

Final project report  
MPSE2201 System design and engineering

Group 10

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## **Abstract**

Final project report in Systems Design and Engineering. The report explains how we would design a system to make large apartment complexes reach a zero-emission goal and how to employ a system engineering approach to develop the product.

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## Abbreviations

- API** Application Programming Interface
- BRA** Bruksareal
- BYA** Built-up area
- COVID-19** Corona Virus Disease 2019
- CRUD** Create Read Update Delete
- FFBD** Functional Flow Block Diagram
- INCOSE** International Council on Systems Engineering
- JSON** JavaScript Object Notation
- KPP** Key Performance Parameters
- MCU** Main Communication Unit
- MTTF** Mean Time to Failure
- MTTL** Mean Time to Learn
- MTTR** Mean Time to Repair
- NVE** Noregs Vassdrags- og Energidirektorat
- PHP** Hypertext Preprocessor
- PIM** Probability and Impact Matrix
- PVGIS** Photovoltaic Geographical Information System
- RAMS** Reliability Availability Maintainability Safety
- SMART** Specific Measurable Attainable Relevant Time-bound
- SQL** Structured Query Language
- UML** Unified Modeling Language
- V2B** Vehicle-to-Building
- Wp** Watt-peak

# **Introduction**

## **Assignment**

People are getting more conscious to the impact we make on the environment, and we need to find ways to reduce our emissions as well as reducing the amount of fossil fuel we are consuming.

We can also see that we are using more and more power in our homes. According to Norges vassdrags og energidirektorat (NVE), the amount of power consumption in homes accounts for 48% [14] of Norway's power consumption. About 70%[5] of this is used for heating of space and domestic hot water.

If we can find ways to harvest power in or around the buildings as well as reducing the amount of electrical heating we rely on, we can make a positive impact on the world.

We will design a smart system to help buildings reduce energy consumption and increase energy production, using these systems engineering activities as described in the formal project requirements:

- Plan the system engineering approach, to help with our system engineering activities.
- Identify system functional input requirements and needs from stakeholders that have an impact on the system of interest.
- Identify system functional input requirements and needs from stakeholders that have an impact on the system of interest.
- Identify system boundary and use cases.
- Capture system functions and logical interfaces.
- Identify logical architecture.
- Allocate functions to logical architecture.
- Identify physical architecture.
- Create test, verification and validation plan.

## **Report**

This report will explain our approach to solving the assigned problem using systems engineering, as well as presenting our solution. We start by explaining our planning and some tools we chose to aid our engineering work.

Understanding the problem and understanding what our customer cares about is important. We also map out other essential stakeholders and their concern. We then talk about the context in which our system will operate.

To explain our product, we start at a high abstract level, then as we go deeper into subsystems, we explain what design choices were made and why.

We touch on the verification plan for some of the most critical requirements from our requirements document and talk about the performance verification of our system.

We finish the report with a risk analysis for the operation of the system. We explain how we will monetize the product and how our customers will end up profiting from buying it.

## Our Systems Engineering Process

In this report we have tried presenting the process in a linear fashion, but of course in reality it was anything but.

The first iteration of the process was kickstarted by Gerrit in the first few weeks of the course, here we went through the 20 steps that would make up the final homework we submitted to Gerrit at the end of February. This was helpful as we knew nothing about systems engineering at the time. Gradually however, we would start to own the process more and more.

After the initial exploration we had a frame for further elaboration. The main goal onward was to unfold the system and to apply the systems engineering process on the subsystems as well. Along the way these explorations led to us revisiting all the previous steps and reconsidering several aspects of our system. For example, the fact that we had to increase the roof area to living area ratio would never have been found as early as it was, if the process had been linear. If this was a real project this could have led to major setbacks both in terms of time and money.

There were also several investigations into technologies and options that led to a dead-end, but it was still valuable to dive into them in order to make sure that we found the most viable concept available to us.

In addition to the material offered by the lecturers we have also relied heavily on two of the books[19][20] recommended by the teacher when learning about and applying the methods of systems engineering.

# **Planning**

## **Contract of Operations**

In order to make the teamwork function properly, one of the first things we agreed upon was the contract of operations. This was important in order to consolidate how the dynamics of the group should function, and to avoid conflicts.

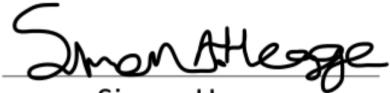
## Contract of Operations

Terra Solaris Borealis

- The team members are obligated to attend all group meetings.
- If a team member is unable to attend a meeting, he shall inform the systems engineer in advance.
- All assigned work shall be submitted before its deadline.
- In case of disagreement, the systems engineer shall call a vote.
- In the case of a tie, the systems engineer has the final say.
- Every opinion and idea have the right to be expressed freely.
- All members of the team shall act with respect towards the others



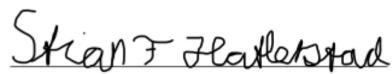
Tarald Vestbøstad



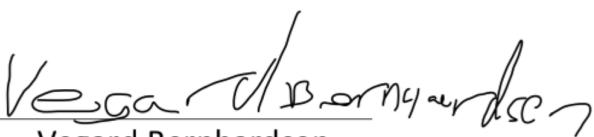
Simen Hegge



Erik Kvalvik



Stian Hatlestad



Vegard Bernhardsen



Kent Odde

## Complications due to COVID-19

After the COVID-19 breakout of 2020, we had to change our plans and “reiterate” our development process in and of itself. Pure online meetings, no more ink and paper. Although we already had connected online using several tools, moving our physical meetings online was an interesting change. In addition to our meetings, our classes were shifted online.

In general, panic and lockdown spread nationwide, and even though we were not smitten with the virus ourselves, all of these factors were indirectly impacting this group.

## Development Risk Analysis

We performed risk analysis for our ongoing development so that one of these scenarios would not bankrupt us and cancel the project.

The risk analysis matrix shows how likely each scenario is and how much it will affect us or the stakeholders negatively. The recommended action is what we can do to reduce the risk or the severity.

| RISK                                 | AREAS AFFECTED        | SEVERITY | LIKELIHOOD | RISK IMPACT | RECOMMENDED ACTION(S)   |
|--------------------------------------|-----------------------|----------|------------|-------------|---|
| Covid-19 pandemic                    | Developers health     | LOW      | HIGH       | MEDIUM      | Home office, and no physical meetings   |
| Project goes over budget and delayed | Investor retention    | MEDIUM   | LOW        | MEDIUM      | Use proper system engineering method  |
| Low sales                            | Developers salary     | HIGH     | LOW        | MEDIUM      | Customer surveys, make sure our product is wanted before starting development |
| Construction/installation delays     | Customer satisfaction | MEDIUM   | LOW        | MEDIUM      | Promise economic incentive in the contracts, to finish on time                |

Figure 1: PIM for development

## Tools

### Jira

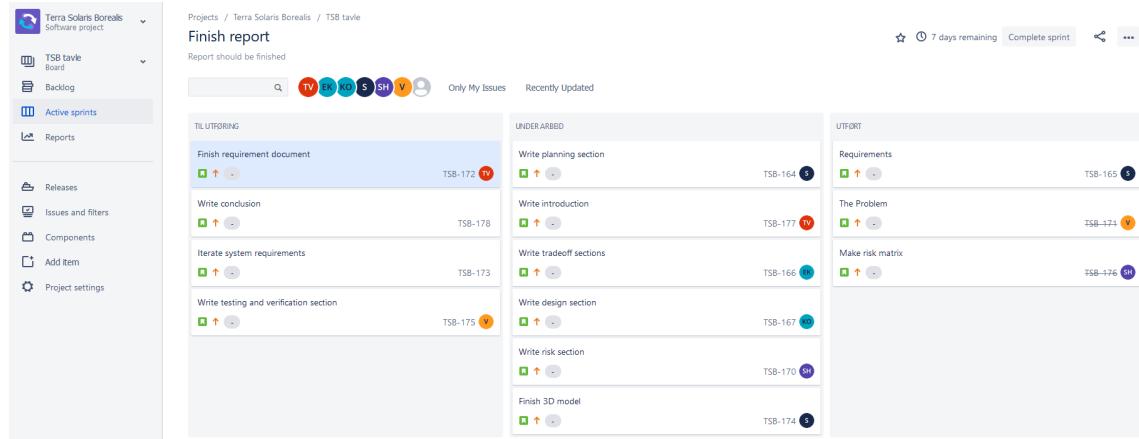


Figure 2: Jira screenshot

Jira is a site/tool used for all types of group work. Originally a software meant to track bugs and issues, reformatted for common use. It has several functions leaning towards iteration and managing projects, through workflows, tracking of issues, progress reports, logging, scrum boards, backlogs, and more, all in all making a good fit for use in our systems engineering project. Especially since we followed a scrum model for our workflow.

## Microsoft Teams

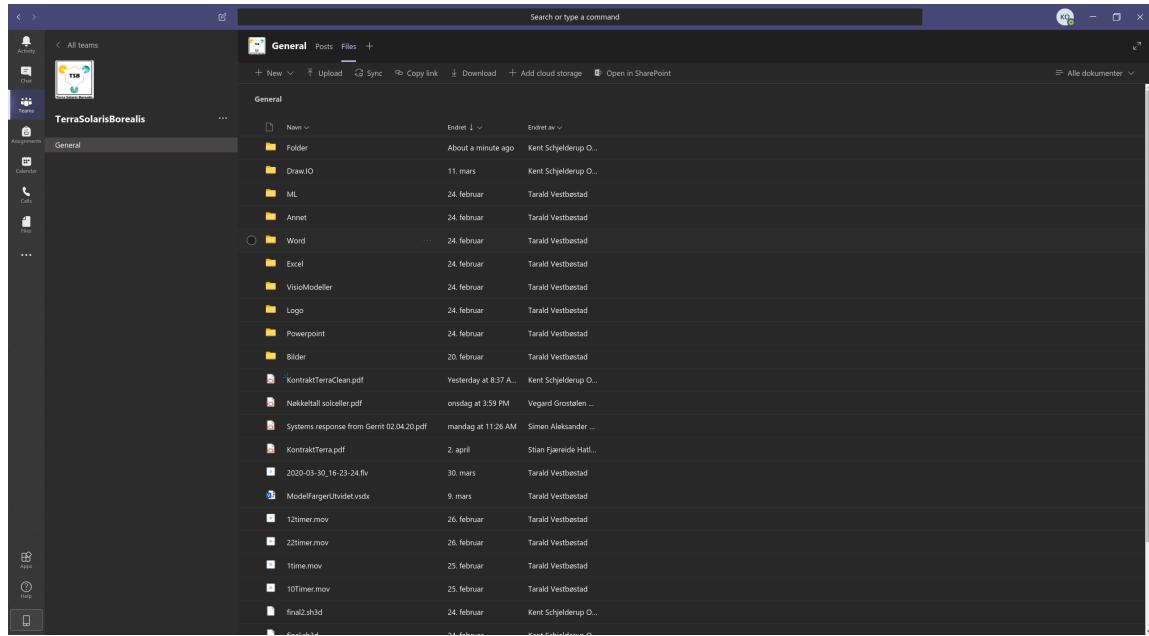


Figure 3: Microsoft Teams screenshot

Teams is a communication platform that includes chat, video conferencing, file storage, file sharing, and application integration. It is the evolution and upgrade path from Microsoft Skype for Business. It allows for efficient collaboration and sharing, keeping us all up to date with the project at all times. Having such a tool was important for our systems engineering project.

## Facebook Messenger

Another communication platform that includes chat and calls, more lightweight than Microsoft Teams. Good for fast messaging and important announcements.

## Microsoft Visio

Visio is a diagramming and vector graphics application, capable of mind-mapping, concept design, and flowcharts used in for example systems engineering in general. To our group it was vital in visualizing our project.

## Microsoft Word

Word is a commonly used writing tool with a wide variety of uses. When using Teams, Word is an obvious choice for text documents. As it allows multiple people to work on the same document in real time.

### **Microsoft Excel**

Excel is a commonly used spreadsheet tool with a wide variety of uses.

### **L<sup>A</sup>T<sub>E</sub>X**

Latex is a document typesetting and formatting tool and is widely used in academia. In our project it was used for this report.

### **Adobe Illustrator**

Another tool used to visualize our project, for example mind-mapping, concept design, flowcharts, in addition to logo development for our group.

## Gantt

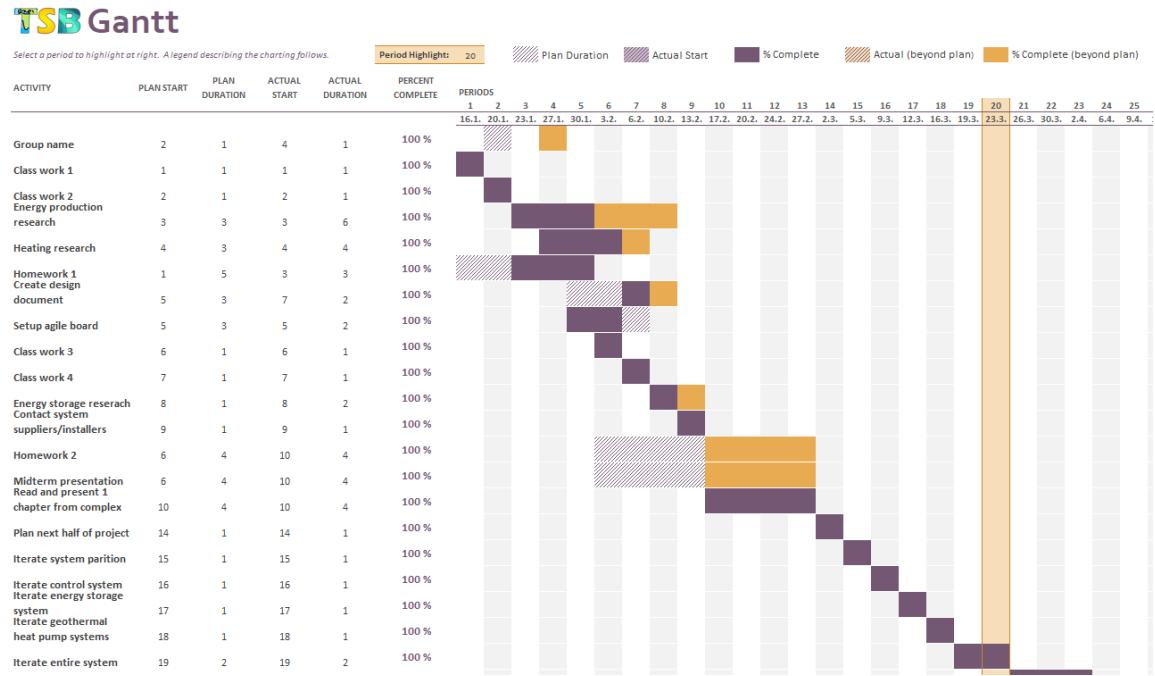


Figure 4: Gantt diagram screenshot

A Gantt chart, commonly used in project management, is a way to view activities displayed over time. On the left side of the chart is a list of activities and along the top is a suitable time scale. Each activity is represented by a bar; the length and position of the bar reflects the start date, duration and end date of the activity. This allows you to see, what the various activities are, when each activity starts and ends, how physician each activity is scheduled to last, where activities overlap with other activities, and the start and end date for the entire project. To our project, having such a chart gives an overview to easier plan ahead and divide the contents among each other.

## Draw.io

Yet another tool used to visualize our project, for example mind-mapping, concept design, and flowcharts. This program is online and in browser, for easy access and completion, again making it easier to iterate consecutively.

## Sweet Home 3D

An open source modeling tool. Used to draw a 3D model of the building.

## **Solidworks**

A modeling and simulations tool. Used to model the apartment complex in 3D, with further thermal simulation and static simulation to simulate situations visually.

## **Programming Languages**

One can use programming to develop programs to automate all kinds of time-consuming tasks.

Different languages have different advantages, but mainly it is up to the developer and his/her proficiency in the language to decide if it's the right tool for the job.

We have used programming for our machine learning prototype, the website prototype, parse data, communicate with API's, and download data.

We used a mix of Python, C++, Java and PHP.

## Github

No description, website, or topics provided.

Manage topics

Branch: master ▾ New pull request

Create new file Upload files Find file Clone or download ▾

| taraldv       | Juster litt for screenshots                | Latest commit 3bc3938 1 hour ago |
|---------------|--|----------------------------------|
| app           | Juster litt for screenshots                | 1 hour ago                       |
| public        | Juster litt for screenshots                | 1 hour ago                       |
| .gitignore    | Landing page demo                          | 2 months ago                     |
| Makefile      | Make and .htaccess                         | 2 months ago                     |
| README.md     | Update README.md                           | last month                       |
| sftpBatchFile | Gjorde url norsk, og noen bootstrap greier | last month                       |
| sql.sql       | ferdig med romPlan                         | last month                       |

README.md

<https://tsb.energy/>

Figure 5: Github web-application repo screenshot

We used GitHub to maintain the codebase for all our programs as well as the final report. It helps multiple developers work simultaneously on the same program, and offers version control.

## MySQL

For relational databases, described in detail at page 54

## MongoDB

MongoDB is a widely used NoSQL implementation suitable for big data. This helped us prototype our machine learning, and is described in detail on page 54

The screenshot shows the MongoDB Compass interface. On the left, there's a sidebar with a tree view of databases: 'Terra' (which contains 'powerPrices', 'suneast', 'sunroof', 'sunsouth', 'sunwest', 'weather' which is selected, and 'testdb'), and 'testdb'. The main area has tabs for 'Find', 'Indexes', and 'Aggregation'. A search bar says 'Search BETA'. Below it, a 'FILTER' button with the value 'filter: "example"' is shown. The results section is titled 'QUERY RESULTS 1-20 OF MANY' and lists five documents:

```
_id: ObjectId("5e6516b214f6be4bcd248db2")
time: "2005-01-01T00:00"
air_temperature: -5.9
cloud_area_fraction: 1
cloud_base_height: 2500
sum(duration_of_sunshine 1m): 59.2
weather_type: 4

_id: ObjectId("5e6516b314f6be4bcd268db3")
time: "2005-01-01T01:00"
air_temperature: -6

_id: ObjectId("5e6516b314f6be4bcd268db4")
time: "2005-01-01T02:00"
air_temperature: -5

_id: ObjectId("5e6516b314f6be4bcd268db5")
time: "2005-01-01T03:00"
air_temperature: -3
cloud_area_fraction: -3
weather_type: 43

_id: ObjectId("5e6516b314f6be4bcd268db6")
time: "2005-01-01T04:00"
air_temperature: -4.5
```

Figure 6: MongoDB screenshot

## FFmpeg

FFmpeg is a command line tool for manipulating videos. We used it to fix the format of the videos from some of our smartphone cameras.

## Adobe Premier

Adobe Premier is a video editing software. It provides a easy to use GUI and tools to edit video and audio. We used it to edit our video presentation.

## **Adobe Photoshop**

Adobe Photoshop is a powerful image editing software. We used it to do some more detailed image manipulation for our presentation and for some of our models where Visio fell short.

## **Internal Discussions**

At the very beginning, we started out getting to know each other throughout the first couple of meetings, establishing a system engineer as well, that would have an overview over the whole process. Having an established systems engineer is an advantage so that the rest can focus on their areas of interest and skill. In general, a good systems engineer will combine the efforts of all disciplines, while having a leveled head and an overview. They will be focusing on the implementations. They will need an agile mindset. Always being able to move on, shifting focus back and forth to iterate. Never quite nailing down anything, and always keeping an open mind for changes.

As mentioned, we chose to divide the tasks among ourselves to efficiently tackle all disciplines needed. Being able to have this wide range was not only beneficial in general but enabled us to delve deeper into specifics, than if we were to handle every subject as a group, as that would include a lot of meddling and internal discussions.

Much like what can be referred to as trade-off, our group had many internal discussions regarding the problem and process itself, leading to new viewpoints and crucial decisions directing us onto a certain path onward. While yes, we have had to backtrack, as this is an essential part of reiterating, but some decisions, such as work ethics, group synergy and division among the group are not relevant to this specific systems engineering project, but more our abilities to work together efficiently as a group/group projects in general.

# The Problem

## Understanding the Problem

In order to find a solution, we needed to properly understand the problem, to do this we made the scope smaller. By placing our building in a specific location and making it an apartment complex we made the problem more manageable. These are the conditions we set out to produce a solution for:

- Location: Oslo
- Number of separate buildings: 4
- Floors per building: 4
- Apartments per floor: 4
- Squaremeter per apartment: 100



Figure 7: The location of our building situated in Oslo

To see the problem from the point of view of the people that are living with the problem and are supposed to interact with the solution, we made this user story:

*Hans Kammerfast (45), his wife Birgit (46) and their two children lived in a mansion, having three gas cars and oil heating. They lived great, but spent a lot of energy on heating and had difficulties: They struggled with the children, that didn't get to heat their room after the cold night before they had to leave for school. Birgit felt like an environmental pig, and Hans wasn't too convinced whether what they did necessarily was bad for the environment. In addition, Hans was annoyed owning to the unreasonable electricity prices, and it affected the well-being of the whole family.*

*Following the first time Hans really got to see the statistics over his own emissions, he got a revelation. He felt dirty and wasteful. Unhappy with today's environmental decline due to fossil fuels, the family found that they wanted to contribute to a better everyday life. So they are currently searching for something better: a solution...*

When we see the problem this way it illuminates the possibilities to make life easier for the users at the same time as we offer a solution to the problem.

So, who will our solution affect when we take location into account? How do we interact with the municipality? How will our system affect neighbors? What sort of laws do we have to uphold? These are some of the questions we need answers to.

## Context

We first made a quick sketch of the building. As it is the most important man-made system our system will interact with.

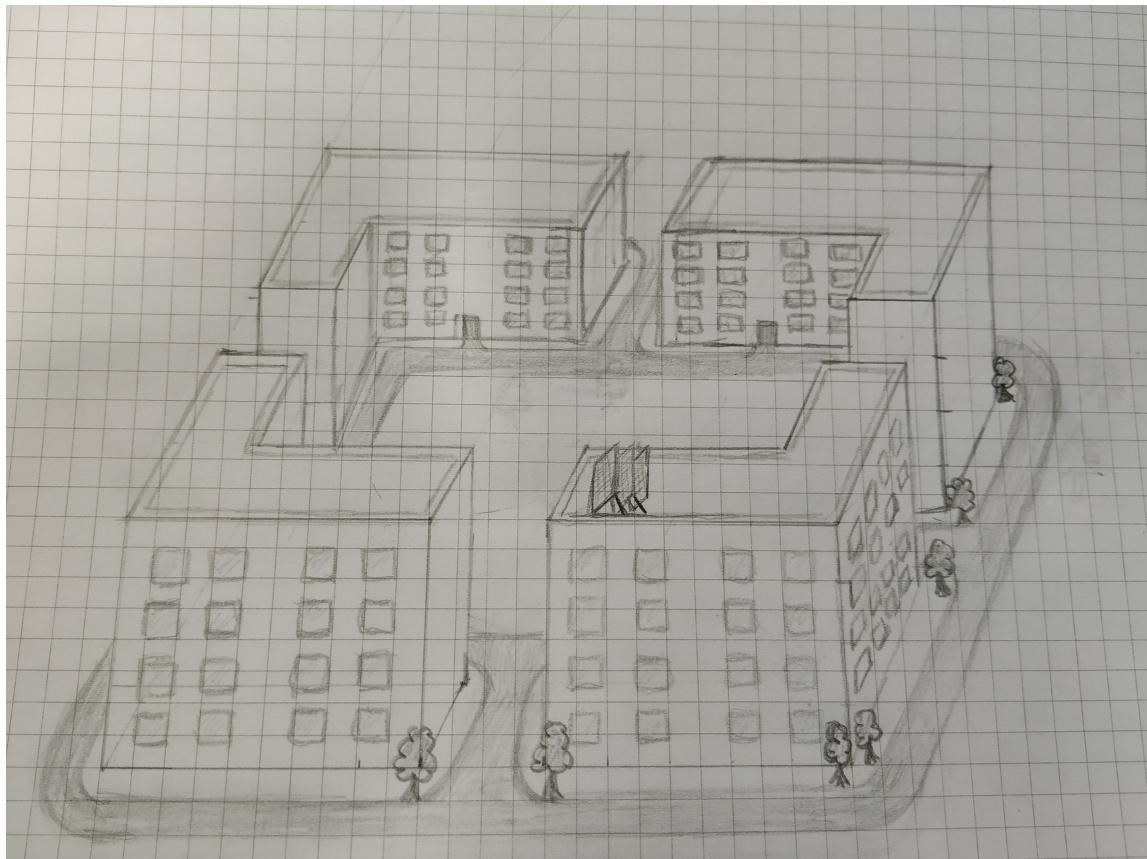


Figure 8: The initial sketch of the context

In order to have any realistic hope of achieving a 100% self-sustainable system, the building will have to be built according to these requirements:

- The building shall fulfill all requirements specified in NS3700
- The building shall fulfill all requirements specified in TEK17

The NS3700 is a standard that specifies requirements for buildings in order to be classified as a

passive house. Enova has found that this will only cost developers about 1200 NOK more per square meter[7].

We also made a 3D model of the building to better show our stakeholders how it would affect their building.



Figure 9: A 3D model of the building

A video of the 3D model can be seen at:

[https://drive.google.com/open?id=1G\\_30d9ilNBDxjQSbs0yWnLitGcMBMf15](https://drive.google.com/open?id=1G_30d9ilNBDxjQSbs0yWnLitGcMBMf15)

We then spent some time finding out all the man-made systems which will interact with our system. We found problems which might ordinarily only be discovered near the end of development or even after the system is finished and placed in the real world.

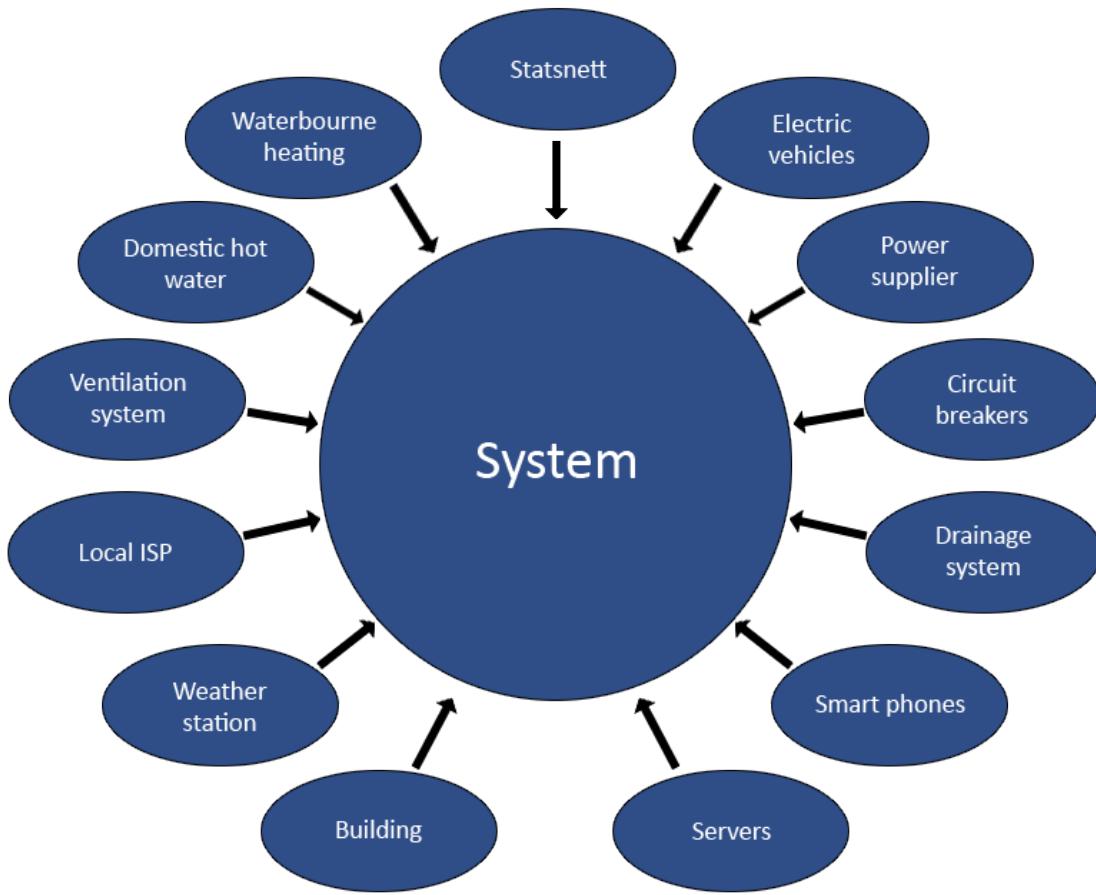


Figure 10: The man-made systems in our systems immediate context

## Stakeholders

We wrote down a list of as many stakeholders we could possibly think of.

When looking at our system from their point of view, we find a good solution early. We avoid working on a bad solution because we did not consider, for example, how the neighbor would be affected.

Then we made an onion-diagram to place the stakeholders according to how “close” they are to the system, and how much they are affected by the system.

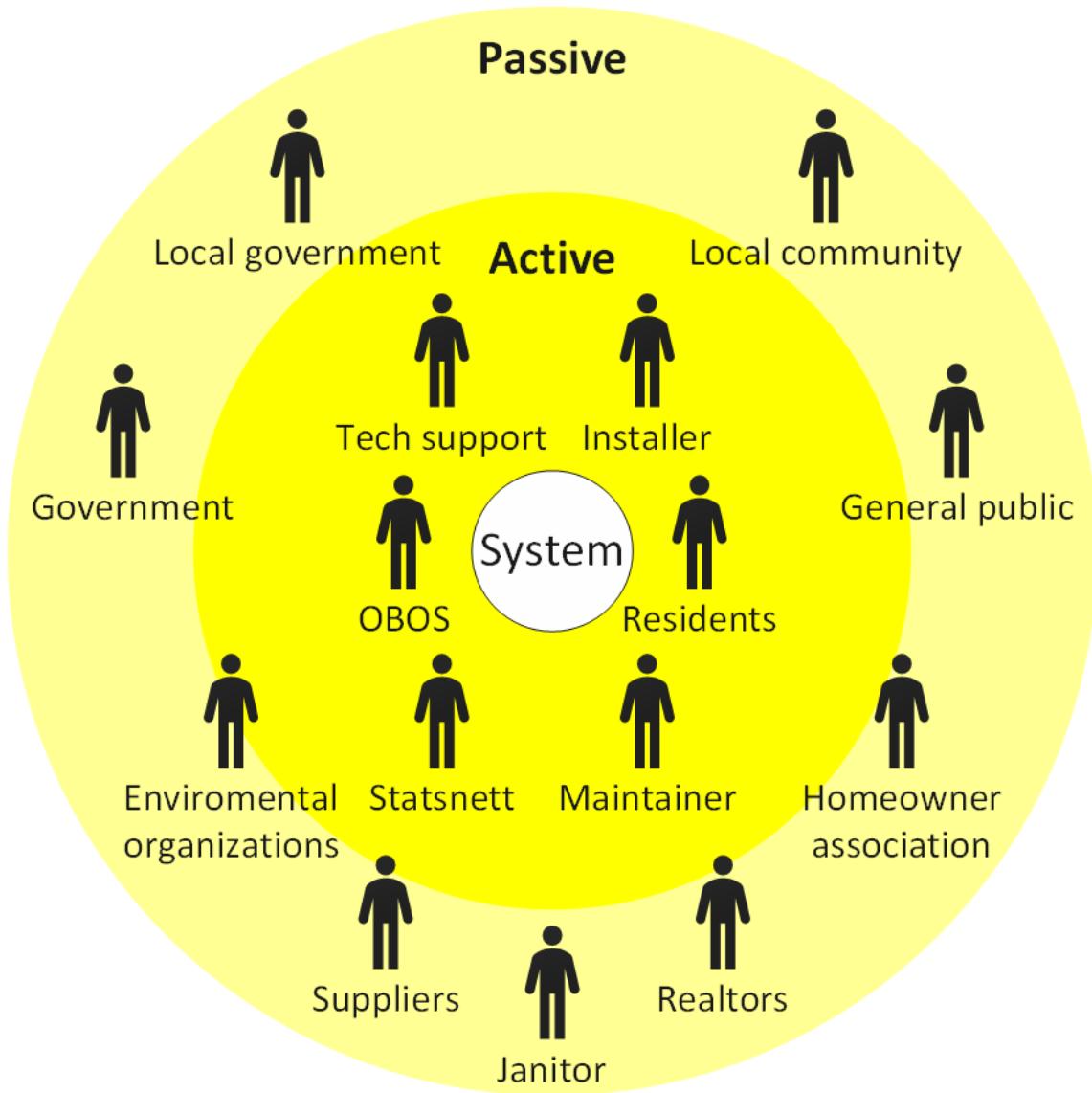


Figure 11: An onion diagram showing the stakeholders

After we determined who our most important stakeholders are and their “proximity” to the system, we started finding their concerns, these are crucial for developing the system, from the concerns of the stakeholders we can develop requirements for our system.

# Requirements

## Customer Requirements

This is the Mecca of requirements. The holy grail. Finding these are crucial to understanding what the system should do and be, on a leveled basis. We started out with a viewpoint from a potential resident in our system/apartment complex in addition to scouring the internet for similar viewpoints to gain insight of the situation. With these viewpoints, we could find certain key words and phrases that were important enough for our group to focus on in our system equation. We were also asked to focus on the viewpoint of another type of stakeholder, which we decided was going to be OBOS. (As mentioned earlier, stakeholders) In our “constructed situation”, OBOS has hired us to take on this task.

### Stakeholder concerns

#### 1. OBOS

- Marketability
- Environmental
- Profit margin
- Installation time
- Reliable
- Regulations

#### 2. Residents

- Affordable
- Enough energy
- Non-intrusive service
- Prestige
- Adjustable temperature
- Environmental
- User friendly app

#### 3. Statsnett

- Energy demand
- Energy supply

#### 4. Installer

- Simplicity
- Safety

## 5. Maintainer

- Easy access
- Good documentation
- Safety

## 6. Tech support

- Good documentation

These concerns will all have to be addressed, and in figure Figure 12 we can see the customer requirements which will serve as the basis for the system requirements. We have not delved deeper into the translation of other stakeholder concerns into system requirements in this project, but this would of course be necessary in a real world design.

### 1. Customer Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall be reliable                        |
| 2  | The system shall be cheap                           |
| 3  | The system shall maintain a comfortable temperature |
| 4  | The system shall be optimized for fast maintenance  |
| 5  | The system shall be safe                            |
| 6  | The system shall be prestigious                     |
| 7  | The system shall follow all regulations             |
| 8  | The system shall be profitable                      |
| 9  | The system shall be easy to use                     |
| 10 | The system shall be able to charge vehicles         |

Figure 12: Customer requirements, taken from our requirement document

## Analysis of Competition

After finding some main guidelines, we chose to research our competitors, both immediate (other groups with the project) and real (established companies), to compare and assess the reality of the situation. The research gave us clear trends, opportunities and problems, that are both outside of our system, in addition to potential problems our system could have.

Some reoccurring trends were the focus of “Green energy”, having a clean conscience and future planning, where future planning is including the distant future’s impact on the product in the calculations. We understood this was a necessary part in the development of our project, so we

used that to make both a schedule for the lifetime of our product in addition to finding some new requirements.

As with trends, there were some opportunities for our group, with companies wanting new blood and fresh eyes to keep up in an ever-changing society.

The problems with the market in which our group are resigning in, is that it is saturated with large multimillion-dollar companies, who are trusted in what seems to be something among the lines of monopoly, with an example being the Ramboll group (engineering, architecture and consultancy company), involved in many Norwegian projects like Vestsiden ungdomsskole in Kongsberg.

In addition to these, we also found some internal policies for an example company connected to engineering as they were using an approach called RAMS. RAMS is a characteristic of a system's long term operation and is achieved by the application of established engineering concepts, methods, tools and techniques throughout the lifecycle of the system.

European railway standard according to INCOSE[15]:

*In railway engineering, as in most forms of transport, safety is a paramount. However, it is influenced by, and interlinked to, availability of the system. Availability is influence by operations and maintenance practices as these determine the reliability and maintainability of the system.*

This is an example of a RAMS the European railway standard uses according to INCOSE. This is not directly connected to our system, but shown as an example. Having this example was crucial when setting the MTTF for our system.

## Effectiveness Measures

The book Engineering Complex Systems[19] define effectiveness measures in this way:

*Effectiveness measures are the small subset of the requirements that are so important that the system will fail if they are not met and will be a huge success if they are met.*

In figure Figure 13 we can see the customer requirements we identified as crucial to the success of our system

### 3. Effectiveness Measures

| Id | Requirement                               |
|----|---|
| 1  | The system shall provide adequate heating |
| 2  | The system shall provide green energy     |
| 3  | The system shall be reliable              |
| 4  | The system shall minimize energy waste    |
| 5  | The system shall be cheap                 |
| 6  | The system shall be easy to use           |

Figure 13: Our effectiveness measures taken from our requirement document

## System Requirements

The problem with the customer requirements (and the effectiveness measures) is that they are not specific and that they may be conflicting. One of the most important things we do as systems engineers, is to translate these requirements into SMART system requirements. This is a task that may be helped by using a key-driver graph.

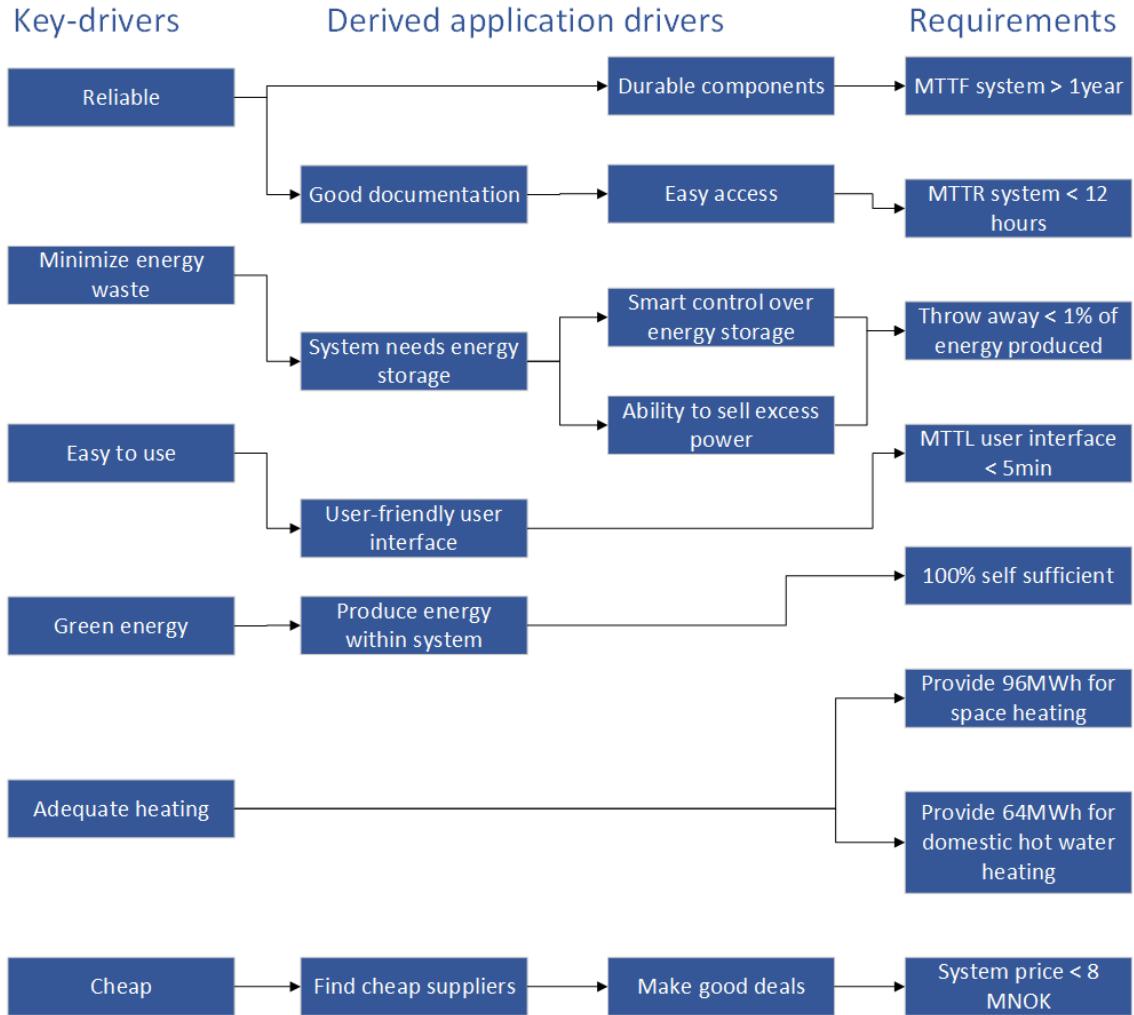


Figure 14: Key-driver-graph for the users of our system

From this diagram we found for example the mean time to failure (MTTF) of our system should be longer than 1 year, which changes the system in a mechanical way, perhaps changing the price range, in addition to ensuring a longer lifetime of said part. It is important to pay attention to the make-or-break requirements in this way as they yield some of the highest gains one could get. Another example is that the MTTL should be less than 5 minutes, this will have consequences when designing the user interface and will have to be tested and verified at some point

There are many ways to divide and categorize system requirements, each with different benefits. We separated ours into these because of the recommendation from the book [19], which we liked:

- **Functional** - Requirements which state what the system must do. For example solar panels convert sunlight to DC electricity
- **Temporal Performance** - Performance requirements that contains a time component. For example MTTR of the system
- **Non-Temporal Performance Requirements** - All the other performance requirements. For example the total cost of the system
- **Interface Requirements** - Requirements which specify a physical interface between systems. For example Cat5e ethernet
- **Design Requirements** - Requirements derived from design choices. We have intentionally avoided the use of these requirements, as they only complicated the process while giving small benefits in return.

We made a word document to contain our requirements, and continually added and updated it as we progressed through the assignment. We chose to categorize them by tiers.

At page 88 we can see our requirement document.

It was really beneficial to have a collection of requirements. It meant everyone could quickly and easily check they were working on a solution which would fit the problem.

Our focus was to find Key performance parameters (KPP), as they were referred to as. In reality, these parameters are a mix of the other types of requirements molded and mixed together.

At page 89 we can see the requirements for our system at the highest level of abstraction.

## Energy Consumption

The energy consumption of the apartments and the whole building complex will decide what kind of system is viable.

Finding numbers is important when it comes to trade-off analysis, but as students we are not always equipped to simulate all our estimates. We did not want to spend too much time learning different software to simulate a buildings energy consumption. We wanted to focus on the subject at hand, which is system engineering.

For our estimates we decided to use the Norwegian building standard Tek17 as a guideline. It contains energy consumption regulatory limits for new buildings. It has maximum numbers per  $m^2$  for ventilation and total energy consumption[18][10].

For heating we used another Norwegian standard which has maximum numbers for heating per  $m^2$ [11].

For lights and appliances, we used numbers from an average home gathered by a popular power supplier in Norway, Hafslund strøm. The average light in Norway is not LED however. So, we divided the light consumption by 10[17].

Electrical vehicle charging consumption is estimated from how far an average personal vehicle in Norway drives per year, which is 12000km[9]. How much energy an electric vehicle use per 10km driven, is between 1 and 2.5kWh[16]. We decided to estimate on the safe side and use 2kWh per 10km driven.

For elevators we used a popular calculator online and used the most energy efficient solution[6].

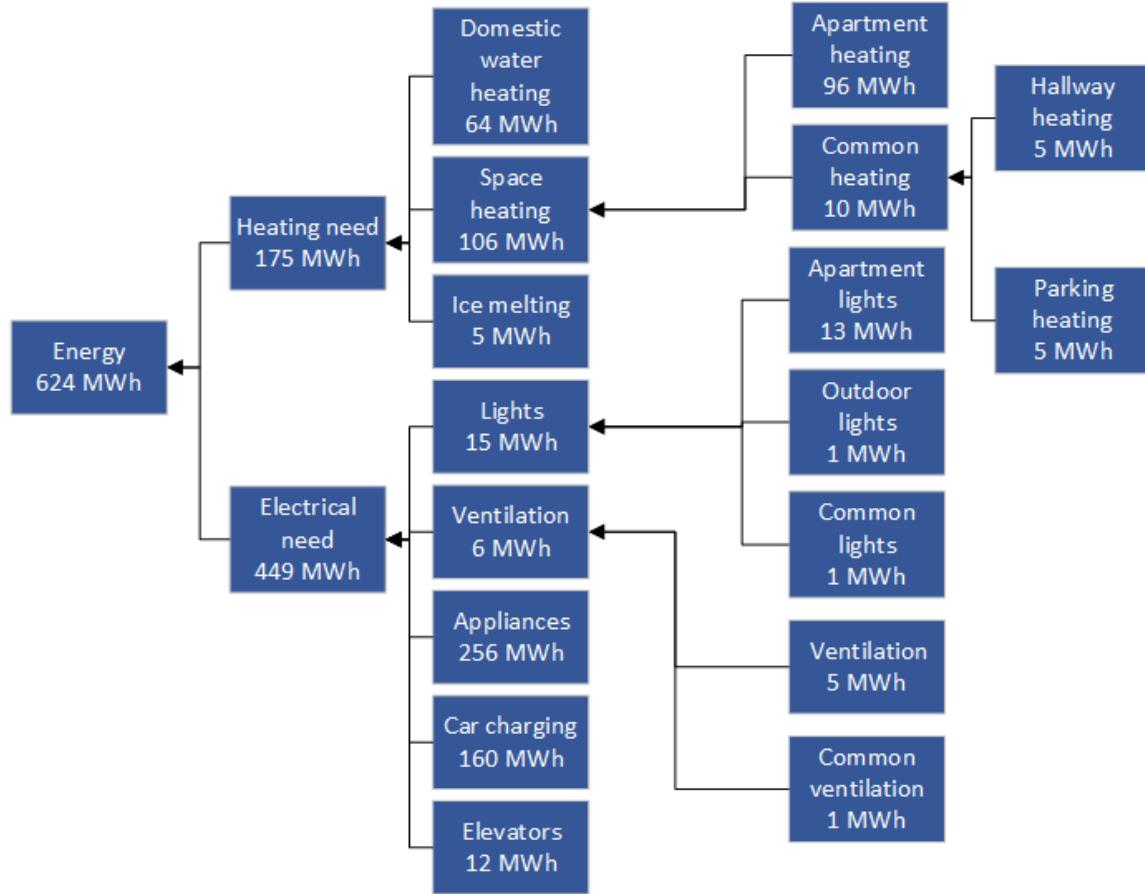


Figure 15: A technical budget displaying the energy needs of the building

## System Architecting

We will now look at the architecture of the system. This is a process which takes place on many levels or tiers. At tier 0, we will look at the system in the highest level of abstraction. This means that one views the system in its context and avoid considering details within the system.

Later, in tier 1, we will look at the subsystems, how they relate to each other and the dynamics between them.

Finally, in tier 2 we look at the subsystems and components within the subsystems which we have considered critical, and therefore focused especially on.

Tier 0

Operation

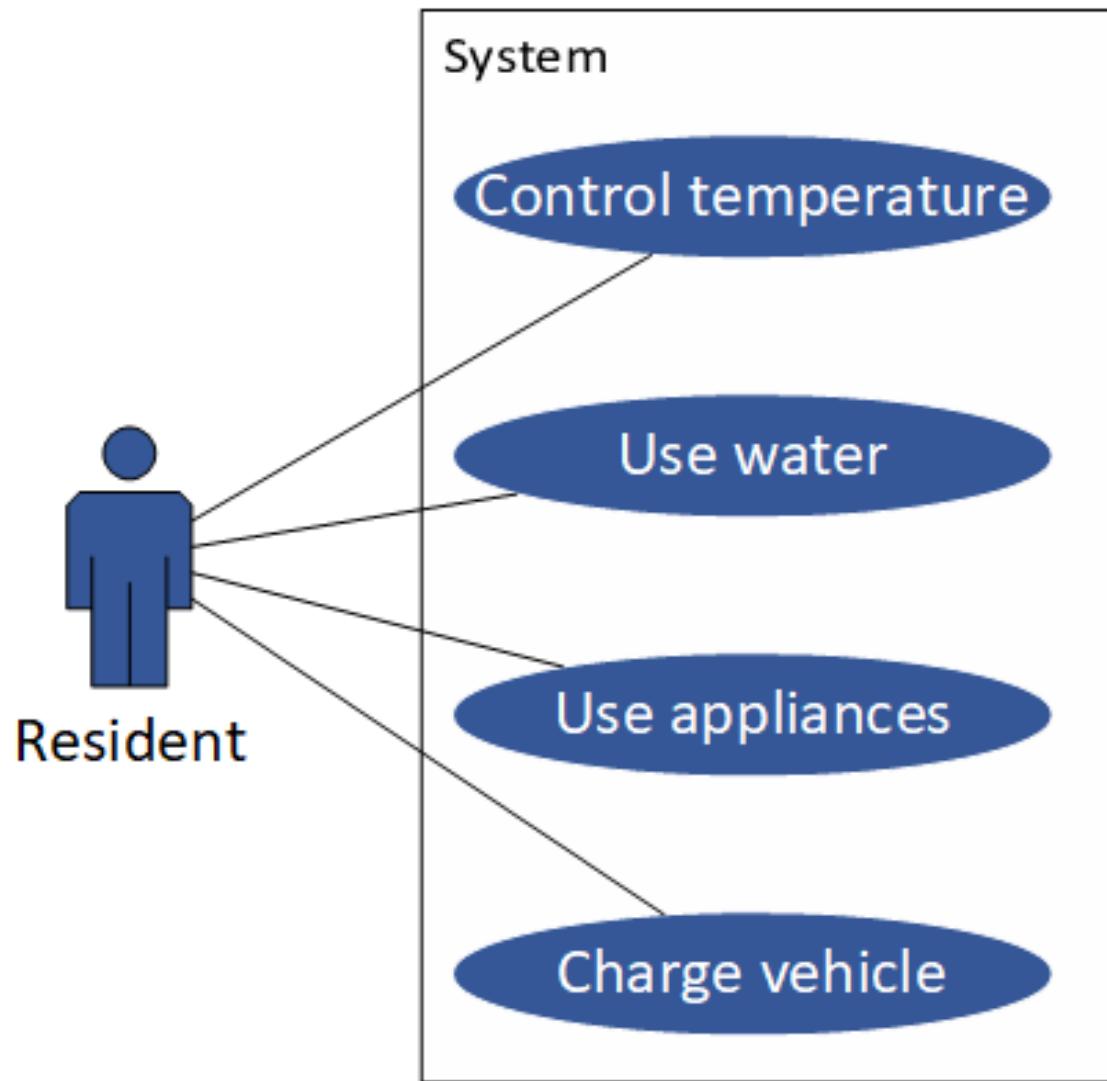


Figure 16: Use case diagram for the system

Here we can see at the top level what the base use cases of our system will be for its users. They will derive the systems inputs and outputs, as well as the functions we need in our system. Doing it this way, helps us make sure that the system fills the needs of our user, as well as avoiding adding

functionality that doesn't fill a purpose.

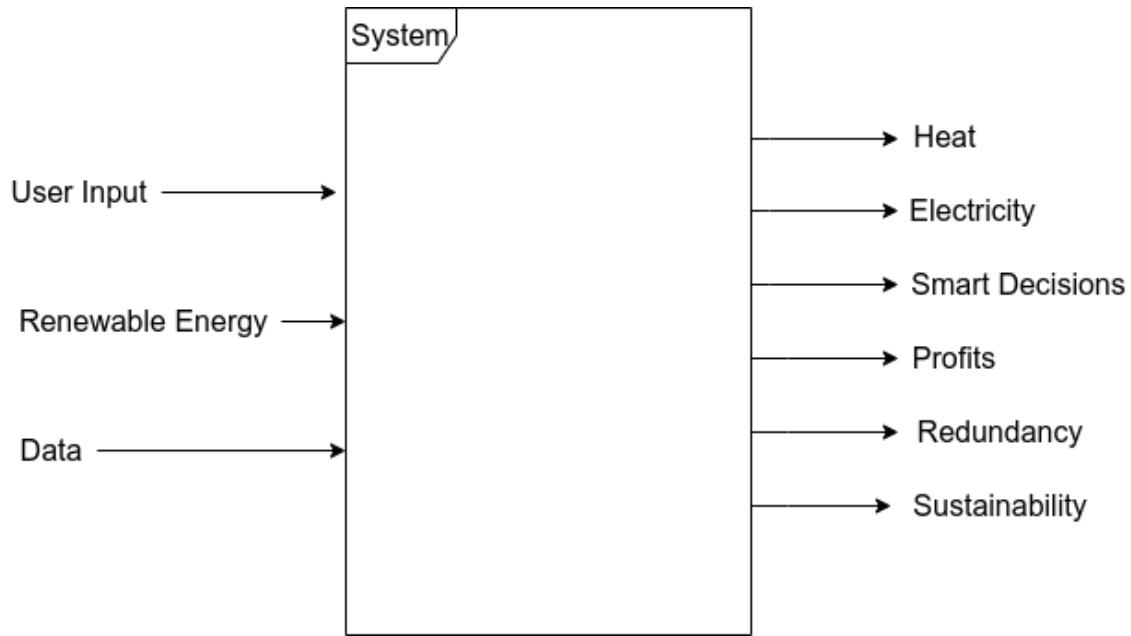


Figure 17: Black box of our system

In figure Figure 17 we see the system as a black box. We found that the system will receive/gather renewable energy, needs from the user as well data from various sources. Then we identified the wanted outputs. These were all derived from our investigations into the customer, the users, as well as the context of the system. This helped us explore what functions our system will need to have.

## Behavior

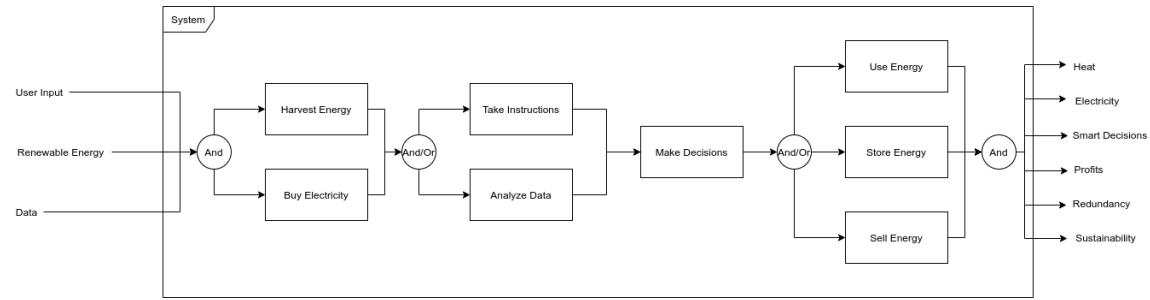


Figure 18: FFBD within our system

In order to provide heat and electricity in a sustainable way, we will need to harvest energy, but we will also need the option to buy power from the grid. To make the system smart, it will need to make decisions based on both data and the wishes of the user. Finally, it will need to allocate the energy in an optimal way in any given moment, that may involve using it, storing it, or even selling it.

## Structure

This structure of the system describes how it will be built. At this point we start with dividing it up into subsystems:

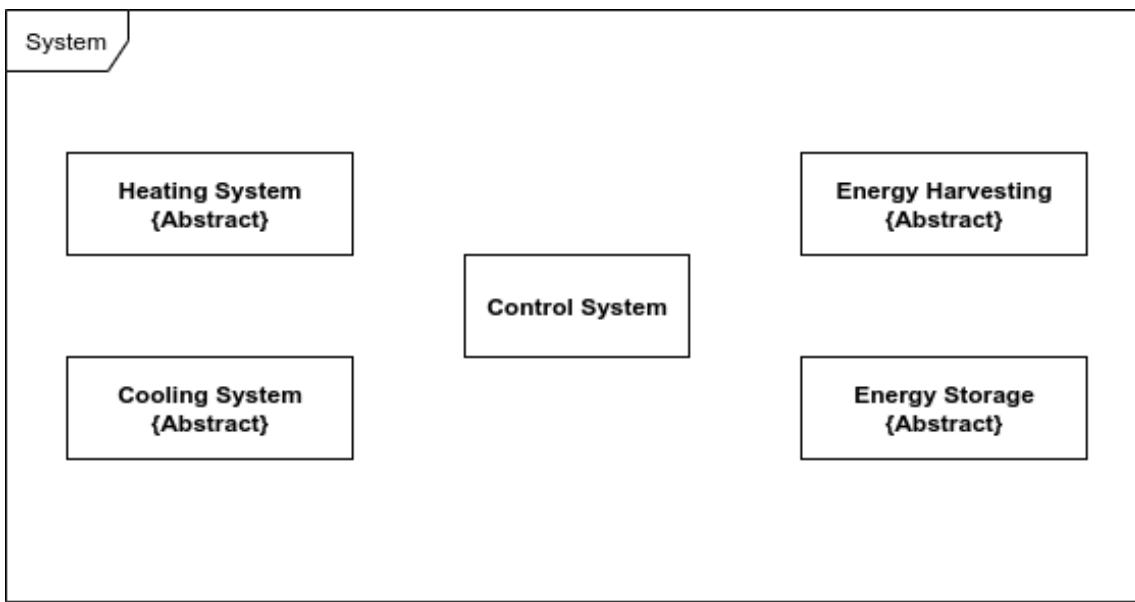


Figure 19: The system modeled as a UML class diagram, where all the classes are still abstract

There are many technologies available for us in order to make our system attain the wanted functions and behavior. The different combinations of them gives us thousands of possible concepts. These are the options we initially considered, where we have looked closer into some of them:

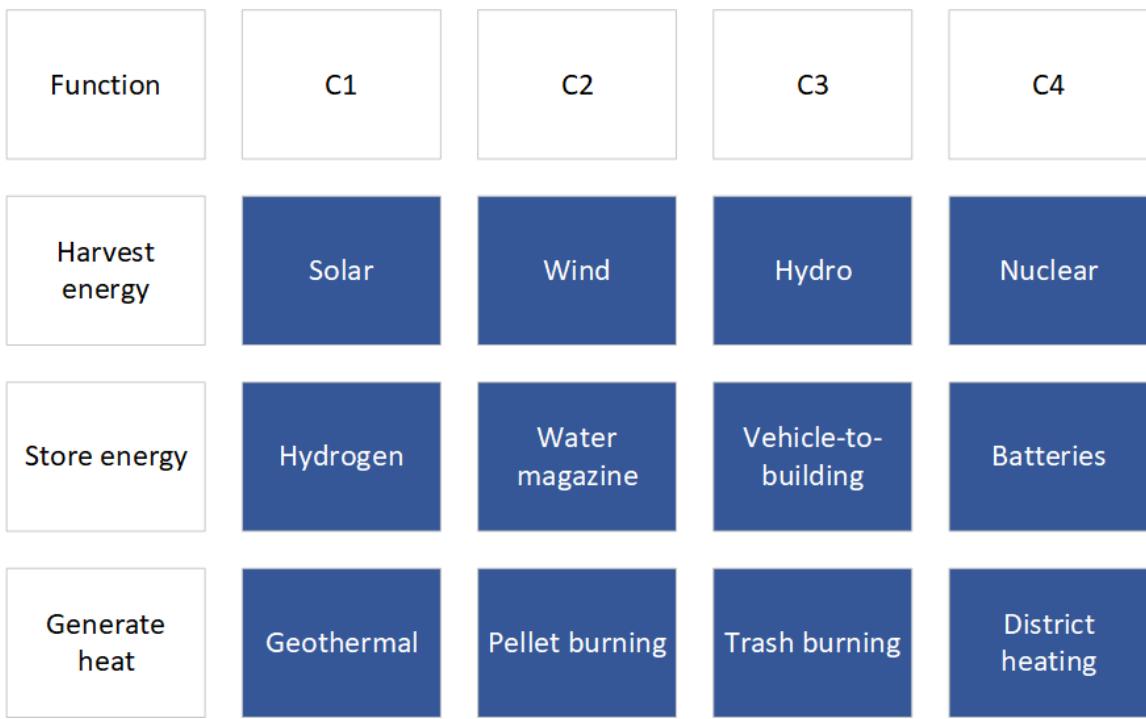


Figure 20: Morphological diagram, showing possible concepts

## Harvesting Energy

### Solar

Solar-power is growing at a tremendous rate. It is easy to implement and is getting cheaper by the day. Given the context of our system, one may think that the Nordic climate wouldn't be favorable to this technology. However, even though we have less sun here, the cold makes the panels more economically efficient in Norway, than in for example a place like Milano[8].

### Hydro

The earliest recorded use of hydro for harvesting energy is from the times of the Roman Empire and is very widespread today, especially in Norway. It is a very mature technology, can produce massive amounts of energy and the potential worldwide still is not near begin filled. However, in Norway the government owns the right to harvest energy from almost all viable locations, which makes it hard to implement for a private residence. The locations of our customer group also makes it difficult as the availability of waterfalls and rivers is even less in urban areas.

## **Wind**

Harvesting wind-energy is another very old approach to relieving humans of manual labor and has in modern times become a means to generate large amounts of electricity. A single windmill with a diameter of 120 meters, can generate up to 4.5 MW on average[4]. Because of this they have become very widespread the last 20 years, even in Norway. However, because of their size, the noise they generate and the dangers they present to the fauna, windmills have become the source of huge political controversy lately.

Our main customer group are in urban environments, and this means that windmills will be difficult to implement in an effective way. There does exist so-called urban windmills to be placed on rooftops, but the electricity they generate is most often not worth the cost[3].

## **Nuclear**

Nuclear energy has a bad name, even though it produces completely clean energy. The trouble with nuclear waste storage, as well as public fear of accidents makes this option a practical impossibility. It is extremely expensive to realize, not renewable, and requires a much larger scale, than we can facilitate.

## **Storing Energy**

### **Batteries**

For storing the electrical energy our system will generate, the most obvious option is lithium-ion-batteries. They are popular because of their high charge density, as well as their effectiveness. They are simple to implement but have a high cost.

Another problem with them is that they are made from non-renewable elements, and the world is running out of cheap and accessible lithium. The process of manufacturing them is also not considered to be environment friendly.

### **Vehicle-to-Building (V2B)**

Vehicle-to-building is a concept where you connect a two-way charger to an electrical car. It lets us use the car-batteries to both store and fetch electricity when needed. This can reduce the needed capacity of other energy storage and may help reduce the costs of the system. In order to make use of it of course, you will need electric cars, but this does fit our customer-group very well.

## **Hydrogen**

Hydrogen can be used as an energy carrier for many different applications, often releasing the energy stored in the hydrogen gas in a fuel cell. Hydrogen can also be burned in an engine, but the industry has largely departed from that technology, since fuel cells convert energy much more efficiently.

The benefits of hydrogen as an energy carrier are that hydrogen per mass has an energy density

that is three times as high as traditional fuels such as gasoline and diesel and that it does not result in emissions other than water vapor when hydrogen and oxygen are converted into electricity in a fuel cell. The challenge is that hydrogen is a very voluminous gas and is therefore more demanding to handle and distribute than traditional fuel. There is an opportunity to solve this challenge by producing the hydrogen gas in the same place it is consumed.

### **Water Magazine**

This approach basically consists of pumping water to a magazine at a higher altitude. When you want to ‘withdraw’ the energy, you release it and funnel it through a hydro power generator. For obvious reasons this will not be a viable approach for us, because of our scale and location.

### **Generating Heat**

#### **Burning Trash**

Burning trash may initially sound like a bad idea, but it is a quite widespread way of generating heat and electricity. Most notable in Viken is perhaps the plant in Fjell, Drammen. Fjell is a suburb of Drammen and consists of a large number of apartment complexes. Their heat facility provides all of them with heating exclusively from burning trash. The waste of this process is pure ash, and this is sold to businesses who use it to produce concrete and asphalt. The method is generally seen as environmental-friendly, as it mostly releases steam into the air. However, it does release several other elements into the environment like NO<sub>x</sub>, SO<sub>2</sub>, CO and mercury, though in small amounts. This may make it unsuitable for our purposes.

Another problem with this approach is that, in order to be economically viable, you will need quite a large-scale facility. In other words, it does not fit the problem we are trying to solve.

#### **Geothermal**

Geothermal energy is often separated into two categories. The first one is the concept of drilling down to the boundaries between tectonic plates and extracting the extremely high temperatures found there. If this is ever accomplished in practice, some prophesize that it will generate enough energy for the entire earth, several times over.

The concept we are looking into is ground source heating. It involves drilling holes in the ground, and putting tubes filled with brine in them. They can be anywhere from six meters, to several hundred meters deep, dependent on the area. You also need a heat pump, which will pump cold brine down, and extract the heat located in the ground. The brine that reappears in the other end, will have a constant temperature, year-round. The heat pump will then use the gain in temperature to heat water in a much more efficient way than it would otherwise be able to. The process can also be done in reverse, and in that way provide cooling in the summer. State-of-the-art heat pumps can even provide heat with an effectiveness factor of 5. This means that for every kWh of electricity you put in, you may get 5kWh of heat out. This has been a popular concept for existing apartment buildings lately, because Norwegian law banned all forms of oil and paraffin heating in all buildings from 01.01.20.

## **Burning Pellets**

This option is basically the same as burning trash, but instead of trash we burn pellets made of bio-matter that is compressed. In contrast to burning trash, this option is much more viable on a small scale, and there are companies specializing in delivering pellets to apartment complexes today. However, we found that in urban environments they release particles into the air, which makes for a worse environment for people in its surroundings. This will probably not meet the profile of our system, nor will it make it easier to market.

## **District Heating**

Probably the most widespread way of heating apartment complexes in Norway today, is district heating. It provides cheap, reliable heating from external, most often local plants. They vary in their environmental factor, but most often they are considered to be environmentally friendly.

## **Trade-Off**

In this section we will have a look at the options and analyze which ones may be best suitable for our system.

## **Harvesting Energy**

We looked at a few different ways of harvesting energy for our building complex. Considering that one of our effectiveness measures is to provide green energy, we could narrow our options down to Solar, Thermal-Generator, Nuclear, Wind and Hydro. When it came to finding out which one of these options would be most suitable for our system we had to look back at our measures of effectiveness and requirements. We picked out a handful of these that were most relevant to energy harvesting and set up this PUGH matrix:

| Criteria          | Solar     | Nuclear   | Wind      | Hydro     | Thermal-Generator |
|-------------------|-----------|-----------|-----------|-----------|-------------------|
| Sustainability    | 5         | 3         | 5         | 3         | 2                 |
| Cost              | 5         | 1         | 4         | 3         | 2                 |
| Difficulty        | 5         | 1         | 5         | 3         | 3                 |
| System complexity | 5         | 1         | 5         | 3         | 3                 |
| Lifetime          | 3         | 5         | 3         | 3         | 3                 |
| Improvability     | 1         | 2         | 1         | 2         | 2                 |
| Support           | 4         | 1         | 2         | 4         | 3                 |
| Outsourcing       | 4         | 2         | 4         | 4         | 3                 |
| Controversy       | 5         | 1         | 3         | 5         | 3                 |
| Availability      | 5         | 1         | 5         | 1         | 3                 |
| Safety            | 5         | 5         | 2         | 5         | 2                 |
| Efficiency        | 3         | 5         | 3         | 3         | 4                 |
| <b>SUM</b>        | <b>50</b> | <b>28</b> | <b>42</b> | <b>39</b> | <b>33</b>         |

Figure 21: Pugh matrix for harvesting energy

By using this PUGH matrix, we were able to evaluate our options and we concluded that solar panels would be best suited for our system. It would not only be best suited for this specific system with the current location of medium density Oslo, but it's also the option that would be easiest to implement at any other location. Comparing it to the nuclear option, it's clear that solar is way more doable in terms of cost and difficulty. If we compare it to wind and hydro, solar panels do not depend as much on the location and outside factors as the other options. By choosing solar panels we make it easier for us to distribute our system virtually anywhere.

For a large building complex with multiple floors the current generation solar panels do not provide enough energy to provide 100% of the building consumption. However, with four floors it is close enough. In Norway renewable energy from the grid is very easy to guarantee. We will simply change our goal from 100% to 60% self-sustainable. We will get the other 40% from a power supplier with a guarantee that comes from a renewable source.

### Storing Energy

Since our system is harvesting energy we need some way of storing it. There are several forms of having grid energy storage. Among them are batteries, compressed air, hydrogen and electric vehicles. Some of the important factors we had when choosing a storage method was: sustainability, we want to leave as little of a footprint as possible, the cost of it, we want it to be affordable for our customers, how safe it is and how efficient it is, we want to minimize the energy waste. From researching different methods of grid energy storage we picked three options we thought would fit our system most and compared them using this PUGH matrix:

| Criteria          | V2B       | Hydrogen  | Only batteries |
|-------------------|-----------|-----------|----------------|
| Sustainability    | 2         | 5         | 3              |
| Cost              | 4         | 1         | 3              |
| Difficulty        | 2         | 1         | 5              |
| System complexity | 2         | 3         | 4              |
| Lifetime          | 2         | 4         | 2              |
| Tenant capacity   | 2         | 3         | 3              |
| Location          | 3         | 5         | 5              |
| Independency      | 3         | 2         | 4              |
| Improvability     | 4         | 5         | 3              |
| Support           | 1         | 2         | 5              |
| Outsourcing       | 5         | 1         | 1              |
| Parking           | 5         | 1         | 1              |
| Park              | 4         | 5         | 5              |
| Availability      | 4         | 3         | 5              |
| Strength          | 5         | 3         | 4              |
| Safety            | 5         | 2         | 5              |
| Uniqueness        | 5         | 4         | 1              |
| Solar cell area   | 5         | 2         | 2              |
| Energy need       | 2         | 3         | 3              |
| Efficiency        | 5         | 2         | 5              |
| <b>SUM</b>        | <b>70</b> | <b>57</b> | <b>69</b>      |

Figure 22: Pugh matrix for storing energy

As one can see from the PUGH Matrix, Vehicle-to-building (V2B) won with a slight edge over batteries. We decided to go for V2B, but because this option has some irregularities in that we cannot guarantee that the amount of cars we need for storage is available at any time we opted for a solution that incorporates lithium batteries as a backup.

## Generating Heat

If we want our system to meet our effectiveness measure of minimizing energy waste, we will need a way of generating heat without the use of electricity. We looked into using Geothermal heat pumps, Waste-to-energy and pellet burning. Then we used our requirements to set up a PUGH matrix with the relevant factors we needed to evaluate the options.

| Criteria                | Waste-to-energy | Geothermal heat pump | Pellet burning | Electricity |
|-------------------------|-----------------|----------------------|----------------|-------------|
| Heat generation / price | 4               | 5                    | 3              | 1           |
| Size                    | 2               | 3                    | 4              | 5           |
| CO2 emissions           | 2               | 4                    | 3              | 5           |
| Electricity/heat ratio  | 4               | 5                    | 4              | 1           |
| Renewable               | 3               | 5                    | 3              | 4           |
| Cooling synergy         | 1               | 5                    | 1              | 1           |
| Safety                  | 1               | 4                    | 1              | 4           |
| Lifetime                | 3               | 3                    | 3              | 5           |
| <b>SUM</b>              | <b>20</b>       | <b>34</b>            | <b>22</b>      | <b>26</b>   |

Figure 23: Pugh matrix for generating heat

When comparing our options, we found the geothermal heat pump to be the most optimal solution. It is the only solution among our chosen options that has any synergy with our planned cooling feature, which is an important aspect to the system as a whole. There is also the safety concern in which Waste-to-energy and Pellet burning does not come well out of, since both options poses a fire hazard for our system. Space is a major concern for our system, and we do not want to spend unnecessary money on increasing our heat generation facilities. Pellet burning proved to be the subsystem that required the least amount of space, but the geothermal heat pumps other redeeming qualities weighed up for the larger size.

## Recommendations

After analyzing our options for the power harvesting, power storing and heat generating subsystems, we decided on a solution that we would consider to be the most viable for our system.

The solution would consist of solar panels for our power harvesting. A combination of Vehicle-to-Building(V2B) and lithium batteries for our power storage. Geothermal heat pump for our heat

generation.

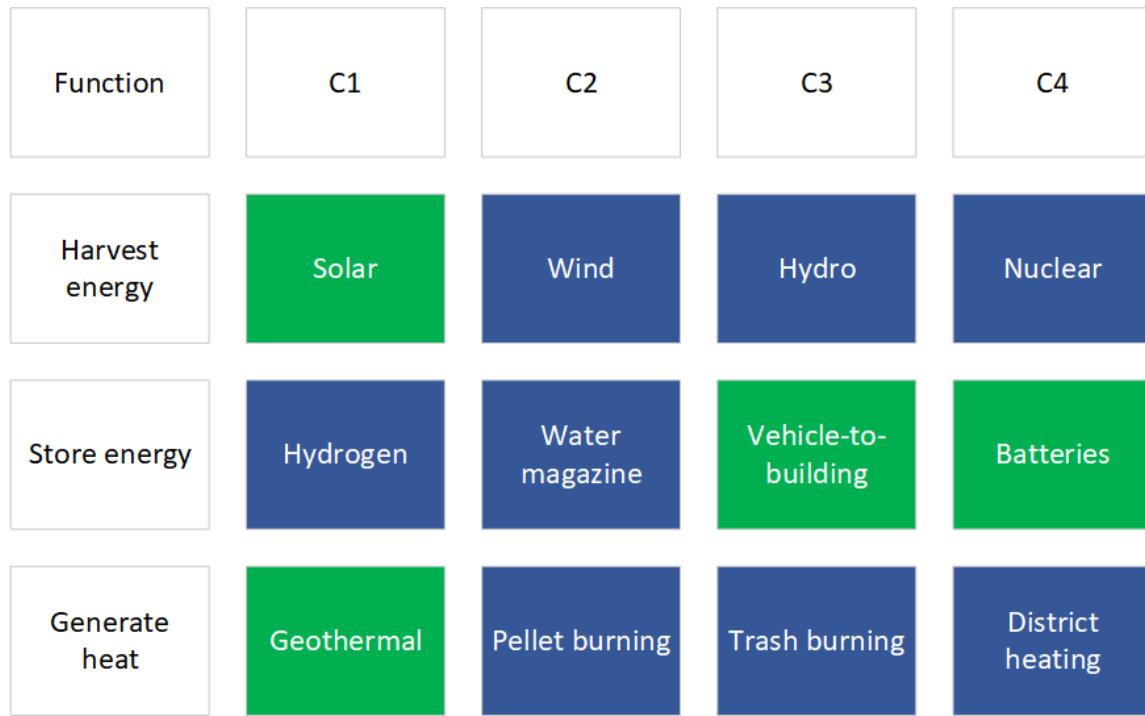


Figure 24: Morphological diagram, showing the recommended concept

### Derived Requirements

There were uncovered several new requirements after making these trade-offs and recommendations, here we will have a look at a few of them.

In order to find the best buy and sell windows for power we got this data from NordPool [1]. To maximize profits for our customers, we need to buy/sell as much as possible at the optimal hours.

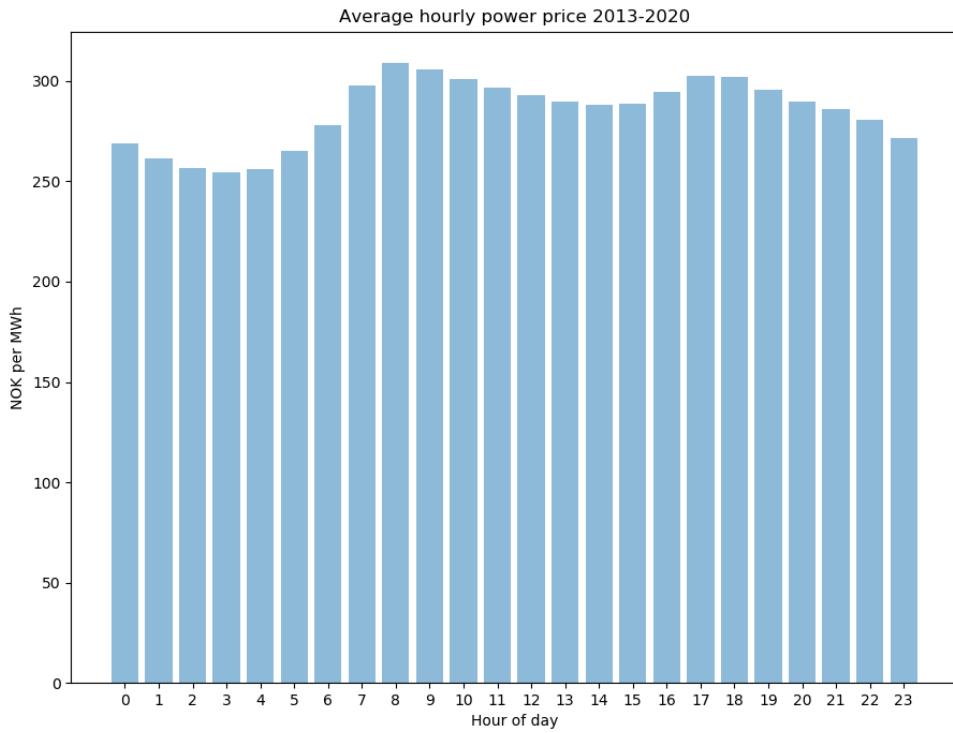


Figure 25: Average hourly power prices 2013-2020 (Source code on page 104)

This research resulted in these requirements:

- Requirement 5.1.3.2
- Requirement 5.1.3.3

At page 90 we can see the rest of the requirements for tier 1, which we derived from our work in this tier. These new requirements will help us design the subsystems.

## Tier 1

At this tier we are focusing our look inwards try to look at the dynamics and structure between the subsystems in our system.

### Operation

These are the use cases found at the system level:

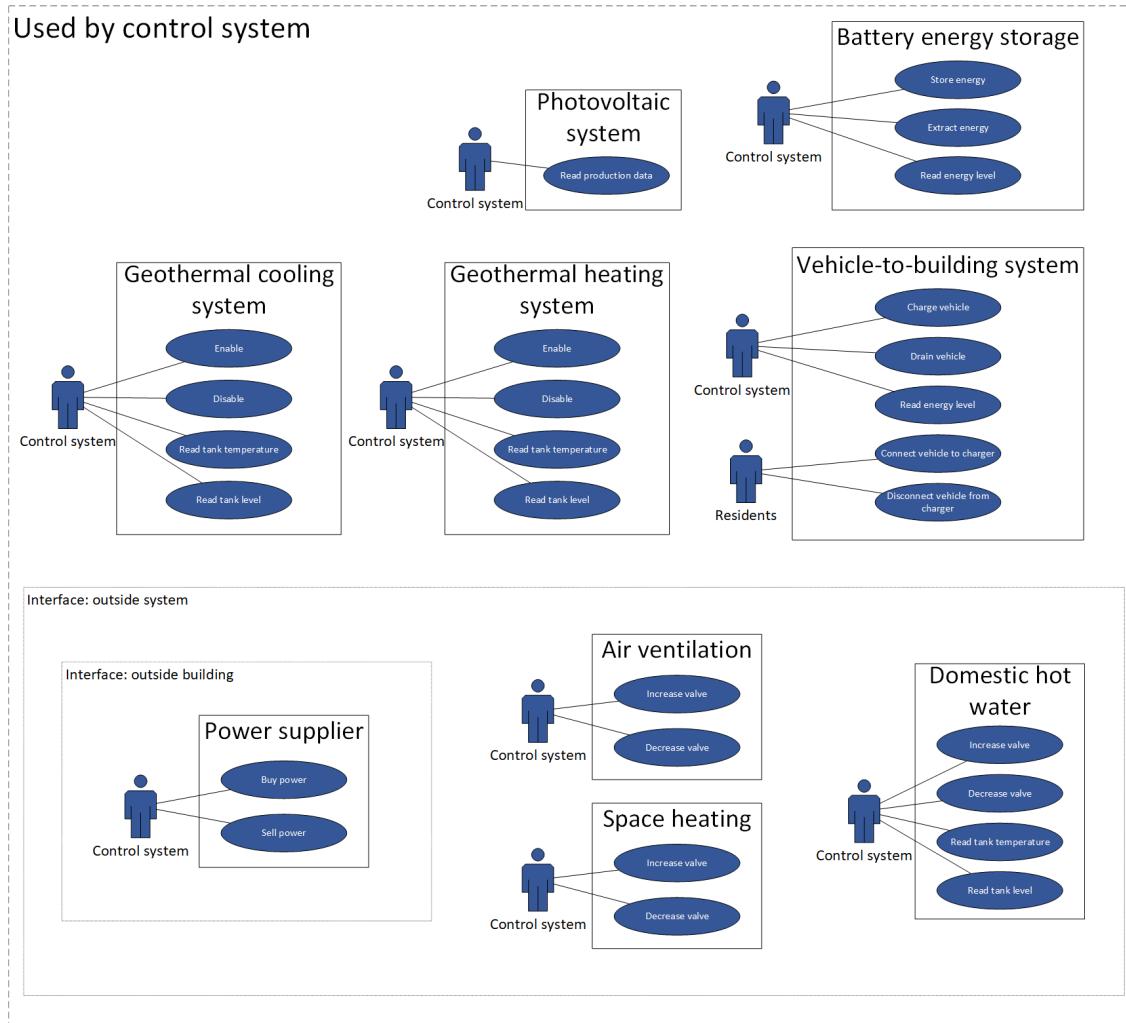


Figure 26: Use case diagram, between subsystems

These use cases were crucial to define the wanted behavior of the subsystems, and how they should relate to each other.

The design choices made at tier 0 will at this point function as requirements. This is a natural phenomenon in the unfolding of a system. Analyzing the behavior of the system is most easily done by looking at the abstract functions of its subsystems.

## Control System

A control system is essential in order to fulfill the requirements of the system. This is something we will have to develop ourselves, and is what will make our system smart, as well as giving us an edge on our competitors.

The black box exercise left us with these inputs and outputs:

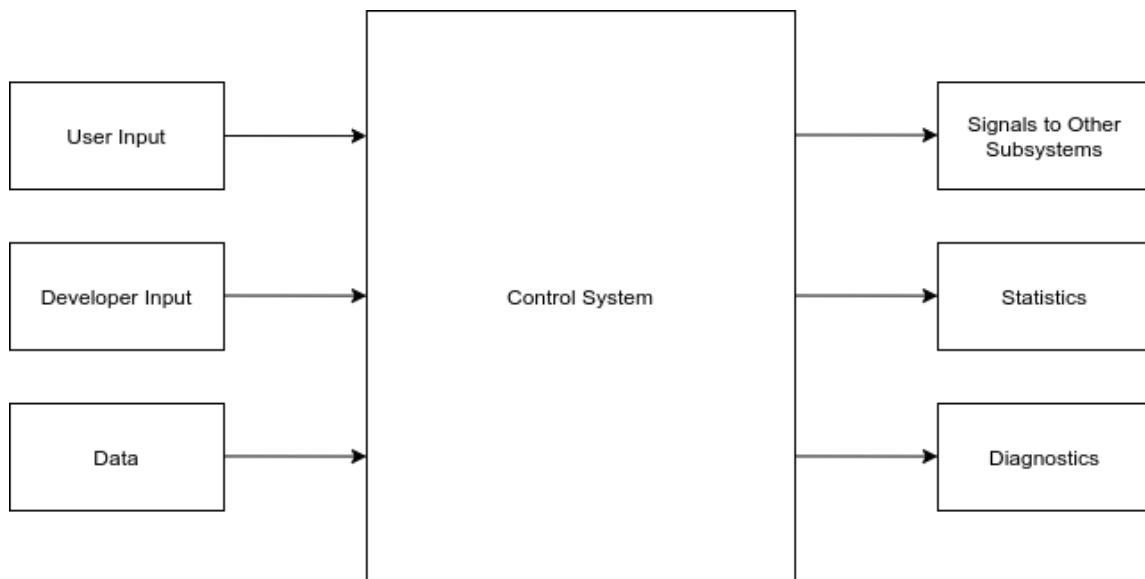


Figure 27: Black box of Control System

As the control system is the main focus of our engineering efforts, this will be further elaborated in the next tier.

### Photovoltaic System

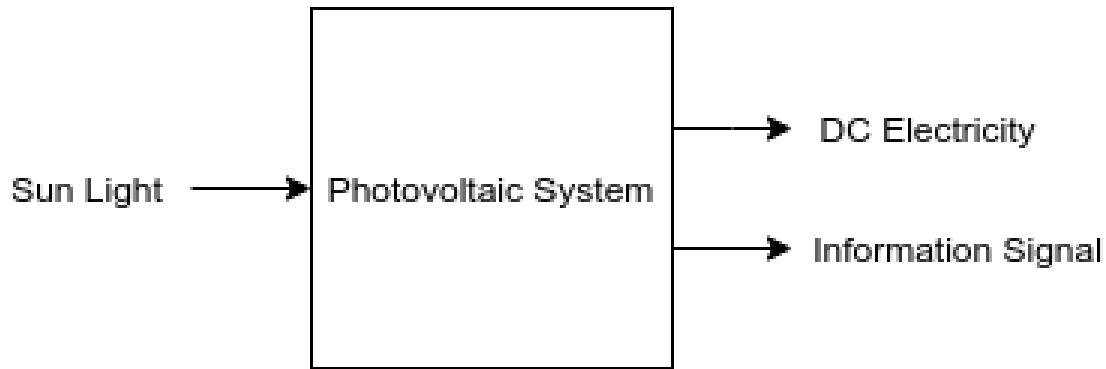


Figure 28: Black box of Photovoltaic System

This is the whole functionality we need from the photovoltaic system and will be bought as a complete package from our supplier. The only thing that needs designing is the software to read the signals, which we will get back to later.

### Energy Storage System

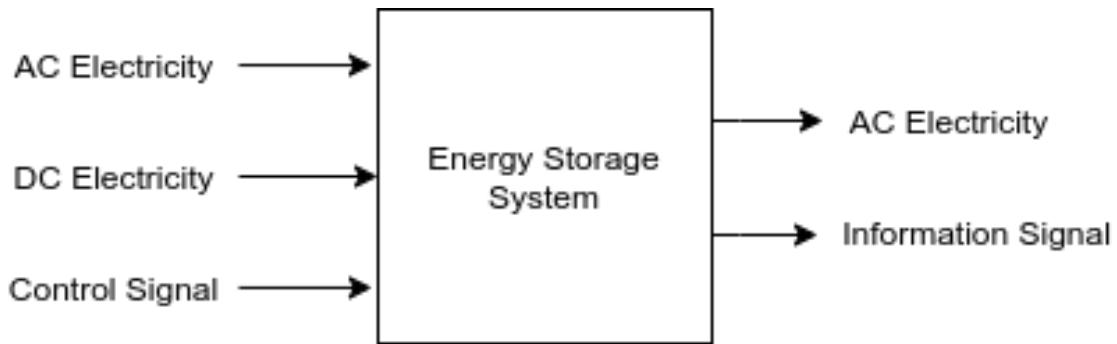


Figure 29: Black box of Energy Storage System

As our concept takes several storage approaches in use, this will be elaborated in the next tier as the allocation of the energy harvested will be crucial for success.

## Geothermal Heating/Cooling

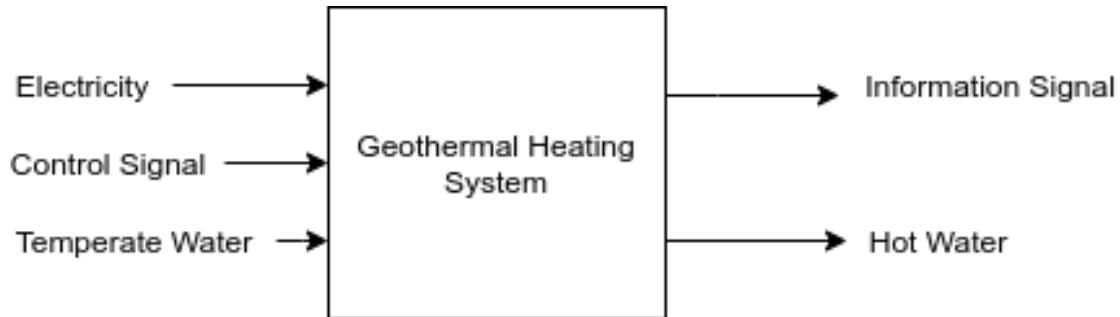


Figure 30: Black box of Geothermal Heating System

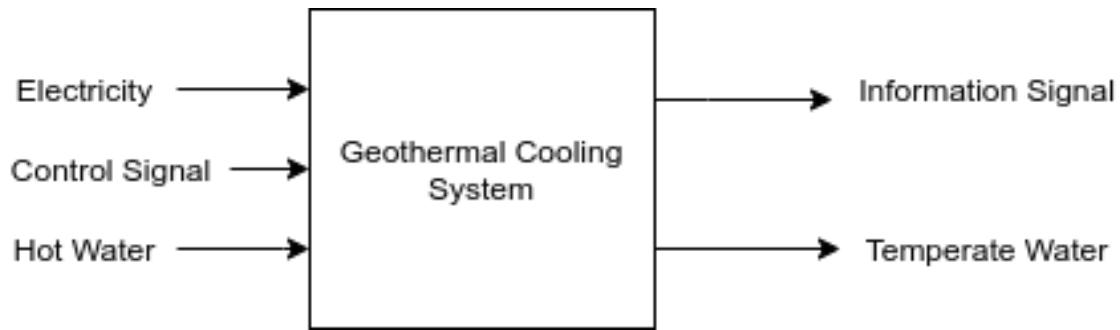


Figure 31: Black box of Geothermal Cooling System

The geothermal heating and cooling systems will receive a signal which tells the heat pumps to either turn on or off. The signal will come from the control system and will be based on different sensor readings throughout the buildings.

## Behavior

In figure Figure 32 we can see the functions within the subsystems, that are necessary to achieve the inputs and outputs we need from them. We see how they will relate to each other, and how the outputs of a subsystem, may be the input of another.

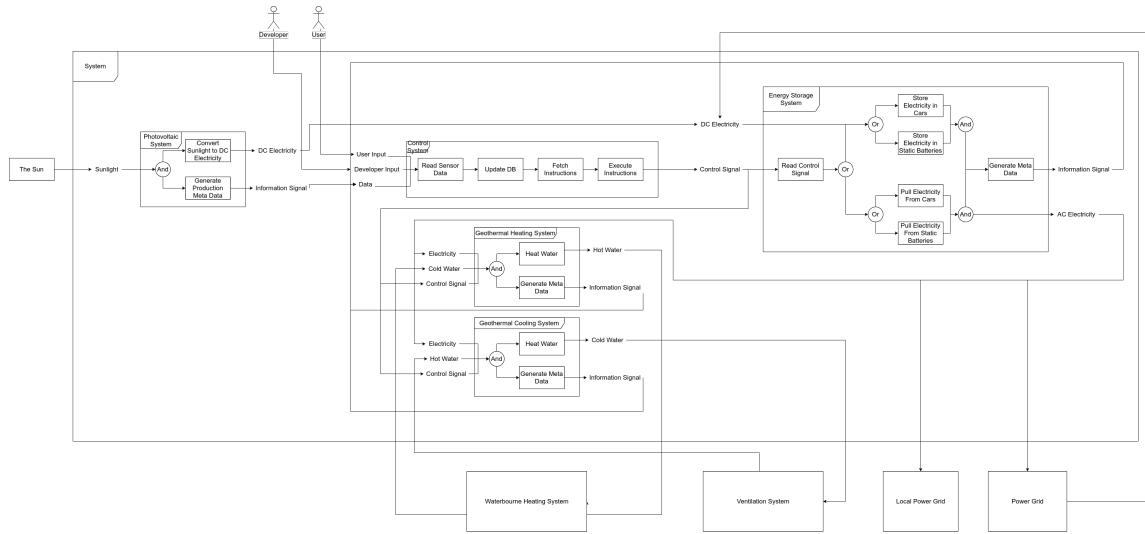


Figure 32: FFBD of the respective subsystems

## Structure

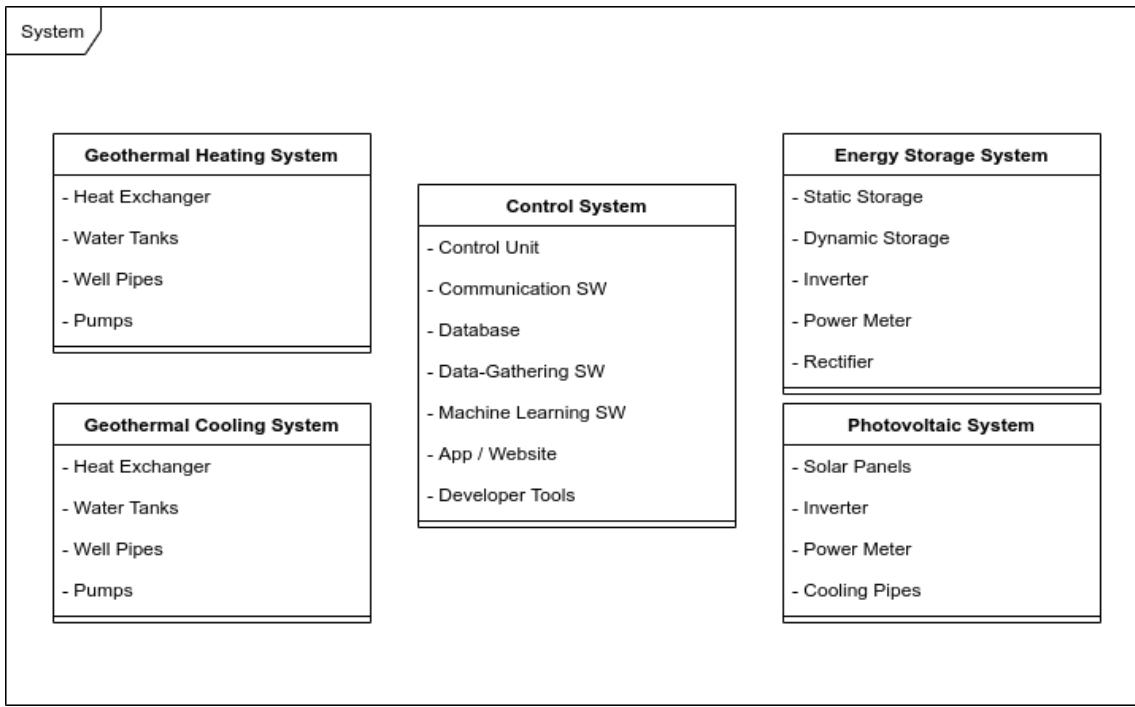


Figure 33: Class diagram showing the subsystems

In figure Figure 33 we can see the structure of our system at this level of detail.

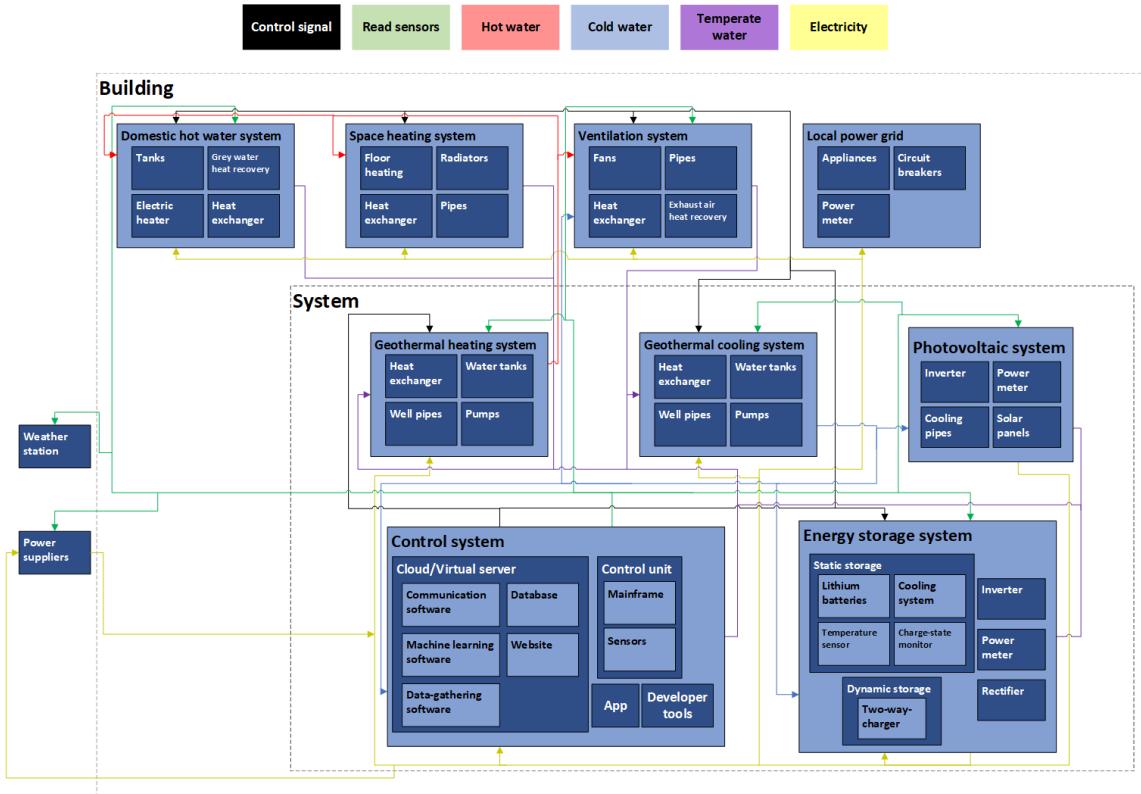


Figure 34: A more detailed structural model of our system and its context

In figure Figure 34 we have taken the subsystems from figure Figure 33 and put them in context with the building. We have added multiple interfaces and differentiated between types of interfaces. This helped us tremendously when writing requirements and gives a good view of the system partitioning.

## Trade-Off

### Control System

Our system needs to store large amounts of data and do a lot of computing. It will need continuous updates and adjustments to the machine learning algorithm. Buying a server with the capacity to store 20 years of data from day 1 is not a good economic option. We need to add vertical and horizontal scaling as the data amount and computing power need increases.

Each building complex will need a control unit in the physical building to communicate with the actual subsystems and even take some decisions in the case of internet loss.

But the main computing, data storage, and data gathering software does not need to be in the physical building complex. So we made this PUGH matrix to compare the two options.

| Criteria                | Common cloud server | Individual building server |
|-------------------------|---------------------|----------------------------|
| Response                | 2                   | 5                          |
| Computing power / price | 3                   | 4                          |
| Modularity              | 5                   | 3                          |
| Simplicity              | 4                   | 3                          |
| Updating software       | 5                   | 2                          |
| Hardware maintenance    | 5                   | 1                          |
| Storage / price         | 5                   | 3                          |
| Physical access         | 1                   | 5                          |
| Safety                  | 4                   | 5                          |
| <b>SUM</b>              | <b>34</b>           | <b>31</b>                  |

Figure 35: Pugh matrix for Control System

The main disadvantage with a server in each building is the need to update an increasing number of servers with the latest version of our software, as well as having to travel between the locations to add hardware for performance increases. However, it would have 99% of full functionality when the building complex loses contact with the internet and the response time would be very low and not dependent on other companies/systems.

### Recommendations

A common cloud server will be the best option for our system. It will save money and a better response time and full functionality without internet is not worth the complexity it adds.

### Derived Requirements

At page 93 we can see the tier 2 requirements which we derived from this tier. We will use these to help us design the next tier.

## Tier 2

### Energy Storage System

The energy storage system is not the main focus of this project, however, we have decided to include a greater level of detail of it, in order to more easily dive into the specifics of the control system.

### Behavior

Here we can see how we envision the allocation of electricity in our system. Even though most of the logic seen here actually lies with the control system, we find found it suitable to display the energy storage system with some of its context included. This is to help the reader understand which parameters the functions depend upon.

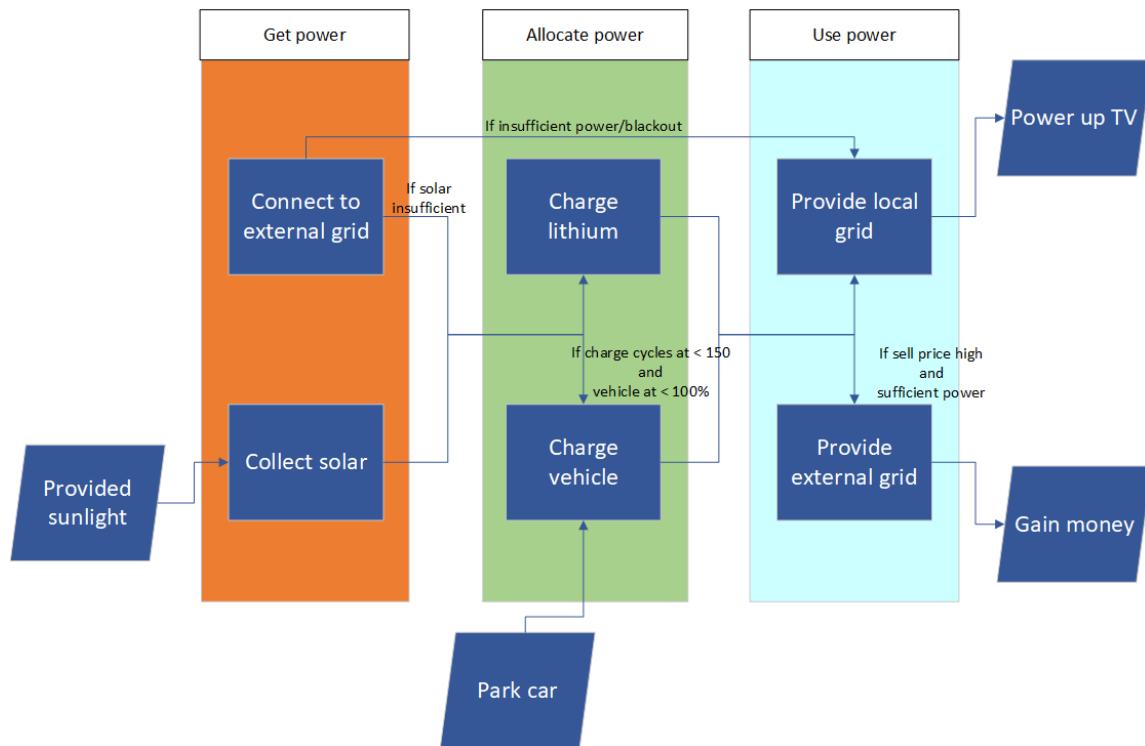


Figure 36: Behavior of the Energy Storage System

The main thing to draw from this model is that the energy storage system will receive electricity and store it in either the static batteries placed in the building, or in the vehicles owned by the

residents. It will also have to quickly allocate energy to power outlets, sell to grid or move electricity between the two storages.

### Structure

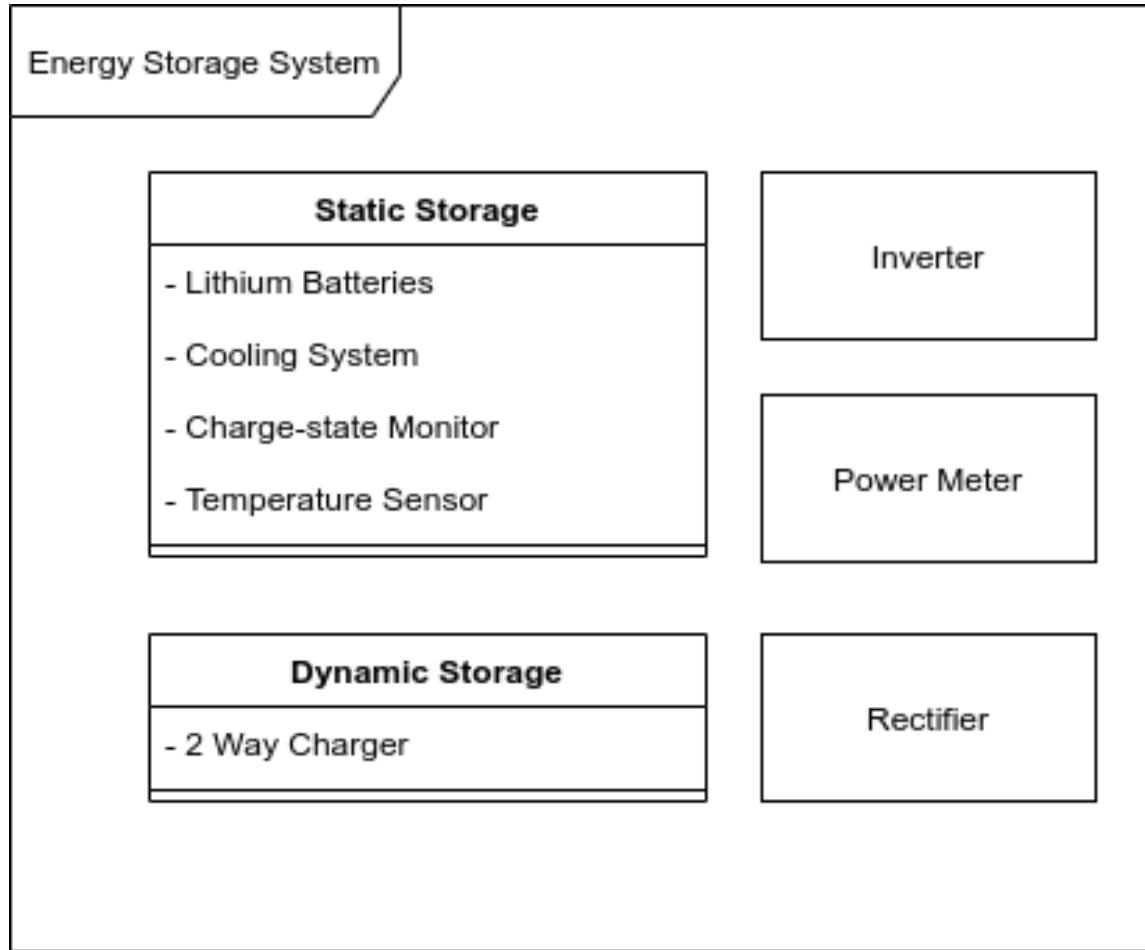


Figure 37: Class diagram of the Energy Storage System

The structure of the system is quite simple. We chose this partitioning because both static and dynamic storage needs access to the power meter, the inverter and the rectifier.

## Control System

### Operation

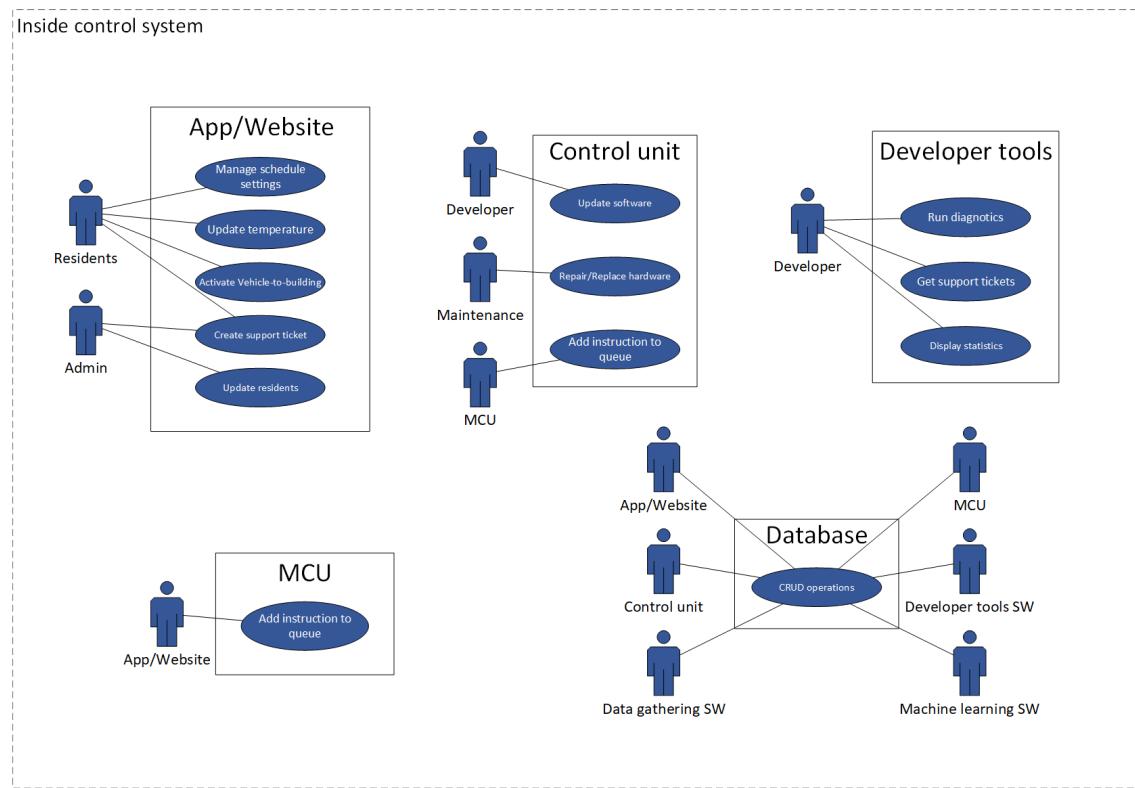


Figure 38: Use case diagram within the control system

These are the use cases we identified within the control system. They are very abstract, but they helped us do the functional analysis for all the subsystems in the control system. We will get back to the structure of the components later, for now we will look at their behavior.

### Behavior

#### Control Unit

The control unit is the component which will be installed in the building and will communicate with all the physical subsystems of our system as well as some systems that are not part of it.

In figure Figure 39 we can see the functions it will need to execute:

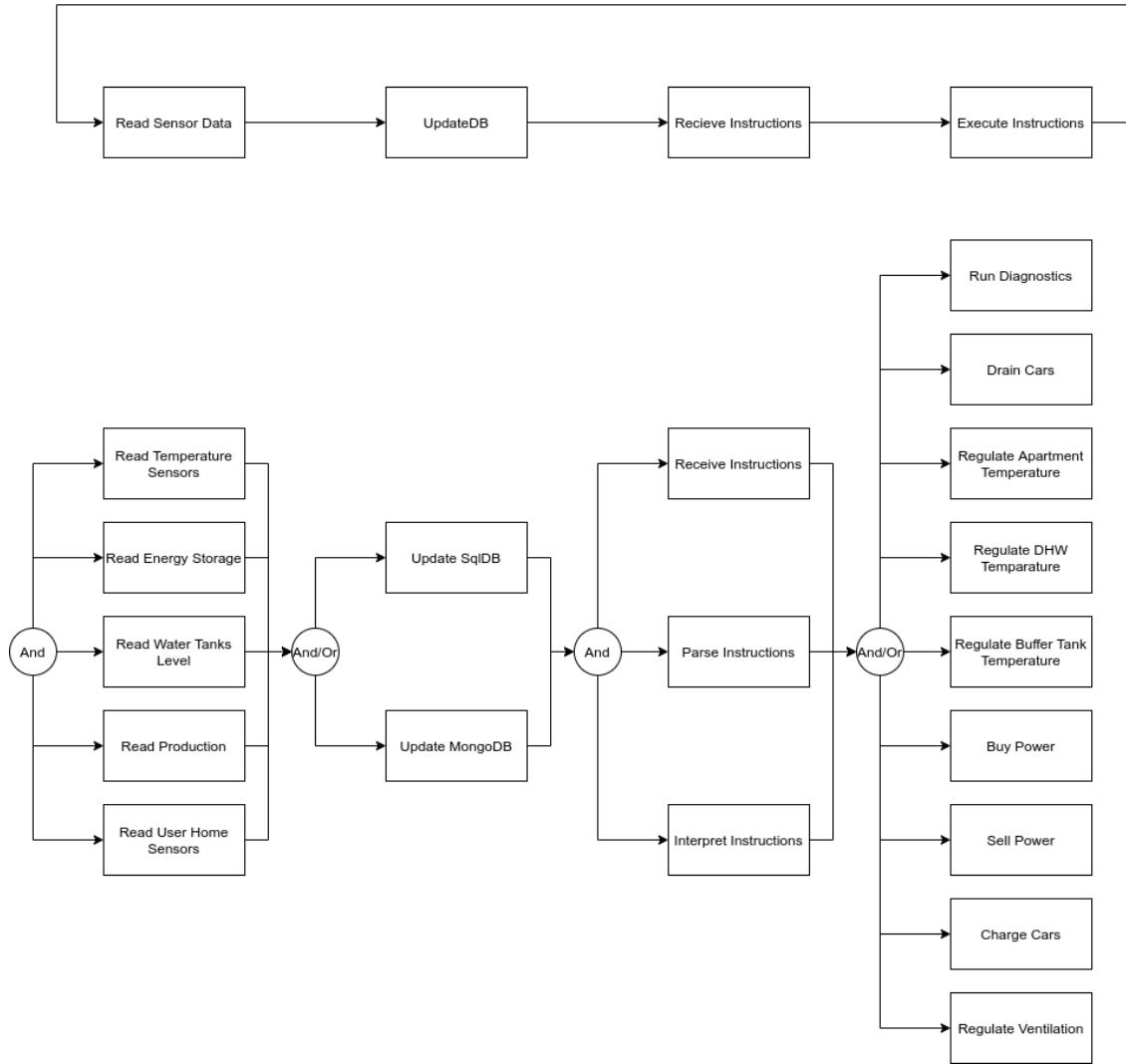


Figure 39: FFBD for the Control Unit

In the top of the figure we can see its main functions, and the respective functions are elaborated in the bottom. It will directly communicate with the sensors located in the buildings. This includes temperature sensors, the sensors in the physical components as well as sensing whether the residents are at home. All this data will have to be stored, so it will have to write it to the suitable database. Next, it will have to receive instructions from the MCU, and execute them. These instructions will determine the behavior of all parts of our system, as well as several others.

## MCU (Main Communication Unit)

As mentioned in the last section, the MCU will send instructions to the control unit, and we can see the functions it will need in order to accomplish this in figure Figure 40:

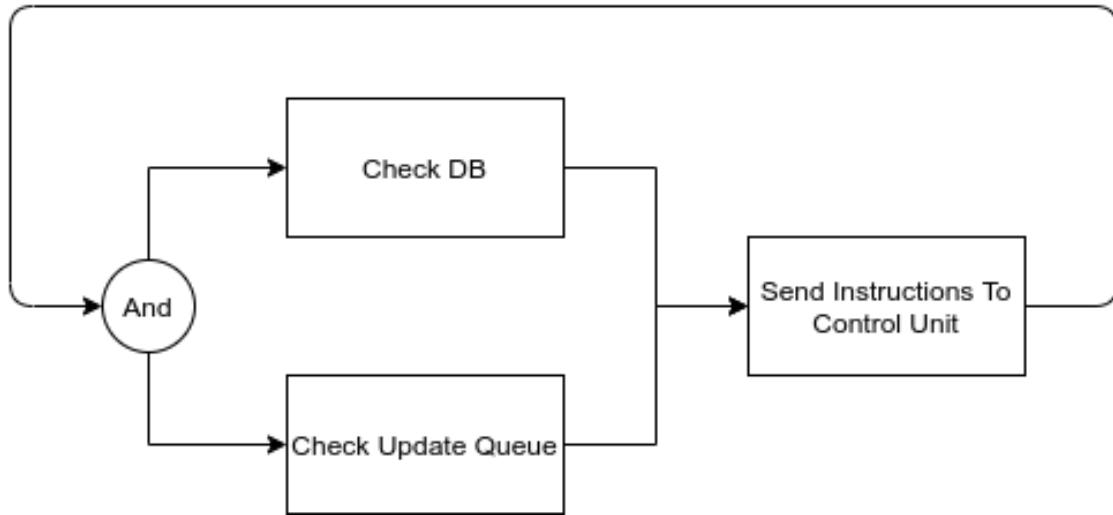


Figure 40: FFBD for the MCU

The MCU will gather instructions from the database and the update-queue. In the database we will store the scheduled and long-term instructions for the system. However, this is not very suitable for real-time changes in wanted behavior. These instructions will have to be gathered from the update-queue. This data-structure is mainly meant for unpredictable events, such as user inputs etc.

## Databases

The basic functions we need in the databases are obvious. CRUD is common expression in database management, and it refers to the essential operations:

- Create
- Read
- Update
- Delete

However, the types of data we will need are quite different, so we need databases with different capabilities.

### *MySQL*

Often called the most successful software ever designed and is based on the Structured Query Language (SQL). MySQL stores its data in rows and columns and is optimal for relational databases. These are suitable for storing data that will have to be changed, as they are quite flexible. They are also easy to implement and offers strong data integrity. We will use SQL for storing user data, instructions, errors and many other things.

### *MongoDB*

The great majority of our data, however, will be stored in a MongoDB cluster. In order to make our system smart and able to make decisions, we will need tremendous amounts of data. MongoDB, whose name refers to humongous DB, is designed for this. The main difference in MongoDB, is that data is not stored in predetermined rows and columns in a table, but rather handled as collections of documents. The documents are JSON files which consist of key-value pairs. This means that we can store any attribute we will in every record of the table, but not every document needs the same attributes. Because of this, queries in MongoDB are much quicker than conventional SQL databases.

## **Data-Gathering Software**

Now that we know how we will store the data; we will get into how we will obtain the data. As mentioned previously we will have probably hundreds of sensors in the buildings. However, we also need some external data. These data can be divided into two kinds:

### *Historical Data*

We will need hourly historical solar, weather and power price data. Solar and weather are quite easy, as there exists free API's that provides us with accurate and extensive records. Power prices are a bit harder to acquire in the detail necessary. Nord Pool, the power exchange owned by the Nordic and Baltic countries do provide this, and for a yearly fee they allow access to rich amounts of data, so that cost will have to be factored in. This software will run only once per implementation and will therefore not be elaborated further on in this part.

### *Continuous Data*

In addition to this we also need to continuously gather data. This includes getting weather forecasts and power prices. In figure Figure 41 we can see how we have defined the behavior of the data-gathering software for storing continuous data:

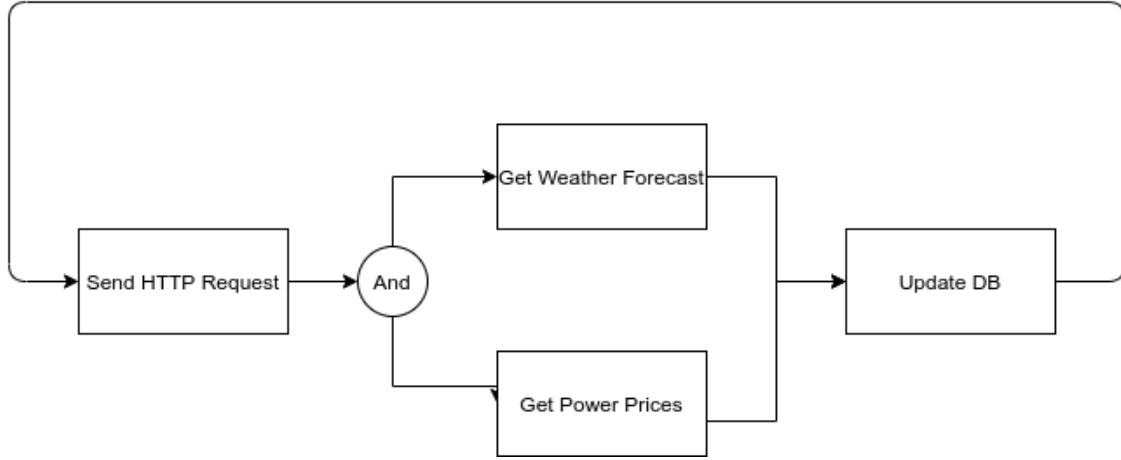


Figure 41: FFBD for the continuous data gathering software

This is a quite simple model, much like the software it depicts.

### Machine Learning Software

The software for machine learning is essential in order to make our system smart and attractive and will be focused greatly on.

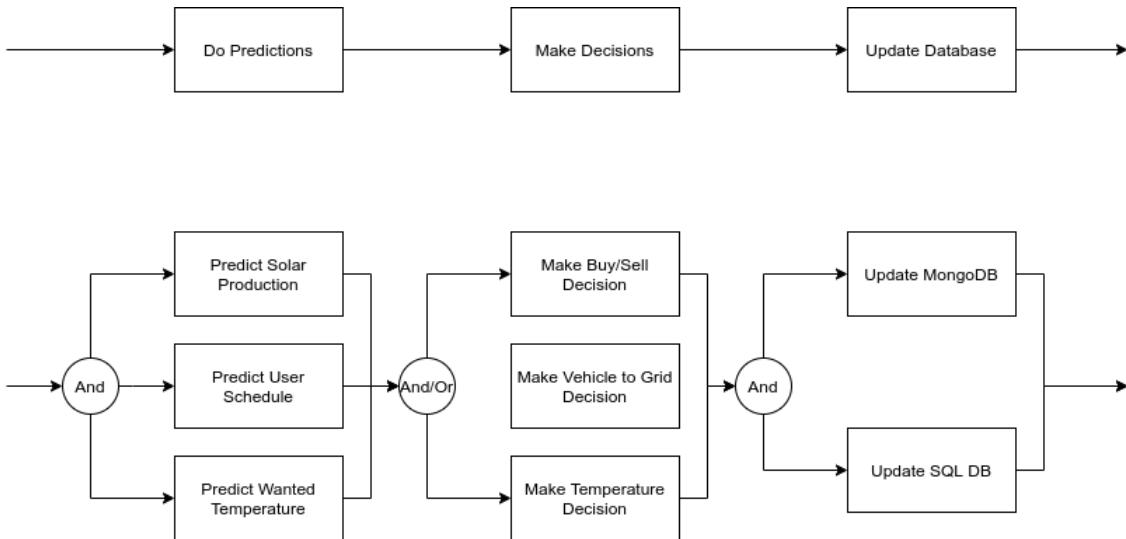


Figure 42: FFBD for the machine learning software

In the top model we see the abstract functions it will need to execute, and as we did with the Control Unit, we have also here found it necessary to unfold them. First, we will try and make predictions concerning the context of the system, how much power production we can expect and the needs and behavior of the user. In the next phase the software will have to make concrete decisions as to how the system should behave and operate. Lastly, we store these decisions as data and instructions in the databases.

## Application / Website

Even though the system will be smart, there is no such thing as perfect. That is why we will need an opportunity to override the systems decisions. This is circular of course, because in order to be smart, the system will require large amounts of data about the users and their preferences. The smart device application and website will also be a platform for communicating information and statistics to the user.

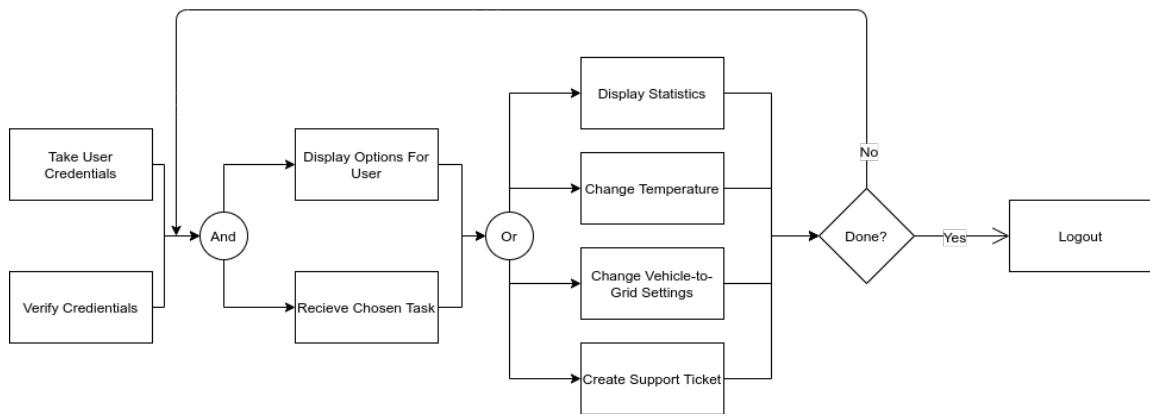
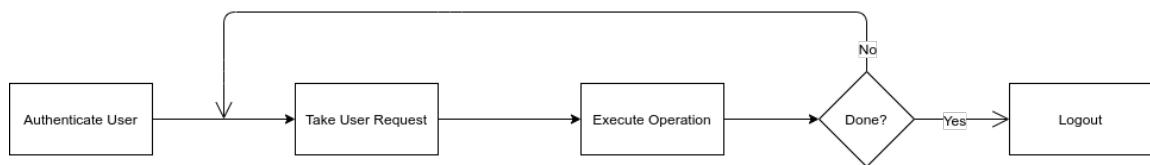


Figure 43: FFBD for the application/website

These are the main functions the application should offer the user. It should let them change the wanted temperature in their apartments, display statistics, configure the V2B system, as well as requesting support online.

## Developer Tools

The Control System will need continuous monitoring, upgrading and maintenance. In order to do this effectively we have seen the need for a software which encapsulates tools for all of this.

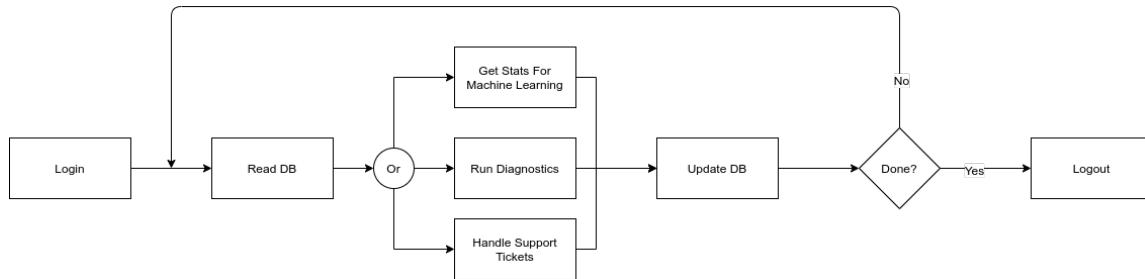


Figure 44: FFBD for the developer tools

Here we see among other things that the support tickets generated by the users, will be handled here. Now we have come full circle and will have a look at these subsystems will relate to each other.

## Structure

After analyzing the functions of the subsystems within the control system, we were ready to look at the structure. In figure Figure 45 we can see what components will make up the respective subsystems, where they will be located, and how they will be connected with each other.

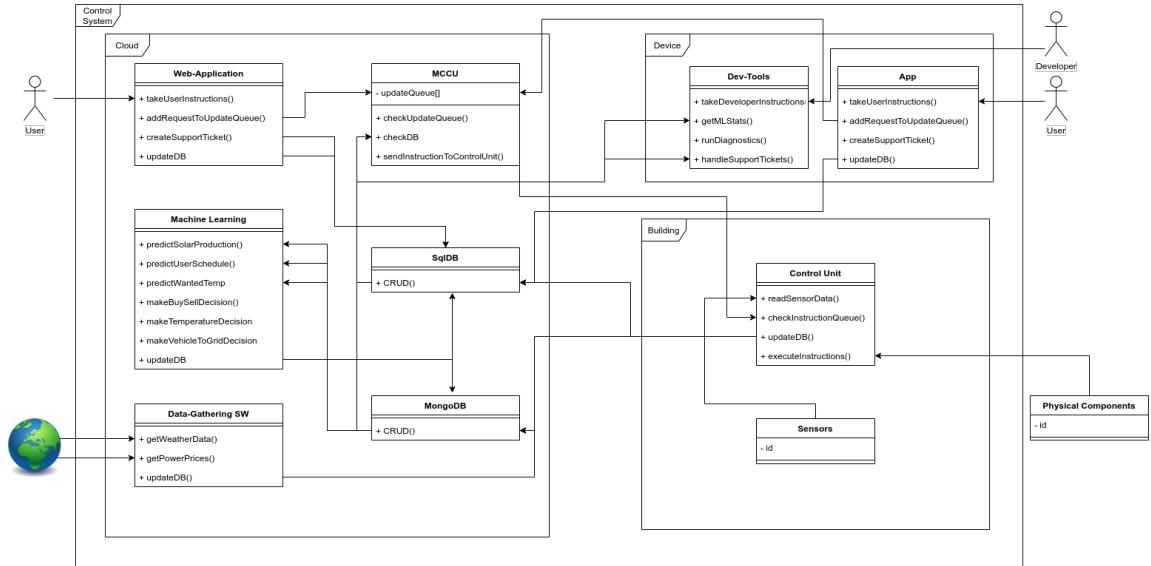


Figure 45: Class diagram for Control System

This is the deepest point of the system we have looked at, and we will now proceed with other aspects of our project.

## Build and Test Plan

## Verification

Verification plan is how we will use the data measured to verify the system matches the design requirements. “Did we build what we said we would”

To make sure that our system is ready for installation we set up this verification matrix where we listed the requirements and found test cases and methods of testing to confirm that the requirements are met.

We have only found methods for the most important requirements. The numbers in the left most columns are requirements and can be traced back to the requirement document on page 88

## Verification Matrix

| Customer and Regulatory Requirement | System Requirement | Verification Method  | Verification Criteria  |
|-------------------------------------|--------------------|--|--|
| 1.1                                 | 5.4.3.1            | Contact supplier   | Make sure supplier guarantees a MTTF > 1 year  |
|                                     | 5.3.3.1            |  | Make sure supplier guarantees a MTTF > 5 years   |
|                                     | 5.2.3.1            |  | Make sure supplier guarantees a MTTF > 1 year  |
| 1.2                                 | 4.5.1              | Calculate the price of sub-systems   | Verify that total price will be lower than or equal to 8MNOK                                     |
|                                     | 5.1.5.1            | Contact supplier   | Verify that the annual cost will be lower than or equal to 30kNOK                                |
|                                     | 5.1.5.2            | Calculate the price of sub-systems   | Verify that total price will be lower than or equal to 50kNOK                                    |
|                                     | 5.2.5.1            | Contact supplier   | Verify that total price will be lower than or equal to 3MNOK                                     |
|                                     | 5.3.5.1            | Contact supplier   | Verify that total price will be lower than or equal to 1.8MNOK                                   |
|                                     | 5.3.5.2            | Contact supplier   | Verify that total price will be lower than or equal to 1.3MNOK                                   |
|                                     | 5.3.5.3            | Calculate the price of sub-systems   | Verify that total price will be lower than or equal to 3.3MNOK                                   |
|                                     | 5.4.5.1            | Contact supplier   | Verify that total price will be lower than or equal to 1.4MNOK                                   |
|                                     | 6.1.5.1            | Contact supplier   | Verify that total price will be lower than or equal to 50kNOK                                    |
| 1.3                                 | 5.4.2.1            | Connect a microcontroller to heatpump with RS-485 cable, and send data instructions  | The heatpump shall turn on and off according to instructions                                     |
|                                     | 5.4.2.2            | Connect a microcontroller to heatpump with RS-485 cable, and read metadata   | Verify that the heatpump sends metadata over the cable.  |
|                                     | 5.4.4.1            | Turn on heatpump and measure rated heat output   | The rated heat output shall be larger than 67 kW   |
|                                     | 5.4.4.2            | Turn on heatpump and measure rated heat removal output   | The rated heat removal output shall be larger than 20kW  |
|                                     | 5.4.4.3            | Measure heat energy ratio when -7 °C outside   | Verify that ratio is larger than 1:3:1   |
|                                     | 5.4.4.4            | Measure heat energy ratio when 2 °C outside  | Verify that ratio is larger than 1:3.6   |
|                                     | 5.4.4.5            | Measure heat energy ratio when 7 °C outside  | Verify that ratio is larger than 1:4   |
|                                     | 5.4.4.6            | Measure heat energy ratio when 12 degrees C outside  | Verify that ratio is larger than 1:4.3   |
|                                     | 5.4.4.7            | Measure cooling energy ratio when outdoor temperature is -7 °C   | Verify that ratio is larger than 1:4   |
|                                     | 5.4.4.8            | Measure cooling energy ratio when outdoor temperature is 12 °C   |  |
|                                     | 6.1.2.6            | Turn on heathump in -10C and measure the rated heat output   | The rated heat output shall be larger than 67 kW   |
|                                     | 6.1.2.7            | Send change temperature signal to control unit for different apartments and rooms.   | Verify temperature in apartement and rooms matches the signal sent                               |
|                                     | 6.1.2.8            |  |  |
|                                     | 6.1.2.9            |  |  |
| 1.4                                 | 5.2.3.2            |  |  |
|                                     | 5.3.3.2            |  |  |
|                                     | 5.4.3.2            |  |  |
|                                     | 6.1.3.4            | Fabricate faults and have maintenance search and repair the faults while taking the time   | Verify that the components can be repaired within the set timelimit                              |
|                                     | 6.2.3.4            |  |  |
|                                     | 6.3.3.4            |  |  |
|                                     | 6.4.3.4            |  |  |
|                                     | 6.5.3.2            |  |  |
| 1.5                                 | 6.6.3.3            |  |  |
|                                     | 6.7.3.3            |  |  |
|                                     | 6.6.2.5            | Do penetration-testing on the server hosting the user interface  | Make sure the penetration does not succeed   |
|                                     | 6.7.2.5            | Do penetration-testing on the server hosting the Dev. tools  |  |
| 1.6                                 | 6.1.2.20           | Do penetration-testing on the server hosting the MCU   |  |
|                                     | 4.4.1              |  | Make sure we achieve 60% self-sustainability   |
| 1.7                                 | 4.4.2              | Simulate energy need and energy production over a year   | Make sure we dont throw away more than 1% of the energy produced                                 |
|                                     | 5.1.3.1            | Simulate giving the software more than 100kWh energy for selling, and record the decisions made  | Confirm the decisions made by the control system does not break the Norwegian regulations        |
| 1.8                                 | 6.3.1.2            | Feed database with dummy data  | Make sure all data are anonymized  |
|                                     | 5.1.3.2            | Simulate 24 hours of system running with dummy production, consumption, storage and price data. Store the results in a log                                   | Confirm in the log that 80% of total power sales was during said power price peak window         |
|                                     | 5.1.3.3            |  | Confirm in the log that 80% of total power purchases was during said cheapest power price window |
|                                     | 6.5.4.1            | Feed the ML software dummy weather data and dummy power price data   | Verify the predictions are within set error margins  |
| 1.9                                 | 6.5.4.2            |  |  |
|                                     | 6.6.3.1            | Gather a test group of different people with varying fields of interests and age. And let them use the website/app to see how fast they learn how to use it. | Verify the slowest people in the test group can meet the required MTTF                           |
| 1.10                                | 5.3.4.3            | Connect a power source and a power storage to the system. Then measure the amper and voltage.  | Verify the system provide the correct amper and voltage.   |
| 2.1                                 |                    |  |  |
| 2.2                                 |                    |  | See 1.7  |

## **Validation**

Validation plan is how we will use the data measured to validate the system matches the business requirements. "Did we build what we need"

To confirm that the system operates according to its designed purpose we will have to put it through a validation test, we will be doing prospective validation which is validation before we install the system, and retrospective validation which is validation that is done while the system is running on location

### **Prospective Validation**

- Is the system easy to learn? We will give the users access to user manuals and gain access to the user interface and get reports back whether learning the system is satisfactory.
- Does the system follow regulations? Invite inspectors for relevant government offices to confirm that the system is up to regulations.

### **Retrospective Validation**

- Is the system regulating the apartment temperatures correctly? We will monitor the temperature provided to the apartments and verify that the temperatures matches the desire of the users.
- Is the system giving the correct information to the users? We will monitor the users input and confirm that the system fulfills those inputs.

## **Verification**

In this section we have tried to test, simulate and/or calculate that the some of the key features for the system are achievable.

## **Production**

To find photovoltaic production numbers we first guessed with a little help from some articles.

Then we sent out emails to local installers in the Oslo area and got a response containing the price and kWp effect of commonly used solar panels.

See the attached email at page 87

The building roof area is  $1800m^2$  and to simulate what our photovoltaic production numbers would be, we used the average solar data from 3 different satellites. This simulation calculates kWh produced using a static kWp effect solar panel. In reality this will vary based on temperature and wind speed. Oslo has a good combination of solar radiation, wind speed and temperature.

For the angles we used the suggested optimal slope and azimuth from the website tool[13]. The roof panels will be mounted with a slope angle of  $40^\circ$  and an azimuth angle of  $2^\circ$ . Azimuth angle of  $0^\circ$  means it is facing directly south.

The solar panels mounted on the facade will use a slope angle of  $90^\circ$ . For simplicity we used the azimuth angles for directly west, south and east. We did not have time to simulate which azimuth angle the entire building complex should be in for the best power production from all the walls put together.

In total the system will have  $1350m^2$  of solar panels spread evenly across the west, south and east facing walls.

Production will of course have some variation throughout the year, but the amount of power we need to buy from the external power grid is less than 40% of our total power production. As we can see on the following graph our average self-sustain percent is  $\sim 64\%$ .

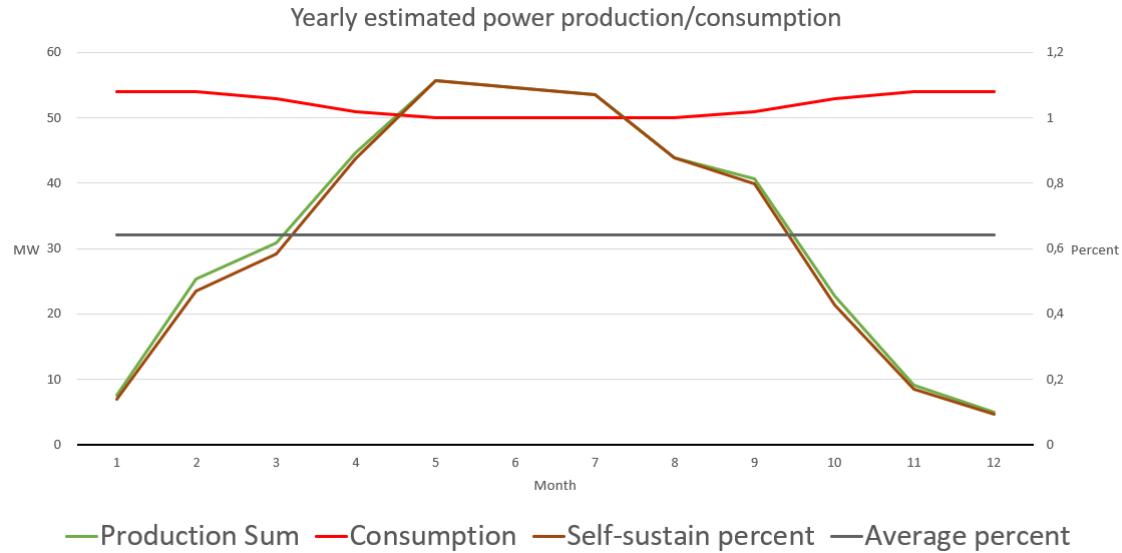


Figure 46: Graph of estimated yearly power production and consumption

## Capacity for Storage

We estimate the average electric vehicle our residents will use to have a capacity of 75kWh, and the historical day with the highest solar radiation made our system produce 1.4MWh above the maximum sell limit. To make sure it truly is the worst-case scenario we also put consumption at 0. The challenge for our system is to not throw away energy. From 6 o'clock to 17 o'clock we need ~19 electric vehicles to store all the energy. The problem is that most people are at work from 9 to 15. We need ~16 electric vehicles to store all the energy between 9 and 15.

For economic reasons we can only cover ~3/8 of the total energy storage need with our static storage.

See the attached email at page 86

If the system has access to 0 electric vehicles, we will have to throw away 0.7MWh. Odds of 0 consumption, 0 electric vehicles and record-breaking solar radiation are low, but it can happen. These odds are acceptable when the alternative is to almost triple our static storage. We cannot cover all the scenarios.

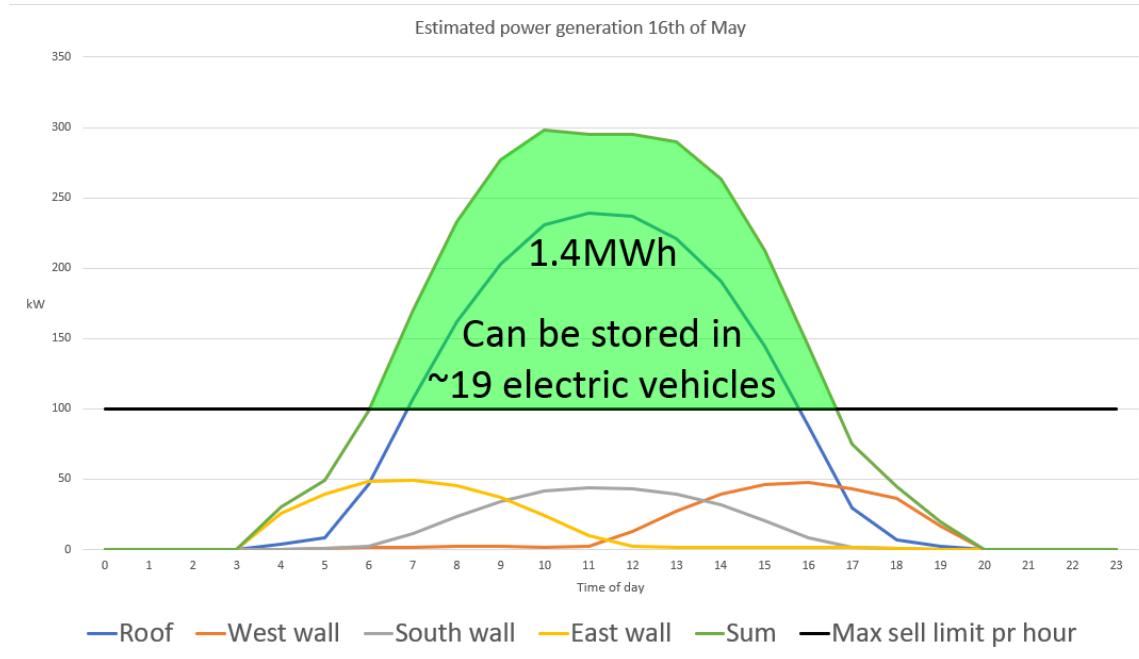


Figure 47: Graph of estimated 24 hour peak power production

Hopefully in the future Norway manages to update some current laws to make it easier for large

apartement complex to have their own energy production, without any need for energy storage. If we could "store" the energy by sending it to the external grid where someone else in Norway could use the power instead and have the same amount removed from our power bill. It would be a much more economical and enviromental way to store energy compared to lithium batteries[2].

## Thermal Calculations/Simulation

To validate some of our calculations and gather whether our data for the technical budget in regard to watt used for heating are in any way realistic, we took some simple calculations and compared them.

North American method (non-neutral home simplification):

$$Area \times height \times 1.25 \rightarrow 1024ft^2 \times 10ft \times \frac{1.25Wh}{ft^3} = 12800Wh = 12.8kWh \quad (1)$$

By using the formula from our source (NS3700)[11]:

$$15 + 5.4 \times \frac{(250 - 100)}{100} \rightarrow \frac{\frac{23.1kWh}{m^2}}{year} \quad (2)$$

Thermodynamic formula:

$$\begin{aligned} Q &= \frac{KA(Thot - Tcold)}{d} \rightarrow \frac{0.2W}{mK} \times 30m^2 \times \frac{24C - (-10C)}{1m} = 204Wh \\ &\rightarrow 0.2kWh \times 24 \times 365 = \frac{1752kWh}{year} = \frac{\frac{17.52kWh}{m^2}}{year} \end{aligned} \quad (3)$$

But this is for the cold days.

When the inside temperature is equal to outside temperature, no heating will be required. Therefore, for simplification, we halve the number, and get

$$\frac{\frac{8.76kWh}{m^2}}{year}. \quad (4)$$

Our earlier estimate, which was

$$\frac{\frac{15kWh}{m^2}}{year} \quad (5)$$

was based on the requirement for a passive home larger than  $250m^2$ .

Using their formula, the requirement for our passive home based on its size and location is

$$\frac{23.1 \text{ kWh}}{\frac{m^2}{\text{year}}}.$$
 (6)

*Tabell 1.2-1 Krav til oppvarmingsbehov for passivhus i NS 3700:2010 (kWh/m<sup>2</sup> oppvarmet BRA)*

| Årsmiddel-temperatur    | Oppvarmet BRA < 250 m <sup>2</sup> | Oppvarmet BRA ≥ 250 m <sup>2</sup> |
|-------------------------|------------------------------------|------------------------------------|
| T <sub>m</sub> ≥ 6,3 °C | 15 + 5,4 · $\frac{250 - BRA}{100}$ | 15                                 |

Figure 48: Heating requirements for BRA (BYA)

We made a simulation in Solidworks. Although it was not possible to show a realistic simulation because air always moves and has convection, we got a view of how the floor heating would affect the room had the air stood still.

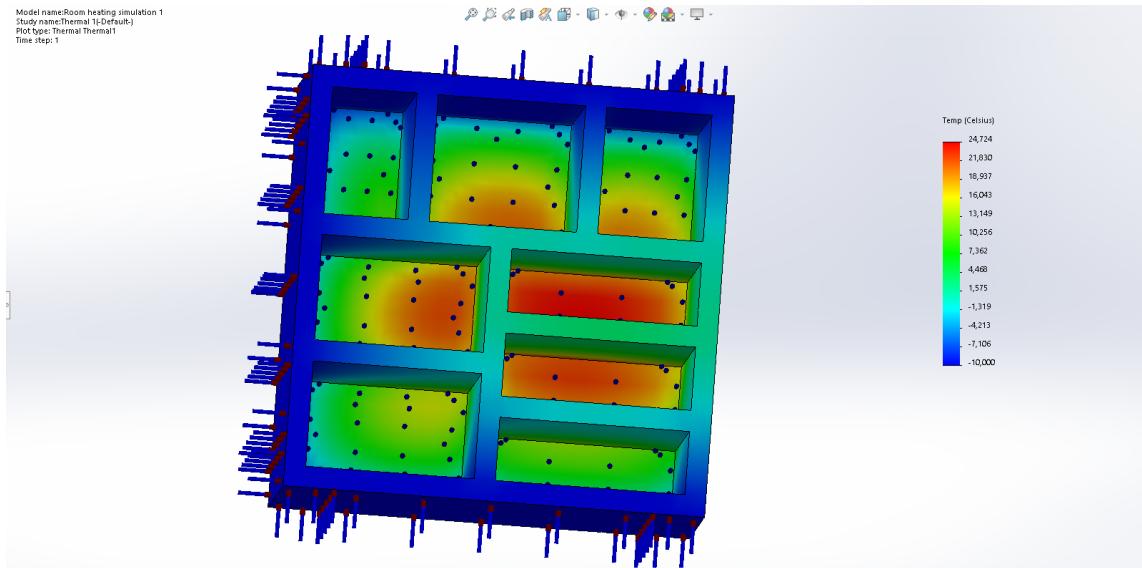


Figure 49: Thermal simulation of the apartment

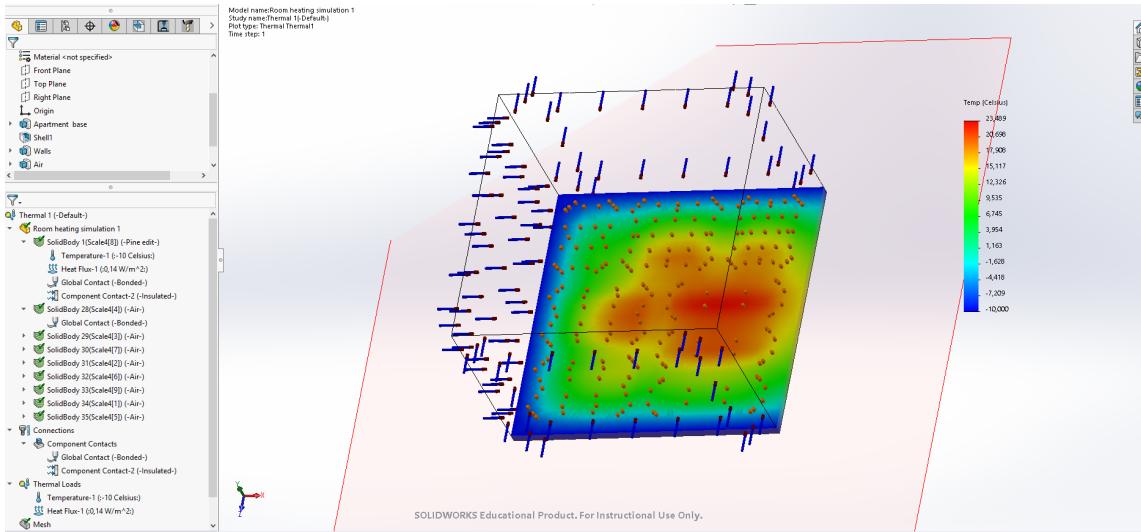


Figure 50: Thermal simulation with air in the apartment

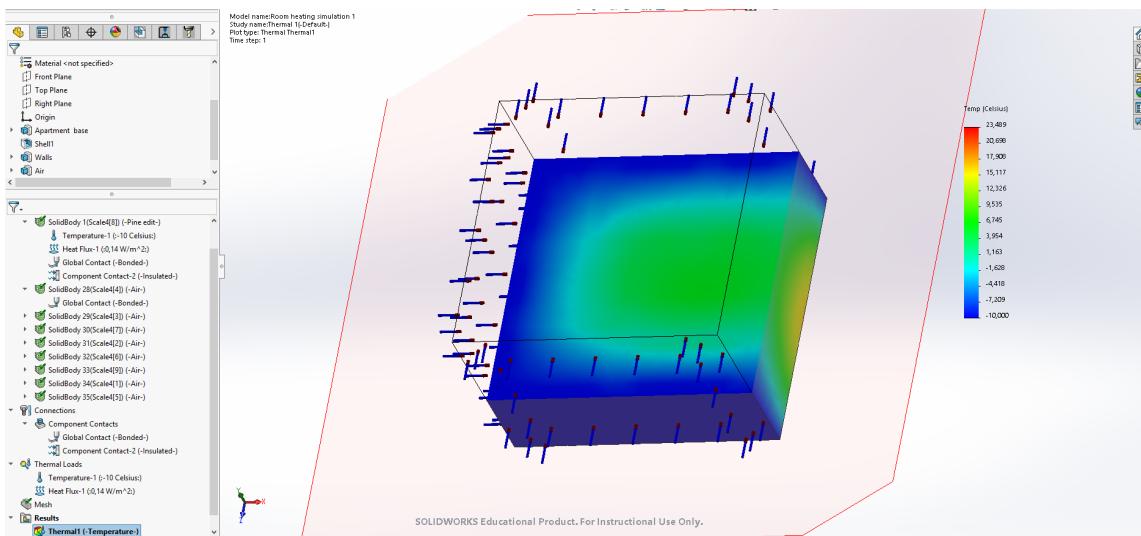


Figure 51: Thermal simulation with air, higher up in the apartment

Due to the results of this simulation, the electrical need for heating the building will be about half of our original estimate. Because of this we have calculated that our actual self-sufficiency will be 67%. However, since these results came in at the eleventh hour, neither the rest of this report nor the presentation, will be adjusted for this number.

## Solar Panels Static Calculations/Simulation

In addition to the thermal simulation, we ran a simulation to assess whether the roofing of our apartment complex would hold the weight of the solar panels.

- Estimated solar panel weight per  $m^2$ : 12kg.
- Roof size per building:  $450m^2$ .
- Combined weight: 5400kg.
- Converted to newtons: 53kN.
- Using Balsa as placeholder building material.

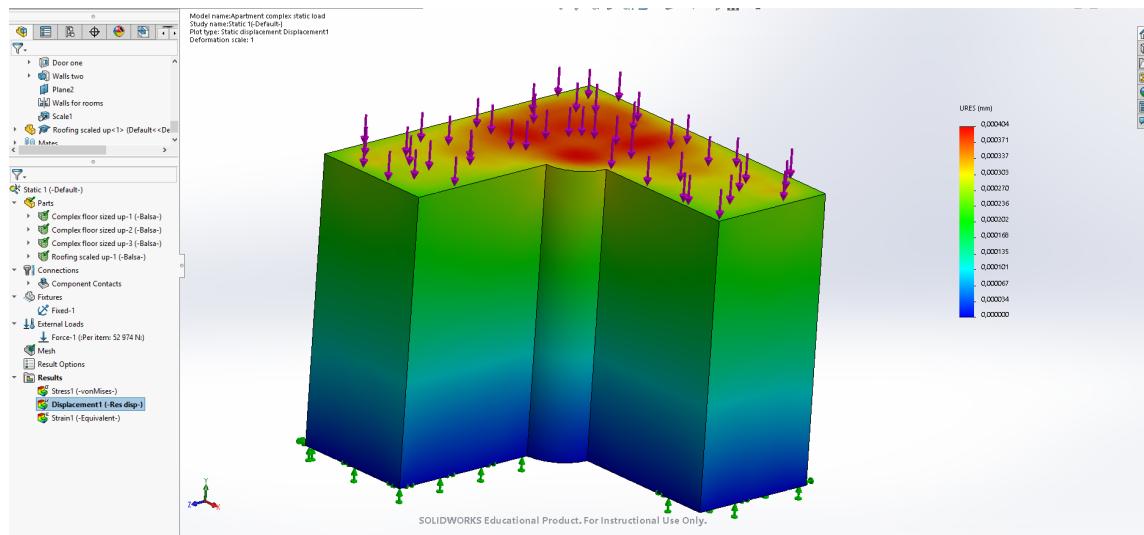


Figure 52: Static simulation for roof displacement

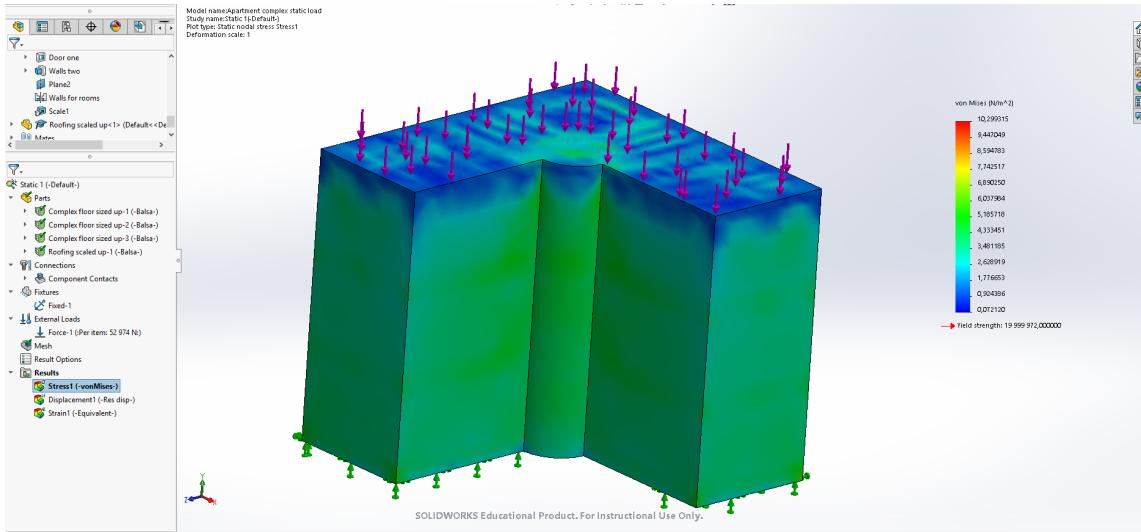


Figure 53: Static simulation for roof stress

It shows the building has enough rigidity to withstand it and does not experience any stress higher than it can take.

## Prototypes

### Machine Learning

As we've mentioned several times, machine learning will be heavily relied upon for making our system function properly and making it attractive. Because of this we found it necessary to verify the feasibility of this by prototyping and testing some of the key functions the machine learning software will have to perform.

The way we handle buying and selling of power are very important in order to not waste the energy we produce. We also want to buy and sell for the best possible price. To accomplish this, we need among other things to:

- Predict our solar panel power production
- Predict the power prices

## Predicting Solar Panel Power Production

In order to predict the solar panel power production, we needed historic weather and sun data. Luckily for us the European Commission provides a free API which offers data from the Photovoltaic Geographical Information System (PVGIS). This let us specify the location and direction of our solar panels, and outputted hourly data production data from 2005-2016. We stored the data in our MongoDB cluster, one table for each of the walls, according to which cardinal direction they are facing, as well as one for the solar panels on the roof.

Weather data is easily available from many different sources, we chose to use the API of the Norwegian Meteorological Institute which provides extended information about cloud density and height. This also was stored in the cluster.

Python is a very good tool for prototyping machine learning and holds several libraries for different machine learning approaches. The ones we touched on work like this:

- Import the dataset
- Divide the data into two, one training set and one test set.
- Let the algorithm find a fitting model from the training set.
- Apply the model on the test set
- Calculate deviations and error-margins.

Next, we analyzed the results, and evaluated whether the approach was good enough. We tried a few approaches, among them linear regression, but eventually got good results with a decision tree regressor algorithm. These are for the south wall solar panels:

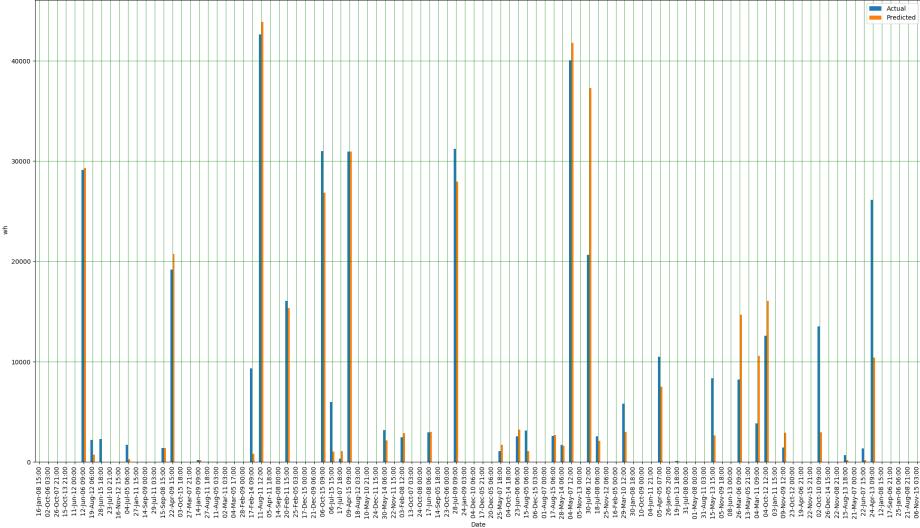


Figure 54: Machine learning prediction results for shuffled solar production

$$MeanAbsoluteError = 1.7kWh \quad (7)$$

The blue bars in this graph shows the actual power production during an hour, the orange bars show the predicted production and the number shows the accuracy of all the predictions, not just the data displayed in the model.

This looks a bit too good to be true, and in a way it is. When dividing the data into two, one can chose to shuffle the dataset, or to do it chronologically. Of course, it is easier for the algorithm to ‘guess’ on a value between a group of others, than if it had to predict the production for an extended period without as much information from the context. The chronological way is how it will work in a proper implementation, so it’s crucial that this also produces acceptably results. These are the data we got for the panels on the south wall:

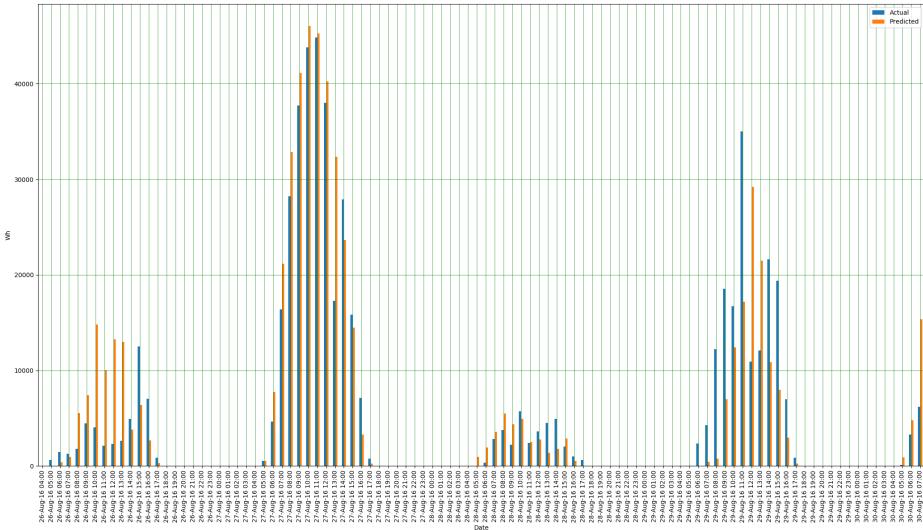


Figure 55: Machine learning prediction results for chronological solar production

$$MeanAbsoluteError = 2.3kWh \quad (8)$$

As expected, these results are much less accurate. However, we still find it viable, and these predictions will keep getting better as the data increases in size.

The source code is found on page 105

### Predicting Power Prices

The price of electricity depends on supply and demand at any given moment. These two factors however are the results of a tremendous number of variables, which makes this task very difficult.

The first thing we looked at was the historical data:

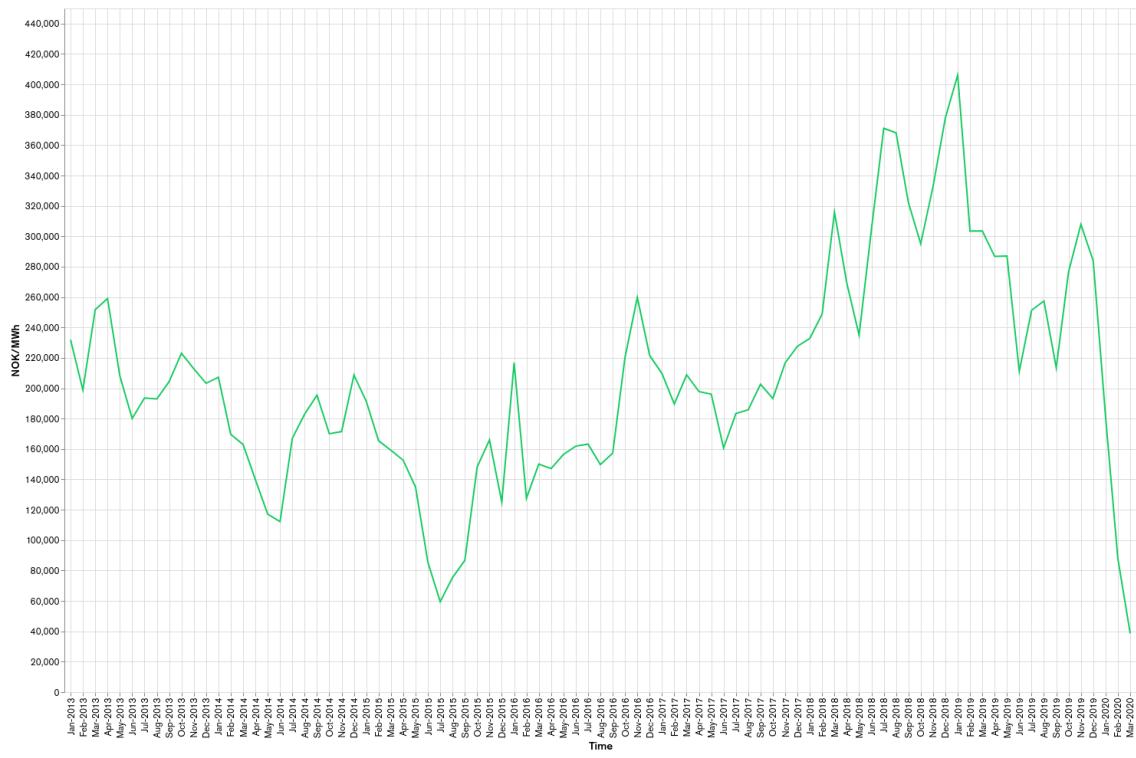


Figure 56: Power prices 2013-2020 in NOK/MWh

We gathered hourly historical data and analyzed them. The fact that they wary so greatly and abruptly brings further complexity to the problem. Still we fed the data to the same algorithm we used for predicting our production and got these results for a shuffled dataset:

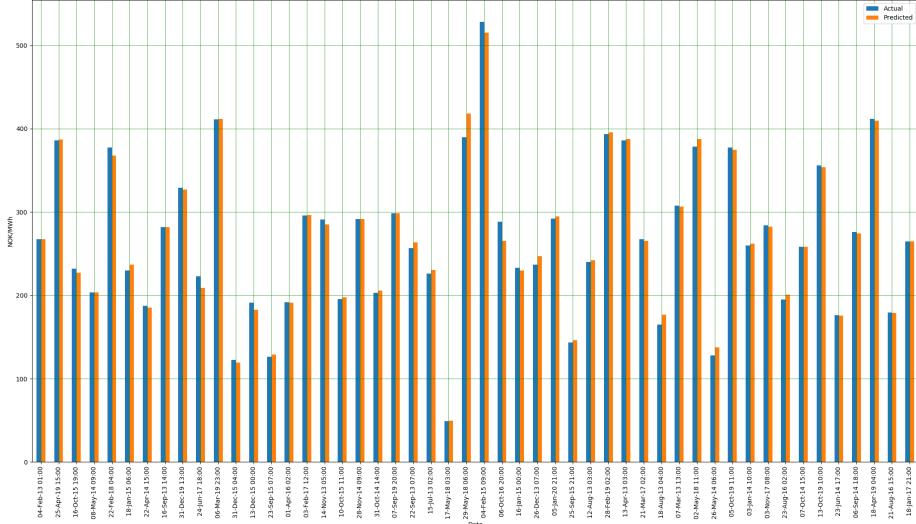


Figure 57: Machine learning prediction results for shuffled power prices

$$MeanAbsoluteError = 6.9 \text{ NOK/MWh} \quad (9)$$

The results are perfect, but they are still a victim of the same symptom we saw with shuffled lists with solar power, and to an even stronger degree. Still, this did seem promising with respect to chronological testing which ended up like this:

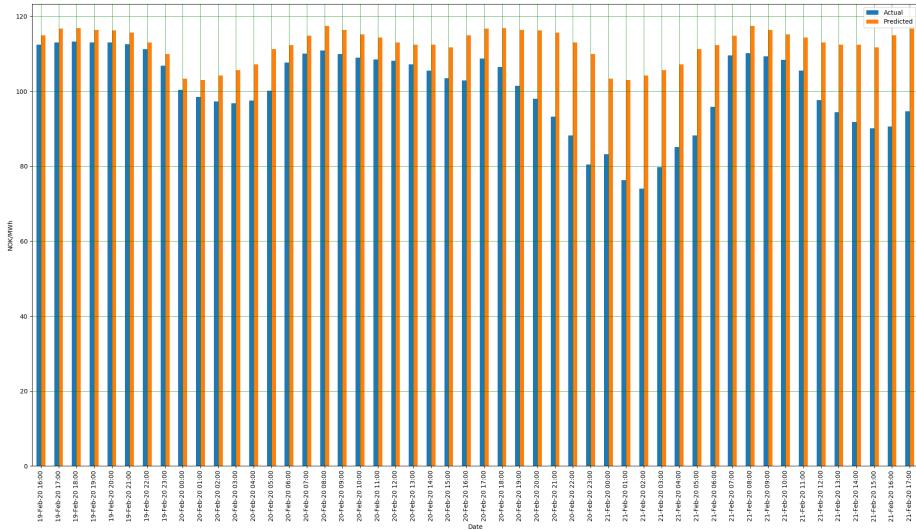


Figure 58: Machine learning prediction results for chronological power prices

$$MeanAbsoluteError = 33.6 \text{ NOK/MWh} \quad (10)$$

The accuracy of the results dropped much more than what was the case with solar power, because the variables are too many, and we don't factor in anything but the historical data. Still, we concluded with that they are better than one would expect. We are confident that if more data, and more types of data are gathered, the results will increase in quality.

The source code is found on page 107

## Web-Application

Residents should have an easy way to adjust their temperature and change their vehicle charge settings. They should be given detailed statistics over their energy consumption the last 24 hours, week, month and year. We have focused on simplicity and provide both a website which will work on all modern browsers. We will also compile the website code into an app for both Android and iOS.

We want our customers to have options to choose between website, app or both for their devices and having our app on the respective app stores provides us with a tiny amount of marketing.

Which means we will only have one codebase to work on and update, but we will need to depend on other software for the actual conversions.

We have made a prototype of the “change temperature in apartment” function. If we had more time we would continue with the “change electrical vehicle charge settings” and “energy consumption statistics”.

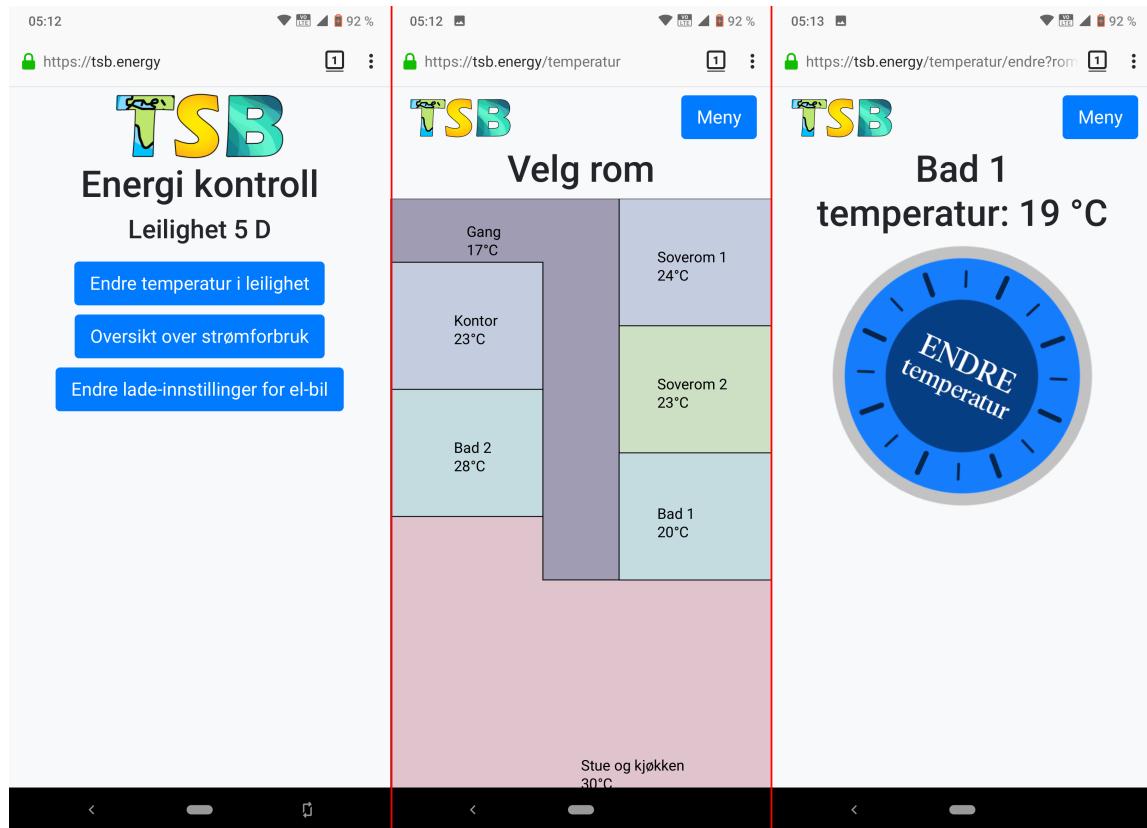


Figure 59: Screenshots of the website prototype

A video demonstration of the website/app interface can be seen at:

[https://drive.google.com/open?id=1qdpW8sEy\\_y\\_6B09mgFI1ST6dhzji0jjQ](https://drive.google.com/open?id=1qdpW8sEy_y_6B09mgFI1ST6dhzji0jjQ)

## System Risk Analysis

We perform risk analysis for our system operation so one of these scenarios do not cause physical, economical, psychological or social damage to our customer.

The risk analysis matrix shows how likely each scenario is and how much it will affect us or the stakeholders negatively. The recommended action is what we can do to reduce the risk or the severity.

| RISK            | AREAS AFFECTED                        | SEVERITY | LIKELIHOOD | RISK IMPACT | RECOMMENDED ACTION(S)  |
|-----------------|---------------------------------------|----------|------------|-------------|--|
| Internet loss   | Residents can not control temperature | LOW      | MEDIUM     | MEDIUM      | Control unit has default values to fall back on for temperatures                               |
| Sensor failure  | Temperature adjustment accuracy       | LOW      | MEDIUM     | MEDIUM      | Control unit try to hit set temperature by guessing at correct energy usage from historic data |
| Software bugs   | Control system                        | LOW      | MEDIUM     | MEDIUM      | Clean code, documentation, testing   |
| Security breach | Control system                        | HIGH     | LOW        | MEDIUM      | Encrypt or hash personal information   |

Figure 60: PIM for system operation

## Economics

Our business plan consists of selling our subsystems:

- Geothermal heat pump
- Vehicle-to-building
- Solar panels
- Lithium batteries

as a one-time sale and to provide a smart energy management service.

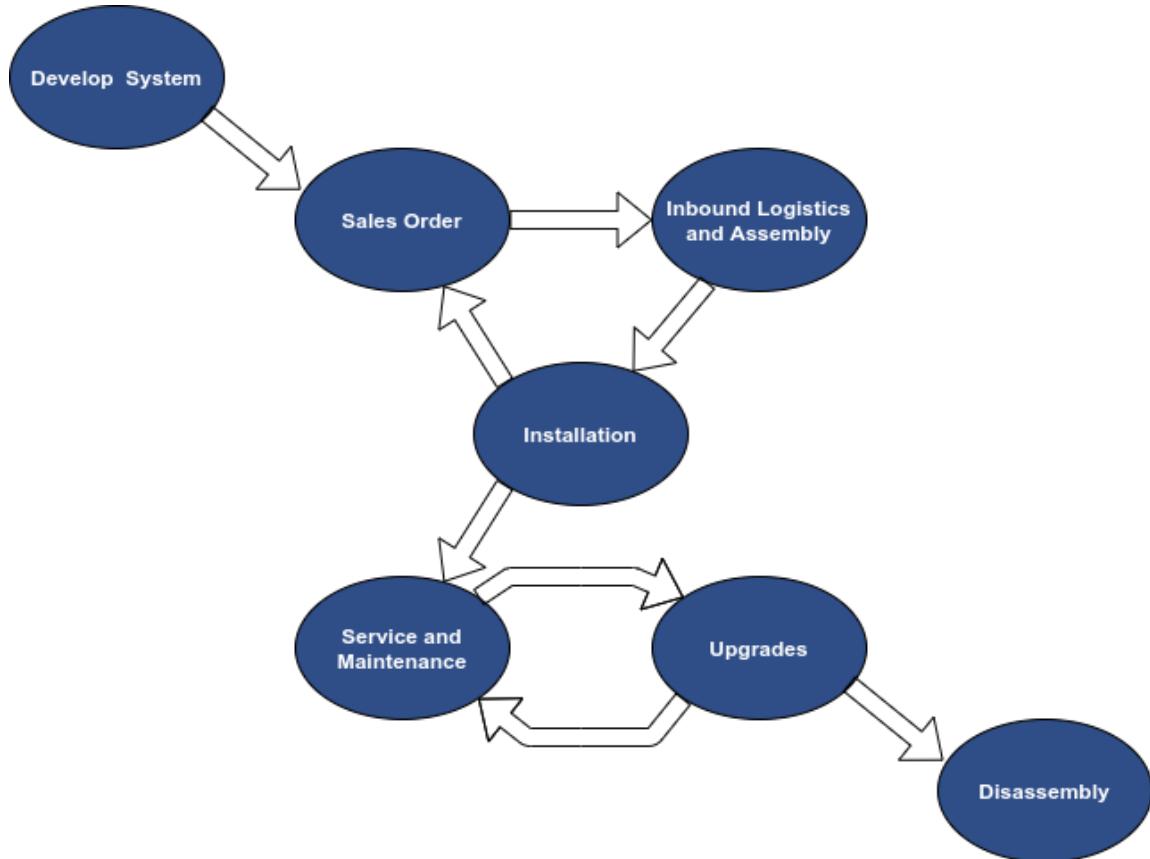


Figure 61: The life cycle of our system

The subsystems we sell as a box are not crucial and are interchangeable if they match our subsystem requirements

The smart energy management service we provide has one physical mainframe in each building complex, temperature sensors inside and outside, and a proximity sensor in every apartment.

The mainframe and sensors provide essential data to our machine learning software, this data needs to be stored continually and the machine learning software needs fine tuning and adjustments. Selling this as a service means less risk for us and the customer. Easier for us to maintain software with annual income, and the customer is guaranteed up to date software.

## Our Budget

We made a budget to estimate our expenses and income. Unit sales will have a one-time expense/income while service will have annual expense/income. We will pay our engineers 1MNOK in the start and expect other expenses to be 100k annually.

For the most crucial and expensive sub-systems we tried to reach out to suppliers in the Oslo area and get a price from them. Some of them did generously respond to our queries. However, for other sub-systems and atomic parts we simply guessed.

See the attached emails at pages: 85, 86, 87

The unit will cost us 7.7MNOK and the annual service will cost us 20k.

The unit will cost the customer 10MNOK and the annual service 50k.

|                              | Year 1  |         | Year 2  |         | Year 3   |          | Year 4   |          | Year 5   |          | Year 6   |          |
|------------------------------|---------|---------|---------|---------|----------|----------|----------|----------|----------|----------|----------|----------|
|                              | Half 1  | Half 2  | Half 1  | Half 2  | Half 1   | Half 2   | Half 1   | Half 2   | Half 1   | Half 2   | Half 1   | Half 2   |
| Investments                  | 3 050k  | 3 050k  | 0       | 0       | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| <b>Sales</b>                 | 0       | 0       | 1       | 1       | 2        | 2        | 3        | 3        | 4        | 4        | 4        | 4        |
| Volume                       | 0       | 0       | 1       | 2       | 4        | 6        | 9        | 12       | 16       | 20       | 24       | 28       |
| <b>Cumulative Income</b>     | 0       | 0       | 10 000k | 10 000k | 20 000k  | 20 000k  | 30 000k  | 30 000k  | 40 000k  | 40 000k  | 40 000k  | 40 000k  |
| Unit sales                   | 0       | 0       | 50k     | 100k    | 200k     | 300k     | 450k     | 600k     | 800k     | 1 000k   | 1 200k   | 1 400k   |
| <b>Unit service Expenses</b> | -3 000k | -3 000k | -3 000k | -3 000k | -4 000k  | -4 000k  | -4 000k  | -4 000k  | -5 000k  | -5 000k  | -5 000k  | -5 000k  |
| Salary                       | -50k    | -50k    | -50k    | -50k    | -100k    | -100k    | -100k    | -100k    | -120k    | -120k    | -120k    | -120k    |
| Other                        |         |         |         |         |          |          |          |          |          |          |          |          |
| <b>Service</b>               | 0       | 0       | -20k    | -40k    | -80k     | -120k    | -180k    | -240k    | -320k    | -400k    | -480k    | -560k    |
| Labour                       |         |         |         |         |          |          |          |          |          |          |          |          |
| <b>Sales</b>                 | 0       | 0       | -7 590k | -7 590k | -15 180k | -15 180k | -22 770k | -22 770k | -30 360k | -30 360k | -30 360k | -30 360k |
| Material                     | 0       | 0       | -100k   | -100k   | -200k    | -200k    | -300k    | -300k    | -400k    | -400k    | -400k    | -400k    |
| Labour                       |         |         |         |         |          |          |          |          |          |          |          |          |
| <b>Profit</b>                | -3 050k | -3 050k | -710k   | -680k   | 640k     | 700k     | 3 100k   | 3 190k   | 4 600k   | 4 720k   | 4 840k   | 4 960k   |
| Half year                    | -3 050k | -6 100k | -6 810k | -7 490k | -6 850k  | -6 150k  | -3 050k  | 140k     | 4 740k   | 9 460k   | 14 300k  | 19 260k  |
| <b>Cumulative</b>            |         |         |         |         |          |          |          |          |          |          |          |          |

Figure 62: Budget for our company

We expect to make a profit after 2 years and be debt free from the 6 MNOK we loaned from investors after 3.5 years.

## Our Cash Flow

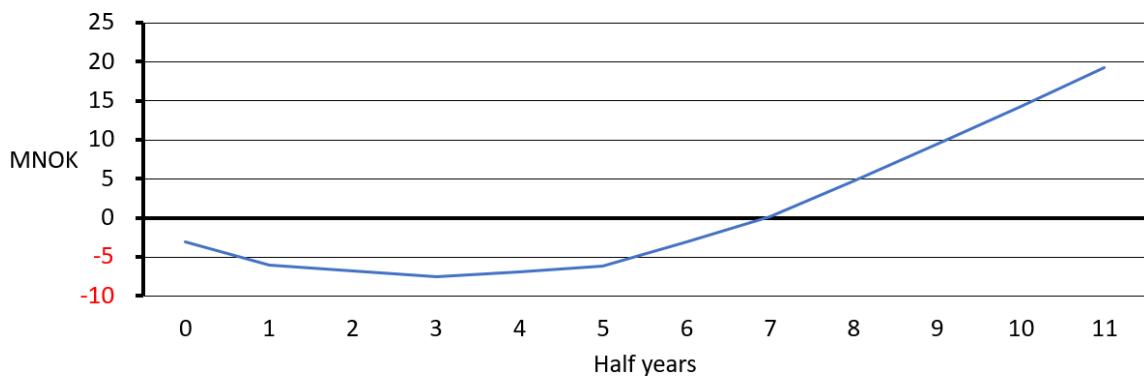


Figure 63: Cash flow graph for our company

## Residents Budget

|                               | Year 1   | Year 2   | Year 3   | Year 4   | Year 5   | Year 6   | Year 7   | Year 8   | Year 9   | Year 10  |
|-------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| System purchase               | -13 000k | 0        | 0        | 0        | 0        | -1 350k  | 0        | 0        | 0        | 0        |
| <b>Expense without system</b> |          |          |          |          |          |          |          |          |          |          |
| Power                         | -253k    | -296k    | -338k    | -380k    | -422k    | -465k    | -507k    | -549k    | -591k    | -634k    |
| System expenses               | -4 000k  | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| Cumulative                    | -4 253k  | -5 098k  | -5 774k  | -6 534k  | -7 379k  | -8 308k  | -9 322k  | -10 420k | -11 603k | -12 870k |
| <b>Costs with system</b>      |          |          |          |          |          |          |          |          |          |          |
| Clean solar panels            | -104k    |
| Service-agreement             | -50k     |
| <b>Income with system</b>     |          |          |          |          |          |          |          |          |          |          |
| Surplus power sale            | 18k      | 20k      | 23k      | 26k      | 29k      | 32k      | 35k      | 38k      | 41k      | 44k      |
| <b>Profit</b>                 |          |          |          |          |          |          |          |          |          |          |
| Year                          | -13 136k | -134k    | -131k    | -128k    | -125k    | -1 472k  | -119k    | -116k    | -113k    | -110k    |
| Cumulative                    | -13 136k | -13 270k | -13 401k | -13 528k | -13 653k | -15 125k | -15 244k | -15 360k | -15 473k | -15 583k |

Figure 64: Budget for customer

Our system costs 10 MNOK, but the customer also needs to dig wells for the geothermal heat pumps. Which we estimate will cost 3 MNOK, putting the total at 13 MNOK.

## Residents Cash Flow

Subsystem replacement schedule:

- Geothermal heat pump: 5 years
- Lithium batteries: 10 years
- Solar panels: 20 years
- Vehicle-to-building: 20 years

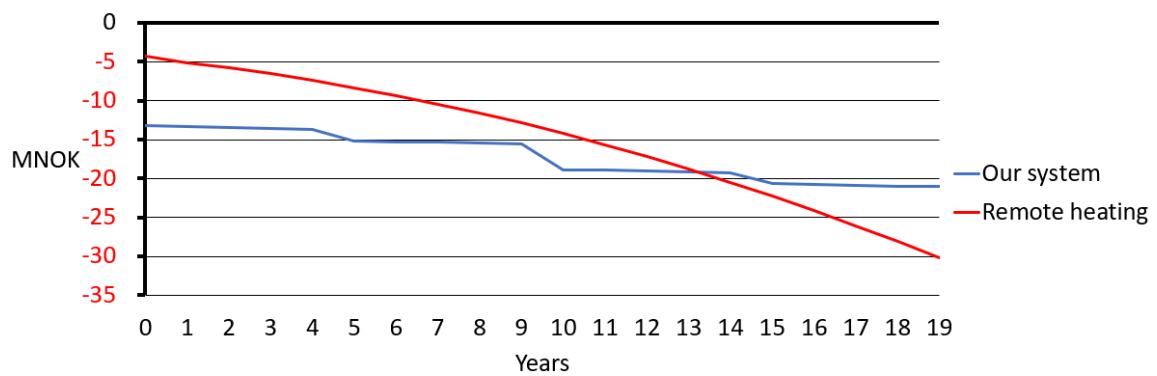


Figure 65: Cash flow graph for customer

Our remote heating cost estimation is very generous and the residents will still end up saving money with our system after  $\sim 13$  years. We suspect remote heating is more expensive in reality.

# Conclusion

## About Our System

Even though our system does not make a large multi-floor building 100% self-sustainable, it is still a huge help. It puts unused roof area to use, provides efficient heating and smart energy storage. Due to the urban environment we aimed our system at, it narrowed the opportunities for energy harvesting.

However, since most people live in these urban environments, we feel that our system will make a much bigger impact than for instance a 100% renewable house in the countryside. The opportunities for scaling a smart energy system is much more important than the actual percentage of renewable energy achieved.

One of the problems we see with large buildings having their own power production is the need for energy storage. If the regulations do not let you sell all excess power, there will be a lot of unnecessary energy waste. Producing lithium batteries for all large and small buildings is not a good long-term solution as the world population grows. In a country like Norway where virtually all power comes from renewable sources, it is better to rely on the power grid.

## What Did We Learn

- Working in a team
- How to attack large problems
- View the system from different stakeholders point of view
- Modelling, a picture says a thousand words
- Communicate ideas and concepts (T-shape)
- The importance of time-boxing
- Separating problem from solution
- Synthetic vs analytic thinking
- How to cooperate using digital platforms
- There is always another interface
- Reading and understanding technical datasheets

## **What Could Be Improved**

It was difficult to scope the problem, and we should have put more focus on this earlier. This would have prevented us from spending time designing a building.

The focus of this assignment was to learn system engineering, and we were told not to focus too much on numbers. However, poor research can lead to a poor product solution. The system is only as good as its worst sub-system.

The energy consumption of the building is a crucial starting point. The entire system is dependant on how much power we need. Research into this area should have had a larger focus early on, to make sure we were solving the correct problem.

## References

- [1] Nordpool Group ,. <https://www.nordpoolgroup.com/>. Accessed: March-20.
- [2] Plusskunder, nve. <https://www.nve.no/reguleringsmyndigheten/nettjenester/nettleie/tariffer-for-produksjon/plusskunder/>. Accessed: March-20.
- [3] Rooftop Wind Turbines: Are They Worthwhile? , engineering.com. <https://www.engineering.com/ElectronicsDesign/ElectronicsDesignArticles/ArticleID/9556/Rooftop-Wind-Turbines-Are-They-Worthwhile.aspx>. Accessed: March-20.
- [4] Siragrunnen vindpark , multiconsult. <https://www.multiconsult.no/prosjekter/siragrunnen-vindpark/>. Accessed: March-20.
- [5] Dette bruker du strømmen til , smartepenger.no. <https://www.smartepenger.no/boligokonomi/2438-dette-bruker-du-strommen-til>. Accessed: March-20.
- [6] Elevator energy calculator, thyssenkrupp. <https://www.thyssenkruppelevator.com/tools/energy-calculator/>. Accessed: March-20.
- [7] Fremtidens bolig, enova. [https://www.enova.no/upload\\_images/42B0BD408ABB4271A1CDEABF9C402A6E.pdf](https://www.enova.no/upload_images/42B0BD408ABB4271A1CDEABF9C402A6E.pdf). Accessed: March-20.
- [8] Ikke nok sol til solceller i Norge? , fremtiden.no. <https://www.framtiden.no/myteknusing/ikke-nok-sol-til-solceller-i-norge.html>. Accessed: March-20.
- [9] Kjørelengder, ssb. <https://www.ssb.no/transport-og-reiseliv/statistikker/klreg>. Accessed: March-20.
- [10] Krav til energieffektivitet TEK17 , direktoratet for byggkvalitet. <https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/14/14-2/>. Accessed: March-20.
- [11] Krav til passivhus NS3700 , tekna.no. <https://www.tekna.no/fag-og-nettverk/bygg-og-anlegg/byggbloggen/krav-til-passivhus>. Accessed: March-20.
- [12] Norwegian household power consumption, ssb. <https://www.ssb.no/energi-og-industri/artikler-og-publikasjoner/vi-bruker-mindre-strom-hjemme>. Accessed: March-20.
- [13] Photovoltaic Geographical Information System , european commision. [https://re.jrc.ec.europa.eu/pvg\\_tools/en/tools.html](https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html). Accessed: March-20.
- [14] Samlet energibruk , nve. <https://www.nve.no/energibruk-effektivisering-og-teknologier/energibruk/samlet-energibruk/?ref=mainmenu>. Accessed: March-20.
- [15] Specialty Engineering, incose. [https://www.incose.org/docs/default-source/Working-Groups/infrastructure-wg-documents/005-specialty-engineering-pamphlet.pdf?sfvrsn=9c2c82c6\\_6](https://www.incose.org/docs/default-source/Working-Groups/infrastructure-wg-documents/005-specialty-engineering-pamphlet.pdf?sfvrsn=9c2c82c6_6). Accessed: March-20.
- [16] Strømforbruk for elbil, fjordkraft. <https://www.fjordkraft.no/strom/stromforbruk/elbil/>. Accessed: March-20.

- [17] Strømforbruk og strømsparing, hafslund strøm. <https://www.hafslundstrom.no/strom/privat/stromforbruk/2025>. Accessed: March-20.
- [18] Veileddning TEK17 , direktoratet for byggkvalitet. <https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/>. Accessed: March-20.
- [19] David W. Oliver, Timothy P. Kelliher, and James G Keegan. *Engineering Complex Systems, With Models and Objects*. McGraw-Hill, 1997.
- [20] Richard Stevens, Peter Brook, Ken Jackson, and Stuart Arnold. *Systems Engineering, Coping with Complexity*. Pearson, 1998.

# Appendices

## A Emails

### A.1 Geothermal Heat Pump Supplier Email

**Tarald Vestbøstad**

---

**From:** Øivind Botnevik <ob@abkqviller.no>  
**Sent:** mandag 9. mars 2020 15.15  
**To:** Tarald Vestbøstad  
**Subject:** NIIBE

Hei,  
Budsjettpris for 9 stk. F1345-60 er 1 350 000,-.

Med vennlig hilsen

**Øyvind Botnevik**  
Leadskoordinator

ob@abkqviller.no  
+47 53 00 72 61 | +47 970 84 211



**ABK-Qviller AS** | Region Bergen  
Hardangerveien 72, seksjon 21, 5224 Nesttun  
abkqviller.no | +47 23 17 05 20

Meld deg på årets arrangement for våre forhandlere:



Kundehenvendelse fra kontaktskjema på NIIBE.no

E-post: [141462@usn.no](mailto:141462@usn.no)

Hei NIIBE  
Mitt navn er Tarald og jeg studerer data ingeniør ved USN.  
Vi har et prosjekt som handler om smarte bygninger, og vår gruppe trenger en pris estimering på en varmepumpe.

Vi er veldig takknemlig hvis dere kunne hjelpe oss med en ca. pris for en bedrift å kjøpe inn ni stk NIIBE F1345-60?

Mvh  
Tarald Vestbøstad

## A.2 Lithium Battery Supplier Email

### **Tarald Vestbøstad**

---

**From:** Kjell Are Sangvik <kas@skanbatt.no>  
**Sent:** tirsdag 10. mars 2020 07.06  
**To:** Tarald Vestbøstad  
**Subject:** Re: Skanbatt lithiumbatteri pris estimat for skoleprosjekt

Hei igjen.

Uten å ha noen videre spesifisering på hvordan denne batteribanken skal være, så vil prisen være ca 1,8 mill eks mva.  
Dette er ut ifra dagens dollar kurs.  
Dersom dette er noe dere tenker å gå videre med, trenger jeg litt mer opplysninger om denne batteribankens behov.

Med vennlig hilsen / Best regards

**Skandinavisk Batteriimport AS**

**Kjell Are Sangvik**  
Tlf:+47 47245325  
Web: [www.skanbatt.no](http://www.skanbatt.no)

Supportforum: <https://www.facebook.com/groups/SkanbattForum/>



man. 9. mar. 2020 kl. 10:50 skrev Kjell Are Sangvik <[kas@skanbatt.no](mailto:kas@skanbatt.no)>:  
Hei.

Takk for deres henvendelse.  
Jeg skal sjekke med leverandør på en slik stor pakke, hva dette kan komme på.  
Kommer med en tilbakemelding når jeg vet noe.

Med vennlig hilsen / Best regards

**Skandinavisk Batteriimport AS**

### A.3 Solar Panel Supplier Email

4/8/2020

Gmail - Nøkkeltall



Vegard Bernhardsen <vegard.g.bernhardsen@gmail.com>

---

#### Nøkkeltall

2 e-poster

Torgersen, Morten <Morten.Torgersen@smartly.no>  
Til: "vegard.g.bernhardsen@gmail.com" <vegard.g.bernhardsen@gmail.com>  
Kopi: Support Smartly <support@smartly.no>

17. februar 2020 kl. 14:09

Hei Vegard

Et anlegg som dekker 6400kvm, vil normalt sett gi følgende tall:

- Med ca 160 Wp/kvm gir dette 1 024 000Wp, altså 1 024kWp
- Med en markedspris på ca 9kr/ Wp vil et slikt anlegg koste ca 9,2 mill NOK.

Men det bør være fullt mulig å få det rimeligere med en god tilbudsrounde, så 7-8 mill bør være innen rekkevidde.

Dette er veldig omrentelige tall, men kan være greit å bruke som eksempel.

Vennlig hilsen

Morten Torgersen

Prosjektleder - Fagansvarlig

**Smartly AS**

Mobil: +47 475 09 187

E-post: [morten.torgersen@lyse.no](mailto:morten.torgersen@lyse.no)

[www.smarly.no](http://www.smarly.no)



---

Vegard Bernhardsen <vegard.g.bernhardsen@gmail.com>  
Til: "Torgersen, Morten" <Morten.Torgersen@smartly.no>

17. februar 2020 kl. 14:36

Hei  
tusen takk for raskt svar, det er til stor hjelp.

hilsen  
Vegard Bernhardsen

<https://mail.google.com/mail/u/0/?k=5b4bb5c59a&view=pt&search=all&permthid=thread-f%3A1658789534803704150&simpl=msg-f%3A1658789...> 1/2

## B Requirement Document

### 1. Customer Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall be reliable                        |
| 2  | The system shall be cheap                           |
| 3  | The system shall maintain a comfortable temperature |
| 4  | The system shall be optimized for fast maintenance  |
| 5  | The system shall be safe                            |
| 6  | The system shall be prestigious                     |
| 7  | The system shall follow all regulations             |
| 8  | The system shall be profitable                      |
| 9  | The system shall be easy to use                     |
| 10 | The system shall be able to charge vehicles         |

### 2. Regulatory Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall follow sensitive data storage regulations                            |
| 2  | The system shall follow all regulations relating to the power grid and power supplier |

### 3. Effectiveness Measures

| Id | Requirement                               |
|----|---|
| 1  | The system shall provide adequate heating |
| 2  | The system shall provide green energy     |
| 3  | The system shall be reliable              |
| 4  | The system shall minimize energy waste    |
| 5  | The system shall be cheap                 |
| 6  | The system shall be easy to use           |

## B.1 Tier 0 Requirements

### 4. Tier 0: System Requirements

#### 1. Functional Requirements

| Id | Requirement                               |
|----|---|
| 1  | The system shall harvest renewable energy |
| 2  | The system shall store energy             |
| 3  | The system shall provide heat             |
| 4  | The system shall be emission neutral      |

#### 2. Interface Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall interface with external power-grid |
| 2  | The system shall interface with internal power-grid |
| 3  | The system shall provide a user interface           |

#### 3. Temporal Performance Requirements

| Id | Requirement   |
|----|---|
| 1  | The MTTF of the system panels shall be > 1 year           |
| 2  | The MTTR of the system shall be < 2 days                  |
| 3  | The user interface of the system shall have a MTTL < 5min |

#### 4. Non-temporal Performance Requirements

| Id | Requirement  |
|----|--|
| 1  | The system shall provide 60% of the buildings energy consumption over a year |
| 2  | The system shall not throw away more than 1% of energy produced              |
| 3  | The system shall provide 96MWh for space heating                             |
| 4  | The system shall provide 64MWh for domestic hot water heating                |
| 5  | The system shall cost no more than 8MNOK                                     |

## B.2 Tier 1 Requirements

### 5. Tier 1: Subsystem Requirements

#### 1. Control System

##### *1. Functional Requirements*

| Id | Requirement                               |
|----|---|
| 1  | The system shall process data             |
| 2  | The system shall manage heat distribution |

##### *2. Interface Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall provide data interface with the photovoltaic system   |
| 2  | The system shall provide data interface with the energy storage system |
| 3  | The system shall provide data interface with the geothermal system     |
| 4  | The system shall provide user interface to customers                   |
| 5  | The system shall provide user interface to developers                  |
| 6  | The system shall interface with the internet                           |

##### *3. Temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall not sell more than 100KWh per hour   |
| 2  | The system shall sell minimum 80% of total power sales during the peak power price window (08:00->09:00 & 17:00->18:00) |
| 3  | The system shall buy minimum 80% of total power purchase during the cheapest power price window (02:00->04:00)          |

##### *4. Non-temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system service shall cost no more than 30k NOK annually |
| 2  | The system shall cost no more than 50k                      |

#### 2. Photovoltaic System

##### *1. Functional Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall convert sunlight to DC electricity   |
| 2  | The system shall measure its current power production |

##### *2. Interface Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall provide metadata using RS-485   |
| 2  | The system shall send DC electricity to the energy storage system                      |
| 3  | The system shall send AC electricity to the local power grid                           |
| 4  | The system shall send AC electricity to the external power grid                        |
| 5  | The system shall provide a heat exchanger interface with the geothermal cooling system |

*3. Temporal Performance Requirements*

| Id | Requirement                                    |
|----|--|
| 1  | The MTTF of the solar panels shall be > 1 year |
| 2  | The MTTR of the solar panels shall be < 1 day  |

*4. Non-temporal Performance Requirements*

| Id | Requirement  |
|----|--|
| 1  | The solar panels shall have a Wp of minimum 160                                  |
| 2  | The solar panels mounted on the roof shall be placed with a slope angle of 40°   |
| 3  | The solar panels mounted on the roof shall be placed with an azimuth angle of 2° |
| 4  | The system shall cost no more than 3MNOK   |

**3. Energy Storage System**

*1. Functional Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall be able to store energy in the dynamic storage     |
| 2  | The system shall be able to store energy in the static storage      |
| 3  | The system shall be able to provide energy from the static storage  |
| 4  | The system shall be able to provide energy from the dynamic storage |

*2. Interface Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall provide metadata using RS-485   |
| 2  | The system shall receive data instructions using RS-485                                |
| 3  | The system shall be able to receive DC electricity from the photovoltaic system        |
| 4  | The system shall be able to receive AC electricity from the external power grid        |
| 5  | The system shall be able to send AC electricity to the building power grid             |
| 6  | The system shall provide a heat exchanger interface with the geothermal cooling system |

*3. Temporal Performance Requirements*

| Id | Requirement  |
|----|--|
| 1  | The MTTF of the static batteries shall be > 5 years  |
| 2  | The MTTR the static batteries shall be < 1 day   |
| 3  | The system shall not increase the battery cycles of the vehicles with more than 150 cycles per year. |

*4. Non-temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The static batteries shall provide storage capacity of minimum 0.5 MWh                  |
| 2  | The V2B system shall provide storage capacity of minimum 5MWh                           |
| 3  | The V2B system shall provide a two-way DC charger with 200 A at up to 450 V per vehicle |

### *5. Design Requirements*

| Id | Requirement  |
|----|--|
| 1  | The static batteries shall cost no more than 1.8MNOK |
| 2  | The V2B system shall cost no more than 1.3MNOK       |
| 3  | The system shall cost no more than 3.3MNOK           |

### *4. Geothermal System*

#### *1. Functional Requirements*

| Id | Requirement                   |
|----|-------------------------------|
| 1  | The system shall produce heat |
| 2  | The system shall absorb heat  |

#### *2. Interface Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall receive data instructions using RS-485                                  |
| 2  | The system shall provide metadata using RS-485   |
| 3  | The system shall provide a heat exchanger interface to the waterborne heating system     |
| 5  | The system shall provide a heat exchanger interface to the energy storage cooling system |
| 6  | The system shall provide a heat exchanger interface to the ventilation system.           |
| 7  | The system shall accept AC electricity with maximum 50A at 400V                          |
| 8  | The system shall provide a heat exchanger interface to the photovoltaic cooling system   |
| 9  | The system shall provide a heat exchanger interface to the domestic hot water system     |

#### *3. Temporal Performance Requirements*

| Id | Requirement                             |
|----|---|
| 1  | The system shall have a MTTF > 1 year   |
| 2  | The system shall have a MTTR < 12 hours |

#### *4. Non-temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall have a rated heat output of >= 67 kW   |
| 2  | The system shall have a rated heat removal output of >= 20 kW   |
| 3  | The system shall produce heat with an energy ratio of at least 1:3.1 when the outdoor temperature is -7°C                     |
| 4  | The system shall produce heat with an energy ratio of at least 1:3.6 when the outdoor temperature is +2°C                     |
| 5  | The system shall produce heat with an energy ratio of at least 1:4 when the outdoor temperature is +7°C                       |
| 6  | The system shall produce heat with an energy ratio of at least 1:4.3 when the outdoor temperature is +12°C                    |
| 7  | The system shall produce cooling with an energy ration of at least 1:4 when the outdoor temperature is between +12°C and -7°C |
| 8  | The system operational temperature shall be > -10°C   |
| 9  | The system shall cost no more than 1.4MNOK  |

### B.3 Tier 2 Requirements

#### 6. Tier 2: Sub-Subsystems Requirements:

##### 1. Control Unit Requirements

###### *1. Functional Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall be able to turn geothermal heat system on/off                                    |
| 2  | The system shall be able to turn geothermal cooling system on/off                                 |
| 3  | The system shall be able to store temperature sensor data from all the apartments in the database |
| 4  | The system shall be able to store proximity sensor data from all the apartments in the database   |
| 5  | The system shall be able to interpret instructions from the MCU                                   |

###### *2. Interface Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall provide a RS-485 interface with the Geothermal system                                 |
| 2  | The system shall provide a RS-485 interface with the photovoltaic system                               |
| 3  | The system shall provide a virtual interface over the internet with the MCU                            |
| 4  | The system shall provide a RS-485 interface with the energy storage system                             |
| 5  | The system shall provide a Cat 5e ethernet interface with the local router                             |
| 6  | The system shall provide RS-485 interfaces to all apartment radiator valve adjusters                   |
| 7  | The system shall provide RS-485 interfaces to all apartment floor heating valve adjusters              |
| 8  | The system shall provide RS-485 interfaces to all apartment heating ventilation valve adjusters        |
| 9  | The system shall provide RS-485 interfaces to all apartment cooling ventilation valve adjusters        |
| 10 | The system shall provide RS-485 interface to temperature sensors attached to apartment ventilation     |
| 11 | The system shall receive AC electricity with maximum 16A at 250V                                       |
| 12 | The system shall receive data instructions using Cat 5e ethernet                                       |
| 13 | The system shall provide RS-485 interface to the energy storage system cooling valve adjuster          |
| 14 | The system shall provide RS-485 interface to the photovoltaic system cooling valve adjuster            |
| 15 | The system shall access the database system using a C++ connector                                      |
| 16 | The system shall provide a heat exchanger interface with the geothermal cooling system                 |
| 17 | The system shall provide RS-485 interface to temperature sensors attached to domestic hot water system |
| 18 | The system shall provide RS-485 interface to temperature sensors inside apartments                     |
| 19 | The system shall provide RS-485 interface to proximity sensors inside apartments                       |
| 20 | The system shall use end to end encryption for communication with the server                           |

###### *3. Temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall execute instruction within <= 10ms of receiving them |
| 2  | The MTTF of the system shall be > 5 year                              |

|   |   |
|---|---|
| 3 | The MTTR of the system shall be < 12 hours  |
| 4 | The system shall produce an error if the instruction fails to execute within the time limit |

#### 4. Non-temporal Performance Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall use maximum 5GB random access memory |
| 2  | The system shall cost no more than 50k NOK            |

### 2. Main Communication Requirements

#### 1. Functional Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall provide a data structure: updateQueue                  |
| 2  | The system shall put received real-time instructions in the updateQueue |
| 3  | The system shall be able to interpret instructions in the updateQueue   |
| 4  | The system shall be able to interpret instructions from the database    |

#### 2. Interface Requirements

| Id | Requirement  |
|----|--|
| 1  | The system shall access the database system using a C++ connector                      |
| 2  | The system shall provide an interface to the web-application / smart-phone application |

#### 3. Temporal Performance Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall empty and send instructions from the updateQueue within an interval of maximum 10 seconds. |
| 2  | The system shall pass on scheduled instructions with a maximum delay of 60 seconds                          |
| 3  | The MTTF of the system shall be > 5 year  |
| 4  | The MTTR of the system shall be < 1 day   |

#### 4. Non-temporal Performance Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall use maximum 1GB random access memory |
| 2  | The system shall cost 0 NOK                           |

### 3. Database Requirements

#### 1. Functional Requirements

| Id | Requirement                              |
|----|--|
| 1  | The system shall provide CRUD operations |
| 2  | The system shall anonymize personal data |

## *2. Interface Requirements*

| <b>Id</b> | <b>Requirement</b>                                 |
|-----------|--|
| 1         | The system shall provide a C++ connector interface |

## *3. Temporal Performance Requirements*

| <b>Id</b> | <b>Requirement</b>   |
|-----------|--|
| 1         | The CRUD time in the MongoDB shall not be larger than 0.01 seconds per 10000 documents |
| 2         | The CRUD time in the MySQL DB shall not be larger than 0.01 seconds per 1000 rows      |
| 3         | The MTTF of the system shall be > 5 year   |
| 4         | The MTTR of the system shall be < 1 day  |

## *4. Non-temporal Performance Requirements*

| <b>Id</b> | <b>Requirement</b>   |
|-----------|--|
| 1         | The system shall be able to horizontally scale when reaching 80% of maximum RAM capacity |
| 2         | The system shall be able to vertically scale to maintain <1 ms read time                 |
| 3         | The system shall be able to vertically scale to maintain <10 ms write time               |
| 4         | The system shall cost 0 NOK  |

## 4. Data-Gathering Software Requirements

### *1. Functional Requirements*

| <b>Id</b> | <b>Requirement</b>                              |
|-----------|---|
| 1         | The system shall gather continuous weather-data |
| 2         | The system shall gather continuous power-prices |

### *2. Interface Requirements*

| <b>Id</b> | <b>Requirement</b>  |
|-----------|---|
| 1         | The system shall access the database system using a C++ connector                                 |
| 2         | The system shall provide a virtual interface with a weather forecasting service over the internet |
| 3         | The system shall provide a virtual interface with a power price database over the internet        |

### *3. Temporal Performance Requirements*

| <b>Id</b> | <b>Requirement</b>  |
|-----------|---|
| 1         | The system shall gather weather forecasts for the next 24 hours every day between 23:50 and 23:59 |
| 2         | The system shall gather power-prices for the previous day, every day between 00:00 and 00:10.     |
| 3         | The MTTF of the system shall be > 1 year  |
| 4         | The MTTR of the system shall be < 2 days  |

#### 4. Non-temporal Performance Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall use maximum 100MB random access memory |
| 2  | The system shall cost 0 NOK                             |

#### 5. Machine Learning Software Requirements

##### 1. Functional Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall make decisions for temperature settings, allocation of energy, |
| 2  | The system shall predict solar power production                                 |
| 3  | The system shall predict power prices   |

##### 2. Interface Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall access the database system using a C++ connector |

##### 3. Temporal Performance Requirements

| Id | Requirement                              |
|----|--|
| 1  | The MTTF of the system shall be > 1 year |
| 2  | The MTTR of the system shall be < 2 days |

#### 4. Non-temporal Performance Requirements

| Id | Requirement   |
|----|---|
| 1  | The system shall be able to predict the hourly solar power production for the next day with an error margin of 2.3 kW |
| 2  | The system shall be able to predict hourly power prices for the next day with an error margin of 33.6 NOK/MWh         |
| 3  | The system shall cost 0 NOK   |

#### 6. Application/Website Requirements

##### 1. Functional Requirements

| Id | Requirement  |
|----|--|
| 1  | The system shall let the user specify wanted temperature in every room of the apartment                              |
| 2  | The system shall let the user turn vehicle-to-building on or off   |
| 3  | The system shall let the user specify the estimated time until electric vehicle is needed.                           |
| 4  | The system shall provide the user with statistics for power consumption, current temperature, vehicle battery status |
| 5  | The system shall let the user specify desired state of charge for their electric vehicle at any set time             |

*2. Interface Requirements*

| Id | Requirement   |
|----|---|
| 1  | The web-application shall work in the following browsers: Google Chrome, Mozilla Firefox, Apple Safari, Internet Edge |
| 2  | The system shall work on both Android and iOS.  |
| 3  | The system shall access the database system using a C++ connector   |
| 4  | The system shall provide a user interface   |
| 5  | The system shall use end to end encryption for communication with the server  |

*3. Temporal Performance Requirements*

| Id | Requirement                               |
|----|---|
| 1  | The system shall have a MTTL <= 5 minutes |
| 2  | The MTTF of the system shall be > 1 year  |
| 3  | The MTTR of the system shall be < 2 days  |

*4. Non-temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The application shall use maximum 500MB random access memory        |
| 2  | The website shall use maximum 10MB random access memory per request |
| 3  | The system shall cost 0 NOK   |

**7. Developer Tools Requirements**

*1. Functional Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall present the user with statistics for machine learning performance |
| 2  | The system shall let the user run diagnostics on the system                        |
| 3  | The system shall let the user handle support tickets                               |

*2. Interface Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall work on Windows versions >= 10                              |
| 2  | The system shall work on Debian based Linux distributions with kernels > 5.0 |
| 3  | The system shall access the database system using a C++ connector            |
| 4  | The system shall provide a user interface                                    |
| 5  | The system shall use end to end encryption for communication with the server |

*3. Temporal Performance Requirements*

| Id | Requirement  |
|----|--|
| 1  | The system shall deploy machine learning algorithm changes within 24 hours |
| 2  | The MTTF of the system shall be > 1 year                                   |
| 3  | The MTTR of the system shall be < 2 days                                   |

*4. Non-temporal Performance Requirements*

| Id | Requirement   |
|----|---|
| 1  | The system shall use maximum 1GB random access memory |
| 2  | The system shall cost 0 NOK                           |

## C Code

### C.1 Historical Weather Web-Crawler

---

```
package frostapi;

import java.io.BufferedReader;
import java.io.File;
import java.io.FileWriter;
import java.io.IOException;
import java.time.YearMonth;
import org.apache.commons.codec.binary.Base64;
import org.jsoup.Connection;
import org.jsoup.Jsoup;

public class FrostAPI {

    private final static String STASJON = "18700";
    private final static String[] DATAELEMENTS = {"air_temperature",
        "cloud_area_fraction",
        "cloud_area_fraction1",
        "cloud_area_fraction2",
        "cloud_area_fraction3",
        "cloud_area_fraction4",
        "surface_air_pressure",
        "wind_speed",
        "wind_speed_of_gust",
        "dew_point_temperature",
        "wind_from_direction",
        "relative_humidity",
        "precipitation_amount",
        "weather_type",
        "weather_type_automatic"};
    private final static String AUTH = "REDACTED";
    private final static String BASE64AUTH = new
        String(Base64.encodeBase64(AUTH.getBytes()));
    private static BufferedWriter bw;
    private static BufferedWriter logWriter;

    public static void main(String[] args) throws Exception {
        logWriter = new BufferedWriter(new FileWriter(new File("errors")));
        bw = new BufferedWriter(new FileWriter(new File("fixedData.json")));
        bw.write("{");
        bw.newLine();
        for (int i = 2005; i <= 2016; i++) {
            loopYear(i);
        }
        bw.newLine();
        bw.write("}");
    }
}
```

```

        bw.close();
        logWriter.close();
    }

    private static void loopYear(int year) throws Exception {
        for (int i = 1; i <= 12; i++) {
            YearMonth yearMonthObject = YearMonth.of(year, i);
            int daysInMonth = yearMonthObject.lengthOfMonth();
            for (int j = 1; j <= daysInMonth; j++) {
                sendRequest(year, i, j);
            }
        }
    }

    private static void sendRequest(int year, int month, int day) throws Exception {
        String concat = ",";
        for (int i = 0; i < 24; i++) {
            try {
                Connection.Response get =
                    Jsoup.connect("https://frost.met.no/observations/v0.jsonld?sources=sn"
                        + STASJON + "&referencetime=" + fullNumber(year) + "-"
                        + fullNumber(month) + "-" + fullNumber(day) + "T" + fullNumber(i)
                        + "&elements=" + constructElements())
                    .header("authorization", "Basic " + BASE64AUTH)
                    .method(Connection.Method.GET)
                    .ignoreContentType(true)
                    .execute();

                if (i != 0) {
                    concat += ",";
                }
                concat += "\n" + fullNumber(year) + fullNumber(month)
                    + fullNumber(day) + fullNumber(i) + ":" + get.body();
            } catch (IOException e) {
                logWriter.write(fullNumber(year) + fullNumber(month)
                    + fullNumber(day) + fullNumber(i));
                logWriter.newLine();
                logWriter.write(e.toString());
                logWriter.newLine();
                logWriter.write(e.getMessage());
                logWriter.newLine();
            }
        }
        bw.write(concat);
    }

    private static String fullNumber(int number) {
        if (number < 10) {

```

```

        return "0" + number;
    } else {
        return Integer.toString(number);
    }
}

private static String constructElements() {
    String elements = "";
    for (int i = 0; i < DATAELEMENTS.length; i++) {
        if (i != 0) {
            elements += ",";
        }
        String dataElement = DATAELEMENTS[i];
        elements += dataElement;
    }
    return elements;
}

```

---

## C.2 MongoDB Filler

```

#include <iostream>
#include <fstream>
#include <string>
#include <bsoncxx/builder/stream/document.hpp>
#include <bsoncxx/json.hpp>
#include <mongocxx/client.hpp>
#include <mongocxx/instance.hpp>
#include "boost/property_tree/ptree.hpp"
#include "boost/property_tree/json_parser.hpp"
#include "boost/date_time/posix_time/posix_time.hpp"
#include <boost/foreach.hpp>
#include <thread>
#include <vector>
#include <functional>
#include <algorithm>
#include "power.h"
#include <boost/algorithm/string/replace.hpp>

using boost::property_tree::ptree;
using boost::posix_time::ptime;
using boost::posix_time::from_iso_string;

bool fillSunWall(std::string, mongocxx::client&);
bool fillWeather(mongocxx::client&);
bool parseSun();

```

```

bool fillPowerPrices(mongocxx::client&);

std::string powerPath = "data/PowerData/El";
std::string powerExt = ".csv";

std::string weatherPath = "data/WeatherData/data2.json";
std::string sunPath = "data/SolarData/";
std::string jsonExt = ".json";

int main(int, char**)
{
    mongocxx::instance inst{};
    mongocxx::client conn{
        mongocxx::uri{
            "mongodb+srv://kent:<Password>@terrasolaris-robmp.azure.
            mongodb.net/test?retryWrites=true&w=majority"}};

    fillSunWall("roof", conn);
    fillSunWall("south", conn);
    fillSunWall("west", conn);
    fillSunWall("east", conn);
    fillWeather(conn);
    fillPowerPrices(conn);

    return 0;
}

bool fillSunWall(std::string direction, mongocxx::client& conn)
{
    for(int i = 1; i <= 3; i++)
    {
        std::cout << "Document: " << direction + std::to_string(i) << "\n";
        std::ifstream ist(sunPath + direction + std::to_string(i) + jsonExt);
        ptree pt;
        read_json(ist, pt);

        pt = pt.get_child("outputs").get_child("hourly");

        for (auto & array_element : pt) {

            std::string time = array_element.second.get<std::string>("time");
            time.replace(8, 1, "T");
            ptime t = from_iso_string(time);
            double p_val = array_element.second.get<double>("P");

            bsoncxx::builder::stream::document document{};
            auto builder = bsoncxx::builder::stream::document{};
            bsoncxx::document::value doc_value = builder
                << "time" << to_iso_extended_string(t)

```

```

        << "p" << p_val
        << bsoncxx::builder::stream::finalize;
    auto collection = conn["Terra"]["sun" + direction];
    collection.insert_one(doc_value.view());
}
}

return true;
}

void fillData(boost::property_tree::ptree &pt, std::string time, mongocxx::client& conn)
{
    bsoncxx::builder::stream::document doc{};
    time = time.substr(0, 16);
    doc << "time" << time;

    for (auto & array_element : pt) {

        std::string elementId = array_element.second.get<std::string>("elementId");
        double value = array_element.second.get<double>("value");
        doc << elementId << array_element.second.get<double>("value");
    }

    auto collection = conn["Terra"]["weather"];
    collection.insert_one(doc.view());
}

void fillDoc(boost::property_tree::ptree &pt, std::string time, mongocxx::client& conn)
{
    if(pt.empty())
    {
        return;
    }
    else
    {
        for (boost::property_tree::ptree::iterator pos = pt.begin(); pos != pt.end();)
        {
            if(pos->first == "referenceTime")
            {
                time = pos->second.data();
            }
            else if(pos->first == "observations")
            {
                fillData(pos->second, time, conn);
            }
            fillDoc(pos->second, time, conn);
            ++pos;
        }
    }
}

```

```

bool fillWeather(mongocxx::client& conn)
{
    std::ifstream ist(weatherPath);
    ptree pt;
    read_json(ist, pt);
    bsoncxx::builder::stream::document doc{};
    std::vector<std::thread*> threads;

    fillDoc(pt, "", conn);

    return true;
}

bool fillPowerPrices(mongocxx::client& conn)
{
    const int dateIndex = 0;
    const int hourIndex = 1;
    const int osloIndex = 10;

    for(int year = 2013; year <= 2020; year++)
    {
        std::cout << "Year: " << year << "\n";
        std::ifstream file;
        file.open(powerPath + std::to_string(year) + powerExt);
        auto table = readCSV(file);
        for(int i = 3; i < table.size(); i++)
        {
            std::string date = table[i][dateIndex];
            std::string hour = table[i][hourIndex];
            std::string price = (table[i][osloIndex]);
            boost::replace_all(price, ",", ".");
            if(price.empty())
            {
                continue;
            }
            double priceNum = std::stod(price);
            std::string time = date.substr(6, 4) + "-" + date.substr(3, 2) + "-" +
                date.substr(0, 2) + "T" + hour.substr(0, 2) + ":00:00";

            bsoncxx::builder::stream::document document{};
            auto builder = bsoncxx::builder::stream::document{};
            bsoncxx::document::value doc_value = builder
                << "time" << time
                << "price" << priceNum
                << bsoncxx::builder::stream::finalize;
            auto collection = conn["Terra"]["powerPrices"];
            collection.insert_one(doc_value.view());
        }
    }
}

```

```

        }
    }

    return true;
}

```

---

### C.3 Historical Hourly Avg. Power Price

```

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.tree import DecisionTreeRegressor
from sklearn import metrics
import datetime as dt
import pymongo
from mongoConfigFile import *

hourPrices = [0] * 24
hourPoints = [0] * 24
hours = list(range(0, 24))

clientUrl =
    ("mongodb+srv://{}:{}@terralsolaris-robmp.azure.mongodb.net/test?retryWrites=true&w=majority".
     format(mongoUsername, mongoPassword))
client = pymongo.MongoClient(clientUrl)
db = client["Terra"]

def main():
    fillData()
    drawPower()

def fillData():
    print("Fyller priser..")
    collection = db["powerPrices"]
    #cursor = collection.find({"time": "2005-01-01T00:00:00"})
    cursor = collection.find({})
    for document in cursor:

        date = pd.to_datetime(document["time"])
        hourPrices[int(date.hour)] += document["price"]
        hourPoints[int(date.hour)] += 1

def drawPower():
    print("drawing")
    X = []

```

```

for i in range(0, len(hours)):
    X.append(hourPrices[i] / hourPoints[i])

y = hours

objects = hours
y_pos = np.arange(len(hours))
performance = X

plt.bar(y_pos, performance, align='center', alpha=0.5)
plt.xticks(y_pos, objects)
plt.ylabel('NOK per MWh')
plt.xlabel('Hour of day')
plt.title('Average hourly power price 2013-2020')

plt.show()

main()

```

---

## C.4 Machine Learning

### Solar Power Production

```

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.tree import DecisionTreeRegressor
from sklearn import metrics
import datetime as dt
import pymongo
from mongoConfigFile import *

power = []
dates = []
weather = {}
data = {'Year': [], 'Month': [], 'Day': [], 'Hour': [], 'Temp': [],
        'CloudAreaFraction': [], 'CloudBaseHeight': [], 'WeatherType': [], 'Power': []}
clientUrl =
    ("mongodb+srv://{}:{}@terrassolaris-robmp.azure.mongodb.net/test?retryWrites=true&w=majority".
     format(mongoUsername, mongoPassword))
client = pymongo.MongoClient(clientUrl)
db = client["Terra"]

def main():
    fillData()
    fillWeather()

```

```

dataset = fillPanda()
betterPredictWithWeather(dataset)

def fillData():
    print("Fyller sol..")
    collection = db["sunsouth"]
    cursor = collection.find({})
    for document in cursor:
        dates.append(document["time"])
        power.append(document["p"])

def fillWeather():
    print("Filling weather..")
    collection = db['weather']
    cursor = collection.find({})
    for document in cursor:
        arr = []
        arr.append(document.get('air_temperature'))
        arr.append(document.get('cloud_area_fraction'))
        arr.append(document.get('cloud_base_height'))
        arr.append(document.get('weather_type'))
        weather[document['time'] + ':00'] = arr

def fillPanda():
    print('Fyller Panda..')
    db = client["Terra"]
    collection = db["weather"]

    for date in dates:
        l = weather.get(date)
        date = pd.to_datetime(date)
        data['Year'].append(int(date.year))
        data['Month'].append(int(date.month))
        data['Day'].append(int(date.day))
        data['Hour'].append(int(date.hour))
        default = None
        data['Temp'].append(l[0] if l is not None and 0 < len(l) else default)
        data['CloudAreaFraction'].append(l[1] if l is not None and 1 < len(l) else default)
        data['CloudBaseHeight'].append(l[2] if l is not None and 2 < len(l) else default)
        data['WeatherType'].append(l[3] if l is not None and 3 < len(l) else default)

    data['Power'] = power
    df = pd.DataFrame(data=data)
    df.fillna(df.mean(), inplace=True)
    df = df.reset_index()
    return df

def betterPredictWithWeather(dataset):

```

```

X = dataset[['Year', 'Month', 'Day', 'Hour', 'Temp', 'CloudAreaFraction',
             'CloudBaseHeight', 'WeatherType']].values
y = dataset['Power'].values

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.01, shuffle=False)
regressor = DecisionTreeRegressor(random_state = 0)
regressor.fit(X_train, y_train)
y_pred = regressor.predict(X_test)

print('Mean Absolute Error:', metrics.mean_absolute_error(y_test, y_pred))

X_dates = []
for date in X_test:
    X_dates.append(dt.datetime(int(date[0]), int(date[1]), int(date[2]), int(date[3])))

df = pd.DataFrame({'Actual': y_test, 'Predicted': y_pred}, index = X_dates)

df1 = df.head(100)
ax = df1.plot(kind='bar', figsize=(200,100))
plt.grid(which='major', linestyle='-', linewidth='0.5', color='green')
plt.grid(which='minor', linestyle=':', linewidth='0.5', color='black')

x_labels = df1.index.strftime('%d-%b-%Y %H:00')
ax.set_xticklabels(x_labels)
ax.set_xlabel('Date')
ax.set_ylabel('Wh')
plt.show()

main()

```

---

## Machine Learning, Power Price Prediction

---

```

import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.tree import DecisionTreeRegressor
from sklearn import metrics
import datetime as dt
import pymongo
from mongoConfigFile import *

powerPrices = []
dates = []
data = {'Year': [], 'Month': [], 'Day': [], 'Hour': [], 'PowerPrice': []}
clientUrl =
    "mongodb+srv://{}:{}@terrassolaris-robmp.azure.mongodb.net/test?retryWrites=true&w=majority".

```

```

        format(mongoUsername, mongoPassword))
client = pymongo.MongoClient(clientUrl)
db = client["Terra"]

def main():
    fillData()
    dataset = fillPanda()
    betterPredict(dataset)

def fillData():
    print("Fyller priser..")
    collection = db["powerPrices"]
    #cursor = collection.find({"time": "2005-01-01T00:00:00"})
    cursor = collection.find({})
    for document in cursor:
        dates.append(document["time"])
        powerPrices.append(document["price"])

def fillPanda():
    print('Fyller Panda..')

    for date in dates:
        date = pd.to_datetime(date)
        data['Year'].append(int(date.year))
        data['Month'].append(int(date.month))
        data['Day'].append(int(date.day))
        data['Hour'].append(int(date.hour))

    data['PowerPrice'] = powerPrices
    df = pd.DataFrame(data=data)
    df.fillna(value=pd.np.nan, inplace=True)
    df = df.reset_index()
    return df

def betterPredict(dataset):
    X = dataset[['Year', 'Month', 'Day', 'Hour']].values
    y = dataset['PowerPrice'].values

    X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.01,
                                                       shuffle=False), random_state=0)

    regressor = DecisionTreeRegressor(random_state = 0)
    regressor.fit(X_train, y_train)
    y_pred = regressor.predict(X_test)

    X_dates = []
    for date in X_test:
        X_dates.append(dt.datetime(date[0], date[1], date[2], date[3]))
```

```

df = pd.DataFrame({'Actual': y_test, 'Predicted': y_pred}, index = X_dates)

df1 = df.head(50)
ax = df1.plot(kind='bar', figsize=(200,100))
plt.grid(which='major', linestyle='-', linewidth='0.5', color='green')
plt.grid(which='minor', linestyle=':', linewidth='0.5', color='black')

x_labels = df1.index.strftime('%d-%b-%y %H:00')
ax.set_xticklabels(x_labels)
ax.set_xlabel('Date')
ax.set_ylabel('NOK/MWh')
plt.show()

print('Mean Absolute Error:', metrics.mean_absolute_error(y_test, y_pred))

main()

```

---

## C.5 Web-Application

### script.js

```

//Every room area is built with x,y coordinates. Always starting at top left corner, then
//going clockwise
function Plan(width,height) {
    this.bedroom1={color:"#C4CDE0",
    name:"Soverom 1",
    area:
    width*3/5+", "+0+" "
    +width+", "+0+" "
    +width+", "+height*1/6+" "
    +width*3/5+", "+height*1/6,
    x:width*3.5/5,y:height*1/6/2};

    this.bedroom2={color:"#CDEOC4",
    name:"Soverom 2",
    area:
    width*3/5+", "+height*1/6+" "
    +width+", "+height*1/6+" "
    +width+", "+height*2/6+" "
    +width*3/5+", "+height*2/6,
    x:width*3.5/5,y:height*1/4};

    this.bedroom3={color:"#CDEOC4",
    name:"Soverom 3",
    area:
    0+", "+height*5/6+" "
    +width*2/6+", "+height*5/6+" "

```

```

+width*2/6+", "+height+" "
+0+", "+height,
x:width*1/10,y:height*11/12};

this.hallway={color:"#A09CB3",
name:"Gang",
area:
0+", "+0+" "
+width*3/5+", "+0+" "
+width*3/5+", "+height*3/6+" "
+width*2/5+", "+height*3/6+" "
+width*2/5+", "+height*1/12+" "
+0+", "+height*1/12,
x:width*1/5,y:height*0.6/12};

this.office={color:"#C4CDE0",
name:"Kontor",
area:
0+", "+height*1/12+" "
+width*2/5+", "+height*1/12+" "
+width*2/5+", "+height*1.5/6+" "
+0+", "+height*1.5/6,
x:width*1/6,y:height*1/6};

this.livingroomAndKitchen={color:"#E0C4CD",
name:"Stue og kjokken",
area:
0+", "+height*2.5/6+" "
+width*2/5+", "+height*2.5/6+" "
+width*2/5+", "+height*3/6+" "
+width+", "+height*3/6+" "
+width+", "+height+" "
+width*2/6+", "+height+" "
+width*2/6+", "+height*5/6+" "
+0+", "+height*5/6+" ",
x:width*1/2,y:height*3/4};

this.bathroom1={color:"#C4DBE0",
name:"Bad 1",
area:
width*3/5+", "+height*2/6+" "
+width+", "+height*2/6+" "
+width+", "+height*3/6+" "
+width*3/5+", "+height*3/6,
x:width*3.5/5,y:height*4.2/10};

this.bathroom2={color:"#C4DBE0",
name:"Bad 2",
area:
0+", "+height*1.5/6+" "

```

```

+width*2/5+" "+height*1.5/6+" "
+width*2/5+" "+height*2.5/6+" "
+0+" "+height*2.5/6,
x:width*1/6,y:height*2/6};
};

function applyTempIndexEventListeners(){
//temperatureValueArray contains temperatures matching the index from Plan obj.
let container = document.getElementById('svgContainer');
let svg = document.createElementNS("http://www.w3.org/2000/svg","svg");
let width = document.body.clientWidth;
let height = width*2;
let romPlan = new Plan(width,height);
let keys = Object.keys(romPlan);
for (var i = 0; i < keys.length; i++) {
    let tempGroup = document.createElementNS("http://www.w3.org/2000/svg","g");
    let roomName = romPlan[keys[i]].name
    tempGroup.setAttribute("data-url",roomName);
    tempGroup.addEventListener("click",function(){
        let roomName = this.getAttribute("data-url");
        //console.log(roomName);
        window.location.href = "/temperatur/endre?rom="+roomName.toLowerCase();
    });
    let tempPolygon = document.createElementNS("http://www.w3.org/2000/svg","polygon");
    let tempTextRoom = document.createElementNS("http://www.w3.org/2000/svg","text");
    tempTextRoom.innerHTML = roomName;
    tempTextRoom.setAttribute("x",romPlan[keys[i]].x);
    tempTextRoom.setAttribute("y",romPlan[keys[i]].y);
    let tempTextTemperature =
        document.createElementNS("http://www.w3.org/2000/svg","text");
    tempTextTemperature.innerHTML = temperatureValueArray[i]+"C";
    tempTextTemperature.setAttribute("x",romPlan[keys[i]].x);
    tempTextTemperature.setAttribute("y",romPlan[keys[i]].y+20);
    tempPolygon.setAttribute("points",romPlan[keys[i]].area);
    tempPolygon.setAttribute("stroke","black");
    tempPolygon.setAttribute("fill",romPlan[keys[i]].color);
    tempGroup.appendChild(tempPolygon);
    tempGroup.appendChild(tempTextRoom);
    tempGroup.appendChild(tempTextTemperature);
    svg.appendChild(tempGroup);
}

svg.setAttribute("width",width);
svg.setAttribute("height",height);

container.appendChild(svg);
}

function findRoomId(roomName){

```

```

let romPlan = new Plan(0,0);
let keys = Object.keys(romPlan);
for (var i = 0; i < keys.length; i++) {
  if (roomName==romPlan[keys[i]].name) {
    return i+1;
  }
}
}

function applyTempChangeEventListeners(){
  //Smaller variable = quicker temperature update
  var responsiveness = 50;

  var currentAngle = 0;
  var tempChange = 0;

  var roomId = findRoomId(document.getElementById("romDiv").innerText);
  setInitialTemperature(roomId);

  var temperatureWheel = document.getElementById('temperatureWheel');
  var region = new ZingTouch.Region(temperatureWheel);
  region.bind(temperatureWheel, 'rotate', function(e){
    tempChange += e.detail.distanceFromLast;
    currentAngle += e.detail.distanceFromLast;
    temperatureWheel.style.transform = 'rotate(' + currentAngle + 'deg)';
    let temperatureDerivedFromAngle = Math.round(tempChange/responsiveness);
    if(temperatureDerivedFromAngle != 0){
      tempChange = 0;
      updateRoomTemperature(temperatureDerivedFromAngle,roomId);
    }
  });
}

function setInitialTemperature(id){
  var roomTemperatureDiv = document.getElementById('degrees');
  var oReq = new XMLHttpRequest();
  oReq.addEventListener("load", function(){
    let data = JSON.parse(this.response);
    roomTemperatureDiv.innerText = data.temperatureValue;
  });
  oReq.open("POST", "/temperatur/getSpecificTemperature");
  oReq.setRequestHeader("Content-Type", "application/x-www-form-urlencoded");
  oReq.send("temperatureId="+id);
}

function updateRoomTemperature(degrees,id){
  let roomTemperatureDiv = document.getElementById('degrees');
  let oldTemperature = parseInt(roomTemperatureDiv.innerText);
  let newTemperature = oldTemperature+degrees;
  //User limit on temperature control
}

```

```
if(newTemperature<=30 && newTemperature>=15){
    roomTemperatureDiv.innerText = newTemperature;
    var oReq = new XMLHttpRequest();
    oReq.addEventListener("load", function(){
    });
    oReq.open("POST", "/temperatur/updateSpecificTemperature");
    oReq.setRequestHeader("Content-Type", "application/x-www-form-urlencoded");
    oReq.send("temperatureId="+id+"&temperatureValue="+newTemperature);
}
}
```

---

### nav.php

```
<?php
$action = $this->getAction();
?>
<nav class="navbar navbar-light bg-light">
    
    <a href="/temperatur"><button class="btn-lg btn-primary" type="button">Tilbake</button></a>
    <a href="/"><button class="btn-lg btn-primary" type="button">Meny</button></a>
</nav>
```

---

### header.php

```
<!DOCTYPE html>
<html>
<head>
    <meta charset="UTF-8">
    <title>TSB App</title>
    <meta name="viewport" content="width=device-width, initial-scale=1">
    <link href="/main.css" type="text/css" media="all" rel="stylesheet">
    <link href="/lib/bootstrap/bootstrap.min.css" type="text/css" media="all"
          rel="stylesheet">
    <script
        src='https://cdnjs.cloudflare.com/ajax/libs/zinctouch/1.0.6/zinctouch.min.js'></script>
</head>
<body class='bg-light'>
<script src='/script.js'></script>
```

---

### footer.php

```
</body>
```

```
</html>
```

---

## Temperatur index.php

```
<?php include VIEW.'header.php';?>
<?php include VIEW.'nav.php';?>
<div class='container-fluid p-0'>
    <h1 class="text-center">
        Velg rom
    </h1>
    <div id='svgContainer' class='media'>
    </div>
</div>
<script>
    let temperatureValueArray = [
        <?php
        foreach ($this->viewData as $row) {
            echo $row['temperatureValue']. ",";
        }
        ?>
    ];
    applyTempIndexEventListeners();
</script>
<?php include VIEW.'footer.php';?>
```

---

## endre.php

```
<?php include VIEW.'header.php';?>
<?php include VIEW.'nav.php';?>
<div class='container-fluid'>
    <h1 class="text-center">
        <div class='d-inline-block' id='romDiv'>
            <?php
                echo ucfirst("$this->viewData");
            ?>
        </div>
        <br>
        <div class='d-inline-block'> temperatur:</div>
        <div class='d-inline-block' id='degrees'></div>
        <div class='d-inline-block' id='celcius'>C</div>
    </h1>
    <div id='temperatureWheelContainer' class='media ml-5 mr-5'>
        
    </div>
</div>
```

```
<script>
    applyTempChangeEventListeners();
</script>
<?php include VIEW.'footer.php';?>
```

---

## index.php

```
<?php include VIEW.'header.php';?>
<div style='text-align: center;'>


<h1>Energi kontroll</h1>
<h3>Leilighet 5 D</h3>
</div>
<div class="indexDiv">
    <a href="/temperatur"><button class="btn-lg btn-primary" type="button">Endre temperatur
        i leilighet</button></a>

    </div>
    <div class="indexDiv">
        <a href="/"><button class="btn-lg btn-primary" type="button">Oversikt over
            stromforbruk</button></a>

    </div>
    <div class="indexDiv">
        <a href="/"><button class="btn-lg btn-primary" type="button">Endre lade-innstillinger
            for el-bil</button></a>

    </div>
<?php include VIEW.'footer.php';?>
```

---

## TemperaturModel.php

```
<?php
class TemperaturModel extends Model{

    public function getAllTemperatures(){
        $data = $this->query("SELECT temperatureValue FROM temperatureTable")->fetchAll();
        return $data;
    }

    public function getSpecificTemperature($id){
        $data = $this->query("SELECT temperatureValue FROM temperatureTable WHERE
            temperatureId = $id")->fetch();
        return $data;
    }
}
```

```
public function updateSpecificTemperature($temperature,$id){
    $data = $this->query("UPDATE temperatureTable SET temperatureValue = $temperature
        WHERE temperatureId = $id")->fetch();
    return $data;
}
?

```

---

### TemperaturController.php

```
<?php
class TemperaturController extends Controller{

    public function updateSpecificTemperature(){
        $this->model('TemperaturModel');
        $temperatureId = $_POST['temperatureId'];
        $temperatureValue = $_POST['temperatureValue'];
        $this->model->updateSpecificTemperature($temperatureValue,$temperatureId);
    }

    public function getSpecificTemperature(){
        $this->model('TemperaturModel');
        $temperatureId = $_POST['temperatureId'];
        $data = $this->model->getSpecificTemperature($temperatureId);
        echo json_encode($data);
    }

    public function endre(){
        if(count($_GET) > 0){
            $this->view('temperatur' . '/' . 'endre.php',$_GET['rom']);
            $this->view->render();
        } else {
            header("/");
        }
    }

    public function index(){
        $this->model('TemperaturModel');
        $temperatures = $this->model->getAllTemperatures();
        $this->view('temperatur' . '/' . 'index.php',$temperatures);
        $this->view->render();
    }
}
?

```

---

## HomeController.php

---

```
<?php
class HomeController extends Controller{
    public function index(){

        $this->view('home' . '/' . 'index.php');
        $this->view->render();
    }
?>
```

---

## Application.php

---

```
<?php
class Application{
    protected $controller = 'HomeController';
    protected $action = 'index';

    public function __construct(){
        $this->prepareURL();
        $this->controller = ucfirst($this->controller);
        if(file_exists(CONTROLLER.$this->controller.'.php')){
            $this->controller = new $this->controller;
            if(method_exists($this->controller,$this->action)){
                call_user_func_array([$this->controller,$this->action],[]);
            }
        }
    }

    protected function prepareURL(){
        $request = trim($_SERVER['REQUEST_URI'], '/');
        if(!empty($request)){
            $token = explode('?', $request);
            $urlArray = explode('/', $token[0]);
            if(isset($urlArray[0])){
                $this->controller = $urlArray[0] . 'Controller';
            }
            if(isset($urlArray[1])){
                $this->action = $urlArray[1];
            }
        }
    }
?>
```

---

## Model.php

---

```
<?php
class Model extends PDO{
    private $dsm = 'mysql:dbname=tsb;host=localhost;charset=UTF8';
    private $user = 'tsb';
    private $pw = '';
    public function __construct(){
        parent::__construct($this->dsm,$this->user,$this->pw);
    }
}
?>
```

---

## View.php

---

```
<?php
class View{

    protected $viewData;
    protected $viewFile;

    public function __construct($viewFile,$viewData){
        $this->viewData = $viewData;
        $this->viewFile = $viewFile;
    }
    public function getAction(){
        return (explode('/', $this->viewFile)[1]);
    }
    public function render(){
        if(file_exists(VIEW.$this->viewFile)){
            include VIEW.$this->viewFile;
        }
    }
}
```

---

## Controller.php

---

```
<?php
abstract class Controller{
    protected $model;
    protected $view;
    public function model($modelName){
        $this->model = new $modelName;
    }
    public function view($viewName,$data=[]){


```

```
    $this->view = new View($viewName,$data);  
}  
}
```

---