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Investigation of Grid Rent Business Models as Incentive for Demand-Side Management in Buildings

A case study on fully electric operated houses in Norway

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Abstract

The increase in power drain on the grid, and increased penetration of inflexible, renewable energy sources, is creating a need for reduction in peak demand on the grid and matching the demand with supply, by demand-side management. Demand-side management techniques aim at reducing the system peak loads, the operational cost, and provide the customers with the greater control over their energy consumption. Demand-side management can increase the matching between supply and demand, and reduce the power peaks to ensure that the power drain is within the capacity limit of the grid. To give incentive to load shift and reduction of peaks in buildings, NVE want to introducing a new grid rent tariff by the end of 2020. They are suggesting three different business models for grid rent, with either higher cost for higher power drain (Measured power tariff and Tiered rate tariff), or higher cost during high demand periods (Time of use tariff).

The object of this thesis has been to investigate the three models for different building cases, with the aim to detect which model gives the better incentive for demand-side management in buildings. As the larger amount of the total electricity consumption in Norway is used for space heating in households, space heating has been investigated with load shifting. Heating can, with improvements in building physics, be a shiftable load. Heat load shift creates a large potential for peak reduction on the grid, and could result in a more efficient use of the grid.

The research includes investigation of which business model that gives the largest economical incentive to improve building physics, and largest incentive to shift loads, which one is the most achievable, and which will give the lowest total cost for the end-consumer. To be able to perform the cost calculations, an algorithm has been developed in Excel. The algorithm is calculating the total cost of the different tariffs, the ideal heat load shift of the buildings, and the savings per kWh of load shifted. A single family house is constructed in the simulation software IDA ICE, according to the requirements from the current Norwegian standard TEK17. The energy demand is simulated with IDA ICE, and the cost is post processed with the developed Excel algorithm.

The results show that for different building cases, different tariffs give the best incentive to building physics improvement and load shift. An implementation of any of the suggested three tariffs will increase the grid rent for customers whom continue to use electricity with the typical consumption pattern of today. Improvements in building physics reduce the grid rent cost, both due to reduction in demand and change in demand profile. With ideal heat load shift, all the business models obtain a lower price for the investigated cases than the tariff model used today. This indicates that the models will work as incentive to load shift and a change in consumption pattern.

The Measured power tariff have the smallest daily heat shift necessary to obtain the maximum cost reduction. With heat shift, this tariff also give the lowest annual grid rent cost for most cases. But this tariff give incentive to shift loads all day, all year. The Tiered rate tariff have the largest cost saving per kWh of shifted heat, and a small amount of ideal heat shift. But for most cases this tariff result in the highest annual cost. The Time of use tariff have the largest amount of heat shift necessary to obtain the maximum cost reduction, and the smallest cost saving per kWh. But the tariff is the most accurate regarding which hours the shift is encouraged to happen.

Sammendrag

Økningen i effektuttak på nettet, og økningen av ufleksible, fornybare energikilder, skaper et behov for å redusere effekttoppene på el-nettet, og å møte etterspørsel med forsyning, ved bruk av demand-side management. Demand-side management-teknikker sikter mot å redusere systemets effekttopper, driftskostnader, og å gi kunden større kontroll over sitt eget energiforbruk. Demand-side management kan øke samsvaret mellom forsyning og etterspørsel, og redusere effekttoppene for å sikre at strømforbruket er innenfor nettets kapasitet. For å oppfordre til endring i strømbelastningen og reduksjon av effekttoppene fra bygninger, vil NVE introdusere en ny nettleietariff innen utgangen 2020. De foreslår tre forskjellige businessmodeller for nettleie, som enten får høyere kostnad for høyere effektforbruk (som for tariffene Målt effekt og Abonnert effekt), eller høyere kostnad på forbruk i perioder med høy etterspørsel (som for tariffen Time of use).

Formålet med det utførte arbeidet for denne avhandlingen har vært å studere de tre businessmodellene for forskjellige bygninger, med mål om å identifisere hvilken modell som gir det beste insentivet for demand-side management i bygninger. Ettersom at den største andelen av det totale strømforbruket i Norske husstander brukes på romoppvarming, har det i modellen blitt utført en teoretisk lastflytting (load shifting) av romoppvarmingen i byggene. Strømbelastningen fra romoppvarming kan, med bygningsfysikke forbedringer, være mulig å flytte i tid. Flytting av romoppvarming gir et stort potensiale for reduksjon av effekttoppene på nettet, og kan resultere i en mer effektiv bruk av nettet.

Arbeidet undersøker hvilken businessmodell som gir det største økonomiske insentivet til å forbedre bygningsfysikken, hvilken som gir størst insentiv til lastflytting, hvilken som er det mest oppnåelige, og hvilken som vil gi sluttbrukeren den laveste utgiften. For å kunne utføre kostnadsberegningene har det blitt utviklet en algoritme i Excel. Algoritmen kalkulerer den totale kostnaden for de forskjellige tariffene, den ideelle varmeflyttingen, og besparelsene per kWh. En enebolig har blitt modellert i energisimuleringsprogrammet IDA ICE, etter kravene fra den gjeldende norske standarden TEK17. Energibehovet i bygget er simulert med programmet IDA ICE, og utgiftene til nettleie er kalkulert ved å kjøre resultatet fra IDA ICE gjennom algoritmen i Excel.

Resultatene viser at for forskjellige bygningstilfeller gir forskjellig tariff det beste insentivet til forbedring i bygningsfysikk og lastflytting. Alle tre tariffene vil føre til en økning i nettleie for kunder som fortsetter å bruke elektrisitet i samme forbrukermønsteret som det som er typisk i dag. Forbedring i bygningsfysikk reduserer nettleiekostnaden, både på grunn av reduksjon i energibehovet til bygget, og forandring i forbruksmønsteret. Med ideell varmeflytting vil alle businessmodellene oppnå en lavere pris for de simulerte byggene enn med den nettleietariffen som benyttes i dag. Dette indikerer at modellene vil fungere som insentiv til lastflytting og endring i forbrukermønster.

For tariffen Målt effekt er den daglige varmeflyttingen som er nødvendig for å oppnå maksimal kostnadsreduksjon lavest. Med varmeflytting vil denne tariffen også gi den laveste årlige nettleieprisen for de fleste av de undersøkte tilfellene, men denne tariffen gir insentiv til lastflytting hele dagen, hele året. Tariffen Abonnert effekt har størst kostnadsbesparelse per kWh med lastflytting, og en lav mengde med ideell varmeflytting, men for de fleste byggene resulterer denne tariffen i høyest årlig utgift. Time of use-tariffen har størst varmemengde som må flyttes for å oppnå maksimal kostnadsreduksjon, og den minste kostnadsbesparelsen per kWh, men denne tariffen er den mest nøyaktige med tanke på hvilke timer flyttingen oppfordres til å skje.

Preface

This masters thesis was written during the spring of 2018, as the final chapter of my education to become a Civil Engineer in building physics, at the Department of Civil and Environmental Engineering at NTNU Trondheim. The goal of this thesis has been to investigate how economical incentives can change user behavioural patterns regarding electricity usage in buildings.

In preparation of this thesis, topics regarding energy on the grid and in buildings, in both a local and a continental context, had to be researched. In order to carry out the investigations, an algorithm for calculations of grid rent was developed in Excel. This produced a diverse amount of results and material.

I wish to extend gratitude to Mohamed Hamdy, whom has been extraordinary in offering his time, help and guidance during the development of this thesis. The possibility for thorough discussions has given me the opportunity to gain a deeper understanding of the topic. Furthermore, the Ph.D. student Stian Backe has assisted in inspiring my work and debating the subject in an insightful manner. I also wish to thank Vilde Christine Hagen for supplying the basis for the reference model used in the IDA ICE simulation. Hafslund Nett, by Ragnar Ulsund, has contributed with information about the grid in the Oslo area. Thale Schönfeldt Karlsen has assisted in creating graphics for the thesis, as well as encouragement and assistance when the deadline came rushing upon me. And lastly, thanks to Erling Hannaas for offering his LaTeX-skills and proofreading.

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Contents

Abbreviations

AC	alternating current
AMS	advanced metering system (smart meter)
ASHP	air source heat pump
COP	coefficient of performance
DC	direct current
DER	distributed energy resources
DG	distributed generation
DHW	domestic hot water
DLC	direct load control
DSM	demand-side management
DSO	distribution system operators
DR	demand response
EC	energy carriers
EE	energy efficiency
ES	energy storage
EV	electrical vehicle
HV	high-voltage
ICT	information and communication technology
LM	load matching
LV	low-voltage
GI	grid interaction
MV	middle-voltage
OOW	occupant opened windows
RES	renewable energy sources
SSM	supply-side management
STC	solar thermal collector
TCW	temperature controlled windows
TOU	time of use
TSO	transmission system operator
PCM	phase change material
PV	photovoltaics

1 Introduction

1.1 Background

To be able to deliver electricity to the consumers through the electrical grid, two objectives must be fulfilled. The load factor always has to be more or less equal to 1.0, which means that the amount of supply and demand need to be equal at all times. Also, the system capacity has to be larger than the peak load of the system, as the demand can at no times be larger than the amount of energy the supply system is able to deliver (AboGaleela et al., 2012).

The last few years the power drain on the electricity grid in Norway has increased more than the energy demand. Grid strain is high during peak demand periods, especially in the afternoon of cold winter days. When the peaks increase, the need for more power capacity on the grid increases as well, even though the critical, peaks only occur a few hours every year. If the grid distribution companies have to enlarge the capacity of the grid, it will bring on large investments. The grid rent will increase, and the electricity customers will in the end receive larger grid rent bills. A more efficient use of the grid will decrease the need for reinforcement. Reduced or postponed investments will keep the grid rent costs down, and give value on a social-economic level. To achieve this, the consumers have to become active market players (NVE, 2017).

A hearing from NVE (Norwegian Water Resources and Energy Directorate) in November 2017 suggest to introduce a new tariff model for grid rent in Norway, to reflect the pressure on the grid and make customers aware of their power drain. The cost will be divided differently between the customers depending on their load profile. Using electricity at hours with high pressure will cost more, and should work as an incentive for the customers to change their demand profile to achieve a reduction in cost. The goal of the tariff change is to reduce the peak demand, and divide the cost more fair between the customers. A long-term change in the electricity load profile from buildings is the main aim (NVE, 2017). Many of the stakeholders that have given their responses regarding the hearing, point out that the tariff models have not been researched enough, and that there is a need to know what kind of impact the tariffs will have.

Also, during high peak loads, the demand is often higher than the capacity of renewable energy sources. To be able to match the supply with peak demand, fossil fuels like oil and coal are used. This results is unwanted pollution, high electricity prices, and high pressure on the grid with high peaks. A generation-follows-demand perspective like this is called supply-side management (SSM) (Eid et al., 2016).

Smart houses and demand-side management, with a demand-follows-generation perspective, can contribute to decrease the peak loads and increase the matching between generation from renewable energy sources and the demand. This can decrease the use of fossil fuels and lessen the pressure on the grid, so that even for the expected increase in future demand, an expansion of the grid can be postponed or avoided (NVE, 2017).

1.2 Objectives

This thesis will investigate how household customers in single family houses are affected by a change in tariff, and how they can reduce their cost by load shifting and improvement in building physics. NVE is suggesting three different tariff models, and these are compared, together with the cost of today's model. The main objective is to find an approach and develop a tool to investigate different models, and be able to calculate the ideal heat load shift for a building based on the hourly demand profile.

1.3 Structure of the thesis

The thesis begins with an introduction to the energy situation in Europe and Norway today, and why the thesis of this thesis is relevant. The build-up of the grid and demand-side management is described in detail. In the third section there is a deeper explanation of the hearing from NVE and the stakeholders responses, including a thorough description of each of the investigated tariffs. The forth section describes the method and algorithm developed to compute the tariff calculations. The fifth section include the results from the calculations with some descriptions. A discussion of the results is done in section six, followed by a conclusion in section seven. In the last section, suggestions for future work is presented.

2 Theory

2.1 Energy situation in the European context

2.1.1 Energy by source

Figure 1 illustrates the evolution of the energy production by fuel in EU-28 countries from 1990 to 2015. The figure shows that renewable energy sources (RES) are increasing, while all other non-renewable energy sources are decreasing. The share of renewable energy is expected to continue to increase, due to the ambitious targets by the European Union of cutting the domestic green house gas emissions by 80% and reach 100% renewable energy production by 2050 (Szalay and Zöld, 2014).

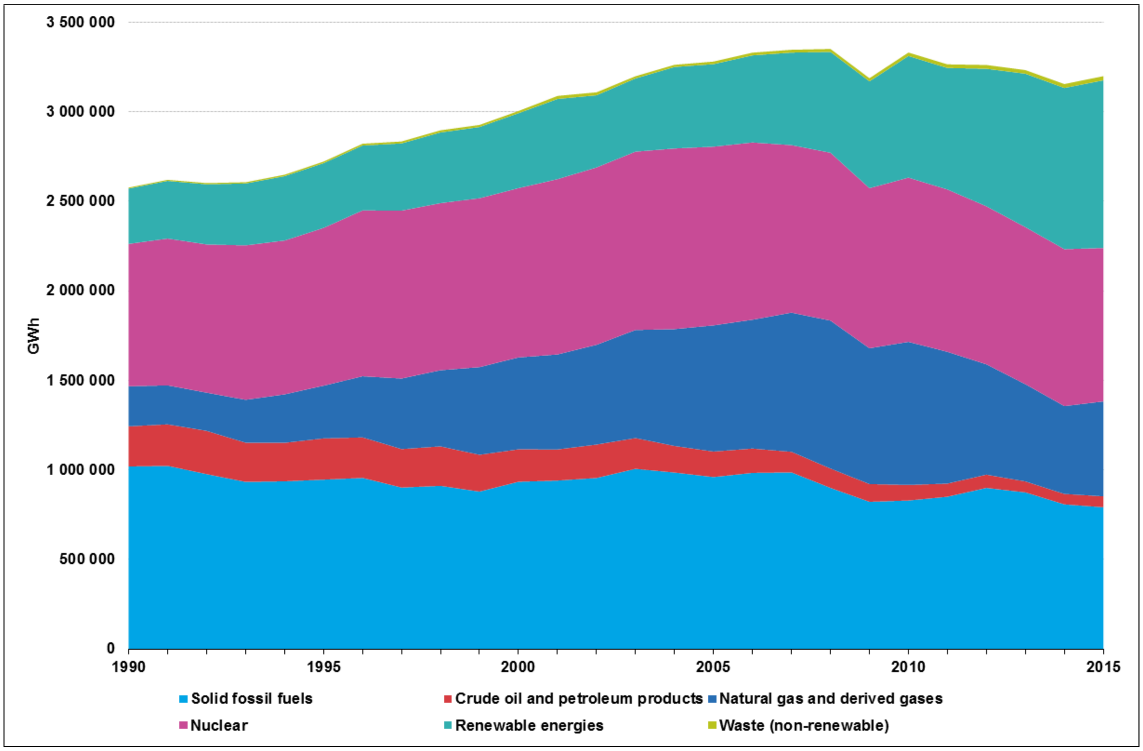


Figure 1: Gross energy production by fuel (Eurostat, 2017a).

In the Figure 2 (Bøeng, 2014) the energy use per person by source in some selected countries are presented. Looking at Norway in this context the figure reveals two things. First, Norway is one of the countries with the highest energy demand per person. Second, the amount of electricity used for energy is very large compared to most other countries.

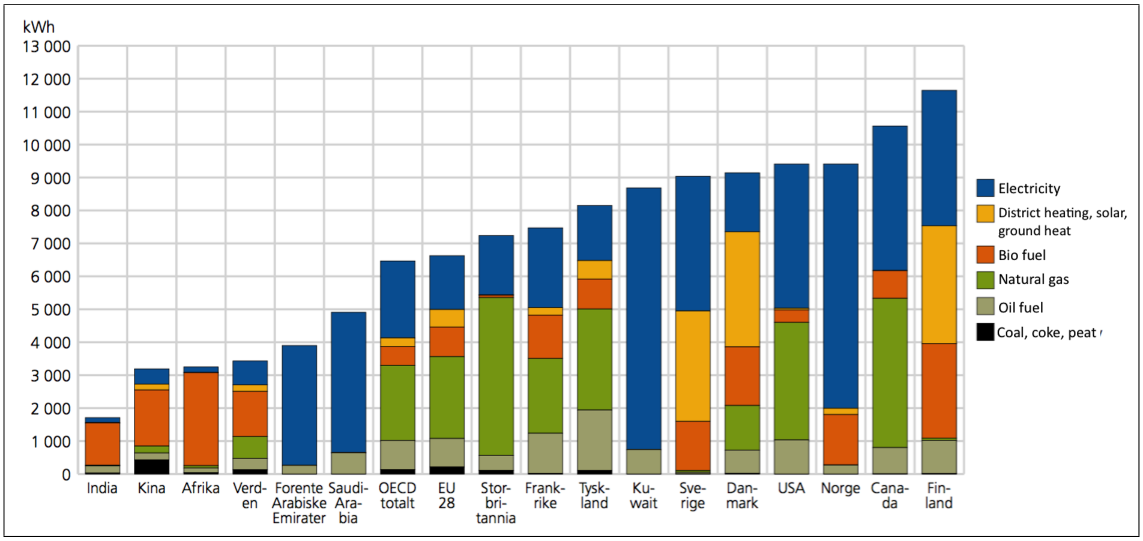


Figure 2: The total energy use per person by source in selected countries in the world in 2012 (Bøeng, 2014).

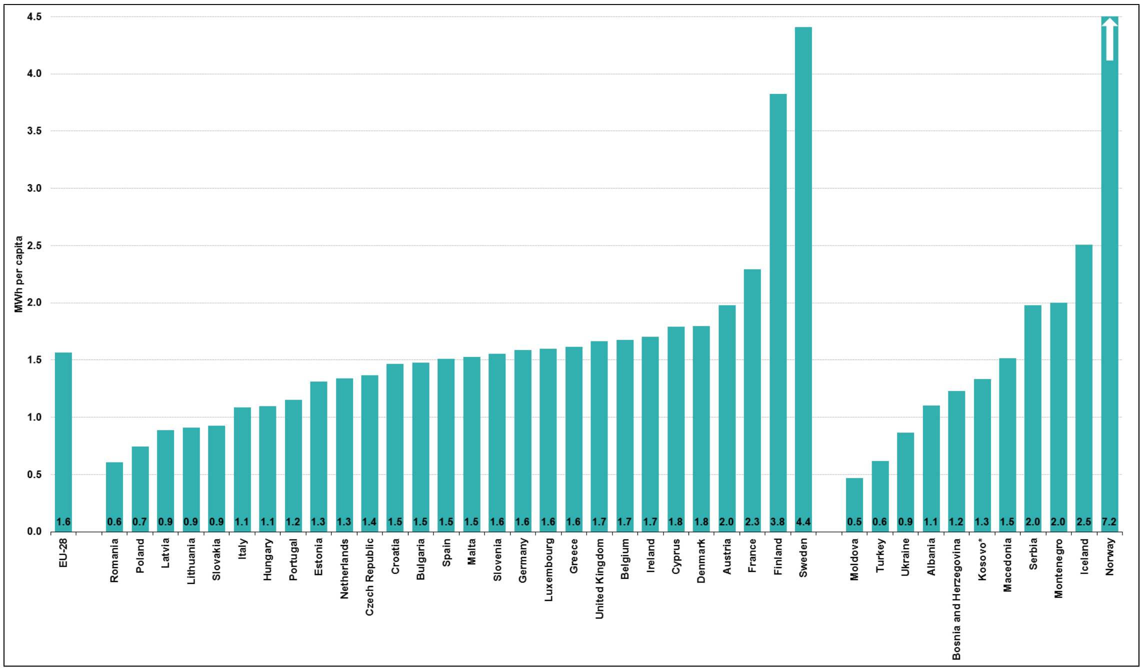


Figure 3: Households consumption of electricity per capita in 2015 (Eurostat, 2017b).

Figure 3 is focused only on the electricity consumption in households per capita in 2015. Norway is unquestionably the European country with the highest electricity consumption per capita, with almost twice the amount of Sweden on second place. This states that Norway is utilising electricity in their households to a much larger extent than other countries in Europe.

2.1.2 Energy by purpose

The energy in households is used for mainly three purposes – space heating, water heating and electricity-specific energy consumption. A breakdown of the average distribution of the consumption in the European households is illustrated in Figure 4. The figure is made with information from the European Environment Agency (2012) and NVE (Bergersen et al., 2013). The figure shows how the larger part of the energy consumption in households is used for space heating in all countries. The amount of energy used per household in Norway is amongst the highest in Europe.

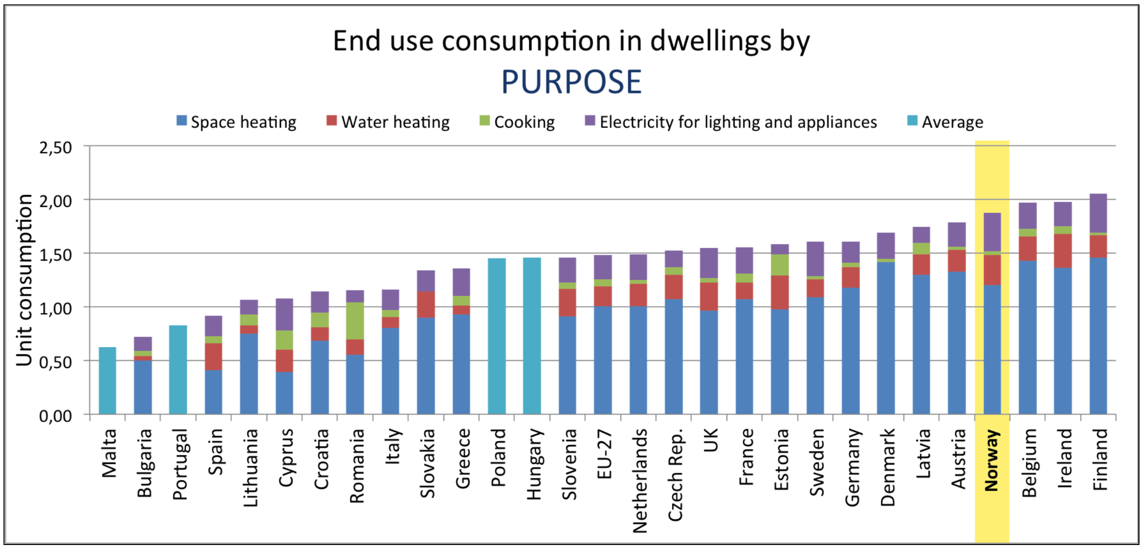


Figure 4: End use consumption by purpose in European dwellings.

2.1.3 Energy for heating

The larger part of the energy demand in Europe is for heating. Figure 5 illustrates the distribution of energy sources used for heating in typical EU households (Odyssee-Mure, 2015) and Norwegian households (Statistics Norway (SSB), 2014). For a typical European household the main heating source comes from natural gas, wood and oil, while the electricity use for heating is quite small. A typical Norwegian household on the other hand is mainly heated by electricity.

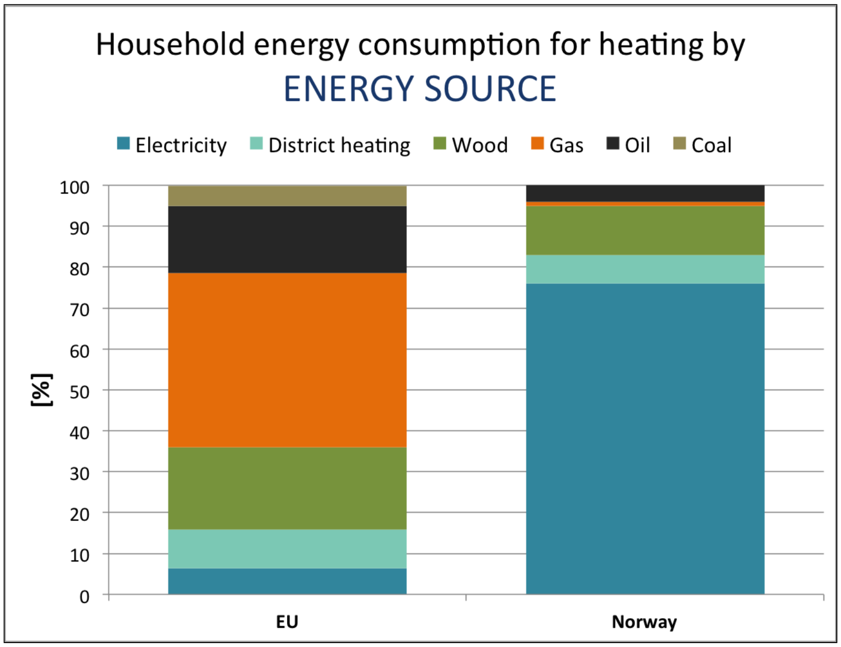


Figure 5: Household heating energy consumption by energy source in EU and Norway. (Based on: (Odyssee-Mure, 2015; Statistics Norway (SSB), 2014)).

Looking at the energy consumption in Norway in context of Europe it is clear that the energy situation is quite different, and the challenge regarding demand and peak load on the grid needs to be handled differently, according to the individual country. The largest potential for electric load shifting and efficiency in Norway is found in the heating systems, while this is not the case for most other European countries. In the next section the energy consumption in Norway will be investigated further.

2.2 Energy situation in Norway

2.2.1 Energy by source

The evolution of energy consumption in Norwegian households by energy source the past 40 years can be seen in Figure 6. The graph is made based on information from Statistics Norway (2017) and Bergersen et al. (2013). The figure shows that the energy consumption in households had a large increase up to 1990, but since then it has almost flattened out. The year 2010 was a particularly cold year, and makes an exception in the graph (Bergersen et al., 2013). During this period the amount of electricity and district heating have increased, while coal, oil, gas and fuelwood have decreased.

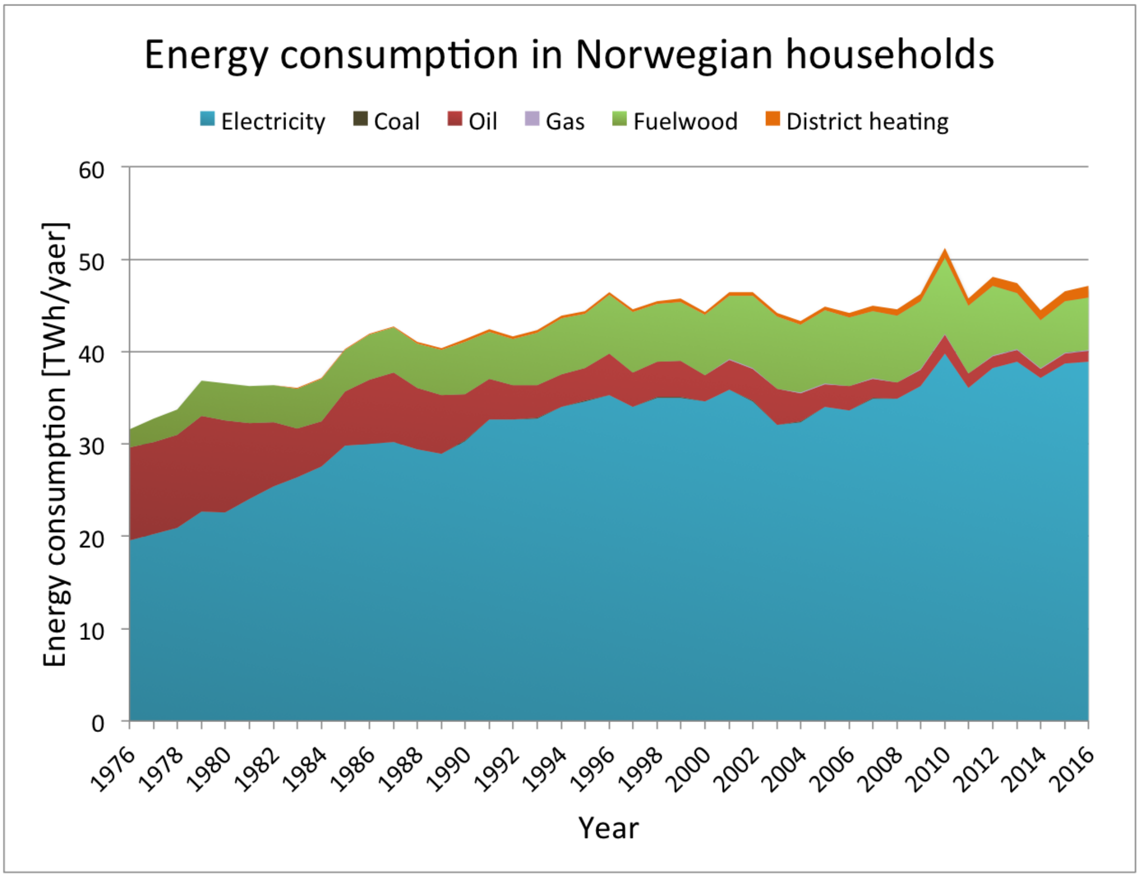


Figure 6: The total energy consumption from Norwegian households from 1976 to 2016. (Based on: (Fedoryshyn, 2017; Bergersen et al., 2013)).

Figure 7 describes the amount and type of energy use in households in the different counties of Norway (Bøeng, 2014). In Oslo the demand is the smallest, which is caused by smaller apartments in Oslo than in the rest of the country. Oppland is a county with a large amount of farms, which each have large gross areas and barns often heated with pellets or bio fuel. This is also reflected in the figure.

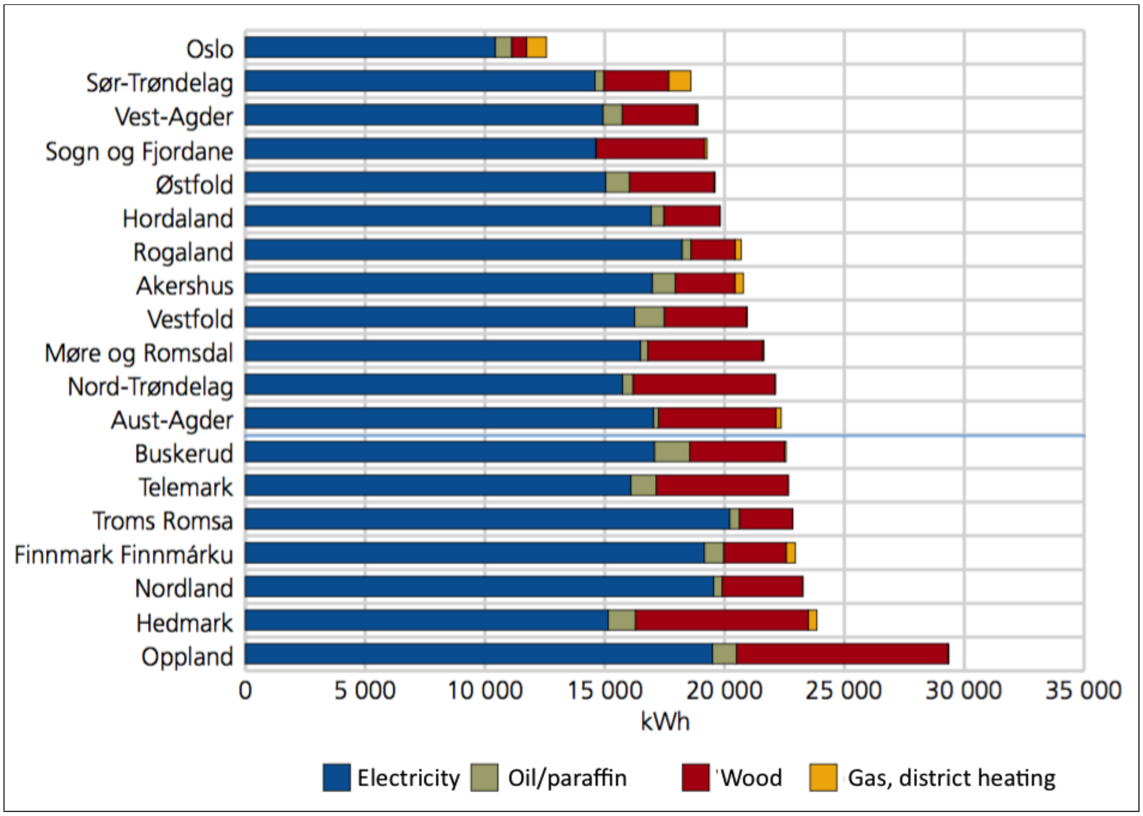


Figure 7: The energy use per household in the different counties in Norway in 2012 (Bøeng, 2014).

2.2.2 Energy by purpose

The average distribution of electricity consumption on Norwegian residential units is illustrated in Figure 8 (Feiber and Grinden, 2006). In total is 79% of the electricity consumption in Norwegian households is used for heating, while plug loads make up only the last 21%.

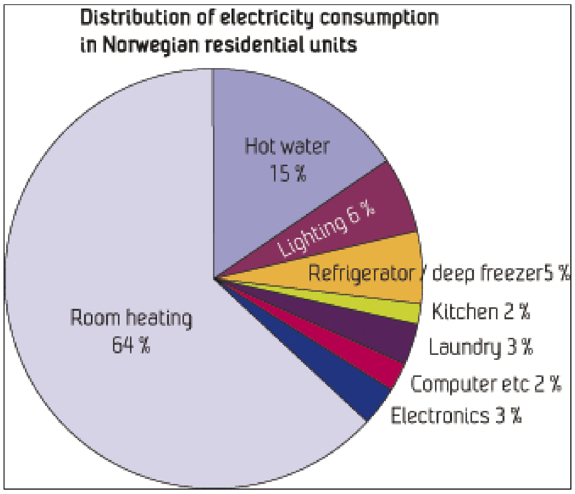


Figure 8: Distribution of electricity consumption in Norwegian residential buildings (Feiber and Grinden, 2006).

2.2.3 Energy for heating

Figure 9 illustrates the share of different heating systems in Norway (Statistics Norway (SSB), 2014). In connection to Figure 5, it can be seen that the non-electric heating sources are district heating, wood, gas, oil and coal, and accounts for 24% of the total heating in households. The remaining 76% of the heating is done by electricity, out of which direct electric heating systems accounts for 53% and indirect systems 23%. Direct electrical heating systems are typically electrical radiators, and is the most common form of heating in Norway. The COP for electrical radiators is 1, which means that the radiator delivers the same amount of heating as electricity supplied. Indirect heating sources are heating sources that is driven by electricity, but the heat is gained through another source. A typical example is air, ground and seawater heat pumps. These pumps often have a COP in the range of 2-5, which means that they deliver more heat than the amount of electricity supplied, as the heat is gained through energy in the air, ground and seawater. Indirect electric heating systems decrease the heating demand in buildings.

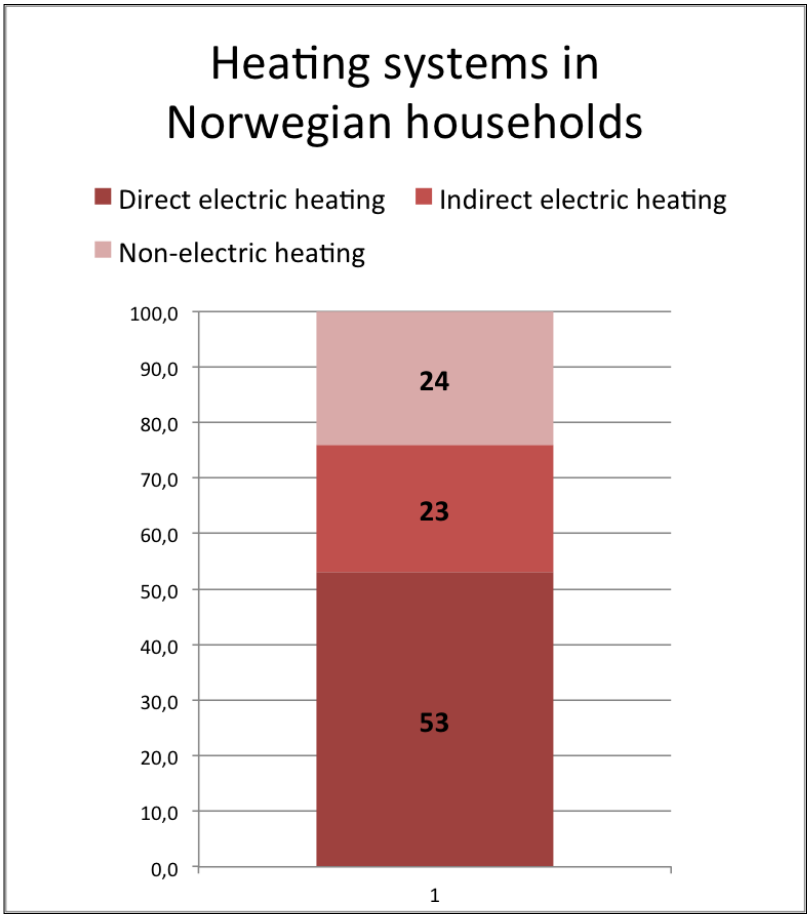


Figure 9: Share of heating system types in Norwegian households. (Based on: (Statistics Norway (SSB), 2014)).

2.3 Energy situation in Oslo

The grid distribution company operating in the Oslo region is Hafslund Nett. Information about this grid is obtained through direct contact with Ragnar Ulsund in the Grid Strategy Department, in the Division for Grid Development. In Figure 10, the power drain on the grid is plotted against the outdoor temperature, and there is an obvious correlation between the two. The yearly energy delivered through the grid is 9.23 TWh. The highest stress occur on the grid when the temperature is at its coldest. This correlates nicely with the findings that the largest part of the energy consumption in Norwegian households is used for heating, and that electricity is the main heating source. Weekends can also be clearly viewed in the plot, as less energy is consumed compared to weekdays.

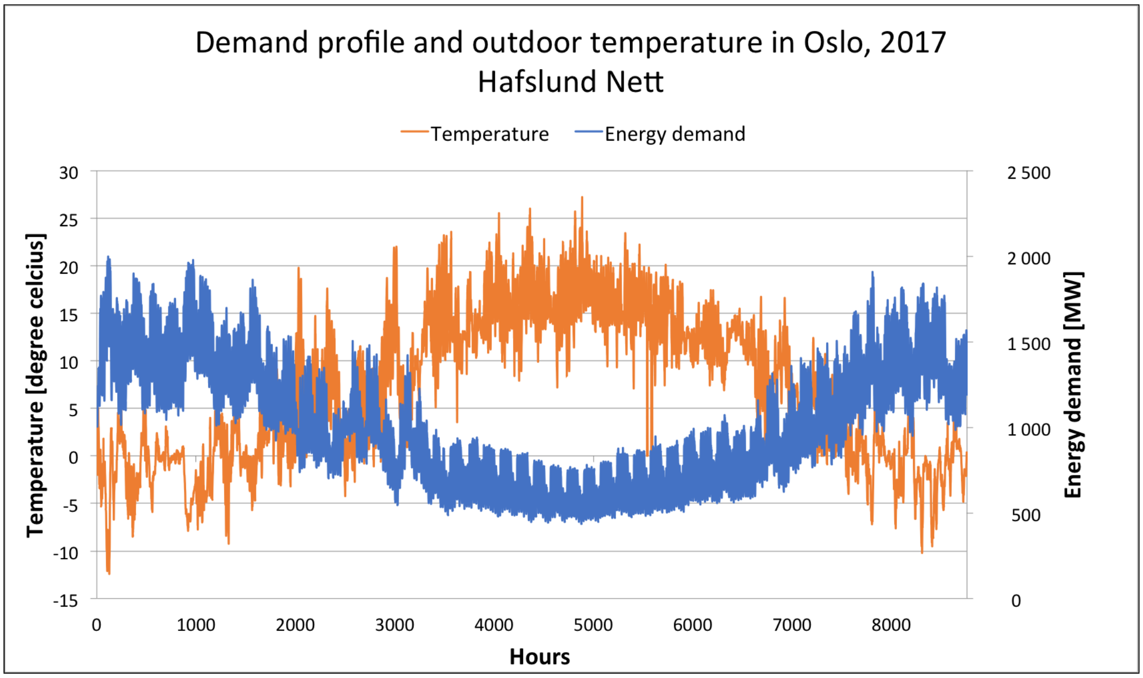


Figure 10: Load on the distribution grid in Oslo in 2017, plotted against the outdoor temperature.

At the moment there are no capacity issues on the grid during summer, and only a few hours during winter. In the future however, the load profile may change due to increased amount of electrical vehicles and energy efficient appliances. Moreover, the available electricity resources will become less stable, as the amount of renewable, inflexible energy sources are expected to increase.

The duration curve for the distribution grid in Oslo is shown in Figure 11, and displays that the highest drains only happens very few hours of the year. The capacity limit depends on many factors, like the number of transmissions and inputs to the grid, and where in the grid the loads are consumed. The capacity will therefore vary along the lines and with type of drain. The limit of 2500 MW illustrated in the figure is more a theoretical limit, but if the loads where to approach this amount of power drain, the operators will need to take action.

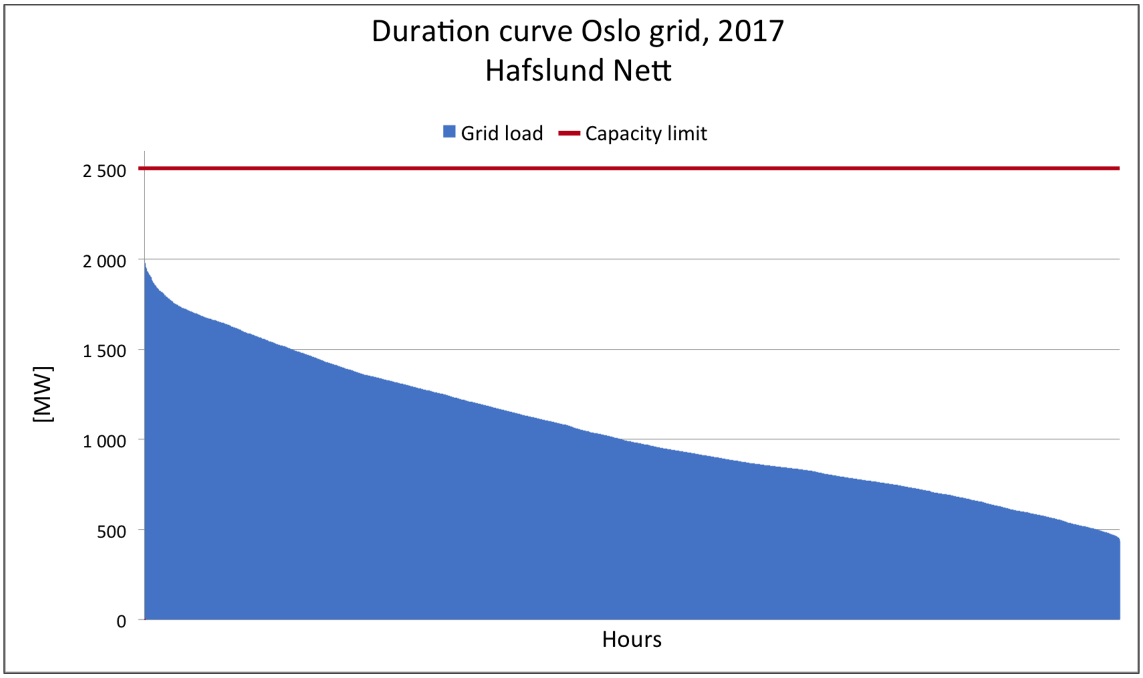


Figure 11: Duration curve for the distribution grid in Oslo in 2017.

The utilisation time and load factor of a grid refers to how many hours of the year the available capacity is utilised. The utilisation factor for this grid is 3692 hours, with a load factor of 0,42. This means that only 42% of today's grid capacity in Oslo is utilised, and the amount of energy demand could in theory be more than doubled before the capacity is maximised. But as the peak power drain is the limiting factor, today's pattern of energy consumption are already getting close to a need for grid enlargement. With increased use of electrical vehicles and efficient alliances, the peaks will continue to increase even though the demand is kept down, if change is not incorporated.

2.4 Energy flexibility

To obtain a more efficient use of the electricity grid, and decrease the need to invest in upgraded capacity, flexibility must be added to the system. Figure 12 (Jensen et al., 2017) illustrate, how flexible loads in buildings can decrease the need for grid enlargement. In this example heat pumps and electrical vehicles is introduced in the building loads, and they are made flexible to not exceed the capacity limit.

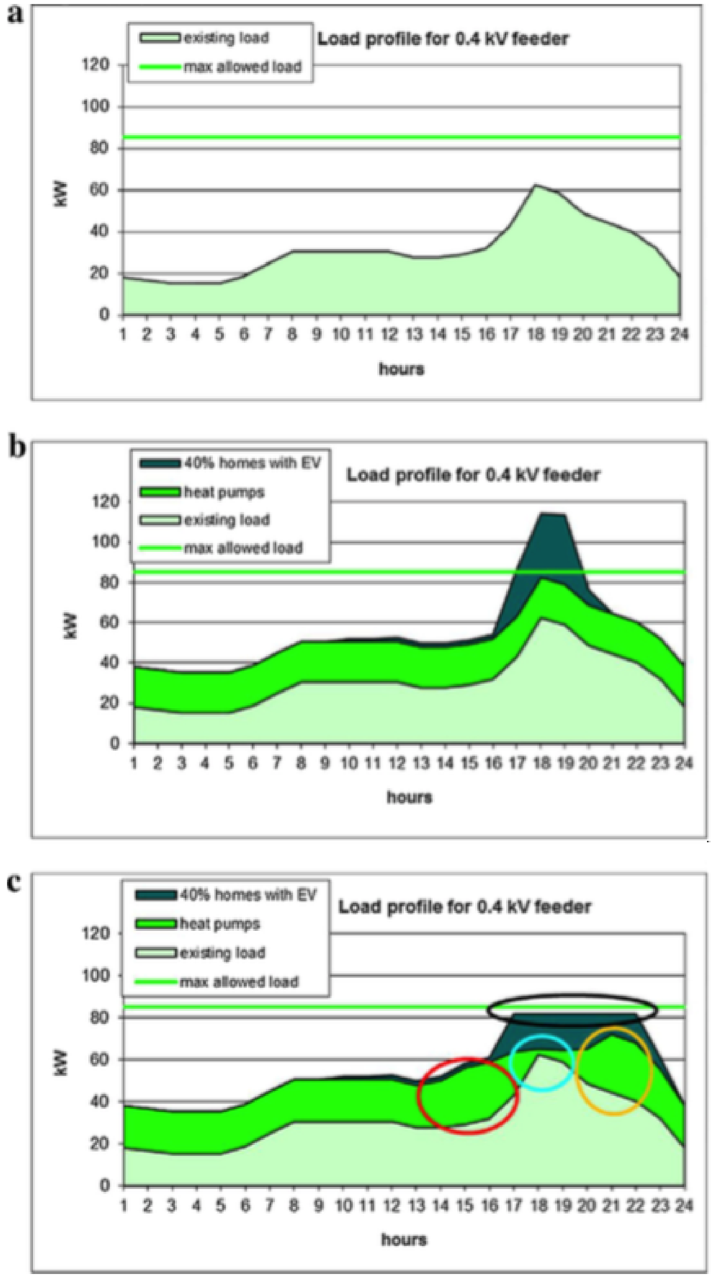


Fig. 1. The graphs show an example of the introduction of heat pumps and electrical vehicles in a 0.4 kV outlet/feeder [16]:
a) the existing situation. The peak from 17:00 to 20:00 is called the cooking peak due to people coming home from work and start cooking. The peak also is due to swithching on other applieaancies.
b) business as usual: heat pumps and electrical vehicles (EVs) in the system will demand a reinforcement of the grid as the demand exceeds the max allowed load.
c) a Smart Grid solution where the buildings prior to the cooking peak (17:00-20:00) are excess heated within the comfort band of the room temperature (red circle). The buildings are mainly free floating during the cooking peak (blue circle) but need extra heat after the cooking peak (orange circle). The charging of the EV's is controlled intelligently in order to keep the demand below the max allowed load (black circle).

Figure 12: Prediction for future grid load (Jensen et al., 2017).

Energy use in buildings will both affect and at the same time be dependent on the security of supply. As seen, electricity is largely used for heating purposes in Norway, the power demand is highest in periods with low outdoor temperatures. Buildings with low need for heating therefore means a lot to the energy and power load on the grid, especially during winter. Improved insulation, flexible heating systems, and converting to other heating sources than direct electricity are examples of actions that will reduce the grid pressure from buildings in the coldest hours of the year. Additionally will increased use of local energy production in high demand periods, as bio energy, heat pumps and solar power plants with sufficient storage capacity, be able to contribute positively to the security of supply (Leistad, 2018).

However, many building owners state that they don't see how energy efficiency can profit the energy costs of their building. An important reason for this is probably the missing link between investments in retrofitting and effective appliances, and the operation of the household. A price differentiated tariff, sending price signals to the customer when the load needs to be reduced, will make a direct link between the investment and the cost reduction. This will encourage consumption change, and may create a long lasting behavioural change of consumption pattern (Leistad, 2018).

2.5 Dynamic pricing tariffs

Electricity pricing is an important method by which the end-user can get incentive to perform demand response, while at the same time maintaining voluntary choice. Price-based demand response refers to the changes in electricity consumption patterns as a response to changes in the price of electricity over time (Eid et al., 2016). Introducing dynamic pricing tariffs will be a drive to flexibility in the market and innovation.

2.6 The Grid

To be able to deliver electricity to the consumers through the electrical grid network, two objectives must be fulfilled. The load factor always has to be more or less equal to 1.0, which means that the amount of supply and demand has to be equal at all times. Also, the system capacity has to be larger than the peak load demand of the system, as the demand can at no times be larger than the amount of energy the supply system is able to deliver. (AboGaleela et al., 2012).

Many of our renewable energy sources, like wind and solar, can be unreliable in terms of producing energy at the time we need it. Even though some renewable sources, like hydro, can be turned on and off as we want, in peak hours the maximum capacity of these sources will not always be large enough to meet the consumption demand (Eid et al., 2016).

Therefore, when peak load is higher than the capacity of the renewable energy sources, fossil fuels like oil and coal have to be used to meet the demand. This results in unwanted pollution, high electricity prices, and high pressure on the grid with high peaks. A generation-follows-demand perspective like this is called supply-side management (SSM) (Eid et al., 2016). The grid is dimensioned for the maximum peak load, which occurs only a few times a year, and the amount of power needed from the grid is a lot smaller on a normal day.

Smart houses and demand side management, a demand-follows-generation perspective, can contribute to decrease the peak loads and increase the matching between generation from renewable energy sources and the demand. This can decrease the use of fossil fuels and lessen the pressure on the grid, so that even for an increased demand in the future the grid does not necessarily need to be expanded.

2.6.1 Electricity definitions

In the following are some definitions for those not quite so familiar with electricity and the grid.

Voltage is the electrical potential difference between two points in the electrical field, and is a measure for the force that makes the electricity move through the cables (Andersen, 2018).

Energy is described as the ability to execute work. The unit for energy is joule [J], but electrical energy is measured in kWh (W=J/s). 1 kWh = 3 600 000 J. A characteristic of the electrical energy is that is has to be utilised in the same moment as it is produced. Storage of electrical energy can therefore only happen if the electricity is transformed into other forms of energy, like chemical energy in a battery (Hofstad, 2017).

Power is the electrical energy that goes through a system per time unit, and is measured in W (Andersen, 2009). The power can be illustrated as water going through a pipe. If the pipe is half full, less energy is going through the pipe per unit, and the power is low. If the pipe is full, more power is going though the pipe per unit, and the power is high. In other words, with higher power, more energy is delivered at a time.

Power balance is the calculation of a certain period in time of the balance between power supply and power demand (Statkraft).

Power plant or **generation plant** is the plant for production of electrical energy, with power stations, turbines, magazines, generators and tunnel systems, with belonging buildings and installations (Statkraft).

Power producer is a company that produce electrical energy and/or is providing gross distribution og energy (Statkraft).

Prosumers are end-users that both consume and produce electricity, for instance with solar PV panels or small wind turbines (Salom et al., 2014).

Grid is the system of connected power lines and other electric equipment for transmission of electricity from the power plant to the end-user (Statkraft).

Transformer is a device that convert electric alternating current of one voltage level to alternating current of another voltage level (Statkraft).

Substation is an electrical site for transforming electric energy (usually voltage transformation), and/or connecting power lines (Statkraft).

Long-term marginal cost describes the socio-economical cost for an increase in the power systems ability to deliver firm power to the receivers that is already connected to the power system (Statkraft).

Firm power is electrical power delivered according the a contract, normally applicable for a longer time period. The contract usually state how large the power and energy amount the receiver have the right to take out during a given time (Statkraft).

End-consumption is the amount of energy that reaches the end-users. In other words, it is the gross production minus transmission losses and own consumption used for the power stations (Statkraft).

Alternating current (AC) is electric current that changes direction periodically. On average, the same amount of current is flowing in both directions along a conductor. AC have smaller losses than direct current (DC) when distributing the energy over large distances. All energy supply is mainly based on AC (Sandstad, 2018).

Direct current (DC) is electric current with an unchanged flow of direction and more or less constant power. DC is often used when high voltage levels are to be transported in cables, as AC gives unacceptable high losses in cables. Batteries also consist of DC energy (Gunvaldsen, 2009). Therefore, the chargers for your mobile phone, computer and tablet all have transformers, to change the AC electricity from the socket in your house to DC in the batteries of the devices.

2.6.2 The grid actors

Figure 13 illustrates the five market players in the power market.

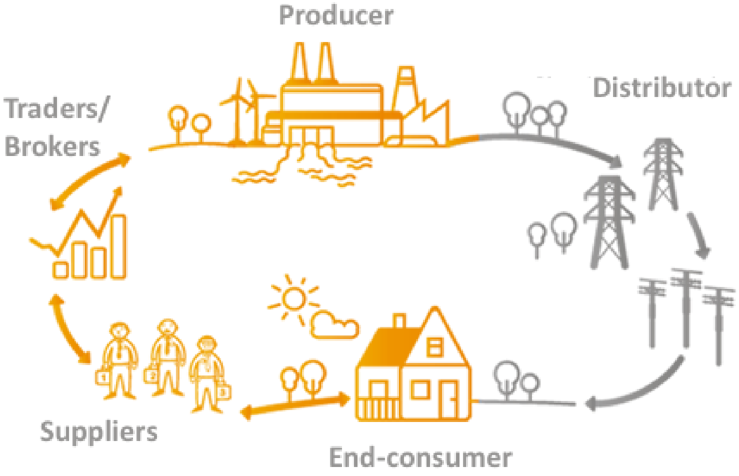


Figure 13: Illustration of the power market.

The producers are responsible for power production and supplying the right amount of energy into the grid. The distributors are responsible for maintaining the grid, and ensures that power is transferred from the producer to the end consumer. The suppliers buy the electricity and resell it to the end-consumers on the retail market. The end-consumers are often smaller companies and households, that can not buy electricity through the wholesale market. Between the producer and supplier there is also traders or brokers. The trader buys power from the producer and sell it to the supplier, while the broker acts as an intermediary, whom may for example find a producer for the supplier, willing to sell a given amount of power at a given time. Nord Pool is a broker, and 80% of the electricity in Northern Europe is traded through Nord Pool (Nord Pool, 2017a,b,c,d).

2.6.3 Electricity cost

The electricity cost paid by the end-consumer have to cover the costs of the whole power market, illustrated in Figure 14. The energy bill consists of two parts. The first part cover the electricity used, paid to the electricity supplier for distributing the energy. The second part is the grid rent, covering grid connection and energy transfer provided by the grid distribution company. In Norway there is only one grid distribution company responsible for each geographical area, and the end-user can therefore not choose their distributor or cost. The customers are however free to choose any supplier within the country. This thesis is considering only the grid rent part of the energy bill.

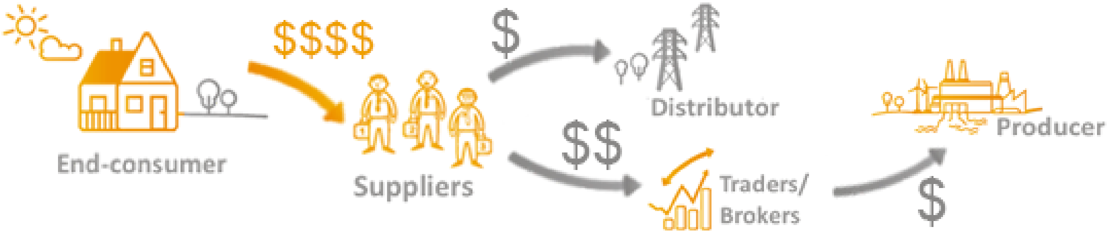


Figure 14: Illustration of the payment of energy cost.

2.6.4 The construction of the grid

Figure 15 sketch up the main parts of the electricity grid. The grid consists of high-voltage (HV) grids, middle-voltage (MV) grids, and low-voltage (LV) grids. The large generation plants are connected to the high-voltage grids, and the consumers and prosumers with distributed generation are in general connected to the low-voltage grids. The power system is constructed with a one-way flow of electrical power from a set of large-scale power plants to a large number of individual customers. Voltages are successively transformed to lower levels downstream in the grid (Salom et al., 2014).

The grid is divided into a Transmission System and a Distribution System. The Transmission System is HV grids, and they are operated by Transmission

System Operators (TSO). The HV grids have voltage levels above 1 kV in Norway. The TSO have the responsibility of economic dispatch and planning the operation of generation plants and transmission lines based on expected loads (Salom et al., 2014).

The Distribution System is covering the two lower voltage levels, MV and LV, and is operated by the Distribution system operators (DSO). They are required to keep network voltages within prescribed limits. In Norway, the MV grid span from 250 V to 1 kV, while the LV grid have voltage levels below 250 V. In other countries the voltage levels are often higher for each of the different grid levels. The grids are normally constructed based on radial feeders, with the transformer substation at one end, the last customer at the other, and a number of customers connected along the way. The limiting factor of a distribution feeder is the voltage drop downstream along the feeder, which increases with the total load and the cable resistance (Salom et al., 2014).

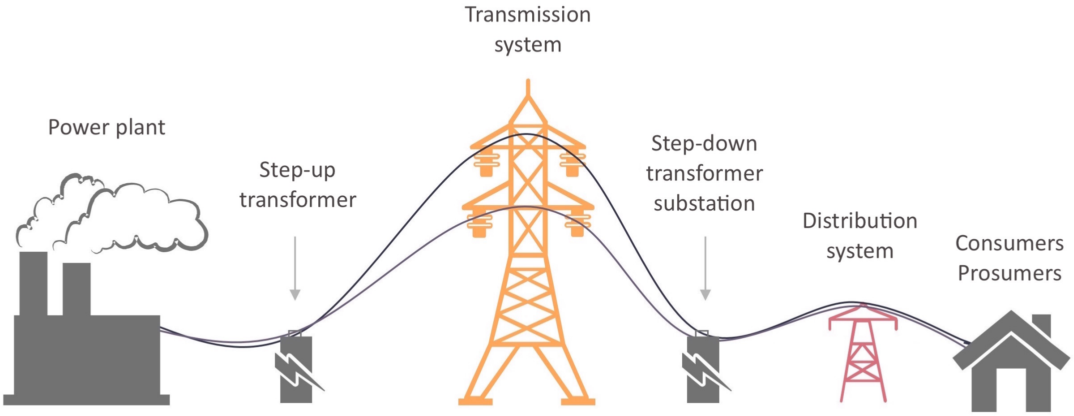


Figure 15: Build-up of the electricity grid.

Transformer substations connect the MV grid and the HV grid. These substations typically have automated voltage control through on-load tap changers to keep the voltage within bounds, but otherwise the distribution grid normally lacks surveillance and control. Secondary substations connect the MV grid and LV grid with manual tap-charger control that boosts the voltage to counteract the voltage drop in the MV grid (Salom et al., 2014).

In the far end of the grid is where the customers are situated, receiving electricity for heating, ventilation, cooking, and electrical appliances. Traditionally, buildings have largely been considered as passive consumers. But some buildings are also producing electricity, for instance with solar PV panels. These buildings, that both produces and consumes energy, are called prosumers. Their relationship with the utility grid is far more complex than that of conventional, passively consuming buildings (Salom et al., 2014).

2.6.5 Distributed generation

Distributed generation (DG) is generation happening on the distribution system, and is of limited power size, less than 10 MW. The DG units are interconnected at substations or customer load levels. The power can typically be produced from solar photovoltaics, solar thermal collectors, wind turbines, or small or micro sized hydro turbines. As inflow of these sources vary, they can impact the flow of power and voltage conditions at customer and utility equipment on the grid. Normally, the impact of individual residential scale DG units that is generating less than 10kW is negligible. However, when the capacity of many small units is aggregated they can cause a significant impact. And as the amount of DG currently is expanding at a high rate, the interconnections between the generation units and the grid has to be carefully installed, maintained, and have minimum standards for control, to not cause degradation of power quality, reliability, and control of the utility system (Barker and Mello, 2000). The interconnection of producers, consumers and prosumers makes the grid prone to power imbalance, but it also provides the opportunity of compensating this imbalance by modification of flexible loads at individual consumers (Tahersima et al., 2011).

2.6.6 Load matching and grid interaction

Load matching (LM) refers to the degree of agreement or disagreement of the on-site generation with the building load profiles. It is the relationship between a buildings own generation and the buildings load, and refers to how the local energy generation compares with the building load (Salom et al., 2014).

Grid interaction (GI) refers to the energy exchange patterns between a building and the utility grid, and its impact on the overall load of the grid.

It is the relationship between the exported and imported energy to the grid from the building, and the load conditions of the grid itself. Grid interaction refers to the energy exchange between the building and an energy infrastructure, typically, the power grid (Salom et al., 2014).

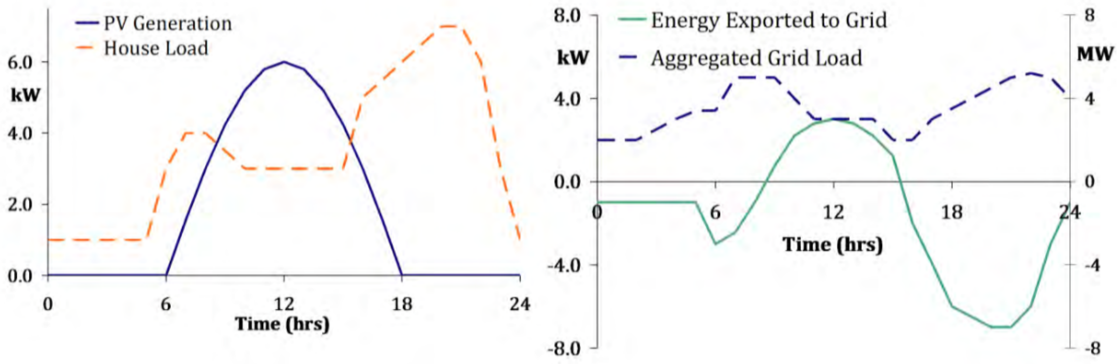


Figure 16: Load matching (left) refers to the relationship between a buildings own generation and load. Grid interaction (right) alludes to the relationship between the energy exported/imported to the grid and the load conditions of the grid itself. (Salom et al., 2014).

LM and GI are independent, but intimately related issues. see Figure 16. The main distinction is that the load matching index describes the degree of utilisation of on-site energy generation related to the local energy demand or building load. The higher the index is, the better the coincidence between the load and the on-site generation. On the other hand grid interaction factors measure the unmatched parts of generation or load profiles, e.g. peak generation delivered to the electricity distribution grid. The GI factors describe the utilisation of grid connection in relation to the building or cluster of buildings (Salom et al., 2014).

The limiting factor, in a building or utility network, is the maximum power that may be delivered or received. That means that even if a building is in an electricity balance in the long-term between energy generated and consumed, shorter time scales may not be in balance. This is often the case for buildings with solar power production and ordinary demand profiles. These buildings are consuming more energy in winter due to increased space heating, while the solar panels produce more energy during summer when the demand from the building is low (Salom et al., 2014).

As prosumers usually receive a smaller payment for electricity sold to the utility grid than what they pay for buying electricity from the grid, it is beneficial to maximise self-consumption, i.e. minimising export of electricity to the grid. More flexible demand will make the building more capable of profiting from its on-site production (Salom et al., 2014).

With more renewable energy sources the importance of load matching and grid interaction increases. The energy system needs to become more complex, flexible and dynamic. This also requires energy storage devices, control devices and smart metering, with exchange of energy and information between smart buildings and the smart grid (Salom et al., 2014).

2.6.7 Load coincidence

When planning the distribution grid, the major factor is the expected peak load on the grid. This determines the largest power flows the grid components have to handle. Load coincidence is the effect of aggregated demand from several buildings. For a set of buildings, their respective peak loads may be occurring around the same time but not exactly simultaneously, which effectively reduces the total peak load per customer. Therefore, when sizing equipment connecting several customers, load coincidence has to be taken into account. This method is referred to as the Velander Method, see Figure 17 (Salom et al., 2014).

However, this is not the case for the total PV generation, as clear weather will cause all systems to produce their maximum power at the same time. For a large number of prosumers, their load demand will be much more evenly distributed over time than their PV generation. Therefore, if the total aggregated annual demand and on-site generation are equal, higher grid capacities are required to deal with the PV supply than the demand, and the grid capacity needs to be dimentioned according to aggregated load from PV production (Salom et al., 2014).

The hosting capacity of a distribution grid is the amount of distributed generation that can be connected before the performance of the grid becomes unacceptable. In general, city grids have a higher hosting capacity and are more robust than suburban or rural grids. Tested representative rural and suburban grids could allow 60% DG penetration of the annual demand before the allowed voltage was exceeded. A representative city grid allowed DG

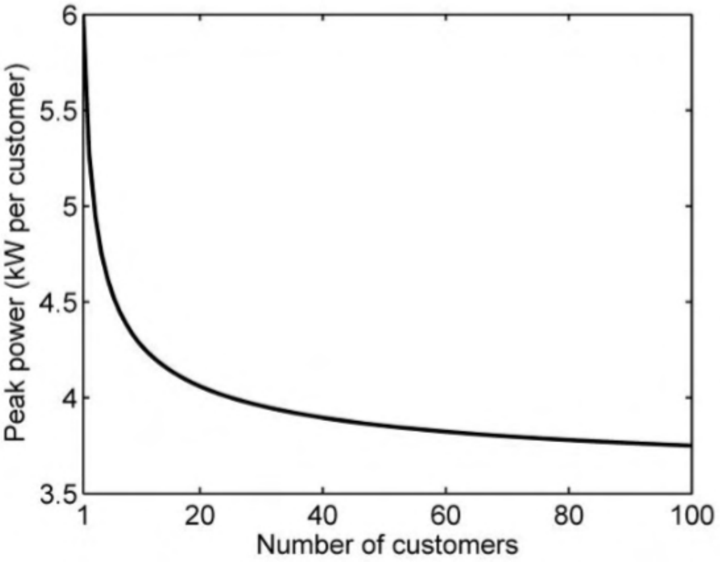


Figure 17: Peak power contribution of customers in a distribution grid as predicted by the Velander method (Salom et al., 2014).

penetration three times higher than the annual demand (Salom et al., 2014).

2.6.8 Smart grid

A smart grid is an intelligent power system connecting all the producers, consumers, and prosumers of energy, and integrating the behaviours and actions of the users, to deliver sustainable, economical and safe energy on the grid (Tahersima et al., 2011).

Smart grids, or the internet of energy, are a solution to the problem of supply-demand balancing of power systems. A smart grid is making a balance between power supply and power demand side of the grid. A smart grid consists of smart houses connected to a power system and a control system through transmission lines and communication infrastructure, see Figure 18. The interconnection point power flow is the power flow from the power system to the smart grid, P_{It} in the figure. The aim is to achieve balance of this interconnection point power flow with fluctuations within the acceptable range. Some of the loads in the smart houses are controllable, and balancing the system can be done by altering these loads when needed (Tanaka et al., 2012).

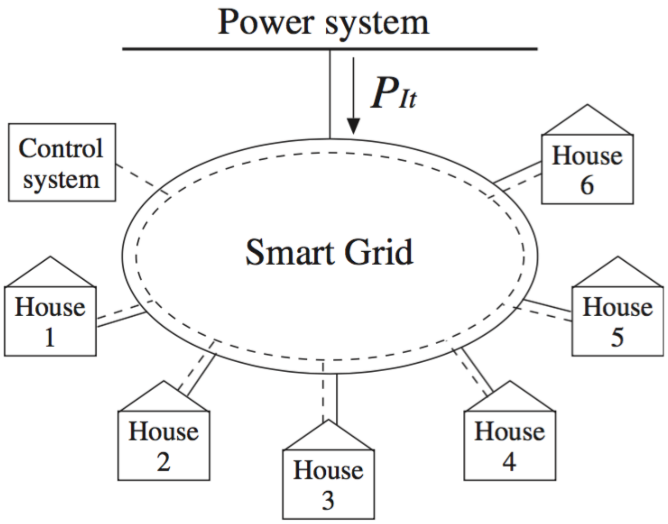


Figure 18: Model of a smart grid (Tanaka et al., 2012).

The purpose of a smart grid is to supply electricity in a smarter, more user friendly way. The smart grid integrate advanced sensing technologies at transmission and distribution levels, to have the ability to accommodate all types of generation and storage options, have efficient operations, high power quality, and flexibility to balance the demand with the supply. A smart grid involves the consumer in the system, and create active consumers. An upgrade to a smart grid has been evaluated as a critical step to address the future energy requirements (Esther and Kumar, 2016).

The electricity prices on the trading market varies with the balance of the grid, and this changing price is called spot price. The spot price is normally changing every hour or more often. Consequently, when the supply-demand balance is changing, the electricity price is changing. The control system sends signals to the smart grid with information about the price, and the controllable loads in the smart houses can be changed accordingly. The spot price is low when the power production, and so the flow, is higher than the demand. Load needs to be turned on, and incentive is given with low prices. When the price is high the power production is lower than the current demand, and loads need to be turned off. When flexible loads respond to the price signals, it helps the grid to maintain balance, and it also decreases the energy cost for the consumers that have flexible loads.

Optimal operation of smart grid is determined to minimise the interconnection point power flow fluctuations, increase the efficiency of power supply, conserve energy and in the end decrease the carbon emissions from electricity productions (Tanaka et al., 2012).

2.6.9 Smart houses

A smart building is a building where appliances have controls and can be programmed to fit the personal schedules and routines of the occupants, according to the length of the day and outside temperature. A smart building can save energy for the consumer at the same time as a higher comfort for the occupant is obtained. Loads like heating, air conditioning, washing machines, dryers, dishwashers and charging of electrical vehicles can be shifted from the typical peak hours in the evening to run at night when electricity prices are lower (Rokach, 2012). Energy and cost is saved by turning off appliances when they are not needed and shifting the flexible loads according to price signals. Smart controls and a smart meter in the house is necessary to be able to program and control the units according to price.

2.6.10 Smart meter

A smart meter enables interaction with the control systems in a house and can perform actions like selling and buying electricity if the building has district generation (Karnouskos and Holanda, 2009). The smart controllers need to be connected to the smart meter to be able to control each unit according to price (NVE, 2017). Implementation of smart meters and new information and communication technology (ICT) infrastructures creates a paradigm shift in the way electricity systems are operated. The traditionally passive end-users are transformed into active market players (Eid et al., 2016).

In Norway, advanced metering systems (AMS) are to be installed at all consumption units by 01.01.2019. The grid distribution companies are responsible for the installation and funding of about 3500 NOK in each household. The funding is covered through increased yearly grid hire, paid by the end-user. The price will be around 300 NOK per year per household for 10 years (NVE, 2017).

The AMS meter is provided with a physical port, called the HAN-interface (Home Area Network). Through this port the customer can get access to information about their own electricity consumption. Customers will have to ask the grid distribution company to open the port to be able to use it, and only the customer themselves will have access to it. The following information is given through the interface:

- Power drain
- Energy consumption the previous hour
- Voltage level
- Excess power from DG exported to the grid

(NVE, 2018)

2.6.11 Microgrid

A microgrid is an example of a smart grid. It is a localised group of electricity sources and loads that is connected to the conventional utility grid, but acts as a single controllable entity when synchronised with the utility grid. The microgrid can be disconnected from the utility grid according to physical or economic conditions, and operate independently. It is one of the most practical solutions for green and reliable power, and is serving the three main goals of society – reliability, sustainability, and economic efficiency. A typical microgrid constitute of seamless transition with utility, renewable power generation and a high level of automation(Hossain et al., 2014).

The goal of a microgrid is to reduce the amount of generation, storage, and backup units, and still maintain a reliable power supply. If each and every user have to provide their own units to achieve reliable power, this system would be the most expensive power system there is. In a microgrid the assets for generation and storage is shared, as not all loads in a system needs energy at the same time. The microgrid serves energy security to the power industry, reduces transmission losses, costs and emissions, without requiring change in daily lifestyles. Microgrids can also work better for underdeveloped transmission infrastructure like remotely located villages and islands. The excess power from a microgrid can either be sold to the utility grid, or stored in a storage system (Hossain et al., 2014).

2.7 Demand-side management

Demand-side management (DSM) provides support for the smart grid functions, and is an important factor of the energy management of the smart grid. Basic components of a DSM framework is local generators, smart devices, sensors, energy storage systems, energy management units, and smart grid domains. The strategy is to control and influence the energy demand to match the supply. A DSM framework can reduce peak load demand, reshape demand profiles, and increase grid sustainability. The overall cost and carbon emission level is reduced (Esther and Kumar, 2016). The demand-follows-generation perspective increases the matching of demand with supply from renewable energy sources by changing the end-user consumption pattern. This matching is beneficial for the customers, the programme sponsor and the society (AboGaleela et al., 2012). In the short term the energy costs, network peak loads, and risk of system collapse is reduced, by keeping electricity flows within technical constraints (Eid et al., 2016).

In the long term utilities can get the maximum possible energy from the already installed units and limit the need for constructing new power plants, distribution-, and transmission lines. The profit is maximised and the average cost per kWh minimised, without having to expand the capacity of the system (AboGaleela et al., 2012). This creates secondary effects including reduction in CO_2-emissions (Eid et al., 2016). DSM techniques aim to reduce the system peak load demand, the operational cost, and provide the customers with greater control over their energy consumption (Esther and Kumar, 2016). Demand-side management includes demand response, energy efficiency, and energy storage (Eid et al., 2016).

2.8 Demand response

Demand response does not reduce the amount of energy used, but encourages shifting parts of the load to times when the demand is lower and the electricity is cheaper. To obtain this there is a need for installation and utilisation of end-user technologies (AboGaleela et al., 2012). Demand response refers to the ability of the demand side to be flexible, responsive and adaptive to economic signals (Eid et al., 2016).

2.8.1 Load shifting

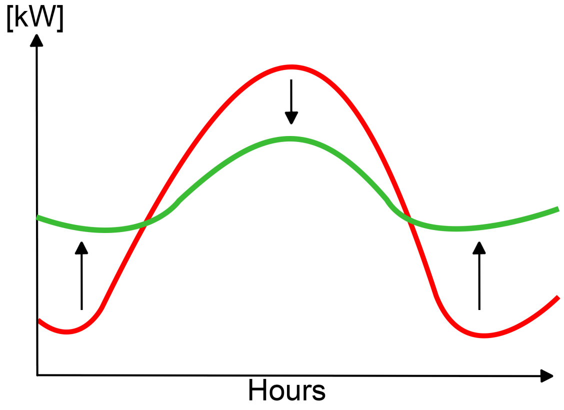


Figure 19: Load shifting

The DR technique load shifting, illustrated in Figure 19, allows the system to move loads from peak hours to off-peak hours. The advantages of load shifting is that the total system peak demand and the cost of energy consumption for the customers will decrease, and the overall system load factor, utility revenue and the matching of supply and demand is increased and creates a better utilisation of the supply. (AboGaleela et al., 2012).

Storing electricity during low load periods for use in peak load periods is a method to reduce the peak demand. In many developed countries heating, cooling and air conditioning is responsible for the large part of the total electricity consumption. It is therefore possible to shift a significant amount of the peak load by storing heat or cold from the low load period, and releasing it during the peak load period (Barzin et al., 2015).

Other examples of load shifting is delaying washing machines, dishwashers, and charging of electrical vehicles, from peak hours in the evening, to off-peak hours in the night.

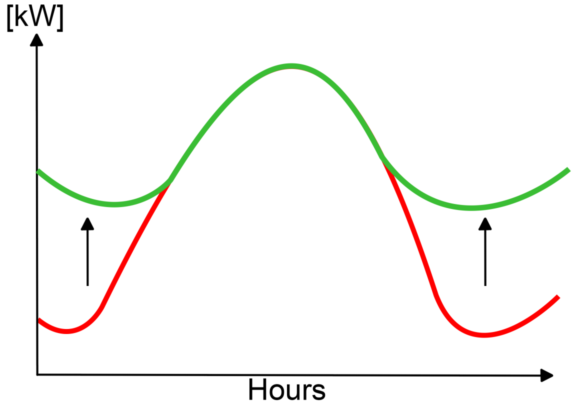


Figure 20: Valley filling

2.8.2 Valley filling

The system load factor can be improved by increasing load during off-peak hours if the production at the time is larger than the consumption (AboGaleela et al., 2012). This is especially relevant for grids with renewable energy sources like wind and solar power, which can not be saved for later when the demand is lower than the production. To utilise this energy we can turn on flexible loads in the building, like water and

room heating, which may have been turned off at peak hours, or charging an electric car or a battery. The energy can also be used to pump water back up in a pumped-storage hydro power reservoir, and make this water reusable for the next peak hour when the demand is higher than the wind and solar production. This process is called valley filling, see Figure 20.

2.8.3 Load building

Increasing the load throughout the day is called load building, see Figure 21, and can be done by utilising less energy efficient appliances or by increasing overall consumption (AboGaleela et al., 2012).

This tactic is more often used to raise the consumption and profit by the energy companies, and is usually the opposite of the aim of a demand-side management program. But in some cases it might be relevant for renewable energy grids with a general production higher than the demand, for example an area with a micro grid that is not connected to the regional grid, like an island or remotely located buildings. If the electricity source is providing more energy than the total demand of the area, load building can be applied to utilise the rest of the potential energy.

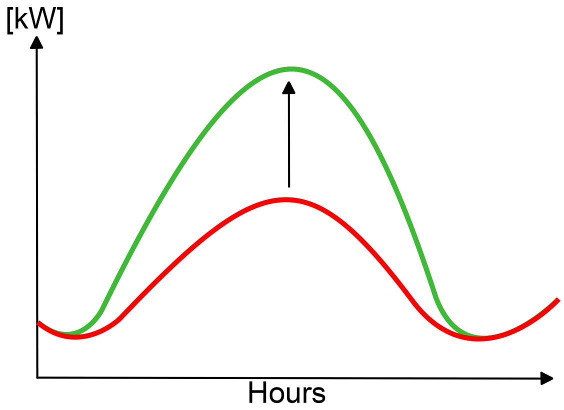


Figure 21: Load Building

2.8.4 Flexible load shape

Flexible load shape, Figure 22 or dynamic energy management, is a directly controllable demand response method of load modification. The method is applied in order to maintain electricity supply reliability of smart grids. There are three main methods of dynamic energy management. (Eid et al., 2016)

Direct load control (DLC) is when the system operator or a balancing authority has direct access to the load and can adjust it when required (Eid et al., 2016).
With this type of flexible load shape the electricity company has a specific contract which allows them to control the customers equipment, and in return they offer a cost reduction (AboGaleela et al., 2012). This is mostly done with larger companies and industries, which are not depending on electrical power at specific times.

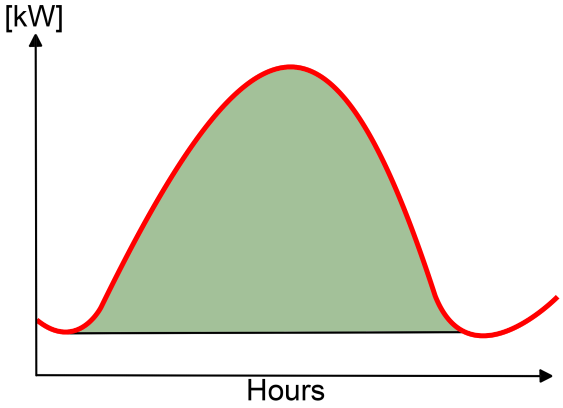


Figure 22: Flexible Load Shape

The other two methods are load shedding, which refers to reduction of consumption in network zones, and intentional brown outs. Brown outs reduces the voltage frequency slightly, which reduce the needed electricity transport capacity and generation capacity, but maintaining the supply quality within limitations (Eid et al., 2016).

The need for demand flexibility by residential sector is currently not critical in Europe, as there is sufficient capacity within the distribution grid and flexibility provision from industrial consumers. But in the near future, with increased demand and penetration of renewable energy sources on the grid, the residential flexibility will become increasingly important (Eid et al., 2016).

2.9 Energy efficiency

An energy efficiency (EE) program encourage reduction of the overall energy demand (AboGaleela et al., 2012).

2.9.1 Peak clipping

Peak clipping is reducing the grid load, mainly during peak demand periods (AboGaleela et al., 2012), see Figure 23. Peak clipping is important to reduce the high power drain that occur during peak hours.

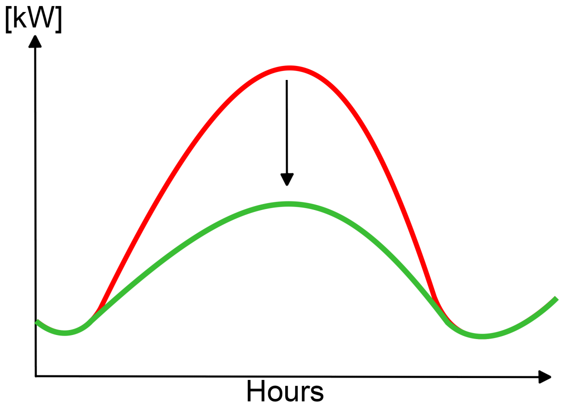


Figure 23: Peak Clipping

In relation to the building industry, adding or improving the materials in the envelope, or install a heating system with higher efficiency, will reduce the space heating demand, and the peaks in cold temperature periods will be reduced.

2.9.2 Conservation

Conservation, illustrated in Figure 24, is reducing the over all load by utilising more energy efficient appliances or reducing consumption (AboGaleela et al., 2012). Improved envelope materials, heating system with higher efficiency, ventilation with heat recovering system, reusing hot water from showers to preheat cold water, lighting system with sensors and LED-bulbs, and natural ventilation for cooling are some of the technologies that may reduce the over all demand, as well as peak load if the units are turned of at peak hours. Using a heating system which is not run on electricity, like a bio boiler, is also a way to reduce both the electricity demand and the peak load.

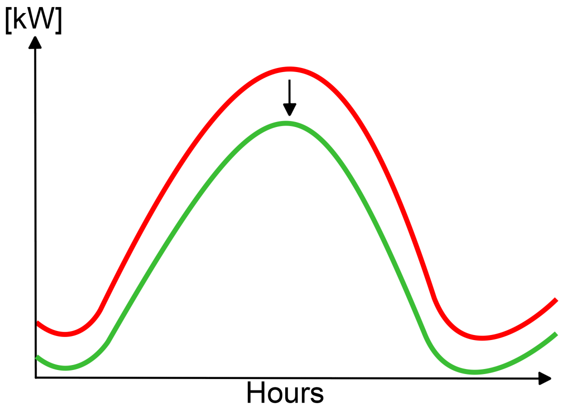


Figure 24: Conservation

2.10 Incentives to DSM

There are different approaches to achieve behavioural change amongst energy consumers. One incentive can be environmental care. The environmental and social driven demand response decrease energy use, increase energy efficiency, define commitment to environmentally friendly generations, and reduce greenhouse gas emissions. Another incentive is reliability driven demand response. This type of demand response is aiming to maintain system reliability by decreasing demand in a short period of time and reducing the need to enhance generation of transmission capacity (Eid et al., 2016).

But even though environment and reliability are factors with increasing importance amongst people today, neither of these incentives are usually enough to improve the consumption pattern. An economic driven incentive that reduces the general cost of energy supply for the customer is commonly the most efficient incentive to change user behaviour (Eid et al., 2016).

2.11 Energy storage

Energy storage (ES) is believed to be an essential part of the modern energy supply chain. As energy is a fresh product, that needs to be consumed when it is produced, energy is often wasted. Energy storage can reduce the waste from domestic and industrial areas by saving the energy in another form for later. Also, with the penetration of renewable energy sources like wind and solar, energy storage is essential to make these sources reliable and steady, by introducing the flexibility that energy storage provides. When energy waste is reduced, the energy needed to be produced decrease, and so does accordingly the CO_2 emissions (Aneke and Wang, 2016). Energy storage achieves higher asset utilisation rate for the grid and contribute to the reliability of the power system. The storage is considered a flexible resource, but not an electricity generation resource (He et al., 2011).

On the large scale, storing energy can be done by pumping water back up in hydro reservoirs in pumped storage power stations at times when other renewable sources like wind and solar are producing more energy than what is demanded. A pumped storage power station usually has a large capacity of storage, compared to a battery. Of all the energy stored today, 95% is stored in pumped hydro storage, while only 0,0001% is stored in lithium ion batteries (DOE Global Energy Storage Database, 2016). The hydro plant buys electricity in periods with low demand and low price, and is at these times working as a load when the supply is larger than the demand, performing the demand response valley filling. During high demand and pricing periods the stored water is discharged, and the plant is operating as a hydraulic generator. In this way the plant is balancing the production from wind and solar power, increasing the stability of the grid. The energy efficiency is about 70-80%. This means that the plant utilises more electricity when pumping the water up, than what is produced when releasing the water back down. Nevertheless the price difference between high and low periods makes it nevertheless profitable for the plant (Duque et al., 2011).

On the small scale, energy storage can be used in individual buildings or for aggregated neighbourhoods to save excess energy from DG, or charge the storage in times with low cost to use at high-cost periods. Buildings that produce electricity can either be connected to the grid, and export and import energy whenever they have to much or too little, or they can have a source of storage to save the energy. A combination between the two is also possible. As buying electricity from the grid is usually more expensive than selling it back into the grid, energy storage that reduce the amount of electricity sold to the grid can be a profitable solution. The source of storage is usually a battery. However, when using a battery, the energy have to be transformed into a storable form of energy, and recovered back into electric energy usable for electrical services when needed. Each time the electricity is transformed energy is lost.

To minimise the losses, a third option is to make the building itself flexible, and in this way use more energy when it is produced and available, and less when it is deficit. A control system to perform the load matching in the building will be necessary for this process. Loads in the building that can be flexible is heating systems, both space heating and domestic hot water, washing machines, dryers and dish washers, and charging of electrical vehicles. Cooking and light are sources that are less accessible to flexibility. The machines and the charging can be made flexible only by implementation of a control system. For heating to be flexible some upgrade in the building physics is usually necessary, either by a battery, storage tank, or other more advanced inventions.

2.11.1 Heat storage

Heating of buildings are typically done by electricity, heating oil, firewood, wood pellets or district heating. A drop in outdoor temperature is affecting these heating sources to increase in consumption. Electricity is also used for electrical appliances and lighting, which is not influenced by the outdoor temperature. Due to the fade out of oil-fired boilers in Norway, these heating systems are decreasing in number, while district heating, fuelwood and electric heating is increasing (Bergersen et al., 2013).

Heating systems with heat storage capacity is a source of energy buffer. The system can consume energy when there is surplus energy on the grid by storing heat in a thermal storage tank, or a thermal mass like a concrete floor. When there is a power shortage on the grid the system can pause the use of power, and instead release the stored heat (Tahersima et al., 2011).

Oil-fired boilers are based on a pipe system, bringing hot fluid around in the building. This system can without large renovation be upgraded to a water borne heating system, heated by a ground source heat pump, or electric or bio boiler. With a water borne heating system comes also the ability of heat storage for space heating in a hot water tank. This is only relevant to the systems driven by electricity, as the bio boiler would not affect the grid strain.

Another innovative installation is phase changing materials (PCM), which can be used for storing heat or cold. The material utilises heat to absorb and release energy through phase change, which creates a large amount of heat storage with small fluctuations in temperature. PCM used to shift the loads can therefore reduce energy peaks, and energy costs for a building (Barzin et al., 2015).

In Nordic countries heating systems are used almost all year round, and is constantly a large part of the energy demand. This means that there are potential flexibility sources in every house - numerous and geographically well distributed (Tahersima et al., 2011).

2.11.2 Prosumer subscriptions

A prosumer is a consumer connected to the grid which also produces electricity by solar panels or other forms of renewable energy sources. These customers will at times produce more than they consume, and at other times less. The grid has to be able to both deliver and receive electricity from these users, and a prosumer needs to have a contract with both the grid distribution company and the supply company. The maximum power a prosumer is allowed to deliver to the grid in Norway is 100 kW (NVE, 2017).

The prosumer exports excess energy to the grid, and the supply company by the energy from the prosumer. The sell price is dependant on the contract with the individual supply company. The customer will also be compensated by the grid distribution company for the contribution to reduced grid losses. The compensation reflects the useful effect of shorter transportation of electricity in geographical areas where the total production is lower than the demand. The price the prosumer receives for exporting energy to the grid will however in most cases be lower than the cost of importing energy from the grid (Nett, 2018).

2.12 Enova

Enova is a Governmental organisation supporting renewable energy sources and energy efficient solutions, by giving funding to investments in renovations of private and public buildings. Enova is working for Norway's transformation towards the low emission society (Lavutslippssamfunnet). Enova is working to get new, good solutions for energy- and climatic technology into the market (Enova, 2018). Some of the improvements private households can get funding for is described in the following. A household will in all cases pay the largest amount themselves, but the cost will be reduced.

Electrical production by for example solar or wind power is renewable and environmental friendly energy sources. PV panels are relatively easy to install, and there are many tenders on the market. For the installation Enova supports with 10.000 NOK, and 1.250 NOK per kW installed power, up to 15 kW. In total a household can get up to 28.750 NOK (Enova, 2018).

A Solar Thermal Collector (STC) can cover about 50% of the hot water demand, or 30% of the total energy demand, by heating water with solar power. An STC system is supported by 10.000 NOK for the installation, and 200 NOK per m^2, up to 25 m^2. In total, installation of STC can get up to 15.000 NOK in reduced cost. This system can also be combined with a water borne heating system or heat recovering from grey water, which will result in further funding (Enova, 2018).

A renovation of the building envelope including improvements of external walls, roof, windows, doors and foundation will reduce the heat loss considerably, and cut the energy demand and cost. Renovating to TEK10 standard receives support of 100.000 NOK, and renovations to passive house standard get up to 150.000 NOK in reduced costs. The renovation will also result in an improved indoor climate and comfort (Enova, 2018).

A heat control system is relatively easy to install, and will give reduced amount and better control of the energy consumption for heating. The temperature should be able to decrease for a period of at least five hours for the heating control system to be profitable. Enova support with up to 4.000 NOK for installation of a heat control system (Enova, 2018).

Installation of an air source heat pump (ASHP) is not economically supported by Enova, but they do recommend the implementation. An ASHP is easy to install, can be used in most buildings, give large reductions in electricity cost, have relatively low installation costs, and ensures an even heating of the building. This installation is especially profitable for buildings with direct electrical heating by radiators (Enova, 2018).

Enova does however support the installation of fluid-to-water heat pump, which can be a ground source or seawater heat pump. This heat pump is using the energy stored in rock, earth or seawater to heat the building. The installation is more expensive than for the ASHP, and the building needs a water borne heating system, which will need large renovation in existing buildings. But the heat source is more stable than an ASHP, the heat factor (COP) is larger and the heat pump will work even at very low outdoor temperatures. This heat pump is therefore most profitable for new buildings that can build a water borne system into the building, or buildings with oil-fired heating that already have the pipe system, but need to remove the oil-fire (Enova, 2018).

3 New grid hire tariffs

3.1 Hearing document from NVE

A hearing from NVE (Norwegian Water Resources and Energy Directorate) in November 2017 (NVE, 2017) suggest to introduce a new tariff model for grid rent in Norway. The reason for the hearing is due to a need to increase the efficiency of the grid utilisation and the awareness amongst consumers.

A hearing is an arrangement to gather opinions and knowledge concerning the processing of cases in public administration and political bodies like Stortinget or municipal councils. Hearings often give access for the involved parties, such as stakeholders or special interest organisations, to state their opinion before the resolution goes through. The respondents can also be persons or organisations with special knowledge in the field (Gisle et al., 2017).

3.1.1 Background

The last few years the power drain in Norway has increased more than the energy demand. The population and energy need is increasing, but improved effectiveness of appliances and better insulation in houses is keeping the total energy use stable. But the amount of buildings and electrical vehicles in Norway is growing. Also, energy efficient appliances demand a smaller total amount of energy, but they often have a higher power drain (higher energy use per time unit). This increases the need for power capacity on the grid at a few hours during the year. The result will be that grid distribution companies have to invest to enlarge the capacity of the grid. The grid rent will increase, and the electricity customers will in the end receive larger grid rent bills.

As the power drain varies over the year, the maximum grid capacity is only utilised a few hours every year, typically on very cold winter days. A more efficient use of the grid will decrease the need for reinforcement. Reduced or postponed investments will keep the grid rent costs at low level, and give a value on a social-economic level.

The distribution grids are dimensioned for the aggregated power load from all the consumers in the area. The potential of the tariff to reduce the demand in the peak load hours depend on the amount of consumers that are given an incentive to reduce the demand at times when the aggregated demand is high.

The pressure on the grid is peaking when many consumers are using a large amount of power at the same time, not when the individual customer has their peak demand.

A new tariff model has to give the same total income to the grid companies for the whole customer segment. In other words, an average customer will have the same annual cost with the model of today as with a new model, but the cost will be divided differently between the customers depending on their load profile. Using electricity at hours with high pressure will cost more, and should work as an incentive for the customers to change their demand profile.

NVE suggest that the grid rent to a larger extent should reflect how the costs in the grid arises. Customer decisions and consumer patterns influence the costs of the grid. If the grid rent is reflecting the structure of these costs, the customer may be motivated to use the grid more efficient by using more energy when there is excess energy on the grid, and less when there is a pressure on the capacity. An example is to charge your electrical vehicle when the electrical demand on the grid in general is low.

There are three goals for the design of the new tariffs:

- The tariff should cover expenses for the grid companies within the permitted revenue, and the distribution should be reasonable and divided fairly between the customers.
- The design should as far as possible contribute to efficient use and efficient development of the grid. The tariff should stimulate change in the consumption pattern, which in turn can reduce or postpone the grid investments.
- The tariffs should be easy and understandable for the customers, so they have the possibility to respond to them and influence their own tariff cost.

The roll out of the smart meters (AMS) will make it possible for grid distribution companies to calculate the power drain (kWh/h) from each individual customer, and base the grid rent on power tariffs that are dependant on how much electricity the customer is using during one hour. The roll out is planned to be finished by 01.01.2019, and NVE suggests to introduce the new grid rent tariff by 01.01.2021, or alternatively by 01.01.2020 if the stakeholders prefer an earlier starting date.

In the next section follows a description of the energy model used today and the three models suggested by NVE. The illustrations and values presented are based on information from the hearing, and does not include taxes or levies (NVE, 2017).

3.1.2 Energy rate tariff

The model used for grid rent cost today is an energy rate tariff, consisting of two parts. One part is a fixed annual cost equal for all customers, and the other is an energy cost based on the individual customers energy consumption. Today the grid rent cost in Norway varies between the different grid distribution companies, and the pricing costs presented here are average numbers (NVE, 2017). The tariff and according prices is shown in Table 1 and Figure 25.

Table 1: Division of cost for the energy rate tariff.

ENERGY RATE TARIFF	
Fixed cost Annual	Energy cost Total amount of energy use
1749 NOK/year	0.194 NOK/kWh

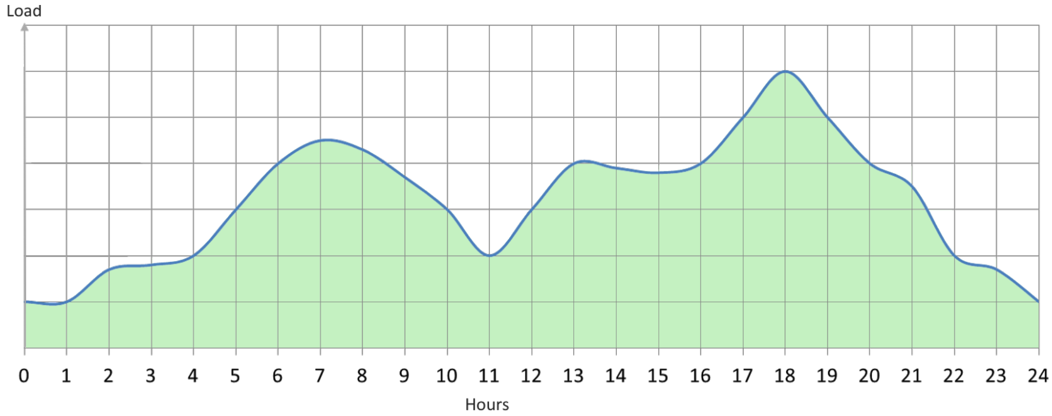


Figure 25: Illustration of cost for energy rate tariff.

3.1.3 Measured power rate tariff

Measured power rate tariff model consist of three parts. A fixed part, an energy part and a power part, see Table 2. The power part is based on the highest power drain (kW) during the measuring period, see Figure 26.

Drawbacks of this model is that customers with atypical use may be charged for large power drain at times when the grid has good capacity. The longer the measuring period, the smaller is the probability for coincidence between peak demand for customers and the grid. Also, if a peak has already occured in the measuring period, the customer can continue to keep a high power drain within the size of the peak, without extra charge.

Today many industrial customers have a measured power rate tariff, and the measure period is usually one month. In this approach the peak is set to be measured daily to reduce the drawbacks.

Table 2: Division of cost for the measured power rate tariff.

MEASURED POWER RATE TARIFF		
Fixed cost Annual	Energy cost Total amount of energy use	Measured power cost Highest peak daily
1749 NOK/year	0.050 NOK/kWh	1.86 NOK/kWh/h

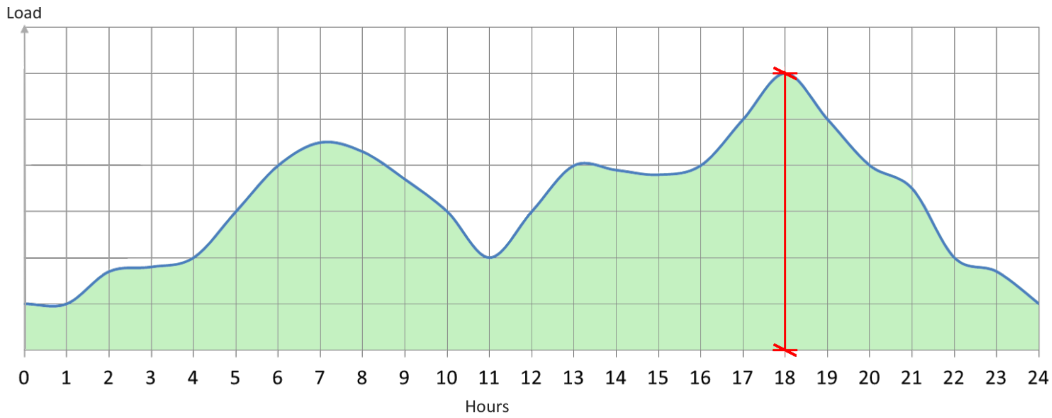


Figure 26: Illustration of cost for a measured power tariff.

3.1.4 Tiered rate tariff

In the tiered rate tariff the customer pays an additional overuse cost if their power drain is above an in advance set limit. This tariff consist of four parts. One fixed part, one subscription limit, an energy part, and an overuse part, see Table 3 and Figure 27.

For most customers the overuse will match with the hours there is a high stress on the grid, as well as most customers have a smaller power drain at times with good capacity on the grid. As the overuse part of the tariff is accounting for all hours and power size that is above the subscription limit, one hour of overuse will not lessen the customers economical incentive to avoid overuse at later hours.

Table 3: Division of cost for the tiered rate tariff.

TIERED RATE TARIFF			
Fixed cost Annual	Energy cost Total energy use	Subscription power limit cost Annual	Overuse cost Power used above limit
1060 NOK/year	0.050 NOK/kWh	689 NOK/(kWh/h)/year	1.00 NOK/kWh/h

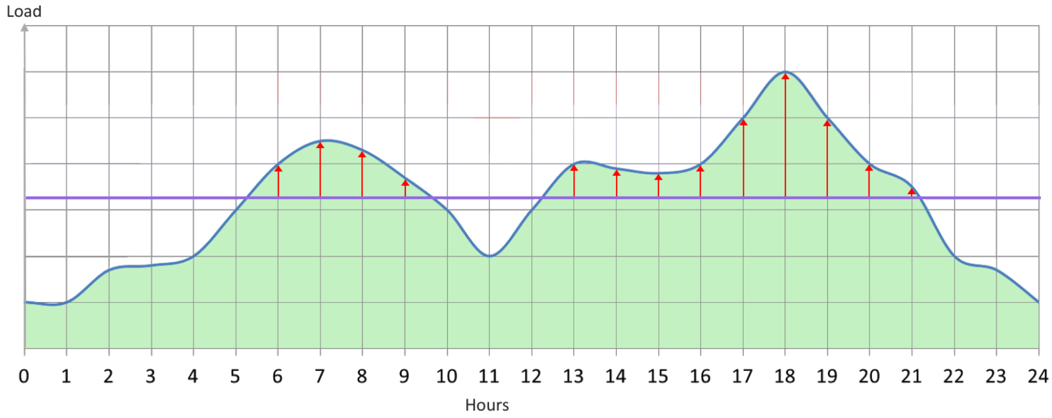


Figure 27: Illustration of cost for a tiered rate tariff.

Drawbacks with the model is that customers using power above the limit at hours with good capacity on the grid will also be charged overuse cost. If these customers adjust their demand to avoid the overuse cost it will have no value to the grid, and it represents a social-economical loss. Also, if customers reduce their power drain to the subscripted limit, there is no economical incentive to reduce it further, even though there is still a peak on the grid.

The exact number of power limits is not decided by NVE, but 10 limits ranging from 1 to 10 kW is a suggestion. Some limits above 10 kW may also be necessary, but the step is suggested to be larger than 1 kW, and the limits are not set. In this approach 10 limits are used for the model when investigated. The customer themselves can choose the limit, but is not allowed to change more often than every 12 months. If the limit is set too high, the subscription power cost will be higher than necessary. If the limit is set too low, the overuse cost will be higher than necessary. The grid distribution companies are supposed to help the customers to choose the best limit for their consumption.

3.1.5 Time of use tariff

In the time of use tariff some hours have higher energy price than others. see Table 4 and Figure 28. The hours with high pricing are the hours which historically have a high grid pressure. All customers will get incentive to reduce all their load in these hours, and not only the customers with the highest consumption, or consumption above their limit, as for the other two suggested models.

The model is suggested to have a higher price during winter, especially in daytime, as these are the critical hours for stress on the grid today. A drawback of this model is that the income of the grid distribution companies will to a larger extent rely on consumption that depend on the outside temperature, which vary largely from year to year.

The model is intuitively easy to communicate to the customers, and also relatively easy for the customers to understand and react to as the pricing is attached to energy (kWh), and not power (kW).

In the hearing NVE is considering the tiered rate model to be the most accurate model to achieve the goals of the tariff change (NVE, 2017). But in the answers to the hearing many stakeholders disagree. In the next section follows a summery of these answers.

Table 4: Division of cost for the time of use tariff.

TIME OF USE TARIFF			
Fixed cost Annual	Energy cost winter night 20pm - 6am, Nov to March	Energy cost winter day 6am - 20pm, Nov to March	Energy cost summer All day, April to Oct
1749 NOK/year	0.152 NOK/kWh	0.380 NOK/kWh	0.122 NOK/kWh

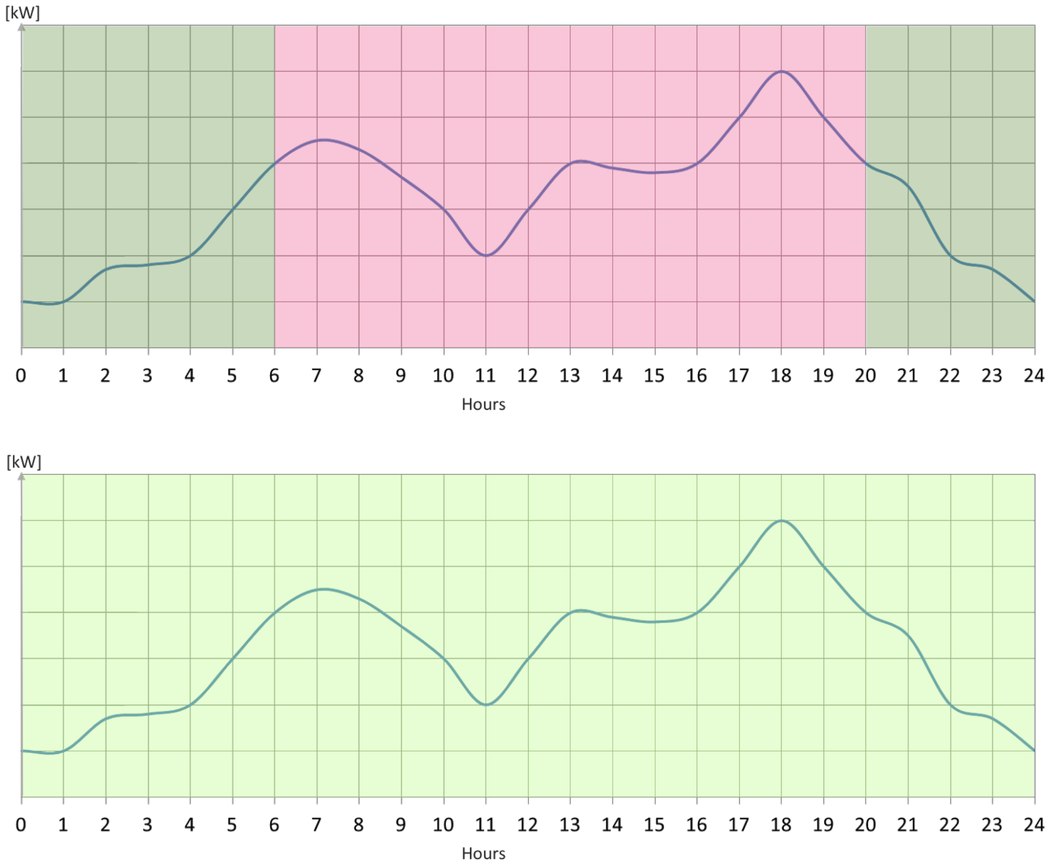


Figure 28: Illustration of cost for a time of use tariff. On top: winter rates. Below: summer rates.

3.2 Stakeholders

3.2.1 Definition

A stakeholder is any individual, social group, or actor who possesses an interest, a legal obligation, a moral right, or other concern in the decisions or outcomes of an organisation, typically a business firm, corporation, or government. Stakeholders either affect or are affected by the achievement of an organisation's objectives (Modvar and Manuel-Navarrete, 2018).

In this project there are several stakeholders, whom are affected in different ways by a change of the grid rent tariffs from energy tariffs to power tariffs. To make a new tariffs effective and obtain the aim of the project, it is necessary that there is some benefit for every stakeholder involved.

3.2.2 Stakeholders in this study

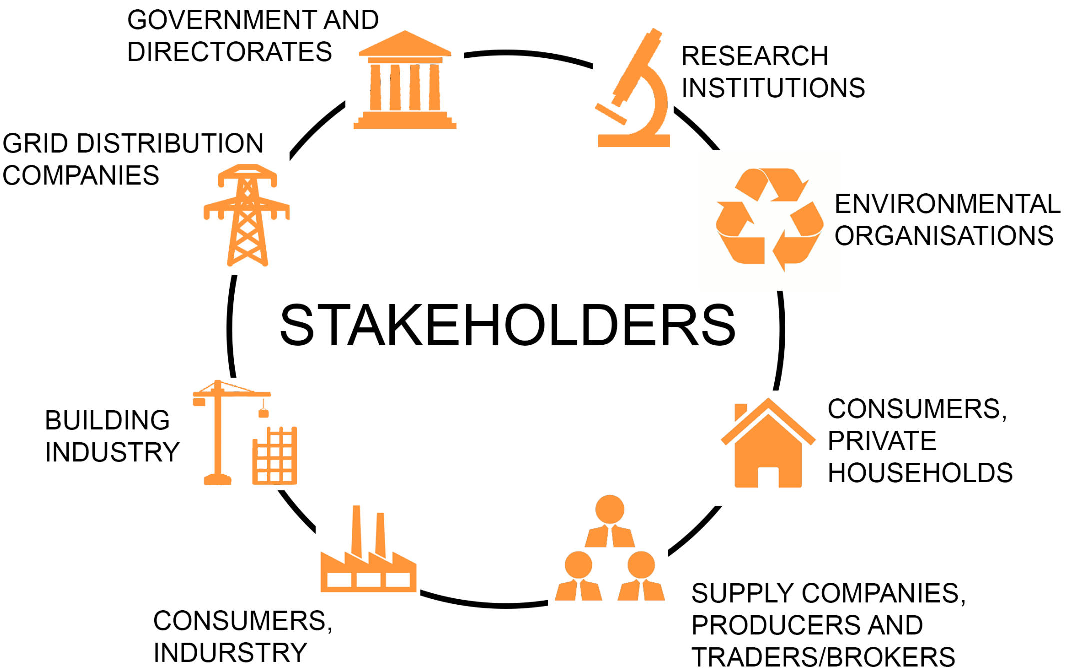


Figure 29: The stakeholders related to implementation of a new grid rent tariff.

3.2.3 General hearing responses

The stakeholders have been invited to respond to the hearing. A total of 79 responses were received, and the main content of these answers is presented below.

Near to all of the stakeholders are sharing the concern that there will be a need for increased grid capacity in the future. They agree that there is a need to motivate the consumers to behaviour that give more efficient use of the grid and reduction in power peaks, to keep the grid investments down. But 77% of the stakeholders do not support the suggested tiered rate tariff model as a sufficient model to fulfil the goals (Løvik, 2018). Most of them are suggesting that a time of use model or a measured power tariff will be a better solution.

Counter-arguments suggest that the tiered tariff model is a complex model, difficult for the grid companies to administrate, and for the customer to understand. If the customers do not understand it, there is no reason to believe they will change their behaviour. The incentives should be easy for the customer to understand, and it should be clear what to do.

NVE haas already introduced a program regarding end-user market, constituting that the electricity supplier is supposed to take over all contact with customers also for the grid distribution companies, and that only one invoice for both electricity use and grid rent are to be sent to the customers. The tiered rate tariff model is in conflict with this program, as the grid distribution companies are obliged to guide the customers, whom they are not supposed to be in contact with, to the right subscription.

To be able to make an active choice, the customer needs to have good information about their own energy use and power need. They also need to understand the four different pricing parts in the tiered rate model, and the different levels and time of the overuse rates. For this model it is difficult for the customer to foresee their own cost. When choosing the subscription historical values for the building is used, and not the actual use measured by the new AMS. The model is not using the possibilities that comes with the AMS to more direct use of hourly values.

The guidance obligation gives the grid distribution companies an unfair responsibility for choosing the right subscription. It is a complex process to choose the subscription, and when the wrong tariff is chosen or there is a change of user pattern during the subscription period there is no clear answer to whom is responsible. This can cause conflict between company and customer, and create customer dissatisfaction.

It is too rigid to be able to change the subscription only once a year, but also clear that customers can not change more often. Local exceptions will result in high administrative costs and loss of reputation for the companies.

It is essential, whatever model chosen, that the price signal is received by the customers, for them to be able to take action and change their demand profile. The tiered rate and measuerd power rate, for which cost is depending on power, will favour resourceful consumers, as the HAN-interference that allows customer interaction with the AMS needs to be installed on the customers own initiative.

For efficient use of the grid, the incentives that possibly can be put into the tiered rate model are very small, and the model is missing flexibility and positive incentives. The change is found in long term behavioural change at end-user, and to achieve this the customer needs to have information about their own real time use.

customers using high power during low pressure hours should not be punished for that, and all customers should be given incentives to reduce power drain during high pressure periods, also the ones with low drain during the peak.

The tiered rate tariff is focused on the demand profile and peak load of the individual customer, not the total grid, which is dimensioning for the capacity of the grid and the reason for the peak. This is not helping to achieve the goal of efficient use and development of the grid. To be able to reduce or delay investments, the total demand during peak hours are dimensioning.

Many companies are pointing out that the suggested tiered rate model is not tested or analysed properly, and it is uncertain whether the model is contributing to the wanted change. There are no studies about the effect of the suggested model, not in Norway or any other countries, and no other countries have implemented a similar model either.

Most stakeholders want a time of use model, and emphasise that the model will direct the incentive towards only the hours the grid normally is highly loaded. It will therefore have a higher accuracy than the tiered and measured power rates, for which it is random when the incentive to load shift occur. A time of use model will give dynamic in the billing which gives the customers the opportunity to see the effect of a conscious electricity consumption directly on the bill. This will give active consumers.

3.2.4 Grid distribution companies

All the grid distribution companies stress that the tiered rate model is time consuming and will give a large increase in administration time and costs for the grid distribution companies, as they will have to explain and guide the customers to the right subscription. This increase of administration is also in conflict with the implementations of AMS and Elhub which are supposed to make the grid distribution companies more efficient.

The model will contribute to reduce the reputation of the whole industry, as it is incomprehensible for the customer that they can not change their subscription limit more often than every 12 months. The model is very difficult to explain to customers, which is not making it a user friendly model.

The majority of the grid distribution companies want a time of use tariff for the private customers, and continue with a measured power tariff with a monthly measuring period for larger and industrial customers, as this already works well today.

3.2.5 Government and directorates

The government has set an ambitious goal when it comes to expanding solar power production and reducing energy use in existing buildings. It is important that the new tariff support these goals. The tiered rate model seems to reduce the incentive to implement energy efficient and solar installations. This can affect the aggregated power drain from the grid and will make it harder to reach the energy goals.

They suggest to wait with the tariff change until data and experience from the AMS is collected. Especially will the transport sector change in the future, with all new vehicles having to be electric within a few years. As the grid tariffs are not changed very often, the tariffs made today have to take these issues into account.

A good and easily accessible user-interface is very important to communicate the information about how the end-user's consumption is affecting the grid and their costs. The interface should encourage action from the consumer to realise profit of efficient energy use. Information about time with high load and price should work as a guidance for customers who wish to take action to avoid overuse and reduce their demand during peak hours. Over time this may change behaviour, and will give a more efficient use of the grid. The tariff should be easy to understand for the end-user, and open for a more dynamic model when the technology and market is ready for this. Access to the HAN-interface is essential, but for instance in apartment buildings the meters are typically placed in the basements. The Government asks for clearer requirements to ensure that every unit has access to the HAN-interface.

3.2.6 Consumers, private households

The consumers are worried that their choice of tariff is supposed to be guided by the companies that will profit from the choice. Most customers do not have a good enough understanding of the system, and there are many doubtful operators in the market. The electricity industry was in 2017 the industry with the most complaints in Norway, which indicates that the industry does not need an even more complicated model than the one used today.

Use of electric machines like washing machines, dryer and dishwasher during night and daytime when residents are not home should be avoided due to fire safety reasons.

The tiered rate model is not stimulating energy saving or local energy production. It is making solar power production less profitable. The private household organisations ask for a tariff that improve the conditions for distributed generation.

3.2.7 Consumer, industry

Many Norwegian industries are sensitive to energy cost, and can often not regulate their operation due to the energy pricing. Also, many industries, like nurseries, cooling storage, water for agriculture, grain drying, timber production, and the food and fish industry, are using most of their demand during summer, when the capacity on the grid is high. These industries will have small opportunities to adjust to the tariff models without reducing the yearly production capacity of the factories, and the profitability for the company will be reduced. Most of these industries have a measured power tariff today, and want to continue with this model.

The district heating in cities and urban settlements increase the energy flexibility and reduce the demand on the electricity grid, which is one of the main goals of the implementation of a new grid rent tariff. With the tiered rate model the district heating companies do not have the same possibility in the market, and their competition will be reduced. This will affect the investment need in the grid directly. The district heating and bioenergy companies are asking for a more overall solution to encourage behavioural change to decrease the use of direct electric heating.

3.2.8 Building Industry

Flexibility is the future in buildings, and should be an important factor in the development of the new tariff. Heating storage in cooperation with the electric grid making the heating and cooling systems flexible will be the best solution for the future. Two other important actions at household level are control of electrical vehicle charging and use of alternative indirect heating systems. Companies from the building industry suggest to increase the existing system of subsidies for energy efficiency improvements of building from Enova (see page 35 for information about Enova).

Technology, automation, and demand-side management are better solutions to reduce the peaks in the electricity demand. The tiered rate model give few or no incentives to reduce the energy consumption, and it has a negative impact on the innovation and investment in solar energy. There is large potential for reduction of peak power load in the local grid with technical solutions, and this should be reflected in the grid rent tariff. The building industry suggest that neighbourhood subscriptions should be possible, as it is the aggregated peaks that matter for the grid. Third party actors that can offer coordination services and products to reduce the power load in an area should also be possible. This will create a market for flexibility in the system.

3.2.9 Research institutions

The research institutions NTNU and SINTEF are in the opinion that the proposed model is static. The grid capacity is stressed only a few hours during the year, and the consumers will get an incentive to change their load profile even when this is not necessary. The new tariff is similar to one that was taken away during the 80s. They suggest instead that no extra fee should be added at hours with large capacity on the grid, as this will not give the resource utilisation NVE is looking for.

As it is the aggregated power demand from the grid that is the issue, they suggest that neighbourhoods could chose a common subscription on power. This will help a third party that contributes to load control and end-user-flexibility into the market. These type of actors can add flexibility into the system by taking responsibility for coordinating tasks, and this will be a way to reduce the capacity needed on the grid.

The institutions encourages NVE to work for solutions which make sure that local instant flexibility is taken into use in a cost efficient way, both locally and for the whole power system.

3.2.10 Environmental organisations

The environmental organisations stress how important it is that the new model is able to both avoid an enlargement of the grid, which will result in large land disturbances and affecting the wild life and their living areas, and also contribute to achieve Norway’s climatic goals towards 2030.

Important challenges we face today is to replace the fossil energy by renewable energy, use the energy more efficiently (so less fossil fuel is used), and utilise the power distribution grid more efficiently (which reduce the investments on the grid). With the tiered rate tariff solar energy, electric vehicles and energy efficiency is in many cases less attractive. The model will not give incentive to load shifting inside a subscription value.

The organisations point out that fair division of the costs in the society is not more important than realising the Norwegian climatic goals and the decision from the Norwegian Parliament of reduced energy use in the building stock with 10 TWh by 2030.

Electrical vehicles should get incentives to charge at the right time, energy efficiency should be continued to be stimulated, and renewable energy sources should be given incentives.

3.2.11 Summary of the stakeholders views

The new tariff model needs to:

- help the customer make good choices when it comes to energy- and power use
- ensure that correct pricing is taking care of more correct allocation of the grid expenses amongst the users of the grid
- have low administration time and cost for the grid companies
- obtain high customer satisfaction
- utilise the possibilities form the AMS implementation
- be easy to understand and react to, access to the HAN-interface is essential
- prepare for new technology and innovative markets that can reduce cost or increase utility and end-user flexibility
- work as an incentive to solar power innovation and investment, and implementation in buildings
- encourage more efficient power use
- encourage use of indirect heating systems
- encourage controlled charging of electrical vehicles
- encourage heat storage in buildings to create flexibility

4 Method

From the hearing from NVE and the answers from the other stakeholders, we see that the most important purposes the implementation of a new grid rent tariff have to fulfil, are to decrease the future grid investments, and allow for better utilisation of renewable energy sources. The following research questions will be investigated in this thesis:

- Which business model give the largest economical incentive to improve building physics?
- Which business model give the largest economical incentive to load shift?
- Which business model is financially the best for the end-user?
- Which business model make the ideal heat shift most achievable for the consumer?

The survey has been conducted through simulations with the energy performance software IDA ICE and post processing with the calculation software Microsoft Excel. No suitable tool for calculation of power tariffs were found, and a generic algorithm has been developed to evaluate the different business models. The algorithm works as a tool to investigate the effectiveness of different business models as incentive to building renovation, installations of energy efficient appliances and control systems, as well as a theoretical heat load shifting within the building. The approach has been applied on a set of building cases in the Norwegian context.

4.1 IDA ICE

The energy simulations are done by the building performance simulation software IDA ICE (EQUA, 2018).

4.1.1 Reference model

Currently there does not exist an official reference building for the Norwegian context. A reference model in IDA ICE, for a single family house, is made by the master student Vilde Christine Hagen, at NTNU in 2018. This is not an official reference model, but constructed according to the technical requirements in TEK17. TEK17 represents the current minimum technical requirements for new buildings in Norway. In this thesis the model developed is therefore referred to as a reference model of a representative single family house.

The house consist of two floors with a total floor area of 149.46 m^2, and is built on flat ground with no basement. The building is placed in a suburban area in Oslo.

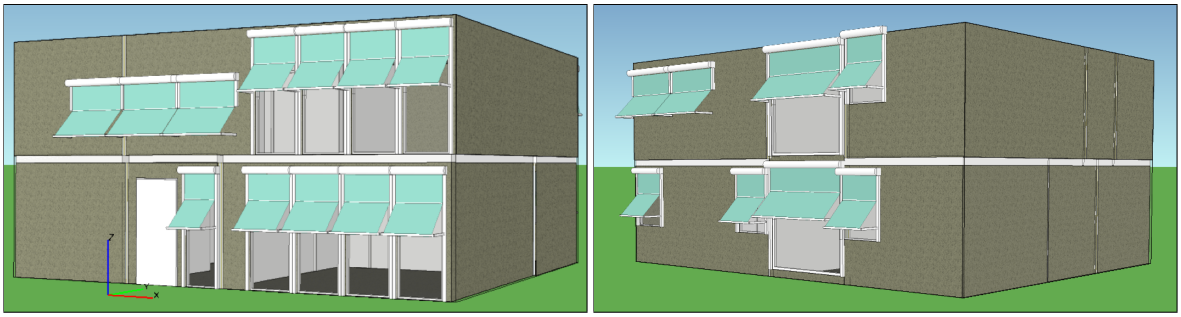


Figure 30: IDA ICE model of the representative building.

4.1.2 Schedules

Realistic schedules for light, equipment and domestic hot water (DHW) is used to increase the reliability of the energy demand profiles in the model.

The technical specification SN/TS 3031:2016 (Standard Norge, 2016) is a standard made for calculation of the energy performance of buildings with standardised requirements, and are developed as reference conditions for simulation. Typical load from DHW and technical equipment is found in Table A.2 and A.3, *"småhus"* (single family house), in SN/TS 3031:2016 (Standard Norge, 2016). A schedule for light is also found in the standards, but this one is static, with the same amount of light all day, every day. As lighting in Norway is changing over both the year and day due to different amounts of solar light, the schedule is made dynamic to create a more realistic scenario. For instance, typically more light is used during winter evening than summer day. The total annual amount of lighting is set equal to the amount in SN/TS 3031:2016, and the distribution is based on the lighting schedule created after a survey from households in Finland (Hamdy et al., 2013). The schedules reproduced from SN/TS 3031:2016 is in Table 5, for normalised input values. See Table 6 for the dynamic lighting schedule.

Table 5: Different load schedules for a single family house, from SN/TS 3031:2016 (2016). For lighting, only the daily amount is used.

Hour	DHW [Wh/m^2]	Equipment [Wh/m^2]	Lighting [Wh/m^2]
1	0.00	0.96	~~0.00~~
2	0.00	0.96	~~0.00~~
3	0.00	0.96	~~0.00~~
4	0.00	0.96	~~0.00~~
5	0.00	0.96	~~0.00~~
6	0.96	0.96	~~0.00~~
7	6.87	0.96	~~1.84~~
8	13.74	1.92	~~1.84~~
9	6.87	1.92	~~1.84~~
10	0.96	0.96	~~1.84~~
11	0.96	0.96	~~1.84~~
12	0.96	0.96	~~1.84~~
13	0.96	0.96	~~1.84~~
14	0.96	0.96	~~1.84~~
15	0.96	0.96	~~1.84~~
16	0.96	2.88	~~1.84~~
17	0.96	4.81	~~1.84~~
18	13.74	4.81	~~1.84~~
19	13.74	4.81	~~1.84~~
20	1.37	4.33	~~1.84~~
21	1.37	4.33	~~1.84~~
22	1.37	2.40	~~1.84~~
23	0.96	2.40	~~1.84~~
24	0.00	0.96	~~0.00~~
Daily	68.67	48.05	31.28
Operational hours	18	24	~~17~~

Table 6: Lighting schedule. Distribution is taken from Hamdy et al. (2013) and annual amount from SN/TS 3031:2016 (2016).

Hour	Winter [Wh/m^2]	Spring [Wh/m^2]	Summer [Wh/m^2]	Autumn [Wh/m^2]
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00
5	2.59	1.55	1.24	1.55
6	5.18	3.16	2.44	3.16
7	5.18	3.16	2.44	3.16
8	2.59	1.55	1.24	1.55
9	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00
15	1.30	0.78	0.62	0.78
16	2.59	1.55	1.24	1.55
17	2.59	1.55	1.24	1.55
18	5.18	3.16	2.44	3.16
19	5.18	3.16	2.44	3.16
20	3.89	2.38	1.87	2.38
21	3.89	2.38	1.87	2.38
22	2.59	1.55	1.24	1.55
23	2.59	1.55	1.24	1.55
24	1.30	0.78	0.62	0.78
Total	46.64	28.30	22.18	28.30
Days	90	92	92	91

The distribution of the light, equipment and DHW demand for winter is illustrated in Figure 31. For the other seasons of the year the profile will be similar, but the light demand will be lower.

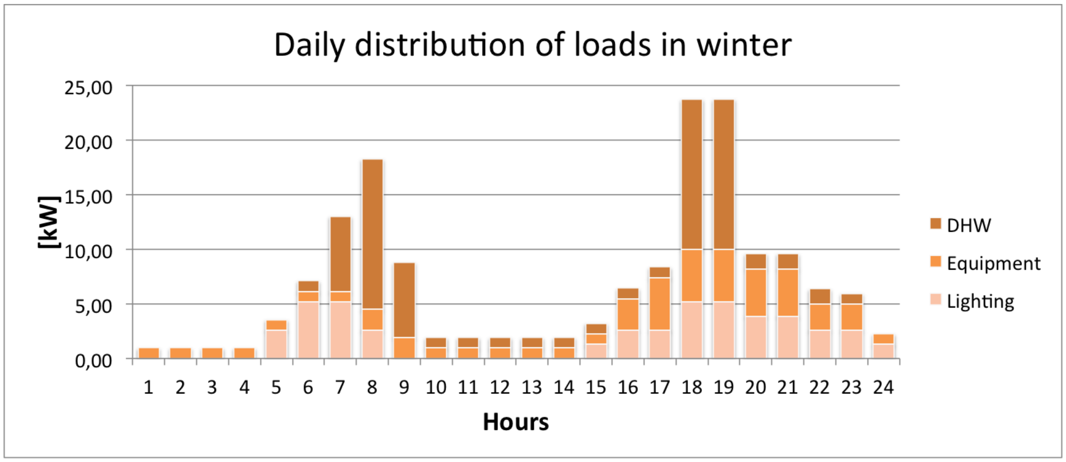


Figure 31: Illustration of the daily distribution of plug loads and DHW during winter.

4.1.3 Set point temperatures

The set points for temperature and operation hours are also used as in SN/TS 3031:2016, taken from Table A.8 and A.9 (Standard Norge, 2016). These schedules and set points are equal for all building cases.

Table 7: Set point temperatures for a single family house, from SN/TS 3031:2016 (Standard Norge, 2016).

	Heating	Cooling
Set points during operating hours	22°C	24°C
Set points outside operating hours	20°C	24°C
Daily operative hours	16	24

4.2 Cases

6 groups, with a total 13 of different building physics design parameters, have been investigated. They are presented in Table 8, with explanation and notation. All possible combinations of the parameters have been conducted, and in total 96 cases have been compared in the study.

Table 8: Building physic cases.

Group	Parameter	Notation
Envelope	TEK17 requirements	TEK17
	Typical standard in a house for the ’60s	’60s
Heating system	Direct electic heating	Direct
	Air source heat pump	ASHP
Solar thermal collector	Without solar thermal collector	NoSTC
	With solar thermal collector	STC
Photovaltaic panels	Without PV panels	NoPV
	With PV panels	PV
Windows	Windows with normal openings	WN
	Windows with occupants openings	WO
Electric vehicles	No electrical vehicle	NoEV
	Typical charging of electrical vehicle	EVc
	Delayed charging of electrical vehicle	EVd

The reason for interest in these groups of building physics is presented in the following. The two types of building envelopes represent the old buildings in the building stock, and new buildings or renovated buildings. It is of interest to investigate the cost for each grid rent tariff for buildings of different age, and the potential saving of deep renovation of old buildings.

The ASHP, STC and PV panels are all examples of expected future installations of renewable energy sources implemented directly in the buildings to decrease the electricity demand. The answers to the hearing also indicate that it is of large importance to stakeholders that the new tariff that is implemented makes it beneficial for the household owners to continue to invest in these installations.

The different openings of windows is an example of typical behaviour in Norway, where the electricity is low-priced, and people are used to have freedom to consume energy in the pattern and amount they desire. Occupants often open windows during nighttime if more ventilation is needed, without turning down the space heating in the rooms. It is investigated how this end-user behaviour affect the cost with a new tariff.

Electric vehicles is an example of the future way to travel. Electrical vehicles drastically change the demand profile of households, as they normally are put to charge in the afternoon and increase the already high evening peak. The amount of electrical vehicles will most likely increase a lot in the near future. The hearing responses also point out the importance of keeping the incentive for electrical vehicles, as the Governmental goal is to decrease fossil fuel consumption by 40% by 2030 and 80% by 2050. A comparison between an early afternoon charging and a delayed charging is done.

Some of the results are presented in a parametric arrangement to illustrate how the different groups are affected by the business models. A total of 8 cases represent the groups, see Table 9.

Table 9: Parametric arrangement of the group parameters.

Number	Parameter	Notation
1.	**Reference case**	**TEK17 Direct WN NoSTC NoPV NoEV**
2.	’60s	’60s Direct WN NoSTC NoPV NoEV
3.	ASHP	TEK17 ASHP WN NoSTC NoPV NoEV
4.	STC	TEK17 Direct WN NoSTC NoPV NoEV
5.	PV	TEK17 Direct WN NoSTC PV NoEV
6.	WO	TEK17 Direct WO NoSTC NoPV NoEV
7.	EVc	TEK17 Direct WN NoSTC NoPV EVc
8.	EVd	TEK17 Direct WN NoSTC NoPV EVd

4.2.1 Envelope

Two different kinds of envelopes have been compared, one representing new buildings and one representing the old building stock. The new building is constructed according to the requirements in TEK17. The old building is based on the same model, but with insulation and windows equal to a typical building from the ’60s. See Tabel 10 for the differences between the two building types.

Table 10: Differences between the two building types.

	TEK17 house	**’60s house**
U-value walls [W/m^{2}K]	0.40	0.18
U-value roof [W/m^{2}K]	0.38	0.13
U-value floor [W/m^{2}K]	0.60	0.10
U-value windows [W/m^{2}K]	2.90	1.20
Air tightness (50 Pa) [h^{-1}]	10.0	0.6
Thermal bridges [W/m^{2}K]	0.10	0.06

4.2.2 Heating system

The two heating systems evaluated are a direct electric heating system and an indirect heating source in the form of an air source heat pump (ASHP). The direct electric heating system has a COP equal to 1, which means that the supply power is equal to the delivered heating to the space. When 1 kWh electricity is supplied to the system it delivers 1 kWh of heating to the space. The ASHP has a higher COP than 1, which means that it delivers more heating to the space than the amount of electricity supplied. The ASHP used for this case is based on the power values and COP from the Toshiba Heat Pump Daiseikai 9 RAS-35 (Toshiba Varmepumper, 2017), see Table 11.

Table 11: Characteristics for the heat pump (Toshiba Varmepumper, 2017).

	ASHP	**RAS-35**
At -7 °C	Maximum heating output [W]	5500
	COP	2.41
	Supply power [W]	2280
At -15°C	Maximum heating output [W]	4500
	COP	2.21
	Supply power [W]	2040

Assuming the graphs for the power output and COP to be linear and mainly dependant on the outdoor temperature, the equations for the heat output of the heat pump are as given in Equation 1 and 2. The outdoor temperature is taken from hourly weather data for Oslo, Gardermoen, from IDA ICE. The power demand from the heat pump is calculated hourly depending on the heating demand and outdoor temperature. For the hours with very cold weather the heat pump will deliver less energy than the demand. For the hours when it is too cold to gain any heat form the outside air the COP is equal to 1, as the heating coil in the heat pump will heat the space with direct electricity.

$$P(T_0) = 6375 + 125 \times T_0 \qquad \text{[W]} \tag{1}$$

$$COP(T_0) = 2.585 + 0.025 \times T_0 \qquad \text{[-]} \tag{2}$$

4.2.3 PV panels

The energy production from the PV panels are simulated separately with IDA ICE. The panels is placed on the roof of the building, with the optimal angles of 15° from south towards west, and 60° from horizontal position, to obtain the highest gain. Default values for PV panels are used, and the overall efficiency is set to 0.15. The production by the panels are 5152 kWh/year, distributed as shown in Figure 32.

The calculations with the energy from the PV panels are not considered in the cost. That means that when the PV panels are producing more energy than what is needed in the building in the same moment, the excess energy is lost. In real life the energy would most likely either be exported to the grid, or stored in a battery. If the energy is exported, there will be a charge for grid rent from the customer to the grid distribution company, and a payment from the supply company. The total cost for grid rent will therefore increase with energy export, while the cost for supply will decrease. The total cost will in total be decreased with PV panels, but the exact price will depend on the subscription with the supply company. In this case the cost and sell prices are therefor not included in the analysis, and the excess production is considered as lost.

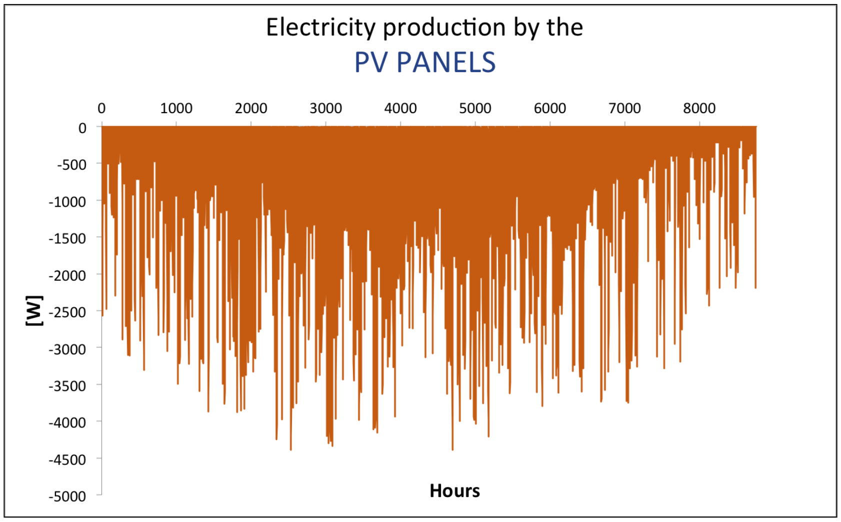


Figure 32: PV production from the PV panels over the year.

For hours when load shift is relevant to save cost, only the heat is shifted and DHW and plug loads are kept unaffected. Therefore, in these calculations the electricity from PV production is first used on the load from DHW and plug loads, and then on heating. In this way the potential amount of load for shift is kept as large as possible, and the cost saving is optimised.

4.2.4 Solar thermal collector

The effect of a Solar thermal collector (STC) is simulated separately in IDA ICE. The collector is connected to a domestic hot water tank with the demand and schedule as described previously. Default values for a flat plated STC in IDA ICE is used. The collector is chosen to be 6 m^2, which is within the typical range recommended for a collector only connected to DHW. If the collector were to be used for space heating as well it should be larger. The STC is put on the roof, 5 meters above ground. To optimise the gain, the angles are set to 15° from south towards west, and 60° from horizontal position, similar as for the PV panels. Figure 33 displays the heat collected with the panels. This illustrates that the collector is even able to gain some heat during winter. When there is not enough heat gained through the STC the hot water tank is supplemented with an electric top heating with a COP of 1. The STC is able to reduce the DHW demand with 1718 kWh a year.

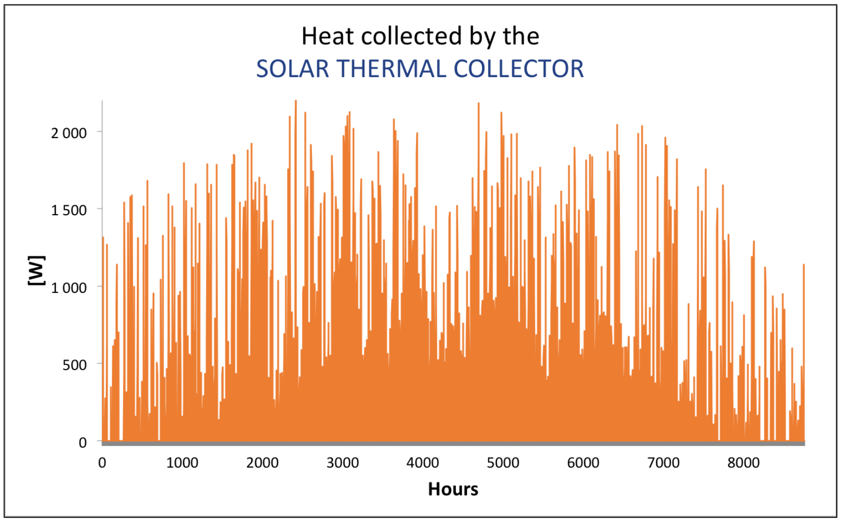


Figure 33: Heat collection from the solar thermal collector over the year.

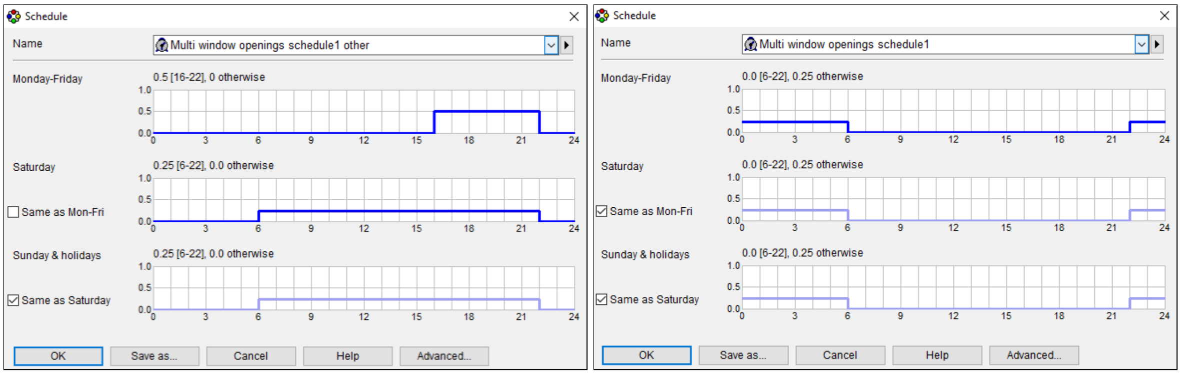
4.2.5 Window openings

occupant opened windows temperature controlled windows

Two different window schedules were simulated. With temperature controlled windows (TCW), the windows open when the temperatures gets higher than the set point value for cooling, 24°C, and the heating system is turned of. In the other case occupants open the windows (OOW) when the temperatures reach the set point for heating, without turning down the heating system. The set points are 20°C at night and 22°C during day. The windows are opened in bedrooms during night and in other rooms in evening if the temperatures reach the set point temperatures, to improve the ventilation and admit cool air during night. The heating demand will increase due to occupants ignorance. The schedule for the opening by occupants is found in Table 12.

Table 12: Schedule for occupant openings of windows.

Hour	Bedroom windows [%]	All other windows [%]	
Hour	All week	Weekdays	Weekends
1	25	0	0
2	25	0	0
3	25	0	0
4	25	0	0
5	25	0	0
6	25	0	25
7	0	0	25
8	0	0	25
9	0	0	25
10	0	0	25
11	0	0	25
12	0	0	25
13	0	0	25
14	0	0	25
15	0	0	25
16	0	50	25
17	0	50	25
18	0	50	25
19	0	50	25
20	0	50	25
21	0	50	25
22	0	50	0
23	25	0	0
24	25	0	0



Schedule

Name: Multi window openings schedule1 other

Monday-Friday: 0.5 [16-22], 0 otherwise

Saturday: 0.25 [6-22], 0.0 otherwise

☐ Same as Mon-Fri

Sunday & holidays: 0.25 [6-22], 0.0 otherwise

☑ Same as Saturday

Schedule

Name: Multi window openings schedule1

Monday-Friday: 0.0 [6-22], 0.25 otherwise

Saturday: 0.0 [6-22], 0.25 otherwise

☑ Same as Mon-Fri

Sunday & holidays: 0.0 [6-22], 0.25 otherwise

☑ Same as Saturday

Figure 34: Schedule for the openings of windows in IDA ICE.

To make the opening of windows react to both temperature and schedule a macro have been made in IDA ICE. Figure 35 illustrates the build up of the macro.

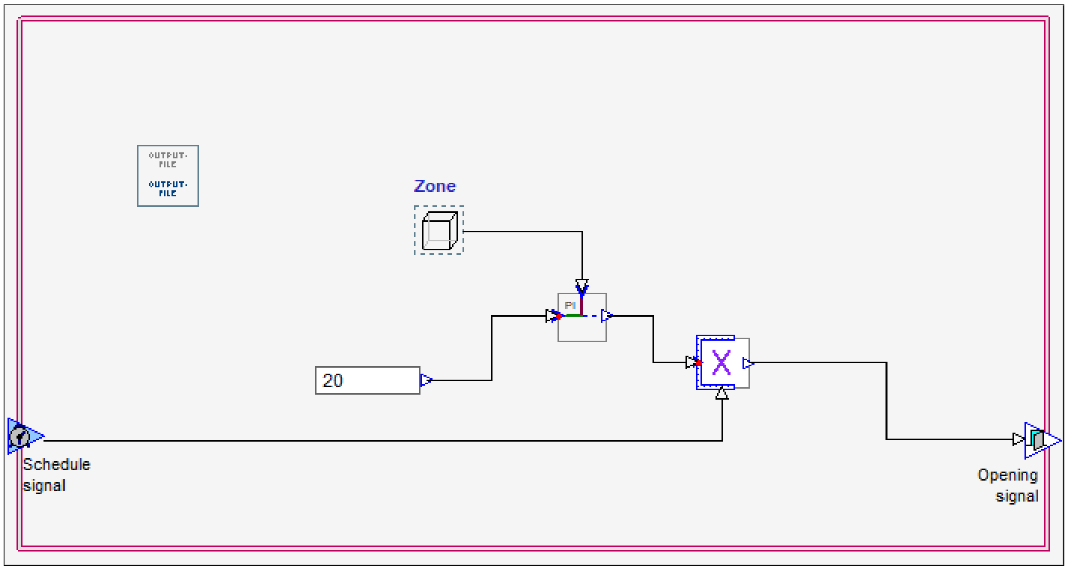


Figure 35: Build up of macro for window openings in IDA ICE.

4.2.6 Electrical vehicle charging

To illustrate the charging of an electrical vehicle the very popular e-Golf from Volkswagen is used as an example. If a typical home charging station is installed in the household, with 20A and 3,6 kW power, an e-Golf will need 10 h 50 min to charge form 0 to 100% (Volkswagen, 2018).

In the calculations the car is assumed to be using about 80% of maximum capacity every day, and will need 9 hours of charging. Typical charging hours for an electrical vehicle starts at 16:00, when people are coming home from work. To examine the effect of a controlled charging, charging with 5 hours delay is also calculated. The charging is started with a smart control at 21:00, to avoid the main evening peak on the grid and still be fully charged by morning. See the schedules for the different alternatives in Table 13.

Table 13: Schedule for charging of electrical vehicle.

Hour	No EV [kW]	EV typical charging [kW]	EV delayed charging [kW]
1	0	0	3.6
2	0	0	3.6
3	0	0	3.6
4	0	0	3.6
5	0	0	3.6
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	3.6	0
17	0	3.6	0
18	0	3.6	0
19	0	3.6	0
20	0	3.6	0
21	0	3.6	3.6
22	0	3.6	3.6
23	0	3.6	3.6
24	0	3.6	3.6

4.3 Ideal heat shift

The goal of the change of grid rent tariff is to change the way people consume energy. As mentioned before, the loads that can be made flexible is space heating, domestic hot water heating, washing machines, dryers and dishwashers, and charging of electrical vehicles. Some of the stakeholders point out that running washing machines, dryers, and dishwashers during off peak periods often means running them at night or when people are not home. This includes a risk, in case of fire, the reaction time will be longer. This load is therefore not shifted, and it is assumed that people continue to utilise these machines in the evening when they are home and awake. Delay of charging electrical vehicles is already created as one of the cases described above. As heating of buildings is the largest part of the energy consumption in buildings, and also the reason for the critical peaks during winter, shifting of the heat load has been surveyed for all cases. The heat shift is assumed to be ideal. Ideal heat shift is a theoretical optimal amount of load shifted to obtain the lowest cost according to the business model. Ideal heat shift is considered differently for each business model in regards to the amount and time of shift. These are also important factors in the research.

Assumptions that have been made for heat shifting in this research is that:

- the heat shift is ideal
- all heat load can be shifted
- heat load can be offset within the same day for up to 24 hours
- there are no losses when heat is shifted
- there is no need to increase the heating when it is shifted

For Norwegian households the heating is for most buildings done by electricity. Heat shifting can therefore happen by use of a battery. For buildings with water borne heating a hot water storage tank can save the heat. Thermal mass and phase change materials in the building can also be utilised to delay the need for heating. The method to achieve shifting of the heat load is outside of the scope of this research.

4.4 Excel

The post processing to calculate the cost of the cases were done in Excel. The algorithm is made as a template used to compute the 96 cases, with one workbook for each case. This workbook computes all the cost options and amount of ideal heat shift for each case. Another workbook combines and compare all the cases, by importing the results from the 96 workbooks of tariff computations. Both these workbooks, Tariff_computation_template.xlsm and Case_comparison.xlsx, are added to the thesis, see Appendix A and B.

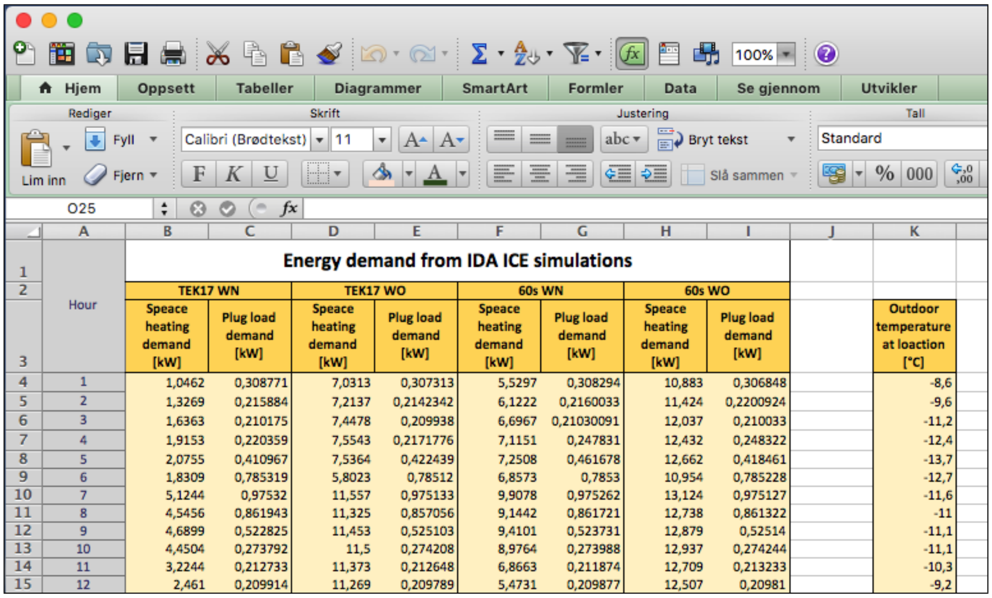
4.4.1 Tariff computation

There exists many energy simulation softwares that are able to calculate energy cost. IDA ICE, HOMER and SAM have been investigated. All these programs can calculate different types of energy rates, but none of them are able to calculate power rates. To calculate the price for Measured power rate, Tiered rate, and also shifting of the load for all models, another tool would have to be used. As no sufficient program was found, a new algorithm was made in Excel, and all tariffs and heat shift were investigated with this new tool. To easily follow the calculations in the Excel workbook, colour codes are differentiating the functions of the cells, see Figure 36.

The Excel program takes the energy demand of the building and the outdoor temperature at the location as inputs, see Step 1, Figure 37. The energy demand for buildings with different envelopes and window openings is simulated with IDA ICE. The heat collection and energy production by STC and PV is simulated separately in IDA ICE. The change of demand according to heating system, STC, PV and EV with typical and delayed charging is all post processed in Excel. Macro buttons ensure that all the parameters can easily be chosen, see Step 2, Figure 38. Step 3 in the workbook is the calculation done by the algorithm itself. Excel post processes the calculation of total demand, cost for all tariffs, both with and without shifting, amount of daily heat shifted and amount of saving per kWh, when Step 1 and 2 are done. An example of some of the results is shown in Figure 39. The building physics installations described earlier is used as default values. These can however be changed by changing the input from each of the installations. For different STC and PV panels, new simulations would have to be run with IDA ICE. A different heat pump would need a new equation input, and a different electrical vehicle would need new charging time or power drain.

(MANUAL) INPUTS
OUTPUT_RESULTS
CALCULATIONS
VALUES TAKEN FROM SOMEWHERE ELSE IN THE SPREADSHEET

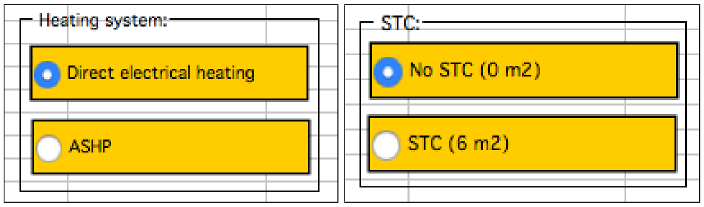
Figure 36: Colour differentiation in the Excel algorithm.



Energy demand from IDA ICE simulations

Hour	TEK17 WN		TEK17 WO		60s WN		60s WO			Outdoor temperature at loaction [°C]
	Speace heating demand [kW]	Plug load demand [kW]	Speace heating demand [kW]	Plug load demand [kW]	Speace heating demand [kW]	Plug load demand [kW]	Speace heating demand [kW]	Plug load demand [kW]		
1	1,0462	0,308771	7,0313	0,307313	5,5297	0,308294	10,883	0,306848		-8,6
2	1,3269	0,215884	7,2137	0,2142342	6,1222	0,2160033	11,424	0,2200924		-9,6
3	1,6363	0,210175	7,4478	0,209938	6,6967	0,21030091	12,037	0,210033		-11,2
4	1,9153	0,220359	7,5543	0,2171776	7,1151	0,247831	12,432	0,248322		-12,4
5	2,0755	0,410967	7,5364	0,422439	7,2508	0,461678	12,662	0,418461		-13,7
6	1,8309	0,785319	5,8023	0,78512	6,8573	0,7853	10,954	0,785228		-12,7
7	5,1244	0,97532	11,557	0,975133	9,9078	0,975262	13,124	0,975127		-11,6
8	4,5456	0,861943	11,325	0,857056	9,1442	0,861721	12,738	0,861322		-11
9	4,6899	0,522825	11,453	0,525103	9,4101	0,523731	12,879	0,52514		-11,1
10	4,4504	0,273792	11,5	0,274208	8,9764	0,273988	12,937	0,274244		-11,1
11	3,2244	0,212733	11,373	0,212648	6,8663	0,211874	12,709	0,213233		-10,3
12	2,461	0,209914	11,269	0,209789	5,4731	0,209877	12,507	0,20981		-9,2

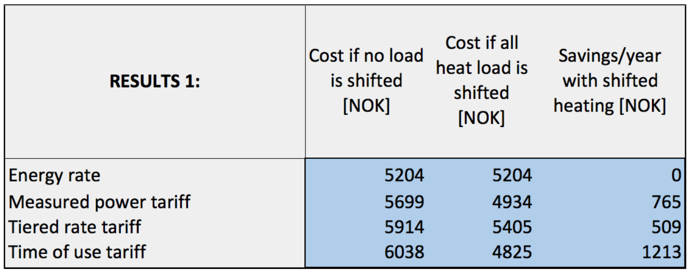
Figure 37: Step 1: Input of the energy demand from IDA ICE in the Excel algorithm.



Heating system:
● Direct electrical heating
○ ASHP

STC:
● No STC (0 m2)
○ STC (6 m2)

Figure 38: Step 2: Examples of the macro buttons in the Excel algorithm.

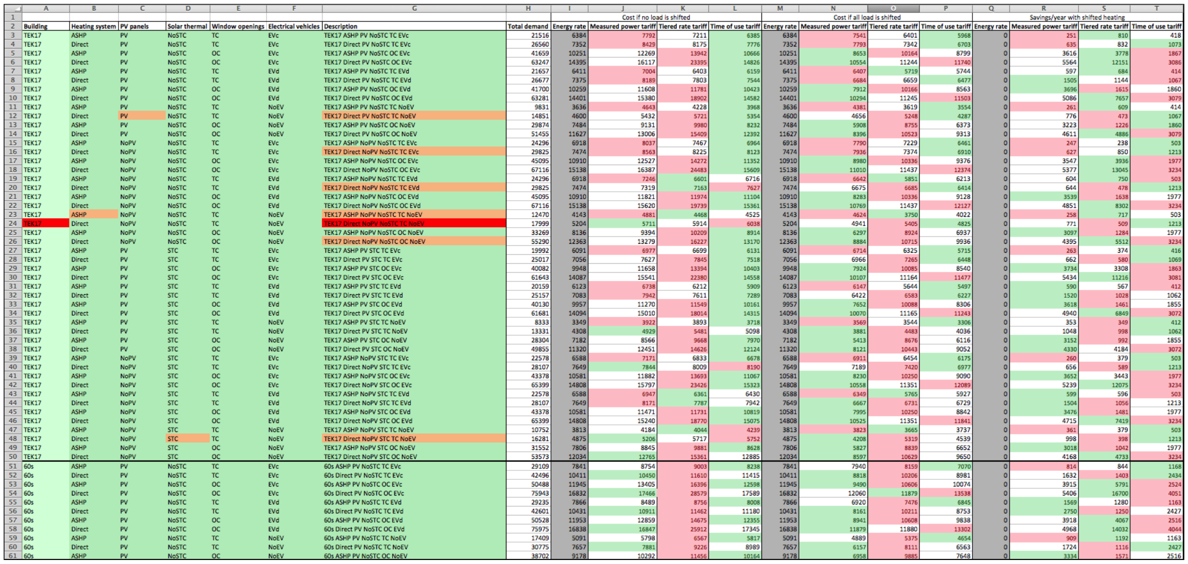


RESULTS 1:	Cost if no load is shifted [NOK]	Cost if all heat load is shifted [NOK]	Savings/year with shifted heating [NOK]
Energy rate	5204	5204	0
Measured power tariff	5699	4934	765
Tiered rate tariff	5914	5405	509
Time of use tariff	6038	4825	1213

Figure 39: Step 3: Examples of some of the result outputs from the Excel algorithm.

4.4.2 Case comparison

To compare all the 96 different cases, another Excel workbook is importing the results of each case by direct links. The cost results for the cases are compared for each different group, by sorting them in different spread sheets according to envelope, heating system, PV, STC, window opening and EV. The annual demand variations, tariff costs, ideal heat shift, load profiles and standard deviation is calculated in this workbook, and compared. The robustness and achievability of the tariffs are also investigated here.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1									Cost if no load is shifted				Cost if all load is shifted				Savings/year with shifted heating			
2	Building	Heating system	PV panels	Solar thermal	Window openings	Electrical vehicles	Description	Total demand	Energy rate	Measured power tariff	Tiered rate tariff	Time of use tariff	Energy rate	Measured power tariff	Tiered rate tariff	Time of use tariff	Energy rate	Measured power tariff	Tiered rate tariff	Time of use tariff
3	TEK17	ASHP	PV	NoSTC	TC	EVc	TEK17 ASHP PV NoSTC TC EVc	21516	6384	7792	7211	6385	6384	7541	6401	5968	0	251	810	418
4	TEK17	Direct	PV	NoSTC	TC	EVc	TEK17 Direct PV NoSTC TC EVc	26560	7352	8429	8175	7776	7352	7793	7342	6703	0	635	832	1073
5	TEK17	ASHP	PV	NoSTC	OC	EVc	TEK17 ASHP PV NoSTC OC EVc	41659	10251	12269	13942	10666	10251	8653	10164	8799	0	3616	3778	1867
6	TEK17	Direct	PV	NoSTC	OC	EVc	TEK17 Direct PV NoSTC OC EVc	63247	14395	16117	23395	14826	14395	10554	11244	11740	0	5564	12151	3086
7	TEK17	ASHP	PV	NoSTC	TC	EVd	TEK17 ASHP PV NoSTC TC EVd	21657	6411	7004	6403	6159	6411	6407	5719	5744	0	597	684	414
8	TEK17	Direct	PV	NoSTC	TC	EVd	TEK17 Direct PV NoSTC TC EVd	26677	7375	8189	7803	7544	7375	6684	6659	6477	0	1505	1144	1067
9	TEK17	ASHP	PV	NoSTC	OC	EVd	TEK17 ASHP PV NoSTC OC EVd	41700	10259	11608	11781	10423	10259	7912	10166	8563	0	3696	1615	1860
10	TEK17	Direct	PV	NoSTC	OC	EVd	TEK17 Direct PV NoSTC OC EVd	63281	14401	15380	18902	14582	14401	10294	11245	11503	0	5086	7657	3079
11	TEK17	ASHP	PV	NoSTC	TC	NoEV	TEK17 ASHP PV NoSTC TC NoEV	9831	3636	4643	4228	3968	3636	4381	3619	3554	0	261	609	414
12	TEK17	Direct	PV	NoSTC	TC	NoEV	TEK17 Direct PV NoSTC TC NoEV	14851	4600	5432	5721	5354	4600	4656	5248	4287	0	776	473	1067
13	TEK17	ASHP	PV	NoSTC	OC	NoEV	TEK17 ASHP PV NoSTC OC NoEV	29874	7484	9131	9980	8232	7484	5908	8755	6373	0	3223	1226	1860
14	TEK17	Direct	PV	NoSTC	OC	NoEV	TEK17 Direct PV NoSTC OC NoEV	51455	11627	13006	15409	12392	11627	8396	10523	9313	0	4611	4886	3079
15	TEK17	ASHP	NoPV	NoSTC	TC	EVc	TEK17 ASHP NoPV NoSTC TC EVc	24296	6918	8037	7467	6964	6918	7790	7229	6461	0	247	238	503
16	TEK17	Direct	NoPV	NoSTC	TC	EVc	TEK17 Direct NoPV NoSTC TC EVc	29825	7474	8563	8225	8123	7474	7936	7374	6910	0	627	850	1213
17	TEK17	ASHP	NoPV	NoSTC	OC	EVc	TEK17 ASHP NoPV NoSTC OC EVc	45095	10910	12527	14272	11352	10910	8980	10336	9376	0	3547	3936	1977
18	TEK17	Direct	NoPV	NoSTC	OC	EVc	TEK17 Direct NoPV NoSTC OC EVc	67116	15138	16387	24483	15609	15138	11010	11437	12374	0	5377	13045	3234
19	TEK17	ASHP	NoPV	NoSTC	TC	EVd	TEK17 ASHP NoPV NoSTC TC EVd	24296	6918	7246	6601	6716	6918	6642	5851	6213	0	604	750	503
20	TEK17	Direct	NoPV	NoSTC	TC	EVd	TEK17 Direct NoPV NoSTC TC EVd	29825	7474	7319	7163	7627	7474	6675	6685	6414	0	644	478	1213
21	TEK17	ASHP	NoPV	NoSTC	OC	EVd	TEK17 ASHP NoPV NoSTC OC EVd	45095	10910	11821	11974	11104	10910	8283	10336	9128	0	3539	1638	1977
22	TEK17	Direct	NoPV	NoSTC	OC	EVd	TEK17 Direct NoPV NoSTC OC EVd	67116	15138	15620	19739	15361	15138	10769	11437	12127	0	4851	8302	3234
23	TEK17	ASHP	NoPV	NoSTC	TC	NoEV	TEK17 ASHP NoPV NoSTC TC NoEV	12470	4143	4881	4468	4525	4143	4624	3750	4022	0	258	717	503
24	TEK17	Direct	NoPV	NoSTC	TC	NoEV	TEK17 Direct NoPV NoSTC TC NoEV	17999	5204	5711	5914	6038	5204	4941	5405	4825	0	771	509	1213
25	TEK17	ASHP	NoPV	NoSTC	OC	NoEV	TEK17 ASHP NoPV NoSTC OC NoEV	33269	8136	9394	10209	8914	8136	6297	8924	6937	0	3097	1284	1977
26	TEK17	Direct	NoPV	NoSTC	OC	NoEV	TEK17 Direct NoPV NoSTC OC NoEV	55290	12363	13279	16227	13170	12363	8884	10715	9936	0	4395	5512	3234
27	TEK17	ASHP	PV	STC	TC	EVc	TEK17 ASHP PV STC TC EVc	19992	6091	6977	6699	6131	6091	6714	6325	5715	0	263	374	416
28	TEK17	Direct	PV	STC	TC	EVc	TEK17 Direct PV STC TC EVc	25017	7056	7627	7845	7518	7056	6966	7265	6448	0	662	580	1069
29	TEK17	ASHP	PV	STC	OC	EVc	TEK17 ASHP PV STC OC EVc	40082	9948	11658	13394	10403	9948	7924	10085	8540	0	3734	3308	1863
30	TEK17	Direct	PV	STC	OC	EVc	TEK17 Direct PV STC OC EVc	61643	14087	15541	22380	14558	14087	10107	11164	11477	0	5434	11216	3081
31	TEK17	ASHP	PV	STC	TC	EVd	TEK17 ASHP PV STC TC EVd	20159	6123	6738	6212	5909	6123	6147	5644	5497	0	590	567	412
32	TEK17	Direct	PV	STC	TC	EVd	TEK17 Direct PV STC TC EVd	25157	7083	7942	7611	7289	7083	6422	6583	6227	0	1520	1028	1062
33	TEK17	ASHP	PV	STC	OC	EVd	TEK17 ASHP PV STC OC EVd	40130	9957	11270	11549	10161	9957	7652	10088	8306	0	3618	1461	1855
34	TEK17	Direct	PV	STC	OC	EVd	TEK17 Direct PV STC OC EVd	61681	14094	15010	18014	14315	14094	10070	11165	11243	0	4940	6849	3072
35	TEK17	ASHP	PV	STC	TC	NoEV	TEK17 ASHP PV STC TC NoEV	8333	3349	3922	3893	3718	3349	3569	3544	3306	0	353	349	412
36	TEK17	Direct	PV	STC	TC	NoEV	TEK17 Direct PV STC TC NoEV	13331	4308	4929	5481	5098	4308	3881	4483	4036	0	1048	998	1062
37	TEK17	ASHP	PV	STC	OC	NoEV	TEK17 ASHP PV STC OC NoEV	28304	7182	8566	9668	7970	7182	5413	8676	6116	0	3152	992	1855
38	TEK17	Direct	PV	STC	OC	NoEV	TEK17 Direct PV STC OC NoEV	49855	11320	12451	14626	12124	11320	8121	10443	9052	0	4330	4184	3072
39	TEK17	ASHP	NoPV	STC	TC	EVc	TEK17 ASHP NoPV STC TC EVc	22578	6588	7171	6833	6678	6588	6911	6454	6175	0	260	379	503
40	TEK17	Direct	NoPV	STC	TC	EVc	TEK17 Direct NoPV STC TC EVc	28107	7649	7844	8009	8190	7649	7189	7420	6977	0	656	589	1213
41	TEK17	ASHP	NoPV	STC	OC	EVc	TEK17 ASHP NoPV STC OC EVc	43378	10581	11882	13693	11067	10581	8230	10250	9090	0	3652	3443	1977
42	TEK17	Direct	NoPV	STC	OC	EVc	TEK17 Direct NoPV STC OC EVc	65399	14808	15797	23426	15323	14808	10558	11351	12089	0	5239	12075	3234
43	TEK17	ASHP	NoPV	STC	TC	EVd	TEK17 ASHP NoPV STC TC EVd	22578	6588	6947	6361	6430	6588	6349	5765	5927	0	599	596	503
44	TEK17	Direct	NoPV	STC	TC	EVd	TEK17 Direct NoPV STC TC EVd	28107	7649	8171	7787	7942	7649	6667	6731	6729	0	1504	1056	1213
45	TEK17	ASHP	NoPV	STC	OC	EVd	TEK17 ASHP NoPV STC OC EVd	43378	10581	11471	11731	10819	10581	7995	10250	8842	0	3476	1481	1977
46	TEK17	Direct	NoPV	STC	OC	EVd	TEK17 Direct NoPV STC OC EVd	65399	14808	15240	18770	15075	14808	10525	11351	11841	0	4715	7419	3234
47	TEK17	ASHP	NoPV	STC	TC	NoEV	TEK17 ASHP NoPV STC TC NoEV	10752	3813	4184	4044	4239	3813	3823	3665	3737	0	361	379	503
48	TEK17	Direct	NoPV	STC	TC	NoEV	TEK17 Direct NoPV STC TC NoEV	16281	4875	5206	5717	5752	4875	4208	5319	4539	0	998	398	1213
49	TEK17	ASHP	NoPV	STC	OC	NoEV	TEK17 ASHP NoPV STC OC NoEV	31552	7806	8845	9881	8628	7806	5827	8839	6652	0	3018	1042	1977
50	TEK17	Direct	NoPV	STC	OC	NoEV	TEK17 Direct NoPV STC OC NoEV	53573	12034	12765	15361	12885	12034	8597	10629	9650	0	4168	4733	3234
51	60s	ASHP	PV	NoSTC	TC	EVc	60s ASHP PV NoSTC TC EVc	29109	7841	8754	9003	8238	7841	7940	8159	7070	0	814	844	1168
52	60s	Direct	PV	NoSTC	TC	EVc	60s Direct PV NoSTC TC EVc	42496	10411	10450	11610	11415	10411	8818	10206	8981	0	1632	1403	2434
53	60s	ASHP	PV	NoSTC	OC	EVc	60s ASHP PV NoSTC OC EVc	50488	11945	13405	16396	12598	11945	9490	10606	10074	0	3915	5791	2524
54	60s	Direct	PV	NoSTC	OC	EVc	60s Direct PV NoSTC OC EVc	75943	16832	17466	28579	17589	16832	12060	11879	13538	0	5406	16700	4051
55	60s	ASHP	PV	NoSTC	TC	EVd	60s ASHP PV NoSTC TC EVd	29235	7866	8489	8756	8008	7866	6920	7476	6845	0	1569	1280	1163
56	60s	Direct	PV	NoSTC	TC	EVd	60s Direct PV NoSTC TC EVd	42601	10431	10911	11462	11180	10431	8161	10211	8753	0	2750	1250	2427
57	60s	ASHP	PV	NoSTC	OC	EVd	60s ASHP PV NoSTC OC EVd	50528	11953	12859	14675	12355	11953	8941	10608	9838	0	3918	4067	2516
58	60s	Direct	PV	NoSTC	OC	EVd	60s Direct PV NoSTC OC EVd	75975	16838	16847	25912	17345	16838	11879	11880	13302	0	4968	14032	4044
59	60s	ASHP	PV	NoSTC	TC	NoEV	60s ASHP PV NoSTC TC NoEV	17409	5091	5798	6567	5817	5091	4889	5375	4654	0	909	1192	1163
60	60s	Direct	PV	NoSTC	TC	NoEV	60s Direct PV NoSTC TC NoEV	30775	7657	7881	9226	8989	7657	6157	8111	6563	0	1724	1116	2427
61	60s	ASHP	PV	NoSTC	OC	NoEV	60s ASHP PV NoSTC OC NoEV	38702	9178	10292	11456	10164	9178	6958	9885	7648	0	3334	1571	2516

Figure 40: Examples of some of the comparisons done in the case comparison workbook.

5 Results and discussion

In this section, a selection of the results from the simulations and calculations are presented. To see all outputs and results from all the cases, please refer to the Excel workbook *Case_comparison.xlsx*, see Appendix B.

First in this section, the total energy demand of the cases is presented, then the load profile and cost according to business models for each group is given. Ideal heat shift, robustness and achievability is shown in the end of the results. The average day load profile presented for each group is calculated as the daily average demand for each hour over the whole year.

5.1 Energy demand

To compare the difference in energy demand, all of the cases have been investigated according to the different groups envelope, heating system, PV, STC, window openings, and EV charging. Each of the groups contains all 96 cases, and to investigate the influence from the parameters on the energy demand, the results in each group have been divided in two, or three, according to the parameters. All the results have been inserted into one box plot for comparison, see Figure 41.

The first two boxes in the plot illustrates the two different envelopes, TEK17 and ’60s. The cases with envelope as a typical ’60s house have a significantly higher energy demand than the ones with envelope according to TEK17. The standard deviation between the cases is quite similar, but the TEK17 cases have a median that lies lower in the range. This indicates that more cases with the TEK17 envelope have a demand in the low section of the range, than the cases with ’60s envelope, which have more cases in the upper part of the range.

The next group is the different heating systems, and it is clear that ASHP is largely reducing the energy demand in buildings. The buildings which already have low energy demand with direct electric heating can save about 5000 kWh a year if they change the heating source from direct electrical heating to ASHP, while the buildings with high heating demand can save up to about 25000 kWh a year. This is a huge reduction in demand. The standard deviation decrease with ASHP, indicating that the ASHP makes the demand

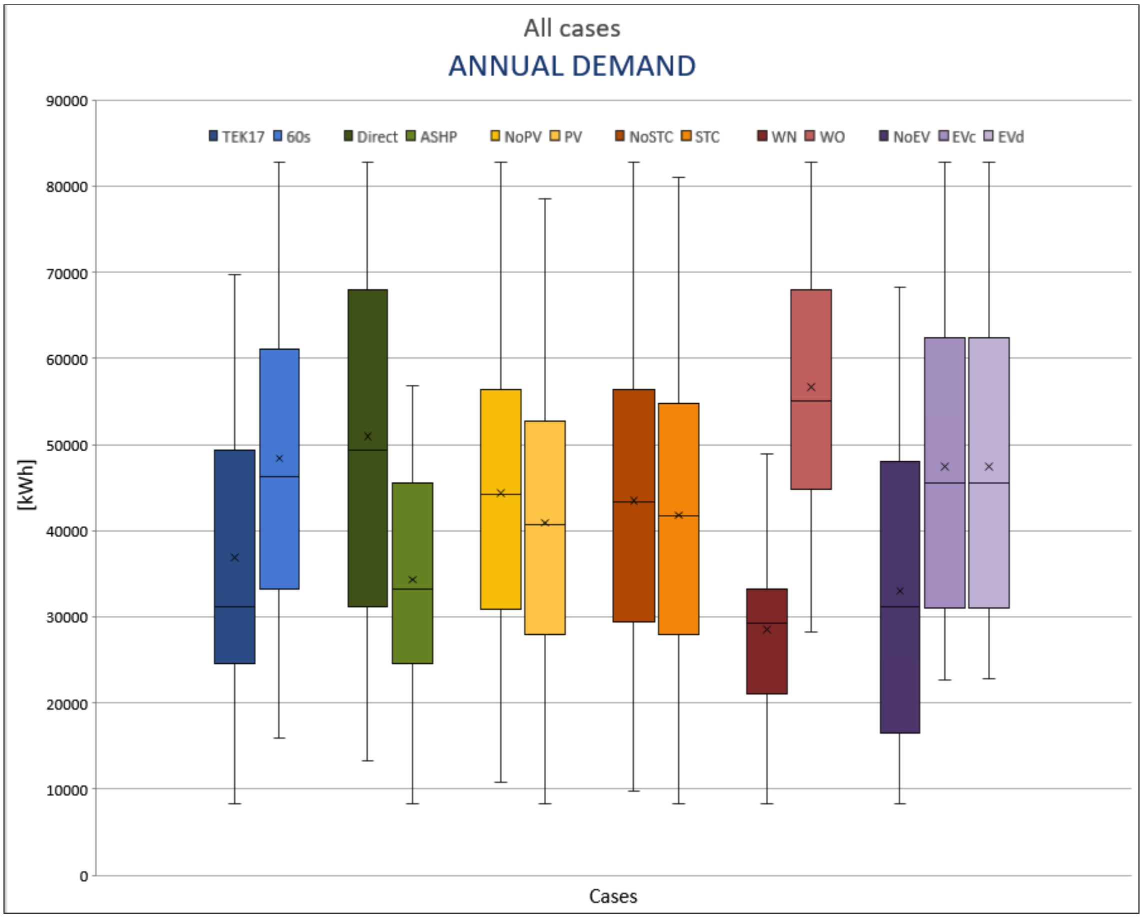


Figure 41: Box plot comparing annual demand between all the groups of cases.

more stable.

The group with and without PV panels shows that PV panels do decrease the energy demand with about 3000 kWh a year for cases with high demand. Cases with high demand save more than cases with less demand, even though the panels produce the same amount for all cases. This is due to the fact that the excess production from the PV panels is not considered in this study. Buildings with higher demand also have a higher demand during the hours when energy is produced from the panels. More of the energy produced with PV will therefore be used, and less will be exported. If the buildings had battery storage or matching of the demand with the production, more of the produced energy would have been used, and buildings with lower energy demand would have the same reduction in cost as buildings with higher demand. If the customer has a prosumer contract with a supply company, they will also get paid an amount for the energy they export to the grid. The price in these contracts usually have a higher price for selling energy to the grid than for buying from the grid. With a battery there will be losses for inserting and withdrawing energy. The most beneficial will however be to match the demand directly with the PV production. This gives minimal losses and highest reduction in import of high-cost energy. But this problem of discussion is outside the scope of this survey, and further research is necessary to investigate whether battery, export to the grid, or installation of smart controllers is the most beneficial for the customer.

The next group in the chart is illustrating the groups with and without solar thermal collector. As the collector is only affecting the hot water, which has the same schedule and amount of demand for all cases, STC will decrease the demand with equal amount for all cases, 1718 kWh a year.

The largest difference in demand in the chart is found between buildings with and without windows opened by occupants. The demand and standard deviation is a lot larger for cases which have openings by occupants. This type of consumer behaviour therefore holds a large potential for demand reduction.

The last cases compared are the three scenarios for charging of electrical vehicles. When the charging of an electrical vehicle is included in the building load the demand increases, but the demand for the cases have the same standard deviation. In other words, the demand is increased with the same amount for all cases. If the vehicle is charged with typical or delayed charging does not affect the demand, and all cases have the exact same demand.

5.2 Envelope

The average day load profile for the reference cases with different envelope is illustrated in Figure 42. The figure shows that the profile for different envelope is quite similar, but the amount is increased for buildings with an older type of envelope.

The cost for the four business models for cases with different envelopes is compared in a box plot in Figure 43. Both for cases with TEK17 and ’60s envelope the Energy rate tariff used today is the one with lowest cost, and Tiered rate with clearly the highest cost and a very large standard deviation. Especially for the buildings with high energy demand the cost will become very large with a Tiered rate compared to the other models. Amongst the three new models Time of use gives the lowest cost and smallest standard deviation for cases with TEK17 envelope, while Measured power tariff has a slightly lower cost for ’60s envelope, but with about the same standard deviation. For buildings with low demand and TEK17 envelope, the price is similar for all of the three new models. For a ’60s house envelope the cost of the Tiered rate is higher also for low demand buildings.

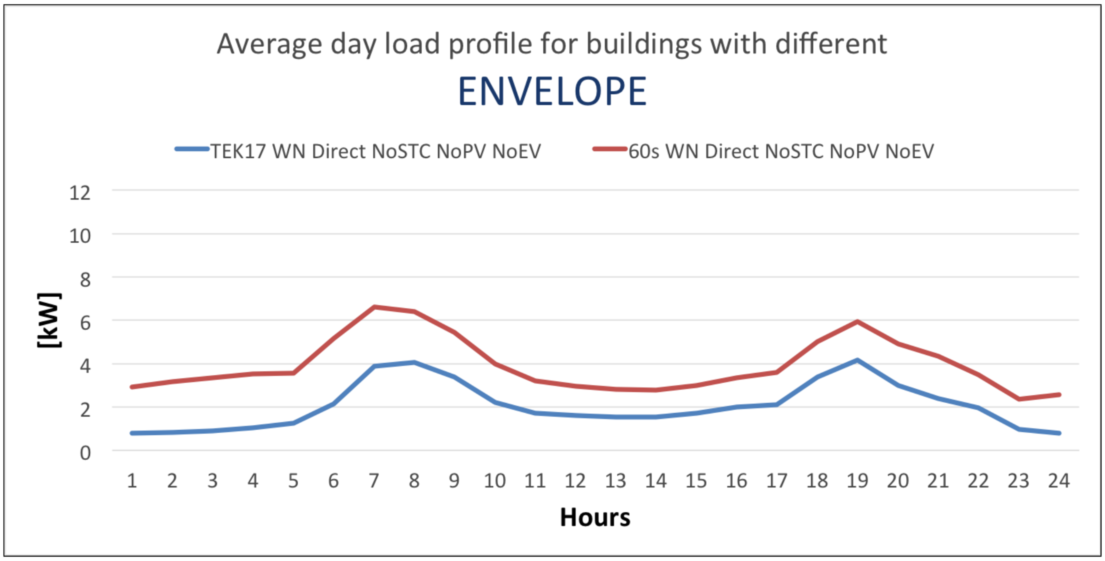


Figure 42: Load profile for the two different envelopes.

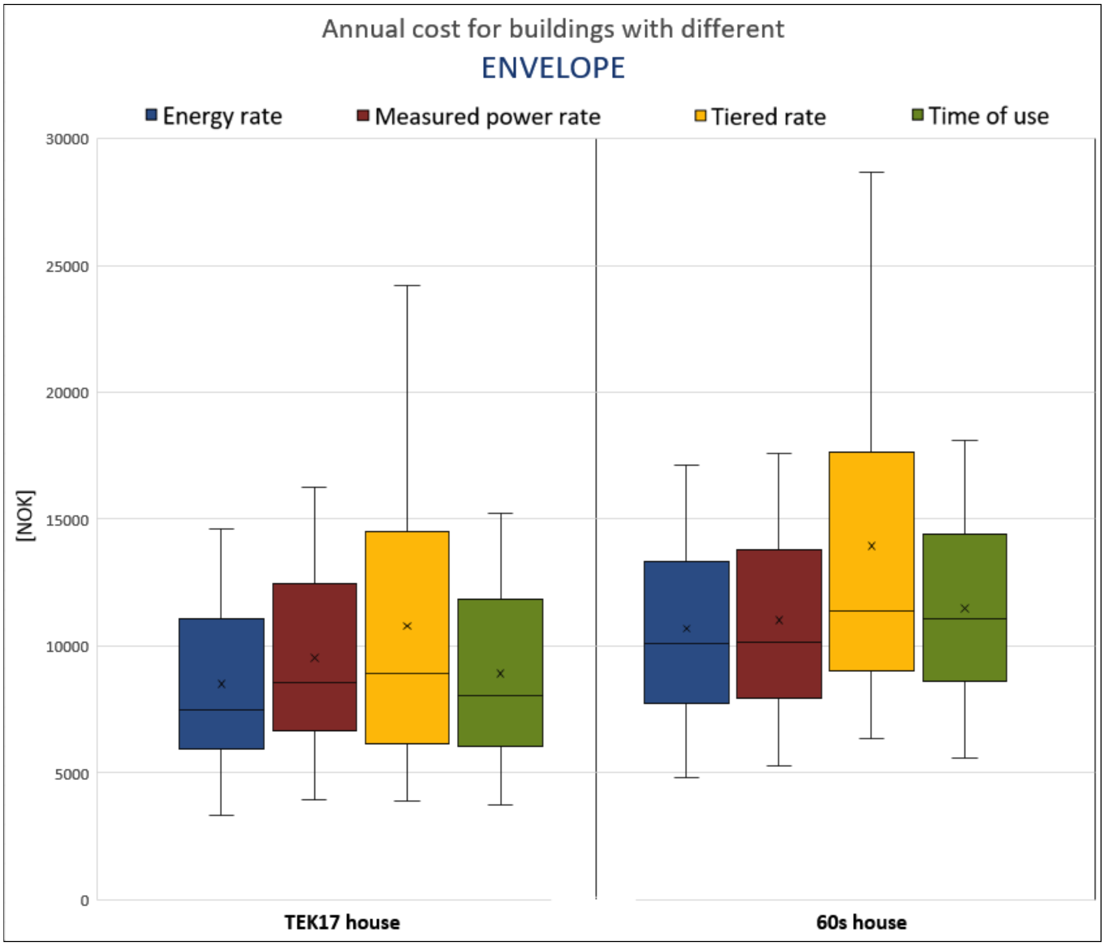


Figure 43: Box plot comparing the cost of different envelopes.

5.3 Heating system

The average day load profile for the reference cases with different heating systems in Figure 44 shows that the demand decreases with implemented ASHP. The demand decreases most in the morning, as there is a large peak on the heating system in the morning due to increased temperature set point.

Figure 45 displays the cost for different heating systems for the four business models. In this plot the Tiered rate has the larges range and the highest cost for both heating systems. Implementation of an ASHP does decrease the cost for all models. With a direct electric heating system the Measured power rate has the lowest cost, but larger range than Time of use. With an ASHP heating system the Time of use rate has lower cost and range.

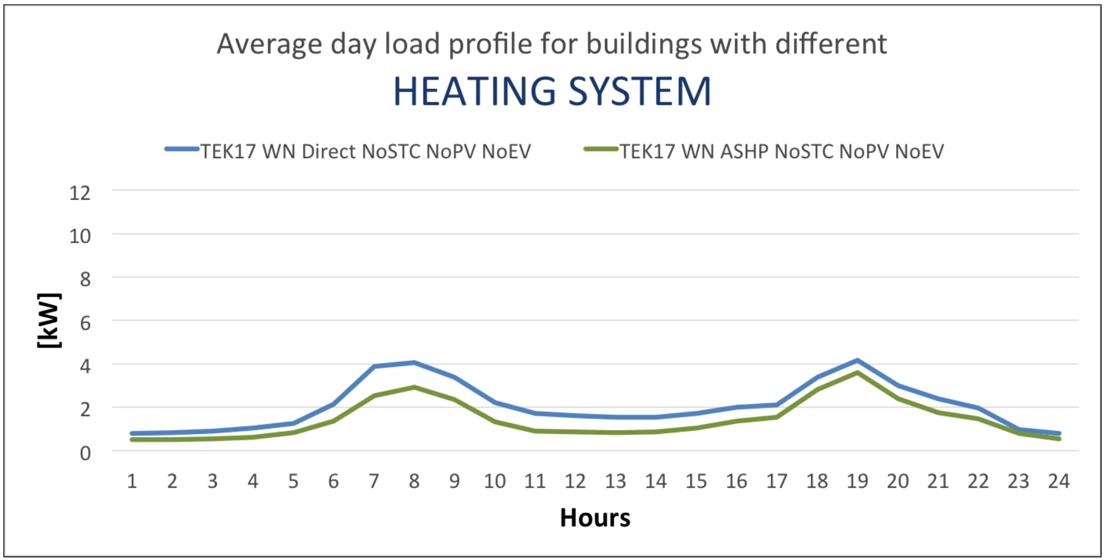


Figure 44: Load profile for the different heating systems.

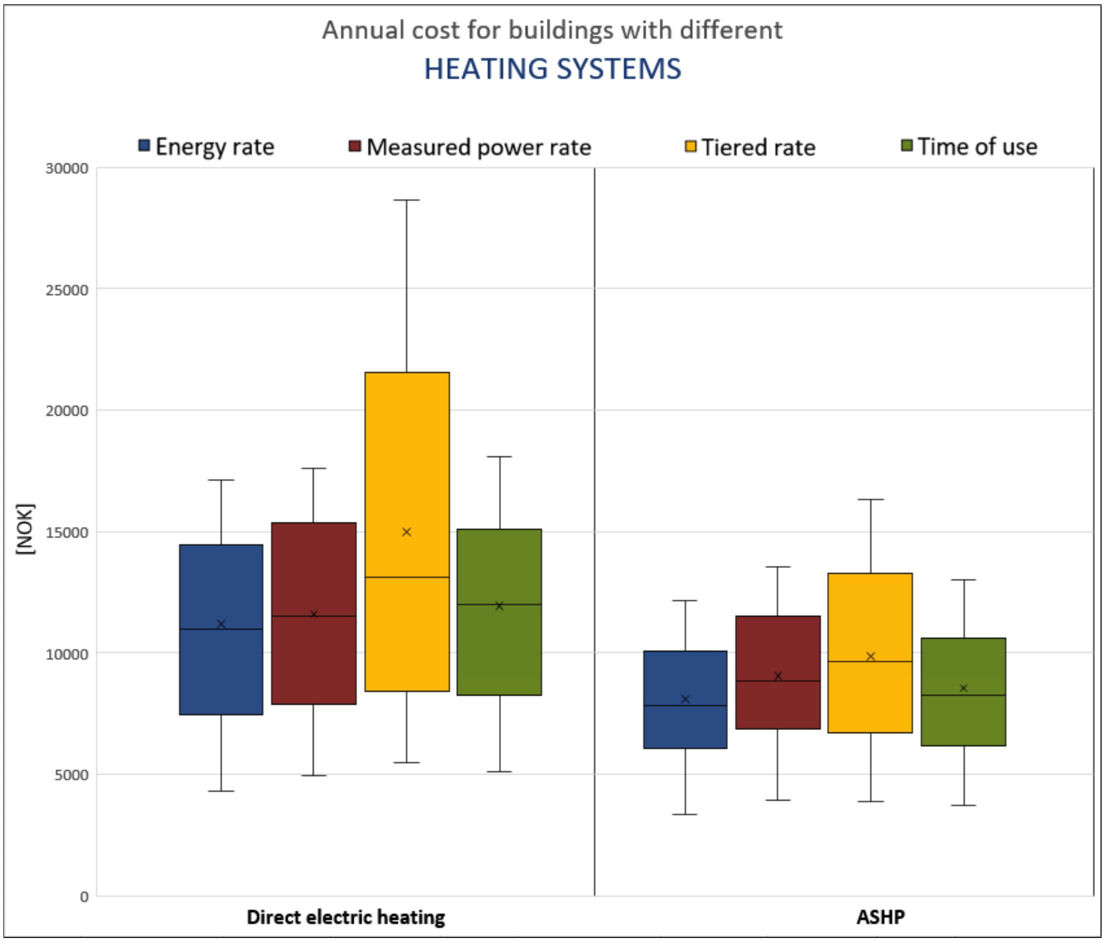


Figure 45: Box plot comparing the cost of different heating systems.

5.4 Solar thermal collector

The load profile in Figure 46 shows how a solar thermal collector decrease the peaks both in morning and evening. The largest peak reduction happens in the evening, as the hot water demand is larger, and the solar power is heating better in the evening, due to the angle of the collectors.

The cost for the cases with and without solar thermal collector according to business models is shown in Figure 47. The difference between the groups are quite small. Tiered rate has a higher cost for all cases, and a range that is a lot larger. But the improvement in cost and range when implementing STC is also largest for the Tiered rate. Measured power rate has the lowest cost, and Time of use has slightly higher cost and standard deviation.

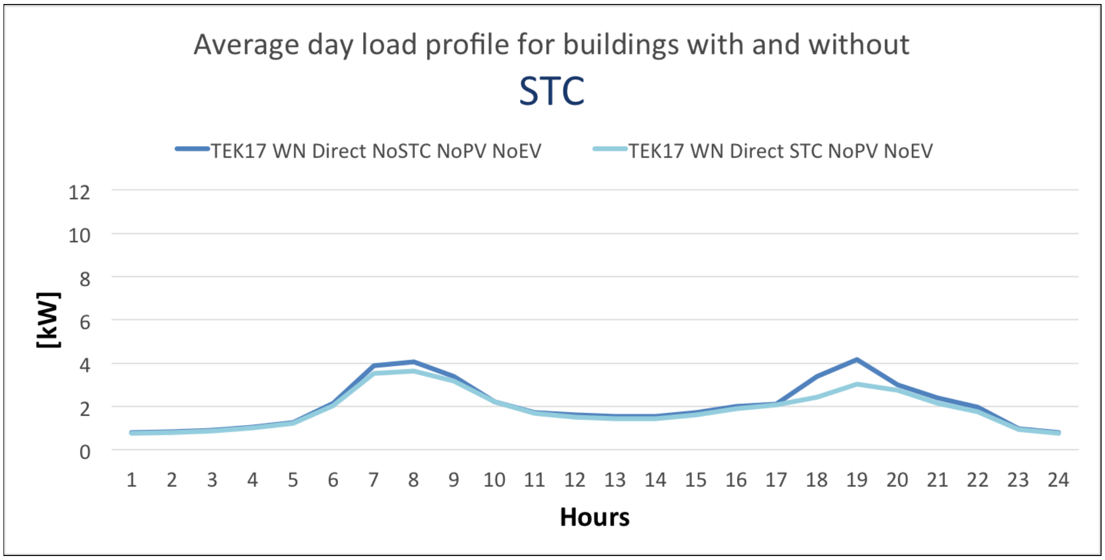


Figure 46: Load profile for the buildings with and without solar thermal collector.

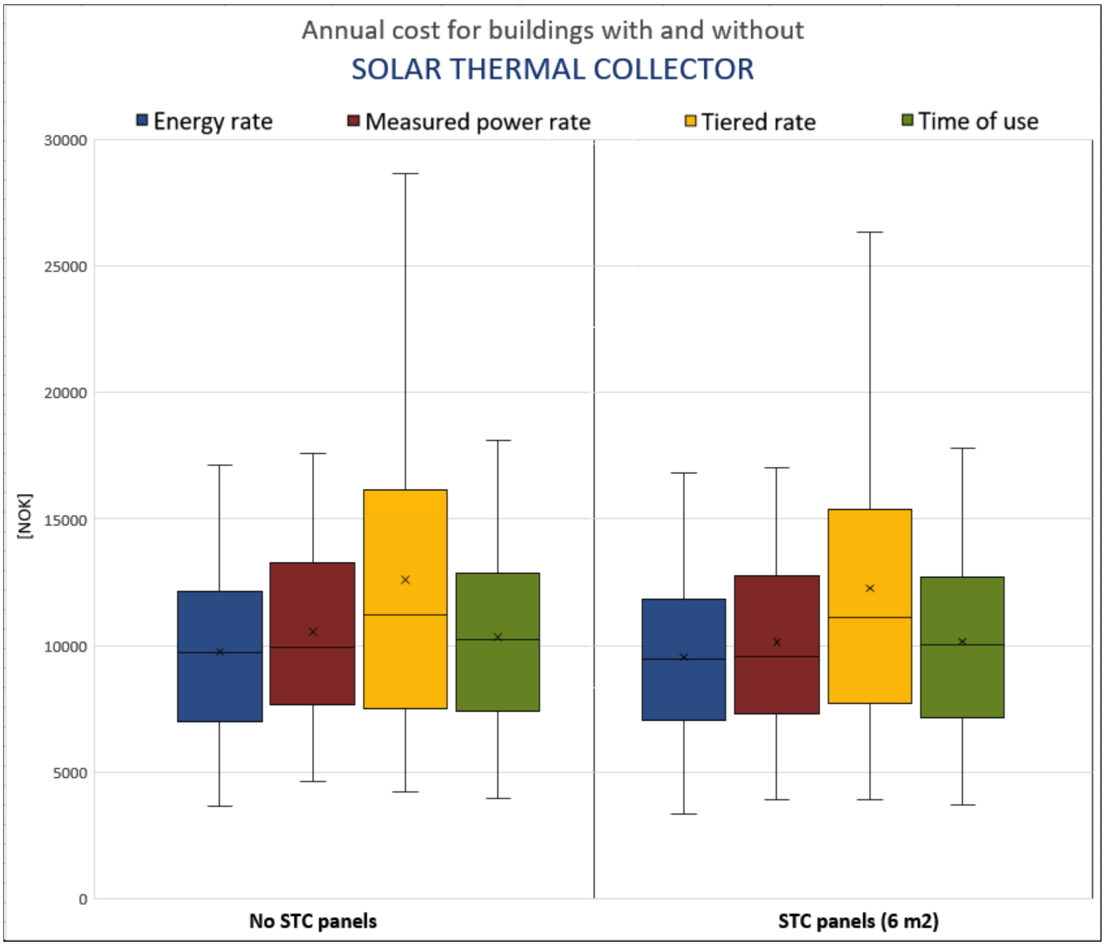


Figure 47: Box plot comparing the cases with and without solar thermal collector.

5.5 PV panels

The load profile for PV panels, shown in Figure 48, displays that when PV panels are included in the building, the load is decreased during the day, and most at midday. The morning peak from the building is slightly reduced, but the evening peak is not. Many of the hours when the load is reduced occur during hours when the grid strain is high. The demand on the grid during midday is mostly high due to industry and work places, where people tend to stay during the day. Reduction of demand from households in these hours can therefore also affect the aggregated capacity on the grid, even though the individual peaks from the household investigated is not reduced.

The box plot in Figure 49 shows that for cases with PV panels the total cost is reduced. The reduction is largest for the buildings that have a high cost without PV. This is probably due to the fact that buildings with low demand utilise less of the PV produced energy, and export more to the grid than buildings with high demand. The cases have excess energy between 974 kWh/year and 2733 kWh/year, with an average of 1751 kWh/year. This means that for some cases not even half of the energy produced is used. In reality this exported energy will also give a reduction in cost, and for buildings with a large amount of export this will make a noticeable difference on the total energy cost.

With PV panels, Measured power rate has the lowest median, which is almost unchanged compared to the cases without PV. The TOU rate has a median cost slightly higher than for Measured power rate. The Tiered rate has a higher range and median cost for all cases.

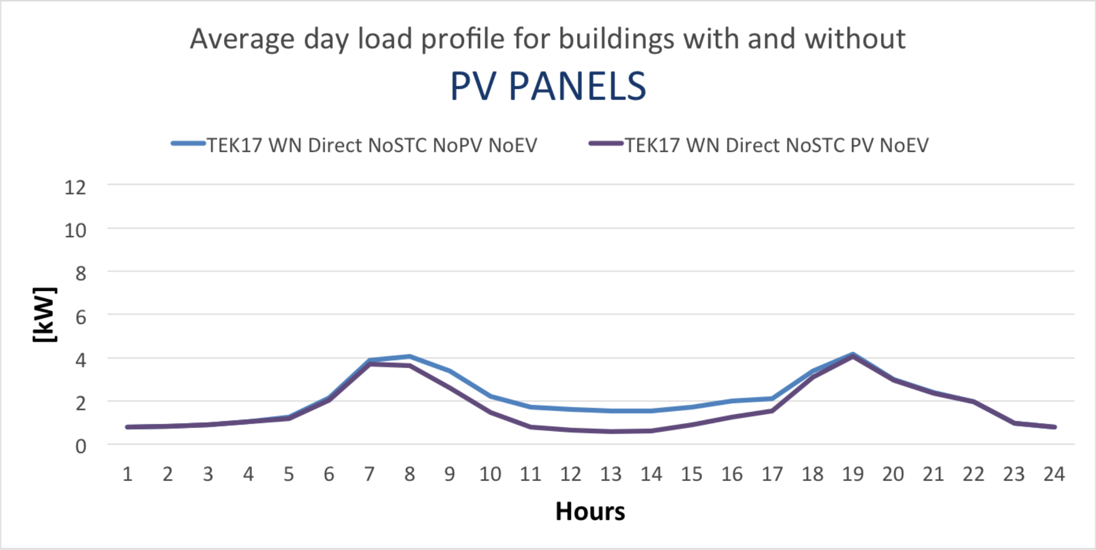


Figure 48: Load profile for the buildings with and without PV panels

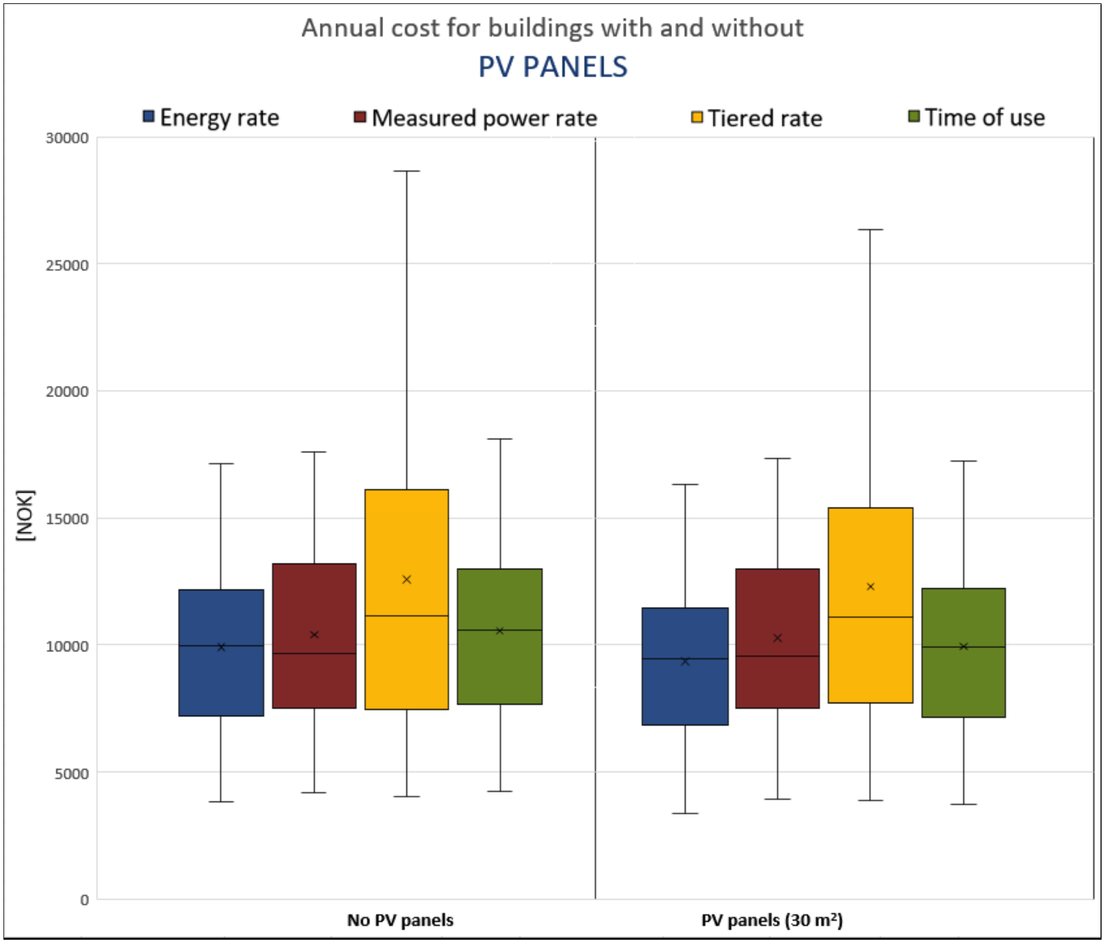


Figure 49: Box plot comparing the cases with and without PV panels

5.6 Window openings

The load profile for temperature controlled (WN) and occupant opened (WO) windows is given in Figure 50. The increase in demand for openings is large, and the increase is largest in the evening, when there is already a peak. The increase is smallest during the daytime, as the windows are only opened by occupants in the daytime during weekends.

The box plot clearly views that there is a huge difference in cost with temperature controlled and occupant opened windows. For WN openings Time of use has the largest range, and Measured power tariff the smallest. Tiered rate has the highest cost. For occupants openings of windows the cost with Tiered rate is far higher than for the other two models. The other two are just slightly higher than Energy rate, while the cost with Tiered rate is almost twice as high.

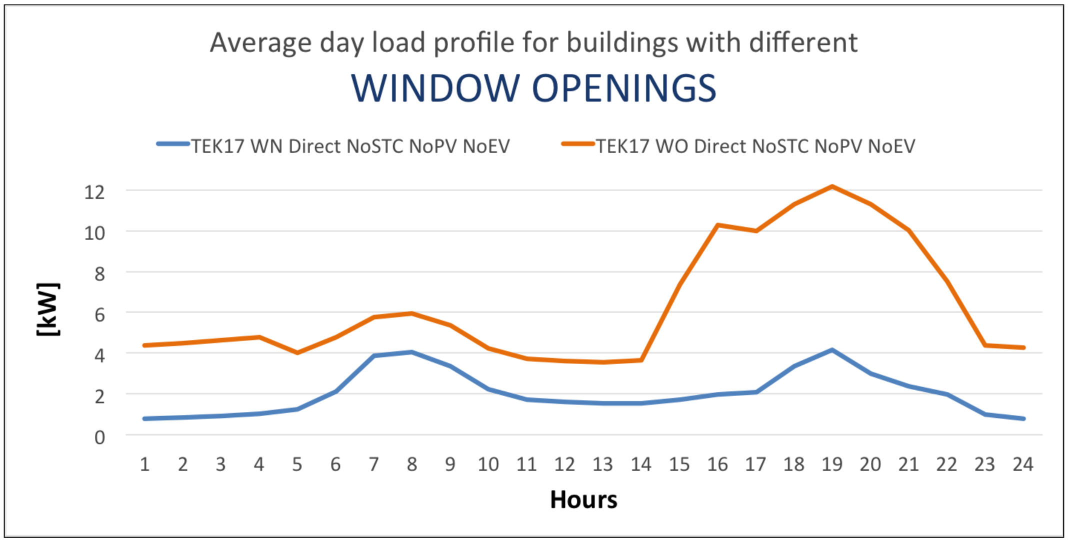


Figure 50: Load profile for the buildings with different window openings.

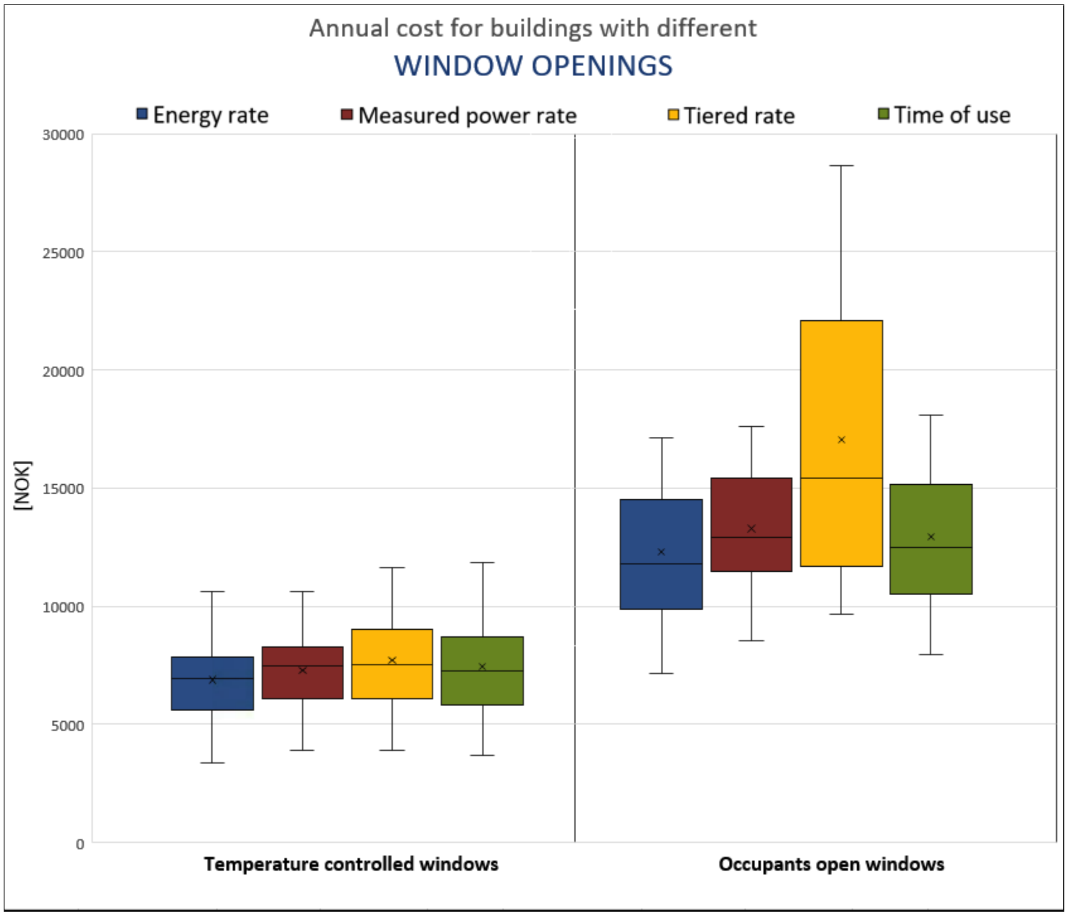


Figure 51: Box plot comparing the cases for different window openings.

5.7 Electrical vehicle charging

The charging of electrical vehicle with typical and delayed charging is illustrated in the load profile in Figure 52. With typical charging the evening peak is largely increased. With delayed charging there is a new peak late in the evening and early in the morning, but not as large as for the typical charging.

In the box plot in Figure 53 it is also clear that delayed charging results in a lower cost than typical charging. The cost for Tiered rate is reduced the most, but this tariff still gives the highest cost for both kinds of charging profiles. The Measured power rate gives the lowest price for both profiles. The TOU rate has a median equal to Measured power rate, but the range is larger. This also means that for buildings with lowest demand, TOU rate has the lowest total cost, and Measured power rate the highest of all the four models.

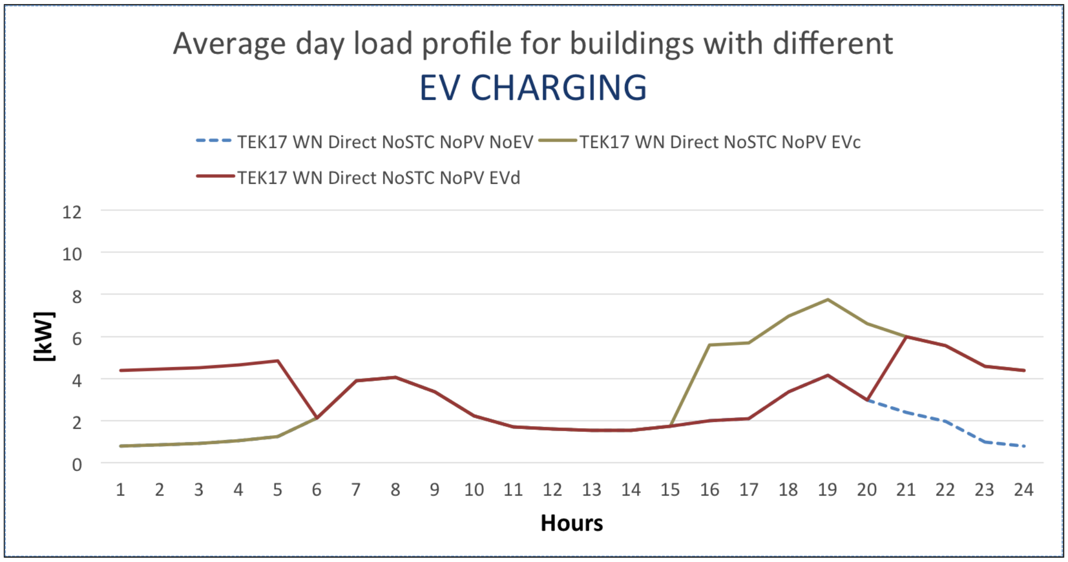


Figure 52: Load profile for cases with typical and delayed charging of electrical vehicle.

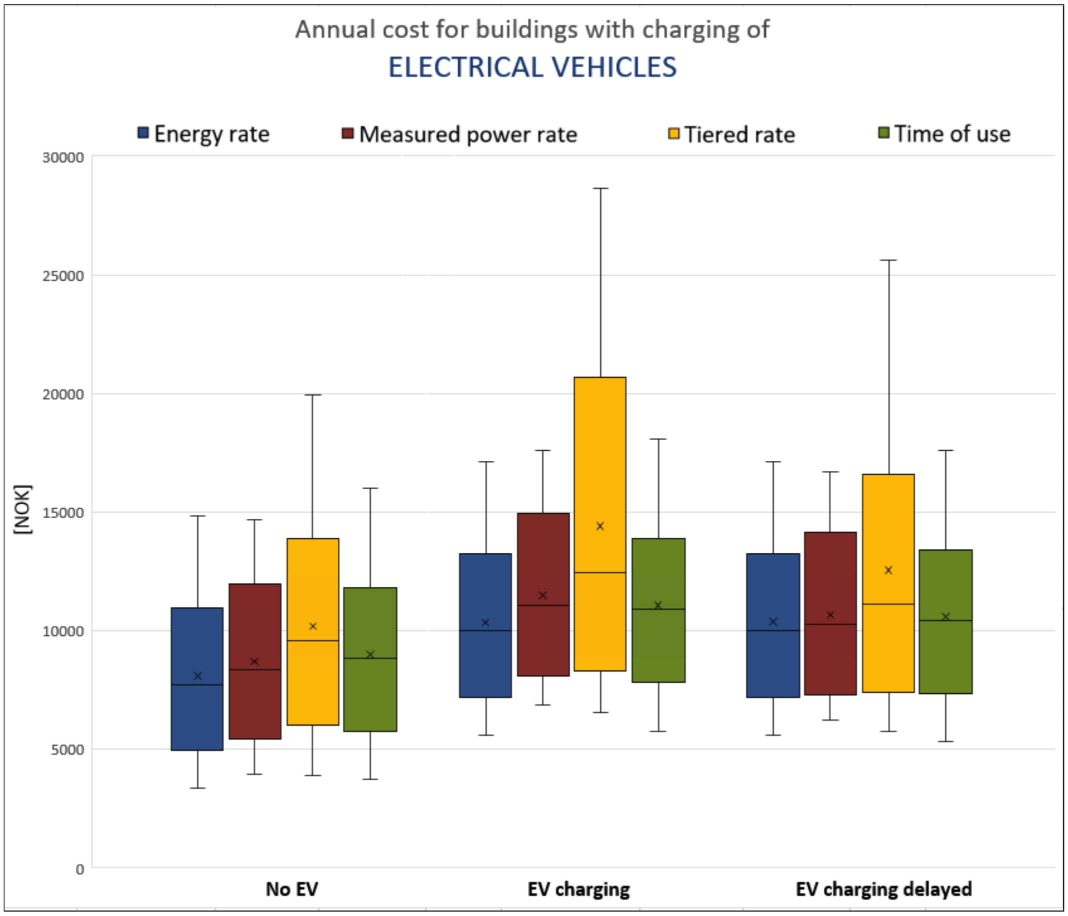


Figure 53: Box plot comparing the cases for charging of electrical vehicles.

5.8 Ideal heat load shift

Ideal heat shift is the load shifting of heat demand that will result in the highest cost reduction in grid rent. For each of the business models, the highest cost reduction is obtained by different patterns of shifts, and the load profiles for ideal heat shift will look very different for each of the business models. Each of these load profiles are demonstrated in Figure 54.

If energy is shifted with the energy rate tariff it can be convenient for the grid, but it will have no effect on the grid rent cost for the customer. It can therefore be assumed that the customer will implement no shift, even if they were encouraged to do so. The first load profile in the figure illustrates a typical load profile for a building without shift, and this is also the ideal load profile for the energy rate tariff, as the price is not changing.

For a Measured power rate the reducible part of the cost without reducing the demand is the power cost. The power cost occur for the highest peak in each day, and minimisation of this cost happens when all load is equally large during each day, and the peak is as low as possible. Ideal heat shift will create a flat load profile. High, short peaks can result in a small load shift but a large cost reduction, while smaller, wide peaks will give a large heat shift with a small cost reduction. This model is therefore good for reduction of short, high peaks.

Ideal heat shift with a Tiered rate tariff will result in shifting all load above the subscription limit, and the overuse cost will be decreased to zero. The ideal heat shift will therefore shift all heat occurring above the peak to hours with available amount of kW below the limit. This model is good for reducing the top of the peak in each individual household.

For the Time of use model the high cost occur for winter day. Optimal heat shift therefore shift all heat during winter from winter day to winter night. In summer no load shifting is necessary, and the profile will stay similar to the profile for the Energy rate.

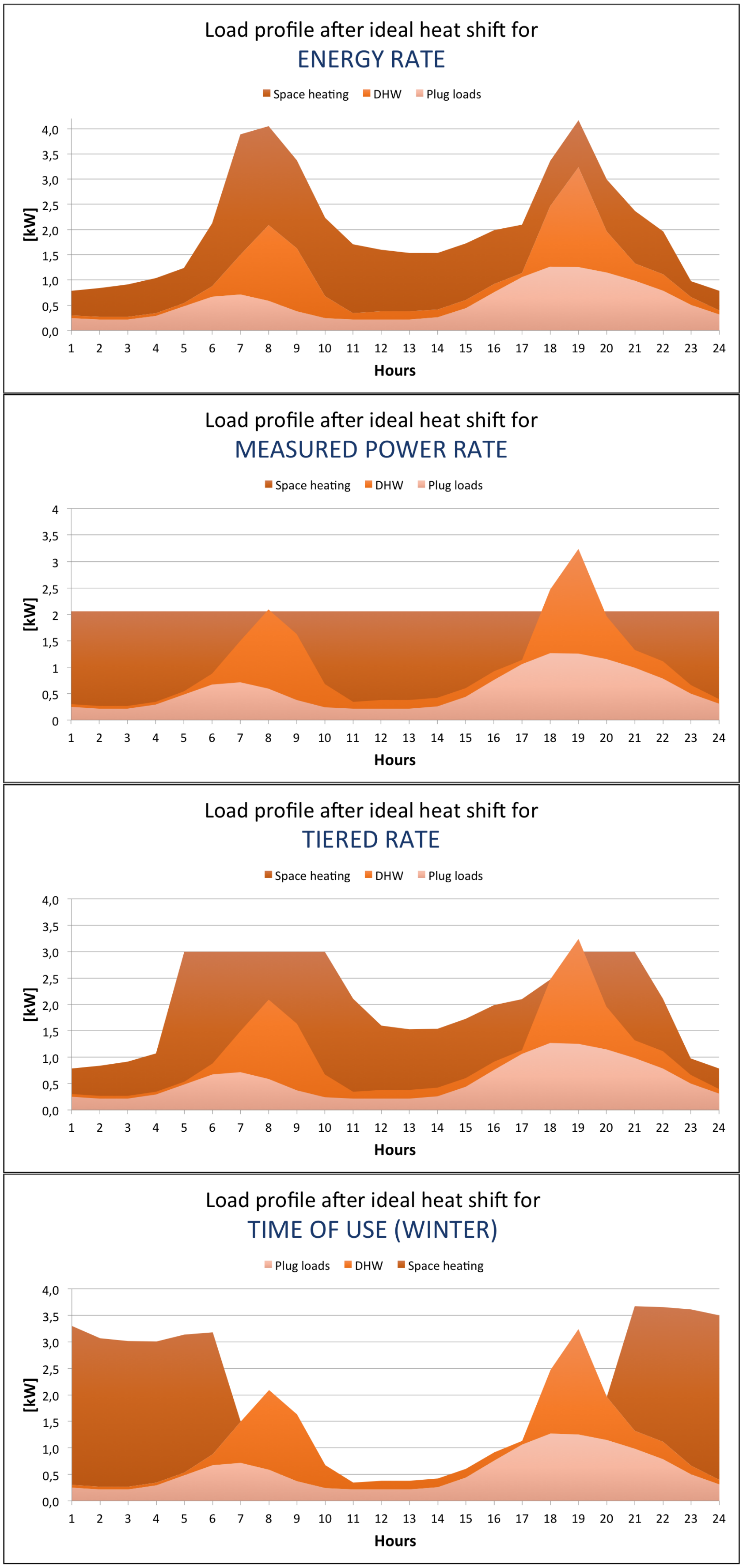


Figure 54: Load profile for ideal heat shifting with different business models.

Figure 55 presents the cost for cases with and without ideal heat shift. For all the business models, cases with high cost without load shift have a large reduction in cost with heat load shift, while the cases with low cost without load shift have about the same cost with shift. Without shift, the Energy rate has the lowest cost, but with it is the tariff with highest cost. The Tiered rate has the largest decrease in cost, but is still the most expensive (except for the Energy rate) with heat shift. The Measured power rate has the lowest cost.

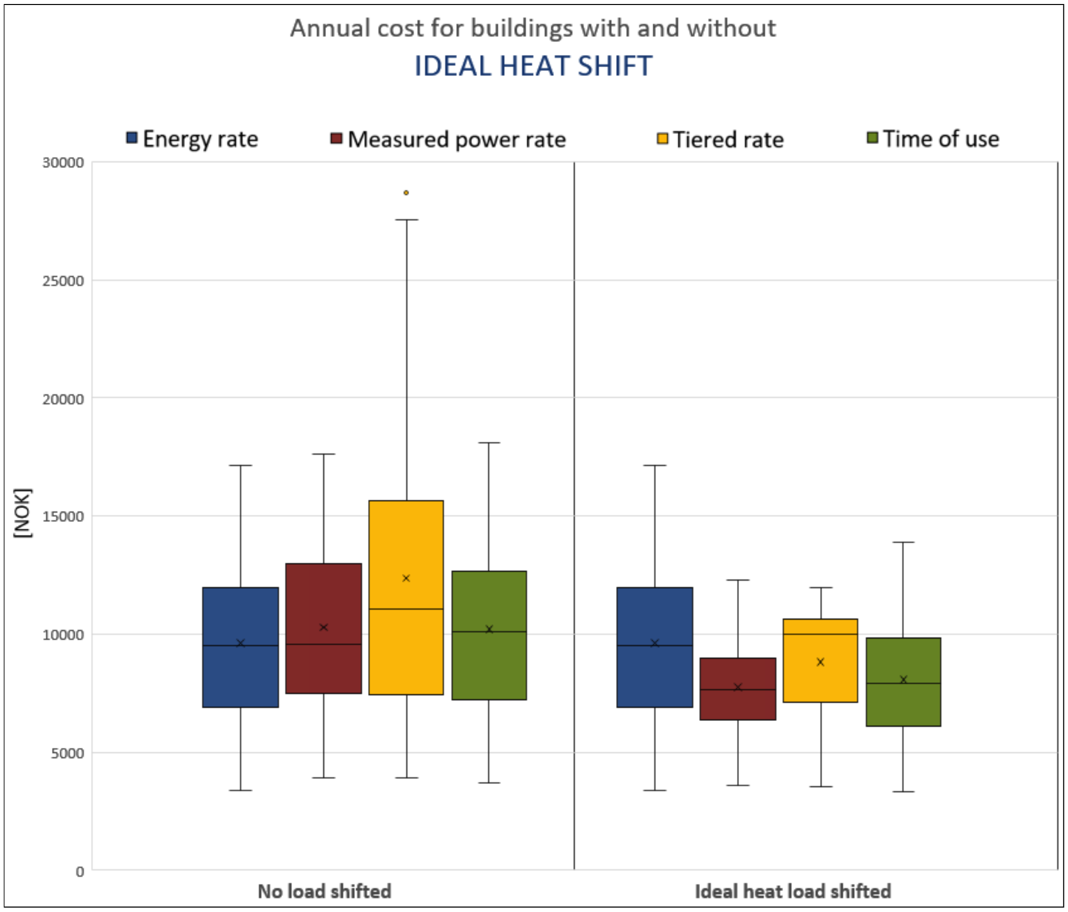


Figure 55: Box plot for cases with and without ideal heat shift.

Figure 56 illustrates the cost of all cases, for all tariffs, both with and without ideal heat shift. The plot reveals clearly that without load shift the Energy rate tariff has the lowest cost for all cases, but with ideal heat shift, Energy rate has the highest cost for all cases. The cost of the other tariffs vary more. For buildings with low energy demand the measured power tariff is cheapest with ideal heat, while the Tiered rate tariff is cheapest for the few cases with the highest energy demand. Time of use tariff is very stable in cost, while Measured power and Tiered rate tariff vary more.

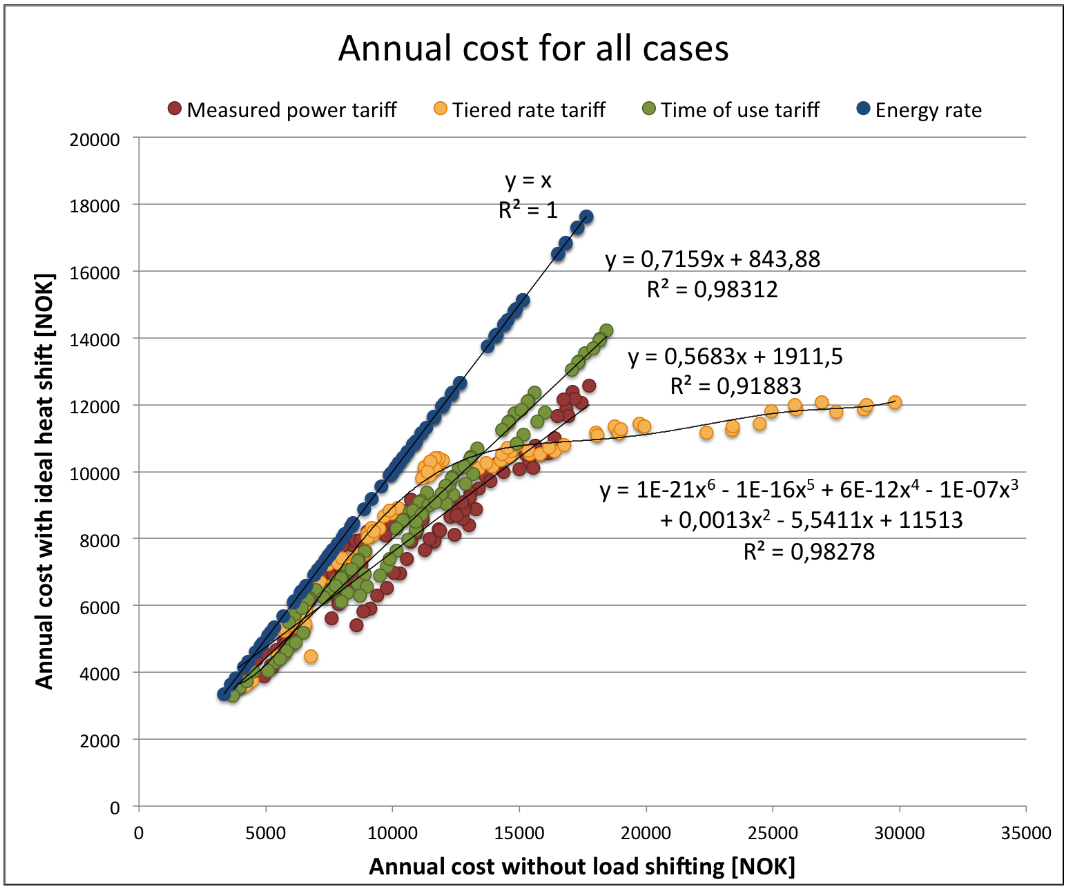


Figure 56: Annual cost for all cases, for all tariffs, with and without ideal heat shift.

5.8.1 Cost division of tariffs

In this section the cost of the tariffs for the eight reference cases are compared with and without shift. The total cost is divided into the parts of the cost for each tariff, to clearly illustrate which part cause high cost, and which part is affected by load shift.

For the Energy rate shift does not affect the cost, see Figure 57. The tariff consists of two parts. The fixed cost is the same for all cases, not depending on the demand. The energy cost is directly dependent on the demand, but time of use does not affect the cost. The only way to reduce the cost with Energy rate is to reduce the demand.

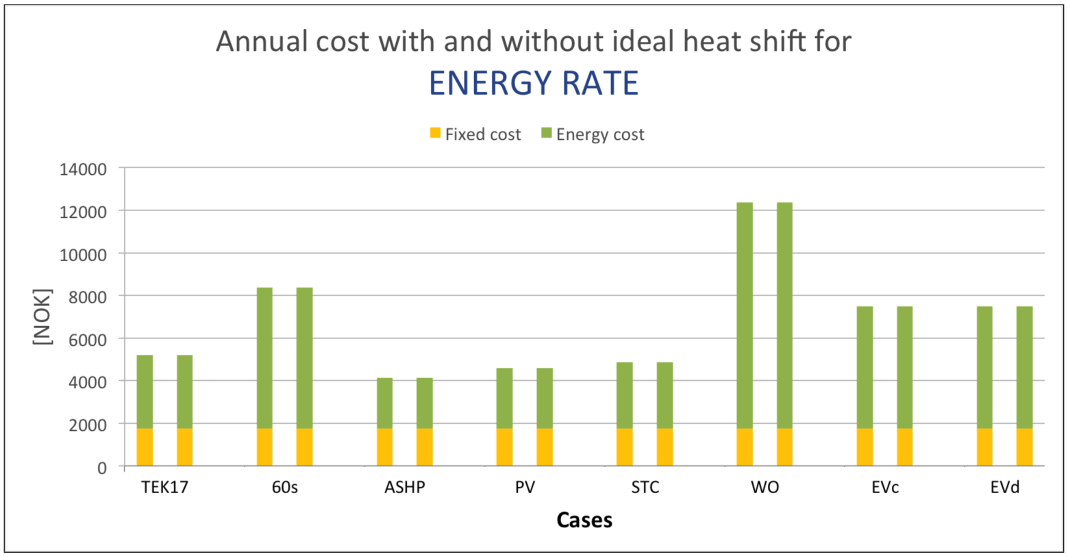


Figure 57: Annual cost with and without ideal heat shift for Energy rate.

For the Measured power tariff the cost is divided into three parts, illustrated in Figure 58. The fixed cost is equal for all cases. The energy cost is directly dependant on the demand, but for this tariff the cost is a lot smaller than the energy cost in the Energy rate tariff. Decrease of demand will therefore affect this part to only a small extent, but load shift will not influence this parameter. The power cost on the other hand will be reduced by load shift. The larger the power cost without load shifting, the larger the possible reduction in total cost with shift. For EV charging the difference of typical and delayed charging is also a form of load shifting. The figure displays that delayed charging does give a reduction in cost for this tariff, even though the annual demand is the same.

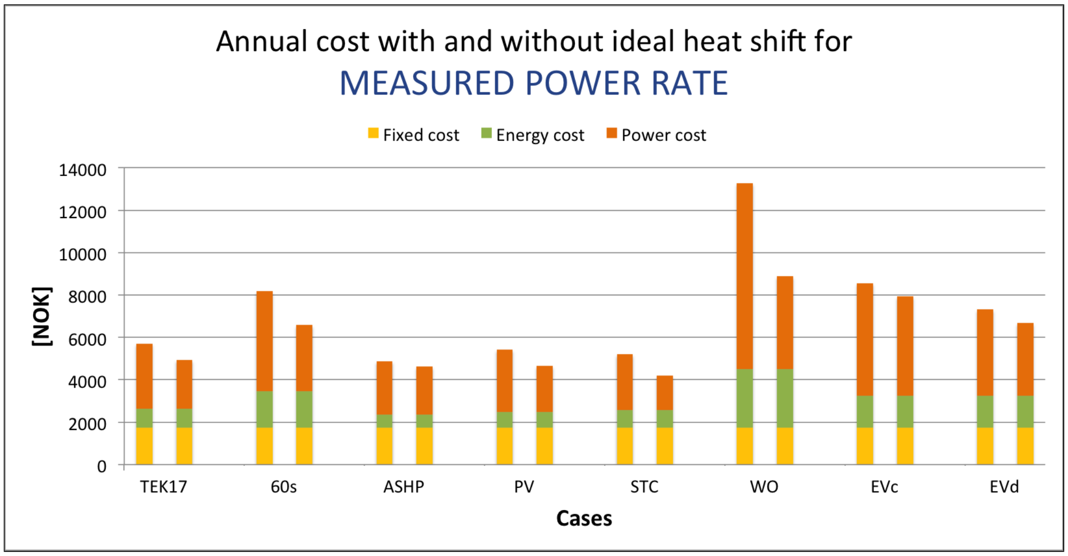


Figure 58: Annual cost with and without ideal heat shift for Measured power rate.

For the Tiered rate the cost division can be seen in Figure 59. The fixed cost is the same for all cases. The energy cost vary, but it is a small part of the total bill. This means that reducing energy demand without changing power limit will not significantly affect the energy bill. The largest part of the bill is the subscription limit cost. The cost vary with different limits, and the optimal limit is different for each case. The optimal limit is the limit which for a certain demand profile gives the lowest cost. See Figure 60 for a visualisation of the optimisation of limits for the reference cases TEK17 and WO. The last part of the total cost is the overuse cost. This part is for most cases a quite small amount of the total bill, and it is the part of the cost that can be affected by heat load shift. The amount of power drain is what will affect the energy bill the most.

From the case with occupants window openings in Figure 60 it appears that if there where more limits, a higher limit could give less overuse and a lower total cost for this case. For households with very high demand, 10 limits are not enough. If the next step is 15 kW off 20 kW the cost for this building will still be higher than necessary compared to other buildings. This can work as an incentive to reduce the demand for these buildings with a large power drain, but can also create unfair high cost for the households that are already paying a large bill.

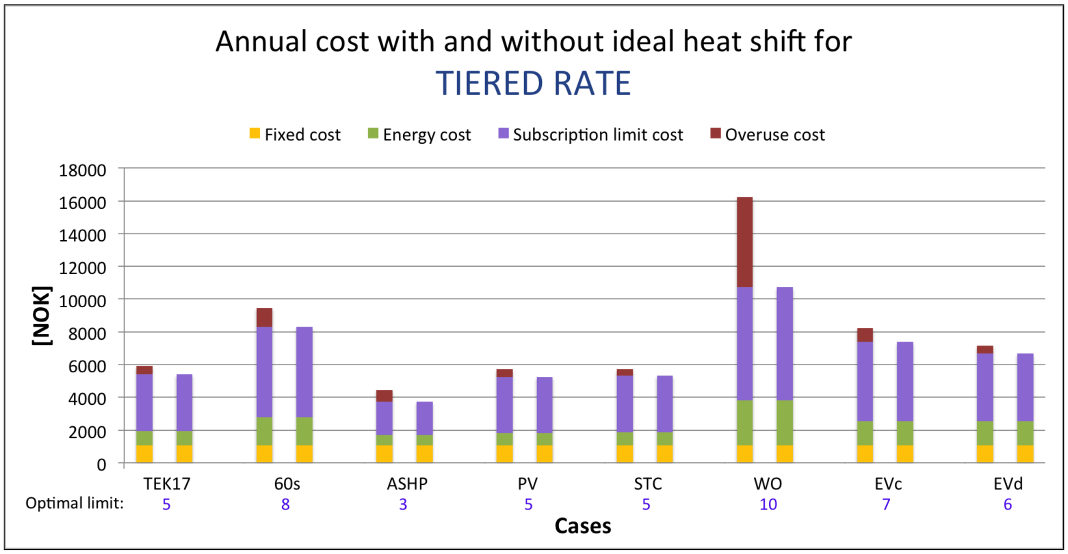


Figure 59: Annual cost with and without ideal heat shift for Tiered rate.

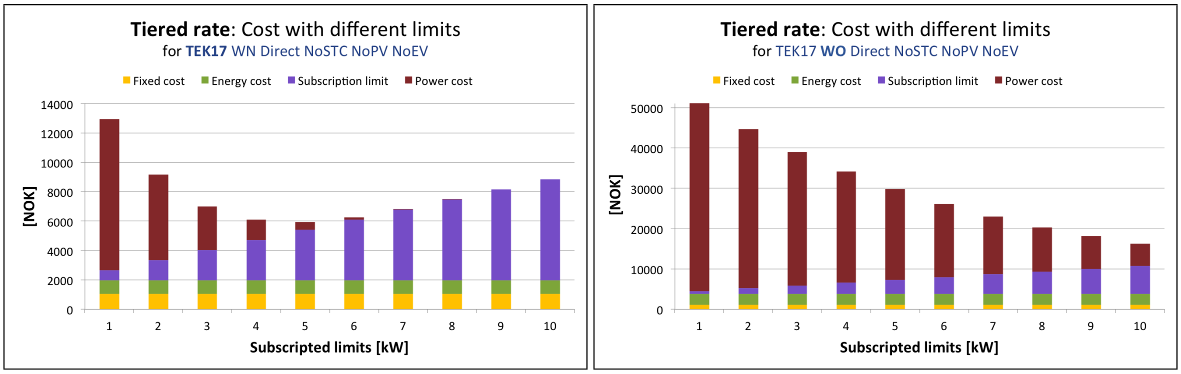


Figure 60: Cost with different Tiered rate limits for two buildings cases.

For Time of use the fixed cost is also the same for all the cases. The three other parts are all different energy costs with pricing according to time of use. Without shift the largest part of the bill is due to the energy cost for winter day. This is the time of use with highest cost per kWh. With ideal heat shift the energy demand is shifted from winter day to winter night, which has a lower cost per kWh. The part of energy cost winter day decrease, and the part of energy cost winter night increase. As the cost for winter night is lower, the total cost will decrease.

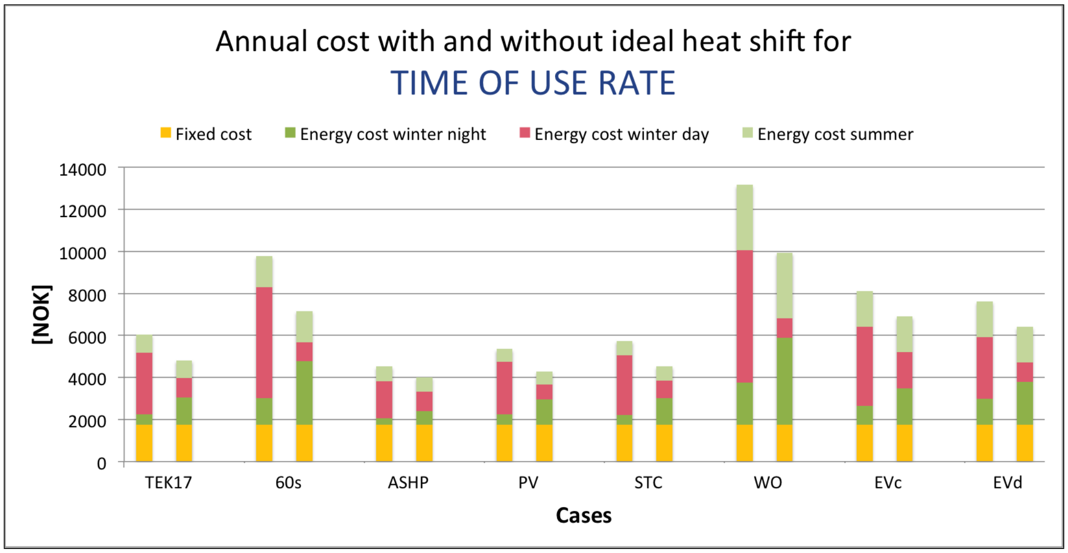


Figure 61: Annual cost with and without ideal heat shift for Time of use rate.

In Figure 62 the cost for grid rent with the different business models is compared for the reference building. The cost is shown for each tariff with and without ideal heat shift. For the case without heat shift all the new tariffs leads to a higher cost than Energy rate. With ideal shift the Measured power rate and Time of use rate has a lower cost than Energy rate, while Tiered rate is still high.

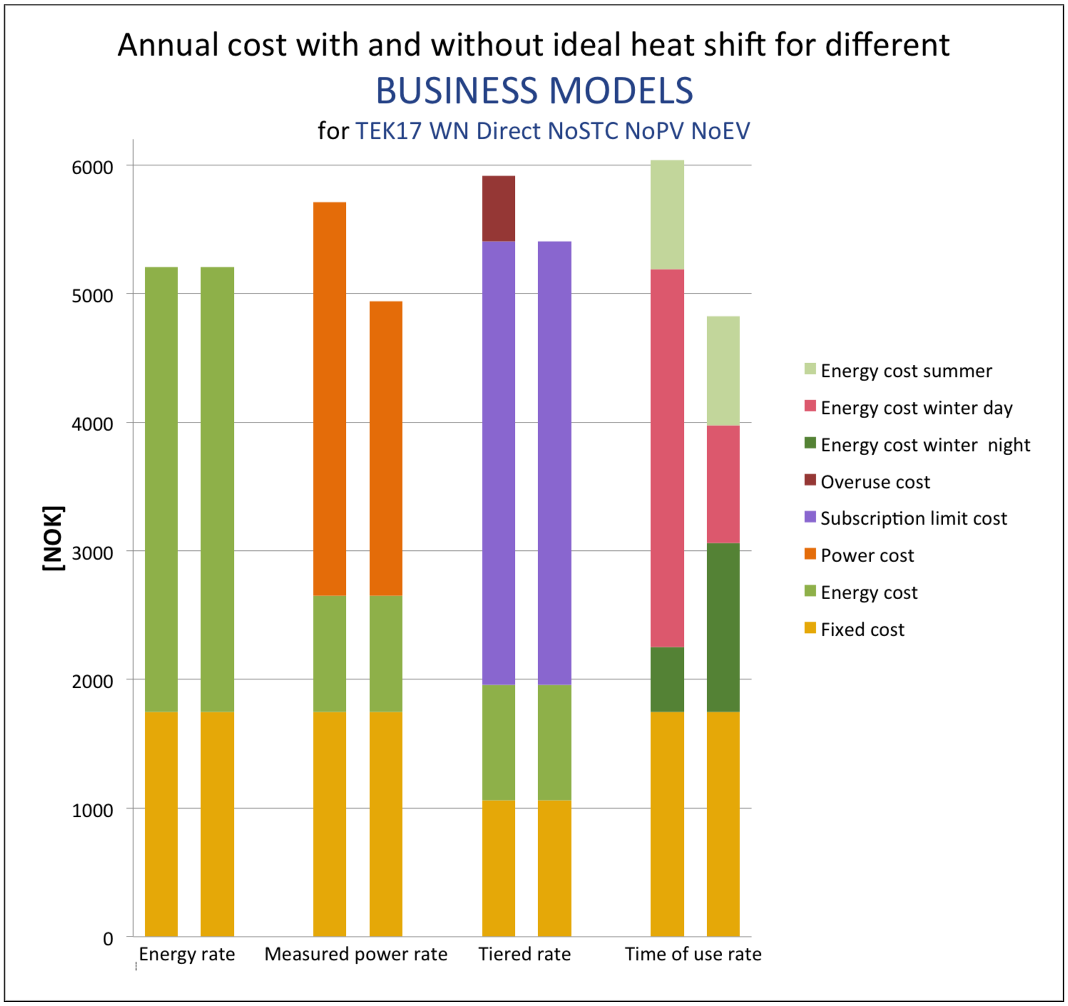


Figure 62: Comparing the cost with different business models with and without idea heat shift, for the reference model TEK17 WN Direct NoSTC NoPV NoEV.

5.8.2 Daily ideal heat shift

As the profile of ideal heat shift is different for each business models, the amount of heat that needs to be shifted to achieve the cost reduction is also different. A higher amount of heat shift requires a larger storage, and will make the cost reduction less achievable. In Figure 63 the maximum daily storage capacity that is needed to daily shift the heat necessary to obtain the highest possible cost reduction is illustrated for each business model. The heat shift for the energy rate is zero.

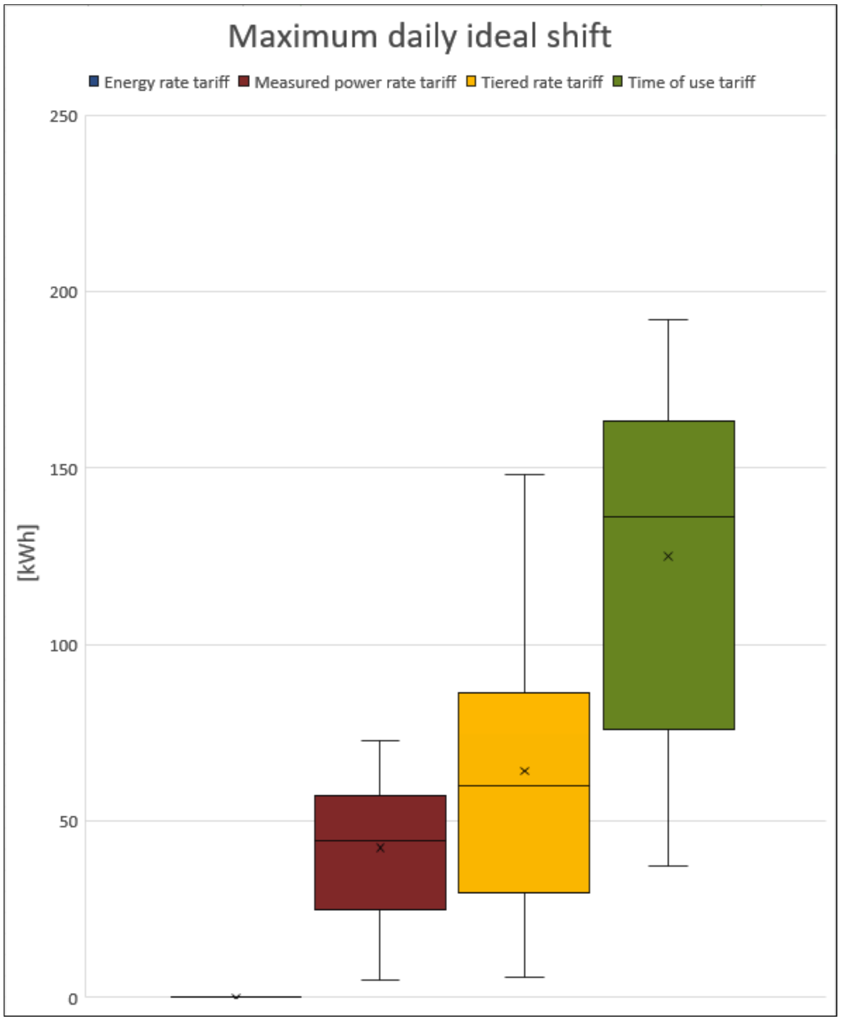


Figure 63: Box plot for maximum daily ideal heat shift.

Each business model has a different pattern for the optimal load shift, and the amount shifted and cost reduced is different for each case. The saving per kWh shifted heat is therefore also unlike for each tariffs, and this saving is plotted in Figure 64.

The Figure reveals that the amount of saving is 0 NOK/kWh for the Energy rate, as the cost is not affected by load shift. For the Tiered rate the saving is constantly 1 NOK/kWh. As the price for overuse is 1 NOK/kWh, is is logic that every kWh of reduced overuse will save this same amount of money.

The Measured power rate has a range of different savings per kWh for the cases. The reason for this variation is the difference in shape of the peaks. High, short peaks will give large cost saving per kWh, while low, wide peaks will give a low saving per kWh. The business model works very well for cost reduction for cases with large power difference between peak and off-peak hours. There are a few cases with even higher saving per kWh than for Tiered rate. These are the cases with a very high demand, which have a subscription cost limit of 10 kW, but could be better off with a higher limit. They have a large amount of overuse that is available for shift. If there were more limits in the tariff these cases would have a lower amount of overuse, less shifted heat, and a lower saving per kWh.

The Time of use tariff has the smallest saving per kWh. As the heat is shifted from winter day with the cost of 0.380 NOK/kWh, to winter night with 0.152 NOK/kWh the saving is equal and constant to the difference of 0.228 NOK/kWh.

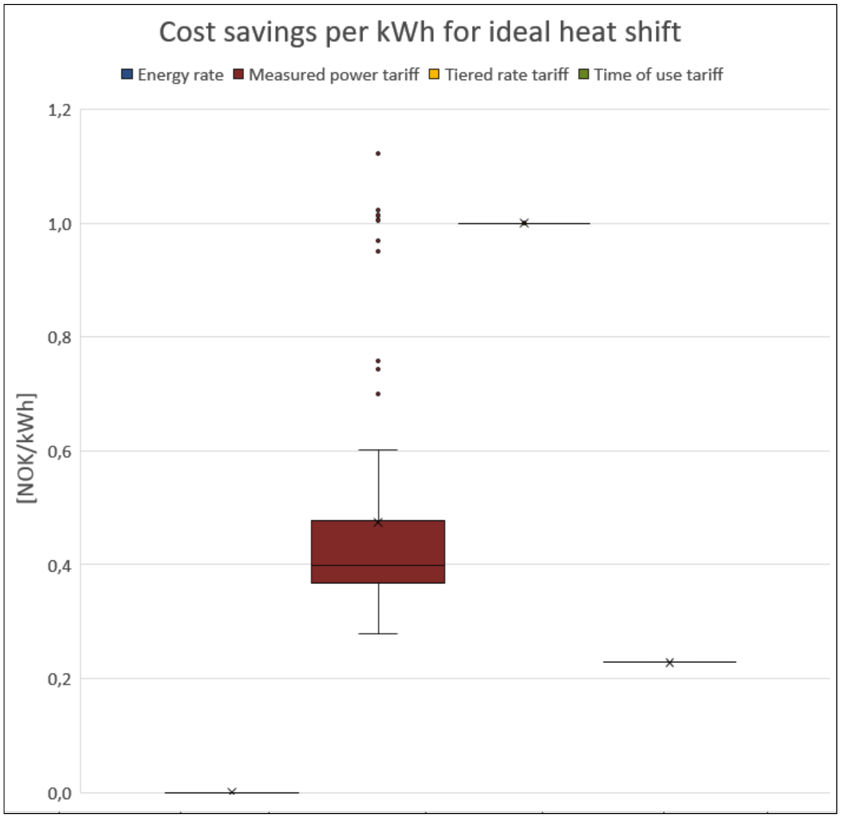


Figure 64: Box plot for the cost saving per kWh with ideal heat shift.

5.9 Robustness

The robustness of a model reflects how strong it is. The more robust the business model is, the smaller the range of the cost between the cases. The robustness of the business models for different building design with and without shift is illustrated in the plots in Figure 65. In this plot the standard deviation is plotted against the median cost.

The plots reveal that without heat shift the Measured power tariff and the Time of use tariff has about the same standard deviation as the Energy rate tariff, while the Tiered rate has a very high standard deviation. With heat shift most cases for all the three tariffs gets a standard deviation lower than the Energy rate. The most robust model is for most cases the Measured power rate. The median cost also decreases for all models with heat shift. This indicates that the business models will work as an incentive to load shift.

5.9.1 Measured power tariff

For most cases with shift The Measured power tariff is the tariff with the lowest cost, and for some cases also the lowest standard deviation. Without shift the standard deviation is often smaller than for Energy rate, but always with a higher cost.

For ASHP with heat shift, all PV, STC and EV cases, Measured power rate is the tariff with the lowest standard deviation and cost. When STC is implemented for cases with heat shift the cost decrease more for Measured power rate than for the other models, but the standard deviation increases slightly.

5.9.2 Tiered rate tariff

The Tiered rate tariff does in general improve a lot in standard deviation with heat shift. For cases with higher demand the improvement in standard deviation and cost is larger. For instance, including heat shift for envelopes have a larger improvement in standard deviation and cost for the ’60s house cases than for the TEK17 cases. The same goes for heating system, window openings, and EV charging.

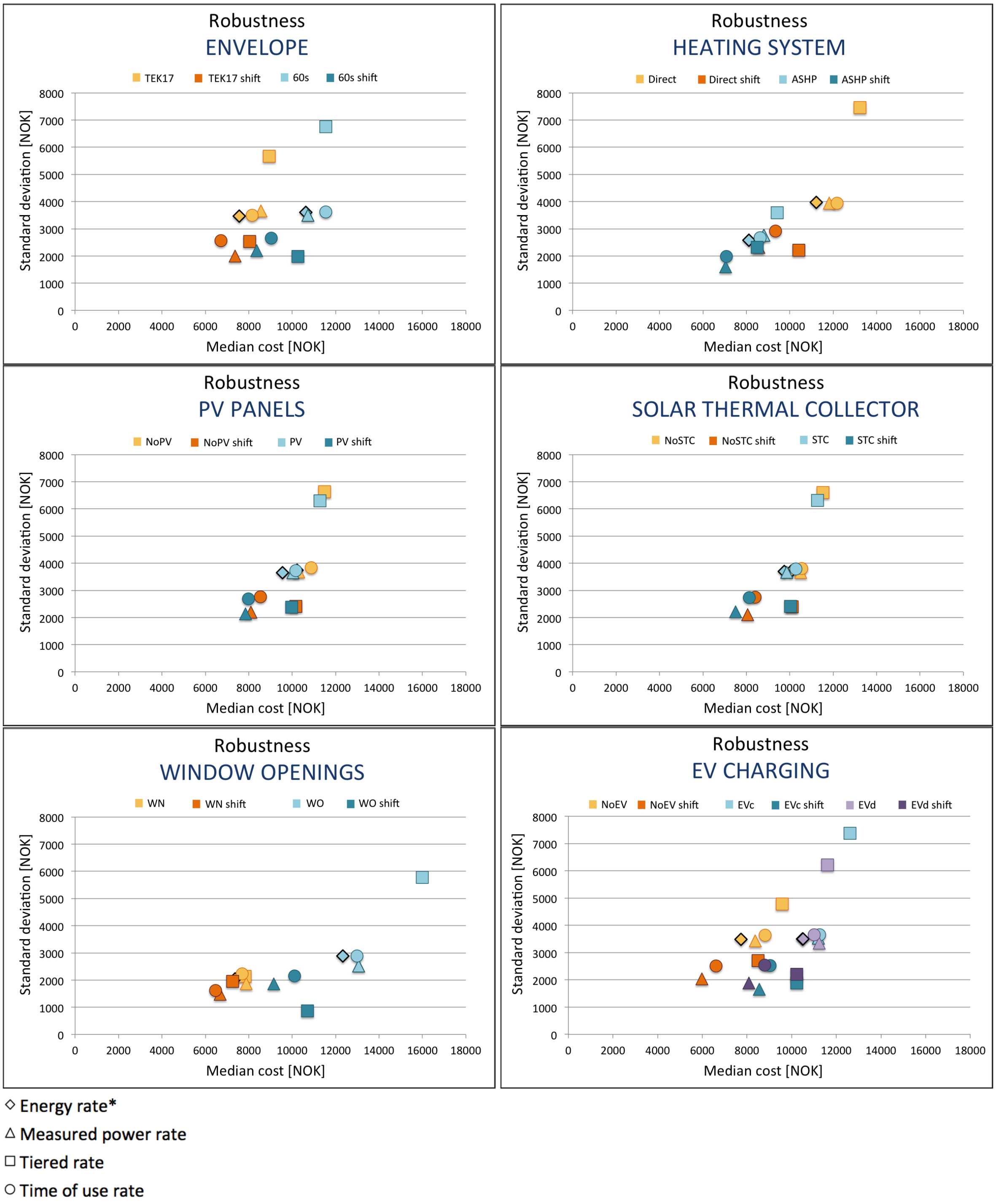


Figure 65: Robustness of the business models for different building designs, with and without ideal heat shift. *The Energy rate have no ideal heat shift, and the cost and standard deviation will be the same with and without any shift.

For implementation of PV, the Tiered rate shows larger improvement in standard deviation for the cases without heat shift. This is due to the face that the heat is usually shifted from the day, and in the calculation algorithm the heat shift happens without considering the production from the PV. A more accurate calculation would be to use as much PV as possible and then shift what is left of the heat demand. In that way less energy would be exported to the grid, and the PV would have a better effect also on the cases with heat shift.

For EV charging the standard deviation is improving hugely for typical charging when heat shift is implemented. The improvement is larger for typical charging than for delayed charging. This is due to the fact that without heat shift typical charging have a higher evening peak than delayed, which gives a higher cost and standard deviation. But including heat shift results in a higher heat shift for the cases with typical charging, and both groups end up with the same median cost.

Without heat shift Tiered rate tariff has the largest standard deviation, and the highest cost for most cases. But the tariff has the biggest change in robustness with heat shift. The standard deviation with heat shift is usually in between the values for Measured power and Time of use tariffs. It also has quite a large improvement in cost, but is still usually the tariff with the highest cost, also when the heat is shifted.

5.9.3 Time of use tariff

Time of use is normally very close to the Energy rate in standard deviation for cases without heat shift, and with a slightly higher cost. The time of use tariff is with heat shift improved to be better than Energy rate, but for most cases have a higher standard deviation than both Measured power and Tiered rates with shift. The cost is better than Energy and Tiered rate. For TEK17 envelope, direct electric heating system and temperature controlled window openings, the TOU rate have a lower cost than Measured power tariff.

For implementation of PV panels the Time of use tariff gives a larger decrease in cost than for the other two models.

5.10 Achievability

How well a model is achieving the aim of the project depends on the cost difference before and after ideal heat shift, and the amount of heat that needs to be shifted to obtain this cost reduction. If a very high amount of heat needs to be shifted, a large storage tank or battery is needed, and it is more difficult to achieve the full cost reduction. Also, if the cost reduction is low, the probability that people will invest in a system to shift heat is less.

In the following graphs in Figure 66 the load shift and cost for each of the groups, with and without shift, is plotted to illustrate the trade off for each of the groups. For all of the models without ideal heat shift the price is higher than with shift. Usually the Energy rate is the cheapest model without shift. This means that for any of the models introduced, this will for most customers mean an increased grid rent if they do not change their load profile. This itself will be an incentive to change the profile.

5.10.1 Measured power tariff

The Measured power tariff needs, in general, a low heat shift to obtain the ideal cost saving. For most cases the annual cost for the Measured power rate with ideal heat shift is lower that the price with Energy rate.

For the TEK17 envelope with ideal heat shift the Measured power tariff has a higher cost than Time of use tariff, and slightly higher ideal heat shift than Tiered rate tariff. For the ’60s envelope and the other five building designs Measured power tariff is clearly the model which has the highest achievability to obtain the cost reduction for the customer. The model needs the smallest amount of daily heat shift and with ideal heat shift it reaches the lowest or equal annual cost compared to the other models.

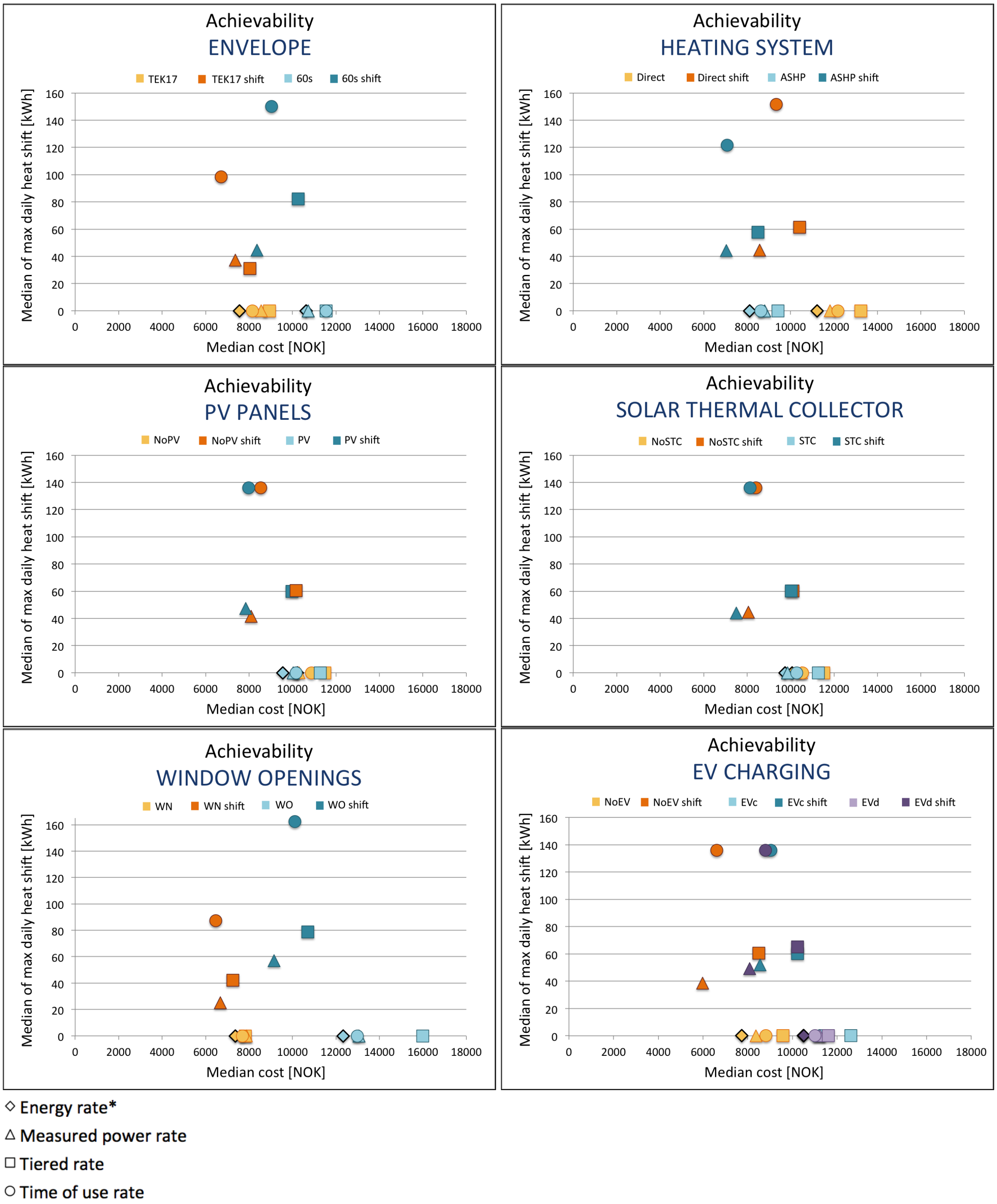


Figure 66: Achievability of the business models for different building design, with and without ideal heat shift. *The Energy rate have no ideal heat shift, and the cost will be the same with and without whatever shift.

5.10.2 Tiered rate tariff

The Tiered rate tariff has for most cases the highest cost, both with and without ideal heat shift. For some cases the possible cost saving is quite large, with an ideal heat shifting a bit higher than for Measured power rate. Even though the cost with shift is not lower than for Measured power rate, the incentive to shift load is higher with this model, and the cost without shift is highest for most cases. For some cases the cost even after heat shift will not reach below the cost with Energy rate. This means that the total income of the grid distribution companies will be higher with Tiered rate than with today's Energy rate, even with a large shift in the demand profile. One of the goals for the model is to ensure correct allocation of the grid expenses amongst the users. The survey on these cases indicates that this model creates a higher average cost amongst the users than the energy rate does today.

It is important to remember that the Tiered rate tariff has several limits. The ideal heat shift in these plots include only the overuse within the limit optimal for the case without shift. This means that the customer could change limit and increase the heat shift, and further increase the saving. If a household reduce their limit one step, and shift the ideal amount of demand according to this step, they save 689 NOK a year, due to the saving of the subscription limit cost. In the achievability plots, the cost difference between the cases with shift for Measured power rate and Tiered rate can be found to vary between 683 NOK and 2505 NOK, with an average of 1839 NOK. This means that to achieve similar low cost as for Measured power rate, the the households have to decrease their limit with an average of almost 3 steps to reach the same cost as for the Measured power rate. The ideal heat shift necessary to maintain all demand below the chosen limit will for most cases be higher than what is physically possible without reducing the demand. Figure 67 illustrates the amount of kWh left available for shift provided that the household reduce their limit with one step below the optimal limit. Consequently, choosing a lower limit will for most cases result in an overuse cost even with a high amount of heat shift. The total cost will then still be higher than for Measured power rate, and the amount of necessary heat shift a lot larger.

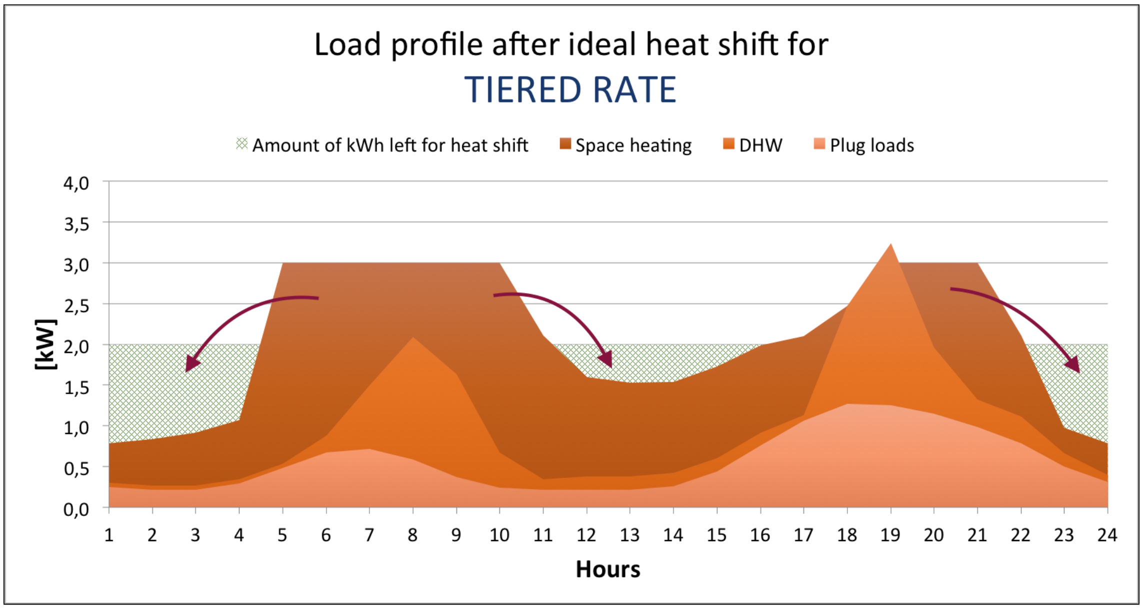


Figure 67: Amount of kWh available for heat shift if a lower power limit is chosen for the reference case TEK17 WN Direct NoSTC NoPV NoEV.

5.10.3 Time of use tariff

The Time of use (TOU) tariff has in all cases the largest ideal heat shift, 2-4 times larger than for Measured power rate. With heat shift TEK17 envelope have a lower cost for TOU rate than for both Measured power rate and Tiered rate. For all other cases with heat shift the cost is lower than for Tiered rate and higher than for Measured power rate. This makes the TOU rate less achievable for reaching the ideal cost reduction than both of the other two models. It is also an important issue that large shifting of electricity load can potentially also create stress on the grid.

6 Discussion

6.1 Tariffs

6.1.1 Measured power rate

From the results we see that for the Measured power rate the daily amount of shift is small, and the saving for each kWh is varying largely. This tariff gives incentive to shift load at all hours, all year. This gives a large annual amount of load shift, even though the daily amount is small. The cost reduction is achievable with a smaller sized storage device than for the other business models, but load shift during summer is not necessary to improve the peak power hours which stress the grid. Load shift during summer can still be wanted due to reasons such as matching the demand with supply from renewable energy sources. But in that situation a flat demand profile is most likely not the optimal solution, and a business model with flexibility would be a better tariff for this purpose.

To obtain the flat load profile ideal for the Measured power rate is almost impossible, as it is very difficult to predict when the load shift should occur during the day to create this profile. If the customer has access to their load data, they will be able to find patterns in their use, and reduce load at typical peak hours. Large reduction in peaks will be possible to obtain with this tariff, but the amount of savings presented from ideal heat shift here is higher than what can be expected. Also, if peaks occur at off-peak hours, the customer will be penalised for it with this tariff.

6.1.2 Tiered rate

For the Tiered rate the amount of heat shifted is low, but the cost incentive is very high. The hours which get incentive to shift load is random, but for customers with a typical consumption pattern the incentive will usually occur during peak hours in winter. For power use below the limit there is no incentive for load shift.

For customers with a typical pattern the tariff gives a very good, and precise incentive to reduce the load during high demand periods. As the overuse cost is very high per kWh, and will make a huge impact on the energy bill, it is likely that more households will take action to change their load profile with this tariff, than with the other tariffs where the penalty is smaller per kWh. If many households are able to shift their peaks slightly, this change can be enough for the grid. A disadvantage is that for those who are not able to shift their load the payment will be very large. And, also for this model customers using a high amount of energy during off-peak hours will pay extra, even though there is no stress on the grid at this time.

Tiered rate tariff is easy to react to, and the subscription limit gives a clear picture for the end-consumer of what high energy consumption is for the individual household. Keeping the consumption below the limit for Tiered rate is easier than keeping a totally flat demand profile as for Measured power tariff. Choosing the right limit may however be more difficult.

6.1.3 Time of Use rate

The Time of use tariff gives incentive to shift a large amount of load, but the incentive per kWh is quite small. The model encourages shift only during those hours which strain the capacity of the grid, and all load during those hours have incentive to be shifted. Time of use is the model with the easiest prediction of when to shift the load, as the hours when load should be avoided is clearly defined. No penalty is given if a large amount of load is used during off-peak hours.

6.2 Research questions

The statements in the following discussion of the research questions are based on the comparison in the attached Excel document *Case_comparison.xlsx*, see also Appendix B.

6.2.1 Which business model gives the largest economical incentive to improve building physics?

The largest economical incentive refers to the largest decrease in cost when an aspect of the building physics have been improved.

Improvement of building physics like improved envelope or heating system can reduce the amount of energy demand while the indoor comfort is maintained or even improved. Improved envelope gives the largest cost reduction with TOU tariff for most of the cases. Implementation of ASHP has the highest incentive with Tiered rate tariff for most cases. Both improvement in envelope and heating system have the lowest incentive with Measured power rate.

Utilisation of solar resources can decrease the demand from the grid. Implementation of STC has the largest reduction in both cost and standard deviation with Measured power rate. While PV panels have the largest cost reduction with Time of use, Tiered rate gives the poorest cost reduction for both PV and STC.

Demand-side management like controlling of windows and delay of EV charging can reduce the demand peaks and cost. Temperature controlled windows and delayed charging have both the largest incentive with Tiered rate tariff, and the lowest with Measured power tariff.

The largest economical incentive to improve building physics given by the business models depends on how the the improvement changes the load profile of the building. If reduced demand is the most important, TOU tariff gives the largest incentive. If peak reduction by control systems in the buildings is important Tiered rate tariff gives the largest incentive. Measured power tariff does not give the better incentive for improvement in building physics.

6.2.2 Which business model gives the largest economical incentive to load shift?

Load shift is profitable for the customer if the saving in grid rent cost is higher than the cost of installations in the house. Load shift is profitable for the grid if the stress on the grid is reduced, and kept below the maximum capacity. Load shift for the production and supply companies is profitable if the demand is increased to match the supply from inflexible, renewable energy sources.

The largest potential for cost reduction with heat shift in buildings is obtained with Tiered rate. However, Tiered rate also has the highest total cost both with and without heat shift. The cost is especially large for the customers without possibility to reduce or shift their demand with improved building physics. The amount of ideal heat shift is in between the amount for the other two tariffs, and the size of storage accordingly. The cost saving per kWh is the largest, which means that this model has the largest incentive for shift of each kWh, and a larger incentive to install a smaller storage.

Measured power rate has the lowest cost for the cases with ideal heat shift, but the cost reduction obtained when introducing heat shift is less than for Tiered rate. Measured power tariff has the smallest maximum of daily ideal shift, so amongst the tariffs the storage capacity needed is the least. But even so, the heat is shifted all day, all year, and the system needs an advanced control system to obtain the ideal shift. Measured power has potential for the lowest total cost with heat shift, and the highest potential for cost reduction with delayed charging of electrical vehicles.

The TOU tariff is the tariff which has the largest amount of potential load shift. This creates a large potential for reduction in grid strain, but a large storage tank would be necessary for the customers to obtain the ideal cost reduction with heat shift. The ideal cost saving is therefore less achievable with a TOU tariff. Although, the tariff encourages shift only in the hours with stress on the grid capacity, and all load during those hours have incentive to be shifted. This is a strength with the model.

The best incentive to load shift given by the business models, depends on how it will be most profitable to shift the load, and how large of an amount is necessary to shift. If a large amount of demand needs to be shifted to lessen the strain on the grid, TOU tariff will be the preferred model. If the goal is to reduce only a smaller amount, but with a higher certainty, the Tiered rate tariff is more accurate. Some stakeholders point out that only a few hours a year have a high strain on the grid. Tiered rate and TOU tariffs are moving the load more accurately at those hours with stress than the Measured power tariff. Measured power tariff gives the customers the lowest total cost. Tiered rate tariff gives the largest incentive per kWh to move load. TOU tariff gives incentive to move the largest amount of load.

6.2.3 Which business model is financially the best for the end-user?

The results from the cases surveyed indicates that Tiered rate creates a higher average cost amongst the customers than what the energy rate does today. This means that Tiered rate tariff does not ensure a fair cost division, as is one of the goals. The tariff has a high administration cost and time, but the increase in income for the grid distribution companies could cover these expenses. However, the increase in cost and administration for the customers will not result in high customer satisfaction.

Both Measured power and TOU tariff have administration costs and time similar to today's Energy tariff, as all customers have the same subscription and no interaction between customers and grid distribution companies is necessary. Without heat shift both tariffs have a cost a bit higher than for the Energy rate. With heat shift the cost is for most cases a bit lower. With heat shift, the lowest cost and highest robustness is obtained with the Measured power rate. TOU tariff has a slightly higher cost, which may give an aggregated income closer to the Energy tariff to the companies. This is important as their income needs to be secured for the business model to be sufficient. However, whether the grid distribution expenses will be covered by any of these two tariffs need further research, including the probability of how many customers will shift their load and contribute to a decrease in income.

Without heat shift, TOU tariff is the model which for most cases have the lowest annual cost, and the fewest cases with highest cost. Tiered rate tariff has most cases with the highest annual cost, and fewest cases with the lowest cost. With ideal heat shift, Measured power tariff is the model which for most cases have the lowest annual cost, and the fewest cases with highest cost. Tiered rate tariff has most cases with the highest annual cost, and fewest cases with the lowest cost. For the end-consumer, Tiered rate is not the ideal model, being most expensive for the larger part of all cases. TOU and Measured power tariff is for most cases in the same range, and both have the lowest cost for many cases.

6.2.4 Which business model makes the ideal heat shift most achievable for the consumer?

A model needs to be easily understood, predicted and reacted to, and the amount of load shift has to be within the range of the storage device implemented, to be achievable. The smaller the load shift necessary, the smaller storage device is needed, and the more achievable the ideal heat shift is for the consumer.

The easiest model to understand is the TOU tariff, as it only consist of energy cost (kWh), not power. The Tiered rate consist of many parts, and both

Measured power and Tiered rate needs some explanation to be fully understood by the customers. Regarding which model is easiest to react to, TOU is the easiest model to both predict and react to, even in advance, and to reduce energy in those hours with highest cost. Overuse is not so easy to predict with the Tiered rate tariff, but it is easy to react to it in the moment of overuse. Measured power rate is very difficult to predict, and it is not easy to obtain the ideal demand profile. According to amount of storage needed, TOU needs the largest storage capacity, and Measured power tariff the smallest, to obtain the ideal cost reduction due to ideal heat shift. Time of use and Tiered rate are both less achievable than Measured power rate.

To make the tariff able to achieve the goal of the tariff change, there is also some other aims it needs to fulfil. The goals of the tariff change is to decrease the future grid investments, and allow for better utilisation of renewable energy sources. Future grid investments are avoided with an efficient use of the grid. The load shift needs to create an aggregated load profile that is beneficial for the grid capacity. The tariff should also help customers to take good choices when it comes to energy and power use. All these goals also needs to be taken into account in further research, to investigate which model on an aggregated level will result in the preferred demand profile on the grid.

6.3 Weaknesses of the model

The lack of consideration of excess production from the PV is a clear shortcoming of this calculation algorithm, and an area for improvement.

The model could also drive benefit from being more automated. Easier connections to input and output from the excel workbooks could decrease the number of operations needed to do changes in the workbooks.

7 Conclusion

To be able to answer the research questions a new algorithm had to be made, as no tool able to run the calculations was found. The algorithm had to be able to calculate the total annual cost for different building load profiles due to each four business models, both with and without ideal heat load shift. The algorithm also needed to calculate the according amount of annual and daily heat load shift necessary to obtain the ideal cost reduction. Idealistic, it would be generic, so it could also be used in further work concerning energy rates and load shift in buildings. This algorithm have been developed.

The algorithm have been used to investigate the grid rent cost for 96 different cases, due to combinations of 13 different parameters of building physics design. The cost of each case with and without ideal heat shift, in a Norwegian context, have been investigated for the four different business models. In this thesis the annual cost data from the algorithm have been used to answer the research questions. However, there is still lots of information in the outputs that could be analysed further, and used for further research. New cases can also be investigated with the algorithm.

The main conclusion from these case calculations is that an implementation of any of the suggested power tariffs will increase the grid rent for customers whom continue to use electricity with the typical consumption pattern of today. Improvements in building physics reduce the cost, but only with heat load shift are the models able to reach an annual cost lower than for the Energy rate tariff. This indicates that all models will work as incentives to load shift and a change in consumption pattern.

7.1 Which business model give the largest economical incentive to improve building physics?

Table 14 presents the business models that give the largest, and smallest, incentive for most cases with each of the building physics improvements.

Table 14: Business models giving the largest and smallest economical incentive to improve building physics.

			Business model	
From	→	**To**	**Largest incentive**	**Smallest incentive**
’60s	→	TEK17	TOU tariff	Measured power tariff
Direct	→	ASHP	Tiered rate tariff	Measured power tariff
NoPV	→	PV	TOU tariff	Tiered rate tariff
NoSTC	→	STC	Measured power tariff	Tiered rate tariff
OOW	→	TCW	Tiered rate tariff	Measured power tariff
EVc	→	EVd	Tiered rate tariff	Measured power tariff

7.2 Which business model gives the largest economical incentive to load shift?

The tariffs with the largest, and smallest, cost reduction when heat load shift is implemented in the cases is illustrated in Table 15. For most cases Measured power tariff and TOU tariff is giving the largest economical incentives. Tiered rate tariff is for most cases the tariff giving the smallest economical incentive to shift.

Table 15: Business models giving the largest economical incentive to shift heat load.

	Business model	
Parameter	**Largest incentive**	**Smallest incentive**
TEK17	TOU tariff	Tiered rate tariff
’60s	TOU tariff	Tiered rate tariff
Direct	Measured power tariff	Tiered rate tariff
ASHP	Measured power tariff	Tiered rate tariff
NoPV	TOU tariff	Tiered rate tariff
PV	TOU tariff	Tiered rate tariff
NoSTC	Measured power tariff	Tiered rate tariff
STC	Measured power tariff	Tiered rate tariff
OOW	Tiered rate tariff	TOU tariff
TCW	TOU tariff	Tiered rate tariff
EVc	Measured power tariff	TOU tariff
EVd	Measured power tariff	Tiered rate tariff

7.3 Which business model is financially the best for the end-user?

Looking at all the cases, the tariffs which for most cases give the lowest and the highest annual cost is shown in Table 16.

Table 16: Business models with the lowest and highest total cost for the end-user.

	Without load shift	**With ideal heat shift**
Lowest total cost	TOU tariff	Measured power tariff
Highest total cost	Tiered tariff	Tiered tariff

7.4 Which business model make the ideal heat shift most achievable for the consumer?

Table 17 illustrate the rating of the tariff models according to the designated measures for achievability.

Table 17: Business models according to the different criteria for achievable of ideal heat shift.

	1st	**2nd**	**3rd**
Understandable	TOU tariff	Measured power tariff	Tiered rate tariff
Predictable	TOU tariff	Tiered rate tariff	Measured power tariff
Reactable	TOU tariff	Tiered rate tariff	Measured power rate
Storage capacity	Tiered rate tariff	Measured power tariff	TOU tariff
Cost saving per kWh	Tiered rate tariff	Measured power tariff	TOU tariff

8 Future work

The result from this investigation could be basis many more analysis than those included in this thesis. Also, the algorithm could be used for investigation of new cases.

Several areas will need further investigation. Amongst these are:

- Storage possibilities: What kinds of storage is available, and which ones give the smallest losses and highest cost reduction? What size of capacity will be necessary for different buildings? How many hours is the heat load needed to be shifted?
- Aggregated load shift: A survey of how aggregated load shift for different models will change the grid load profile, the strain on the grid, and the income for grid distribution companies, are important factors when deciding on a tariff that should be the next step to investigate.
- Flexibility: For renewable energy sources like wind and solar power to be a large part of the energy supply on the grid, it is an absolute necessity to incorporate flexibility into the grid. The development of a flexible business model, that can include a third party operator to handle the flexibility, needs more investigation. The new grid rent tariff would benefit from having taken this issues into account before deciding.
- Excess PV production: Investigation of what is most profitable for excess PV production - exporting to the grid, implementing a battery, or implementing a control system to match supply and demand.
- Building cases: A broader building spectre need to be investigated to be able to research which tariff model is the better for the whole building stock, not only single family houses.

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A Attachment I: Excel workbook Tariff_computation_template.xlsm

The Excel algorithm for calculating tariff cost and load shift for each case is attached as the Excel workbook *Tariff_computation_template.xlsm*, shown in Figure 68.

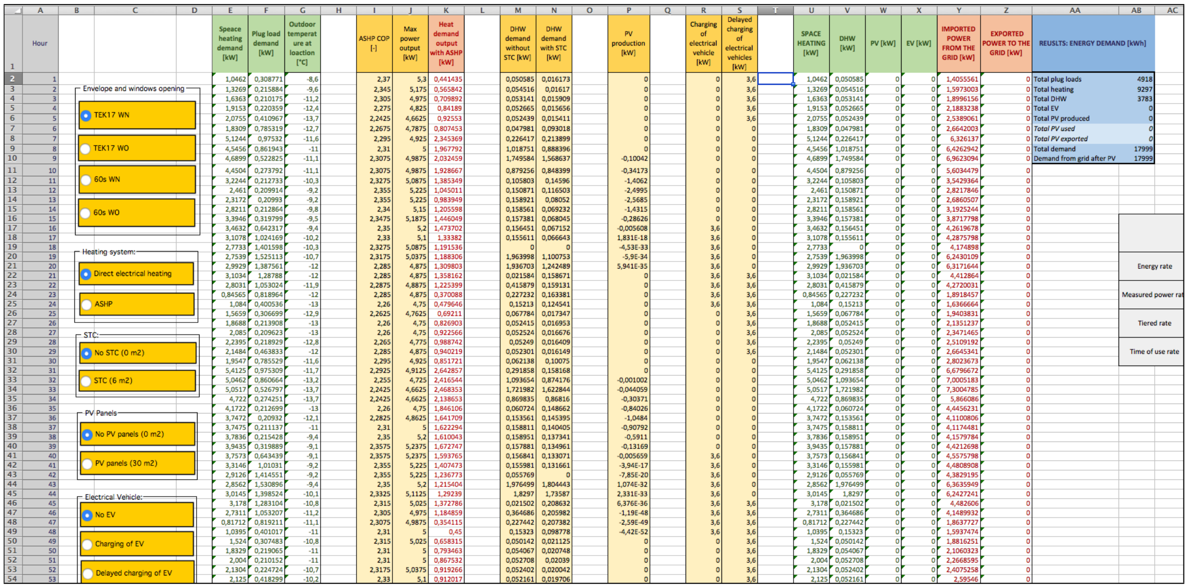


Figure 68: The Excel workbook for the tariff computation.

When the workbook is opened, you will be asked if you want to deactivate the macros in the workbook. To make the algorithm work, choose to activate the macros, see Figure 69.

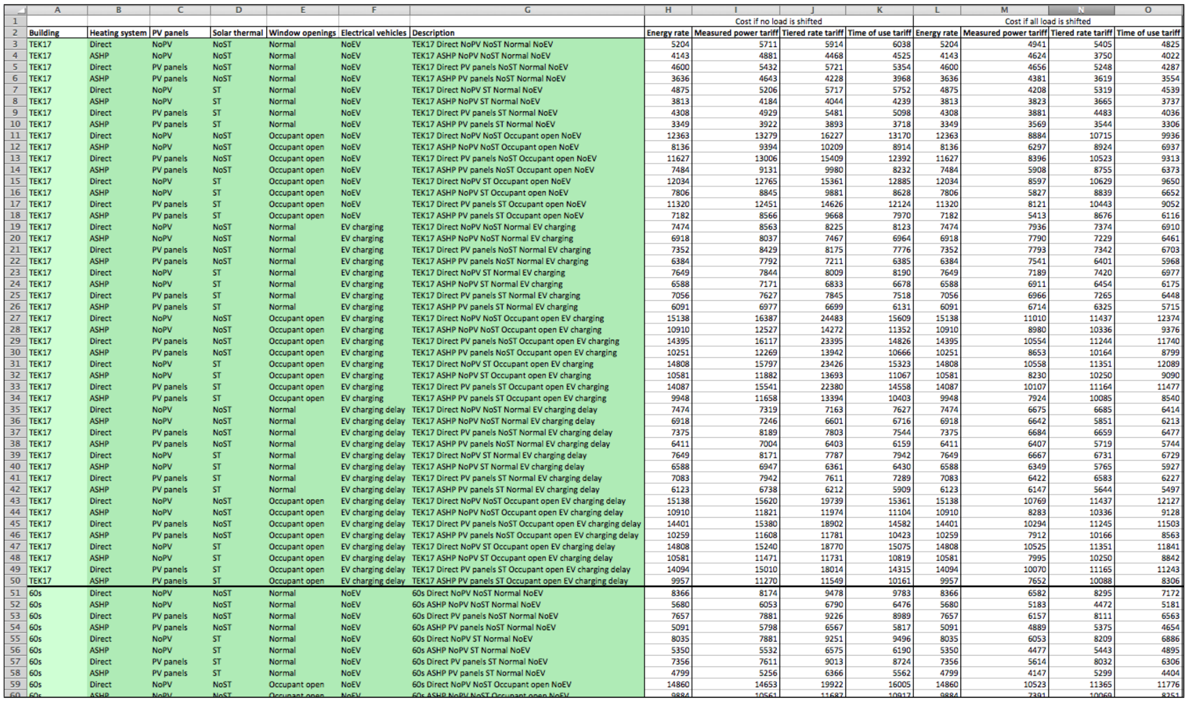
Denne arbeidsbok inneholder makroer. Vil du deaktivere makroer før du åpner filen?

Makroer kan inneholde virus som er skadelige for datamaskinen. Klikk Aktiver makroer hvis filen kommer fra en klarert kilde. Klikk Deaktiver makroer hvis du ikke stoler på kilden.

Figure 69: When you open the workbook, you need to activate the macros.

B Attachment II: Excel workbook Case_comparison.xlsx

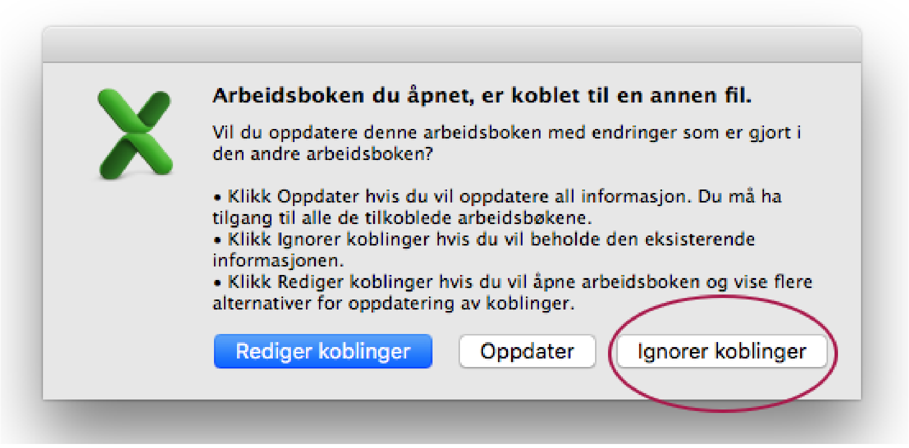
The Excel algorithm for comparing the cases is attached as the Excel workbook *Case_comparison.xlsx*, shown in Figure 70.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1								Cost if no load is shifted				Cost if all load is shifted			
2	Building	Heating system	PV panels	Solar thermal	Window openings	Electrical vehicles	Description	Energy rate	Measured power tariff	Tiered rate tariff	Time of use tariff	Energy rate	Measured power tariff	Tiered rate tariff	Time of use tariff
3	TEK17	Direct	NoPV	NoST	Normal	NoEV	TEK17 Direct NoPV NoST Normal NoEV	5204	5711	5914	6038	5204	4941	5405	4825
4	TEK17	ASHP	NoPV	NoST	Normal	NoEV	TEK17 ASHP NoPV NoST Normal NoEV	4143	4881	4468	4525	4143	4624	3750	4022
5	TEK17	Direct	PV panels	NoST	Normal	NoEV	TEK17 Direct PV panels NoST Normal NoEV	4600	5432	5721	5354	4600	4656	5248	4287
6	TEK17	ASHP	PV panels	NoST	Normal	NoEV	TEK17 ASHP PV panels NoST Normal NoEV	3636	4643	4228	3968	3636	4381	3619	3554
7	TEK17	Direct	NoPV	ST	Normal	NoEV	TEK17 Direct NoPV ST Normal NoEV	4875	5206	5717	5752	4875	4208	5319	4539
8	TEK17	ASHP	NoPV	ST	Normal	NoEV	TEK17 ASHP NoPV ST Normal NoEV	3813	4184	4044	4239	3813	3823	3665	3737
9	TEK17	Direct	PV panels	ST	Normal	NoEV	TEK17 Direct PV panels ST Normal NoEV	4308	4929	5481	5098	4308	3881	4483	4036
10	TEK17	ASHP	PV panels	ST	Normal	NoEV	TEK17 ASHP PV panels ST Normal NoEV	3349	3922	3893	3718	3349	3569	3544	3306
11	TEK17	Direct	NoPV	NoST	Occupant open	NoEV	TEK17 Direct NoPV NoST Occupant open NoEV	12363	13279	16227	13170	12363	8884	10715	9936
12	TEK17	ASHP	NoPV	NoST	Occupant open	NoEV	TEK17 ASHP NoPV NoST Occupant open NoEV	8136	9394	10209	8914	8136	6297	8924	6937
13	TEK17	Direct	PV panels	NoST	Occupant open	NoEV	TEK17 Direct PV panels NoST Occupant open NoEV	11627	13006	15409	12392	11627	8396	10523	9313
14	TEK17	ASHP	PV panels	NoST	Occupant open	NoEV	TEK17 ASHP PV panels NoST Occupant open NoEV	7484	9131	9980	8232	7484	5908	8755	6373
15	TEK17	Direct	NoPV	ST	Occupant open	NoEV	TEK17 Direct NoPV ST Occupant open NoEV	12034	12765	15361	12885	12034	8597	10629	9650
16	TEK17	ASHP	NoPV	ST	Occupant open	NoEV	TEK17 ASHP NoPV ST Occupant open NoEV	7806	8845	9881	8628	7806	5827	8839	6652
17	TEK17	Direct	PV panels	ST	Occupant open	NoEV	TEK17 Direct PV panels ST Occupant open NoEV	11320	12451	14626	12124	11320	8121	10443	9052
18	TEK17	ASHP	PV panels	ST	Occupant open	NoEV	TEK17 ASHP PV panels ST Occupant open NoEV	7182	8566	9668	7970	7182	5413	8676	6116
19	TEK17	Direct	NoPV	NoST	Normal	EV charging	TEK17 Direct NoPV NoST Normal EV charging	7474	8563	8225	8123	7474	7936	7374	6910
20	TEK17	ASHP	NoPV	NoST	Normal	EV charging	TEK17 ASHP NoPV NoST Normal EV charging	6918	8037	7467	6964	6918	7790	7229	6461
21	TEK17	Direct	PV panels	NoST	Normal	EV charging	TEK17 Direct PV panels NoST Normal EV charging	7352	8429	8175	7776	7352	7793	7342	6703
22	TEK17	ASHP	PV panels	NoST	Normal	EV charging	TEK17 ASHP PV panels NoST Normal EV charging	6384	7792	7211	6385	6384	7541	6401	5968
23	TEK17	Direct	NoPV	ST	Normal	EV charging	TEK17 Direct NoPV ST Normal EV charging	7649	7844	8009	8190	7649	7189	7420	6977
24	TEK17	ASHP	NoPV	ST	Normal	EV charging	TEK17 ASHP NoPV ST Normal EV charging	6588	7171	6833	6678	6588	6911	6454	6175
25	TEK17	Direct	PV panels	ST	Normal	EV charging	TEK17 Direct PV panels ST Normal EV charging	7056	7627	7845	7518	7056	6966	7265	6448
26	TEK17	ASHP	PV panels	ST	Normal	EV charging	TEK17 ASHP PV panels ST Normal EV charging	6091	6977	6699	6131	6091	6714	6325	5715
27	TEK17	Direct	NoPV	NoST	Occupant open	EV charging	TEK17 Direct NoPV NoST Occupant open EV charging	15138	16387	24483	15609	15138	11010	11437	12374
28	TEK17	ASHP	NoPV	NoST	Occupant open	EV charging	TEK17 ASHP NoPV NoST Occupant open EV charging	10910	12527	14272	11352	10910	8980	10336	9376
29	TEK17	Direct	PV panels	NoST	Occupant open	EV charging	TEK17 Direct PV panels NoST Occupant open EV charging	14395	16117	23395	14826	14395	10554	11244	11740
30	TEK17	ASHP	PV panels	NoST	Occupant open	EV charging	TEK17 ASHP PV panels NoST Occupant open EV charging	10251	12269	13942	10666	10251	8653	10164	8799
31	TEK17	Direct	NoPV	ST	Occupant open	EV charging	TEK17 Direct NoPV ST Occupant open EV charging	14808	15797	23426	15323	14808	10558	11351	12089
32	TEK17	ASHP	NoPV	ST	Occupant open	EV charging	TEK17 ASHP NoPV ST Occupant open EV charging	10581	11882	13693	11067	10581	8230	10250	9090
33	TEK17	Direct	PV panels	ST	Occupant open	EV charging	TEK17 Direct PV panels ST Occupant open EV charging	14087	15541	22380	14558	14087	10107	11164	11477
34	TEK17	ASHP	PV panels	ST	Occupant open	EV charging	TEK17 ASHP PV panels ST Occupant open EV charging	9948	11658	13394	10403	9948	7924	10085	8540
35	TEK17	Direct	NoPV	NoST	Normal	EV charging delay	TEK17 Direct NoPV NoST Normal EV charging delay	7474	7319	7163	7627	7474	6675	6685	6414
36	TEK17	ASHP	NoPV	NoST	Normal	EV charging delay	TEK17 ASHP NoPV NoST Normal EV charging delay	6918	7246	6601	6716	6918	6642	5851	6213
37	TEK17	Direct	PV panels	NoST	Normal	EV charging delay	TEK17 Direct PV panels NoST Normal EV charging delay	7375	8189	7803	7544	7375	6684	6659	6477
38	TEK17	ASHP	PV panels	NoST	Normal	EV charging delay	TEK17 ASHP PV panels NoST Normal EV charging delay	6411	7004	6403	6159	6411	6407	5719	5744
39	TEK17	Direct	NoPV	ST	Normal	EV charging delay	TEK17 Direct NoPV ST Normal EV charging delay	7649	8171	7787	7942	7649	6667	6731	6729
40	TEK17	ASHP	NoPV	ST	Normal	EV charging delay	TEK17 ASHP NoPV ST Normal EV charging delay	6588	6947	6361	6430	6588	6349	5765	5927
41	TEK17	Direct	PV panels	ST	Normal	EV charging delay	TEK17 Direct PV panels ST Normal EV charging delay	7083	7942	7611	7289	7083	6422	6583	6227
42	TEK17	ASHP	PV panels	ST	Normal	EV charging delay	TEK17 ASHP PV panels ST Normal EV charging delay	6123	6738	6212	5909	6123	6147	5644	5497
43	TEK17	Direct	NoPV	NoST	Occupant open	EV charging delay	TEK17 Direct NoPV NoST Occupant open EV charging delay	15138	15620	19739	15361	15138	10769	11437	12127
44	TEK17	ASHP	NoPV	NoST	Occupant open	EV charging delay	TEK17 ASHP NoPV NoST Occupant open EV charging delay	10910	11821	11974	11104	10910	8283	10336	9128
45	TEK17	Direct	PV panels	NoST	Occupant open	EV charging delay	TEK17 Direct PV panels NoST Occupant open EV charging delay	14401	15380	18902	14582	14401	10294	11245	11503
46	TEK17	ASHP	PV panels	NoST	Occupant open	EV charging delay	TEK17 ASHP PV panels NoST Occupant open EV charging delay	10259	11608	11781	10423	10259	7912	10166	8563
47	TEK17	Direct	NoPV	ST	Occupant open	EV charging delay	TEK17 Direct NoPV ST Occupant open EV charging delay	14808	15240	18770	15075	14808	10525	11351	11841
48	TEK17	ASHP	NoPV	ST	Occupant open	EV charging delay	TEK17 ASHP NoPV ST Occupant open EV charging delay	10581	11471	11731	10819	10581	7995	10250	8842
49	TEK17	Direct	PV panels	ST	Occupant open	EV charging delay	TEK17 Direct PV panels ST Occupant open EV charging delay	14094	15010	18014	14315	14094	10070	11165	11243
50	TEK17	ASHP	PV panels	ST	Occupant open	EV charging delay	TEK17 ASHP PV panels ST Occupant open EV charging delay	9957	11270	11549	10161	9957	7652	10088	8306
51	60s	Direct	NoPV	NoST	Normal	NoEV	60s Direct NoPV NoST Normal NoEV	8366	8174	9478	9783	8366	6582	8295	7172
52	60s	ASHP	NoPV	NoST	Normal	NoEV	60s ASHP NoPV NoST Normal NoEV	5680	6053	6790	6476	5680	5183	4472	5181
53	60s	Direct	PV panels	NoST	Normal	NoEV	60s Direct PV panels NoST Normal NoEV	7657	7881	9226	8989	7657	6157	8111	6563
54	60s	ASHP	PV panels	NoST	Normal	NoEV	60s ASHP PV panels NoST Normal NoEV	5091	5798	6567	5817	5091	4889	5375	4654
55	60s	Direct	NoPV	ST	Normal	NoEV	60s Direct NoPV ST Normal NoEV	8035	7881	9251	9496	8035	6053	8209	6886
56	60s	ASHP	NoPV	ST	Normal	NoEV	60s ASHP NoPV ST Normal NoEV	5350	5532	6575	6190	5350	4477	5443	4895
57	60s	Direct	PV panels	ST	Normal	NoEV	60s Direct PV panels ST Normal NoEV	7356	7611	9013	8724	7356	5614	8032	6306
58	60s	ASHP	PV panels	ST	Normal	NoEV	60s ASHP PV panels ST Normal NoEV	4799	5256	6366	5562	4799	4147	5299	4404
59	60s	Direct	NoPV	NoST	Occupant open	NoEV	60s Direct NoPV NoST Occupant open NoEV	14860	14653	19922	16005	14860	10523	11365	11776
60	60s	ASHP	NoPV	NoST	Occupant open	NoEV	60s ASHP NoPV NoST Occupant open NoEV	9884	10561	11687	10917	9884	7391	10069	8251

Figure 70: The Excel workbook for the case comparison.

When the workbook is opened, you will be asked if you want to edit the links in the workbook. If you do not have all the files that are coupled to the workbook available, you can choose to ignore the links, see Figure 71. The workbook will then open with the values from when the links was last updated. As there is 96 documents attached to this workbook, you will have to go through all of these 96 links if you choose *Edit links*. This will take some time, and is therefor not recommended. If you do want to edit some of the links, this can always be done when the document is opened.



Arbeidsboken du åpnet, er koblet til en annen fil.

Vil du oppdatere denne arbeidsboken med endringer som er gjort i den andre arbeidsboken?

- Klikk Oppdater hvis du vil oppdatere all informasjon. Du må ha tilgang til alle de tilkoblede arbeidsbøkene.
- Klikk Ignorer koblinger hvis du vil beholde den eksisterende informasjonen.
- Klikk Rediger koblinger hvis du vil åpne arbeidsboken og vise flere alternativer for oppdatering av koblinger.

Figure 71: When you open the workbook, choose to ignore the links.