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# Analysis of Correlations between Energy Consumption, Structural Specifications and Climate-Induced Variables to increase Energy Efficiency in Households and Buildings through a Prediction Model

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EOM-3901 Master's thesis in Energy, Climate and Environment
June 2021

# Abstract

In a world where the transition towards increasingly progressive renewable energy sources is of great importance moving towards sustainability for our planet and future generations, a large portion of mundane equipment and machinery will turn to the usage of electricity rather than fossil fuel as a resource. This does however pose some challenges to the infrastructure in place as it increases the strain on the power grid through the vastly increased demand for power, potentially outweighing the supply. As buildings make up a massive part of what takes up effect and power from the power grid, this thesis seeks to being a contributor to decreasing the footprint from buildings onto the power grid, allowing for an easier and more sustainable transition towards electricity-based equipment, machinery or vehicles.

The primary goal of this thesis is to find and analyze correlations between factors of which are expected to have an impact on the energy efficiency of buildings and present a methodology and a model which could be applied to buildings in order to examine the effects of implementing a series of measures to a building's structural envelope. This is done through the usage of advanced prediction/forecasting models for wind, measured data for temperature at specified locations, and through the analysis of energy consumption over time at two locations, where the changes in energy efficiency before and after renovation at one location is used as a measuring stick to predicting post-renovation changes in energy efficiency at the other.

The thesis shows a clear correlation between temperature, wind speeds and energy consumptions both before and after renovation, although post-renovation correlations are significantly lower in comparison to prior to renovation. Similarly, there is a significant decrease in energy consumption before and after renovation, although due to the unexpected usage of an alternate energy sources in form of fireplaces at one of the locations prior to renovation, the decrease is likely to be significantly more extreme than what the data suggests. In combination with the high uncertainties regarding the role of area and inhabitants in comparison to energy consumption, several weaknesses of the model are exposed. The thesis discusses the methodology, results and importance of various variables used throughout the model, as well as potential improvements and changes of which would significantly improve the model in light of the findings of the thesis.

# Acknowledgements

First and foremost, I would like to thank Professor Matteo Chiesa for excellent supervision throughout the entirety of the lengthy process of the thesis and in the selection of relevant subjects through my final year at the study program, as well as for assisting me in developing the project I had in mind from the start regarding energy consumption in Tromsø to a more complex yet concise project, seeing as the idea in its root was far too broad. I would also like to thank Ph.D. Candidate Odin Foldvik Eikeland for contributing to giving me a jump start in terms of the AROME-Arctic Forecasting Model, as well as a variety of good pointers and tips at the beginning of the project which helped me in narrowing down the thesis sufficiently.

There were a multitude of external sources of which have contributed greatly to the thesis in terms of relevant information and datasets, and I would like to express my gratitude towards the boards of Brattbakken Borettslag and Krokelva Borettslag represented through chairmen Maja Stensvold and Bjørnar Høgtun for their roles in providing me with necessary information regarding the two housing tenures, as well as allowing me to use consumption data from the apartments in their tenures throughout this Thesis. On that note I would like to thank Sten-Willy Andreassen and Ishavskraft AS for providing me with consumption data from the two locations on short notice on multiple occasions, making this particular thesis a possibility.

At last, I would like to thank those who contributed to making this education a joyful experience on both a professional and personal level; my fiancée and son, family and friends, classmates, professors, and other faculty employees. I am thankful to have been a part of this study program and for everything it has taught me, and to have been part of a workgroup that has worked towards improvements of the program for future students. On that note I would like to thank Tobias Boström, Yngve Birkelund and the rest of said group for taking the thoughts and concerns of their students seriously, and for their hard work and encouragement towards ensuring positive improvements for one of the most future-oriented programs at the faculty.

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# Abbreviations

| | |
|---|---|
| **ACH** | Air Changes per Hour |
| **API** | Application Programming Interface |
| **BRA** | Utility Floor Space (Bruksareal) |
| **kWh** | Kilowatt-hour |
| **MET** | Norwegian Meteorological Institute |
| **MVHR** | Mechanical Ventilation with Heat Recovery |
| **PCC** | Pearson’s Correlation Coefficient |
| **TDS** | Thredds Data Server |
| **TEK** | Technical Regulations |
| **WPC** | Wood-Plastic Composites |

# Nomenclature

| Symbol | Description | SI Unit |
|---|---|---|
| A | Area | $m^2$ |
| $c_p$ | Heat capacity | J/kg K |
| $C_f$ | Surface Drag Coefficient (Dimensionless Unit) | 1 |
| H | Overall heat loss | W |
| $H_t$ | Heat loss through transmission through walls, doors, floors etc. | W |
| $H_v$ | Heat loss through ventilation | W |
| $H_i$ | Heat loss through infiltration | W |
| $h_x$ | Height | m |
| $l$ | Material thickness | m |
| µ | Kinematic Viscosity | $Ns/m^2$ |
| m | Length (meter) | m |
| n | Ventilation Rate (Dimensionless Unit) | 1 |
| R | Resistivity | $m^2$ K/W |
| $R_i$ | Resistivity of Internal Surface | $m^2$ K/W |
| $R_W$ | Resistivity of Materials | $m^2$ K/W |
| $R_R$ | Resistivity of Reactivity | $m^2$ K/W |
| $R_C$ | Resistivity of Exterior Surface | $m^2$ K/W |
| T | Temperature | K |
| $\Delta T$ | Change in Temperature | K |
| U | Thermal transmittance | $W/m^2$ K |
| u | Velocity | m/s |
| V | Volume | $m^3$ |
| $\lambda$ | Thermal Conductivity | W/m K |
| W | Power (Watt) | W |

# 1 Introduction

## 1.1 Background

In a constantly evolving world where the transition towards increasingly progressive renewable energy sources has become one of the most important topics regarding a sustainable future, it is expected that a large amount of mundane equipment and machinery will transition towards the usage of electricity as a source of energy rather than through fossil fuel (IEA, 2020) (Shepherd, Bonsall & Harrison, 2012). As the global population continues its growth, the demand for energy globally increases with it – which raises significant challenges in several fields of varying importance (Rizvi et al. 2018). With said increasing demand for energy generated through electricity, being able to supply the world with sufficient energy may prove challenging – especially considering the need to downsize the carbon footprint from fossil fuel, as well as the need to increase the portion of the grand total of energy production which comes renewable energy sources in order to meet the goals set by the Paris Agreement. Parts of the 2015 Paris Agreement, a legally binding treaty that entails climate change and is signed by the vast majority of countries, dictates that one of the goals is to limit the global warming at below 2ºC compared to pre-industrial levels; preferably at 1.5 ºC, by the end of the century (Paris Agreement Article 2, 2015). In order to achieve this, being able to produce more energy through renewable energy sources is important, but there are also other factors in play – such as transportation, distribution and accessibility of electricity-based energy, which is the primary motivation behind this thesis.

In remote areas, more specifically areas of which experience high variation in seasonal climate behaviour through high variance in temperature, wind, rainfall and such – this may prove to be particularly challenging due how the power grids are designed to withstand extreme weather conditions and highly variable weather, and an exponential increase in demand from the power grid may not be as easily supplied because of it (The Norwegian Smartgrid Centre, 2014). In the region of Troms- and Finnmark, where distances are long and overall populations are low - these power grids are spread out over enormous areas, meaning upgrading the power grids to more recent technology and making sure they withstand a higher level of strain in terms of consumer demand is challenging. In order to be able to ensure that the level of demand does not overtake the level of supply in said areas, taking measures to minimalize energy consumption by consumers; buildings in particular, is a necessity in order to be able to adapt to this shift from fossil fuel to electricity, and pave way for the necessary changes in order to meet the demands of the Paris Agreement.

In Tromsø, a city of which has seen immense growth in population over the past decades and is expected to see a similar growth in the foreseeable future, there is a high spread in age of the various buildings in the city, which in turn yields a high gap in energy efficiency in said buildings (Tromsø Kommune, 2020). With such a high gap in energy efficiency in buildings in combination with a growing city and thus a seemingly constant influx of buildings requiring power grid access, the demand for electricity continues to rise, especially considering more and more equipment and machinery transitions from fossil fuel to electricity as a power source. Comparing this demand to the increasing popularity of electric vehicles alone (as seen in Figure 1), it is natural to assume that demand may outweigh supply in the foreseeable future, which in turn will result in a regional crisis as the unconditional supply of electricity is absolute essential to today's society. In order to ensure that said supply will continue to be constant and unconditional in the future, taking measurements to decrease the footprint each individual building has on the power grid is a necessity, while remaining within a financial framework of which is reasonable, sustainable and sound.

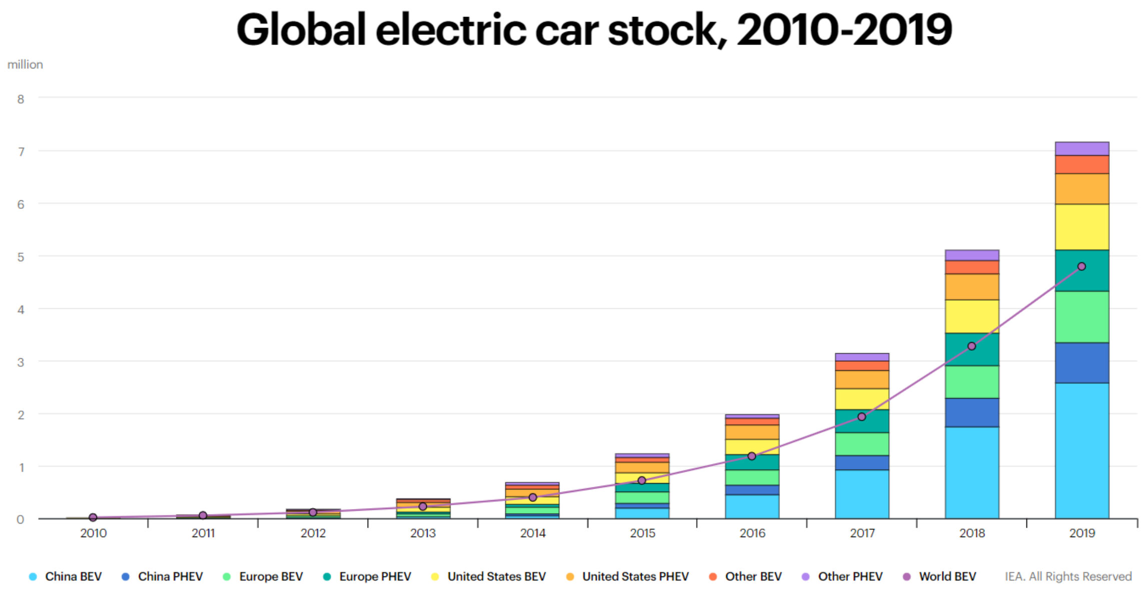


*Figure 1: Global Electric Car Stock 2010-2019 (IEA, 2020).*

## 1.2 Idea and Aim of Thesis

The idea for this thesis was conceived and developed through a discussion between Author and Professor Matteo Chiesa, which entailed topics of energy efficiency in various buildings depending on the quality and materiality in their structural envelope, there are and age, as well as their intended usage. Given the many remotely situated areas in the region, it is both difficult, time-consuming and expensive to arrange inspections from sufficiently knowledgeable personnel to get a proper analysis of the state of any building in said areas, which makes it natural to believe that the threshold for owners of buildings in remote areas to go to the step of renovating their building(s) is significantly higher than in urban areas. As such, the idea of this thesis is to examine the possibilities of comparing correlations between multiple variables in combination with an analysis of data regarding energy consumption, temperature, wind – and if by doing so one could paint a sufficient picture of the state of a building, and thus contribute to significantly lowering threshold of which the consumer must reach in order to upgrade the structural envelope of their building.

Furthermore, we were curious if the usage of said data in combination with data regarding power consumption analyzed through machine learning could give any clear pointers towards whether or not a building could receive funding through Enova, a state-owned enterprise aiming to contribute to reducing energy efficiency by partly funding a project going for cutting-edge and innovative solutions in the building process yielding energy efficiency considered to be as close to the highest standards achievable in the current market (Enova, 2018). In February 2021 however, it was announced that Enova would no longer be funding upgrades to a building's structural envelope for applications sent in after March 24$^{th}$ 2021 as they would dissolve funding of said aspects to a building (Enova, 2021). Through this paper Author will discuss whether this makes sense for the region at hand, a region of which arguably has taken way less advantage of said funding due to the so-mentioned long distances.

As per the above, the idea for the thesis is not only to focus on examining various measurements one could make in order to increase energy efficiency in various types of buildings but also examine if it is possible to draw a conclusion regarding public funding based on the available data, through an analysis of data from the power grid in combination with information about the given structure's materiality and structural envelope, as well as historical and/or predicated data regarding temperature, wind and so forth. Through doing this, the thesis will focus on highlighting the possibilities of creating a model that could pave way for determining the state of a building from the perspective of energy efficiency, and thus also be used for processes of which determines whether or not a building is eligible for funding through Enova to upgrade their structural envelope. The potential upsides to such a model might prove to be many, as it would not only paint a good picture of the state of a building from the perspective of energy efficiency, but significantly lower the threshold for a consumer to go through with the steps of renovating their building's exterior. Additionally, it would lower the needs for engineers or other relevant personnel to spend an entire (or several) workday(s) on travelling back and forth from a location to analyze the energy efficiency of a building or decide if the building is eligible for public funding, and thus potentially lower both the time consumption and the financial strain of such a process.

In short, the main aim of the thesis is to find correlations and differences between information regarding a building's structural envelope, energy consumption (in the form of electricity) as well as weather data – and use the information gained through an analysis of said data and their correlation in presenting the state of the building from an energy efficiency point of view, and potentially help deciding on which measurements could (and perhaps should) be made in said buildings in order to ensure an acceptable level of energy efficiency in comparison to the pre-renovation level. The methodology of this thesis intends to review the possibilities of using an analytical model for determining if it is worthwhile for a building to undergo exterior renovation based on variables such as insulation, area, temperature, wind and more. The methodology entails a simple model of which may contribute to paving way for a future model that is significantly more developed than the one used throughout this thesis, on that is able to give a larger quantity of information as well as more accurate indications to the state of a building in terms of energy efficiency.

## 1.3 Significance

In a market where minimizing global warming is of such importance, taking advantage of as large of a percentage of generated electricity-based energy as possible is necessary to meet the projected goals of the Paris Agreement. In areas like Tromsø, where supplying sufficient power in the event of an exponential growth may expose the weaknesses of the power grid and face a multitude of difficulties, being proactive in order to reduce energy usage across the board is important in order to prepare for a world where renewable energy sources and non-fossil fueled electricity generation is the very center of providing power to day-to-day equipment and machinery. This thesis intends to make an attempt at showcasing the importance of various measures that may be taken advantage of in older buildings in order to reduce the magnitude of their footprint onto the power grid, while simultaneously increasing their level of energy efficiency. This could pave way for a model proving valuable information moving forward for entrepreneurs, consulting firms and homeowners in particular – and could hopefully help pave way for making the threshold for private houseowners or larger housing tenures to consider taking action on upgrading old and severely outdated structural envelopes significantly lower. To put things in perspective, installing a solar cell system on an old building with 40-year-old insulation standards would be inefficient both financially and in terms of energy efficiency. Similarly, upgrading the insulation of a 5-year-old building may be equally inefficient in terms of cost versus benefit – and while this thesis will not provide an analysis of the financial aspects of these measures, it will open up the possibility of doing so in combination with the findings of the thesis. Through the usage of said findings, the hope is to be able to provide the necessary insights on the many possibilities presented through data analysis and machine learning, being able to present a way that in the future may save immense amounts of time, manpower and energy just through a change of methodology in the industry, more specifically to one similar to the one used throughout this particular thesis.

## 1.4 Limitations

Based on the availability of data and large number of variables and parameters that could be included in a potential model, there are a few limitations which must be applied to the thesis as a whole. Due to the differences between buildings and the lack of some details in the available data, not all variables and parameters are available for analysis due to a lack of information. This means that certain variables have to be neglected through this thesis, despite the fact that said variables are relevant to the energy efficiency of a building. While there are many factors in play to determine the energy management or the energy efficiency of a building, such as heat recovery through ventilation (Greenbuildingstore, Unknown Date), heat loss through the air infiltration in ventilation systems, cracks or weaker areas in the walls (Younes, Chadi et al. 2011) and much more – there is a need to take a step back and view the specifics of a building in a less detailed manner in order to be able to use the available information to form a sound analysis throughout this thesis. As such, the building-specific information examined throughout this thesis is limited to the insulation of walls, roof and windows as well as the effect wind and temperature has on them – while the likes of ventilation and air infiltration have been neglected. Said variables are neglected due to vast differences between the buildings, and due to the difficulties and costs knit to acquiring them – which would have be done through the installation of measuring equipment in all of the apartment types that are a part of the analysis of later chapters.

## 1.5 Thesis Structure

**Chapter 2** provides valuable background theory deemed necessary to form an understanding of the methodology of the thesis, as well as provide a strong foundation for the information presented in later chapters of the thesis.

**Chapter 3** presents the methodology used throughout the thesis in order to acquire and analyze necessary information, as well as develop the prediction model applied through Chapter 5. It describes the processes behind many analytical tools and methods used; tools of which are tied to analytical work done through programming and/or machine learning.

**Chapter 4** is a case study of Krokelva Housing Tenure, which entails calculations before and after renovation, the presentation and visualization of the data analyzed through Chapter 3, and a comparison of values and correlations on both ends of the renovation. This chapter servers as the foundation of the prediction model applied to Chapter 5.

**Chapter 5** is a case study of Brattbakken Housing Tenure, which entails calculations prior to the renovation, the presentation and visualization of the data analyzed through Chapter 3, and the results of the applied prediction model developed through the previous chapters.

**Chapter 6** provides the reader with a discussion of all the findings of the thesis in the previous chapters. The chapter also seeks to highlight and discuss the many similarities and differences between the findings of Chapter 4 and Chapter 5, and presents and discusses the many problems of the thesis. Additionally, this chapter contains a discussion of potential improvements to the model and methodology, and the future benefits of continuing with the model.

**Chapter 7** summarizes and concludes the findings of the thesis and proposes suggestions for future work to improve both the methodology and the model used throughout the thesis, be it at the hands of Author or the hands of others.

# 2 Theoretical Background

## 2.1 Altitude-dependent Temperature

In the troposphere layer of the Earth's atmosphere (the layer closest to surface-level), altitude plays a significant role in local temperatures. This is due to the fact that while sunlight is absorbed and reflected by the surface, the surface is heated up through this very process. This leads to the process turning the surface into a heating source to its surroundings. While there are a lot of variables knit to calculating change in temperature based on altitude (meaning the temperature is altitude-dependent), the purpose of this thesis allows for the usage of a simple equation to describe this relationship, a simple equation of which could be defines as

$$T = T_0 - (h_x * 6.5) \tag{2.1}$$

, where T = Temperature in Celsius, $T_0$ is initial temperature in Celsius, $h_x$ is height in regard to the initial point of reference in kilometers, and 6.5 is lapse rate defined the changes in temperature (Celsius) per kilometer (UCAR, 2013).

## 2.2 Transmission of Heat

In any system consisting of several thermodynamical systems in contact with one another, a continuous "force" will be applied by all systems to their surrounding systems, with the mere goal of achieving thermal equilibrium between said thermodynamical systems (Rakhyun et al. 2017). Buildings are no exception to this, where a difference in temperature between the inside and the outside of a building will cause the laws of thermodynamics to play their part in attempting to equalize the difference in temperature and thus achieve thermal equilibrium. In any building, this transmission of heat between the inside and the outside of the building is a combination of three major parts of which contribute to the transmission of heat (or heat loss if you will); namely the transmission of heat in materials (walls, roofs, doors, floors etc.), the transmission of heat in ventilation, and the transmission of heat in infiltration. The joint equation for said transmission of heat is defined as

$$H = H_t + H_v + H_i \tag{2.2}$$

, where H is total heat loss, while $H_t, H_v$ and $H_i$ are heat losses in W (Watt) in their respective categories; materials, ventilation and infiltration (Engineering Toolbox, 2003a). As explained through Chapter 1, only transmission of heat through materials will be considered due to the nature of this thesis, although the relevant theory for transmission of heat through ventilation and infiltration will be included for the sake of understanding the process. Additionally, it should be clarified that this thesis is only interested in heat loss and not in using outsider temperature for heat gain, due to the specific area in question.

### 2.2.1 Transmission of Heat in Materials

The transmission of heat in a building's materials can vary greatly based on the U-values of the materials at hand. Each type of material has a different U-value, a value measuring the transmission of heat through the rate of which the heat is transferred through the material. The lower the U-value, the better equipped said material is to withstand a transfer of heat through the material, meaning the insulating abilities of said material is better. In Equation 2.2, $H_t$ is the summarized heat loss through all materials in walls, windows of roof, each material of which is represented as $H_m$, a heat loss defined as

$$H_m = U * A * \Delta T \tag{2.3}$$

, where $H_m$ is the heat loss of a material, U is the overall heat transfer coefficient for the given material (often referred to as the U-value, see subchapter 2.2), A is the area and $\Delta T$ is difference in temperature on each side of the material seen from an inside perspective (Engineering Toolbox, 2003a).

### 2.2.2 Transmission of Heat in Ventilation and Infiltration

Heat transfer through ventilation systems in buildings is often a fair portion of the total heat loss of a building, especially in older buildings where it is natural to have more frequent occurrences of places for air to exit the building; through the likes of chimneys, extraction fans, open windows and such. As air is circulated, hot air exits the building while cold air enters the building. The more frequently the entirety of the air is exchanged with new air, the more energy is lost in the form of heat loss. Natural ventilation in combination with mechanical ventilation has throughout the 20th century been sufficient in terms of ventilation

(Kleiven, 2003), and because of it the loss of heat through ventilation has historically been rather higher. This is primarily due to how the ventilation rate (ACH) is higher in older buildings that rely on natural ventilation, which is due to a combination of unideal ventilation systems and suboptimal insulation levels from the perspective of a modern measuring stick. The ventilation rate ACH may vary greatly depending on the age and location of the building; an older building that is exposed to a lot of wind will experience a significantly higher ACH than a newer building of which is well insulated and airtight in comparison to the older building. In a newer building the ACH is expected to be around 1 - 1.5 (Number of complete changes of air per hour), while an exposed old building built by the standards of the 1970s may lie somewhere between 2 – 2.5 (DIBK, 2007) (DIBK, 2018). The transfer of heat through ventilation is defined as

$$H_v = c_p * n * V * \Delta T \tag{2.4}$$

, where $c_p$ is heat capacity per cubic meter (which is a constant of 0.33), n is the ventilation rate ACH, V is the building's volume, and $\Delta T$ is difference in temperature on each side of the ventilation system (Everett, 2015) (Engineering Toolbox, 2003a).

## 2.3 Thermal Transmittance, Insulation and Regulations

### 2.3.1 Thermal Transmittance (U-Value)

Thermal transmittance is a concept used to describe how resistant a given material is towards the laws of thermodynamics. As briefly explained in subchapter 2.2, in a system where air is in contact with one or multiple materials – the laws of thermodynamics states that the system will continuously attempt to reach thermal equilibrium between all parties in contact with one another in said system. From the perspective of a building, the materials of which the building has been built up with will constantly attempt to reach thermal equilibrium with its surroundings, meaning the air on both sides of the materials will attempt to reach thermal equilibrium between them. This forms the very foundation of structural engineering in the modern world, where energy efficiency is of vast importance – as shown through the development of building regulations of the years 50 years (see subchapter 2.3.3).

Thermal transmittance (U) is in essence the rate of which heat transfers, and is given by material thickness and material conductivity, which forms the resistance value R (Lymath, 2015). The more commonly known U-value is reciprocal to the R-value, where the two values are defined as

$$U = \frac{1}{R} \rightarrow R = \frac{l}{ƛ} \tag{2.5}$$

, where U is U-Value, R is R-value, $l$ is thickness of the material and ƛ is the thermal conductivity of the material. These two formulas are simplified versions, which will be explored in more advanced forms in Subchapter 2.4 regarding wind and temperature. Due to the relationship between U and R, a high R-value equals high resistivity, which in turn results in a low U-value – meaning the materials are well-insulating materials. The higher the U-value, the weaker the insulating abilities of the materials are (Lymath, 2015).

### 2.3.2 Insulation of Walls, Windows and Roof

Insulation of walls, windows and roof are of vast importance to ensure a low transmission of heat between the exterior and interior of a building, and is directly knit to its thermal transmittance (Lymath, 2015). Walls and roof have the potential to reach much higher resistivity (R-value) than modern windows, which is due to the materiality differences between the three of them – where thermal conductivity in glass is substantially lower than materials used an insulation in walls, i.e glass wool. As the R-value of a structure depends on the resistances of multiple variables, namely interior surface, the wall, roof or window itself, exterior surface radiation and exterior surface convection, defining $R_{tot}$ to understand the effect of wind as an isolated variable is necessary. $R_c$ is defined as

$$R_{tot} = R_i + R_w + \frac{R_r + R_c}{R_r\, R_c} \tag{2.6}$$

, where $R_i$ is resistance of internal surface, $R_w$ is resistance of materials, $R_r$ is resistance of the radiation, and $R_c$ is the resistance of the exterior surface convection (Williams & Arens, 1977).

### 2.3.3 Building Regulations

There are fair amounts of regulations knit to buildings and demand in terms of thermal transmittance, regulations that must be met for the building to be deemed acceptable by authorities. These regulations have evolved quite a lot over time, where buildings from the 1950s had close to no insulation – whereas buildings built in accordance to the TEK-2017 building regulations have set requirements for insulation thickness as well as thermal transmittance for walls, roof and windows (Regjeringen, 2018). Table 1 below shows a bunch of minimum requirements to thermal transmittance based on building regulations from various years and showcases large variety in thickness and/or U-values between 1949 and 2017.

| **Minimum requirements to Thermal Transmittance (U-Values)** | | | | | |
|---|---|---|---|---|---|
| | **Thickness (cm)** | | **U-Values (W/m$^2$ K)** | | |
| Regulation Year | Walls | Roof | Walls | Roof | Windows |
| 1949 | - | - | - | - | - |
| 1969 | 15 | 15-20 | - | - | 3.0 |
| 1985 | 15 | 20 | 0.25 or 0.35 | 0.23 | 2.1 or 2.74 |
| 1997 | - | - | 0.22 | 0.15 | 1.6 |
| 2017 | - | - | 0.18 | 0.13 | 0.8 |

*Table 1: Collection of U-Value Requirements through historical building regulations (Regjeringen, 2018).*

## 2.4 Effect of Weather

The level of which the wind flows around a building may vary quite a lot depending on the specifics of how the buildings is designed. Flowing wind causes forced heat transfers through convection from and to the walls and roof primarily through the turbulence it generates in the building's exterior layer itself, in combination with the wind-flow patterns around the building (Williams & Arens, 1977). The primary factor in play here is the turbulence it generates in the building's exterior, and is based on Reynold's analogy which states that the fluid motion near the turbulent boundary layer of the wall, any air flowing parallel to plane of the wall will result in the thermal transfer mechanism to be equal to the momentum transfer mechanism through the behaviour of turbulent vortices, which is the cause for some heat transfer (although one that is hard to measure). In close proximity to the wall however, this heat transfer primarily comes from molecular diffusion across the boundary layers for velocity, temperature and concentration. In addition to this, heat transfer and mass transfer are close to equal to another; meaning the heat loss due to the effect of wind can be expressed as

$$N_u = \frac{1}{2} R_e C_f \tag{2.7}$$

, $N_u$ is Nusselt's Number, $R_e$ is Reynold's Number and $C_f$ is surface drag coefficient (Williams & Arens, 1977). While this formula does not appear to be related to previous equations for heat loss, deriving an equation for the $R_c$-value through the information provided by equation 2.7 and the proportionality between surface drag coefficient and velocity in a fluid with a fixed conductivity and viscosity. $R_c$ is defined as

$$\frac{hl}{\lambda} = \frac{ul}{2\mu} C_f \rightarrow h = \frac{ul\lambda}{2\mu l} C_f \rightarrow R_c = \frac{1}{h} = \frac{2\mu}{u\lambda} \frac{1}{C_f} \tag{2.8}$$

, where h = thermal conductivity coefficient (Bell, 2001), $\mu$ is kinematic viscosity, $R_c$ is the resistance of exterior surface convection, u is wind velocity, and the rest are defined in previous equations.

# 2.5 Correlation

## 2.5.1 Pearson Correlation Coefficient

The Pearson's Correlation Coefficient (PCC) is a coefficient of which calculates the coherence between two variables over a series of examples. PCC describes the relationship between two variables, and said relationship will be presented somewhere on the interval [-1, 1], where -1 equals a perfect negative correlation between the variables, and 1 equals a perfect positive correlation between the variables. This means that the closer the PCC is to -1 or 1, the better two variables correlate with one another – where 0 equals no correlation at all. In the example of a positive correlation the data, for every positive increase in variable x, there is a positive increase in variable y. For a negative correlation, for every positive increase in variable x, there is a negative increase in variable y. If either of these correlations are perfect correlations, there is a 1 to 1 relationship between x and y (UWE, 2021). PCC is defined as

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} - \sqrt{\sum_i (i - \bar{y})^2}} \tag{2.9}$$

, where r is the PCC, $x_i$ and $y_i$ are values of the two valuables at step n, and $\bar{x}$ and $\bar{y}$ are the average values of the two variables. Table 2 below shows the corresponding strength of correlation depending on the correlation coefficient calculated through the PCC method.

| **Coefficient Value** | | **Corresponding Correlation Strength** | |
|---|---|---|---|
| Positive | Negative | Positive | Negative |
| 1 | -1 | Perfect Positive Correlation | Perfect Negative Correlation |
| 0.8 | -0.8 | Strong Positive Correlation | Strong Negative Correlation |
| 0.6 | -0.6 | Moderate Positive Correlation | Moderate Negative Correlation |
| 0.4 | -0.4 | Weak Positive Correlation | Weak Negative Correlation |
| 0.2 | -0.2 | Minimal Positive Correlation | Minimal Negative Correlation |
| 0 | | Absolutely No Correlation | |

*Table 2: Correlation coefficient and corresponding correlation strength.*

### 2.5.2 Linear Regression Model

A linear regression model is a statistical method used in regression analysis to examine the relationship between one dependent variable and up to several independent variables through modelling them towards one another. The higher the amount of samples is for each of the variables, the more accurate the regression analysis becomes – meaning the more accurate the regression model could be used in terms of predicting future events in a statistical manner, which for this thesis would mean predicting energy consumption from temperature (CFI, 2021). The linear regression model is defined as

$$y = ax + b \tag{2.10}$$

, where x is a function of y in a coordinate system with regression coefficients a and b. Figure 2 is an example plot of how a linear regression model looks through plotting a regression line based off a large quantity of data. Through following the path of the line, estimating the average value of y at any given point x (or vice versa) is doable, and is a helpful tool in the analysis of data.

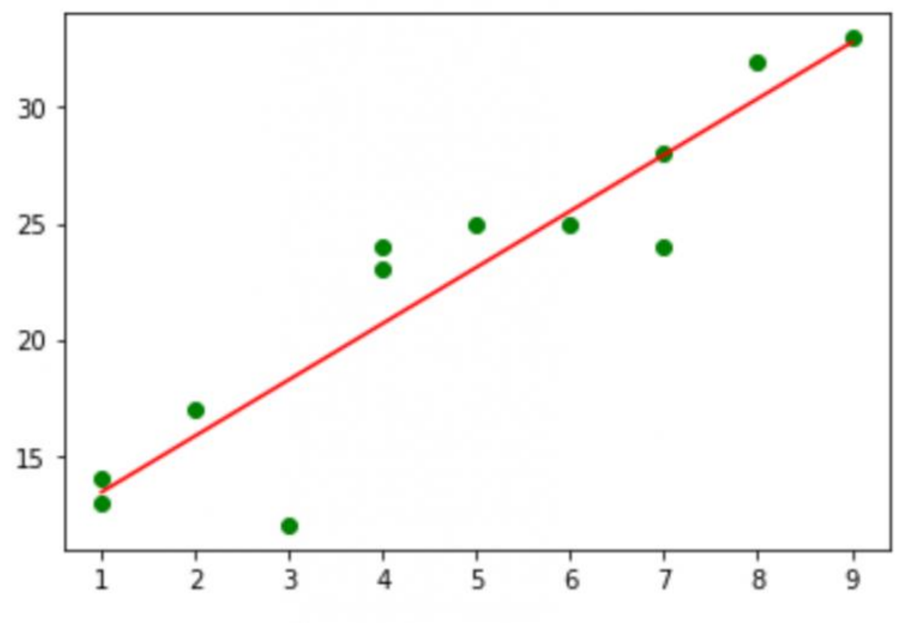


*Figure 2: Example of Linear Regression plot (Bobbit, 2020).*

# 3 Methodology

## 3.1 Overview

The methodology of this thesis primarily entails analysis of many factors in combination with one another, in order to find correlations between said factors and determine which information said correlations may convey regarding the data of which has been collected. In essence, the methodology seeks to investigate the levels of correlation between said variables and explain the results behind them with practical and theoretical examples. The backbone of the thesis lies in the many datasets collected, as they make up most of necessary information to perform a proper analysis. The datasets have been collected and analyzed through a quantitative approach, where some are presented in a time series over the duration of multiple months or years, while others provide averaged statistical information. In order to provide the most accurate information available regarding the case studies especially, some datasets contain measured data, while other sets of data contain information accumulated through prediction models and machine learning programs.

## 3.2 Structural Calculations

In order to compare calculations regarding U-values with information provided through the datasets, setting up detailed calculations based on the theory chapter allows for a rough overview of expected U-values depending on insulation type as well as insulation thickness, where multiple factors are at play. For the purposes of this thesis, assuming outer walls in aluminum plates, glass wool insulation in between the outer and inner layer, as well as a layer of plaster as the inner layer is natural based on the nature of both case studies both prior to and after the renovation – although the values for conductivity and thickness will vary due to the difference in minimum standards and updated technologies.

Through equation 2.6 that entails the total calculation of the R-value of a building, the exterior surface convection is a small part of the total resistance of a material, and thus the wind velocity only affects an equally smart portion of the total resistance. Due to this fact, the insulation material used in the wall is the part of which truly matters, and wind velocity only really plays a significant part in poorly insulated materials, such as single-pane glass windows

(Williams & Arens, 1977). This goes to show that while wind does not play a major part in the insulation of a solid material in a wall, it may affect outdated and older windows with lower insulation than newer, well-insulated windows. Through the physics behind equation 2.6, the expectations going forward towards the case studies is a significantly lower correlation between wind speeds and energy consumption in comparison to that of temperature and energy consumption, meaning the effect of wind in terms of the U-value for walls and roof has proven to be a factor of which is neglectable moving forward.
Calculating the combined U-values for walls and roof is done through Equation 2.5, where each individual R-value is calculated and them summarized into a total R-value which is then rewritten to a U-value. In practice this is a rewrite of Equation 2.6 based on the findings of this subsection, neglecting the effect wind has on the U-value on all the materials used as it only truly has any effect on very thin materials with poor insulation effects. The specific information used to calculate the U-values for walls and roof are based on the elements the walls consist of and is further explained in Chapter 4. As an example, concrete blocks with the conductivity of 0.090 W/mK assuming a thickness of 100mm or 0.100m the R- and U-values of said concrete blocks are calculated as

$$R = \frac{l}{\lambda} = \frac{0.100}{0.090} \left[ \frac{m}{\frac{W}{m\,K}} \right] = 1.111 \ \left[ \frac{K\,m^2}{W} \right]$$

$$U = \frac{1}{R} = \frac{1}{1.111} \left[ \frac{1}{\frac{K\,m^2}{W}} \right] = 0.900 \ \left[ \frac{W}{m^2\,K} \right]$$

The corresponding values for transmission of heat through the material used in the example above is calculated through Equation 2.2 and 2.3, where a concrete wall with an area A of 10 square meters ($m^2$), an outdoor of temperature $T_o$ = 10 degrees Celsius and an indoor temperature of $T_i$ = 22 degrees Celsius has a transmission of heat equal to

$$H_t = H_m = U * A * \Delta T \ \left[ \frac{W}{m^2\,K} * m^2 * K \right] = U * A * (T_i - T_o) = \underline{\ 108\,W}$$

The reasoning for $H_t$ being equal to $H_m$ is simply due to the fact that the thesis neglects the remaining parts of equation 2.2 due to lack of measurement equipment, resulting in $H_t = H_m$.

## 3.3 Datasets

### 3.3.1 Measured and Collected Datasets

There are primarily three types of datasets that are either measured or collected, all of which contains information particularly relevant to the case studies in Chapter 4 and Chapter 5. Two of these types of datasets are timeseries that contain data regarding temperature and energy consumption respectively, with an hourly resolution. The datasets for temperature measurements are datasets of which contains hourly temperature data from Stakkevollan weather station which lies around 640 meters from Brattbakken and 3.98 kilometers from Krokelva (Figure 3 and Figure 5). Even though temperature varies with altitude and pressure, as the difference in altitude between Stakkevollan weather station and the two location of interest does not exceed more than +- of 30 meters in addition to the fact that the three points are acceptably close to one another in distance; it is sufficient to assume based on Equation 2.1 that the feedback of the difference in altitude and exact coordinates should prove to be negligible for the purposes of this thesis. While there will be realistic differences in temperature between these areas and the weather station, said differences will not only be very minor but also be equally different throughout the entire course of the timeseries – meaning the correlations will see negligible feedback from this particular difference. This can be viewed through the example of Equation 2.1, where an initial height of 70m as well as a temperature of 10 degrees Celsius is assumed at the point of reference (Stakkevollan Measuring Station). Based on the heights of Brattbakken Housing tenure (99.45m as shown in Figure 6) and Krokelva Housing tenure (50.89m as show in Figure 4) the change in temperature for both of these locations shows minimal alterations (as seen in the calculations below), and based on the fact that these differences will be constant regardless of the point of view in the time series, neglecting it will not cause any significant effect to the findings of this thesis.

$$T_{brattbakken} = 10\ [℃] - \left(29.45\ [m] * \left(\frac{1}{1000}\left[\frac{km}{m}\right]\right) * 6.5\right) [℃]$$

$$\rightarrow T_{brattbakken} = 10\ [℃] - 0.192\ [℃] \approx 9.80\ [℃]$$

$$T_{krokelva} = 10\ [℃] - \left(-19.11\ [m] * \left(\frac{1}{1000}\left[\frac{km}{m}\right]\right) * 6.5\right) [℃]$$

$$\rightarrow T_{krokelva} = 10\ [℃] + 0.124\ [℃] \approx 10.12\ [℃]$$


*Figure 3: Length between Stakkevollan Measuring Station and Krokelva Borettslag, Retrieved through Google Maps.*

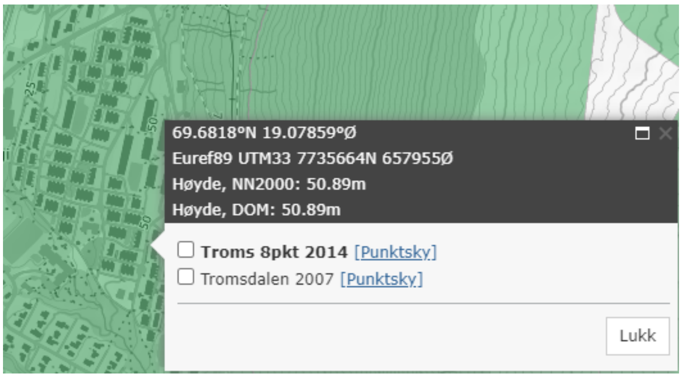


*Figure 4: Altitude of Krokelva Borettslag, retrieved from hoydedata.no.*


*Figure 5: Length between Stakkevollan Measuring Station and Brattbakken Borettslag, Retrieved through Google Maps.*

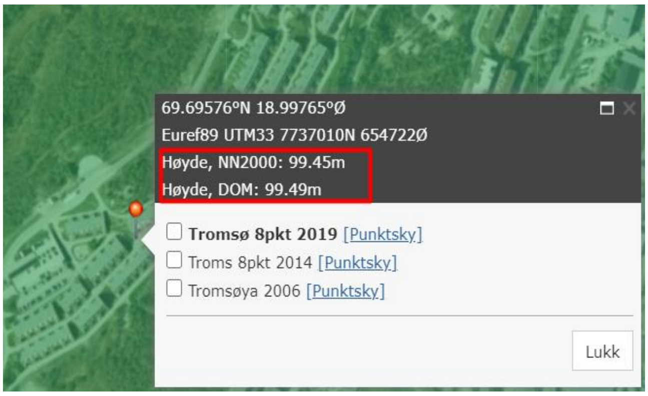


*Figure 6: Altitude of Brattbakken Borettslag, retrieved from hoydedata.no.*

The third type of dataset that is either collected or measured, is a collected dataset of which is time independent in contrast to the previous two types. This set of data primarily contains information regarding the buildings at hand, such as age, area, insulation thickness and so forth for the various apartments – and has been collected through correspondence with board members of the two housing tenures included in this thesis. Acquiring said information enables multi-variable analysis of the buildings at hand and could show which factors correlate to which degree with one another, which in turn opens up for a thorough analysis of which part each factor play in energy efficiency.

The last type of datasets are consumption data for each of the two housing tenures collected separately, both of which are aggregated by an external party to avoid Author being able to tie consumption data to any specific address and thus risk the potential violation of any privacy laws. The major beneficial factor of these two housing tenures is the similarities they present in terms of structural design between the buildings they consist of; where all buildings for Brattbakken and Krokelva contain similar apartments in age and size, meaning differentiating between the energy consumption for each of them depending on apartment type is doable. For each of the datasets there is given hourly data for all apartment types; three apartment types of Brattbakken (two-room, three-room and four-room apartments) and two apartment types for Krokelva (two-room and four-room apartments). This allows for the data for each of the apartment types to be pitched against one another while including other variables available through other datasets, such as area, temperature, age and so forth.

### 3.3.2 AROME-Arctic Prediction/Forecasting Model

In great contrast to the datasets for temperature, acquiring accurate data for wind speeds is significantly more complicated than collecting publicly available data from a weather station. Even though Stakkevollan weather station is relatively close to Brattbakken, the difference in wind characteristics between the two places could prove to be quite drastic even though only 640 meters and 20 meters of altitude separates the two points of measurement. In terms of Krokelva the differences are even more drastic due to the nearly 4km gap between the two locations, and the potentially large geological differences between the two locations. Wind speeds are more reliant on surrounding terrain than temperature is, and as such it is necessary to use information regarding wind specifically at the point of which Brattbakken and Krokelva lies to understand how wind behaves at these very points. Even if this was not the case, Stakkevollan weather station does not provide wind measurement – rendering it to be of no use with respects to wind anyway, which forces the usage of a prediction model such as this one.

To meet the needs of this report, a wind-prediction model called “AROME-Arctic” has been used; a model of which is able to predict wind speeds and directions based on historical data within a given area. The AROME-Arctic model is a numerical prediction model initially made with the goal of increasing accuracy in short-range forecasts in mind. The model is capable of predicting several weather-based regularities and irregularities, such as fog, wind, temperature and probability of polar lows to mention a few. The AROME-Arctic as a modelling system is based on the HARMONIE-AROME configuration of the AROME-model, which enables the usage of the model in countries that are quite far north on the northern hemisphere; such as the likes of Norway, Finland, Iceland, Sweden and more (Bengtsson et al. 2017). The model is a high-resolution system with 2.5km grid spacing, and issues updated forecasts 4 times a day. This means fetching updated information every 6 hours is essential to get the most accurate forecasting values, and a realistic value of the wind at a given location throughout the entire length of the timeseries (Norwegian Meteorological Institute, 2017).

The intended usage of said model in this thesis is to be able to numerically localize the predicted wind value and direction at Brattbakken through machine learning and through Python (programming language). The AROME-Arctic model allows the definition of an area of interest, an area of which depends on user limitation through a defined coordinate system with variables in both latitude and longitude. THREDDS Data Servers (TDS) are frequently used to build a bridge between large sets of metadata and people seeking to use said data for scientific purposes, without having to store them locally. This allows for the extraction of necessary information from the TDS through METs API without downloading them, and as each file can be over 1 Gigabyte in size while it is necessary with 4 files per day to maintain sufficiently accurate predictions, locally stored files would result in over 1 Terabyte of data (UCAR, 2018). As the area of which this thesis wishes to explore is rather small, it is expected that the wind speeds will be similar across the entirety of the area with negligible differences. This allows for the usage of the aggregated energy consumption data to be used in combination with the wind data collected through this method, as if the data for energy consumption were given on a per-unit basis it would also mean that the wind data would have to be collected for each and every unit of the housing tenures for the most accurate results. Through the usage of aggregated data, the unnecessarily complicated parts of comparing data are filtered out without any significant loss to the quality of the analysis.

Due to the previously mentioned 2.5km grid spacing used throughout the model in combination with the limitations of python only allowing one decimal for integers, defining the area to fetch data through the AROME-Arctic model is significantly larger than the areas of interest to this thesis. As seen in Figure 7 below, the squared area stretching between latitudes 69.6 and 69.7 as well as longitudes 18.9 and 19.1 yields an area of 10.0 km (latitude) times 7.5km (longitude). In order to calculate the correct results through the model, defining the area through a grid system with evenly spread-out grids will allow for the code to withdraw information regarding wind speeds at any given grid, as seen in Figure 8 where the targeted area has been split into 12 evenly spaces grids of 2.5 x 2.5 km grids, where the squared grids of interest are grids 5 (Brattbakken) and 9 (Krokelva).

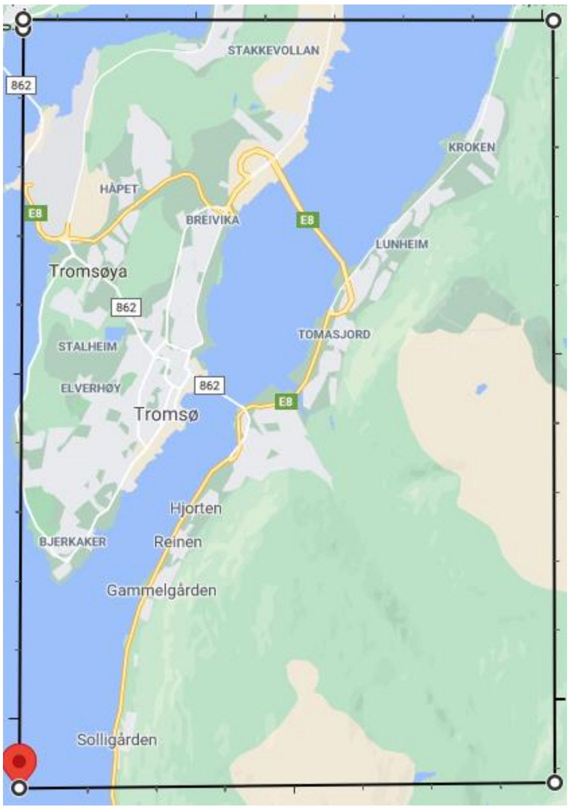


*Figure 7: Area defined by latitudes 69.6 to 69.8 and longitudes 18.9 to 19.1. Retrieved from Google Maps.*


*Figure 8: Area split into 12 grid system for the target area, where grids are numerised from 1 through 12.*

## 3.4 Python Programs

Being able to analyze large quantities of data is a necessity for the purposes of this thesis, where python programs have proven themselves to be a crucial part of the analysis. There are in essence two different types of programs that have been used; one for gathering information regarding wind prediction at a given point through the AROME-Arctic Model thoroughly explained in subsection 3.3, as well as one type of program that have been used to analyze existing information through withdrawing data from .csv type documents.

### 3.4.1 Wind Prediction Program

The AROME-Arctic Model has been used for two different locations, where the example of it being used for Krokelva Borettslag to fetch information regarding wind for October 2017 will be provided through Appendix A. The program uses TDS (see subsection 3.3) to withdraw information within a given time frame, fetching new information every 6 hours of the day. The program stores information from every hour between a defined starting point and a defined end point into a list, before said list in converted into an .xlsx file viewable through spreadsheet-compatible programs, such as Microsoft Excel or Google Sheets.

### 3.4.2 Data Analysis & Plotting Program

The many data analysis programs used throughout this thesis largely revolve around doing the same operations; checking for a correlation between various variables and making plots with one or multiple variables in them. As an example, the code for fetching, processing and plotting information regarding energy consumption and temperature from Brattbakken has been included in Appendix B, a code of which fetches information from a .csv file through an excel-working library for python, before storing the information in lists and then plotting several plots which may be found throughout this thesis.

## 3.5 Prediction through comparison

Throughout the case studies, the findings from Krokelva Borettslag in terms of energy reduction are intended as an indication of how a similar renovation of Brattbakken Borettslag will look. As seen through the case studies there are significant similarities between the two housing tenures in terms of age, pre-existing level of insulation and area, which will be discussed more thoroughly in Chapters 4, 5 and 6. Although the two housing tenures are quite similar there are bound to be some differences, which is why the potential decrease in energy usage for Brattbakken will be predicted through a comparison of correlations and ratios, more specifically in terms of their differences before and after renovation at Krokelva, where the ratio and correlations between before and after renovation serves as a measuring stick for how Brattbakken Borettslag will look like post-renovation. As an example, if an apartment used 18000 kWh/year prior to renovation and 16 000 kWh/year after renovation, the percentage and/or ratio is calculated as follows:

$$\frac{16000\ KWh\ (After)}{18000\ KWh\ (Before)} = 0.888\ (88.8\%)$$

# 4 Case Study: Krokelva Borettslag

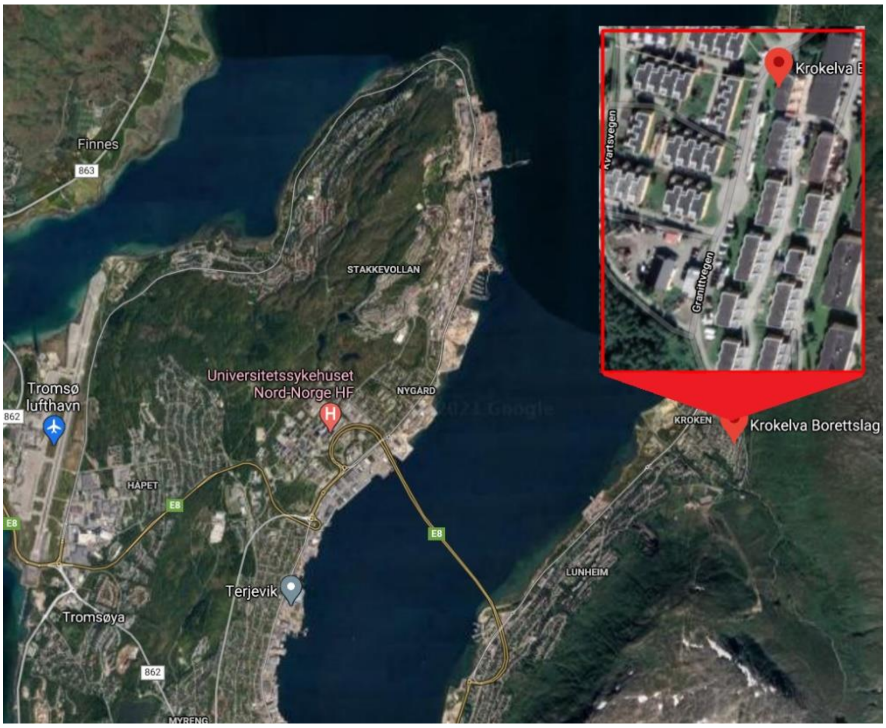


*Figure 9: Krokelva Borettslag. Retrieved from Google Maps.*

## 4.1 Technical Overview

Krokelva Borettslag is a building housing tenure consisting of a grand total of 149 apartments (Johnsen, 2019), located in Kroken, Tromsø with the coordinates 69.681 degrees North and 19.080 degrees East, as seen in Figure 9. The housing tenure was built between 1979 and 1985, and as such the structural standards of the housing tenure prior to renovation have followed the regulations for buildings from 1969, as the next updated regulations for technical structural standards did not come until 1985 (Isola, Unknown Year). The specific information regarding utility floor space (Bruttoareal in Norwegian, abbreviated BRA) and number of apartments that are a part of the analysis are found Table 3. The housing tenure is separated into several larger building complexes, consisting of 8 apartments each. As Figure 10 and Figure 11 shows, each of the building types consists of exclusively four-room apartments and two-room apartments, where the four-room apartments are two-story apartments situated next to one another on a horizontal plane, while the two-room apartments are single-story apartments distributed in both horizontally and vertically in a grid distribution of 2 (vertical) times 4 (horizontal). Based on the layouts of the buildings consisting of multiple apartments, it is expected from a physics standpoint that the apartments on the sides with a larger portion of its outer wall area exposed directly to the air surrounding the building are more prone to a temperature loss than those situated in the middle – although as all buildings are the same and the number of apartments that have been analyzed entail the full buildings, this factor can be partly neglected throughout this thesis as the data is aggregated, and there are no differences between the apartment buildings themselves. The one thing to keep in mind for Chapter 6 however, is that two-rooms only have half of their apartments situated in a position with an outdoor roof, while the other half is located beneath another apartment.

| **Structural Information: Krokelva** | | |
|---|---|---|
| Room Type | Utility Floor Space (BRA) | Number of apartments in analysis |
| 2-Room | 57 $m^2$ | 24 |
| 4-Room | 111 $m^2$ | 32 |

*Table 3: Table of Structural Information from Krokelva Borettslag before and after renovation.*

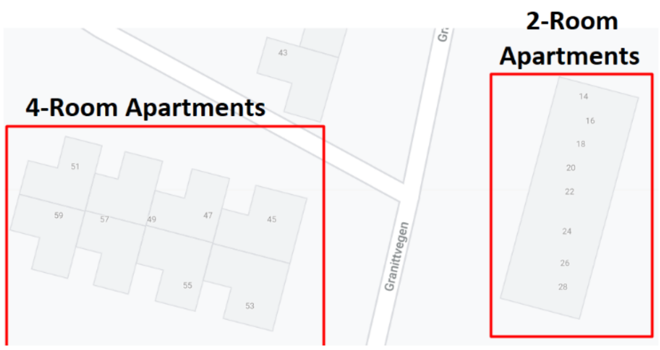


*Figure 10: Layout of 4-Room vs 2-Room Apartments at Krokelva Borettslag. Retrieved from Google Maps.*

*Figure 11: Street-view of 2-Room Apartments. Retrieved from Google Maps.*

## 4.2 Before Renovation

### 4.2.1 Structural Specifications

As mentioned in subsection 4.1, making assumptions regarding the building process based on the regulations of 1969 and the likelihood of them being followed throughout the building process is natural for this thesis. Based on the knowledge of some of the materials used in buildings in combination with knowledge of thickness of insulation based on the 1969 regulations and the norm throughout the 1970s, presenting a wholistic picture close to that of reality is doable. The U-values for the walls and roof are calculated as described through subsection 3.2, while the U-value for windows have been assumed. While the roof and outer walls remained original prior to the renovation, the windows are likely to have been swapped out in the late 90s, and as such windows based on the TEK97 regulations have been assumed – meaning the U-value for windows prior to renovation are assumed to be 1.6 (Enova, Unknown Year). The conductivity (ƛ) of the wall depends on the various materials used in the building process, which prior to renovation is an interior plaster wall with a conductivity 0.026 W/mK (Lymath, 2015), glasswool insulation from the 1970s with 0.040 W/mK (Lymath, 2015), a plasterboard exterior with 0.016 W/mK (Engineering Toolbox, 2003b), and a wooden exterior with 0.16 W/mK (Engineering Toolbox, 2003b).

As dictated by the building regulations of 1969 in combination with the norm throughout the 1970s and early 1980s, a thickness of 150mm of insulation is assumed (Isola, Unknown Year) and a thickness of 19mm for the exterior wooden plates is assumed. Considering the assumption of windows following the standard outline by TEK97 and windows being swapped out around the millennia, a plaster interior wall with a thickness of 13mm is assumed. The values and calculations of the R-values of the various materials for both walls and roof are shown through Table 4, while Table 5 shows the combined values after summarizing those of Table 4. The U-values of the building's walls, roof and windows prior to renovation based on the calculations done throughout this thesis are estimated to be 0.1954 $W/Km^2$ for walls, 0.1909 $W/Km^2$ for roof and 1.6 $W/Km^2$ for windows. Values for aspects of the roof that are considered constants before and after the renovation are ignored in the calculations, such as wind/fume-shielding covers and barge-layers for ventilation.

| Wall | | | |
|---|---|---|---|
| **Material** | **Thickness (m)** | **Conductivity (W/m K)** | **R-Value (K m²/W)** |
| Plaster Wall (Interior) | 0.013 | 0.026 | 0.500 |
| Glasswool Insulation (Old) | 0.150 | 0.040 | 3.750 |
| Plasterboard (Exterior) | 0.012 | 0.016 | 0.750 |
| Wood Exterior (Old) | 0.019 | 0.16 | 0.119 |
| **Roof** | | | |
| Chipboard Plates (Interior) | 0.012 | 0.15 | 0.080 |
| Glasswool Insulation (Old) | 0.200 | 0.040 | 5.000 |
| Wood | 0.019 | 0.16 | 0.119 |
| Roof Shingle Exterior (Old) | 0.003 | 0.79 | 0.004 |

*Table 4: R-value calculations prior to the renovation based on the thickness and conductivity of the given materials.*

| Combined Values | | |
|---|---|---|
| | **R-Value (K m²/W)** | **U-Value (W/K m²)** |
| Walls | 5.119 | 0.1954 |
| Roof | 5.239 | 0.1909 |
| Windows | 0.625 | 1.6 |

*Table 5: Summarized  R-Values and U-Values for walls, windows and roof prior to the renovation.*

### 4.2.2 Temperature and Wind Conditions

The temperatures at Krokelva are represented thoroughly through Figure 12 and below, showcasing the specifics of the temperature data collected through Stakkevollan measuring station between the 9$^{th}$ of October 2017 and the 15$^{th}$ of March 2018. The temperatures at Krokelva show a curve of which should be expected in regards to the seasonal variations in Tromsø, with a minimum extrema located at -14.2 degrees Celsius in March, and a maximum extrema at 10.5 degrees Celsius in October, which results in a difference of roughly 24.7 degrees Celsius between the two of them (see Table 6).  There is a clear trend showcasing continuously decreasing temperatures ranging from October 2017 through February 2018, whereas the temperatures seem to stabilize moving into March 2018. The month with the highest average temperature in the given dataset is October with an average of 2.3 Celsius, while the lowest average temperature is February with an average of -5.7 degrees Celsius – resulting in a difference of roughly 8.0 degrees Celsius between the two averages.

The wind speeds at Krokelva have a significantly different trendline than that of temperature; where the strongest winds are located towards the centre of the graph (see Figure 12) in between the very end of November throughout the entirety of January 2018. On either side of this period of time, the winds are rather stable and remain largely at under 7.5 m/s. Based on a closer look on the data that visualizes, there is a significant rise in wind speeds between October and November (see Figure 13) as well as a smaller decrease between January and February. The maximum values of November and December are over twice as strong as the one if October (17.35 m/s, 16.68 m/s and 8.12 m/s respectively, see Table 7), while the average values of the two aforementioned months are roughly 1.5x as strong as the one in October. This goes to show that for the given timeframe the winds were much more violent and overall much higher in the months of November, December and January than in the remaining 3 months, while the months on each side of the graph (October and March) are identical in average wind speeds.

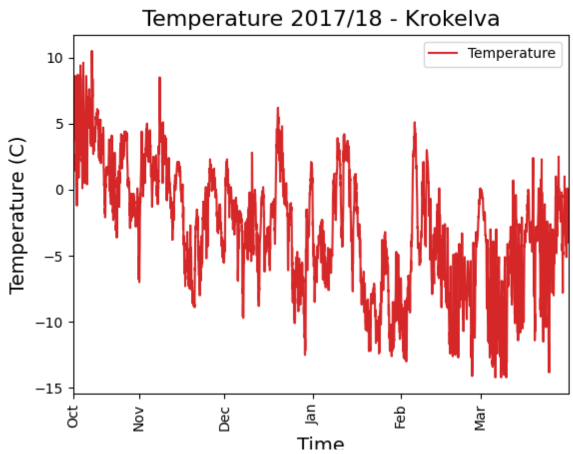


*Figure 13: Variation of temperature over time Stakkevollan Measuring Station in acceptable proximity to pre-renovation Krokelva.*

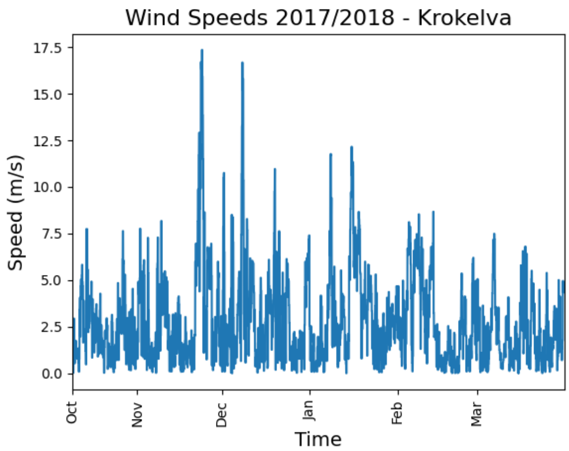


*Figure 12: Variation of wind speed over time at pre-renovation Krokelva based on the AROME-Arctic Prediction Model.*

| Temperature (in Celsius) | | | |
|---|---|---|---|
| **Month** | **Minimum Value** | **Maximum Value** | **Average Temperature** |
| October 2017 | -5.5 | 10.5 | 2.3 |
| November 2017 | -8.9 | 8.5 | -0.9 |
| December 2017 | -12.5 | 6.2 | -2.7 |
| January 2018 | -12.6 | 4.2 | -5.1 |
| February 2018 | -14.1 | 5.3 | -5.7 |
| March 2018 | -14.2 | 2.5 | -5.5 |

*Table 6: Variation of Temperature at Krokelva in 2017-2018.*

| Wind Speeds (in m/s) | | | |
|---|---|---|---|
| **Month** | **Minimum Value** | **Maximum Value** | **Average Value** |
| October 2017 | 0.02 | 8.12 | 2.15 |
| November 2017 | 0.03 | 17.35 | 3.25 |
| December 2017 | 0.00 | 16.68 | 3.23 |
| January 2018 | 0.01 | 12.16 | 3.15 |
| February 2018 | 0.02 | 8.67 | 2.79 |
| March 2018 | 0.01 | 7.66 | 2.15 |

*Table 7: Variation in Wind Speeds at pre-renovation Krokelva in 2017-2018.*

### 4.2.3 Transmission of Heat

As the thesis do not hold any information regarding the wall or windows surface area due to no physical measurements being made, calculating the transmission of heat for these two aspects of the structural envelope is done with that in mind, even though finding the combined surface area of sides of the building is doable in a somewhat accurate manner based on satellite tools allowing for length measurements. The issue lies in the fact that distinguishing which magnitude of the sides of the building are considered as window or wall is not measurable in this way, which also holds true for the height of the building in itself. Although assumptions could be made regarding area for each of the two variables as well as the height of the building, it makes more sense to calculate transmission of heat based on a per-square meter basis for sake of comparison to Brattbakken at a later stage. As such, the calculations for windows and walls presents transmission of heat per square meter, and for the sake of consistency this is also the case for the roof despite the fact that this measurable in its entirety due to the access of satellite measurements of length. The transmission of heat prior to the renovation is outlined through Table 8, which is based on the U-values found in subchapter 4.2.1, where windows sits at 19.2 W/m$^2$ while walls and roof sits at 2.3448 W/m$^2$ and 2.908 W/m$^2$ respectively.

| Transmission of Heat (per m$^2$) | | | | |
|---|---|---|---|---|
| | **Outdoor Temp (C)** | **Indoor Temp (C)** | **U-Value (W/Km$^2$)** | **Transmission of Heat (W/m$^2$)** |
| Walls | 10 | 22 | 0.1954 | 2.3448 W/m$^2$ |
| Windows | 10 | 22 | 1.6 | 19.2 W/m$^2$ |
| Roof | 10 | 22 | 0.1909 | 2.2908 W/m$^2$ |

*Table 8: Transmission of Heat prior to renovation.*

### 4.2.4 Energy Consumption

The energy consumption at Krokelva was prior to analysis expected to increase throughout the time series as the need for increased resources from the power grid put into heating is theoretically required based on the dip in average temperature towards the middle of the time series. The graph in Figure 14 shows the energy consumption for two-room and four-room apartments respectively, where two-room apartments seems to fluctuate largely between 0.5 and 2.0 kWh over the span of nearly six months, while the four-room apartments seems to fluctuate between 1.25 and 4.0 kWh over the same time span. This is confirmed through Table 9, which through a more detailed representation of extremas as well average data yields an absolute low of 0.5625 kWh (October) for two-room apartments, as well as an absolute high of 2.5625 kWh (January). In comparison, the lowest for four-room apartments is 1.0454 kWh (October) while the highest is 4.22 kWh (February). Based on this information in combination with the graph in Figure 14, a clear increase in energy consumption between October and March is evident for both apartment types.

Through comparing the two apartment types, it is evident that the four-room apartments spend a significantly higher amount of energy per month than a two-room apartment. Comparing the average hourly values against one another, the lowest difference between the two apartment types is in October, where the four-room has an average energy consumption of 0.80 kWh (1.62 times) more than the two-room. The highest difference between the two apartment types is in February, where the four-room apartment has an average energy consumption of 1.28 kWh (1.71 times) more than the two-room apartment. Through a direct comparison between the two linear regression lines comparing consumption to time in Figure 15, the regression line for two-room apartments is noticeably steeper than that of the four-room, meaning that the two-room apartments have a smaller spread in energy consumption over the course of the full period in comparison to its four-room counterpart. This indicates smaller spacing between the two extremas in power consumption for two-room apartments than for four-room apartments respectively due to how the variables are located in the graph – an indication which is confirmed by Table 9, yielding a 0.52 kWh and 0.99 kWh difference for the two apartment types respectively. This also means that four-rooms are noticeably more sensitive to temperature change than two-rooms, as a change in temperature yields a higher change in energy consumption for four-room regression line as it is significantly less steep than its counterpart.

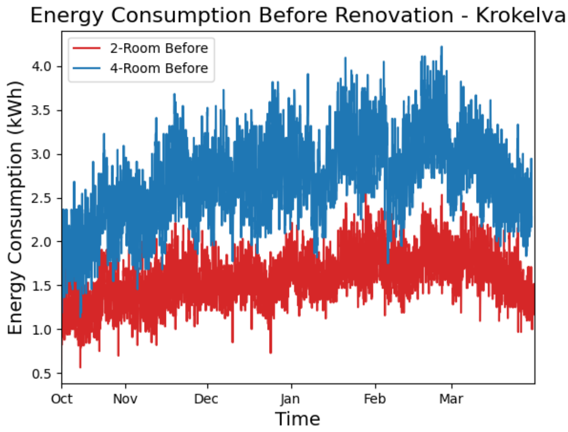


*Figure 14: Energy Consumption 2-room and 4-room apartments at Krokelva prior to renovation.*

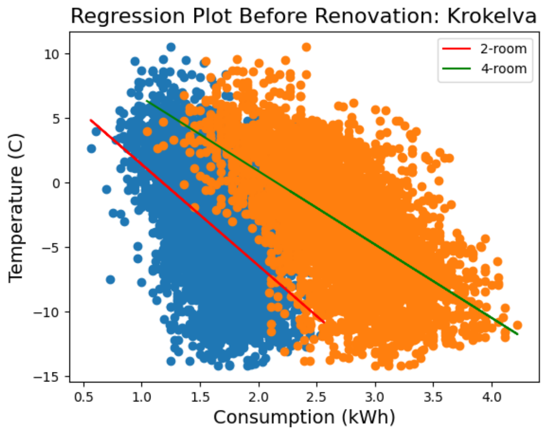


*Figure 15: Regression plots of energy consumption with respects to temperature at Krokelva prior to renovation for both 2-room and 4-room apartments.*

| ***Two-Room Apartments*** | | | |
|---|---|---|---|
| ***Month*** | ***Lowest Hourly (kW/h)*** | ***Highest Hourly (kW/h)*** | ***Average Hourly (kW/h)*** |
| *October 2017* | *0.5625* | *1.9688* | *1.2864* |
| *November 2017* | *0.8181* | *2.3636* | *1.4695* |
| *December 2017* | *0.7272* | *2.3333* | *1.5322* |
| *January 2018* | *1.1212* | *2.5625* | *1.6833* |
| *February 2018* | *1.1563* | *2.5313* | *1.8025* |
| *March 2018* | *1.0938* | *2.4375* | *1.7717* |
| **Entire Period** | **0.5625** | **2.5626** | **1.5789** |
| ***Four-Room Apartments*** | | | |
| ***Month*** | ***Lowest Hourly (kW/h)*** | ***Highest Hourly (kW/h)*** | ***Average Hourly (kW/h)*** |
| *October 2017* | *1.0454* | *3.2273* | *2.0891* |
| *November 2017* | *1.4545* | *3.6818* | *2.5111* |
| *December 2017* | *1.7727* | *3.8181* | *2.7682* |
| *January 2018* | *1.8181* | *4.0952* | *2.9149* |
| *February 2018* | *1.7503* | *4.2222* | *3.0784* |
| *March 2018* | *2.1666* | *3.8235* | *2.9130* |
| **Entire Period** | **1.0454** | **4.2222** | **2.7078** |

*Table 9: Energy Consumption per month for each apartment type at pre-renovation Krokelva.*

### 4.2.5 Correlations

Comparing the similarities between the values in play at Krokelva prior to renovation, using Pearson's Correlation Coefficient (abbreviated PCC, see subchapter 2.5) is a natural way of comparing several variables through correlation coefficients. Through Figure 16and Figure 17 it is clear that there is some form of correlation between temperature and energy consumption for both two-room and four-room aparments at Krokelva, a correlation of which is clearly negative based on the tendencies the two variables present; tendencies of which seem to oppose the growth of the corresponding variable. This is confirmed through the calculations presented through Table 10, which shows a correlation of -0.4865 for two-room apartments and -0.6052 for four-room apartments. Based on the definitions provided by Table 2 in subchapter 2.5.1, this yields a moderate negative correlation for four-room apartments, and a weak negative correlation for two-room apartments. The correlations between energy consumption and wind speeds are evidently quite small based on the findings of Table 10 with correlation coefficients of 0.0027 and 0.0398 – both of which are sufficiently close to a zero-value for there to be assumed close to no correlation between energy consumption and wind speeds prior to renovation.

| Correlations between Energy Consumption, Temperatures and Wind Speeds | | | | |
|---|---|---|---|---|
| | Temperature (C) | | Wind Speeds (m/s) | |
| | r (coefficient) | $r^2$ (%) | r (coefficient) | $r^2$ (%) |
| **Energy Consumption 2-Room** | -0.48649305 | 23.66% | 0.00267653 | Insignificantly Small |
| **Energy Consumption 4-Room** | -0.60521402 | 36.63% | 0.03975308 | Insignificantly Small |
| **Temperature** | - | - | 0.14750217 | 2.176% |

*Table 10: Correlations between Energy Consumption, Temperature and Wind Speeds at pre-renovation Krokelva.*

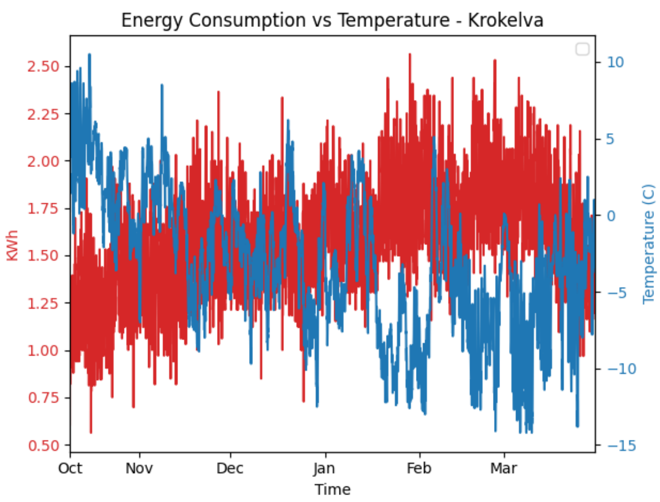


*Figure 16: Energy Consumption vs Temperature at pre-renovation Krokelva for 2-room apartments.*

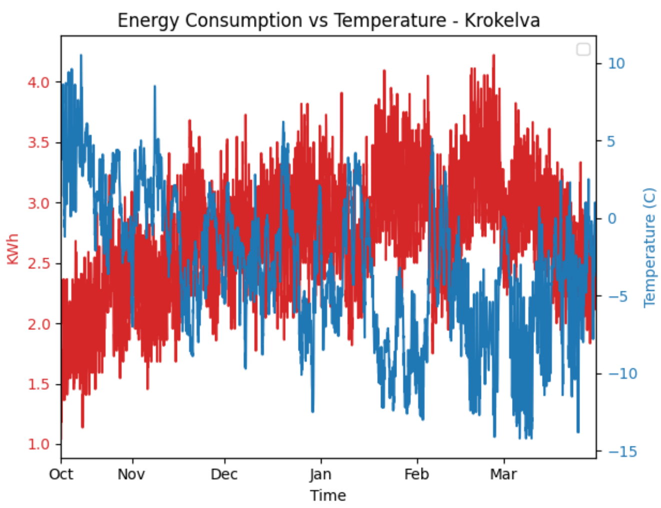


*Figure 17: Energy Consumption vs Temperature at pre-renovation Krokelva for 4-room apartments.*

## 4.3 After Renovation

### 4.3.1 Structural Specifications

The housing tenure at Krokelva has opted into several measures to ensure higher energy efficiency in their building complexes through their renovation of the building's structural envelope. While not all measures are relevant to this thesis due to the limitations outlined in subsection 1.4, the measures deemed relevant are measures which includes replacing the old wind barrier with a modern wind barrier to avoid air penetrating into the apartment through cracks in the exterior, adding an additional insulation thickness of 10cm of insulation with modern conductivity values, as well as new 3-layer windows and doors. The new 3-layer windows are assumed to follow the building regulations outlined by TEK-2017, requiring a U-value of 0.8 or better – which is equivalent to half of the U-value as what was assumed based on the TEK-1997 regulations in subchapter 4.2.

There are small changes to the conductivity of the materials used in the calculations, where the additional 100mm of insulation in both walls and roof has a conductivity of 0.034 W/mK, while the wooden exterior a conductivity of 0.14, and the roof shingles have been replace with WPC (Wood-Plastic Composites) materials with a conductivity of 0.53. The calculations and assumptions for U-values after renovation are outlined in Table 12, where the new U-values for walls, roofs and windows are 0.1088, 0.1227 and 0.8 W/Km$^2$ respectively, all of which are well within the building regulations outlined by TEK-2017, which requires U-values less than or equal to 0.18, 0.13 and 0.8 for the three aspects of the building.

| Wall | | | |
|---|---|---|---|
| **Material** | **Thickness (m)** | **Conductivity (W/m K)** | **R-Value (K m$^2$/W)** |
| Plaster Wall (Interior) | 0.013 | 0.026 | 0.500 |
| Concrete Blocks | 0.100 | 0.090 | 1.111 |
| Glasswool Insulation (Old) | 0.150 | 0.040 | 3.750 |
| Glasswool Insulation (New) | 0.100 | 0.034 | 2.941 |
| Plasterboard (Exterior) | 0.012 | 0.016 | 0.750 |
| Wood Exterior (New) | 0.019 | 0.14 | 0.136 |
| **Roof** | | | |
| Chipboard Plates (Interior) | 0.012 | 0.15 | 0.080 |
| Glasswool Insulation (Old) | 0.200 | 0.040 | 5.000 |
| Glasswool Insulation (New) | 0.100 | 0.034 | 2.941 |
| Wood | 0.019 | 0.16 | 0.119 |
| Wood-Plastic Composites (New) | 0.005 | 0.53 | 0.009 |

*Table 11: U-Value calculations based on thickness and conductivity of various materials.*

| Combined Values | | |
|---|---|---|
| | **R-Value (K m$^2$/W)** | **U-Value (W/K m$^2$)** |
| Walls | 9.1881 | 0.1088 |
| Roof | 8.1490 | 0.1227 |
| Windows | 1.25 | 0.8 |

*Table 12: Summarized U-Values for walls, roof and windows, based on Table 11.*

### 4.3.2 Temperature and Wind Conditions

The temperatures at Krokelva during post-renovation conditions are represented through Figure 18 and Table 13 below, both of which are based on hourly data analyzed at Stakkevollan measuring station between 9$^{th}$ of October 2020 and the 15$^{th}$ of March 2021. Similarly to prior to renovation, the temperatures shows an expected development from month to month based on the seasonal expectations in Tromsø, with a minimum extrema located at -12.4 degrees Celsius in February, and a maximum extrema at 13.1 degrees Celsius in October. This yields a difference of 25.5 degrees Celsius between the two extremas. The month with the highest average temperature across the time period is November with 2.6 degrees Celsius, while the month with the lowest average temperature is January with -4.0 degrees Celsius – yielding a difference of 6.6 degrees Celsius between the two averages. In terms of wind, the maximum value peaks in January 2019 with a value of 17.19 m/s, while the minimum value is predicated to be in March 2021 with a value of 0.00 m/s. The highest average wind speed is 3.76 (December 2020), while the lowest average speed is 1.55 (October 2020) – yielding av difference of 2.21 m/s in average wind speeds between the highest and lowest averaging months in terms of wind speeds (Table 14)

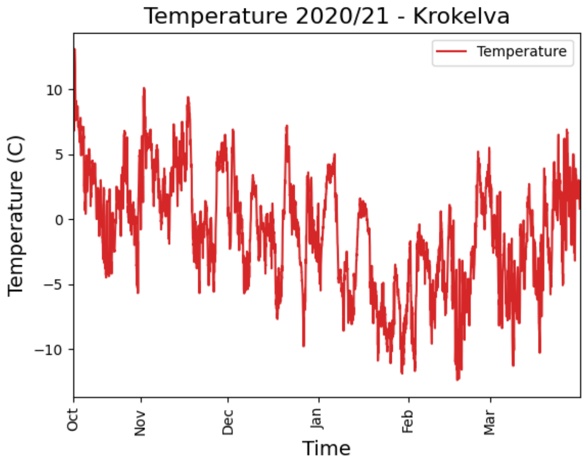


*Figure 18: Temperature over at time post-renovation Krokelva.*

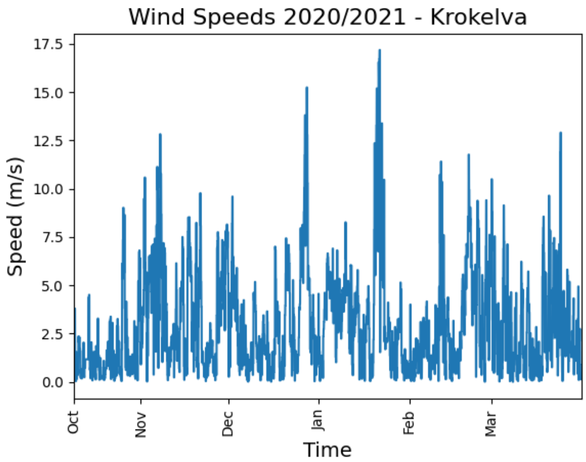


*Figure 19: Wind Speeds over time at post-renovation Krokelva.*

| Temperature (in Celsius) | | | |
|---|---|---|---|
| **Month** | **Minimum Value** | **Maximum Value** | **Average Temperature** |
| October 2020 | -5.7 | 13.1 | 1.9 |
| November 2020 | -5.7 | 10.1 | 2.6 |
| December 2020 | -9.8 | 7.2 | -0.7 |
| January 2021 | -11.9 | 5.0 | -4.0 |
| February 2021 | -12.4 | 5.5 | -3.6 |
| March 2021 | -11.3 | 6.9 | -1.7 |

*Table 13: Temperatures at post-renovation Krokelva.*

| Wind Speeds (in m/s) | | | |
|---|---|---|---|
| **Month** | **Minimum Value** | **Maximum Value** | **Average Value** |
| October 2020 | 0.04 | 9.02 | 1.55 |
| November 2020 | 0.02 | 12.83 | 3.76 |
| December 2020 | 0.01 | 15.25 | 2.95 |
| January 2021 | 0.04 | 17.19 | 3.58 |
| February 2021 | 0.01 | 11.77 | 3.07 |
| March 2021 | 0.00 | 12.91 | 2.60 |

*Table 14: Wind Speeds at post-renovation Krokelva.*

### 4.3.3 Transmission of Heat

Similarly to prior to renovation, there are no real measurements of the area of the wall and windows separately, and as such the transmission of heat post-renovation are given in W/m$^2$ rather than in W as it normally would be. This holds true for walls, window and roof – which means multiplying the values with area to find the actual values is a necessity to find the transmission of heat for the apartments as a unit. The transmission of heat prior to the renovation is outlined through Table 15 , which is based on the U-values found in subchapter 4.3.1. The transmission of heat for walls, windows and roof are at 1.3056 W/m$^2$, 9.6 W/m$^2$ and 1.4724 W/m$^2$ respectively.

| Transmission of Heat (per m$^2$) | | | | |
|---|---|---|---|---|
| | **Outdoor Temp (C)** | **Indoor Temp (C)** | **U-Value (W/K m$^2$)** | **Transmission of Heat (W/m$^2$)** |
| Walls | 10 | 22 | 0.1088 | 1.3056 W/m$^2$ |
| Windows | 10 | 22 | 0.8 | 9.6 W/m$^2$ |
| Roof | 10 | 22 | 0.1227 | 1.4724 W/m$^2$ |

*Table 15: Transmission of Heat at post-renovation Krokelva.*

### 4.3.4 Energy Consumption

The energy consumption in kWh post-renovation shares the same length in respects to time of year as the dataset prior to renovation, although is measured 3 years later. This means that the energy consumption is prone to be influenced by the same factors as before renovation, although their magnitude is likely to be different. Viewing this in combination with the structural changes the buildings have undergone through renovation, it is expected to find significant differences in energy consumption in comparison to prior to the renovation. These differences are explored further in subchapter 4.4 through a more direction comparison. Based on Figure 20, the energy consumption for two-rooms seems to fluctuate between 0.7 and 2.0 kWh while the consumption for four-room apartments sits at between 1.0 and 3.5. As seen on the left-hand side of the graph however, the consumption is remarkably lower towards the start of October than it is throughout the rest of the graph – which is prior to closer analysis expected to be the result of the change in temperature over the course of full year including the summer months - which will be explored further in subchapter 4.4, as well as chapter 5 regarding Brattbakken as the availability of data for Brattbakken extends to the summer months as well.

Table 16 shows a more detailed overview of the energy consumption from October 2020 throughout March 2021 for each apartment type, where the four-room apartments consume significantly more energy than the two-room apartments. For both the apartment types the lowest and highest values are measured in the same months; the two months being October and February. The lowest values for the two apartment types are 0.6012 (two-room) kWh and 0.8912 (four-room) kWh, while the highest values are 2.7782 (two-room) kWh and 3.6835 (four-room) kWh. Comparing the two apartment types against one another in terms of average values, the lowest difference between the two apartment types is in October with a difference of 0.8418 kWh, while the largest difference is in December with a value of 1.0049 kWh. The average value for two-room apartments across the period in its entirety is 1.3992 kWh while the average value for four-room apartments is 2.2939 kWh, which means that the four-room apartments on average consumes 1.6 times as much energy as the two-room apartments.

Through a direct comparison of the two linear regression lines for each of the two apartment types (in respects to temperature), the regression line for two-room apartments is substantially stepper than the corresponding regression line for four-room apartments. This goes to show that the two-room apartments have a smaller spread in their values, and as such experiences a smaller leap between low-end values (minimum extrema) and high-end values (maximum extrema) than the four-room apartments do, which is confirmed through the findings of Table 16 – yielding a difference of 0.4321 kWh and 0.4766 kWh between the average value extremas for two-room and four-room apartments. Said regression plot (Figure 21) also tells a tale regarding the overall spread of data in relation to room type, where the energy consumption for four-room apartments are generally speaking much higher than that of the two-room apartments, and based on the steepness of the two regression lines it is evident that the four-room apartment is more sensitive to temperature change than the two-room apartments are.

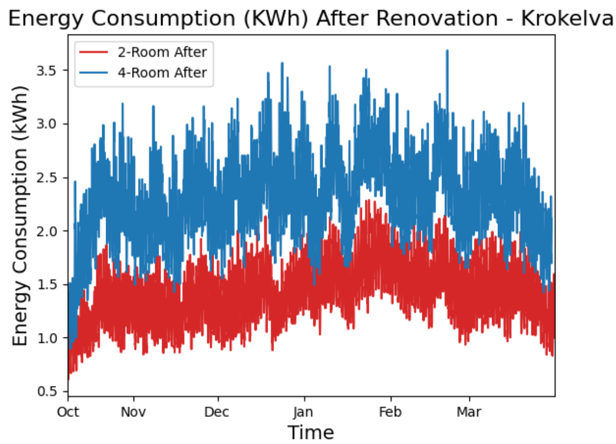


*Figure 20: Energy Consumption for 2-room and 4-room apartments at post-renovation Krokelva.*

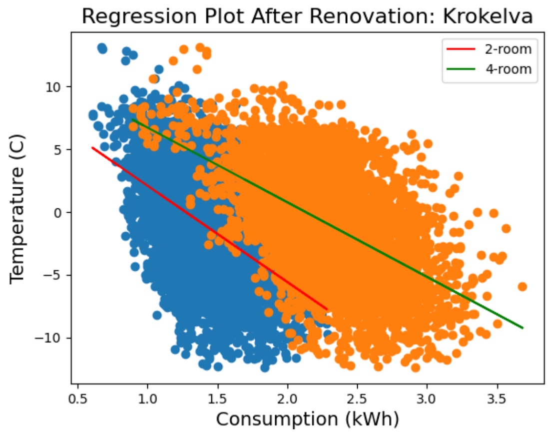


*Figure 21: Regression plots for energy consumption in regards to temperature at post-renovation Krokelva.*

| Two-Room Apartments | | | |
|---|---|---|---|
| **Month** | **Lowest Hourly (kW/h)** | **Highest Hourly (kW/h)** | **Average Hourly (kW/h)** |
| October 2020 | 0.6012 | 1.8636 | 1.1793 |
| November 2020 | 0.8403 | 1.9206 | 1.2784 |
| December 2020 | 0.8800 | 2.1330 | 1.3852 |
| January 2021 | 1.0269 | 2.2850 | 1.6114 |
| February 2021 | 0.9319 | 2.7782 | 1.5491 |
| March 2021 | 0.8278 | 2.2222 | 1.3917 |
| **Entire Period** | **0.6012** | **2.7782** | **1.4074** |
| **Four-Room Apartments** | | | |
| **Month** | **Lowest Hourly (kW/h)** | **Highest Hourly (kW/h)** | **Average Hourly (kW/h)** |
| October 2020 | 0.8912 | 3.1871 | 2.0211 |
| November 2020 | 1.4250 | 3.1639 | 2.1922 |
| December 2020 | 1.5506 | 3.5676 | 2.3901 |
| January 2021 | 1.4906 | 3.5359 | 2.4977 |
| February 2021 | 1.6971 | 3.6835 | 2.4202 |
| March 2021 | 1.4184 | 3.1917 | 2.2422 |
| **Entire Period** | **0.8912** | **3.6835** | **2.3062** |

*Table 16: Energy consumption per month for each apartment type at Krokelva post-renovation.*

### 4.3.5 Correlations

Similarly to the pre-renovation values presented in subchapter 4.2, the correlation between energy consumption and wind speeds are quite small and insignificant post-renovation. In terms of temperature however, the correlation coefficients behave similarly to those prior to renovation – where there seems to be a clear negative correlation between temperature and energy consumption for both the two-room and four-room apartment types as seen through Figure 22 and Figure 23. This negative correlation is confirmed through Table 17, where the correlation between two-room apartments and temperature is -0.4851 post-renovation, while the correlation between four-room apartments and temperature is -0.5457 post-renovation.

| Correlations between Energy Consumption, Temperatures and Wind Speeds | | | | |
|---|---|---|---|---|
| | Temperature (C) | | Wind Speeds (m/s) | |
| | r (coefficient) | $r^2$ (%) | r (coefficient) | $r^2$ (%) |
| 2-Room | -0.48510576 | 23.5% | 0.04705648 | Insignificantly Small |
| 4-Room | -0.54586973 | 29.8% | 0.05745074 | Insignificantly Small |
| Temperature | - | - | 0.0631458 | 3.98% |

*Table 17: Correlations between Energy Consumption, Temperatures and Wind Speeds post-renovation*

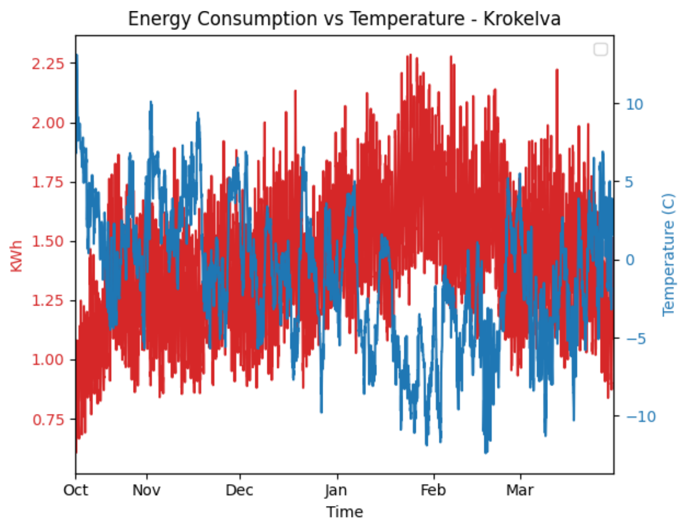


*Figure 22: Energy Consumption vs Temeprature for Two-Room Apartments at post-renovation Krokelva.*

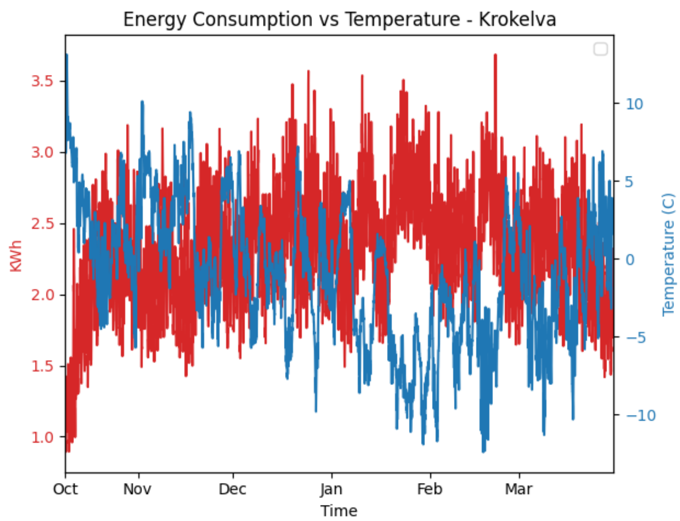


*Figure 23: Energy Consumption vs Temeprature for Four-Room Apartments at post-renovation Krokelva.*

## 4.4 Comparison of post- and pre-renovation data

### 4.4.1 Differences in Strucutral Specifications, Temperatures and Wind Conditions

Prior to renovation as well as after renovation, the structural specifications, temperatures and wind conditions are measured to be quite different. While the area of both the two-room and four-room apartments are the same on both ends of the renovation process – there are some changes made to the building's structural envelope leading to differences in several values knit to insulation (U-values) and transmission of heat through the buildings. As transmission of heat is given as a value of watts per square meter, the differences in area between the two apartment types is not of importance regarding the transmission of heat values in terms of comparison on both sides of the renovation. Table 18 shows a direct comparison in terms of U-values and transmission of heat before and after the renovation, where the post-renovation values for walls, windows and roof have a ratio of 0.56x, 0.5x and 0.64x the values of their respective U-values prior to renovation. Due to the relationship between U-values as well as the assumed constant temperature and area, the ratios for transmission of heat have ratios identical to the U-values.

| Differences in U-Values and Transmission of Heat | | | | | | |
|---|---|---|---|---|---|---|
| | U-Value (W/K m²) | | | Transmission of Heat (W/m²) | | |
| | **Walls** | **Windows** | **Roof** | **Walls** | **Windows** | **Roof** |
| **Before Renovation** | 0.1954 | 1.6 | 0.1909 | 2.3448 | 19.2 | 2.2908 |
| **After Renovation** | 0.1088 | 0.8 | 0.1227 | 1.3056 | 9.6 | 1.4724 |
| **Ratio (After / Before)** | 0.56 | 0.5 | 0.64 | 0.56 | 0.5 | 0.64 |

*Table 18: Differences in U-Value and Transmission of Heat before and after renovation.*

The differences in temperatures before and after the renovation are noticeable, and as seen through Figure 24 the differences in average temperatures vary quite a bit between the two time periods in question. That said, the differences in temperature are not awfully important in terms of a direct comparison, as the thesis focuses on correlation between temperature and other variables, and not on differences in temperatures based on year. This also holds true for wind speeds, as the correlation coefficients are essential to understanding the effect wind and temperature has on energy consumption. A comparison of temperatures and wind speeds between the two time periods are shown through Figure 24 and Figure 25 below, although elaborating further on their contents will not be noticeably helpful to the purposes of this thesis.

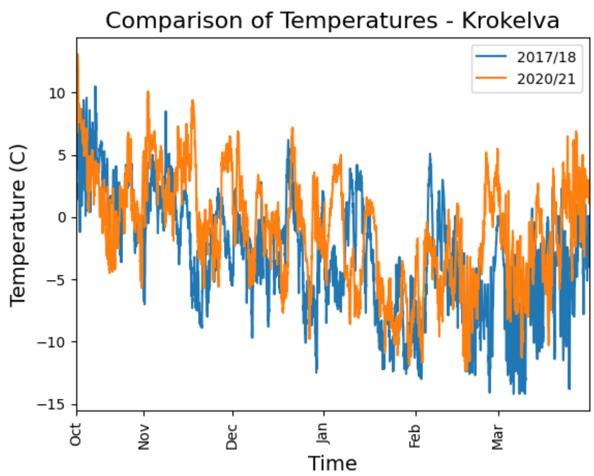


*Figure 24: Comparison of Temperatures at Krokelva before and after renovation.*

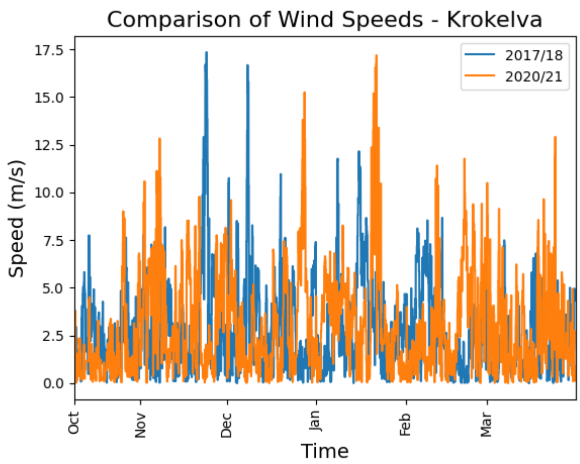


*Figure 25: Comparison of Wind Speeds at Krokelva before and after renovation.*

### 4.4.2 Differences in Energy Consumption

Comparing the differences in energy consumption before and after the renovation shows a clear change in energy consumption for both two-room and four-room apartments, where an average two-room apartment uses 0.89x (from 6562.8 kWh to 5849.2 kWh, see Table 19) as much energy post-renovation, while a four-room apartment uses 0.85x (from 11242 kWh to 9575 kWh). An additional factor to consider here is the fact that prior to renovation, Krokelva partly relied on burning wood as a heating source through enclosed wood-based fireplaces, information of which is not included into the data for energy consumption prior to renovation.

The average Norwegian residence using wood-based fireplaces consumes around 45 percent of its total consumption of energy through these fireplaces, meaning the differences before and after renovation should in theory be significantly larger than what is shown through a direct comparison of the pre- and post-renovation energy consumption based on the available data, simply due to the fact that said residences went from being heated up through part fireplace and part electricity, to being heated up by electricity exclusively (Enova, 2012).

Seeing as the efficiency of a wood-based fireplace varies based on how modern it is (thus how old it is of age), the efficiency assumed for pre-renovation wood-based fireplaces is assumed to be 80%. This makes room for estimating an approximated value (although one with quite large uncertainties) through calculating the total expected value in a reverse manner from the fact that consumption data makes up for 55% of the energy consumption. As seen in Table 19, including information provided through the assumption of the effects of a fireplace yields That said, while Table 19 shows the expected data with information regarding consumption including the usage of a wood-based fireplace as heating source – the information is not sufficiently reliable moving forward throughout the thesis. As such, the values directly access through the datasets will primarily be used moving into Chapter 5, although the high uncertainty data including fireplace assumptions will still be mentioned. The limitations outlined above will be a subject further explained and addressed throughout Chapter 6.

| | Energy Consumption Before and After Renovation | | | | | |
|---|---|---|---|---|---|---|
| | Total | | | Total (Including Fireplace Assumptions) | | |
| | Before | After | Ratio | Before | After | Ratio |
| 2-Room | 6562.8 | 5849.2 | 0.89 | 10858.5 | 5849.2 | 0.54 |
| 4-Room | 11242 | 9575 | 0.85 | 18602.0 | 9575 | 0.51 |

*Table 19: Energy Consumption Before vs After Renovation at Krokelva.*

### 4.4.3 Comparison of Correlations

Seeing as the correlation between wind and energy consumption has proven to be of such minor significance to energy consumption as a whole, only the correlations between temperature and energy consumption in the various apartment types are relevant to present. As shown through Table 20, the difference in correlations varies quite a lot based on the apartment type – where two-room apartments sees a very small change in correlation (a ratio of 0.9971 of the correlation prior to renovation) and the four-room apartment sees a more noticeable change in correlation (ratio of 0.9019). This goes to show that there is presumably a connection between change in correlation and the buildings area, as the four-room apartments (111 $m^2$) are much larger than the two-room apartments (57 $m^2$) – and showcase a much larger change in correlation before and after the renovation. Going back to what was mentioned in subchapter 4.4.2 regarding using wood-based fireplaces as a heating source, it is natural to expect that this has influenced the change in correlation as well – seeing as there is no available data regarding how much wood has been burnt at which times, making it impossible to include the effect this would have on the correlations prior to renovation in the current state of things.

| Comparison of Correlations between Energy Consumption and Temperatures at Krokelva Before and After Renovation | | | | |
|---|---|---|---|---|
| | Pearson's Correlation Coefficient (r) | | | |
| | **Before** | **After** | **Change (r)** | **Ratio** |
| **2-Room** | -0.48649305 | -0.48510576 | 0.00138729 | 0.9971x |
| **4-Room** | -0.60521402 | -0.54586973 | 0.05934429 | 0.9019x |

*Table 20: Comparison of correlations between energy consumption and temperatures at Krokelva before and after renovation.*

Through a direct comparison of regression lines between energy consumption and temperature on both ends of the renovation for each apartment type individually, it is evident that at the overall spread in energy has gone significantly down for both two-room and four-room apartment after the renovation, which is seen based on length of the regression lines. Both the green line in Figure 26 (two-room) and the blue line in Figure 27 (four-room) represent the post-renovation regression lines, and are significantly shorted than their counterparts, meaning that the scatter points in the plots representing the post-renovation values have a lower frequency of occurrence at higher consumption value, which goes to show that the energy consumption for both apartment types have gone down through the renovation process. Comparing the growth of the regression lines against one another, the regression lines for four-room apartments shows a faster decline in its regression line after renovation as in comparison to before, which is the expected behaviour out of comparing regression lines of each side of the renovation - suggesting that the apartment is less sensitive to temperature and handles uses less energy at lower temperatures than prior to renovation. For two-room apartments however, the trend lines are following what appears to be an identical pattern both before and after renovation – showing little difference in energy consumption before and after the renovation. This is likely a side-effect of the added variable of fireplaces, which are likely to have a larger effect in two-room apartments than in four-room apartments due to the difference in area and inhabitants, which will be discussed further in Chapter 6.


*Figure 26: Comparison of Regression Plots for 2-room apartments at Krokelva before and after renovation.*

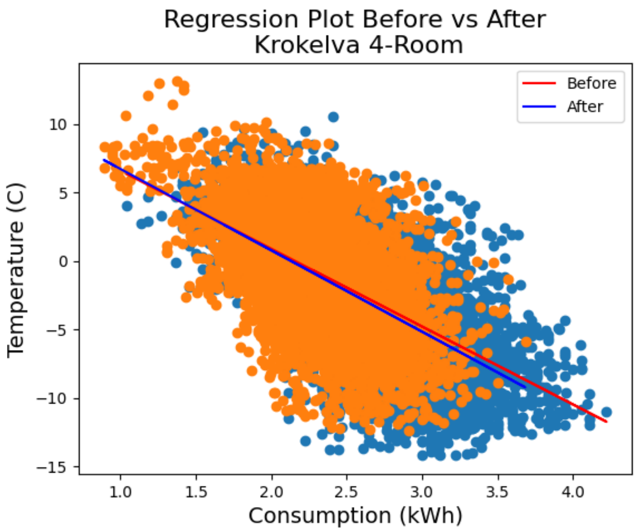


*Figure 27: Comparison of Regression Plots for 4-room apartments at Krokelva before and after renovation.*

# 5 Case Study: Brattbakken Borettslag


*Figure 28: Brattbakken Borettslag (Google Maps, 2021)*

## 5.1 Technical Overview

Brattbakken Borettslag is a building housing tenure consisting of a total of 172 apartments (Brattbakken, 2021), located at Stakkevollan, Tromsø with the coordinates 69.696 degrees North and 18.997 degrees East (Figure 28). The housing tenure was built between 1978 and 1984 (Brattbakken, 2021b), meaning the structural standards the housing tenure is built around is vastly outdated, and similarly to Krokelva said standards follow a bare minimum outlined by the regulations for buildings dating back to 1969. The housing tenure is similarly to Krokelva split into several building complexes containing multiple apartments, more specifically 12 apartment buildings - where the typical building contains a combination of 3-room apartments and one of the two other apartment types. In all 12 buildings the 3-room is located beneath the either a two-room or four-room in the sense that the inner half of the 3-room apartment is located directly underneath the outer half of one of the other room types, as shown in Figure 29. The two-room apartments have a utility floor space (BRA) of 64 $m^2$, while three-room and four-room apartments have a BRA of 87 $m^2$ and 104 $m^2$ respectively (Table 21).

..

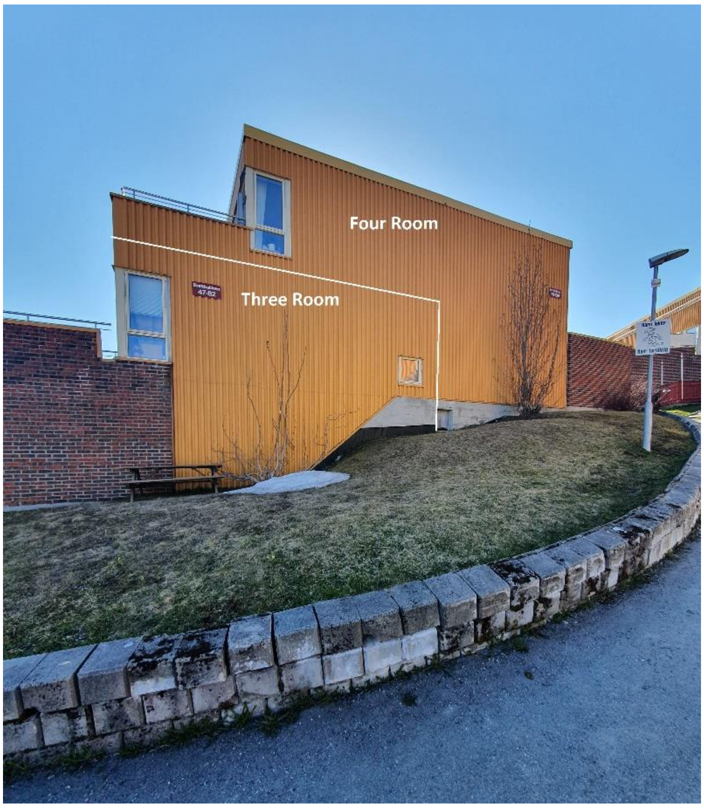


*Figure 29: Typical layout of three-room and four-room apartments at Brattbakken.*

| Structural Information: Brattbakken | | |
|---|---|---|
| **Room Type** | **Utility Floor Space (BRA)** | **Number of apartments in analysis** |
| 2-Room | 64 $m^2$ | 21 |
| 3-Room | 87 $m^2$ | 75 |
| 4-Room | 104 $m^2$ | 56 |

*Table 21: BRA for the various apartment types at Brattbakken.*

## 5.2 Before Renovation

### 5.2.1 Structural Specifications

As mentioned in subsection 5.1 and similarly to what was done for Krokelva, the structural regulations of 1969 serve as a basis for assumptions made state of the details regarding the building's structural envelope. The U-values for walls and roof are calculated through the method showcased in subsection 3.2, while the U-value for windows have been assumed in regard to TEK97 standards. The conductivity of the materials in the walls vary based on the type of materials, although except for the concrete in the roof with a conductivity 0.16 W/mK and the steel plates on the exterior wall with a conductivity of 50 W/mK (Engineering Toolbox, 2003c), the materials used are largely similar to those of Krokelva.

| Wall | | | |
|---|---|---|---|
| **Material** | **Thickness (m)** | **Conductivity (W/m K)** | **R-Value (K m$^2$/W)** |
| Plaster Wall (Interior) | 0.013 | 0.026 | 0.500 |
| Glasswool Insulation (Old) | 0.150 | 0.040 | 3.750 |
| Plasterboard (Exterior) | 0.012 | 0.016 | 0.750 |
| Steel Plate Exterior (Old) | 0.04 | 50 | 0.0008 |
| **Roof** | | | |
| Chipboard Plates (Interior) | 0.012 | 0.15 | 0.080 |
| Glasswool Insulation (Old) | 0.200 | 0.040 | 5.000 |
| Concrete | 0.10 | 0.16 | 0.625 |
| Roof Shingle Exterior (Old) | 0.003 | 0.79 | 0.004 |

*Table 22: R-value calculations at Brattbakken prior to renovation based on the thickness and conductivity of the given materials.*

| Combined Values | | |
|---|---|---|
| | **R-Value (K m$^2$/W)** | **U-Value (W/K m$^2$)** |
| Walls | 5.0008 | 0.1999 |
| Roof | 5.709 | 0.1752 |
| Windows | 0.625 | 1.6 |

*Table 23: Summarized R-Values and U-Values at Brattbakken for walls, windows and roof prior to renovation.*

### 5.2.2 Temperature and Wind Conditions

The temperatures at Brattbakken are represented thoroughly through Table 24 as well as Figure 30, both of which are largely similar to those presented in Subchapter 4.2.2 due to the same measuring station being used for both locations. although the time window has been shifted by 3 months in comparison to Krokelva, stretching from January 1st, 2020 to January 1st, 2021 rather than from April 1st, 2020 to April 1st, 2021 as for Chapter 4. The temperatures at Brattbakken seem to follow a steady curve based on the expectations given the seasonal variation in temperature, as seen in Figure 30. The calculations show an absolute minimum of around -15.5 degrees Celsius in January, and a maximum of around 25.9 degrees Celsius in the middle of July. This yields a gap of roughly 41.4 degrees Celsius between the two points of absolute extrema. Based on the calculations presented through Table 25 below, it is evident that wind speeds at brattbakken are more severe in the winter months than in the summer months, where the lowest average wind speed of 1.36 is during the summer month of July, while the highest average wind speed of 3.20 is in January. Overall, the wind speeds at Brattbakken appears to behave similary to the values at Krokelva depending on time of year.

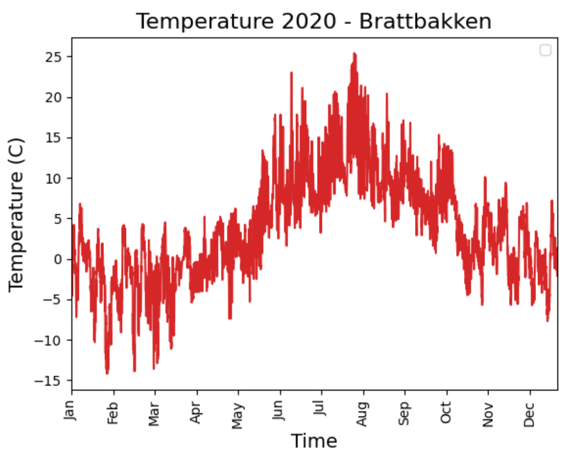


*Figure 31: Variation of temperature over time at Stakkevollan Measuring Station in near proximity to Brattbakken.*

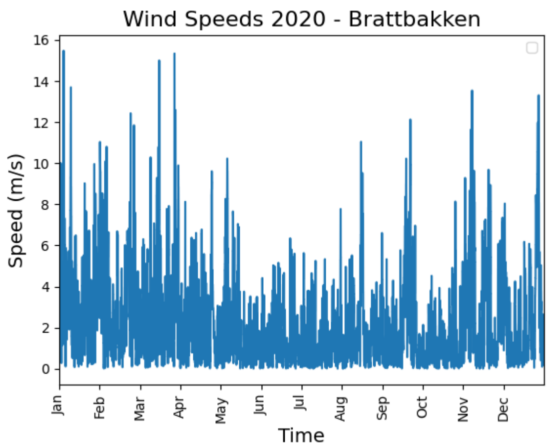


*Figure 30: Variation of wind over time at Brattbakken based on the AROME-Arctic Prediction Model.*

| Temperature (in Celsius) | | | |
|---|---|---|---|
| **Month** | **Minimum Value** | **Maximum Value** | **Average Value** |
| January | -15.5 | 7.2 | -2.3 |
| February | -13.9 | 4.6 | -2.4 |
| March | -14.3 | 4.8 | -2.3 |
| April | -7.4 | 5.6 | 0.1 |
| May | -5.9 | 15.5 | 3.5 |
| June | 1.5 | 23.3 | 10.0 |
| July | 3.0 | 25.9 | 12.7 |
| August | 3.6 | 22.5 | 10.8 |
| September | 0.6 | 17.3 | 8.0 |
| October | -6.4 | 15.1 | 3.8 |
| November | -6.9 | 10.4 | 2.6 |
| December | -10.2 | 7.5 | 0.8 |

*Table 24: Temperatures at Brattbaken throughout 2020.*

| Wind Speed (in m/s) | | | |
|---|---|---|---|
| **Month** | **Minimum Value** | **Maximum Value** | **Average Value** |
| January | 0.07 | 15.48 | 3.20 |
| February | 0.01 | 12.43 | 3.19 |
| March | 0.05 | 15.34 | 3.18 |
| April | 0.02 | 9.61 | 2.11 |
| May | 0.00 | 10.23 | 1.94 |
| June | 0.01 | 6.35 | 1.55 |
| July | 0.00 | 7.77 | 1.36 |
| August | 0.01 | 11.05 | 1.81 |
| September | 0.01 | 12.13 | 2.01 |
| October | 0.00 | 8.14 | 1.38 |
| November | 0.00 | 13.54 | 3.17 |
| December | 0.03 | 13.31 | 2.44 |

*Table 25: Wind Speeds at Brattbakken throughout 2020.*

### 5.2.3 Transmission of Heat

Similarly to the corresponding subchapters for transmission of heat in Chapter 4, transmission of heat will be calculated as a variable of Watts per square meter due to the lack of specific information regarding how the total surface area is distributed between wall area and window area. The transmission of heat throughout 2020 (prior to renovation) assuming an outdoor temperature of 10 Celsius and an indoor temperature of 22 Celsius is presented through Table 26, showing values of 2.3988 W/m$^2$, 19.2 W/m$^2$ and 2.1024 W/m$^2$ for walls, windows and roof respectively.

| Transmission of Heat (per m$^2$) | | | | |
|---|---|---|---|---|
| | **Outdoor Temp (C)** | **Indoor Temp (C)** | **U-Value (W/Km$^2$)** | **Transmission of Heat (W/m$^2$)** |
| Walls | 10 | 22 | 0.1999 | 2.3988 W/m$^2$ |
| Windows | 10 | 22 | 1.6 | 19.2 W/m$^2$ |
| Roof | 10 | 22 | 0.1752 | 2.1024 W/m$^2$ |

*Table 26: Transmission of Heat at Brattbakken prior to renovation.*

### 5.2.4 Energy Consumption

Brattbakken is, similarly to energy consumption of Krokelva, expected to see an increase in energy consumption toward the same periods of time as that of Krokelva. As the timeseries stretches over the course of a full year however, the expected values for energy consumption should be higher towards the end on both sides of the graph, and significantly smaller towards the middle due to the effect temperature is expected to have on energy consumption. The graphs in Figure 32 show a similar trend for all apartment types that confirms the pre-analysis expectations – showing a significantly higher level of energy consumption towards the sides of the graphs during months of which are commonly known to be the colder months in Norway. Viewing the three graphs for the three apartment types next to one another, there is a clear gap between the energy consumptions for the three apartment types – where four-room apartments clearly consume the most energy, while the two-room apartments consume the least energy. Based on the change in thickness of each of the graphs, it appears as if there are larger differences between the various apartment types in the colder months. This is seen through the thickness of the blue graph (two-room) in particular, which experiences a significant drop in distance between its lowest point and the next apartment type in January and December in comparison to the summer months of May, June and July.

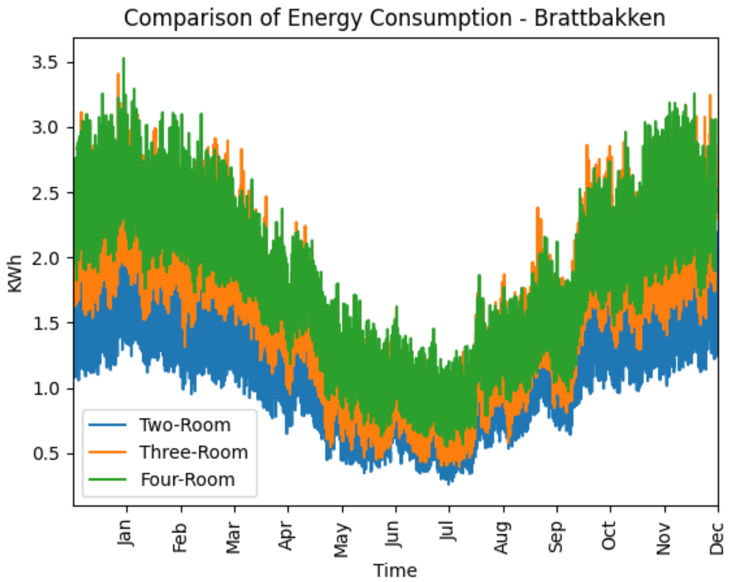


*Figure 32: Energy Consumption (kWh) prior to renovation for all three apartment types at Brattbakken.*

The information visualised through the comparison plot in Figure 32 is presented in more detailed fashion through Table 27, a table of which shows the highest, lowest and average values for each apartment type throughout the entirety of 2020 at Brattbakken. It is evident through said table that there is a clear leap in energy consumption between the three apartment types, which confirms the visualization through the figure above. The biggest leap between apartment types is between the two-room and four-room apartments where the average four-room apartment 1.52x as much energy as a two-room apartment on a yearly basis. That being said, including the three-room apartment into the mix shows that there is a significantly higher leap between the two-room and three-room apartments in comparison to that of between the three-room and four-room apartments. The leap between the two-room and three-room apartments on an annual average is 0.43 kWh, while the leap between a three-room and a four-room is 0.207 kWh. These differences will be further examined and explained throughout Chapter 6.

| Energy Consumption Data for Brattbakken | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month (2020) | 2-Room (kWh) | | | 3-Room (kWh) | | | 4-Room (kWh) | | |
| | Highest | Lowest | Avg. | Highest | Lowest | Average | Highest | Lowest | Avg. |
| January | 2.5623 | 1.0592 | 1.6223 | 3.4079 | 1.5386 | 2.2449 | 3.5275 | 1.8264 | 2.4868 |
| February | 2.4943 | 1.1186 | 1.5978 | 3.0932 | 1.525 | 2.2104 | 3.2924 | 1.7616 | 2.4444 |
| March | 2.2552 | 0.9533 | 1.4768 | 2.9142 | 1.3160 | 2.0593 | 3.1020 | 1.7296 | 2.2864 |
| April | 2.0324 | 0.7686 | 1.2934 | 2.8304 | 1.1113 | 1.7543 | 2.5986 | 1.4100 | 1.9519 |
| May | 1.6686 | 0.4481 | 0.9797 | 2.2714 | 0.5460 | 1.3181 | 2.1999 | 0.9067 | 1.5992 |
| June | 1.1960 | 0.3480 | 0.6617 | 1.5105 | 0.4513 | 0.8761 | 1.7154 | 0.6324 | 1.1665 |
| July | 1.2138 | 0.2995 | 0.6366 | 1.6133 | 0.4031 | 0.8184 | 1.6246 | 0.5514 | 1.0342 |
| August | 1.3190 | 0.2605 | 0.7121 | 1.7769 | 0.3942 | 0.9451 | 1.8643 | 0.5687 | 1.1271 |
| September | 1.7443 | 0.5357 | 0.9892 | 2.3827 | 0.5809 | 1.3386 | 2.1518 | 0.8938 | 1.4297 |
| October | 2.1581 | 0.6419 | 1.2258 | 2.8623 | 0.8107 | 1.7023 | 2.6834 | 0.9722 | 1.7992 |
| November | 2.2076 | 0.9619 | 1.5082 | 2.8907 | 1.2955 | 2.0353 | 3.0443 | 1.4771 | 2.1881 |
| December | 2.4076 | 1.0181 | 1.6777 | 3.2450 | 1.4039 | 2.2585 | 3.2568 | 1.7050 | 2.4388 |
| **YEARLY** | **2.5652** | **0.2605** | **1.1981** | **3.4079** | **0.3942** | **1.6281** | **3.5275** | **0.5514** | **1.8288** |

*Table 27: Energy Consumption at Brattbakken throughout 2020 sorted by apartment type.*

The regression plots prior to renovation at Brattbakken (see Figure 33) show a high variance in steepness based on the various apartment types, which goes to show that there is an evident difference in play based on either area or number of inhabitants (or most likely a combination of both). Two-room apartments have the steepest curve, which essentially means that the two-room apartment type is the least sensitive to changes due to a shift in temperature, and most likely correlates worse with temperature than the other two (more on this in Subchapter 5.2.5). The four-room apartment type is the second steepest out of the three regression lines for the three types of apartments at Brattbakken, although sees an increasingly larger difference from the two-room apartment's regression line as temperatures gets lower. The similarities between those two apartment types seems to grow increasingly different from one another as temperature decreases. Viewing the regression line of the three-room apartment shows a regression of which is far less steep than the other two, which shows that three-room apartments are significantly more sensitive to a change in temperature than the two other apartment types. While the three-room apartment type is closer to the consumption of the two-room apartments at warmer temperatures; the opposite is true for lower temperatures, where it practically grows to match the energy consumption of the four-room apartments. At around negative 7.5 degrees Celsius the three-room and four-room apartment types have an identical energy consumption, which is likely due to a combination of the effect of area and inhabitants as well as the combination of temperature and wind speeds – both of which will be discussed further in Chapter 6.

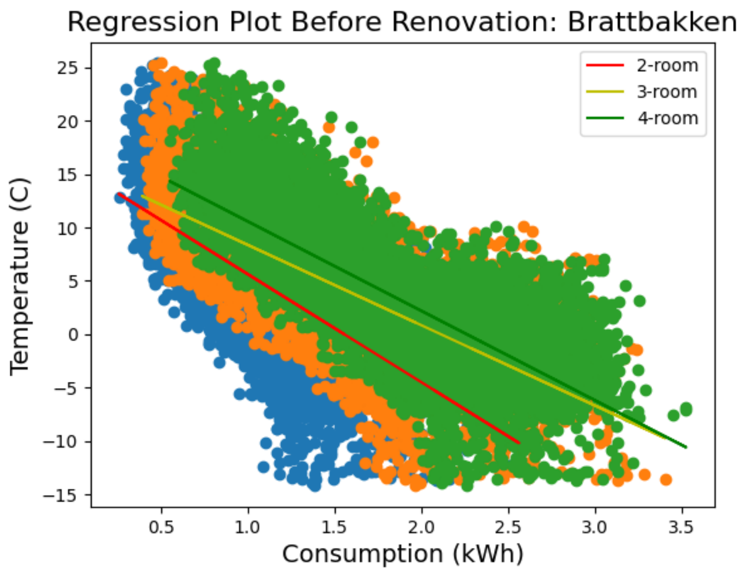


*Figure 33: Regression Plot of Brattbakken prior to renovation.*

### 5.2.5 Correlations

Similarly to subchapters 4.2.5 and 4.3.5, PCC is actively used in finding the relationship between variables in play at the apartments in question. As seen through Table 28, the correlations between all variables are significantly higher for Brattbakken prior to renovation in comparison to Krokelva, yielding correlations of approximately -0.7159, -0.7401 and -0.7787 for two-room, three-room and four-room apartments respectively. The correlations between temperature and all apartment types are visualized through the figures below (Figure 34, Figure 35, Figure 36 and Figure 37). This is likely related to the fact that Krokelva was partly heated through fireplaces prior to renovation and thus did not yield sufficiently realistic values in correlation between temperature and the electrical parts of the energy consumption, which Brattbakken is not. Additionally, a noticeable difference in the correlations in play here is the increased correlation coefficient between energy consumption and wind, a correlation of which was close to non-existent for Krokelva both prior to renovation as well as after the renovation. Comparing the correlations to the regression lines of subchapter 5.2.4, the correlations confirm the suspicion that the two-room apartment types have an energy consumption with a significantly lower correlation to temperature than the other two. Viewing the correlations in light of those of Krokelva it is evident that the differences between the two are of great interest, all of which will be more thoroughly discussed in Chapter 6 as well as subchapter 5.3. An additional factor to take into account is the evident relationship between correlations to temperature and the amount of rooms in the apartment, which is shown through the figures below as well as suggested through subchapter 5.2.4, a relationship of which will be discussed in Chapter 6.

| Correlations between Energy Consumption, Temperatures and Wind Speeds | | | | |
|---|---|---|---|---|
| | Temperature (C) | | Wind Speeds (m/s) | |
| | r (coefficient) | $r^2$ (%) | r (coefficient) | $r^2$ (%) |
| 2-Room Energy Consumption | -0.71588693 | 51.4% | 0.21890295 | 4.8% |
| 3-Room Energy Consumption | -0.74011155 | 54.8% | 0.23437477 | 5.5% |
| 4-Room Energy Consumption | -0.77865546 | 60.6% | 0.23356675 | 5.4% |
| Temperature | - | - | -0.2069192 | 4.3% |

*Table 28: Correlations between Energy Consumption, Temperature and Wind Speeds at post-renovation Brattbakken.*

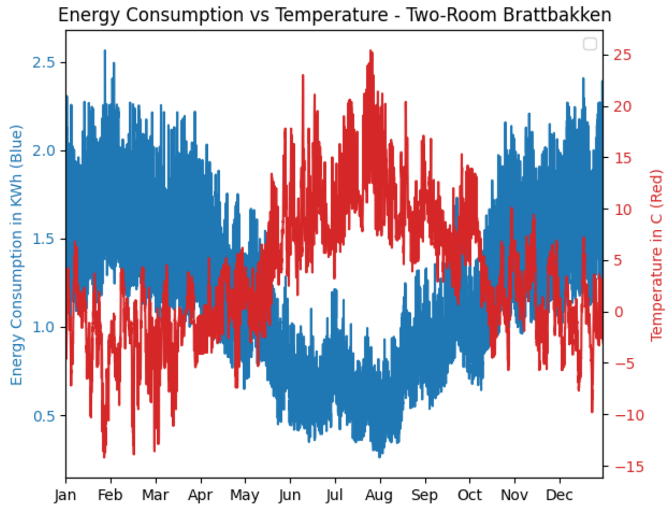


*Figure 35: Visualisation of Correlation between Energy Consumption and Temperature at post-renovation Brattbakken: 2-Room.*

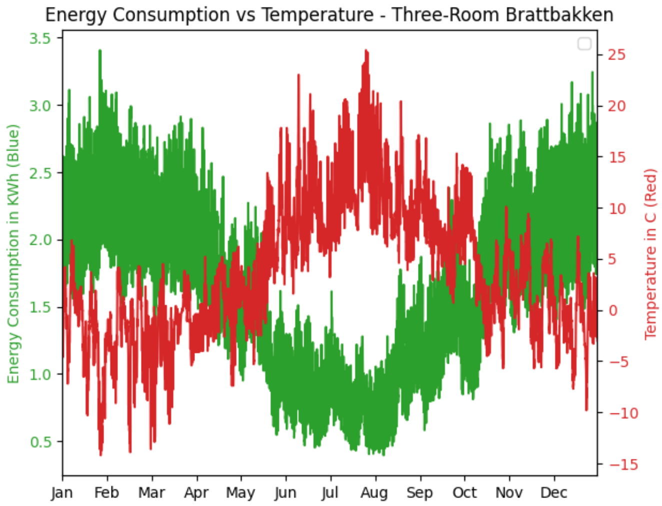


*Figure 34: Visualisation of Correlation between Energy Consumption and Temperature at post-renovation Brattbakken: 3-Room*

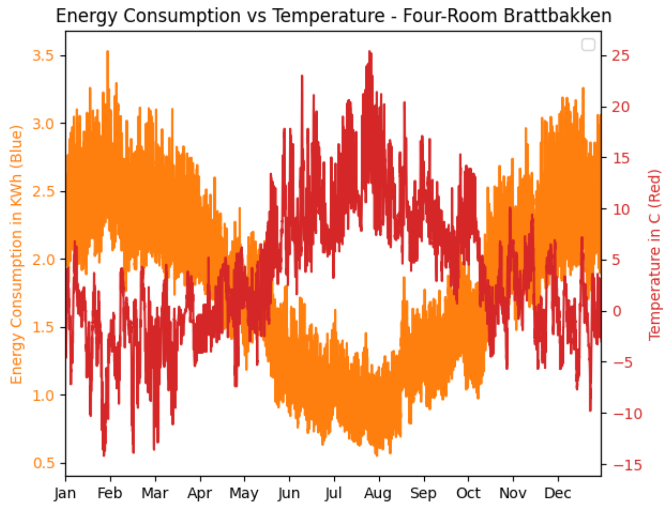


*Figure 37: Visualisation of Correlation between Energy Consumption and Temperature at post-renovation Brattbakken: 4-Room.*

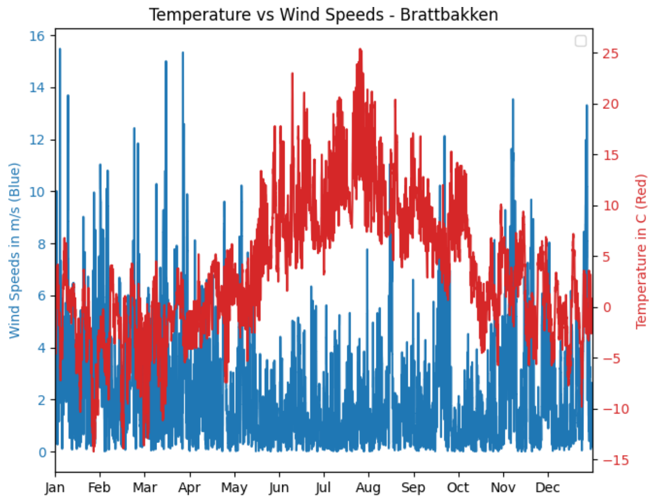


*Figure 36: Visualisation of Correlation between Wind Speeds and Temperature at post-renovation Brattbakken.*

## 5.3 Basic Model Prediction: Post-Renovation Brattbakken

### 5.3.1 Structural Specifications, Temperature and Wind Conditions.

The temperature and wind conditions used for the prediction model used to predict the post-renovation energy consumptions and correlations at Brattbakken are equal to those prior to renovation, which is the most recent data at Brattbakken stretching over a full year ( see subchapter 5.2.2). In terms of structural specifications, post-renovation Brattbakken is expected to be quite similar to Krokelva based on the insights Author sit on through discussions with the board of the housing tenure at Brattbakken. The measures Krokelva opted into are similar to the ones Brattbakken plan to opt into, which will ensure higher energy efficiency in all buildings regardless of apartment types. Similarly to Krokelva, not all measures planned at Brattbakken towards a higher level of energy efficiency are within the scope of this thesis due to the limitations outlined in subsection 1.4, although the relevant measures entails replacement of wind barrier, adding on an additional 10cm of insulation with modern conductivity values, new 3-layers windows and new doors.

The structural-specific values at Brattbakken will follow the same building regulations as Krokelva (TEK-2017), meaning the requirements the two housing tenures face from are identical in terms of the technical perspective of the building's structural envelope. The additional 100m of insulation in walls and roof will share a similar conductivity to that of Krokelva (0.034 W/mK), and the roof shingles will be replaced with WPC materials with a conductivity of 0.53 W/mK. The primary difference in exterior between the two buildings have up until this point been the wooden exterior of Krokelva in contrast to the steel plates at Brattbakken. For the purposes of this thesis, a wooden exterior identical to that of Krokelva will be assumed at post-renovation Brattbakken, a wooden exterior with a conductivity of 0.14 W/mK.

| Wall | | | |
|---|---|---|---|
| **Material** | **Thickness (m)** | **Conductivity (W/mK)** | **R-Value ($Km^2/W$)** |
| Plaster Wall (Interior) | 0.013 | 0.026 | 0.500 |
| Concrete Blocks | 0.100 | 0.090 | 1.111 |
| Glasswool Insulation (Old) | 0.150 | 0.040 | 3.750 |
| Glasswool Insulation (New) | 0.100 | 0.034 | 2.941 |
| Plasterboard (Exterior) | 0.012 | 0.016 | 0.750 |
| Wood Exterior (New) | 0.019 | 0.14 | 0.136 |
| **Roof** | | | |
| Chipboard Plates (Interior) | 0.012 | 0.15 | 0.080 |
| Glasswool Insulation (Old) | 0.200 | 0.040 | 5.000 |
| Concrete | 0.10 | 0.16 | 0.625 |
| Glasswool Insulation (New) | 0.100 | 0.034 | 2.941 |
| Wood-Plastic Composites (New) | 0.005 | 0.53 | 0.009 |

*Table 29: Predicted/Assumed Values at Post-Renovation Brattbakken.*

| Combined Values | | |
|---|---|---|
| | **R-Value ($Km^2/W$)** | **U-Value ($W/Km^{2)}$** |
| Walls | 9.1881 | 0.1088 |
| Roof | 8.6550 | 0.1155 |
| Windows | 1.25 | 0.8 |

*Table 30: Combined R-Values and corresponding U-values for aspects of the structural envelope at post-renovation Brattbakken.*

The calculations and assumptions for R- and U-values at post-renovation Brattbakken are outlined through Table 29 and Table 30, where the most notable differences in comparison to post-renovation Krokelva is the increased R-value of the roof due to the concrete roof – which yields an U-value that is 0.94x the size of the U-value for post-renovation Krokelva. Beyond this, the U-values for roof and windows are identical to that of post-renovation Krokelva. Comparing the U-Values and corresponding values for transmission of heat based on this (see Table 31), the ratio before and after renovation are slightly different than that of Krokelva – where the ratio for walls and roof on each side of the renovation are 0.54 and 0.66 at Brattbakken, in comparison to 0.56 and 0.64 at Krokelva. As this difference is minimal between the two housing tenures, a similar trend of improvement in terms of energy efficiency between the two housing tenures is expected.

| Differences in U-Values and Transmission of Heat | | | | | | |
|---|---|---|---|---|---|---|
| | U-Value (W/K m²) | | | Transmission of Heat (W/m²) | | |
| | Walls | Windows | Roof | Walls | Windows | Roof |
| Before Renovation | 0.1999 | 1.6 | 0.1752 | 2.3988 | 19.2 | 2.1024 |
| After Renovation | 0.1088 | 0.8 | 0.1155 | 1.3056 | 9.6 | 1.4724 |
| Ratio (After / Before) | 0.54 | 0.5 | 0.66 | 0.54 | 0.5 | 0.65 |

*Table 31: Difference in U-Values and Transmission of Heat before and after renovation at Brattbakken.*

### 5.3.2 Predicting Energy Consumption

Seeing as there are several aspects of the energy consumption at Krokelva to consider, one of which holds high uncertainty (heating through wood-based fireplaces), predicting a value through the model both with and without the fireplaces at Krokelva in mind seems natural. The reasoning behind this being that it is difficult to prove the actual effects of the fireplace at Krokelva, although based on the differences in correlation between Krokelva and Brattbakken prior to renovation – it is evident that that the pre-renovation correlations at Krokelva have been significantly affected by the usages of a fireplace as part of the heating aspects of the apartments seeing as the pre-renovation correlations for two-room apartment (57 m$^2$) and four-room apartment (111 m$^2$) buildings at Krokelva are 0.2294 and 0.1734 less than their Brattbakken counterparts (64 m$^2$and 104 m$^2$ for two-room and four-room apartments respectively).

While potential solutions to solve this problem in the prediction model created for the purposes of this thesis will be further discussed in Chapter 6, moving onwards in the predictions it is difficult saying much about the real changes in correlation while taking the fireplaces into account – although the changes in correlation disregarding the fact that fireplaces have been used at all is doable. Using the information regarding ratios presented in Table 20 under subsection 4.4.3, ratios of 0.9971x for two-room apartments and 0.9019x for four-room apartments have been assumed, while for three-room apartments a ratio of 0.9124 has been assumed based on the relationships between the apartment types in subsection 5.2.4.

Using these rations returns decreased correlation values of -0.7138, -0.6839 and -0.7023 for two-room, three-room and four-room apartments respectively, as seen through Table 32.

| Comparison of Correlations between Energy Consumption and Temperatures at Krokelva Before and After Renovation (Fireplaces Excluded) | | | |
|---|---|---|---|
| | Pearson's Correlation Coefficient (r) | | |
| | Assumed Ratio | Before | After |
| **2-Room** | 0.9971x | -0.71588693 | -0.71381085 |
| **3-Room** | 0.9124x | -0.74011155 | -0.67527777 |
| **4-Room** | 0.9019x | -0.77865546 | -0.70226935 |

*Table 32: Comparison of Correlations before and after renovation at Brattbakken based on assumed ratios disregarding fireplaces.*

Comparing the overall energy consumption of the two apartment types, it is easier to include the factor of the fireplaces due to the information regarding the average percentage of the total energy consumption is filled through the usage of a fireplace. As mentioned in Chapter 4, fireplaces make up for an average of 45 percent of the overall requirements for energy consumption in a typical residence, where a fireplace with an efficiency of 80 percent will result in 36 percent of the theoretical energy consumed by the fireplace to be turned into heat going into said residence. Using the ratios from subchapter 4.4.2 in combination both including and excluding the fireplaces yields a reduction of 1153.6, 1854.1 and 2400.5 kWh per year for two-room, three-room and four-room apartments respectively with ratios excluding fireplaces, as well as 4822.1, 6845.8 and 7841.7 kWh per year for the same apartment types with ratios including fireplaces (see Table 33).

| | Energy Consumption Before and After Renovation at Brattbakken | | | | | |
|---|---|---|---|---|---|---|
| | Total in kWh (Ratio excludes fireplace assumptions) | | | Total in kWh (Ratio includes fireplace assumptions) | | |
| | Before | After | Ratio | Before | After | Ratio |
| **2-Room** | 10482.8 | 9329.2 | 0.89 | 10482.8 | 5660.7 | 0.54 |
| **3-Room** | 14262.1 | 12408.0 | 0.87 | 14262.1 | 7416.3 | 0.52 |
| **4-Room** | 16003.5 | 13603.0 | 0.85 | 16003.5 | 8161.8 | 0.51 |

*Table 33: Energy Consumption before and after renovation at Brattbakken with assumed ratios both including and excluding fireplaces as a factor.*

Through the usage of the ratios above in combination with the assumptions of temperature and wind conditions equal to those of 2020 throughout the prediction model, a visualization of the above table shows a clear reduction in overall energy consumption for all apartment types. Naturally, the figure excluding fireplaces (Figure 39) are way more identical to the post-renovation figure (Figure 38) than the figure including fireplaces as a factor (Figure 40), which is expected based on the large differences between the ratios including and excluding fireplaces as a factor in the overall energy consumption. As fireplaces evidently play a large part in heating up the apartment, the consensus of this very subchapter is that the figure and values including fireplaces are significantly more realistic in terms of actual reduction of energy consumption at Brattbakken than those excluding fireplaces as a factor; although in terms of correlations it is extremely difficult to come to the same consensus seeing as this thesis has no access to data regarding the correlation between energy consumption and temperature coming directly from fireplaces, and as such can not realistically combined any two correlation factors to form the real correlation between energy consumption and temperature at Krokelva. As such, the thesis has no choice but to view energy consumption from the perspective of correlations wholistically in a way that excludes fireplaces, while the opposite is true from the perspective of ratios and the overall reduction of energy consumption.

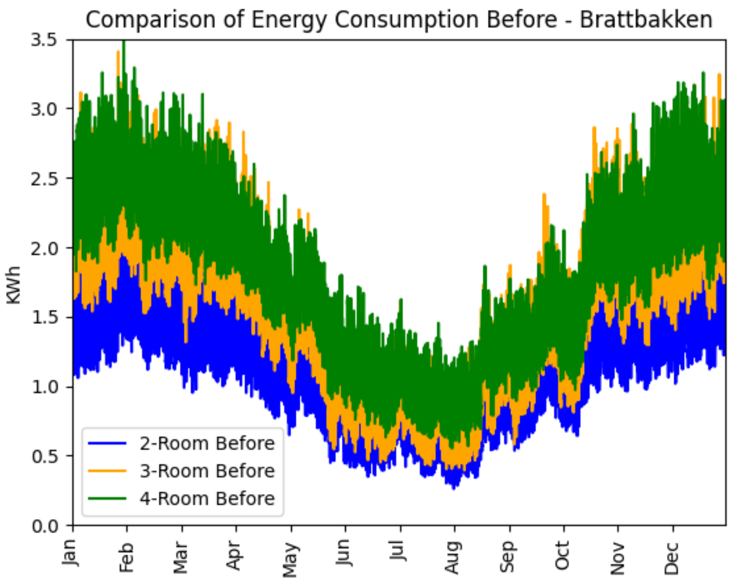


*Figure 38: Energy Consumption of pre-renovation Brattbakken*

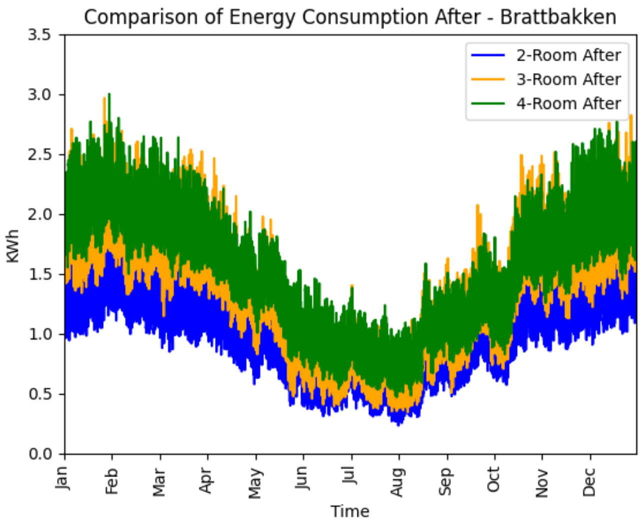


*Figure 39: Energy Consumption of post-renovation Brattbakken with rat from Krokelva excluding fireplaces, sorted by apartment type.*

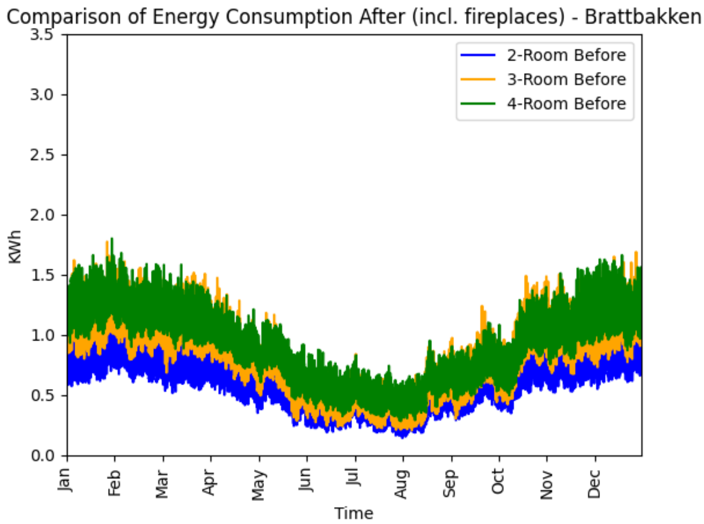


*Figure 40: Energy Consumption of post-renovation Brattbakken with ratios from Krokelva including fireplaces, sorted by apartment type.*

# 6 Discussion

This thesis has examined the possibilities of creating a simple model to predict energy consumption of buildings based on several factors, such as temperature, wind conditions, age and area. The thesis put strong emphasis on examining consumption data from the energy sector using two real-life examples sharing many similarities, with hopes of providing an early start to a more complex project of which can reliably use a multitude of variables (also variables not included in this thesis) in forming a more complex model. This particular chapter includes discussions of the methodology and model used throughout the case studies and puts emphasis on discussing the limitations and insecurities of variables used and not used, and a potential path moving forward with a project of similar nature as the one this thesis entails.

## 6.1 Temperature and Wind Conditions

Temperature and wind conditions are evidently knit to energy consumption based on the data presented in Chapters 4 and 5, showcasing a clear relationship between the increase/decrease in temperature and the decrease/increase in energy consumption. This is shown through the pre-renovation comparisons of the two variables at both Krokelva and Brattbakken, as well as the post-renovation comparison at Krokelva (see Figure 17, Figure 23 and Figure 36). Viewing the correlation between energy consumption and temperature at both locations, there seems to be a connection in correlation based on the apartment-type that is being viewed, which may be due to difference in area or number of residents, or most likely a combination of the two – which will be further explored and discussed in subchapter 6.3. Comparing the pre-renovation and post-renovation values for correlation between energy consumption and wind speeds at Krokelva shows that there is either a clear lack of information regarding the correlation prior to the renovation, or a high number of apartments that are highly shielded for wind at Krokelva prior to renovation. Comparing the pre-renovation results to those of Brattbakken which largely consists of the similar materials and building structure, the latter is likely to be ruled out. This assumption is strengthened by the fact that the correlation of temperature on both ends of the renovation at Krokelva are more similar than they are expected to be, which is strongly believed to be due to the fact that there were fireplaces at

Krokelva prior to renovation in comparison to the post-renovation apartments, which will be outlined further in subchapter 6.2.

Given the similarities between these two housing tenures, comparing the pre-renovation correlations for wind and energy consumption at Brattbakken to the corresponding post-renovation correlations for Krokelva could provide meaningful information regarding the alteration of correlation between energy consumption and wind speeds based on the quality of the structural envelope. While the housing tenures are situated in different parts of Tromsø, correlation takes the relationship between two values of time into consideration rather than the magnitude of the values, which is why comparing the pre-renovation values at Brattbakken and post-renovation value at Krokelva is an acceptable comparison to make. Through viewing the correlation between energy consumption and wind speeds at Brattbakken prior to renovation with a weak positive correlation (0.2189 and 0.233 for two-room and two-room apartments respectively) in context of the close to non-existent correlation at post-renovation Krokelva (0.0471 and 0.0575), it becomes clear that there is a rapidly decreasing correlation between these two variables depending on the quality of the structural envelope at hand. A modern building following constructional standards based on modern building regulations will see a close to non-existent correlation with wind in comparison to buildings following outdated building regulations, such as the one from 1969 which was used for both pre-renovation Krokelva and pre-renovation Brattbakken.

Given the above there are still some limitations and uncertainties regarding the influence of temperature and wind speeds in the simple model used in this thesis, as well as in potential future models of similar nature. Finding reliable sources for measurements of temperatures maybe be challenging in certain areas where there are large differences in climate over short to medium distances from a measurement station, as well as in buildings far from the nearest measurement station. The further away a building is from a given measurement station the higher the uncertainty in terms of accuracy of temperature data for said building – which also holds true for wind. Looking at the AROME-Arctic model specifically, this model provides predicted wind values in a grid with a resolution of up to 2.5km, which may not be of sufficient accuracy in areas of which see very high variation in wind speeds due to nearby geological factors. Seeing as the northern parts of Norway has a lot of fjords, steep mountains and demanding terrain, a 2.5 $km^2$ area may be highly varied geologically speaking, which may significantly affect any correlation between wind speeds and energy consumption. Looking at the differences in correlations for Brattbakken and Krokelva, there is a chance the wind data entailing Krokelva is lacking in terms of accuracy, which would explain why the correlation between wind and energy consumption is practically non-existent for Krokelva specifically. This is strengthened by the fact that Brattbakken lies in a more open area and sees significant correlations between energy consumption and wind speeds, albeit quite a small one. Viewing this in combination with the fact that they are predicted values rather than measured values makes it natural to assume there to be minor uncertainties in wind data, especially if the location examined lies in an area with a lot of variance geologically speaking, such as the area at Krokelva.

## 6.2 Energy Consumption and Fireplaces

Through a direct comparison of energy consumption on both sides of the renovation process with respects to factors such as apartment type, time of year, area and so forth - useful information regarding the change in consumption data based on the quality of a building's structural envelope comes to light. Throughout Chapter 4 and 5 a significant portion of the energy consumption at Krokelva is not accounted for through the consumption data only containing energy consumption in terms of electricity, and not energy consumption provided through the usage of fireplaces. In order to accommodate for the evident impact said fireplaces have on the overall energy consumption required, information regarding the amount of energy requirements met by fireplaces in the average Norwegian household was necessary to account for – information provided through Enova (Enova, 2012) which as previously mentioned make up for an amount equal to the degree of efficiency by the oven itself multiplied with roughly 45% of the overall energy requirements (which is the average energy consumption Norwegian households gets through fireplaces). Through the knowledge of the assumption that the measured consumption data of pre-renovation Krokelva in theory should make up for roughly 55% of the overall need for energy at Krokelva, finding expected values for energy consumption including fireplaces simply requires backtracking through the information and adding the results to the existing data on an hourly basis. Due to this unexpected difference between the two housing tenures, the thesis found it necessary to take two datasets into account in terms of energy consumption; the measured one excluding fireplaces as a factor as well as one formed through the combination of measured data and predicted data based on national averages for fireplaces.

Comparing the energy consumption data to one another, the reduction in energy consumption is split into two parts; reduction in terms of electricity and reduction in terms of fireplaces. While having energy consumption input split into two different parts and the model will give acceptable pointers in the direction of energy consumption with and without fireplaces, there are multiple limitations in place tied to fireplaces specifically. While the assumed 45% may be accurate on a national scale, said percentage may be significantly different in the local area of which has been viewed. Generally speaking, the climate in Tromsø is colder than it is in the southernmost parts of Norway, which may have an effect on the percentage in one way or the other, an effect that is hard to measure through the scopes of this thesis.

In order to get a higher level of accuracy through the model it is absolutely necessary to either get more accurate data regarding the energy consumption of the fireplaces in Krokelva, or compare Brattbakken to a different building with similar specifications and age although without relying on fireplaces as a heating source whatsoever. Through this thesis, finding significant information regarding fireplaces at Krokelva has not been successful, although there are ways of which may be likely to explore in future models, such as moving from a perspective of time that reviews the entirety of a day to an interval-focused view. As an example, there is a fair possibility to get more accurate correlations through defining a time window of each day where the likelihood of fireplaces being used are very slim, namely at late evenings and throughout the night. Through defining a time period between 11pm and 8am, it is likely the correlation between the electricity-based energy data and temperature will be more accurate, although this is not proven throughout this thesis and is a matter of speculation.

## 6.3 Insulation, Transmission of Heat and Regulations

Despite the fact that the uncertainties tied to fireplaces are present, the thesis can with comfortably claim that there is a substantial decrease in energy consumption through the renovation of an older building provided the resistivity (R-values) towards the thermal transmittance of temperature between the outside and the inside of the building. This is proven through a noticeable improvement (decrease) in the U-value through the renovation process, which shows that the transmission of heat decreases hand-in-hand with the decreasing U-value, which is purely related to the thermal conductivity and thickness of the materials in walls, roof and windows. It is evident newer technology and building regulations have had a massive impact on energy efficiency. This is thoroughly shown through Chapter 4 and 5, which proves that there is a direct relationship between insulation and energy consumption.

Using the knowledge of the relationship between insulation, transmission of heat and energy consumption in combination with the knowledge of the norms of the building regulations over the past 50 years, making sound assumptions through the model regarding thickness of materials as well as thermal conductivity of the materials used is a natural addition to this model, and both could and should be included in an improvement of the model and/or future models. This could be done through adding a series of materials with a conductivity that is heavily relying on the time period of which they were installed, and thus defines which building regulations they follow. As an example, glass wool from the 1970s and 1980s have a much higher conductivity than glass wool from the 2010s or 2020s – a difference of 10% (from 0.040 W/mK to 0.036 W/mK) as shown through the calculations in Chapter 4 and Chapter 5. Through adding the time of which the building is planned and built as a variable (in other words the building's age), narrowing down the conductivity and thickness of materials based on this variable alone is doable considering an addition of a library of materials and corresponding conductivities sorted by year, opening up for a lot of information based on this variable alone.

Through viewing the effect wind seems to have on buildings based on the findings of subchapter 3.2 which renders wind of low significance to the transmission of heat through the materials of a building, it is evident wind plays no direct part here in modern buildings due to the low impact it has on resistivity of materials low and medium conductivity. That said, the findings for Krokelva and Brattbakken goes to show that there is a correlation between wind speeds and energy consumption, although through an immeasurable way for the method presented in this thesis. It is likely that this correlation is formed due to wind finding its way through the cracks or other weaknesses in the facade of the building (infiltration, see subchapter 2.2.2), and/or through the ventilation system (or lack thereof) of said building. Old and outdated building methods and materials may allow for air infiltration through cracks, holes, fatigued materials or other weaknesses – which in turn will contribute to an increased overall transmission of heat, as shown briefly through subchapter 2.2.2. In similar fashion, older buildings, Brattbakken and Krokelva included, relies on natural ventilation for air circulation, which means larger amounts of cold air transported by the wind gains access to the building. The information regarding heat loss through infiltration and ventilation is challenging to get access to as it requires manual installations of measuring equipment in the apartments in question, which is out of reach for this very thesis.

## 6.4 Area and Number of Residents

One of the largest limitations of this model is the lack of information regarding number of residents in each apartment type, which leads to a high level of insecurities in comparing the area of the building types and trying to find a correlation between area and energy consumption. Without knowing the average amount of residents in each apartment type it makes little sense attempting to seek for correlations between area, inhabitants and energy consumption – as area and number of residents in the apartments are tied together quite strongly. This information is difficult acquire through this thesis as Author does not have sufficient access to aforementioned information, as it would either require access to privacy-protected data from the energy sector at an apartment-by-apartment basis, or information provided by the apartments in question. As each of the housing tenures only track the owners of the apartments and not the total number of residents, combined with the fact that Section 4 and 5 provide strong indications that area and number of residents play such a major part (the regression lines in particular), trying to assume number of residents will not provide sufficient accuracy for correlations between the three variables (energy consumption, inhabitants and area) to be presented with a confidence or accuracy at an acceptable level to be included in this thesis. Even though area is known, it is such tightly knit to number of residents that using one without the other will not suffice.

## 6.5 Model Improvements and Additional Variables

While the simple model created and used throughout this thesis is functional and has proven to give pointers towards how energy consumption is knit to insulation, transmission of heat and variance in wind and temperature, there is a lot of room for potential improvements to increase the accuracy and reliability of it. Numerous weaknesses and downsides have been uncovered regarding the simple model of this thesis, primary weaknesses of which entail information that is difficult to acquire and/or measure. Through a series of improvements, further developing this simple model into a more complex model that can be widely used for the purposes of analyzing the state of a building from the perspective of energy efficiency is absolutely feasible. Said improvements do however require a lot of investments in terms of time and additional equipment, as well as tweaks to both new and existing parameters and variables. There are numerous of improvements to make on already existing parameters, most of which opens the model up for more possibilities depending on the specifics of the building viewed.

One of the most obvious first steps is adding a parameter allowing the selection of whether fireplaces should be included or not, which will greatly improve the model and is a necessity seeing as fireplaces are a popular heating source in the region this model is initially intended for. This parameter would have to either change how the energy consumption data is viewed (only analyzing data at night-time), change comparison in terms of comparing the building of which the model is aimed for to other buildings with fireplaces, or simply develop a method of predicting the energy consumption of fireplaces based on a series of other variables, such as temperature, area and so forth. This is not an easy task and makes the model significantly more complicated, and should come second in line to tweaking the time intervals of which data is analyzed in an attempt towards a solution, which is a natural first step towards model improvement as far as catering to the usage of fireplaces is concerned.

Viewing the variables of temperature and wind as presented used throughout this thesis, using temperature measurements from nearby measuring stations is arguably a sufficient way of getting accurate data regarding temperatures, especially considering the fact that correlations are not dependent on magnitude but rather on the behaviour of two variables with respects to one another. As such, height differences between a measuring station and the target area will not give any differences in terms of correlation regardless of how the temperature values are recalculated to take altitude variation into account. Wind on the other hand is a significantly more delicate variable, a variable prone to seeing large variations depending on the geological aspects of the surroundings of the point of interest, which may prove to be challenging. As mentioned in subchapter 6.1, a 2.5x2.5km resolution grid may not be sufficiently accurate given the geology of the northern areas of Norway, with deep fjords and steep mountains. As such, a model with significantly higher resolution (preferably as high as 1x1km grids) would likely increase the accuracy of wind data used through this model significantly, although to Author's knowledge there exists no model with such resolution usable in the area this thesis put emphasis on.

Circling back to the limitations of the thesis outlined in subchapter 1.4, said limitations include a few variables it would be natural to include, such as transmission of heat through ventilation and infiltration. Although introducing these variables into the model will be challenging due to the measurements and equipment necessary to do so, through an introduction of said variables the correlations between wind and energy consumption may be more accurately examined through the information provided by these very variables. The primary downsides to this is the need for measuring equipment for each building subject to analysis through said model, although this could be nullified through a system storing large quantities of information based on what is expected through the standards of the building in relation the building regulations. Through the introduction of area and number of inhabitants as variables through a thorough analysis of how area and number of inhabitants impacts energy consumption, making a system depending on defined inputs at the start of the potential model should be achievable, and would increase its accuracy significantly.

# 7 Conclusion and Further Work

## 7.1 Conclusion

The analysis of data throughout the thesis proves that there is an evident correlation between wind, temperature and energy consumption, which deems said variables as relevant to include in the analysis of the energy efficiency of a building. Previous chapters show a clear decrease in correlation between temperature and energy consumption depending on the state of a building's structural envelope, where buildings following modern building regulations as a guideline correlates significantly less with temperature than they would with older regulations. It appears as if the correlation between wind and energy consumption is slim but noticeable depending on the location of the building at hand, and while the correlation between wind speeds and energy consumption is much lower than that of temperature – it is reasonable to believe based on the findings above that there is a way to combined temperature and wind speeds to form a higher correlation factor with energy efficiency than what has been examined throughout this thesis.

A multitude of variables proved to be difficult to measure and define without equipment more complex than those made available to Author, variables that the above analysis suggests being directly knit to the energy efficiency of a building. These variables include the likes of area, number of inhabitants and alternative energy sources, where some information regarding parts of these variables were acquired through the very limited availability of data regarding said variables. Regarding area and number of inhabitants, it is evident that smaller area apartments see a significantly lower change in correlations and energy consumption between the two of the renovation than larger areas apartments, which is assumed to be caused by the area difference in combination with the number of inhabitants, although further analysis of said relationships is not doable within the scopes of the thesis.

As briefly mentioned above, alternative energy sources expose clear weaknesses in the model created through the methodology above, which in this case presented itself in the form of fireplaces. Measuring the energy consumption of an apartment where both electricity and fireplaces are present has proved to be challenging, making the comparison of pre-renovation and post-renovation Krokelva particularly challenging in terms of correlations. While there is a clear relationship between energy consumption and temperature even when alternative energy sources are present, giving a proper view of correlations between overall energy consumption and temperature is challenging due the hardships of measuring energy consumption over time coming directly from fireplaces. Possible solutions to overcome these challenges, such as an interval-based comparison when alternative energy sources are not being used, have been both presented and discussed, and may be included as variables in future models and methodologies.

## 7.2 Further Work

Several improvements may be made to the model presented through this thesis, where significantly more accurate and informative data could be extracted to accommodate to the needs of said improvements. To remain within the scopes of privacy laws while still using qualitative and aggregated information, viewing data from buildings with similar area and number of inhabitants per apartment while simultaneously spread out in terms the building regulations they follow, several improvements tied to the significance of variables such as area and number of inhabitants could be made. In order to get ahold of said data it would be necessary to view housing tenures or housing arrangements with a defined set of rules or tendencies as far as living arrangements goes, which makes student housing facilities a perfect fit. These facilities hold very specific limitations to number of inhabitants per apartment type, which means significantly more accurate and detailed information regarding the variables of area and inhabitants could be used, and their relationship to energy consumption could be more clearly defined through these very limitations.

Moving forward, it is suggested said housing arrangements are being analyzed in similar fashion as through the methodology of this thesis, which could potentially lead to a significantly more accurate model. Through combining this improved model with factors such as a monetary cost-gain comparison and a comparison of environmental benefits of said renovation, it is reasonable to assume that such a product could be used in a commercial setting in order to analyze the state of a building's structural envelope and energy efficiency, and thus potentially be an extremely beneficial tool from multiple perspectives; saving money for the consumer, time for the engineers, and greenhouse gases for the environment.

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# Appendix A

```
import requests
from itertools import product
import threddsclient
import pydap.client
import numpy as np
from datetime import datetime
import matplotlib.pyplot as plt
import matplotlib.patches as patches
import openpyxl as xl
from openpyxl import Workbook

"""We now define empty lists to append to later on in the code, as well as
define
the range of years we are interest in, as well as the specific months we're
interested in"""
timelist = []
windlist = []
years = list(range(2017,2018))
months=[10]
urls = []

"""We create a for-loop to store all desired urls in the defined time
period into a list
of urls, which we can call later on to perform operations on"""
for y, m in product(years, months):
    catalog =
f'https://thredds.met.no/thredds/catalog/aromearcticarchive/{y:04d}/{m:02d}
/catalog.html'
    if requests.get(catalog).status_code == 200:
        datasets = threddsclient.crawl(catalog, depth=1)
        urls += [ds.opendap_url() for ds in datasets if '_pp_' in ds.name]

"""We create a for-loop ranging from 0 to the length of urls, to iterate
through all
of the content in the urls list."""
url = 0
for url in range(0, len(urls)):
    print(url)

    """Opens an url from urls depending on the value of url"""
    ds = pydap.client.open_url(urls[url])

    """We create a target area"""
    lat1 = np.array(ds['latitude'][:]) < 69.7
    lat2 = np.array(ds['latitude'][:]) > 69.6
    long1 = np.array(ds['longitude'][:]) < 19.1
    long2 = np.array(ds['longitude'][:]) > 18.9
    target_area = lat1*lat2*long1*long2
    idy, idx = np.where(target_area)

    """We create two corresponding arrays in order to withdraw the
necessary
    information about both time and wind. """
    timestamp = np.array(ds['time'])
    x_wind_arr = np.array(ds['x_wind_10m'][:, :, idy.min():idy.max(),
idx.min():idx.max()]).squeeze()
```

```
    """We now fetch information from the first 3 values of the time array,
and append them to our lists.
    This is because we want to update the file for every 4th hour iterated,
meaning we only need the first 3
    values of each file we fetch."""
    human_readable_time1 = datetime.fromtimestamp(timestamp[0])
    output = np.abs(x_wind_arr[0][0][1])
    timelist.append(human_readable_time1)
    windlist.append(output)

    human_readable_time1 = datetime.fromtimestamp(timestamp[1])
    output = np.abs(x_wind_arr[0][0][1])
    timelist.append(human_readable_time1)
    windlist.append(output)

    human_readable_time1 = datetime.fromtimestamp(timestamp[2])
    output = np.abs(x_wind_arr[0][0][1])
    timelist.append(human_readable_time1)
    windlist.append(output)
    url=url+1


"""We make a list of lists, and append the entire list of lists to an excel
file"""
wb = Workbook()
ws = wb.active

listoflists = []
o = 0
for o in range(0, len(timelist)):
    listoflists.append((timelist[o], windlist[o]))
    o = o+1

for col in listoflists:
    ws.append(col)

wb.save(filename='KBWind_2017_October.xlsx')
```

# Appendix B

```
import matplotlib.pyplot as plt
import openpyxl as xl
from openpyxl import Workbook
import requests
from itertools import product
import threddsclient
import pydap.client
import numpy as np
from datetime import datetime
from openpyxl import Workbook

"""We define the files we are interested in using"""
wb = Workbook()
bbpowerfile = xl.load_workbook(filename='BBPowerData.xlsx')
powerrange = bbpowerfile['verdier']
bbtempfile = xl.load_workbook(filename='StakkevollanTemperatur2020.xlsx')
temprange = bbtempfile['Sheet']

"""We form 4 empty lists to store future values in"""
temp = []
toroms = []
treroms = []
fireroms = []

"""We now form a for-loop containg 3x if-loops, with the purpose of sorting
values based on room-types into the corresponding list formed above."""
count = 1
for count in range(1, 1098):
    if '2-roms' in powerrange['C{}'.format(count)].value:

toroms.append(str(powerrange['E{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['F{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['G{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['H{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['I{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['J{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['K{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['L{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['M{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['N{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['O{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['P{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['Q{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['R{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['S{}'.format(count)].value).replace(',', '.'))
```

```
toroms.append(str(powerrange['T{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['U{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['V{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['W{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['X{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['Y{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['Z{}'.format(count)].value).replace(',', '.'))

toroms.append(str(powerrange['AA{}'.format(count)].value).replace(',',
'.'))

toroms.append(str(powerrange['AB{}'.format(count)].value).replace(',',
'.'))
    if '3-roms' in powerrange['C{}'.format(count)].value:

fireroms.append(str(powerrange['E{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['F{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['G{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['H{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['I{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['J{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['K{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['L{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['M{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['N{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['O{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['P{}'.format(count)].value).replace(',',
'.'))

fireroms.append(str(powerrange['Q{}'.format(count)].value).replace(',',
'.'))
```

```
firerooms.append(str(powerrange['R{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['S{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['T{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['U{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['V{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['W{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['X{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['Y{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['Z{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['AA{}'.format(count)].value).replace(',',
'.'))

firerooms.append(str(powerrange['AB{}'.format(count)].value).replace(',',
'.'))
    if '4-roms' in powerrange['C{}'.format(count)].value:

trerooms.append(str(powerrange['E{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['F{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['G{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['H{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['I{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['J{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['K{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['L{}'.format(count)].value).replace(',',
'.'))

trerooms.append(str(powerrange['M{}'.format(count)].value).replace(',',
'.'))
```

```
treroms.append(str(powerrange['N{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['O{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['P{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['Q{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['R{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['S{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['T{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['U{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['V{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['W{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['X{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['Y{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['Z{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['AA{}'.format(count)].value).replace(',',
'.'))

treroms.append(str(powerrange['AB{}'.format(count)].value).replace(',',
'.'))
    count=count+1

"""We create a for-loop that appends temperature-data into a list of
similar length
as the lists created in the for-loop above."""
count = 1
for count in range(2, 8786):
    temp.append(str(temprange['D{}'.format(count)].value).replace(',',
'.'))
    count=count+1

"""We create for-loops to re-format all values in all of our lists."""
for el in range(0, len(toroms)):
    toroms[el] = float(toroms[el])
for el in range(0, len(treroms)):
    treroms[el] = float(treroms[el])
for el in range(0, len(fireroms)):
```

```
    firerooms[el] = float(firerooms[el])
for el in range(0, len(temp)):
    temp[el] = float(temp[el])

"""We print the coefficient of correlation"""


"""We now form our plots. This can be repeated for all room types, although
this specific
one is for four-room apartments."""
fig, ax1 = plt.subplots()
ax1.set_ylabel('Energy Consumption in KWh (Blue)', color='tab:blue')
ax1.plot(toroms, color='tab:blue')
ax1.tick_params(axis='y', labelcolor='tab:blue')

ax2 = ax1.twinx()
ax2.set_ylabel('Temperature in C (Red)', color='tab:red')
ax2.plot(temp, color='tab:red')
ax2.tick_params(axis='y', labelcolor='tab:red')

fig.tight_layout()
plt.title('Energy Consumption vs Temperature - Two-Room Brattbakken')
plt.xticks([732*0, 732*1, 732*2, 732*3, 732*4, 732*5, 732*6, 732*7, 732*8,
732*9, 732*10, 732*11],['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', 'Jul',
'Aug', 'Sep', 'Oct', 'Nov', 'Dec'], rotation='vertical')
plt.xlim(0, 8760)
plt.legend()
plt.show()
```

# Appendix C

**Fra:** Krokelva borettslag
**Sendt:** mandag 15. mars 2021 kl. 19.13
**Til:** [redacted]
**Emne:** Re: Innhenting av Forbrukerdata før og etter renovering

Hei [redacted]

2 roms BRA 57 BOA 53,6
4 roms BRA 110,9 BOA 107,4 (en del leiligheter har større bod)
Alle vinduer er byttet ut til 3 lags glass, ytterdør og verandadør er byttet, etterisolert med 10 cm isolasjon på alle yttervegger,ny vindsperre, isolasjon er lagt rundt grunnmur, alle leiligheter har fått ny gang med varmekabler, alle leiligheter har fått ny isolert bod, 4 roms har fått ny veranda.

2 roms leiligheter som var ferdigstillt 01.04.2020
Granittvegen
46,48,50,52,54,56,58,60,74,76,78,80,82,84,86,88,98,100,102,104,106,108,126,128, 130,132,134,136,154,156,158,160,162,164.

4 roms leiligheter som var ferdigstillt 01.04.2020
Granittvegen 45,47,49,51,53,55,57,59,61,63,65,67,69,71.
Kvartsveien 58,60,62,64,66,68,70,72,74.

Se vedlagt tillatelse.
Mvh
[redacted]
Styreleder, Krokelva Borettslag