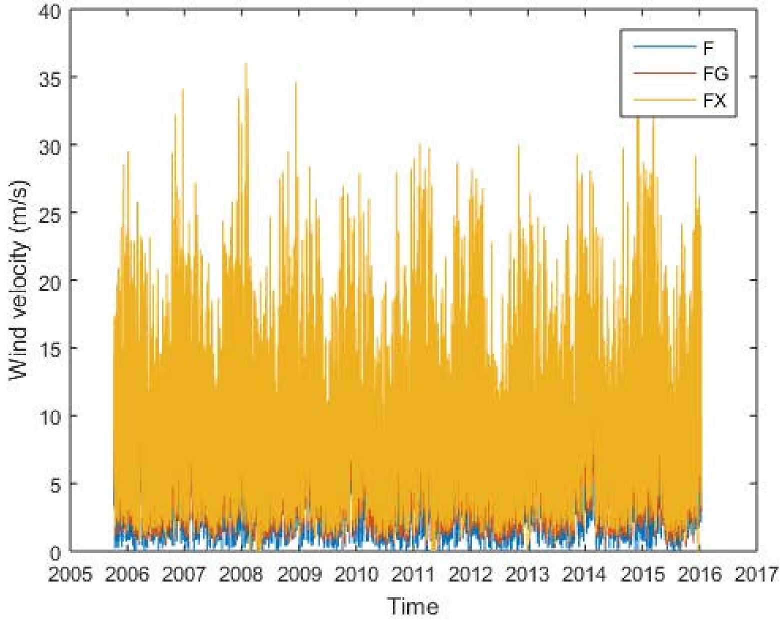


0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
PDF
0
10
20
30
40
50
60
70
80
90
100
Rel. Humidity (%)

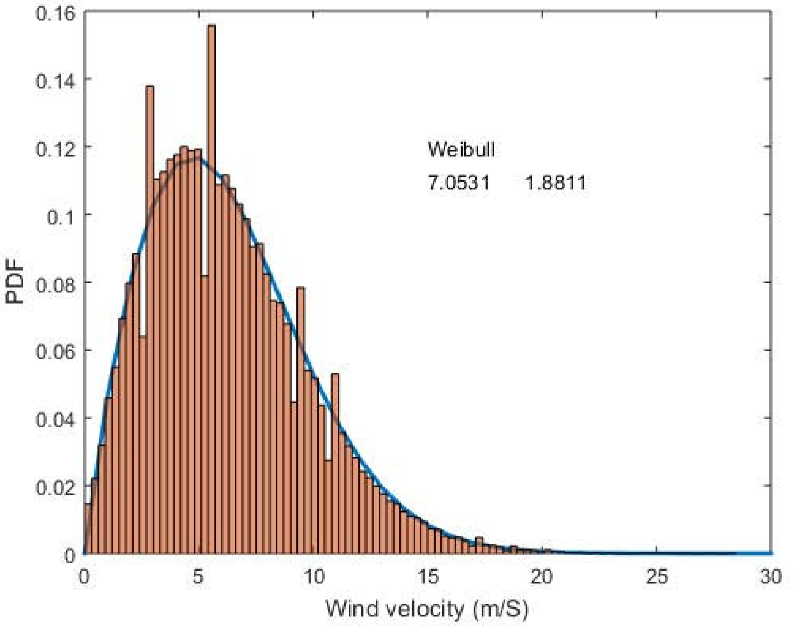


0.012
0.01
0.008
0.006
0.004
0.002
0
PDF
0
50
100
150
200
250
300
350
400
Wind direction (°)

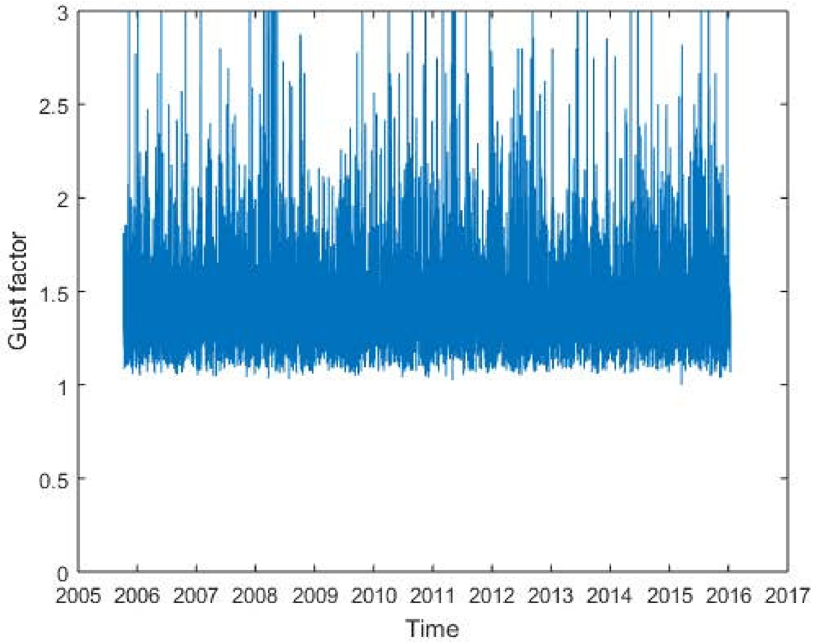

Wind Speeds in m/s
$W_s \geq 30$
$25 \leq W_s < 30$
$20 \leq W_s < 25$
$15 \leq W_s < 20$
$10 \leq W_s < 15$
$5 \leq W_s < 10$
$0 \leq W_s < 5$
Wind Rose
N (0°)
E (90°)
S (180°)
W (270°)
0%
2%
4%
6%
8%
10%

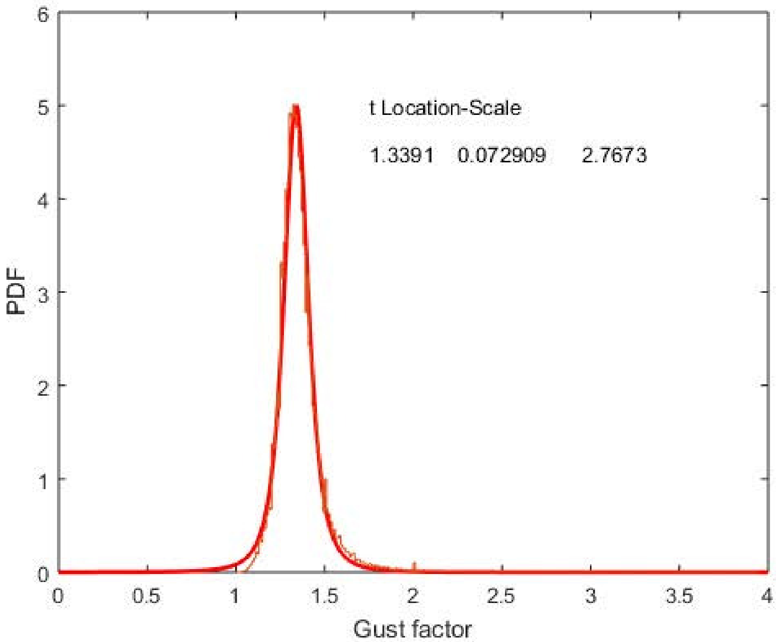


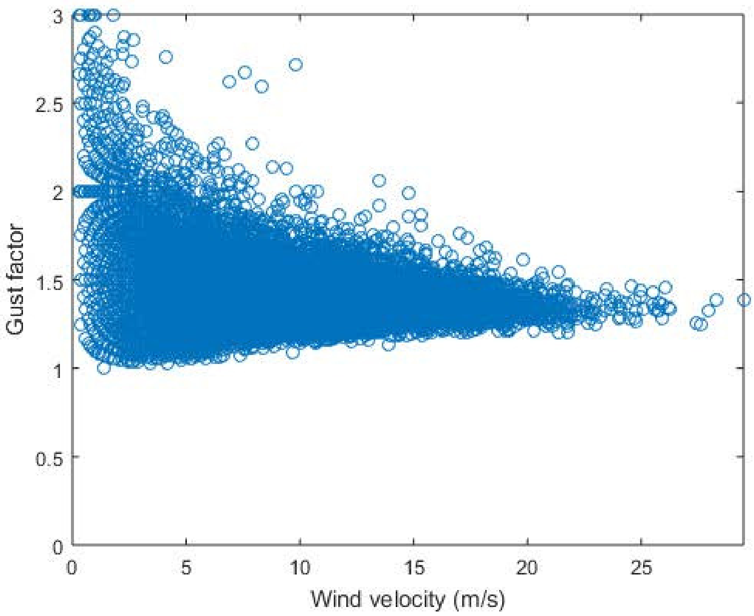
Wind velocity (m/s)
Time
F
FG
FX
0
5
10
15
20
25
30
35
40
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

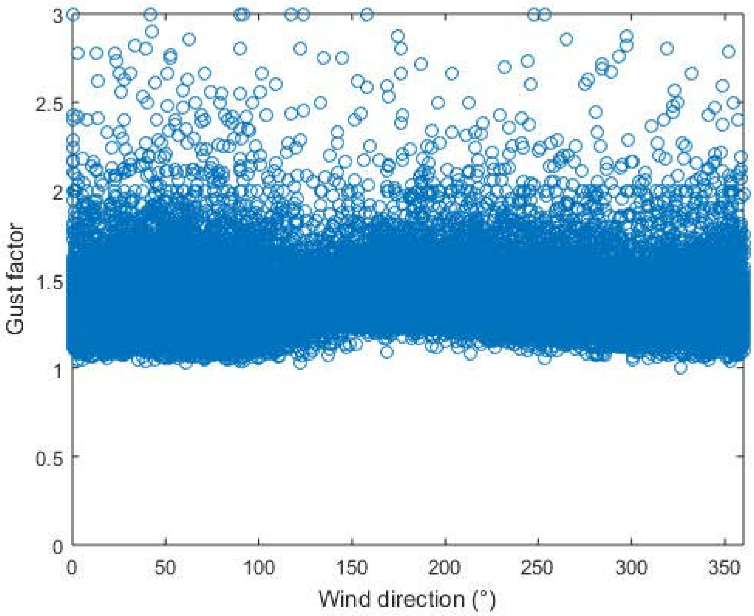


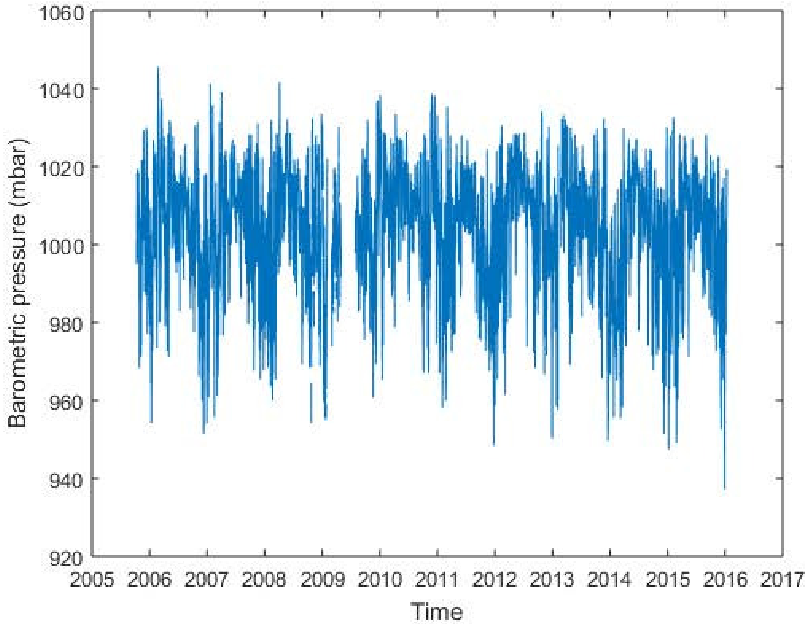
PDF
Wind velocity (m/S)
Weibull
7.0531 1.8811
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0
5
10
15
20
25
30

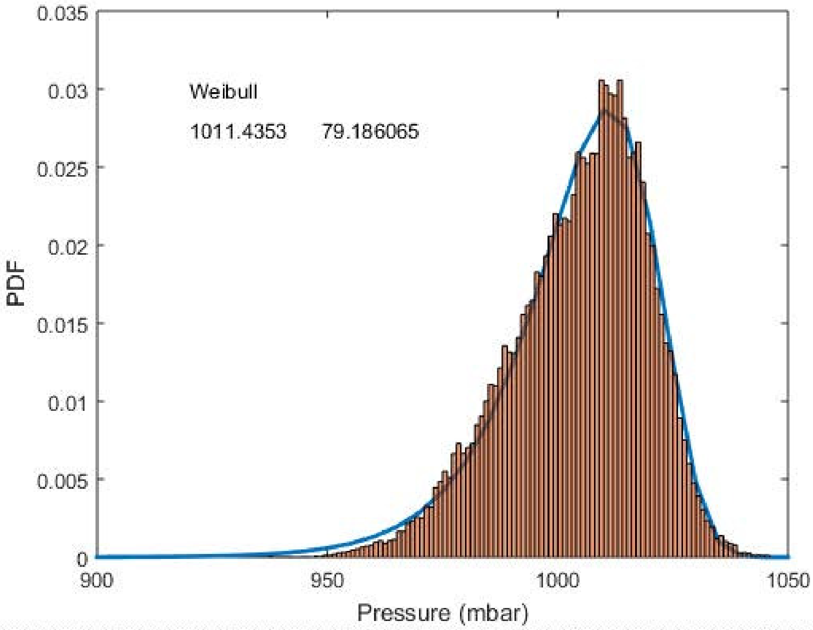

Gust factor
Time
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017


t Location-Scale
1.3391 0.072909 2.7673
PDF
Gust factor


Gust factor
Wind velocity (m/s)


Gust factor
Wind direction (°)





Published with MATLAB® R2015a

Appendix 11. Results from Autodesk Revit and GBS calculation

AUTODESK.

Eyrarbakki THIS ONE!

Eyrarbakki THIS ONE! Analysis (Only heating!) (3)

Analyzed at 1/14/2016 11:52:36 AM

Energy Analysis Result

Building Performance Factors

Location:	Sveitarfélagið Árborg, Sudhurland
Weather Station:	126481
Outdoor Temperature:	Max: 14°C/Min: 4°C
Floor Area:	106 m²
Exterior Wall Area:	99 m²
Average Lighting Power:	10.76 W / m²
People:	1 people
Exterior Window Ratio:	0.30
Electrical Cost:	$0.14 / kWh
Fuel Cost:	$0.14 / Therm

Energy Use Intensity

Electricity EUI:	140 kWh / sm / yr
Fuel EUI:	62 MJ / sm / yr
Total EUI:	566 MJ / sm / yr

Life Cycle Energy Use/Cost

Life Cycle Electricity Use:	444,169 kWh
Life Cycle Fuel Use:	197,918 MJ
Life Cycle Energy Cost:	$27,831

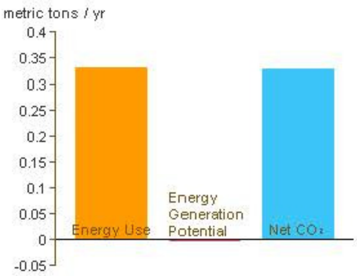
*30-year life and 6.1% discount rate for costs

Renewable Energy Potential

Roof Mounted PV System (Low efficiency):	2,985 kWh / yr
Roof Mounted PV System (Medium efficiency):	5,970 kWh / yr
Roof Mounted PV System (High efficiency):	8,954 kWh / yr
Single 15' Wind Turbine Potential:	19,423 kWh / yr

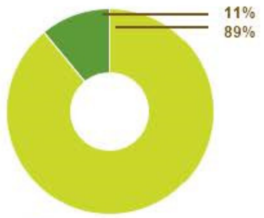
*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems

Annual Carbon Emissions



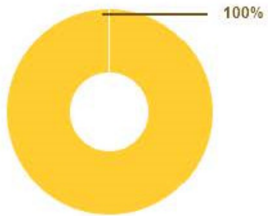
	(metric tons / yr)
Electricity Consumption	0
Fuel Consumption	0
Roof PV Potential (High Efficiency)	0
Single 15' Wind Turbine Potential	0
Net CO_2	0

Annual Energy Use/Cost



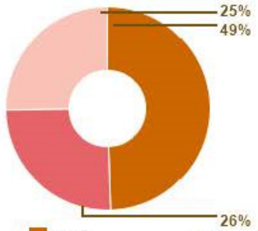
Electricity	89%	$2,034	14,805	kWh
Fuel	11%	$9	6,597	MJ
		$2,043		

Energy Use: Fuel



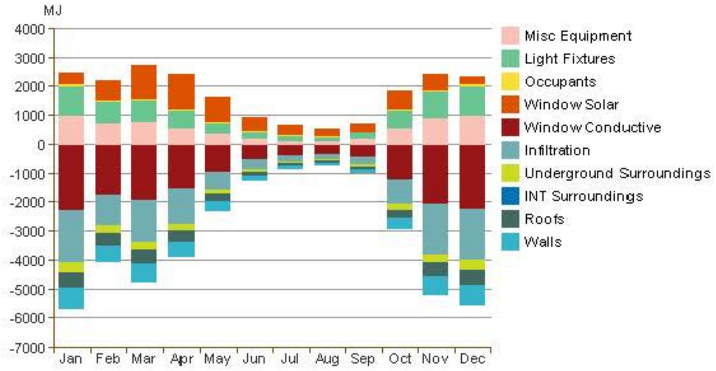
			(MJ)
HVAC	0%	$0	0
Domestic Hot Water	100%	$9	6,597
		$9	6,597

Energy Use: Electricity

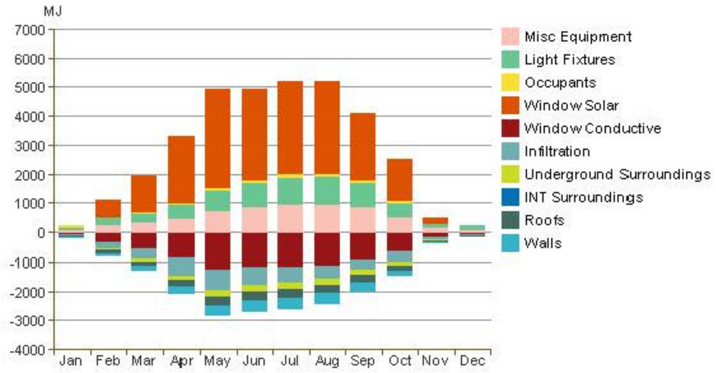


			(kWh)
HVAC	49%	$1,006	7,328
Lighting	26%	$513	3,739
Misc Equipment	25%	$513	3,737
		$2,032	14,804

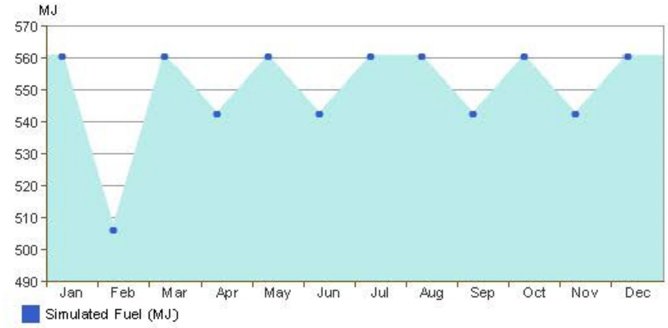
Monthly Heating Load



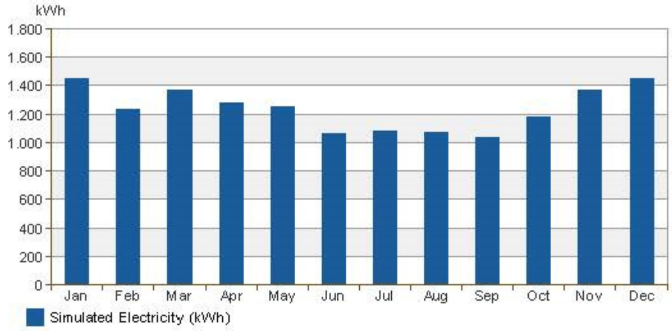
Monthly Cooling Load



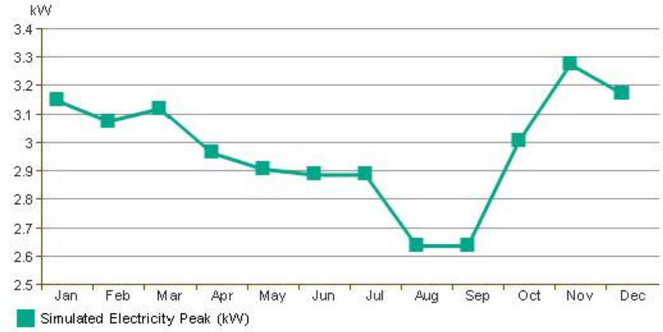
Monthly Fuel Consumption



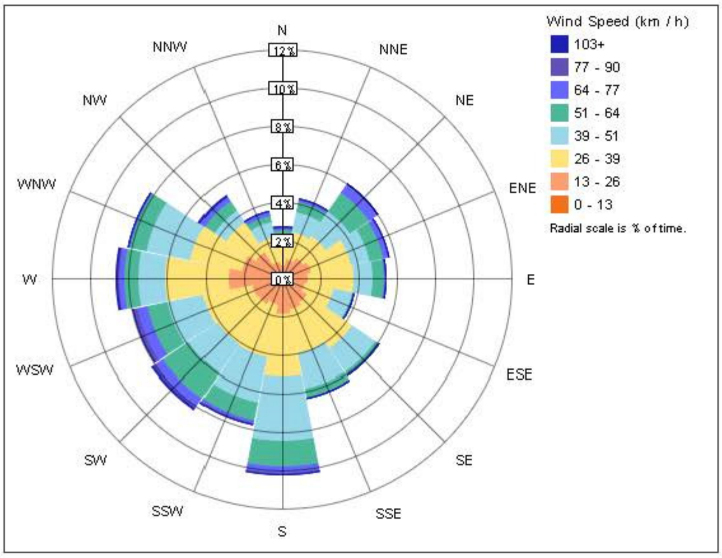
Monthly Electricity Consumption



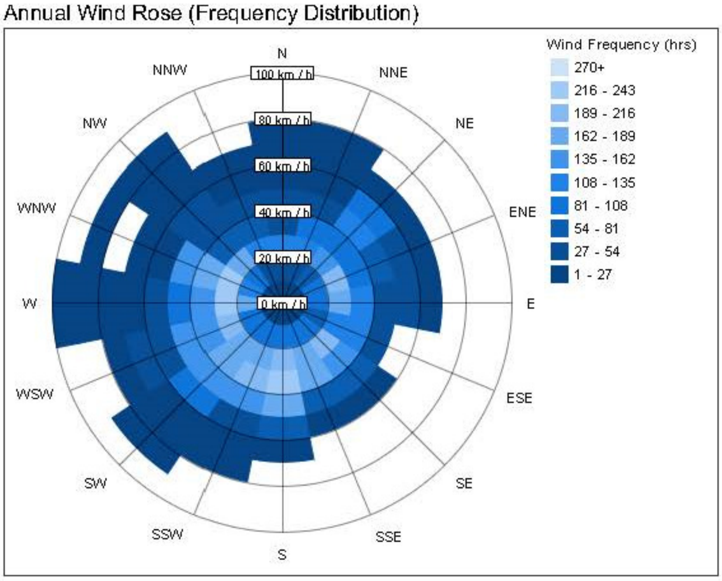
Monthly Peak Demand



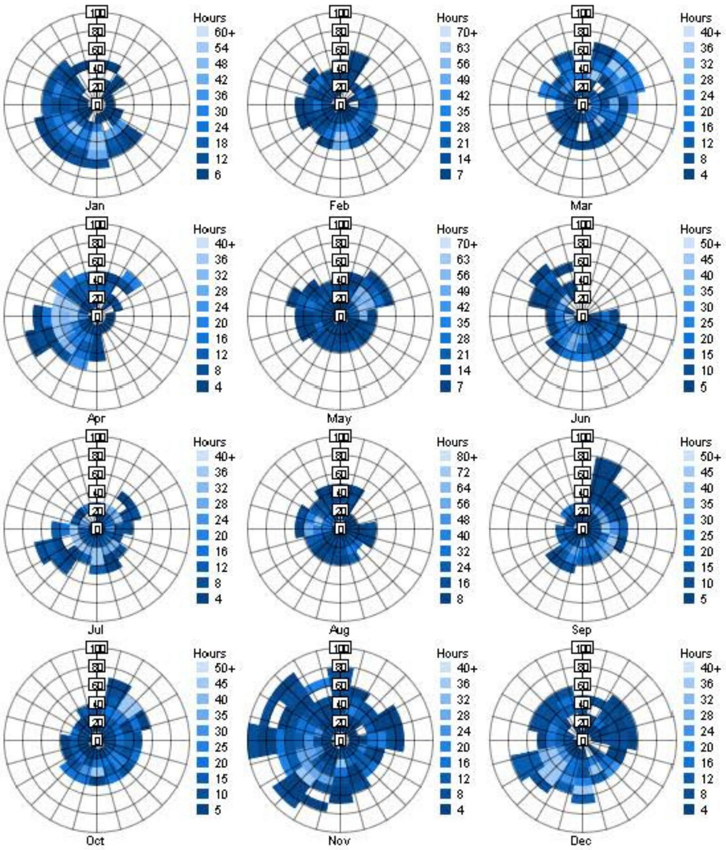
Annual Wind Rose (Speed Distribution)



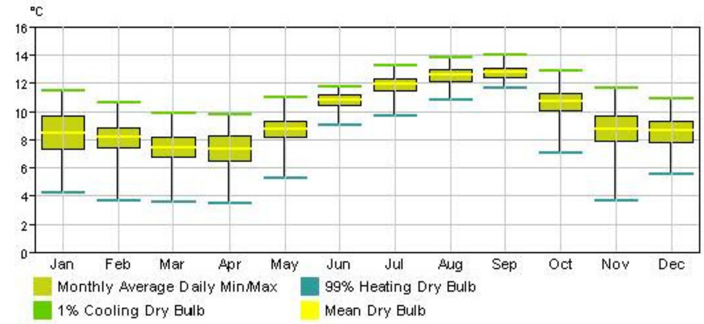
Annual Wind Rose (Frequency Distribution)



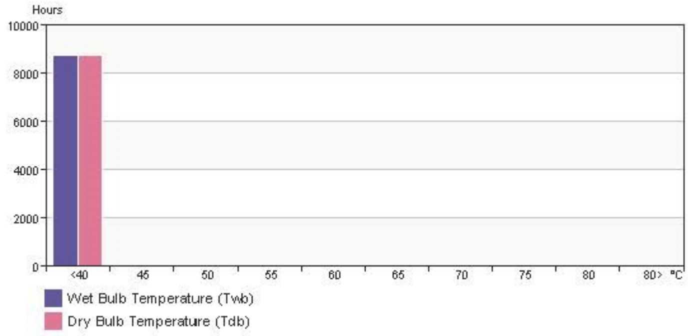
Monthly Wind Roses



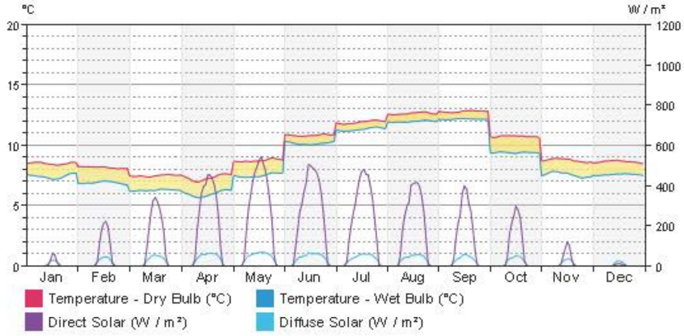
Monthly Design Data



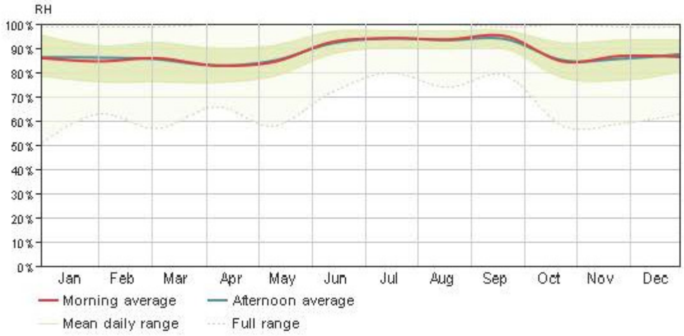
Annual Temperature Bins



Diurnal Weather Averages



Humidity



Energy Analysis Data

Appendix 12. As built drawings of the house

Skráningartafla:	Túngata 9, Eyrarbakka.						Skrásetjari:	Ásgeir Leifsson									
Landnúmer:	204208						Kennitala:	090741-2259									
Matshlutanúmer:	01				Útgáfa: 4.01b		Dags.:	6/10/10									
Uppskipting og lýsing					**Stærðir**												
D0 Lokun	D1 Rými hæð-röð	D2 Notkun texti	D3 Höfuð-flokkun	D4 Eignar-hald	D5 Botnflötur m²	D5M Milliflötur m²	D6 Stigar m²	D7 Op m²	D8 Brúttóflötur m²	D9 Brúttóflötur sh < 1.8	D10a Salarhæð min	D10b Salarhæð max	D11 Brúttó rúmmál m³	D12 Nettóflötur m²	D16 Birt flatarmál m²	Reiknitala skiptarúmmáls	D17 Skipta-rúmmál m³
		Matshluti			127.0	0.0	0.0	0.0	127.0	0.0			425.4	105.9	127.0		333.563
		Botn											25.8				
	01	**1. hæð**			127.0	0.0	0.0	0.0	127.0	0.0			399.6	105.9	127.0		
A	0101	**Íbúð**	N	0101	98.1				98.1		2.70	3.70	313.9	83.0	98.1	3.20	265.600
A	0102	**Inntök/geymsla**	T	0101	6.1				6.1		2.70	3.00	17.1	4.6	6.1	2.80	12.880
A	0103	**Bílskúr**	B	0101	22.8				22.8		2.70	3.30	68.6	18.3	22.8	3.01	55.083
B	0104	**Skyggni**	U	0101	2.7				2.7								
B	0105	**Skyggni**	U	0101	5.0				5.0								

Athugasemdir

Sameignir sumra

Eignarhald

	Eignar-hald	Notkun texti	Birt flatarmál m²	Skiptarúmmál: Séreign m³	Skiptarúmmál: Séreign og sameign m³
	0101	**Íbúð**	127.0	333.563	333.563
		Alls	127.0	333.563	333.563

BYGGINGARLÝSING

Stærðir
Stærð lóðar að Túngötu 9 er 839,3 m².
Staðgreinir: 8200-5-88950090
Landnúmer: 204 208.
Brúttó flatarmál byggingarinnar er: 127,0 m². Brúttó rúmmál er 425,4 m³. Nýtingarhlutfall er 0,15. Á lóðinni er gert ráð fyrir 2 bílastæðum.
Notkun byggingar
Byggingin er íbúðarhús, hannað sérstaklega með þarfir hreyfihamlaðra í huga.
Almennt
Grunnplata hússins er staðsteypt, yfirbygging er úr timbri, einangrað í 150 mm grind með 150 mm steinull og klætt að utan með krossviði og báraðri málmklæðningu á langbönd og timbri en að innan með krossviði á lagnagrind og gifsplötum. Allar klæðningar innan- og utanhúss verða í flokki 1.
Milliveggir
Milliveggir eru úr timbri og blikkstoðum, einangraðir og klæddir með krossviði og gifsplötum. Í baðherbergjum, eldhúsi og þvottaaðstöðu eru rakaþolnar gifsplötur, klæddar með flísum þar sem mest mæðir á.
Gólf
Gólf er staðsteypt og klætt með parketi og flísum.
Þak
Burðarbitar þaks eru úr timbri, einangrað milli bita með 225 mm steinull og klætt að ofan með krossviði, 50 mm steinull og þakdúk. Frágangur þaka skal vera samkvæmt verklýsingu og fyrirmælum framleiðanda þakefnis.
U-gildi byggingar
Byggingin skal einangruð amk. í samræmi við gr. 13.3.2 í byggingarreglugerð.
Einangra skal botnplötu með amk 150 mm frauðplasti.
Tvöfalt k-gler er í öllum gluggum.
Loftræsing / hitun
Gólfhitun er í öllu húsinu frá hitaveitu.
Bygginguna skal loftræsa amk. samkv. gr. 10.2.5 og 10.2.6 í byggingarreglugerð. Loftræsing er annars vegar náttúruleg um opnanlega glugga og innganga en hins vegar er vélrænt útsog úr öllum gluggalausum rýmum.

Útfærslur skulu að öðru leyti uppfylla ákvæði byggingarreglugerðar. Allt litaval skal vera í samráði við arkitekta. Innréttingar sýndar á teikningum gefa aðeins hugmynd að endanlegri útfærslu.

SKIPULAGS- ARKITEKTA- OG VERKFRÆÐISTOFAN ehf.
Garðastræti 17.
101, Reykjavík
kt:701294-8909
sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is

Hönnun:
Gestur Ólafsson
081241-4499

Zoltán Vilmos Horváth
230476-5439

Verk:
Túngata 9.
820 Eyrarbakki

Verknúmer:
027

Teikning:
AFSTÖÐUMYND

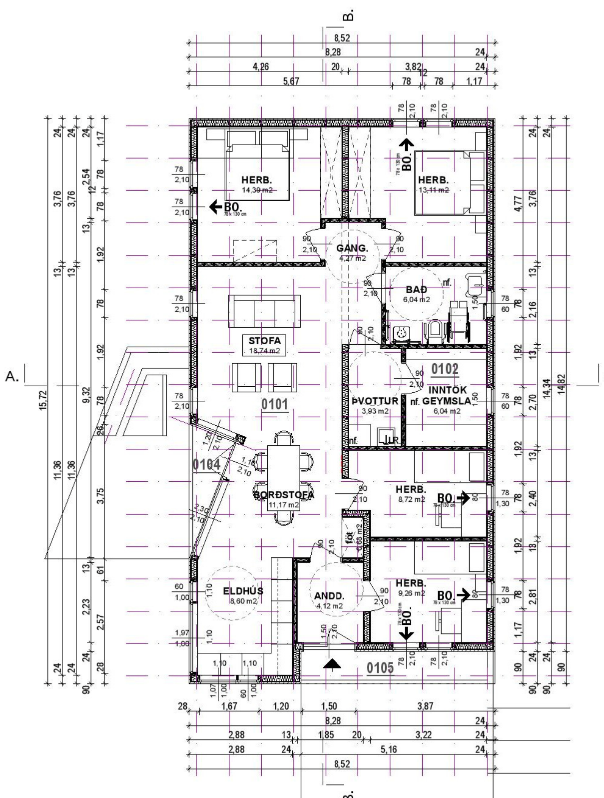
Kvarði:
1:500

Hönnunarstig:
BYGGINGARTEIKNING

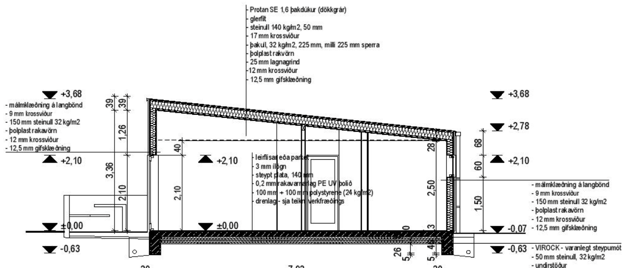
Dags:
11. 06. 2010

Breytt:
13. 12. 2010
28. 06. 2012

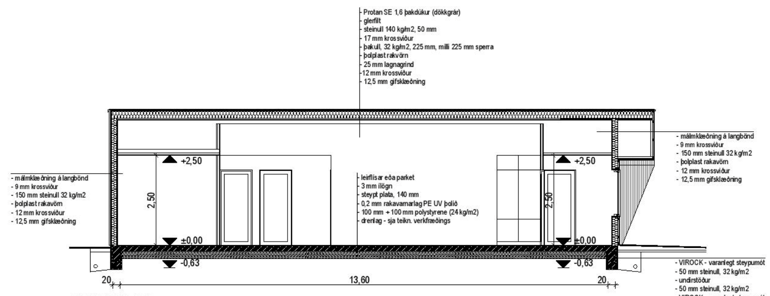
Teikn:
A-01



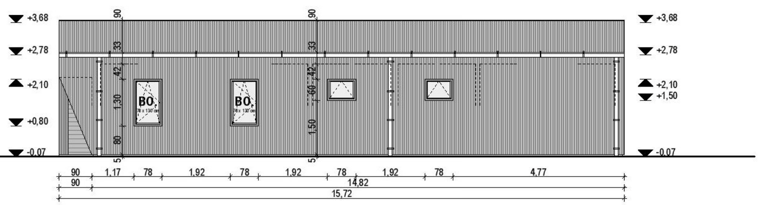
GRUNNMYND



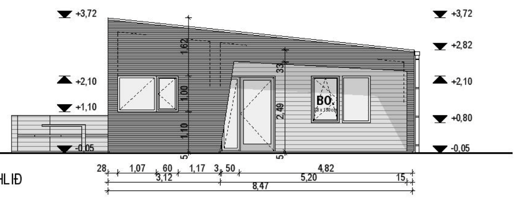
SKURÐUR A-A



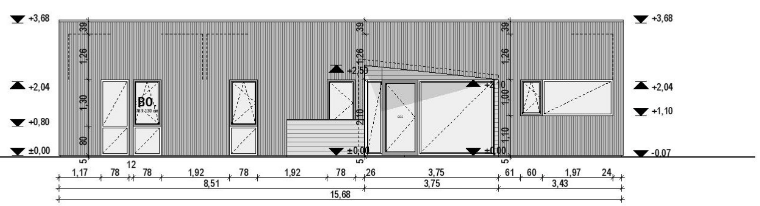
SKURÐUR B-B



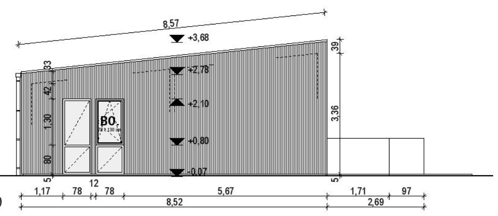
NORÐURHLIÐ



AUSTURHLIÐ



SUÐURHLIÐ



VESTURHLIÐ

SKIPULAGS- ARKITEKTA- OG VERKFRÆÐISTOFAN ehf.
Garðastræti 17.
101, Reykjavík
kt:701294-8909
sími: (+354) 561-6577
fax: (+354) 561-6571
skipark@skipark.is

Hönnun:
Gestur Ólafsson
081241-4499

Zoltán Vilmos Horváth
230476-5439

Verk:
Túngata 9.
820 Eyrarbakki

Verknúmer:
027

Teikning:
GRUNNMYND, HILÐAR, SKURÐIR

Kvarði:
1:100

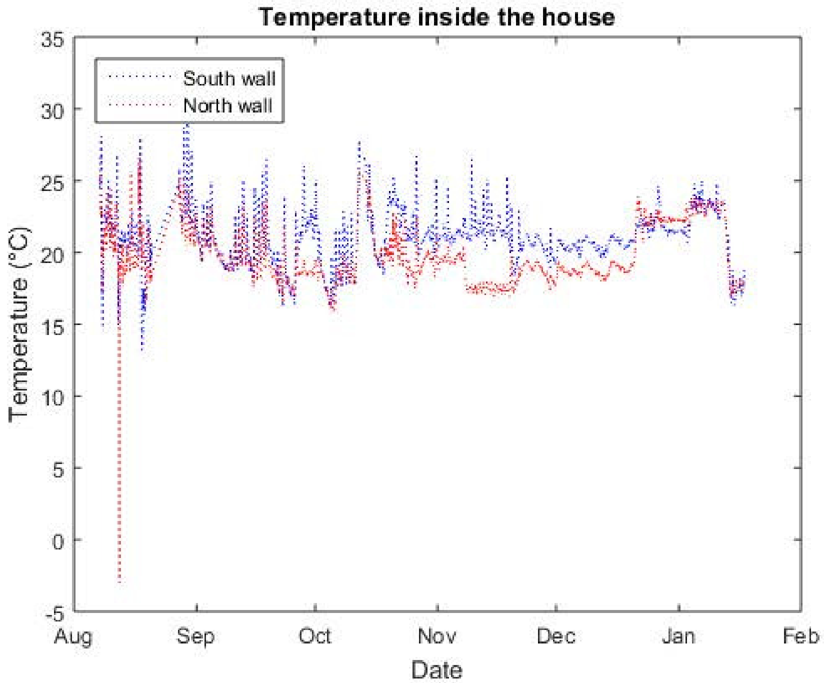
Hönnunarstig:
BYGGINGARTEIKNING

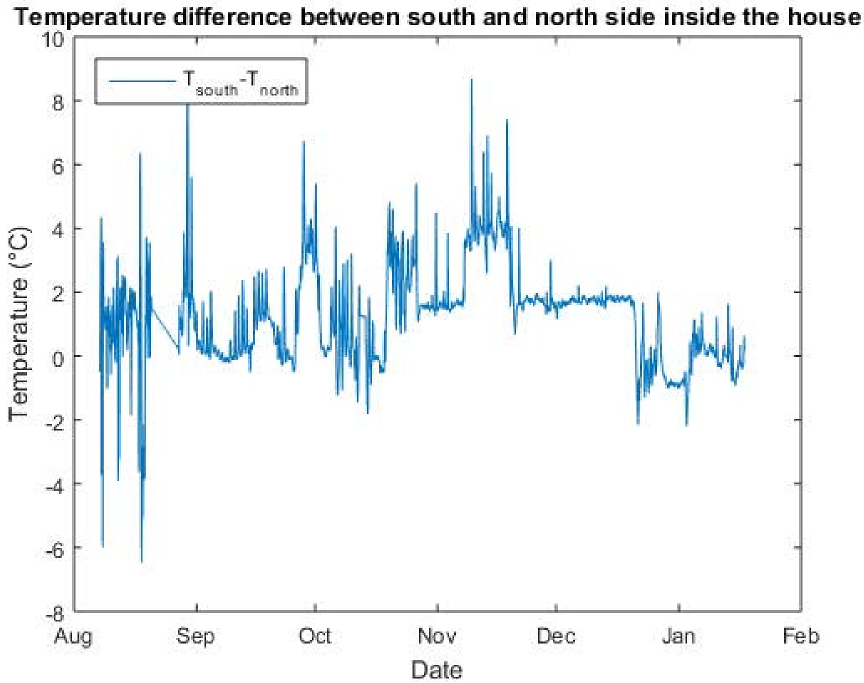
Dags:
11. 06. 2010

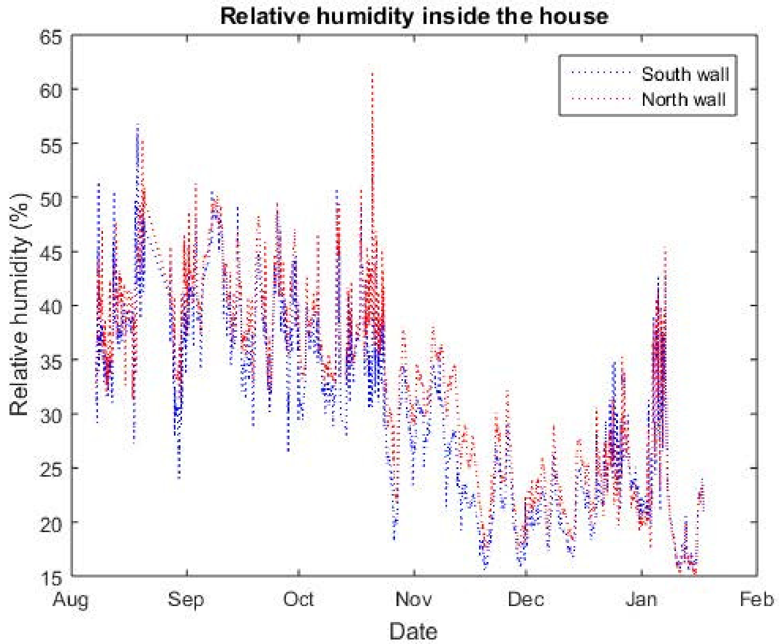
Breytt:
13. 12. 2010
28. 06. 2012

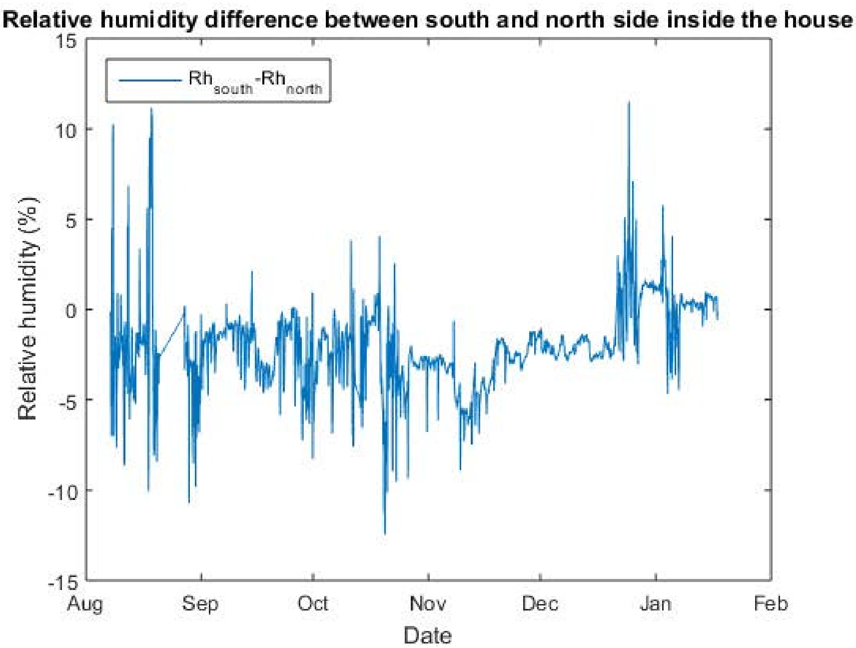
Teikn:
A-02

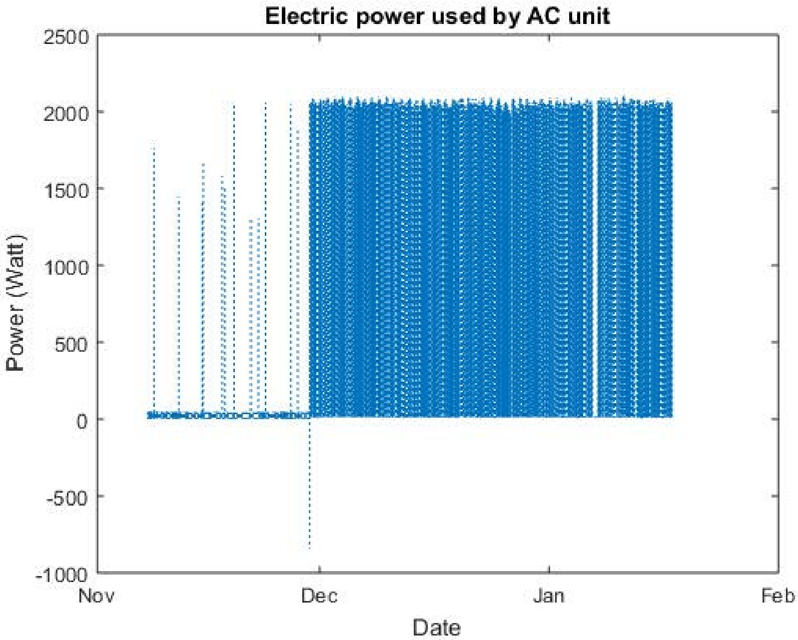
Appendix 13. Sensor data plotted

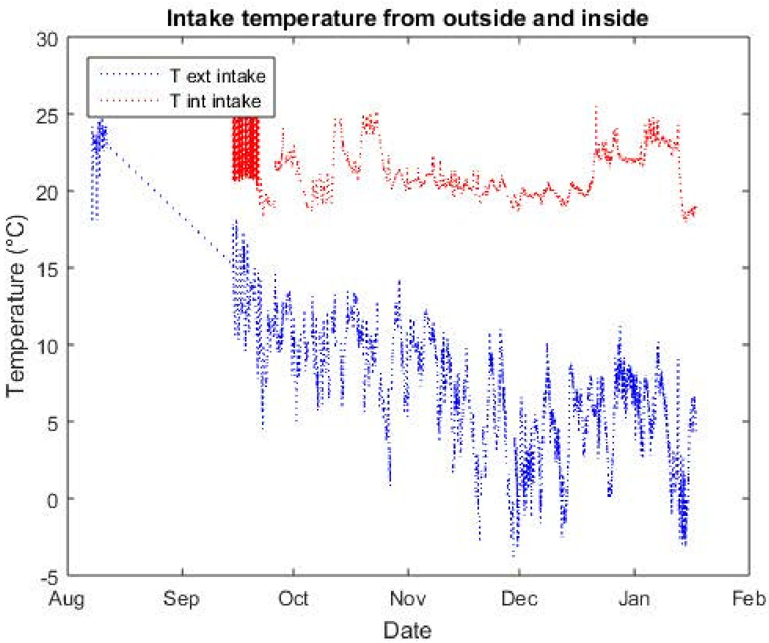

Temperature inside the house
South wall
North wall
Temperature (°C)
35
30
25
20
15
10
5
0
-5
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

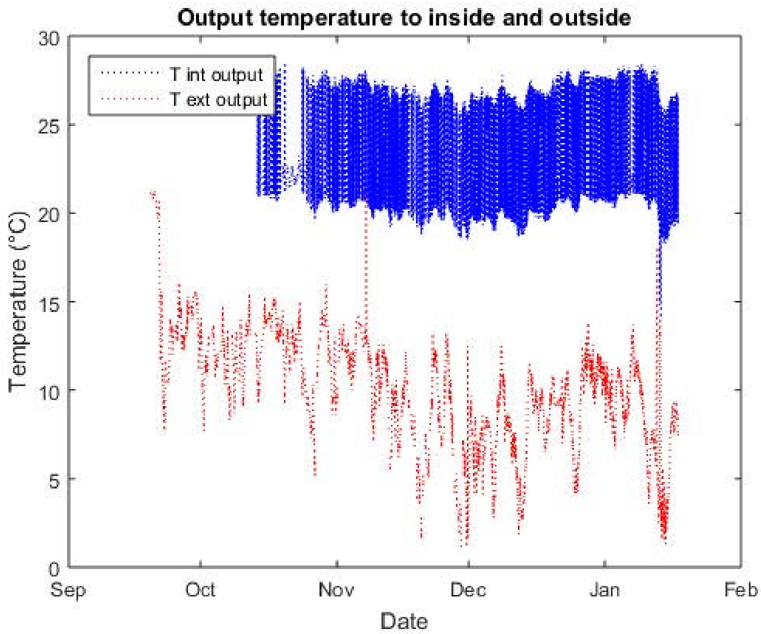

Temperature difference between south and north side inside the house
T_{south}-T_{north}
Temperature (°C)
10
8
6
4
2
0
-2
-4
-6
-8
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

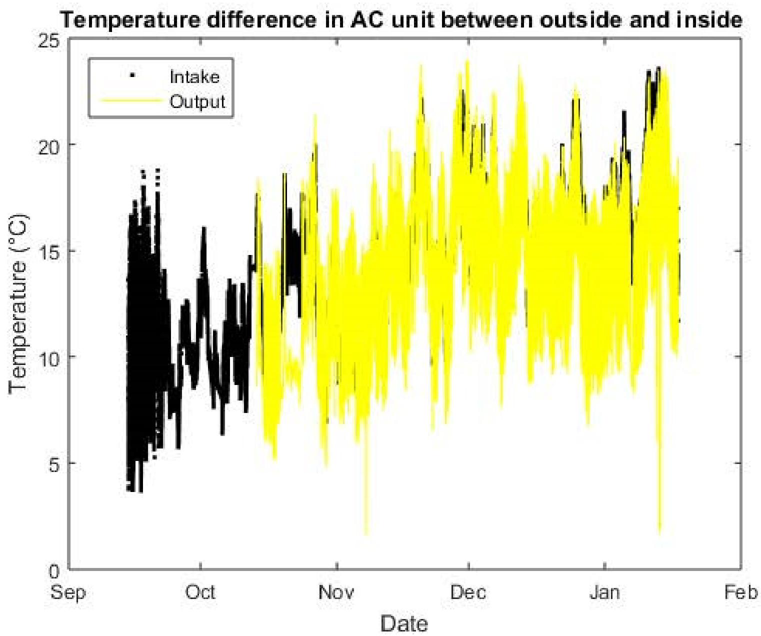

Relative humidity inside the house
South wall
North wall
Relative humidity (%)
65
60
55
50
45
40
35
30
25
20
15
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

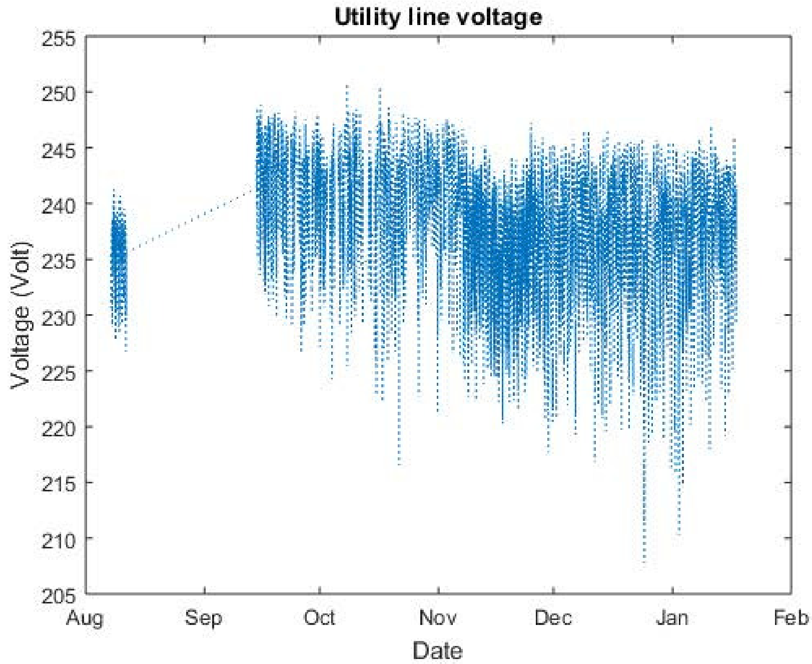

Relative humidity difference between south and north side inside the house
Rh south -Rh north
Relative humidity (%)
15
10
5
0
-5
-10
-15
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

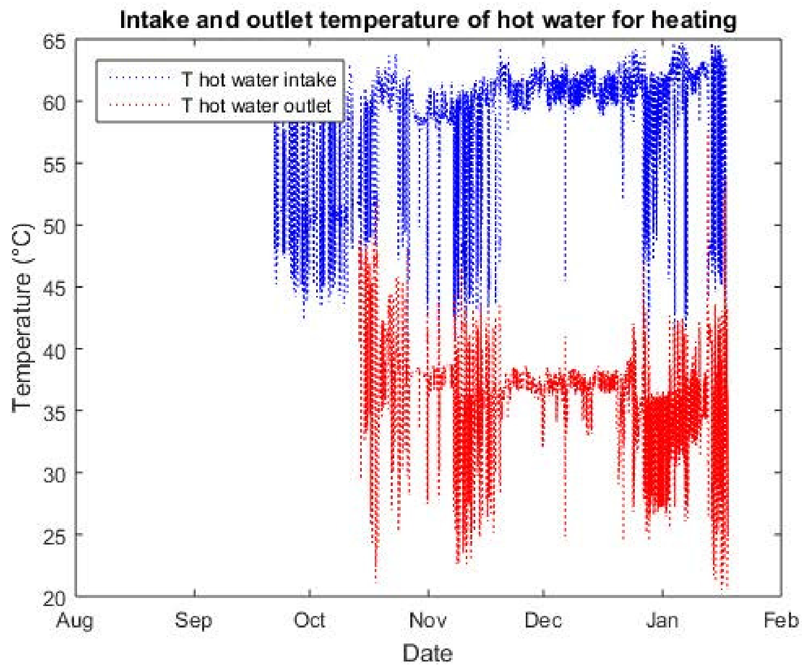

Electric power used by AC unit
Power (Watt)
2500
2000
1500
1000
500
0
-500
-1000
Nov
Dec
Jan
Feb
Date

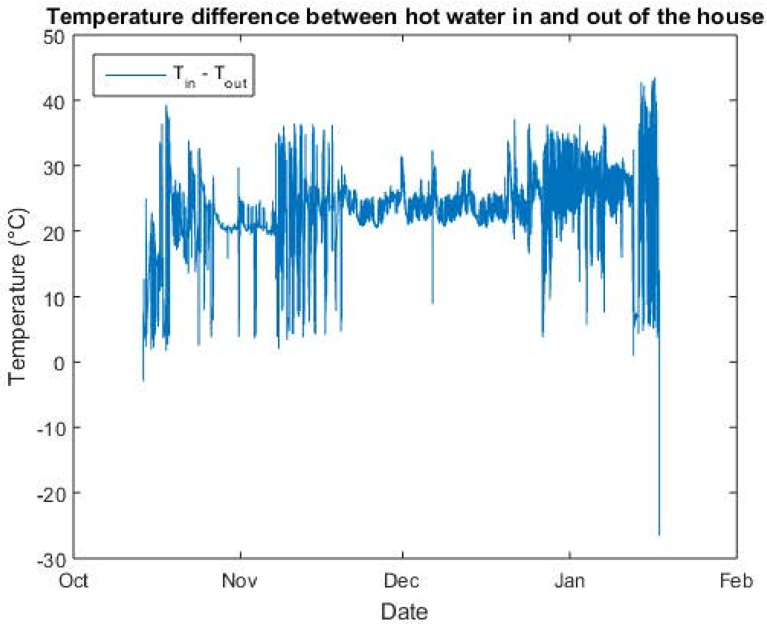

Intake temperature from outside and inside
T ext intake
T int intake
Temperature (°C)
30
25
20
15
10
5
0
-5
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date


Output temperature to inside and outside
T int output
T ext output
Temperature (°C)
0
5
10
15
20
25
30
Sep
Oct
Nov
Dec
Jan
Feb
Date


Temperature difference in AC unit between outside and inside
Intake
Output
Temperature (°C)
0
5
10
15
20
25
Sep
Oct
Nov
Dec
Jan
Feb
Date

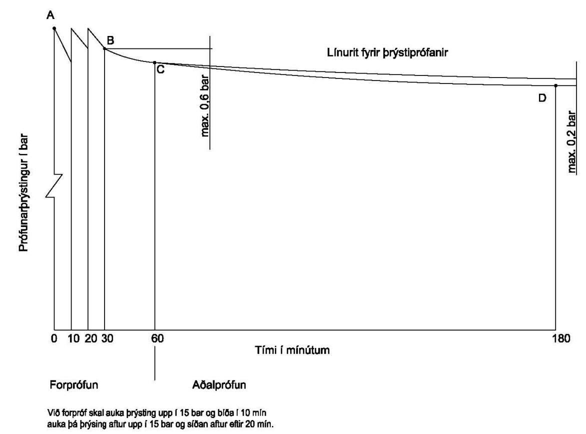

Utility line voltage
Voltage (Volt)
255
250
245
240
235
230
225
220
215
210
205
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

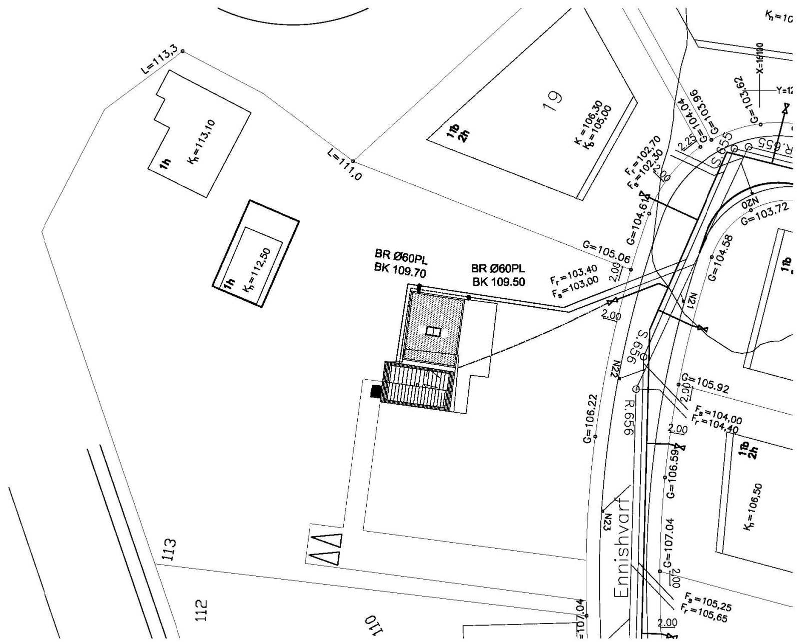

Intake and outlet temperature of hot water for heating
T hot water intake
T hot water outlet
Temperature (°C)
65
60
55
50
45
40
35
30
25
20
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date



Temperature difference between hot water in and out of the house
T_{in} - T_{out}
Temperature (°C)
50
40
30
20
10
0
-10
-20
-30
Oct
Nov
Dec
Jan
Feb
Date

Appendix 14. Installation drawings of the house





SKÝRINGAR GÓLFLAGNIR.

GÓLFLAGNIR Í ERU PEX Ø16
("CROSSLINKED") OG ER MILLIBIL MILLI RÖRA
C/C 200 Í BYGGINGU SKAL RÖRUM FEST NIÐUR Á JÁRNGRIND
MEÐ MEÐ ÞAR TIL GERÐUM FESTUM SAMKV.
FYRIRSKRIFT FRAMLEIÐANDA RÖRA (PLAST).
STEYPUHULA SKAL EKKI VERA MINNI EN
4CM OFAN Á RÖR. HEILDARLENGD SLAUFA ER
417M OG ER REIKNAÐ MEÐ 110W/M2.
FRAMRÁS VATNS SKAL STILLT ÞANNIG AÐ HITI FARI EKKI
YFIR 42 GRÁÐUR.

INNSTEYPTAR PÍPUR SKULU VERA ÁN TENGISTYKKJA.
TENGISTYKKI SKULU VERA ÚR KOPAR OG ÆTLUÐ
SÉRSTAKLEGA FYRIR ÞÆR PÍPUR SEM NOTAÐAR ERU.
KERFIÐ SKAL PRÓFAÐ ÁÐUR EN STEYPT ER MEÐ
4KG/CM2 ÞRÝSTINGU OG SKAL ÞRÝSTINGUR STANDA
Í 24 KLST. ÁN ÞESS AÐ FALLA.

NEYSLUVATN

Lagnir úr plasti og álplasti

Neysluvatnslögn úr plasti skal prófa í þrepum skv. DIN 1988 partur 2. Nota skal þrýstimæli sem sýnir þrýsting í 0,1 bar þrepum. Tengja skal þrýstimæli á lægsta stað í kerfinu. Kerfið er fyllt með vatni og lofttæmt og þrýstingur settur í 15 bar.
Bíða skal í 10 mín, auka þá þrýsting aftur upp í 15 bar og síðan aftur eftir 20 mín.
Eftir 30 mín **B** skal skrá niður þrýsting og aftur eftir 60 mín **C** og má þrýstingur ekki hafaf fallið um meira en 0,6 bar.
Aðalprófið fer fram í beinu framhaldi og þrýstingur í **D** má ekki hafa fallið meira en 0,2 bar á 120 mín frá **C** til þess að próf teljist hafa lokið með fullnægjandi árangri.

Þrýstiprófun skal skrá og skal verktaki afhenda eftirlitsmanni skýrslu yfir prófun á sérstöku eyðublaði. Við ofangreinda prófun skal verktaki kalla eftirlitsmann verkkaupa á vettvang í byrjun og lok prófunar og skal hann taka kerfið út og samþykkja prófunina.

SKÝRINGAR

DRENLÖGN
SKÓLPLÖGN
HEITT NEYSLUVATN
KALT NEYSLUVATN
FRAMRÁS HEITT VATN
BAKRÁS HEITT VATN
BRUNAVATNSLÖGN

HL = HANDLAUG — ÞS = ÞVAGSKÁL
EV = ELDHÚSVASKUR — SV = SKOLVASKUR
RV = RÆSTIVASKUR — SB = STURTUBOTN
VS = VATNSSALERNI — GN = GÓLFNIÐURFALL
UÞ = UPPÞVOTTAVÉL — GO = GUFUOFN
ÞV = ÞVOTTAVÉL — ÞU = ÞURKARI
BS = BRUNASLANGA
PU = MERKIR PÍPUR UPP
PN = MERKIR PÍPUR NIÐUR — GNFMERKIR GÓLFNIÐURFALL
ÍV = MERKIR Í VEGG — ÞN MERKIR ÞAKNIÐURFALL
ÍE = MERKIR Í EINANGRUN — BR MERKIR BRUNNUR
UL = MERKIR UNDIR LOFTI — MERKIR GAT Í SÖKKLI
UG = MERKIR UNDIR GOLFI — MERKIR RENNILOKI
YD = MERKIR YFIR DYR
MERKIR OFNLOKI
MERKIR LOFTSKRÚFA
MERKIR HEITAVATNSKRANI
MERKIR KALDVATNSKRANI

C
B
A
BREYTINGAR

Samþykkt	Samþykki aðalhönnuðar

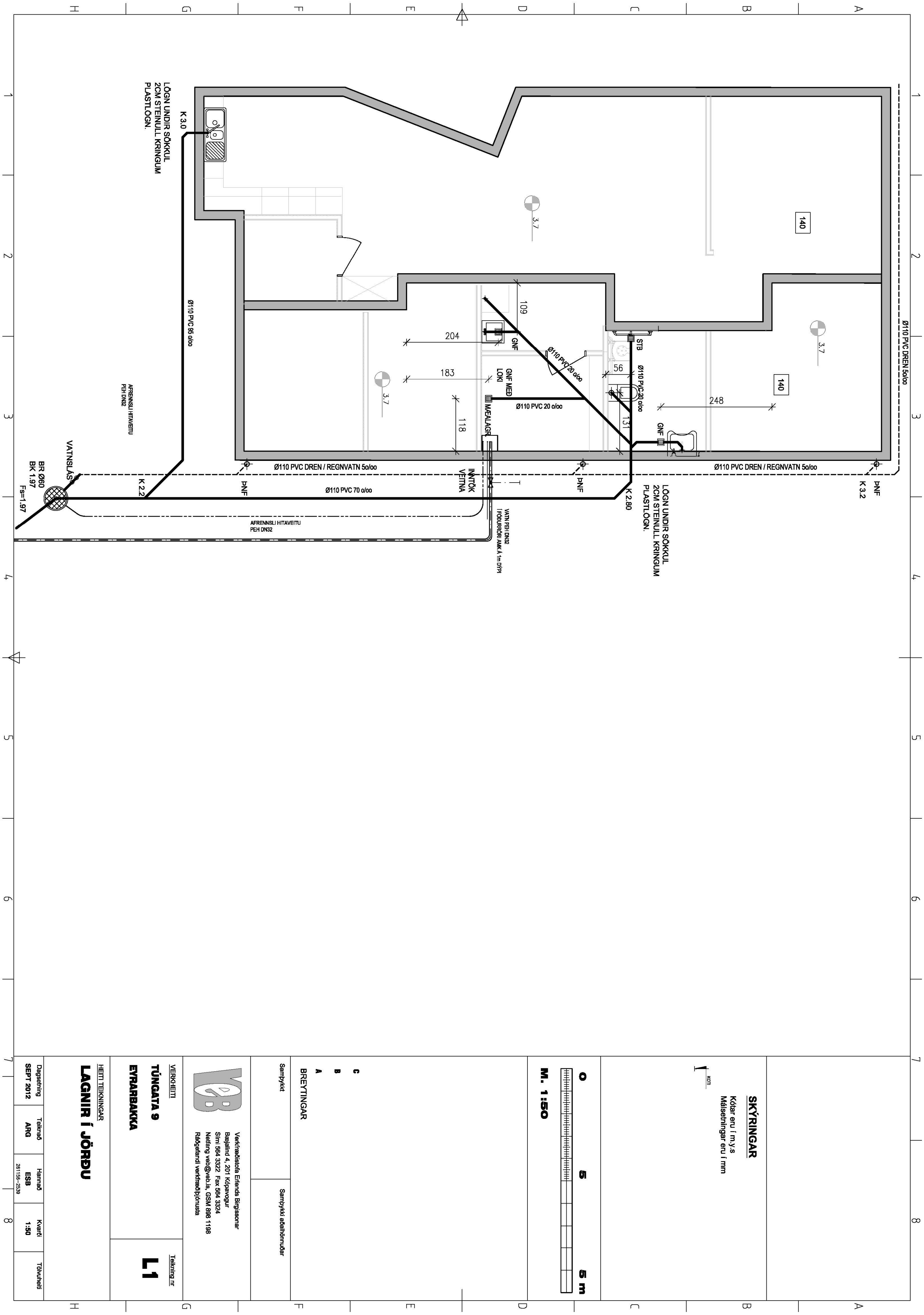
Verkfræðistofa Erlends Birgissonar
Bæjalind 4, 201 Kópavogur
Sími 564 3322 Fax 564 3324
Netfang veb@veb.is, GSM 898 1198
Ráðgefandi verkfræðiþjónusta

VERKHEITI
TÚNGATA 9
EYRARBAKKA

Teikning nr
LO

HEITI TEIKNINGAR
SKÝRINGAR

Dagsetning	Teiknað	Hannað	Kvarði	Tölvuheiti
SEPT 2012	ESB	ESB 261156-2539	1:	



LÖGN UNDIR SÖKKUL.
2CM STEINULL KRINGUM
PLASTLÖGN.
K 3.0
Ø110 PVC 95 o/oo
AFRENNSLI HITAVEITU
PEH DN32
VATNSLÁS
BR Ø60
BK 1.97
Fs=1.97
K 2.2
ÞNF
Ø110 PVC DREN / REGNVATN 5o/oo
Ø110 PVC 70 o/oo
INNTÖK
VEITNA
MÆLAGR
GNF MEÐ
LOKI
Ø110 PVC 20 o/oo
GNF
STB
K 2.80
Ø110 PVC DREN 5o/oo
K 3.2
140
3.7
204
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118
109
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131
248
SKÝRINGAR
Kótar eru í m.y.s
Málsetningar eru í mm
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BREYTINGAR
Samþykkt
Samþykki aðalhönnuðar
Verkfræðistofa Erlends Birgissonar
VERKHEITI
TÚNGATA 9
EYRARBAKKA
HEITI TEIKNINGAR
LAGNIR Í JÖRÐU
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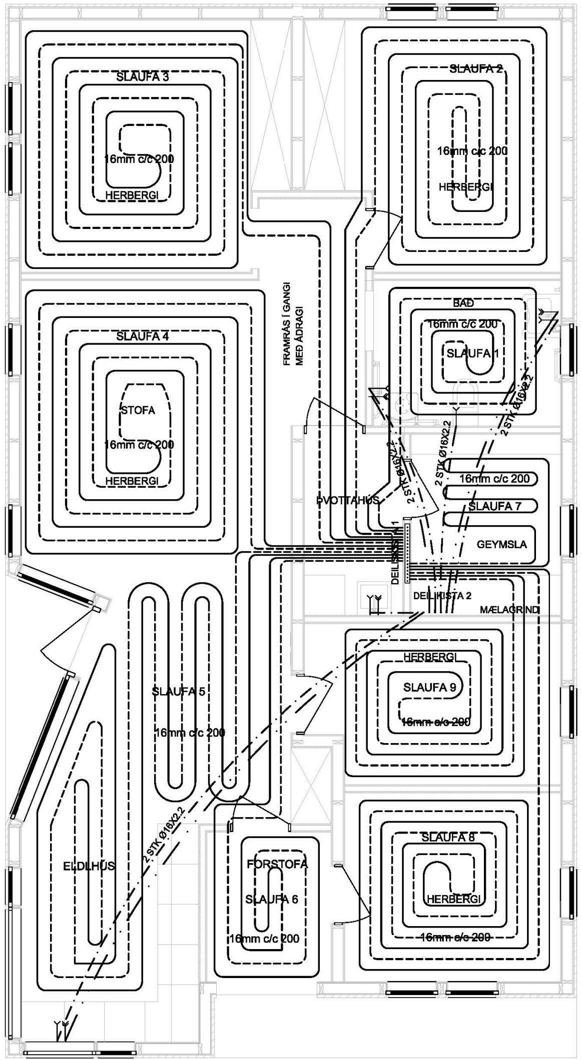
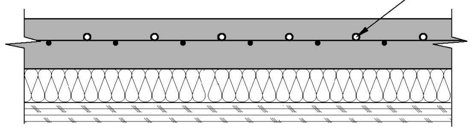
Dagsetning
SEPT 2012
Teiknað
ARG
Hannað
ESB
Kvarði
1:50
Tölvuheiti



Nr	Staður	Lengd slaufu	Gefur
		m	W
SLAUFA 1	BAÐ	26	620
SLAUFA 2	HERBERGI	51	1224
SLAUFA 3	HERBERGI	71	1704
SLAUFA 4	BORÐSTOFA	69	1650
SLAUFA 5	STOFA	63	1510
SLAUFA 6	ELDHÚS/BORÐSTOFA	29	696
SLAUFA 7	GEYMSLA	14	336
SLAUFA 8	HERBERGI	54	1290
SLAUFA 9	HERBERGI	40	960
		417	9990



KENNISNIÐ GÓLFHITA
FYRIR PLÖTU Á FYLLINGU.

0 5 10 m

M. 1:50

C
B
A
BREYTINGAR

Samþykkt | Samþykki aðalhönnuðar

Verkfræðistofa Erlends Birgissonar
Bæjalind 4, 201 Kópavogur
Sími 564 3322 Fax 564 3324
Netfang veb@veb.is, GSM 898 1198
Ráðgefandi verkfræðiþjónusta

VERKHEITI
TÚNGATA 9
EYRARBAKKA

Teikning nr
L2

HEITI TEIKNINGAR
GRUNNMYND
GÓLFHITI & NEYSLUVATN

Dagsetning	Teiknað	Hannað	Kvarði	Tölvuheiti
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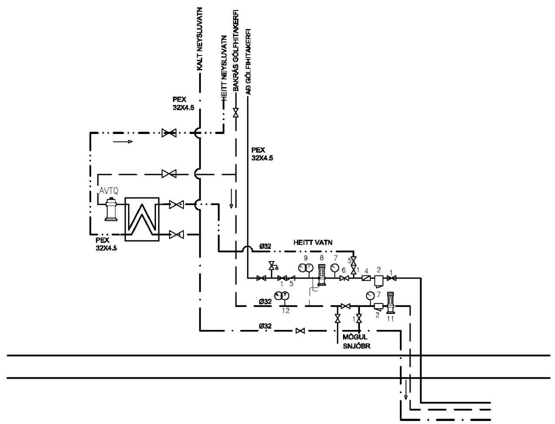
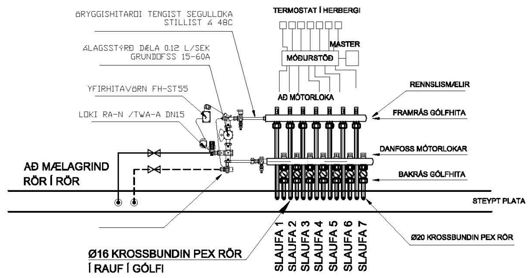




SKÝRINGAR

Kótar eru í m.y.s
Málsetningar eru í mm

KÓTI

0 5 10 m

M. 1:20

C
B
A
BREYTINGAR

Samþykkt | Samþykki aðalhönnuðar

Verkfræðistofa Erlends Birgissonar
Bæjalind 4, 201 Kópavogur
Sími 564 3322 Fax 564 3324
Netfang veb@veb.is, GSM 898 1198
Ráðgefandi verkfræðiþjónusta

VERKHEITI

ENNISHVARF 17
201 KÓPAVOGUR

Teikning nr
L3

HEITI TEIKNINGAR

VIÐBYGGING / TENGIGRIND MÆLAGRIND

Dagsetning	Teiknað	Hannað	Kvarði	Tölvuheiti
JÚLÍ 22012	ESB	ESB 261156-2539	1:50	

Appendix 15. Sensor data sheets

Digital thermometer installed in ventilation ducts and on hot water pipes (in and out)

DS18B20 **Programmable Resolution 1-Wire Digital Thermometer**

General Description

The DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply.

Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus. Thus, it is simple to use one microprocessor to control many DS18B20s distributed over a large area. Applications that can benefit from this feature include HVAC environmental controls, temperature monitoring systems inside buildings, equipment, or machinery, and process monitoring and control systems.

Applications

- Thermostatic Controls
- Industrial Systems
- Consumer Products
- Thermometers
- Thermally Sensitive Systems

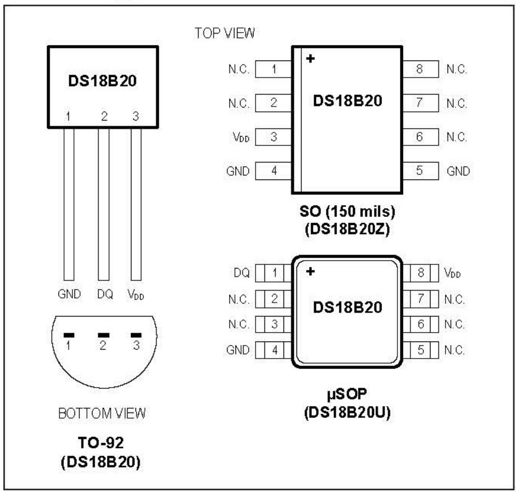
Ordering Information appears at end of data sheet.

1-Wire is a registered trademark of Maxim Integrated Products, Inc.

Benefits and Features

- Unique 1-Wire® Interface Requires Only One Port Pin for Communication
- Reduce Component Count with Integrated Temperature Sensor and EEPROM
  - Measures Temperatures from -55°C to +125°C (-67°F to +257°F)
  - ±0.5°C Accuracy from -10°C to +85°C
  - Programmable Resolution from 9 Bits to 12 Bits
  - No External Components Required
- Parasitic Power Mode Requires Only 2 Pins for Operation (DQ and GND)
- Simplifies Distributed Temperature-Sensing Applications with Multidrop Capability
  - Each Device Has a Unique 64-Bit Serial Code Stored in On-Board ROM
- Flexible User-Definable Nonvolatile (NV) Alarm Settings with Alarm Search Command Identifies Devices with Temperatures Outside Programmed Limits
- Available in 8-Pin SO (150 mils), 8-Pin µSOP, and 3-Pin TO-92 Packages

Pin Configurations



maxim integrated

19-7487; Rev 4; 1/15

Relative humidity and temperature sensor installed on internal and external north and south facade.

Maxdetect
sense the world

Your specialist in innovating humidity & temperature sensors

Digital relative humidity & temperature sensor RHT03

1. Feature & Application:

*High precision
*Capacitive type
*Full range temperature compensated
*Relative humidity and temperature measurement
*Calibrated digital signal
*Outstanding long-term stability
*Extra components not needed
*Long transmission distance, up to 100 meters
*Low power consumption
*4 pins packaged and fully interchangeable

2. Description:

RHT03 output calibrated digital signal. It applys exclusive digital-signal-collecting-technique and humidity sensing technology, assuring its reliability and stability. Its sensing elements is connected with 8-bit single-chip computer.

Every sensor of this model is temperature compensated and calibrated in accurate calibration chamber and the calibration-coefficient is saved in type of programme in OTP memory, when the sensor is detecting, it will cite coefficient from memory.

Small size & low consumption & long transmission distance(100m) enable RHT03 to be suited in all kinds of harsh application occasions. Single-row packaged with four pins, making the connection very convenient.

3. Technical Specification:

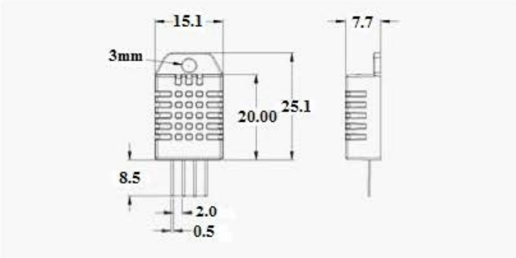
Model	RHT03	
Power supply	3.3-6V DC	
Output signal	digital signal via MaxDetect 1-wire bus	
Sensing element	Polymer humidity capacitor	
Operating range	humidity 0-100%RH;	temperature -40~80Celsius
Accuracy	**humidity +-2%RH**(Max +-5%RH);	temperature +-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH;	temperature 0.1Celsius
Repeatability	humidity +-1%RH;	temperature +-0.2Celsius

MaxDetect Technology Co., Ltd. **http://www.humiditycn.com**

Thomas Liu (Sales Manager)
Email: thomasliu198518@yahoo.com.cn , sales@humiditycn.com

Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Interchangeability	fully interchangeable

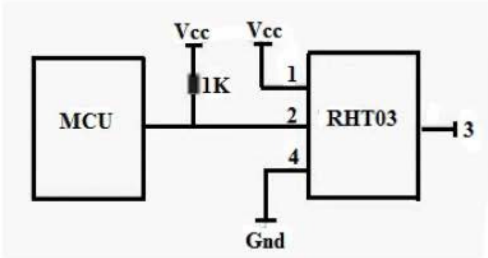
4. Dimensions: (unit---mm)



Pin sequence number: 1 2 3 4 (from left to right direction).

Pin	Function
1	VDD---power supply
2	DATA--signal
3	NULL
4	GND

5. Electrical connection diagram:



6. Operating specifications:

(1) Power and Pins

Power's voltage should be 3.3-6V DC. When power is supplied to sensor, don't send any instruction to the sensor within one second to pass unstable status. One capacitor valued 100nF can be added between VDD and GND for wave filtering.

(2) Communication and signal

MaxDetect 1-wire bus is used for communication between MCU and RHT03. (MaxDetect 1-wire bus is specially designed by MaxDetect Technology Co., Ltd. , it's different from Maxim/Dallas 1-wire bus, so it's incompatible with Dallas 1-wire bus.)

Illustration of MaxDetect 1-wire bus:
Data is comprised of integral and decimal part, the following is the formula for data.
DATA=8 bit integral RH data+8 bit decimal RH data+8 bit integral T data+8 bit decimal T data+8 bit check-sum

MaxDetect Technology Co., Ltd. http://www.humiditycn.com

Thomas Liu (Sales Manager)
Email: thomasliu198518@yahoo.com.cn , sales@humiditycn.com

Velleman WS1080 weather station installed on the roof of the house.

WS1080

WEATHER CENTRE WITH TOUCHSCREEN AND PC CONNECTION
WEERSTATION MET TOUCHSCREEN EN PC-AANSLUITING
STATION MÉTÉO À ÉCRAN TACTILE ET CONNEXION PC
ESTACIÓN METEOROLÓGICA CON PANTALLA TÁCTIL Y CONEXIÓN PC
WETTERSTATION MIT BERÜHRUNGSBILDSCHIRM UND PC-ANSCHLUSS
ESTAÇÃO METEOROLÓGICA COM ECRÃ DIGITAL E LIGAÇÃO AO PC
STACJA POGODOWA Z EKRANEM DOTYKOWYM I INTERFEJSEM PC
STAZIONE METEO CON TOUCHSCREEN E INTERFACCIA PC

CE

USER MANUAL

1. Introduction

To all residents of the European Union

Important environmental information about this product

This symbol on the device or the package indicates that disposal of the device after its lifecycle could harm the environment. Do not dispose of the unit (or batteries) as unsorted municipal waste; it should be taken to a specialized company for recycling. This device should be returned to your distributor or to a local recycling service. Respect the local environmental rules.

If in doubt, contact your local waste disposal authorities.

Thank you for choosing Velleman! Please read the manual thoroughly before bringing this device into service. If the device was damaged in transit, don't install or use it and contact your dealer. Damage caused by disregard of certain guidelines in this manual is not covered by the warranty and the dealer will not accept responsibility for any ensuing defects or problems.

2. Setting up the Stations

Refer to the illustrations on page 2 and following of this manual.

Weather station

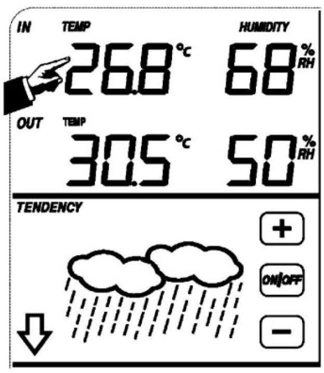
1. Install your outdoor weather station on a suitable location minding the wind direction markings. Connect the anemometer to the wind vane phone jacket.
2. Connect the wind vane to the thermo-hygrometer WIND phone jacket.
3. Connect the rain sensor to the thermo-hygrometer RAIN phone jacket.
4. Finally, insert 3 x AA batteries into the weather station respecting the polarity.

Receiver

1. Insert 2 x AA batteries into the receiver respecting the polarity.
2. Wait for the two stations to synchronize.
   This synchronisation may take a couple of minutes. Do not touch the screen during synchronisation.
3. Once the synchronisation finished, make sure that all components work properly.
4. Choose a suitable mounting location for the receiver.
   Commonly, the communication between the two stations can reach a distance of 100 m in the open field, provided that there are no obstacles such as buildings, trees, vehicles, high-voltage lines, etc. Radio interference such as from PCs, radios and television sets can entirely cut off the communication. Take this into consideration when choosing a mounting location.

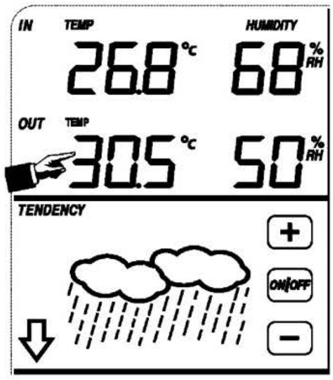
3. The Different Functions

Indoor Temperature



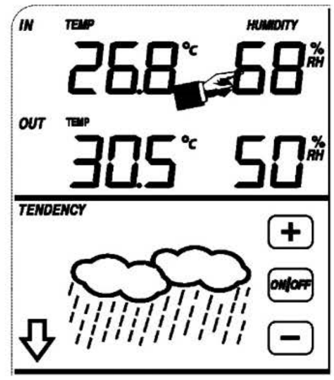
1. Touch the indoor temperature section once and press + or – to switch between the temperature display in °C or °F.
2. Touch the indoor temperature section a second time and press + or – to set the high temperature alarm (HI AL), or press ON/OFF to switch the alarm on or off.
3. Touch the indoor temperature section a third time and press + or – to set the low temperature alarm (LO AL), or press ON/OFF to switch the alarm on or off.
4. Touch the indoor temperature section a fourth time to display the maximum temperature reading. Hold the value pressed to reset the value.
5. Touch the indoor temperature section a fifth time to display the minimum temperature reading. Hold the value pressed to reset the value.

Outdoor Temperature



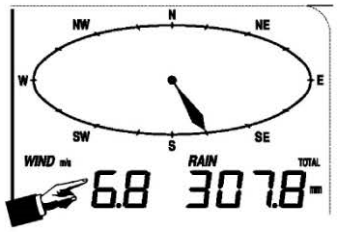
1. Touch the outdoor temperature section once and press + or – to switch between outdoor temperature, wind chill, and dew point display.
2. Touch the outdoor temperature section a second time and press + or – to switch between the temperature display in °C or °F.
3. Touch the outdoor temperature section a third time and press + or – to set the high temperature alarm (HI AL), or press ON/OFF to switch the alarm on or off.
4. Touch the outdoor temperature section a fourth time and press + or – to set the low temperature alarm (LO AL), or press ON/OFF to switch the alarm on or off.
5. Touch the outdoor temperature section a fifth time to display the maximum temperature reading. Hold the value pressed to reset the value.
6. Touch the outdoor temperature section a sixth time to display the minimum temperature reading. Hold the value pressed to reset the value.

Indoor/Outdoor Humidity



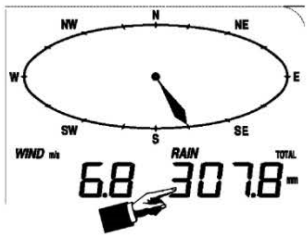
1. Touch the indoor/outdoor humidity section once and press + or – to set the high humidity alarm (HI AL), or press ON/OFF to switch the alarm on or off.
2. Touch the indoor/outdoor humidity section a second time and press + or – to set the low humidity alarm (LO AL), or press ON/OFF to switch the alarm on or off.
3. Touch the indoor/outdoor humidity section a third time to display the maximum indoor/outdoor humidity reading. Hold the value pressed to reset the value.
4. Touch the indoor/outdoor humidity section a fourth time to display the minimum indoor/outdoor humidity reading. Hold the value pressed to reset the value.

Wind Speed



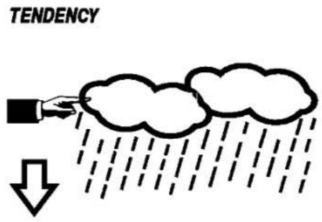
1. Touch the wind speed section once and press + or – to switch between average wind speed and gust speed (GUST).
2. Touch the wind speed section a second time and press + or – to switch between the wind speed display in km/h, mph, m/s, knots, or Bft.
3. Touch the wind speed section a third time and press + or – to set the high wind speed alarm (HI AL), or press ON/OFF to switch the alarm on or off.
4. Touch the wind speed section a fourth time and press + or – to set the wind direction alarm, or press ON/OFF to switch the alarm on or off.
5. Touch the wind speed section a fifth time to display the maximum wind speed reading. Hold the value pressed to reset the value.

Rain



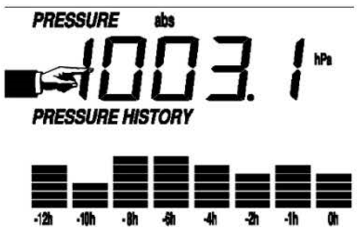
1. Touch the rain section once and press + or – to switch between 1h, 24h, week, month, and total rainfall display.
2. Touch the rain section a second time and press + or – to switch between the rainfall display in mm or inches.
3. Touch the rain section a third time and press + or – to set the high rainfall alarm (HI AL), or press ON/OFF to switch the alarm on or off.
4. Touch the rain section a fourth time to display the maximum rainfall reading. Hold the value pressed to reset the value.
5. Touch the rain section a fifth time and press CLEAR to reset all rainfall values.

Weather Forecast



1. Touch the weather forecast section once and press + or – to switch between sunny, partly cloudy, cloudy, and rainy display.
2. Touch the weather forecast section a second time and press + or – to set the pressure threshold from 2-4 hPa.
3. Touch the weather forecast section a third time and press + or – to set the storm threshold from 3-9 hPa.

Pressure



1. Touch the pressure section once and press + or – to switch between absolute pressure and relative pressure display.
2. Touch the pressure section a second time and press + or – to switch between pressure display in hPa, inHg, or mmHg.
3. Touch the pressure section a third time and press + or – to set the relative pressure value.
4. Touch the pressure section a fourth time and press + or – to set the high pressure alarm (HI AL), or press ON/OFF to switch the alarm on or off.
5. Touch the pressure section a fifth time and press + or – to set the low pressure alarm (LO AL), or press ON/OFF to switch the alarm on or off.
6. Touch the pressure section a sixth time to display the maximum pressure reading. Hold the value pressed to reset the value.
7. Touch the pressure section a seventh time to display the minimum pressure reading. Hold the value pressed to reset the value.

Note: When the absolute pressure is selected, step 3 will be skipped.

Pressure Bar Graph

Touch the pressure bar graph once and press + or – to switch between the 12h and 24h pressure history.

Time

Note: The DCF function will only work if the **outdoor sensor** receives the signal.

1. Touch the time section once and press + or – to adjust the contrast level (from 0 – 8, default 5).
2. Touch the time section a second time and press + or – to select the time zone.
3. Touch the time section a third time and press + or – to select the 12h or 24h time display.
4. Touch the time section a fourth time and press + or – to set the hour.
5. Touch the time section a fifth time and press + or – to set the minutes.

Date

1. Touch the date section once and press + or – to switch between alarm time, date and week.
2. Touch the date section a second time and press + or – to switch between date display in DD-MM and MM-DD format.
3. Touch the date section a third time and press + or – to set the year.
4. Touch the date section a fourth time and press + or – to set the month.
5. Touch the date section a fifth time and press + or – to set the day.
6. Touch the date section a sixth time and press + or – to set the alarm hour.
7. Touch the date section a seventh time and press + or – to set the alarm minutes, or press ON/OFF to switch the alarm on or off.

Memory

1. Touch the memory section once and press + or – to switch between the weather history data. This data can be edited through the included PC software.
2. Touch the memory section a second time. Hold the memory section pressed to clear the contents.

4. PC Connection and EasyWeather Software

- For information about installing and using the EasyWeather software, refer to the manual at the end of this document.

5. Technical Specifications

outdoor unit

transmission range	± 150 m (under ideal circumstances)
frequency	868 MHz
temperature range	-40 °C to 65 °C
resolution	0.1 °C
humidity range	10-99 % RH
rain volume display	0-9999 mm
resolution	0.1 mm (volume < 1000 mm), 1 mm (volume > 1000 mm)
wind speed	0-160 km/h
measuring interval	48 s
IP rating	IPX3
power supply	2 x 1.5 V AA batteries (LR6C, not incl.)
dimensions	Ø 20 x 570 mm

indoor unit

pressure/temperature reading interval	48 s
temperature measuring range	0-60 °C
resolution	0.1 °C
humidity range	10-99 % RH
humidity accuracy	1 %
measuring range air pressure	919-1080 hPa
resolution/accuracy	0.1 hPa / 1.5 hPa
alarm duration	120 s
power supply	3 x 1.5 V AA batteries (LR6C, not incl.)
dimensions	unit: 233 x 145 x 33 mm
	display: 145 x 108 mm
Weight	1300 g (indoor + outdoor unit)

minimum system requirements

Windows®	Windows XP, Vista, 7 (32 and 64 bit), 8
web browser	Internet Explorer 6.0 or above

WS1080	
CPU	Pentium III, 500 MHz
memory	128 MB (256 MB recommended)
hardware	CD-ROM drive

spare parts

WS1080/BR, WS1080/ST, WS1080/AH, WS1080/TH, WS1080/WS, WS1080/WD, WS1080/RM

Use this device with original accessories only. Velleman nv cannot be held responsible in the event of damage or injury resulting from (incorrect) use of this device.
For more info concerning this product and the latest version of this manual, please visit our website www.velleman.eu.
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Appendix 16. DS418:2011 original text in Danish

4 Beregning af ventilationstab

4.1 Ventilationstab

Ventilationstabet for et rum beregnes i almindelighed af

$$\Phi_v = \rho\, c\, q\, (\theta_i - \theta_e)$$

hvor

- Φ_v er ventilationstabet i W
- ρ er luftens massefylde i kg/m³
- c er luftens varmefylde i J/kg K
- q er luftstrøm af udeluft tilført rummet i m³/s
- θ_i er dimensionerende indetemperatur i °C
- θ_e er dimensionerende udetemperatur i °C.

Ved 20 °C og 1 013 mbar er c = 1 005 J/kg K, og ρ = 1,205 kg/m³ (tør luft).

For sædvanlige rum tages ikke hensyn til forskellen mellem lufttemperatur og indetemperatur.

4.2 Naturlig ventilation

I bygninger, hvor luftfornyelsen sker ved naturlig ventilation, beregnes luftstrømmen q ud fra udeluftmængden i l/s pr. m² opvarmet etageareal. Ventilationstabet bliver derved

$$\Phi_v = \rho\, c\, \frac{q_a}{1\,000} A\, (\theta_i - \theta_e) \approx 1{,}21\, q\, A\, (\theta_i - \theta_e)$$

hvor

- q_a er udeluftmængden i l/s pr. m² opvarmet etageareal
- A er opvarmet etageareal i m².

q_a sættes til 0,3 l/s m² for alle sædvanlige rum, dvs. rum i beboelsesbygninger (beboelsesrum, køkkener, wc- og baderum m.m.), samt sådanne rum i andre bygninger, der kan sidestilles med tilsvarende rum i beboelsesbygninger. For meget store rum, lagerrum og lignende sættes q_a til en lavere værdi, fx 0,18 l/s m².

Hvis lækagen gennem fuger ved vinduer og døre forventes at være større end normalt, så luftstrømmen ved lave udetemperaturer overstiger 0,3 l/s m², beregnes ventilationstabet ud fra fugernes længde og luftgennemtrængelighed i de enkelte rum samt bygningens beliggenhed. For vinduer og yderdøre, hvis vindtæthed ikke er nærmere dokumenteret, kan regnes med en luftindstrømning på $0{,}5 \cdot 10^{-3}$ m³/s pr. m fuge mellem karm og gående rammer ved normal beliggenhed og $0{,}8 \cdot 10^{-3}$ m³/s pr. m fuge ved udsat beliggenhed.

4.3 Mekanisk udsugning

I bygninger, hvor luftfornyelsen sker ved mekanisk udsugning, beregnes ventilationstabet på grundlag af den udsugede luftstrøm under normal drift. Ventilationstabet fordeles mellem bygningens rum i forhold til deres volumen, uanset at der evt. kun er udsugning fra enkelte rum.

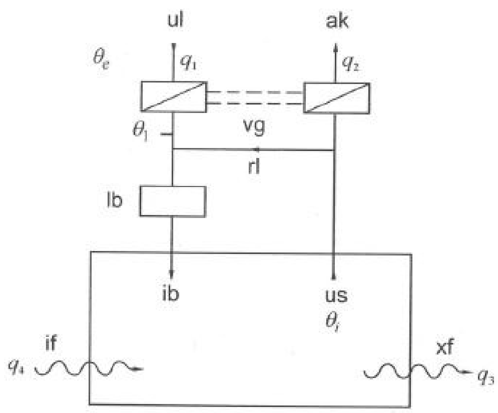
Hvis den derved beregnede udsugede luftstrøm er mindre end 0,3 l/s m², beregnes ventilationstabet som for sædvanlige rum med q = 0,3 l/s m².

Ved mekanisk udsugning forstås ventilering ved hjælp af udsugningsanlæg beregnet til vedvarende drift. Ventilationstabet for rum med ventilatorer, der kun er beregnet til kortvarig drift, beregnes som angivet i afsnit 4.2.

4.4 Andre mekaniske ventilationssystemer

I bygninger, som er udstyret med anlæg til såvel mekanisk udsugning som mekanisk indblæsning, beregnes ventilationstabet i overensstemmelse med anlæggets ydelser. Herunder tages hensyn til, at der tilføres rummene udeluft ved infiltration afhængigt af forskellen mellem den udsugede og indblæste luftstrøm gennem anlægget samt bygningens tæthed.

Der bør regnes med, at der foruden den infiltration/exfiltration, som skyldes ventilationsanlægget, og som dækker en eventuel forskel mellem de luftstrømme, der udsuges hhv. indblæses gennem anlægget, yderligere optræder en infiltration og en lige så stor exfiltration, som skyldes vind- og temperaturpåvirkning. Se figur 4.4.1.



Den store firkant symboliserer det område, som betjenes af ventilationsanlægget, og som kan omfatte ét eller flere rum.

Ordforklaringer:
"ib" er indblæsning
"us" er udsugning
"if" er infiltrationen, og "xf" er exfiltrationen. De er lige store, såfremt $q_1 = q_2$
I almindelighed er $q_4 = (q_2 - q_1) + q_3$
"ul" er udeluft
"ak" er afkast
"vg" er varmegenvinding
"rl" er returluft, og "lb" er luftbehandling.

Figur 4.4.1 – Eksempel på mekanisk ventilation

Beregningen af ventilationstabet afhænger af anlæggets udformning. Som eksempel vises i figur 4.4.1 et ventilationssystem, der omfatter mekanisk indblæsning og udsugning samt varmegenvinding. Såfremt luften ikke befugtes, og der ikke indgår varmepumper i systemet, bestemmes ventilationstabet i det ventilerede område af formlen:

$$\Phi_v = \rho c \, (q_2 + q_3) \, (\theta_i - \theta_e) - \rho c \, q_1 \, (\theta_l - \theta_e)$$

hvor

q_1 er luftstrøm af udeluft tilført gennem anlæg i m³/s

q_2 er luftstrøm af afkastningsluft i m³/s

q_3 er luftstrøm af exfiltration i m³/s

q_4 er luftstrøm af infiltration i m³/s

θ_i er dimensionerende indetemperatur i °C

θ_e er dimensionerende udetemperatur i °C

θ_l er udeluftens temperatur efter varmegenvindingsaggregatet i °C

c er luftens varmefylde i J/kg K

ρ er luftens massefylde i kg/m³.

Det forudsættes, at alle q måles ved samme lufttilstand, fx 20 °C og 1 013 mbar, og at ρ henføres til denne tilstand. Desuden forudsættes, at temperaturstigningen $\theta_l - \theta_e$ af den gennem anlægget tilførte udeluft alene skyldes varmegenvindingen. Temperaturen θ_l bestemmes af varmegenvindingsaggregatets data.

Luftstrømmene q_1 og q_2 bestemmes af ventilationsanlæggets ydelse under normal, vedvarende drift. Sædvanligvis er q_1 lidt mindre end q_2. Exfiltrationen q_3 fastsættes under hensyn til bygningens tæthed, brug og beliggenhed. I bygninger, hvor klimaskærmens lufttæthed er undersøgt ved trykprøvning med 50 Pa (q_{50}), bestemmes exfiltrationen i brugstiden på simpel vis som: $0{,}04 + 0{,}06 \cdot q_{50}$ l/s m². Uden for brugstiden bestemmes exfiltrationen som: $0{,}06 \cdot q_{50}$ l/s m².

Ventilationstabet kan dækkes af varmetilførsel dels fra luftbehandlingskomponenter, dels fra varmegivere, fx radiatorer, i de rum, hvor udeluften tilføres.

Appendix 17. Icelandic requirements

Tafla 13.01 Is the Icelandic requirement for maximum allowed U-values.

[Tafla 13.01 Ný mannvirki og viðbyggingar – leyfilegt hámark U-gilda einstakra byggingarhluta.

Byggingarhluti	**Leyft hámark U-gildis (W/m²K)**	
	Ti ≥ 18°C	**18°C >Ti ≥10°C**
Þak	0,20	0,30
Útveggur	0,40	0,40
Léttur úveggur	0,30	0,40
Gluggar (karmar, gler vegið meðaltal, k-gler)	2,0	3,0
Hurðir	3,0	engin krafa
Ofanljós	2,0	3,0
Gólf á fyllingu	0,30	0,40
Gólf að óupphituðu rými	0,30	0,40
Gólf að útilofti	0,20	0,40
Útveggir, vegið meðaltal (veggfletir, gluggar og hurðir)	0,85	engin krafa

][1)]

Á svæðum þar sem orkukostnaður vegna húshitunar er hár á íslenskan mælikvarða er þó mælt með að leiðnitap sé a.m.k. 10% lægra en fram kemur í töflu 13.01.

[1)] Rgl. nr. 1173/2012, 56. gr.

Gr. 10.2.5 Is the Icelandic requirements for residential space ventilation and related rooms

Gr. 10.2.5

Loftræsing íbúða og tengdra rýma.

Íbúðarhús má loftræsa með náttúrulegri loftræsingu, vélrænni loftræsingu eða blöndu af hvoru tveggja.

Tryggja ber að eftirfarandi loftskipti í íbúðarhúsum séu möguleg óháð gerð loftræsingar:

a. Öll íverurými skulu loftræst þannig að loftmagn sem berst til rýmis sé minnst 0,42 l/s á m² gólfflatar á meðan rýmið er í notkun og minnst 0,2 l/s á m² gólfflatar meðan rýmið er ekki í notkun. Jafnframt skal tryggt að ferskloftsmagn sem berst til svefnherbergis sé aldrei minna en svo að það samsvari 7 l/s á hvert rúm meðan herbergið er í notkun.
b. Herbergi þar sem ekki er gert ráð fyrir stöðugri viðveru er þó heimilt að loftræsa þannig að magn ferskklofts sé minnst 0,24 l/s á m² gólfflatar.
c. Útsog úr eldhúsi íbúðar skal ekki vera minna 30 l/s.
d. Útsog úr baðherbergi íbúðar skal ekki vera minna en 15 l/s.
e. Útsog úr minni snyrtingum skal vera minnst 10 l/s.
f. Útsog úr stökum geymslu- eða kjallaraherbergjum þar sem ekki er stöðug viðvera skal vera minnst 0,2 l/s á m² gólfflatar.
g. Útsog frá þvottaherbergi einnar íbúðar skal minnst vera 20 l/s.

Miða skal við að íbúðir aldraða og sérhæfðar íbúðir fatlaðra séu í notkun allan sólarhringinn.

Aðstreymi ferskklofts að eldhúsi, baðherbergi, salerni eða þvottahúsi skal koma um op sem er að flatarmáli minnst 100 cm². Þegar þessi rými liggja ekki að útvegg má ferskloft til þeirra koma frá aðliggjandi rýmum með minna mengunar- eða rakaálagi. Þegar þau liggja að útvegg skal ferskloft koma að utan, um glugga eða sérstök loftræsiop.

School of Science and Engineering
Reykjavík University
Menntavegur 1
101 Reykjavík, Iceland
Tel.+354 599 6200
Fax +354 599 6201
www.ru.is