Final Report

Project 25
Demand response of electrically heated houses

Date: 17.5.2017

Ville Julin
Olli Vaniala
Esa Myrttinen
Jalmari Laaksonen
Jari Heimonen
Information page

Students
Ville Julin
Olli Vaniala
Esa Myrttinen
Jalmari Laaksonen
Jari Heimonen

Project manager
Ville Julin

Official Instructor
Matti Lehtonen

Other advisors
Jonne Jäppinen (Fingrid)
Jan Segerstam (Empower)
Olli Huotari (Empower)

Starting date
5.1.2017

Completion date
17.5.2017

Approval
The Instructor has accepted the final version of this document
Date: 20.4.2017
### Abbreviations

<table>
<thead>
<tr>
<th><strong>Abbreviation</strong></th>
<th><strong>Definition</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>AGG</td>
<td>Aggregate</td>
</tr>
<tr>
<td>BACS</td>
<td>Building Automation and Control System</td>
</tr>
<tr>
<td>BAOS</td>
<td>Bus Access and Object Server</td>
</tr>
<tr>
<td>CMS</td>
<td>Centralized Management System</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>DoS</td>
<td>Denial of Service attack</td>
</tr>
<tr>
<td>DR</td>
<td>Demand Response</td>
</tr>
<tr>
<td>DSO</td>
<td>Distribution system operator</td>
</tr>
<tr>
<td>FCR-D</td>
<td>Frequency Containment Reserve for Disturbances</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HBES</td>
<td>Home and Building Electronic Systems</td>
</tr>
<tr>
<td>HES</td>
<td>Home electronic systems</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>KNX</td>
<td>Standard for Home and Building Control</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>SMS</td>
<td>Short message service</td>
</tr>
<tr>
<td>SW</td>
<td>Software</td>
</tr>
<tr>
<td>TP</td>
<td>Transfer Protocol</td>
</tr>
<tr>
<td>TSO</td>
<td>Transmission system operator</td>
</tr>
<tr>
<td>VPN</td>
<td>Virtual Private Network</td>
</tr>
<tr>
<td>WAN</td>
<td>Wide Area Network</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
</tbody>
</table>
Abstract
The scope of our project was to investigate how the electric heated households can be used as part of demand response today. To be able to do this investigation, it requires understanding from quite wide area of different topics, from beginning of the control of a single electric heater to Nordic electricity markets.

Main investigation areas were capacity and control of electric heating and implementation of demand response in a big scale. Latter area includes revenue models to profit from demand response, and methods for managing individual loads and aggregating households to bigger clusters. We did a literature study which combines previous investigations and proposes optimal ways to implement DR technology. Because the scope of the project was very wide, also investigated areas were wide. For example, in order to control electric heating optimally to save money, user has to know how different electricity markets operate.

One of our main findings was that DR has a huge potential market in Finland alone, but it’s implementation phase is challenging. One reason is the lack of standards and common protocols. At the moment, only few service providers exist. Positive driver for DR is growth of renewables and EUs laws and regulations. Our study gathers information on how to control different loads for DR purposes and suggests a method (Central Management System) for aggregating households to clusters. Also different markets were analysed for use of DR and a new business model was studied to enter the DR markets. This study can be used as a guideline for further research of DR and tool for developing DR solutions.
# Table of Contents

Abstract ....................................................................................................................... 4  
Table of Contents ......................................................................................................... 5  
1. Introduction ............................................................................................................. 7  
2. Objective .................................................................................................................. 7  
3. Project plan .............................................................................................................. 8  
4. Demand response in power system ...................................................................... 9  
   4.1. Total capacity .................................................................................................... 9  
   4.2. Changes in supply ............................................................................................. 10  
5. Reserve sources in households ............................................................................. 11  
   5.1. Electric heating .................................................................................................. 12  
   5.2. Water heating ................................................................................................... 13  
      5.2.1. Storage water heating tanks ...................................................................... 13  
      5.2.2. Tankless heaters ...................................................................................... 14  
      5.2.3. Solar water heating / air conditioning ..................................................... 14  
   5.3. Home batteries ................................................................................................ 14  
   5.4. Renewable energy ........................................................................................... 15  
      5.4.1. Rooftop solar panels .............................................................................. 15  
      5.4.2. Wind turbines ......................................................................................... 16  
      5.4.3. Hydro power ............................................................................................ 16  
6. House automation and heating control .................................................................. 16  
   6.1. Automation systems in DR solutions ........................................................... 16  
   6.2. Remote control and connectivity .................................................................... 17  
   6.3. Heat regulation in general .............................................................................. 18  
   6.4. Requirements for remotely controlled thermostats ...................................... 19  
      6.4.1. Heat regulation principles in general ..................................................... 19  
      6.4.2. Control principles for direct heating ...................................................... 20  
      6.4.3. Control principles for storage heaters ................................................... 21  
   6.5. Existing thermostats and their compatibility .................................................. 22  
7. Models for measuring power and consumption ..................................................... 22  
   7.1. Energy metering ............................................................................................... 22  
   7.2. Automatic meter reading systems ................................................................... 23  
   7.3. Energy measurements in the FCR-D -reserve market .................................... 23  
   7.4. Energy measurements for household heating in the FRR -reserve market .... 25  
   7.5. Energy metering in water heaters ................................................................... 26  
      7.5.1. Energy metering for direct flow water heaters ......................................... 26  
      7.5.2. Energy metering for boilers .................................................................... 26  
      7.5.3. Usage of water heaters in reserve markets .............................................. 26  
8. Central management system ................................................................................... 27  
   8.1. User groups and GUI requirements (portal) ................................................... 27  
      8.1.1. Main functionalities and information of user groups ............................... 28  
   8.2. System platform ............................................................................................... 29  
   8.3. Aggregation management SW ........................................................................ 29  
   8.4. Connectivity requirements .............................................................................. 30  
9. Markets for DR ........................................................................................................ 31  
   9.1. Balancing power ............................................................................................... 31  
   9.2. Reserves ........................................................................................................... 31  
   9.3. Aggregation ...................................................................................................... 33  
10. Revenue models ..................................................................................................... 34  
    10.1. Electricity retailer ......................................................................................... 34  
    10.2. Service provider ............................................................................................ 35
1. Introduction

The price of electricity is determined by the balance of supply and demand. Price peaks in electricity occur normally by morning and in the evening after 5 pm, when the demand for electricity is largest. The electricity bill of customers can be reduced when part of the consumption is shifted to time when electricity is cheaper, for example during midday. Most of this adjustable consumption is electric heating in its various forms.

On the other hand, electric markets sometimes need to use backup reserves during demand peaks to balance consumption and production of electricity. Utility companies buy electricity from reserves if the base production (coal, nuclear etc.) is not sufficient to cover the demand. By shifting the demand to cheaper hours of electricity, the need for reserves decreases. Reserves are provided by power companies with e.g gas turbines, which react quickly to demand. Also households can act as reserves if they have e.g solar power or electric cars.

Demand response can be adjusted when data is collected to an aggregate. Data is collected with smart meters that measure real consumption. With smart home automation, electric heating, such as direct heating and thermostats can be adjusted to balance demand and supply. There do exist some solutions for demand response, some of which are also covered in this project.

2. Objective

The purpose for this project is to investigate how the demand response can be in practice implemented in today, and which kind of technical developments are possibly needed for the efficient and flexible demand response. The focus of the project is to define the potential of the electric heated households to use as a resource capacity for the demand response. Addition for the technical investigation, the project will cover also a defining of the possible business model for acting as a resource provider in the demand response markets with aggregated resource capacity pool.

Main investigation areas of the project are:

- Control of smart house automation systems and remote control of the heating thermostats
- Nordic demand response markets and involvement of resource capacity providing for the markets
- Requirements for the centralized managements system to handle aggregated capacity resources and providing the capacity based on the demand request.
- Business model possibility
Figure 1: Main investigation areas

The output of the project will be the feasibility study of the possible implementation and high level requirements for the aggregated resource capacity providing for the demand response markets. The feasibility study can be used for the further development and research projects in Aalto University.

3. Project plan

Main points of our projects are:

- planning phase
- conceptualization phase
- literature review phase
- economic feasibility phase
- presentation phase
- documentation phase

Below is also our initial schedule for milestones:

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Description</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project plan ready</td>
<td>25.1</td>
</tr>
<tr>
<td>2</td>
<td>Everyone has familiarized with at least 1 task and written key points of that task</td>
<td>2.2</td>
</tr>
<tr>
<td>2.1</td>
<td>Business analysis ready</td>
<td>27.2</td>
</tr>
<tr>
<td>2.2</td>
<td>Presentation slides ready for business seminar</td>
<td>1.3</td>
</tr>
</tbody>
</table>
4. Demand response in power system

Demand response (DR) means shifting from hours of high consumption and prices to more economical time or temporarily adjusting consumption for demands of power balance management. DR is increasingly needed as the amount of inflexible energy production, e.g. nuclear and renewable energy, increases in the grid. Inflexible production sets challenges to current electricity market model, in which only energy is traded. Increasing DR is one method for trying to secure the future for current market model. [1]

Demand response can increase the cost efficiency of Nordic electric markets by:

- Lowering large price-peaks
- Providing flexibility that electric system needs
- Decreasing the need of network investments [2]

So far, only big industrial loads have been acting for maintaining power balance as usable reserves. Demand response is a natural way to increase supply on both regulating power and reserve markets. A new idea in the electric markets are so called aggregators referring to companies that combine residential consumption and production to a larger entity, which can participate in different markets. Consumer’s own small-scale production can be integrated to demand response, if it reacts to market situation and it can reduce target’s electricity demand from the supplying grid; these include back-up power generators of buildings and commercial premises. At first, participating in demand response may require investments, but on the long run it can provide a cost-effective solution for the company as well as for national economy. [1]

4.1. Total capacity

Households have several ways to adjust their electricity consumption, which are mostly related to electric and water heating. In a report from 2011, heating, warm water and air conditioning were found to make up approximately 60% of total electricity consumption of Finnish households. Heating can be relatively easy transferred to cheaper electricity hours and consumption regulated. This means that there exists a huge potential for demand response using disconnectable loads. [3]

The number of controllable loads is not easy to evaluate. Based on following reports, the total potential in controllable loads is growing rapidly. In a report from year 2016 [2] the total amount of potential controllable load was between 4000 MW and 7600 MW. In 2012, ÅF evaluated that DR potential for households is 600-1200 MW in Finland [4] Similar potential can be calculated from the figure 1 below, where 61 TWh is total energy consumption, 0,34 is the share of electricity and 0,6 is approximation of DR potential in households.
\[
P_{\text{total}} = \frac{61 \text{TWh} \times 0.34 \times 0.6}{t_{\text{year}}} \approx 1420 \text{ MW}
\]

**Figure 2. Energy consumption in Finland 2015 [5]**

**Used energy sources 61 TWh.**

<table>
<thead>
<tr>
<th>Controllable load</th>
<th>Load (kW)</th>
<th>Estimated amount</th>
<th>Total potential (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct heating</td>
<td>3-6</td>
<td>380k – 400k</td>
<td>1140 – 2400</td>
</tr>
<tr>
<td>Storing floor heating</td>
<td>3-6</td>
<td>120k – 150k</td>
<td>360 – 900</td>
</tr>
<tr>
<td>Domestic home water storage</td>
<td>3</td>
<td>430k – 480k</td>
<td>1290 – 1440</td>
</tr>
<tr>
<td>Oil heating with electric load</td>
<td>9-30</td>
<td>50k – 60k</td>
<td>450 – 1800</td>
</tr>
<tr>
<td>Electric storage heating</td>
<td>6</td>
<td>140k – 180k</td>
<td>840 - 1080</td>
</tr>
</tbody>
</table>

**4.2. Changes in supply**

Finland is dependent on electricity import: during a demand peak there is a deficit of 3400 MW and import potential is 5100 MW. This electricity can be bought from Nordic markets, Estonia and Russia. [6] In the long run, this is not beneficial for Finnish economy. Electric energy generated in Finland consists of base load power and peak load power. Base load power is mainly generated with nuclear, coal, bio mass and hydro power. Nuclear power is considered to be inflexible generation, meaning that it produces fixed amount of power. When Olkiluoto 3 power plant starts to operate, amount of nuclear energy increases by 13 TWh [7]. Peak load power can be generated with e.g. hydro power, gas turbines and CHP.
European Union wants the share of renewable energies to grow by 2020. Finnish government has set a target on 2013 to especially increase wind power generation by providing incentives to install wind farms. From figure 3 above, total amount of wind power in 2015 was 2,3 TWh, as in 2025 it should be 9 TWh. Also solar power production is estimated to increase [9]. Because solar and wind power depend on the weather conditions, they are also included as inflexible production. Hourly and daily production can’t be totally controlled, and forecasts are unpredictable. So, due to future increase in inflexible power production, Finnish grid and electricity market are going to face some issues. These reasons described below will increase the need for demand response:

1. Daily electricity generation will have more volatility because of renewables, thus need for balancing power increases.
2. Fault or a maintenance break in a nuclear power plant (or some other big plant) would cause a big imbalance between supply and demand side.
3. Customer consciousness in green values
4. Shift to more intelligent networks where controllability and automation replace expensive investments [6]

5. Reserve sources in households

In Finland, households are already part of demand response program since Spring 2016. In Finland and Sweden the pilot has been made together with the Fortum electricity clients and their local transmission system operators. Fortum has already started to take concrete steps to enable all electricity production to be renewable.

As the share of intermittent electricity production, such as wind and solar power, grows in the electricity system, new solutions are needed to maintain the power balance. Fortum’s solution is a virtual power plant. In the virtual power plant, both business and private clients let their unused assets such as data center or base station reserve power to be used to balance the grid while they are not needed for business use. Same way, in Finland and in Sweden, private clients let their household reserves (for example water boilers) to be used to momentarily lower the output during
peak electricity consumption periods. 100 Households with water heaters can be roughly seen as 100kW of effect reserve. [10]

5.1. Electric heating

In direct electric heating electricity is converted directly into heat in the radiators, in coils in the floor or ceiling or by warm-air heating. The direct electric heating is very economical to install and therefore nowadays popular combined with different ancillary heating modes, such as air heat pumps or pellet-fire stoves. It is however important to note that a system comprising an underfloor and/or ceiling heating usually leads to much higher consumption than system that is composed of traditional radiators. [11]

The benefit of direct electric heating is that the temperature can be set often manually in each room and the heating can be easily switched on and off according to the changes in demand. An efficient control system for direct electric heating can save up to 10% of the heat for electric heating of the household. [12]

Often control systems in houses that are more than 25 years old are poor or nonexistent. In these houses the thermostats of the radiators are often unable to maintain uniform heat and it is difficult to maintain the required temperature in the various rooms of the house in question. This is a problem since uniform heat improves the comfort and with uniform heat we could maintain lower average temperature compared when the temperature curve has uncontrolled variations. In addition older radiators often have no overheating protection, which may cause scorching damage, and in the extreme, even a fire. [11]

One of important properties of the thermostats in direct electric radiators is that they should be able to quickly adjust themselves to changes in the surroundings (for example solar heat or heat from a wood-fired stove.) It should be possible to set the control system for direct electric radiators to a weekly programme, with daytime and night-time reductions and in addition to maintain different temperatures in different parts of the house. [11]

Electric heating usage achieved it’s peak in early 2000s and the usage of it has since been reducing rapidly (for example while electric heating had 50% market share in 2005, in 2008 it had dropped to around 40%). [13]

![Electricity used for electric heating from 1970 to 2006](figure4.png)

*Figure 4. Electricity used for electric heating from 1970 to 2006 [13]*

Converting a house from direct electric heating to some other form of heating may involve a high investment cost but the results are often a better indoor climate and radically reduced energy costs.

The idea of storage electric heating is to store heat during night hours to a boiler or for example to a concrete plate which is placed under the floor.
In reserving floor heating, during the cheaper night electricity hours electricity cables in concrete plate under the floor start to warm up the plate which then reserves the heat. Thermostat monitors the temperature of the floor and cuts off heating if the given maximum temperature is achieved. During more expensive day electricity hours the current going to the cables is cut off and the warmed up floor can be used as a heating source until the next night hours.

Regularly the power required for heating the concrete plate approximately 80-100 Watts per square meter. Electric cables used for heating are put inside the concrete plate, which is usually 6-10 centimeters thick. Due to the thickness of the concrete plate, this method of heating requires rather sturdily structured floor and isn’t usable for lightly structured floors.

In the case of a boiler, idea is to store hot water which then goes through pipes to the radiators. This is far more simple way to reserve energy than the concrete plates and doesn’t have specific requirements for the houses structure as concrete plate reserving has.

Converting a house from direct electric heating to some other form of heating may involve a high investment cost but the results are often a better indoor climate and radically reduced energy costs.

The idea of storage electric heating is to store heat during night hours to a boiler or for example to a concrete plate which is placed under the floor.

In reserving floor heating, during the cheaper night electricity hours electricity cables in concrete plate under the floor start to warm up the plate which then reserves the heat. Thermostat monitors the temperature of the floor and cuts off heating if the given maximum temperature is achieved. During more expensive day electricity hours the current going to the cables is cut off and the warmed up floor can be used as a heating source until the next night hours.

Regularly the power required for heating the concrete plate approximately 80-100 Watts per square meter. Electric cables used for heating are put inside the concrete plate, which is usually 6-10 centimeters thick. Due to the thickness of the concrete plate, this method of heating requires rather sturdily structured floor and isn’t usable for lightly structured floors.

In the case of a boiler, idea is to store hot water which then goes through pipes to the radiators. This is far more simple way to reserve energy than the concrete plates and doesn’t have specific requirements for the houses structure as concrete plate reserving has.

5.2. Water heating

5.2.1. Storage water heating tanks

This type of water heating is most common in North America and in Southern Asia. The heater consists of a cylindrical container that keeps water continuously hot and ready to use. Typical size of the tank is anywhere between 75 to 400 liters and they may use electricity, natural gas, propane, heating oil or renewable energy sources. Storage water heater is most popular where higher flow rates are required for limited periods. Water is heated in a pressure vessel that can withstand a hydrostatic pressure close to that of the incoming mains supply.

Most of the storage water heaters use electric resistance elements to heat the water in the storage tank using two electric resistance elements, which are located at the bottom and top of the storage tank. Storage water heater can also use a heat pump or a gas or oil burner that heats water directly, which may prove handy for example during a longer power outage.

Compared to tankless heaters, storage water heaters have the advantage of using energy (for example gas or electricity) at a relatively slow rate, storing the heat for later use. The disadvantage is however that over time, heat escapes through the tank was and the water cools down, activating
the heating system to heat the water back up. Therefore investing in a tank with better insulation improves this standby efficiency.

5.2.2. **Tankless heaters**

Tankless water heaters which are also known as on-demand water heaters have gained popularity in recent years. The idea of the tankless water heater is to instantly heat water with high 3-phase electric power as it flows through the device and it does not retain any water internally except for what is in the heat exchanger coil. Tankless heaters may be installed at more than one point of the house, far from a central water heater or larger centralized models may still be used to provide all the hot water requirements for an entire house. [17]

Main advantage of tankless water heater is plentiful continuous flow of hot water (as compared to the limited flow of storage water heater tank) and potential energy savings under some conditions. The disadvantage however is its much higher initial cost compared to cheaper storage water heater tank. [18]

5.2.3. **Solar water heating / air conditioning**

The idea of solar water heating is to use the sun to heat a reserve of water, which can then be pumped through the radiators. This system is much cheaper than using electricity to heat the water and it is also easier to install than solar panels. If the customer isn’t willing to completely commit to powering the household with renewable energy, solar water heating can be a good alternative. There are immense amount of different types of solar water heaters, each with their own advantages and disadvantages, so the customer has a wide list of products from to choose the most fitting.

Solar air conditioning uses the same principles of the solar water heater, but uses that hot water in an air conditioning system. Depending on the season and the area where the customer lives, air condition might use more electricity than almost anything else in the households. Air conditioning can cost a substantial amount of money every year (especially central air.) Using hot water to cool a household can save substantial amounts of money and also help the environment.

In addition, the hot water produced for air conditioning can also be used for other applications in the households. Depending on the setup, household can get the benefits of solar water heating with the bonus air condition as well.

5.3. **Home batteries**

The best known example of a home battery today is Tesla Powerwall. Tesla Powerwall is a rechargeable lithium ion battery weighing approximately 90 kilograms that you can mount on your wall. Upon its release there were two versions of the Powerwall: a 6,4kWh model that cost approximately 3000€ and a 10 kWh model that cost approximately 3000€. The average person in Finland uses about 40-45 kWh of power a day. 10kWh version however is discontinued making the 6,4kWh version its only option. The Powerwall is also modular so you can install up to nine batteries side by side to store more power.

The Powerwall can store electricity generated by solar panels and draw electricity from the utility grid when rates are low to store for later use. It also provides homeowners with backup power in the event of an outage. All Powerwall installations must be done by a trained electrician. The Powerwall doesn’t come with an inverter which is required to convert the electricity generated from the solar panels to an alternating current that can be used for power, requiring homeowners to purchase one separately.

Tesla Powerwall 2.0 which was introduced in December 2016 costs approximately 5,500€. It comes with the inverter included and it can store up to 13,5kWh of energy and provide 5kWh of continuous power. This means that the Powerwall 2.0 has twice the energy and twice the storage as
the previous 6.4kWh Powerwall. Tesla estimates it costs approximately 1000€ to install a Powerwall or Powerwall 2.0.

Tesla also has a Powerpack battery option that can power infrastructures bigger than home, like a business or even an entire city. Upon its introduction in 2015, it could store 100 kWh of energy. In addition Tesla has announced Powerpack 2.0 which stores 210kWh per unit. The Powerpack also comes with an inverter.

Tesla has made large investments of approximately $5 billion with its partners to get its giant battery plant, the Gigafactory to achieve full production by 2017. The factory is expected to build 500,000 batteries a year by the end of the decade once it is fully operational.

Teslas largest competitor in the space is the LG Chem RESU battery. LG Chem RESU hold 6.5kWh of energy and costs roughly 4000€, but the inverter is sold separately and the price doesn’t factor the cost installation. Still, the RESU is pretty close to the Powerwall in terms of pricing and has entered the markets roughly at the same time as Powerwall 2.0. There are few real differences between LG Chem RESU and Tesla Powerwall other than appearance.

Another large competitor to Tesla is a start-up named Orison. Orison is an at-home battery system that comes in form of a plug-in unit that looks like a lamp and a flat wall panel that weighs just under 40 pounds. Orison, which costs approximately 1600€ holds significantly less power than the Tesla Powerwall (2.2kWh versus 6.4kWh.) However, the main perk to Orison is the fact that you don’t need a trained electrician to install it. The plug-in unit is called Orison Tower and it provides LED lighting and includes a Bluetooth speaker. Orison energy storage is 110-240V @ 50-60Hz compatible, and is being certified and designed to work all around the globe. The clear strengths of the Orison are far cheaper price and the lack of requirement to pay the electrician to install it while the weakness is its low storage.

In all, Tesla Powerwall and LG Chem RESU are in many ways superior due to their larger capacity to storage energy. Orison is however rather interesting as a design and may prove handy especially in smaller apartments while it’s rather useless for larger apartments, where 2.2kWh is only a rather small portion of the daily energy consumption.

5.4. **Renewable energy**

There are several sufficient ways to use renewable energy in households to lower the electricity bill of the household. It is possible to use just one type of renewable energy (for example solar cells) or use a hybrid of more than one renewable energy sources. Most of the time, the best results are received by using a home battery in addition to the renewable energy source. Some of the most frequently used types of renewable energy are listed below.

5.4.1. **Rooftop solar panels**

When it comes to using renewable energy in households, the first and most obvious method that comes to mind are rooftop solar panels. Depending on the latitude and the orientation of the panels, solar panels could generate up to 10 or more watts per square foot [19]. A typical house consumes anywhere from one to two kilowatts of power, so a few large solar panels should be enough to power significant amount of the households owner’s needs of electricity. Another option besides regular solar panels are solar shingles. Where standard rooftop solar panels are mounted on top of the roof, solar shingles actually take the place of the household’s roof tiles.

The biggest weakness of solar power is that it only works when the sun is up. If you want to power your home when the sun is down, you’ll need to pay for grid electricity or invest in a second type of renewable energy. The use of solar power in a household is more practical with a home battery
(such as Tesla Powerwall) and these together can require rather large investment from the owner of the household.

### 5.4.2. Wind turbines

Wind turbines are most commonly found in wind farms or floating offshore, but with enough real estate you can install a small wind turbine on your property to power your home. The downsides that has made wind turbine less popular in residential areas are the facts that they can be considered ugly, they might make a lot of noise, they take up space and depending on where you live, local laws and zoning regulations may even outright forbid the usage of wind turbines.

If these disadvantages aren’t a problem, wind power may be considered a great asset. Wind power is more stable than solar and a good-sized wind turbine can easily generate most or all of your electricity needs, depending on the area where you live [20]. Depending on the area where the household is located, wind turbine might be a far better renewable investment than solar panels.

### 5.4.3. Hydro power

More uncommon way to use renewable energy in household is hydro power. It won’t work for most people, but if there is a source of water located in the property of the household, it is possible to divert some or all of the stream or river to flow through a turbine and power the household.

There are a number of ways to go about doing this, but at its most basic, the idea is to divert the water flow from the largest vertical distance the water will travel so it flows through a turbine in a controlled manner. Depending on the amount of water and vertical distance, you can produce a substantial amount of power this way. Setting up a hydro power generator however is not easy and you might need a professional to install it for you.

The advantages to hydro power are immense. Unlike solar and wind, hydro is extremely stable and continuous, which means that the input of the generator remains the same no matter what.

### 6. House automation and heating control

#### 6.1. Automation systems in DR solutions

Aggregated demand response solution requires the controlling of the household’s energy loads and the real-time information of power consumption. To allow this, it requires that houses connected to the DR-system are equipped with some smart home automation system including the remote-control functionalities. Minimum requirement for the automation system is that building heating loads, like room heating and water boilers are connected to the system and temperatures and real-time power consumption are measured. The automation system controlling unit must include the controlling interface with the internet connection.

There is numerous amount of the building automation system manufactures and solutions for the households. The remote connection for households which are already equipped with the existing automation system could require e.g. some additional SW plugin to Centralizes Management System to make remote controlling possible. To avoid the need of these extra SW plugin’s it would make sense to focus only the automation systems which are using standard connection and communication protocols like in KNX based solutions. This will simplify the solution implementation and system maintenance work later.

Some of the home automation solution providers are already focused to offer functionalities to optimize the households power consumption. These functionalities allow e.g. to shift the household power consumption load from expensive energy price hours to cheaper hours. Another useful functionally is the possibility to adjust the room temperature according to predefined daily/weekly schedule. In practice the household owner can define the room temperature separately for each room during 24 hours / weekly period. Room temperature can e.g. set to decrease during the night.
times and the working time when home is empty, and then increase at the evening and at the mooning when the comfortable living temperature is required. In this way, the households can decrease the annual use of energy and cut down the energy costs. This kind of home automation solution are also interesting from the aggregated DR-solution point of view. Most of the solution features can be used directly for the aggregated DR-solution needs to control the heating load and read the temperature and power consumption information. [21]

In Finland, e.g. There Corporation has developed this kind of smart solution for the homes energy management. Solution includes personal cloud based user interface for the households to control and manage the heating temperatures. It also offers the possibility to make the personal schedules for the heat temperature adjusting. For the optimization purpose the system is able to follow the price of energy, weather forecast and outside temperature. Addition for the home automation part There Corporation has also developed the solution for the aggregated DR management, which has been piloted in cooperation with Finnish TSO company Fingrid Oyj. Another remarkable home energy management provider in Finland is OptiWatti. Main difference in OptiWatti solution is that they are concentrated purely for the household as end-users and they don’t offer the aggregated DR functionality as a part of the solution. [22]

### 6.2. Remote control and connectivity

As mentioned in chapter 6.1. the households connected to the aggregated DR-system should be equipped with the remote controllable building automation system and the implementation should base to commonly used building automation system standards. By following the standards smooth connectivity and communication between the house automation system and aggregation management SW can be ensured.

E.g. the standards used in KNX are:

- EN 50090 - HBES (Home and Building Electronic Systems)
- EN 13321-1 - BACS (Building Automation and Control System)
- EN 13321-2 (KNXnet/IP)
- ISO/IEC 14543-3 HES (Home electronic systems)

where the standard EN 13321-1 describes the product and system requirements and EN 13321-2 describes the KNXnet/IP communications. [23]

The KNX is quite widely used in house automation systems and there are hundreds of KNX compatible equipment manufactures available. Household where a new home automation system installation is required, it would be reasonable to use KNX based solution. By doing this can be ensured the wide variety of available equipment’s with reasonable prices and standardized interworking between the components.

As the remote-control connection requires the use of Internet between the households and the aggregation managements SW, the standard EN 13321-2 should be followed with KNX based solutions implementation. Standard defines the integration of KNX protocol implementations on top of Internet Protocol (IP) networks, called KNXnet/IP. Implementation offers the fast IP network Ethernet connection to the KNX system for:

- Remote configuration
- Remote operation (including control and annunciation)
- Fast interface from LAN to KNX and vice versa
- WAN connection between KNX systems
Connecting to the KNX IP network from the public networks and clouds can be done by using the VPN-connection (Virtual Private Network). In figure ZZ has been shown a principle of KNX based system topology. [24]

![Figure 5. Principle of KNX topology [25]](image)

Offering a resource for the Frequency Containment Reserve for Disturbances (FCR-D) sets some response time requirements for the communication between the home automation system and the aggregation management system. Resources for the FCR-D should be available under 5 s from the request which means that control commands execution times must also fulfill this time limit.

Another important issue in communication is to ensure the connection availability from the aggregation management SW to home automation system. If some household is not reachable the management SW has to recognize it and drop it out of the active reserve pool until the connection has been restored. This requires some availability check routines between the management SW and the house automation systems. In figure RR has been shown some examples of the communication types between the household automation system and the aggregation management SW. [22]

![Figure 6. Examples of the communication types between the house automation system and the AGG management system.](image)

### 6.3. Heat regulation in general

Heat regulation is one of the main tasks of this project, because it defines the size of usable reserve. The major questions are what is the desired room temperature and how much can that temperature alter. For the first question, there is not correct answer, because people prefer different room temperatures. However, the ministry of social affairs and health has set limits to the room
temperatures. According to this ministry, temperatures below 18°C can be harmful to health and room temperature should never go over 26 degrees due to heating. The ministry of social affairs and health recommends that room temperature should be around 21 degrees but not over 24 degrees. This gives the possibility for 8 degrees of variation in room temperatures (from 18°C to 26°C). Also, MOTVA has given some recommendations for room temperatures and the results are shown in Table 2 below [27]. The temperature variation can be increased even further when people are not at home for example during work hours. Also, in those rooms that are not in use, variation can be more than 8 degrees. This also brings savings to the customer when the room temperatures can be monitored closely.

Table 2: MOTIVAs recommendations for room temperatures. [27]

<table>
<thead>
<tr>
<th>Room</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lounge area</td>
<td>20-21</td>
</tr>
<tr>
<td>Bedroom</td>
<td>18-20</td>
</tr>
<tr>
<td>Storage/Warehouse</td>
<td>12</td>
</tr>
<tr>
<td>Garage</td>
<td>5</td>
</tr>
</tbody>
</table>

As can be seen in the table 2 above, there should be different temperatures for different kind of rooms. For example, most people enjoy a lower temperature in bedrooms while they are sleeping and so on. In garage and warehouses, there is no need for high temperatures. This kind of temperature control brings savings to the customer while temperatures stays in comfortable area. Furthermore, there should be also “in” and “away” switch whether the residents are at home or not. This would drop the room temperatures and allow wider variation in the room temperature.

From a business point of view, the comfort is the sold object. People can choose what is the average temperature and then how much that temperature can alter. For example, end customer A wants the average temperature to be 22 degrees with +/- 2 degrees of variation during daytime and 19 +/- 1 degrees during night. The end customers’ willingness for temperature variation is the factor that decreases the costs of electricity, because the temperature variation defines usable size of reserve. More about this can be found from the appendix: business aspects.

### 6.4. Requirements for remotely controlled thermostats

Electrical heating systems are divided into two main systems: direct heating and storage heating. From the DR point of view, both systems are acceptable, although they require different kinds of controlling procedures. Therefore, thermostats are also divided between these two

#### 6.4.1. Heat regulation principles in general

Setting the correct temperature is a key factor towards achieving energy savings and reasonable DR. However, the correct room temperature is not always fixed. When adjusting the room temperature, the following three settings can be considered: time of day settings, room or zone varying settings and occupancy dependent settings. These settings require different features from thermostats, and therefore, they should be considered when choosing the right thermostat for the heating system.

Time varying settings are already used in some smart thermostats. The purpose of this is to lower temperatures during night and work hours and thus, achieve energy savings. The same principle is used also with more advanced room or zone varying settings. This allows different settings for different rooms for example different temperatures in bedrooms and in living room etc. This kind of temperature control is already used by Optiwatti [28]. The purpose of occupancy settings is the same as time varying settings. However, now a motions sensor is needed to define occupancy. This would be more accurate than pre-set time settings. For example, if no motion is measured in certain
time, the heating control system allows DR to be used in the room and automatically lowers the room temperature.

### 6.4.2. Control principles for direct heating

Direct heating is the most commonly used electrical heating form in electrically heated houses in the Nordic countries. It is usually done with room heaters, which includes electric space heaters and both sealing and floor heating. Also heat pumps are considered to be a form of direct heating. [29]

In some cases direct heating system requires thermostats in every room and therefore, heat regulation principle differs from storage heating system.

When direct heating is used, a couple heat regulation principles can be applied. First one is that every thermostat is remotely controlled by a house automation system or heat controlling unit. In this case, remote control is a definition for both wired and wireless control. In practice, this means that all the old thermostats need to be replaced with new remotely controllable ones. This includes also floor heating thermostat and warm water boiler thermostat. If the room heating is done using built-in thermostat in the radiator, it is possible that the whole radiator needs to be replaced. This could be reasonable in case of an old heating system, which should be replaced in any case due to high energy consumption and poor efficiency. However, this would increase the total investment cost. This control method is shown in figure 7. In the picture, wired thermostats are assumed. This could also be done using wireless connections with the exception of power supply of the heater.

Using this controlling method, heat regulation is mainly done directly in the thermostat. However, additional control interface is also a possibility, for example a digital wall mounted panel, tablet or mobile phone application. These interfaces are already commonly applied by many thermostat manufacturers. Heat control unit is also shown in the picture. This is an additional control module between thermostats and house automation system. It can also be used for direct communication between heaters and the DR provider.

![Figure 7: Control system for remotely controlled thermostat](image)

Communication between thermostats and house automation system or central heating unit is required. There are a couple communication methods considered: wireless communication via WIFI or radio frequency (RF) and wired control via KNX channel or Ethernet. In all these methods, there are both advantages and disadvantages. For instance, Ethernet and KNX channels already exists in some modern houses. During years 2012 and 2013, a KNX system was installed in approximately 8 % of all small houses [30]. However, if not, fitting them afterwards would be difficult and in most cases expensive. In this case, wireless communication would be preferable. In addition, most of the remotely controllable thermostats already supports wireless communication.

Second control method is to control the entire heating groups from the main cabin using relays. This includes, if possible, floor heating and hot water boiler. In this case, only a few remotely readable room heat sensors are needed. The controllable relays in the main cabin and remotely readable
sensors are then connected into the house automation system. The control relays do not necessarily need to be remotely controlled if the house automation system is in the same cabin. This kind of control system would be easiest to install and is the least expensive. Moreover, controlling method like this would be compatible with most of the heating systems including room radiators and ceiling heaters. However, floor heating requires heat sensors within the concrete element and, therefore, causes problems. This kind of control method is shown in the figure 8 below. Again, a wired connection is assumed. This kind of method is used for example in Fortum Fiksu [31].

The controlling principle is as follows: The room thermostats are set into their maximum value, and therefore, the room thermostats are overridden. Then, heat control unit controls room temperature using its own heat sensors and relays or switches from the main cabin. Because all heat regulation is done in the main cabin, a controlling interface is needed for the end customer. This interface can be the same as in previous case.

This kind of control method is the most promising due to its low cost and small amount of new installations. However, there are some difficulties as well. For example, in some old buildings, the main cabin is very small. Therefore, new heat control system and relays can’t be installed and the cabin must be replaced [30]. Other factor that affects to the compatibility of this kind of heat regulation is how the heating groups are designed. If the same heating group covers multiple rooms with different heat consumption, the regulation is not accurate.

![Figure 8: Control system for relay controlled heating](image)

**6.4.3. Control principles for storage heaters**

Storage heating is mainly done using central heating system. In Finland, central heating system includes hot water boiler, piping and radiators or plastic tubing in the floor. The boiler heats water which circulates through pipes to radiators. In this case, heating the boiler is done using electrical resistors. [32] Because the boiler can store hot water, the central heating system works well with DR. When DR is applied and the boiler is large enough, almost 90% of the required heating can be done during night when the overall demand of electricity is low. [33] Floor heating can also be done using electrical resistor cables below the floor instead of plastic hot water tubing. That is also considered to be fully or partly storage heating, because a large concrete plaque can store the heat for a long time. This kind of floor heating is usually used simultaneously with direct heating.

When storage heating is used, the heat regulation needs to be done in the boiler, because small changes in the boiler temperature does not change the room temperatures. Therefore, only the boiler thermostat needs to be controlled by heat regulation system while the room thermostats can be fixed and the room temperature stable. This makes the heat regulation much easier compared to direct heating.

Control principles for storage heating are similar to those in direct heating. For central heating systems, only one controllable thermostat is needed to regulate boiler temperature. This thermostat
can be located directly next to the boiler like in the first control method of direct heating. However, in most of the cases, boiler is wired separately from the main cabin. In this case, also the second control method of direct heating can be applied. Storage heating can be done also using electrical resistor cables under the floor, which is usually combined with direct heating. In this case, both first and second control method can be used.

6.5. **Existing thermostats and their compatibility**

There are currently a few remotely controlled thermostats available. In addition, some pre-built solutions can be installed. Thermostats used in these solutions can also be used separately. Remotely controlled thermostats are listed in table 3.

One pre-built solution comes from Schneider electric. It has two types of remotely controlled thermostats: SE7000 series and SE8000. These thermostats can be controlled locally or remotely via Schneider’s own Smart struxure based solution. Smart struxure is also known for lighting control. [34]

Both SE7000 and SE8000 thermostats support multiple open communication protocols, such as ZigBee alliance, BACnet and LonMark. These thermostats have also motion sensor in addition to heat sensor which can be used as a part of heating control. For instance, if no motion is measured inside the controlled room, the room heater can be used more freely as a part of reserve in DR. Thermostat can deliver this occupancy information forward to the house automation system, which can then define the total amount of usable reserve at each moment.

Another pre-built solution is provided by Danfoss Link. It includes central controller, room sensors and switching units. The system is suitable for both electrical floor and space heaters. In addition, hot water boiler can be controlled by Danfoss Link. The Danfoss systems communicates via WI-FI connection. [35]

Using this solution, temperature can be time varying and the settings can be changed remotely using a mobile application or locally from the central controller. Central controller observes room sensors and connects switching units on or off. Room sensors are battery powered, and therefore, they can be located freely. Switching heat on and off can also be done using hidden relays. Because these relays are remotely controlled, they can be placed inside the old recessed thermostat boxes.

Table 3: Existing wireless thermostats.

<table>
<thead>
<tr>
<th>Company</th>
<th>Model</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devi [36]</td>
<td>DEVIREG SMART</td>
<td>Wi-fi</td>
</tr>
<tr>
<td>Glamox</td>
<td>CRG – radio controlled thermostat</td>
<td>RF</td>
</tr>
<tr>
<td>Schneider electric [34]</td>
<td>SE7000 and SE8000</td>
<td>LR-WPAN [37]</td>
</tr>
<tr>
<td>Danfoss [35]</td>
<td>Danfoss Link</td>
<td>Wi-fi</td>
</tr>
</tbody>
</table>

7. Models for measuring power and consumption

7.1. **Energy metering**

Energy metering is crucial for demand response systems to be able to accurately inform the size of the reserve to the nation-wide high-voltage grid company or provider in the Nordic Power System. Some of these companies are Fingrid in Finland, Svenska Kraftnätt in Sweden and Statnett in Norway. Additionally, although household demand response systems conserves energy rather than produces it to the grid, the amount of conserved energy is regardless considered as produced
energy. Therefore, it is important to charge for the appropriate amount of energy produced by separately measuring the consumption of heating elements in all contributing households.

The traditional household electrical meter, also known as a watt-hour meter, measures the total energy consumption of the house. It works by using inductors connected in series with the load to spin a disc. The amount of rotation is then converted into the measured energy use. The traditional electrical meters only record the overall used energy and the energy companies used averages and manually checking the customers meter to charge consumers for electricity. In the European Union by the year 2020 80% of the traditional electrical meters should be replaced with automatic meter reading (AMR) devices or other smart metering systems [38].

For use in demand response systems, the traditional electrical meter cannot be used to measure the energy saved or transferred back into the grid as a reserve, since the traditional electrical meters have no time based measurements. Moreover, using manual check-ups on meters is not an effective way of collecting usage and reserve size data.

### 7.2. Automatic meter reading systems

Newer meters measure energy consumption using a current shunt and an automatic reading system to give a digital reading of the household energy-per-hour consumption. This data is then once a day sent to a central mobile switching unit, where the metered data of all nearby meter readings are collected. From the central mobile switching unit the energy consumption data is sent to the energy company automatically or by request using GSM networks. The AMR devices or the central mobile switching unit cannot be used to request measurements from the end-users’ meter, so they don’t have any real-time functionality.

For use in measuring electrical heating consumption, AMR meters may be useful to measure the reserve available in the household when demand response is required. However, Fingrid requires the available reserve size to be updated every 45 minutes, so the electric heating consumption must be updated more frequently than once a day [39].

A HEM-system (Home Energy Management) with the ability to send and receive data and control signals in real-time would be the best option for use in household demand response systems. Additionally, the ability to measure and control electric heating consumption separately would make reserve size calculations, demand response activation and control signal processing quick and simple.

### 7.3. Energy measurements in the FCR-D -reserve market

Different reserve markets have various rules for being able to submit a reserve to be used by Fingrid. The FCR-D –reserve is activated when the frequency of the grid drops below a set frequency and therefore no control signals are sent from Fingrid, so local frequency measurements have to be used to utilize households in the FCR-D –reserve.

The FCR-D –reserve must be activated within seconds and the disturbances only last from some seconds up to minutes but occur multiple times a day [39]. Especially for disturbances that only last some seconds, acquiring the saved energy data from all households separately might be unnecessarily complex. Instead an average model of the reserve should be used.

By the average model, the reserve size used could be calculated with the meter data from 10% of the households used as a reserve and multiplying by the number of households that contributed to
the reserve. However, to acquire an accurate average that accounts for weather and other unpredictable variables, the households should for example be divided by provinces and 10% of the households in all provinces should be used to construct the average reserve size.

Using the average model, the overall network traffic would be greatly reduced while producing a sufficient average. However, to ensure the accuracy of the measurements, a direct measurement from all households involved in FCR-D –reserve.

![Figure 9. Heating element power consumption in FCR-D -reserve](image)

In figure 9 the power consumption of a household heating element is shown in an 8 second long frequency drop starting at 7 seconds. As the frequency drops below set minimum frequency, heating elements are quickly disconnected until frequency returns to normal level. The amount of energy supplied back into the grid is calculated as the difference to zero level from the average power consumption in normal use before the demand response over the duration of demand response. The continuous need of the FCR-D is short enough that disconnecting the heating elements should have little to no effect on the temperature of the house.

The heating element used in figure 9 is controlled with a PWM with fast on-off cycling, which is ideal for use in FCR-D reserve. However, not all heating elements are controlled so quickly and the on-off cycle might be longer than the disturbance was present in the grid. In case that a slower acting heating system was in its off cycle when the reserve should have been activated and remained off during the entire disturbance, the household had no involvement in the reserve. Using the average model, the error in reserve size can be approximated by also separating households by the heating system to slow and fast switching elements.
7.4. **Energy measurements for household heating in the FRR -reserve market**

The FRR –reserve is activated only with a control signal from Fingrid and the reserves are activated by offer price in order of lowest offer to the highest. In the FRR –reserve the delay from control signal to relay activation is important to keep as low as possible and the reserve is used for much longer than in the FCR-D –reserve. Due to the longer reserve periods, more infrequent usage of FRR -reserve and the end-user ability to set temperature comfort levels, the average model is not practical. Instead a direct measurement of the involvement to the overall reserve time from all households should be performed.

![Figure 10. Power consumption and temperature behavior in FRR -reserve](image)

The temperature variation caused by disconnecting the heating elements is much more considerable due to the longer reserve periods. Therefore, the temperature inside the house should be taken into account. In figure 2 is shown the average power consumption and house temperature during a 20 minute long reserve. As the control signal from Fingrid arrives, the system cuts off power from the heating element. Due to cold weather outside, temperature inside the house starts to fall. At 27 minute point temperature inside the house has dropped to 20 degrees, which was the user pre-set minimum comfort level for the house and power is returned to the heating elements at a lower power. Incrementally or slowly increasing the heating load to the input power is a good practice in any case since it reduces the consumption spike and avoids causing grid frequency fluctuations caused by reconnecting the heating power of all households. When the reserve request from Fingrid has ended, the heating system returns house temperature to the user set level.

In FRR –reserve usage, calculating the energy fed back into the grid becomes more complex when house temperature falls to or below the set comfort level as power has to be returned to heating elements. There are two possible means to avoid the temperature from falling below the set minimum. One way is the previously shown low power way to still be involved in the reserve at a reduced amount. Another way is to return the heating system to normal operation when the minimum temperature is reached. Whichever way is chosen, the amount of involvement in the
reserve is calculated from the average power consumption before reserve activation to current power consumption.

7.5. Energy metering in water heaters

Water heaters consume substantial amounts of power, so being able to use them with demand response systems, would greatly increase the energy reserve capacity. There are two types of water heaters used in households, a water heater with a water reservoir, also known as a boiler, and a water heater without a water reservoir, also known as direct flow water heaters.

7.5.1. Energy metering for direct flow water heaters

Direct flow water heaters are unpredictable sources of reserve from the point of view of a demand response system operator. This is due to the erratic warm water consumption of an individual. Moreover, direct flow water heaters are used by demand of the user when warm water is desired. Denying the user from using an on-demand appliance is not convenient for the user. Therefore if a network disturbance was to occur on a water heater utilizing a demand response system, the heater would cease from working. For the end-user, this would be an enormous inconvenience to not be able to use warm water at all. Thus, direct flow water heaters should not be considered for use in demand response systems.

7.5.2. Energy metering for boilers

Boilers reservoir however, are much more versatile as they do not require active power to supply warm water. Instead the reservoir is filled with cold water as it is used from the reservoir and heated when the temperature decreases enough, at a set time of day, usually at the beginning of night-rate electricity, or by the lowest Elspot price of a given day. A HEM-system would be able to read the temperature of the reservoir and based on usage could schedule heating for the cheapest hours of the day. The boiler could prepare for demand response utilization during peak warm water usage times. Warm water could be supplied for the end-user, even though heating power was disconnected to help stabilize grid frequency.

The time a boiler is consuming power is dependent on the initial water temperature and final temperature. For example, let’s consider a commercial boiler such as Haato HK 200 [40]. It has a 182 liter reservoir and 3 kW heating element. In this example, the initial temperature is around room temperature, 24°C, and the desired temperature is 70°C. The efficiency of the HK 200 is 40%, so then the time to heat the entire water reservoir would be

\[ Q = cm\Delta T = 4.2 \frac{J}{g \cdot ^\circ K} \cdot 182000 g \cdot 46 ^\circ K = 35.16 \text{ MJ} \]

\[ \Delta t = \frac{Q}{P \cdot \eta} = \frac{35.16 \text{ MWs}}{3 \text{ KW} \cdot 0.4} = 29302 \text{ s} = 8.1 \text{ h} \]

So, if all warm water was used in the 182 liter boiler, it would take 8 hours and 6 minutes to re-heat the water. Even if the change in temperature was reduced to half, the time would still be around 4 and half hours. Therefore, the potential in water heaters lies in boilers and not direct flow heaters.

7.5.3. Usage of water heaters in reserve markets

If boilers are utilized in the FRR-market, all optimization or seeking cheapest Elspot hours for heating times should be left for the HEM-system or simply to the night-rate electricity. The reserved energy for water boilers would be calculated very similarly to the household heating in the FRR-
market, but decreasing boiler water temperature does not need to be taken into account as slightly less warm water is a minor inconvenience for the end-user. Only the length of the interruption and heating power needs to be measured to calculate the size of the used reserve. However, an incremental load increase needs to be used again to reduce the spike caused by rapidly increasing load after the interruption.

However, boilers could also be used in the FCR-D –market since they can be used for both frequency reduction and addition. For reducing the grid frequency, boilers could be used by either increasing the power if possible or when the boiler is not heating, by turning the heating on. For increasing the grid frequency, the boiler would be disconnected when the boiler was heating, just as with household heating.

8. Central management system
Central Management System (CMS), takes care of the aggregation of individual households to resource pools, communication and data transferring between different functional parts in the aggregated DR-system. CMS will also handle the needed user management and user portals in the system. In practice, it contains the needed software (SW) parts for the aggregation management, user management, web services, connections and databases. CMS should also provide the market place for offering the aggregated DR-pool capacity to the electricity DR-markets. For the simplicity, all needed SW parts should be implemented to top of the cloud platform. In figure 11 is shown the main parts of the aggregated demand response solution.

![Figure 11. High level principle of aggregated demand response solution functional parts](image)

8.1. User groups and GUI requirements (portal)
CMS should provide the graphical user interfaces portal for the different user groups to make possible the efficient and informative use of the system. Each user group should have their own basic view to the system, which provides all the needed information and functions based on the user group profile. Inside the user group view the individual user should be able to personalize his/her view and save it as a user own view. Personalized own view will be available after each login to the portal.
There can be define at least three different main user group profiles:

- **Administrator**
  - *System administrator*: access to all data and functionalities in to the system.
  - *Local administrator*: access to DR-provider specific settings and user management
- **Operator**
  - User who operates as DR provider for the DSO (Distribution System Operator)/TSO (Transmission System Operator)
- **Households**
  - Household users, owners of the capacity

Topology and relationship between different user groups are shown in Figure 12.

Graphical portal and user interfaces should be available for the end users as a web based interface which provides the access to the system via standard web browsers. For household users, there should also be available the application for the mobile devices such as a tablets and smartphones to log in to the system. Depending on the implementation, the use of all administrator user group functionalities could require also the separate SW installation to the local server or computer.

8.1.1. **Main functionalities and information of user groups**

**Administrator**

Depending on the service mode there can be two different administrator groups: Local administrators and System administrators. Local administrators could be e.g. the DR-provider personnel where they take care of the DR-provider specific topics such as managing the Operator and Household user group members and DR-provider specific system settings. System administrators belong to the solution provider personnel with
full access to the system. They are e.g. able to setup new instances for the DR-providers, manage the local administrator’s access and troubleshooting the system.

**Operator**

Operator user group personnel are the main user group for operating and running the aggregated DR-solution SW in each DR-provider instance. Operators takes care of the DR-provider data maintaining and supervising the households and reserve capacities connected to the aggregated DR-capacity pool.

**Households**

Household users should be able to follow-up and control their home automation system via Web-browser or mobile device like tablets and smart phones. Main functionalities for the household users are:

- Control and monitor the room temperatures
- Set the threshold values (minimum and maximum) for the room temperature adjustment when actively using DR.
- Able to create daily/weekly temperature profiles for automatic room temperature control
- Monitor the power consumption information (current and history) and used energy prices
- Follow the use of DR: trigger count, amount of energy reserved, overall duration, etc.

**8.2. System platform**

By implementing CMS functional parts to the top of the cloud platform, it can be ensured that there is sufficient CPU, memory and storage capacity for the flexible scaling according to the amount of users in the system. Household users can control and follow-up the home automation system information like room temperatures and heating profiles and see also the demand response information like usage of DR-capacity by connecting to the cloud based personal user portal. Control commands from the user portal will be transferred to the house automation system via cloud service and vice versa. Figure 11 shows a high-level description of the setup.

**8.3. Aggregation management SW**

Aggregation management SW takes care of the individual household’s capacity joining together as aggregated demand response resource pools, illustrated in figure 12. The SW should be able to indicate the real-time information of the DR-capacity availability. In practice the DR-capacity from the individual household consist of the electrically heated water boilers and the room heating capacity. Available capacity from the water boilers can be assumed to be quite constant. For availability of the room heating capacity the SW needs information of household’s total heating capacity, current use of the heating capacity, room temperature information and room temperature adjusting min/max threshold values.

Available capacity should be possible to offer to the demand response markets via AGG management SW. According to the resource need type and agreements with the TSO the capacity should be possible to sell to the markets based on the request automatically or by the operator.
approval. So, joining the markets will require that AGG management SW will interwork with electricity market systems. On the other hand, the AGG management SW should also offer the information of the realized DR-capacity use for the household end users.

Figure 12. Aggregated household pools. Connection between house automation system and AGG Management SW done by using VPN

8.4. Connectivity requirements

CMS will manage the communication and data transferring between the different parts of the aggregated DR-solution. It’s important that the implemented design will take care of the topics like connectivity availability, required system level maximum response times and connectivity security issues.

Some connection parts like TSO - AGG management SW - House Automation System the connection availability is critical for the whole system operating and reliability point of view. All these critical connections should be defined from the system and check the backup routings for the connections. To ensure the required availability and response time limits, all connections in the Centralized Management System should be implemented on the top of Internet Protocol (IP). It means that e.g. house automation systems which are remote controllable only via GSM/SMS can’t be connected to the aggregated DR-solution because of too long response times in the control commands execution. E.g. for the FCR-D 50% of the reserve should be activated within 5 seconds of the request signal and all the needed control commands must execute successfully in that period. Connection requirements between AGG Management SW and Household automation system are described in chapter 6.2. Remote control and connectivity.

From the security point of view the connections in the CMS would be reasonable to do by using Virtual Private Network (VPN) which provides security and tunnelling protocols over the public internet and wireless transactions. As the VPN only allows remote access for authenticated users with tunnelling protocol and content encryption, the VPN can be preventing all anonymous and unauthorized access requests to the system. Other security issues would be the smart house automation systems and the IoT (Internet of Things) devices, which are connected to the same smart home automation system than aggregated DR-solution. If the IoT devices security protection is
neglected, e.g. device default settings for the connection and passwords are in use, it might offer a gateway for harmful Denial of Service (DoS) attacks to the system. [41]

Also, the needed amount of network capacity for used network traffic load should be estimated for the critical connections sections. Based on that there can be defined enough network capacity for critical connections in the implementation designing. E.g. transferring large amounts of data between databases could congest and slow down the VPN and cause too long response times from the system operations point of view if there is not enough network capacity available.

9. Markets for DR

9.1. Balancing power

When supply and demand don’t match in the market, balancing power is needed. Balancing power is more expensive than regular spot-price, because it is generated within short time period of balancing power bid. This kind of short time to initiate generation is possible with gas turbine generators, combined heat and power, diesel generators and hydroelectric sources. Hydroelectric is an efficient way to generate balancing power and it’s used to generate electricity especially in Norway and Sweden, from where it can be bought to Finland. [42] Price of balancing power depends strongly on the water availability: for example, in very dry seasons there is not so much water to use and price increases.

![Figure 13: Price of balancing power in Finland in beginning of 2017](image)

9.2. Reserves

Frequency controlled reserves are divided into three categories based on their purpose:

1. Frequency Containment Reserves (FCR) are used for the constant control of frequency.
2. Frequency Restoration Reserves (FRR) return the frequency to its normal range and release activated Frequency Containment Reserves back into use.
3. Replacement Reserves (RR) help to put formerly activated Frequency Restoration Reserves in ready-state in case of new disturbances. [44]

Automatic Frequency Restoration Reserve (aFRR) has an obligation for 70 MW and Manual Frequency Restoration Reserve (mFRR) an obligation for 880-1100 MW in Finland. Balancing power market is also included in mFRR.
Figure 14. Market places for DR. [44]

FCR-D and FCR-N inside frequency containment reserve are activated automatically when frequency goes out of boundaries. FCR-N tries to maintain frequency between normal frequency limits 49.9 - 50.1 Hz. If the frequency drops below normal limits, FCR-D tries to maintain frequency at least in 49.5 Hz. [45]

The purpose of automatic frequency restoration reserve (aFRR) is to restore frequency back to its nominal value 50 Hz. aFRR is a centrally activated by TSO when Nordic synchronous area has a frequency deviation. [46]

Balancing power bids can be given from resources capable of carrying out a 10 MW change in 15 minutes. Bids are given to Fingrid 45 minutes before the hour of use. Balancing power bids have to include following information of adjustable capacity:

- Power (MW)
- Price (€/MWh)
- Generation or consumption
- Distribution area, in which the resource is located
- Name and type of production [47]
At the moment, minimum power level required to participate in balancing power market is 10 MW. This can consist of multiple smaller sources. Participating in various frequency controlled reserve markets require power levels of the same magnitude: from 0.1 MW to 10 MW. These may consist of aggregated loads making it possible to participate with DR-sources.

Table 4. Market places for DR [49]

<table>
<thead>
<tr>
<th>Market place</th>
<th>Required power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balancing power (mFRR)</td>
<td>10</td>
</tr>
<tr>
<td>Automatic frequency restoration reserve (aFRR)</td>
<td>5</td>
</tr>
<tr>
<td>FCR-D</td>
<td>1</td>
</tr>
<tr>
<td>FCR-N</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Aggregator providing the demand response service must meet the required power levels, which requires a sufficient amount of households in an aggregated cluster. Different estimates of average power consumption exist: Vattenfall estimated average yearly consumption of a 120m2 house with 4 residents to be 18480 kW/h resulting in 2.1 kW[50]. Average winter load was estimated to be 5 kW[2]. These corrected with a factor of 0.6 (the approximate part of controllable load in households) results in a range between 1.3 kW and 3 kW of controllable load per household. In an optimal case, when all the loads could be disconnected at the same time, only 333 households would be enough for the 10 MW level. Because all the loads cannot be disconnected at the same time without affecting the power quality, such a small amount is not enough in practise. One aggregated cluster should consist of thousands of households.

Most important tasks for aggregator:
- Understanding behaviour of demand response capability of different customers
- Evaluation, whether aggregating certain customers is profitable
- Providing incentives for customers to participate in demand response
- Control signals for loads
● Providing different products for markets, which differ by
  ○ Activation time
  ○ Locality
  ○ and behaviour of loads after they are connected again [6]

Because of the required profit and loss statement calculations the current electricity retailers are potential aggregated reserve providers in the markets. Also external aggregators could be possible, but in practice it requires that the datahub system is available for offering the information of realised electricity trades. At the moment, if external aggregator would operate in the markets, balance calculations would not be valid, because the amount of energy supplied by electricity retailers and aggregators must be separated somehow. [6]

10. Revenue models

As demand for the demand response increases in the future, it offers potential ways to make profit for many companies. Those include Transmission system operators (TSOs), electricity retailers, distribution companies, service providers and hardware companies. In case of TSOs, demand response offers possibilities to control power balance, adjust frequency and flexibility in controlling power deficit situations. Biggest potential for profits is for electricity retailers, service providers and hardware companies. As the revenue model for hardware manufacturer is very simple, it won’t be analysed more thoroughly. On the other hand, revenue models for retailers and service providers is more complicated so those are analysed.

10.1. Electricity retailer

Electricity retailers can enter various new markets with the aid of demand response and controllable loads. Price volatility benefits the retailer, because DR is a versatile tool for it. Retailer can exploit demand response in

● planning electricity procurement
● to control balance (between bought and sold energy) in parallel with other operation
● bids in reserve markets and balancing power market
● and in developing new instruments [30]

In planning procurement, retailer can adjust long-term protective levels when it has enough DR resources. Or, when price of electricity peaks and protection level is insufficient, retailer can use its DR resources to cover part of its consumption instead of buying electricity with a high price from the markets. Retailer can also maximise its short-term trade profits by actively using DR resources in various markets or in its own balance control. When planning on strategies for different markets, so called after-peaks should be taken in consideration. After-peaks occur when the disconnected heating loads are turned back and nominal temperatures try to recover. Sizes of after-peaks are difficult to estimate due to lack of measurement data and many factors affecting to amplitude and length of the peak, for example features of loads and methods of control. On a larger scale and hourly level, fluctuations of single loads after-peaks smoothen. In general, the longer the duration of disconnection, the bigger after-peak. [30]

Revenue models for retailers are simulated in a research project in 2015. It simulated entering various markets with demand response by using an aggregated cluster of 1338 households with maximum power of 6 MW.

First simulated revenue model besides non-lucrative spot-market, was retailer’s balance control. Controlling balance resulted in a yield of 11,7 k€/year for retailer. Maximum profit for an hour lasting control was 500 € and average was only 7,3 €. Controlling balance has its own limitations, because the balance error must stay small compared to scale of operation. Also, using the DR
potential in a profitable manner requires that retailer can schedule its control according to demand and price forecasts. [30]

Second revenue model was balancing power market, which had a theoretical maximum profit of 24 k€/year and simulated profit of 15000 k€/year. Maximum profit for an hour lasting control was 1500 € and average was 18,4 €. The simulation was a simplified version of reality, offering capacity at the same price to the market regardless of current price, season or time. By considering the effect of time of the day and season to the electricity price, the profit potential can be substantially increased. On the other hand, obtaining the full theoretical profit is nearly impossible, because retailer should schedule the control optimally according to the demand and price forecasts. Also, forecasts are never perfect. [30]

Third simulated revenue model was participating in FCR-D market. Durations of control in FCR-D market are assumed to be so small that effect on energy consumption is small (transferring mainly power). Thus, the after-peak is small. This revenue model profited approximately 60 k€/year, with a maximum profit per hour was over 1300 € and average was 50€. Total number of controls was 1204 in a year. Profits are high, because prices of electricity in this market are higher and controlling has a low impact on retailer’s balance. [30]

As a conclusion, acting on intra-day markets requires accurate forecasting of prices and demand. In the worst case, demand response can cause losses, if price of after-peak is higher than profit made from controlling the loads. Retailers should pay attention to uncertainties in forecasts with different bidding strategies and risk mitigation procedures, as forecasts are important part of gaining profit in market. [30]

![Cost of Electricity](image1.png) ![Allocation of demand](image2.png)

*Figure 16: Example of trading by using demand response*

### 10.2. Service provider

Service providers and their potential revenue models were analysed in our business aspects document. They provide a software for the electricity retailers which combines forecasts of available DR potential, electricity price, demand and generation. This data is used to plan retailer’s operation, as mentioned above. Retailer can then use the software to control its DR resources. One potential revenue model for service providers is to collect a yearly fee for using the software and a sales commission from retailers’ sales. The same product could be used for example in Finland, Sweden, Norway and Denmark. There are approximately 180 potential customers in that region. The market is very new, and the retailers are waiting results of the ongoing projects. This will give early movers a substantial benefit if they get good customer feedbacks.
11. Future development

11.1. Fingrid datahub

In spring 2015, Fingrid launched a project that will make information exchange in the electricity retail market clearer and more efficient. In the future, information transmitted between electricity users, suppliers and distributors will be saved in Datahub. Usage of Datahub will open doors for many smart and energy-efficient solutions. Datahub can be used for example for saving meter data, storing and transmitting customer and metering point information and monitoring the operational quality.

Use of Datahub is expected to start in 2019 after which it will be used to store information on the 3.5 million metering points in Finland. In 2020 when a Finnish consumer switches electricity suppliers, all the necessary information will be transmitted between the electricity supplier and distribution network company via Datahub. This means that in 2020 different companies will use the same system and information is centralized while at the moment the information is decentralized between several different systems of different companies.[51]

Datahub is being developed in close co-operation with different actors in the energy industry. The industry has jointly defined what kind of information will be collected in Datahub, who has access to the information and how the information is linked to the industry’s business processes. Only information which is necessary for the companies and the markets to run smoothly will be collected in datahub and high data protection and data security will be taken into account. Therefore Datahub is safe database for electric transmission markets which helps both the customer and the companies.

Since in the future information transmitted between electricity users, suppliers and distribution network owners will be saved in datahub, it will be equally available for all market parties. In consequence the quality of customer service will improve significantly. For example, if the customer moves or switches supplier, the changes can be made in real time during the customer service event without waiting time. In addition service providers can develop new kinds of energy use applications and energy advisory services using datahub’s information. The parties and roles in the Datahub process can be seen in the picture below.
11.2. Flexibility gateway

According to article by Empower, the electricity markets and grid will drastically change by the increase of renewables in the system. They present three major drivers for the change:

- Over 50% of energy is renewables in future
  - Shift from generation following to load following system
  - Bids cannot be based on marginal cost of production
- Futures resources portfolio is distributed
  - Necessary to group and control small resources
  - Necessary to manage distributed ownership, cashflows and settlements
  - Possibility for sharing and local independency
- Future is market orientated
  - European Union wants to unify the markets
  - Market mechanism must fund new structures and resources [52]

At the moment electricity markets are a mess with various protocols, standards and IoT-systems confusing the utilities. Companies offering demand response have different solutions for what standards they use, making it difficult for households and retailers to change to another equipment.
To clarify the mess of the whole electric markets, Empower introduces a concept called Flexibility Gateway (FG). The solution should solve the future’s scattered energy system and enable transparent flexibility management by interested parties without closing market opportunities. FG will reduce the workload on point integration between various systems and market parties. The concept also allows new revenue models to form in market environment. [52]

Flexibility gateway will act as an enabler for trading with flexibility between market parties on external markets by unifying the technical flexibility operations into a scalable interface. This is possible regardless of what technology choices are used. Thus, FG has to build interfaces for numerous technical solutions controlling resources. Purpose is to develop a single interface allowing connection to all controllable loads, available markets and grid information. [52] In this sense, it would combine aggregation of loads, market forecasting and control signals from DSOs and TSOs. If flexible gateway concept is approved, there would not be need to build and integrate each field device system to own systems. This will introduce benefits in costs and operation of flexibility resources and also enable optimum value extraction of those resources. Figure 18 below illustrates the whole data management system.

![Data management system diagram](image)

**Figure 18. Data management system. [52]**

### 11.3. Revenue models

Empower is aiming to be the Flexible operator in below figure. Flexibility operator would be responsible of the tasks mentioned earlier in the flexibility gateway concept. So, for resource owners, operator would interface, operate and manage flexibility equipment as part of market party service. Thus, it gives market party, for example electricity retailer, access to entire market of
controllable resource owners. Towards the marketplaces, flexibility operator would operate flexible resources based on realized trades. Flexibility operator could then sell operation of flexibility for a monthly service fee for market parties willing to get revenue from flexibility trading. [Empower] This revenue model is quite similar to our business case, having slightly more advanced data management system than in our case. In both cases, some activation signal is sent, but in addition to receiving the signal from TSO, flexibility operator can receive it also from different marketplaces.

11.4. Metering data

Electricity consumption varies a lot depending on season, weather, day of the week and the hour of day. Fingrid has a forecast for hourly electricity consumption for the next day. This forecast is based on the metering data, air temperature, weather data and forecasts [53]. However, Fingrid has only 116 primary transformer stations and the consumption data from these stations is fairly easy to acquire and calculate. Moreover, for the demand response system proposed by this paper, as many households as possible are to be included and the amount of data to handle and process is much larger.
To achieve accurate estimates of the reserve size metering could be optimized and even predicted as the networking capabilities improve in the future. By omitting the averaging model, which was proposed in chapter 7.3 to be used to reduce networking and computational load, would allow profiling the controllable reserve curve. Creating a profile of the mean power consumption curve of the controllable load for each hour of the day on a specific time of the year, temperature or weather for each house grants a possibility to predict the total available reserve very accurately.

Over time, the profiles create an accurate collaborative forecast for example the following day much like the Elspot electricity price in Nordpool or the day-ahead consumption forecast by Fingrid. The forecast could also include an estimate for the next hour to give more accuracy in the estimate to adapt for inaccuracies in the weather forecast. Since weather forecasting has a very large impact on the accuracy of the reserve size, the HEM system should still be used to for controlling and to send the data after reserve usage for confirming the size of reserve actually used. Forecasting the meter data only reduces the need to actively gather metering data.

### 11.5. Forecasting models

Electrical power generation is currently in transition towards renewable energy sources. One example of this is the growing wind and solar generation. This kind of production can also be problematic, because the production rate of renewable energy is not fixed. For example, wind and solar production is highly weather and season varying. Because electricity is difficult to store, it is important to match the production and generation. One solution is to use back up energy, for example coal, gas and diesel turbines in order to balance demand and generation. However, these are not sustainable forms of energy. Another solution would be new allocation of demand using DR and controllable loads. This, however, requires both accurate generation and demand forecasts.

There are currently algorithms to forecast consumption on demand side. Also, Rejlers is developing an artificial intelligence for this task. Algorithm uses one billion measurements from 120 000 users. Demand was then divided into six different types of customers. In addition, the impact of weather was studied in all those six cases. It’s been said, that it is impossible for human to deal with this
amount of information. This forecast algorithm should be 20% more accurate than the ones before. The whole forecast is done by computer, and therefore, the error made by human is minimal. [54]

While renewable generation grows, also more accurate production forecasts are needed. In figure 21 below, the wind power generation is shown during few days. This information is provided by Fingrid. Two forecasts are also shown: Day ahead forecast and continuously updated wind power forecast. These forecasts are based on weather forecasts. As can be seen in the picture, there is an error between the forecasts and the realized generation. If most of the electricity is generated using wind production in the future, these errors will be very harmful to the power system, and therefore, more accurate forecasts are needed.

![Figure 21: Wind power generation and forecast. [55]](image)

12. Conclusion

Demand response is already possible in Finland in technical sense but at the moment only few service providers exist. With modern technology it is possible to access markets that have response times of seconds. Challenge in DR is the big scale implementation: to get the households interested in DR possibilities. Companies offering demand response should encourage households to invest in DR systems or give some incentives. A positive driver for DR are the EU guidelines and legislation, targeting in the growth of renewables, smarter grids and liberalized markets.

At the moment potential for demand response in Finland is few Gigawatts, but after exploiting different reserve sources, this potential will rise. Most important sources are household’s rooftop solar panels and in the future home batteries and electric vehicles.

Home automation trend is a key driver for implementing affordable DR systems to
all households. Standard connection, such as KNX, would help to unify and simplify planning for DR control, when there would be no need for software plugins to attach different bases together.

Because heating is the biggest controllable entity in households, we examined how its control should be implemented. To make the end customer feel comfortable, some temperature limits have to be set and the control is then based on those limits. Depending on how the heating groups are designed in the house, control can be divided for example for different rooms.

One challenge in implementing control systems for DR is that in some old houses the thermostats need to be switched to newer ones to make control possible. Another challenge is when some houses lack of any home automation system or the system is very outdated, then updating the system to e.g. KNX-system becomes expensive and slow. In that case, it would be better to implement the control using wifi or Ethernet based solution. Still, there is no universal solution to every household, because home automation has some advantages compared to using IP-system. For example, using KNX based home automation is generally cheaper, because many appliances support it. However, using IP-system allows faster control of loads.

Also the actual control of appliances differs. Controlling direct heating is different from control of storage heaters. A HEM-system (Home Energy Management) with the ability to send and receive data and control signals in real-time would be the best option for use in household demand response systems. Additionally the ability to measure and control electric heating consumption separately would make reserve size calculations and demand response activation and control signal processing quick and simple.

In order to participate in different markets with DR, defining real time potential is crucial, especially when response times are in seconds. FCR-D -reserve market needs response in 5 seconds, so analysing each household’s potential from metering data for this market would be unnecessarily complex. Some kind of averaging method is more suitable approach for FCR-D market, for example measuring only 10% of households in one cluster. This method would also decrease network traffic. If DR operator wishes to participate in FRR -reserve market, there should be a direct measurement of the involvement to the overall reserve time from all households and also how much power is available. Because measuring methods for FCR-D and FRR are different, a measuring solution is needed which would allow access to both markets.

Fingrid sets requirements for different markets, thus households can't participate individually, because their power ratings are far from required. Aggregators would have to combine households to clusters and one cluster should be formed of thousands of households. This is solved by creating a central management system, by connecting both households and TSOs. CMS would then have three user groups:

- administrators managing other user groups and setting up new instances for DR-providers
- operators running the DR-solution, data maintaining and supervising aggregated capacity pool
- households following and controlling their system via Web or mobile devices

Demand response provides business opportunities for present companies especially for electricity retailers and also introduces new business models depending on how the legislation will change. Companies aggregating the loads and providing different forecasts can enter the markets in the future. One very profitable business model would be to aggregate the loads and optimize the usage of loads in different markets according to forecasts in weather, production and consumption.
13. Reflection of the Project

13.1. Reaching objective
The project went well compared to what was the expected output in the start. We examined all the main investigation areas and gained a thorough understanding of them. We also expanded the project to cover more on the power system side and investigated how are things in the future. We adjusted our objectives so that we didn’t include a feasibility study neither practical solution defined in our milestones list, because project was only a literature study.

13.2. Timetable
We missed only one schedule defined in our milestones list (4: literature review phase ready). This is because project plans changed and literature review phase was time consuming. Our literature phase continued to early May, but that is still acceptable because literature phase is directly linked to documentation phase.

13.3. Risk analysis
Since our project was only literature study, our risks were very limited. No risks realized in our project and the likelihood for those realizing was very small.

13.4. Project Meetings
We had project meetings with out instructor once in every two weeks and after April once in three weeks. Between other project members, meetings were organized once a week or every other week, depending on how tasks were proceeding. Electronic tools (WhatsApp, email) were used between group members.

Most of our meetings had an agenda prepared, but in some meetings only general things were discussed and some open questions asked. Memos were written from all meetings and those are archived in Google Drive, so that members that missed meeting can see the main points. They also acted as tasks lists when different tasks were discussed. For group meetings to be more efficient, the agenda should be clearer, because sometimes our meetings went to sidetracks.

13.5. Quality management
Quality in our project ment mainly that written text is understandable and technically correct. In order to meet quality standards, our instructor read our texts and pointed out things to correct. We also did cross checks to each others texts as defined in the project plan. There were no serious quality issues.

14. Discussion and Conclusions
Below are few points from group members and what they’ve learned.

Olli:
Gathering information for the project work has vastly improved my knowledge on Elspot hourly electricity pricing. I have also learned about home automation and control systems used for household heating and warm water boilers. And finally of course I have learned about working in as a member of a group and how big of a difference having one person as the group leader has in the overall quality of work.
Jari:
The project scope was to investigate how the electric heated households can be use as part of DR in today. To be able to do this investigation, it requires understanding from quite wide area of different topics, from beginning of the control of single electric heater to Nordic electricity markets. For me, the major learning part was to get an idea that what kind of different parts and actors this whole system requires, how and what kind of information there is needed and what kind of challenges there are currently to use DR more efficiently. Additions for the technical challenge there looks to be also quite a lot of regulations and laws which currently prevent to take in use DR for more large scale as it is today.

Ville:
Besides technical aspects mentioned above, this project has taught me how to think about the big picture: demand response is a sum of many small components. I’ve also learned about project management, especially scheduling and allocating tasks to right persons.

Esa:
During this course, I learned many new skills for working as a part of larger project and group. After this project, I have multiple new tools for group work. I think that these skills are valuable in the future through working life. This project gave me also good knowledge about electricity markets due to our topic. Understanding the big picture of electricity markets together with small details will support me during the rest of my studies and through my future career.

List of Appendixes
- Project plan
- Business aspects document

These can be found from Aalto wiki website: [https://wiki.aalto.fi/display/AEEproject/Demand+response+in+electrically+heated+houses](https://wiki.aalto.fi/display/AEEproject/Demand+response+in+electrically+heated+houses)

References


23) ST-käskirja 21, Kiinteistöjen tiedonsiirtoväylät


52) Materials from Empower [15.5.2017]
54) Tekoäly ennustaa sähkönkulutuksen, Energia uutiset 6/2016