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Cost gain of implementing load shifting in residential buildings

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Master's in Business Administration
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Abstract

There is a clear trend today that we use more and more appliances with a higher power demand, something that is a real challenge for the electricity grid. Also, the shift towards electrification of the transport system gives a high volatility in consumption of electricity which is reflected in the distribution grid. Traditionally, the power distribution companies reinvest in grid upgrades to handle the increase in peak load demand. However, another alternative (short/midterm) solution to this problem is creating incentives to the customers to change their consumption patterns.

This thesis investigates whether it is possible to control the use of household devices in order to reduce the electricity costs, and whether this process is economically feasible for the end users. To achieve this goal, a series of different grid tariff models were tested against real consumption patterns of buildings of different types.

The results show that “Observed power” and “Subscribed power” tariff models compare to other studied models induce higher financial incentive to end-users to change their consumption behavior. In addition, the use of storage units and local solar production is another alternative to further increase the flexibility in Norwegian households.

Abbreviations

AMS	Advanced Metering Infrastructure
ASM	Ancillary Services Market
BEV	Battery Electric Vehicle
CK	Cooking
CL	Cooling
CM	Capacity Market
CPP	Critical Peak Pricing
d	Day of year
DBB	Demand Bidding/Buyback
DLC	Direct Load Control
DR	Demand response
DSO	Distribution System Operator
DSR	Demand Side Response
EDR	Emergency Demand Response
EUR	Euro
EV	Electric Vehicle
GAMS	Optimization software
GDP	Gross domestic product
GWh	Gigawatt hour
Homer Grid	Energy management software
hr	Hour
ICS	Interruptible/Curtailable Service
ICT	Information and Communication Technologies
IFE	Institutt for energiteknikk
JIP	Justert innmatingsprofil
kV	Kilovolt
kWh	Kilowatt hour
L	Lighting
LCOE	Levelised Cost of Energy
M	Media
m	Cost per kW of subscription
MWh	Megawatt hour
NASDAQ	National Association of Securities Dealers Automated Quotations
NOK/kr	Norwegian Krone
NVE	Norwegian Water Resources and Energy Directorate
PHEV	Plug-in Hybrid Vehicle
P_{high}	(kr/kWh/day)
Phyton	Programming software
P_{low}	Variable cost of grid tariff
P_{summer}	Summer time price
PV	Photovoltaic modules (solar power)

$P\alpha=0$	Winter off-peak price
$P\alpha=1$	Winter peak hour price
Q	Peak-Consumption off-peak time without batteries
Q'	Peak-Consumption off-peak time with batteries
Q'off	Consumption off-peak time with batteries
$Q_{d,t}$	Electricity spot price (kr/kWh)
Qoff	Consumption off-peak time without batteries
RTP	Real Time Pricing
S.el	Small electric appliances
SH	Space heating
SSB	Statistics Norway
t	Time of day
TIMES	The Integrated MARKAL EFOM System
ToU	Time of Use
TSO	Transmission System Operator
TWh	Tetra watt hour
TØI	Institute of Transport Economics
VAT	Value added taxes
Wa	Washing
$W_{d\,max}$	The highest hourly consumption per day
$W_{d,t}$	hourly power consumption(kWh)
$W_{d,t\,high}$	hourly consumption exceed subscription
WH	Water heater
ZEB	Zero Energy Buildings
β_A	(kr/year)
γ	size of subscription package (kWh/h)
η	Efficiency of battery
ΔQ	Stored amount of energy

Table of Contents

Tabel of figures

Tabels list

1. Introduction

Electricity is closely tied with all daily activities in an industrialised world. By raising the level of living standards, more technology has been introduced to our daily life and consequently the demand for electricity has been increasing. In order to respond to this demand more power plants and more infrastructure with higher power capacities would need to be built.

On one hand, consumers' increasing demand for electricity and particularly tendency to consume more power at certain periods of the day put pressure on distribution grid. According to Statnett, during a typical cold winter day just around 80% of the installed capacity of the grid is available (NVE, 2016) (IEA). While, the increase in using instant power consumer items such as induction cooktop and electric vehicles would deepen the capacity problem. The power grids are designed to deal with the highest level of electricity demand at peak times. But if the demand for power continues beyond the planned capacity, the distributor must make the expensive decision and upgrade the grid prior to its designed lifetime.

On the other hand, a major part of infrastructures and distribution networks in Norway are old and won't be able to deal with higher power demands in the future. Therefore, the distribution operator in Norway has considered upgrading the distribution and regional grid with an investment plan of 50-70 billion NOK for the next ten years Statnett (2013).

Over 75% of the electricity produced in Norway is regulated (flexible). According to a public report, on long-term power system analysis, the continuous development of peak demands in Norway either has to be covered by regulated production or electricity import in future .(Amundsen, Bartnes, & Øyslebø, 2017). The report also indicates that in the 2016 Nordic region would need 0.4 GW from unregulated production and imports to cover the consumption. It is estimated that the number will grow to 5.6 GW by 2030. This means that in the future the need for flexibility on the demand side will be greater than it is today.

All these resulted that grid operator in Norway is now considering implementing a series of capacity-based grid tariffs, in order to cover the costs of grid investment and also to reduce the grid investment. The new tariffs attempted to create incentive for end-users to reduce their electricity demands. In this report, we will study the economic effect of proposed tariffs on the end-users electricity bill. Also potential solution for reduction of electricity costs will be discussed. To achieve this goal the main drivers and elements behind the power consumption are studied in chapter 2. Theoretical background on demand response and features of the Norwegian power market are presented in chapter 3 before analysis of a case study on energy costs in chapter 5.

2. Theoretical background

2.1 Historical household energy consumption

Historical data from SSB in figure 2-1 shows a negative trend on power consumption on Norwegian household. The power consumption per household has reduced by 2000 kWh from 1930 to 2012. Although the consumption reaches a peak level of 18.5 GWh in 1995, it has been decreasing since. The significant decrease in power consumption in early 21century is probably related to low average temperature and low rainfall in those years. Which both two factors have amplified the increase in electricity price but also awaken the public incentive and focus on energy efficiency measures.

While the wood consumption for space heating has been almost constant over the last 20 years, there has been a high decrease in oil consumption in Norwegian households in recent years. According to NVE's (Norwegian Water Resources and Energy Directorate) estimation of future electricity usage, the tendency to replace fossil fuel products with electricity is expected to continue. The consumption of heating oil and paraffin in homes and commercial buildings, will eventually be phased out and much of this can be replaced by electricity and heat pumps (NVE, 2016a).

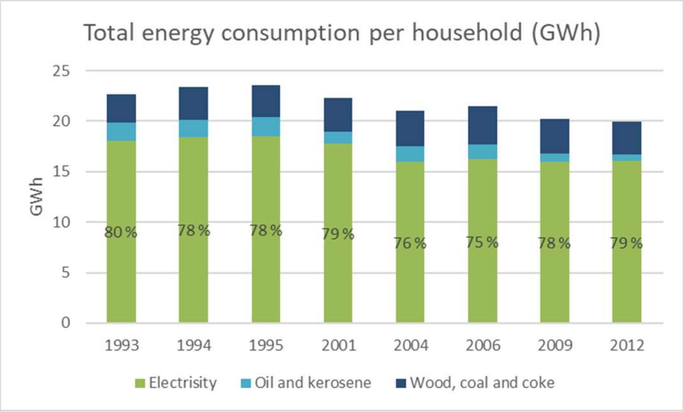

Figure 2-1 Historical average energy consumption per household by energy carrier and content

2.2 Energy drivers in buildings

The main driver used for projection of future energy in households is dwelling area (m^2). This is calculated by total population divided by the number of people per household times the area per household. Based on differences in energy use, households are divided into single-family and multi-family households, as well as existing and new homes (Rosenberg & Espegren, 2014).

2.2.1 Temperature

Electricity usage during the year is very volatile for the household sector in Norway. This is directly related to the outside temperature. SINTEF Energy and Enova have jointly conducted a research study on 100 Norwegian households as a part of a residential measurement campaign. The results from this study show that space heating and hot water contribute to roughly 80% of the power consumption (Grinden & Feilberg, 2009). The correlation between outside temperature and power consumption is evident in Figure 2-2. The figure shows total monthly power consumption in Norway from 2010 to 2017 and the average temperature for the same period. Comparison between weather data and power consumption also suggest that years with lower temperatures had higher peak power demand for the same period of the year.

In this study, weather data such as sunny hours, cloud coverage and wind are not included in estimation of the power consumption. However, these variables would probably affect the electricity demand for space heating and lighting.

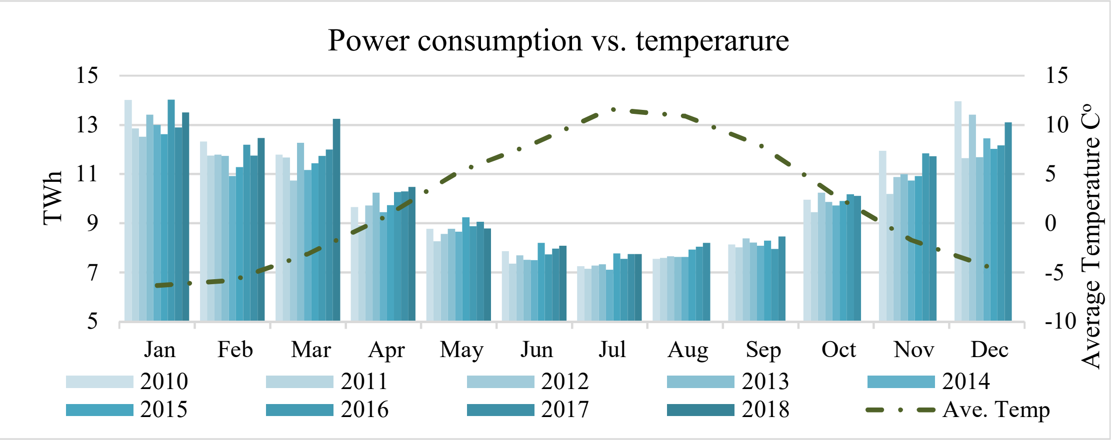

Figure 2-2 Correlation between temperature and total power consumption

2.2.2 Number of people per dwelling

A study carried out by (Amir Kavousian, Rajagopal, & Fischer, 2013) on over 1628 households, indicate that “the larger households have higher aggregated electricity consumption but lower per capita consumption”. They observed that when the number of occupants doubled electricity consumption increased at a slower rate. This is probably related to sharing space and costs related to space heating. In Norway the total average number of people living per dwelling has reduced from 3,27 in 1960 to 2,17 in 2018 (SSB, 2018b). Based on the current trend it would be expected that the number of person per dwelling would be further reduced to 2.15 in 2020 and 2.0 in 2040 (Rosenberg & Espegren, 2014).

Population growth

Population is an important indirect factor for the future energy demand. Population density per household affect the energy consumption and consumption pattern. This is with respect to temperatures in rooms, showering, use of power demanding items and in general consumer behaviour within the buildings. In case of increase in population and decrease in number of occupants per dwelling, the total number of households will increase. As the area per person increases, this would increase the overall consumption (Rosenberg & Espegren, 2014). However increased population per building could have either negative or positive effect on final energy efficiency. The combined effect depends on the behavior of the residents (Rosenberg & Espegren, 2014). The interaction between energy efficiency and behavior of residents is a complex matter and out of scope of this thesis/report.

In order to make estimations for the future energy demand we need to evaluate the population changes too. Statistics Norway (SSB) has made a population projection in 2018. The projection has studied the fertility rate, life expectancy and immigration as main variables and has presented the projection in three different scenarios; Medium/main alternative, High alternative and Low alternative. The other two alternatives are not relevant and disregarded (e.g. constant alternative and zero alternative). The population per Jan 2018 is 5.3 million, with fertility rate of 1.62. Population projections for the three main scenarios are shown in Figure 2-3 (SSB, 2018e). In the main alternative, the fertility rate will continue to decline for a few more years and will reach 1.6 in 2020 before it increases to around 1.8 in 2060. Today's life expectancy for new-born males is 81 years and for new-born women 84 years. In the main alternative, life expectancy is expected to continuously increase toward 88 for men and 90 for women. In the main alternative, it is expected that the net immigration declines from the current level of 21000, to 17000 in 2060 (Syse, Leknes, Løkken, & Tønnessen, 2018).

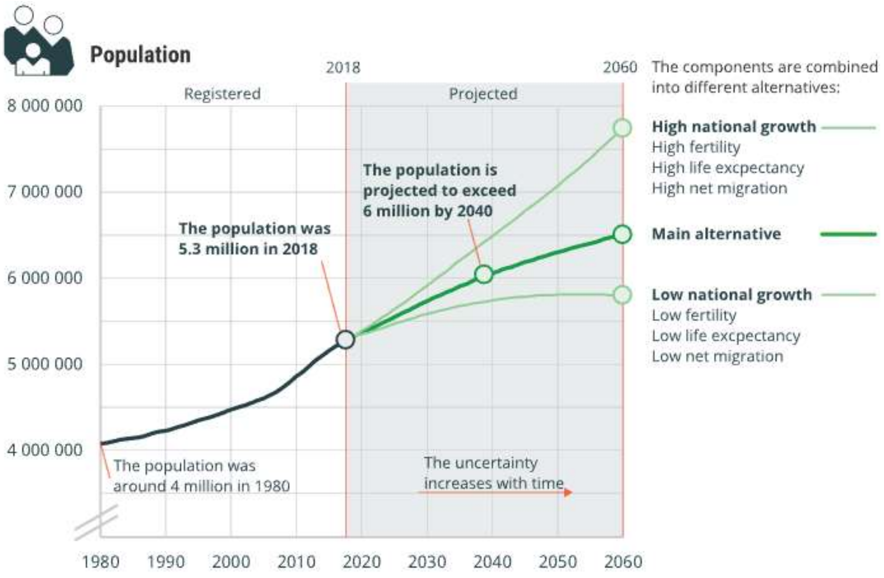

Figure 2-3 Population projections 2018-2060 (Source: SSB,2018c)

2.2.3 Energy consumption per floor area

Energy consumption per floor area has been decreasing during the last decades and has stabilised during the last years. This is probably due to more space utilization in buildings and stricter building standards. The statistic shows as the number of one person households has been increasing by four percent from 1993 to 2012 , the construction of large family houses (e.g. detached house and house with two dwellings) has decreased by 14 percent and apartment building was rising by 16% from 1991-2012 (SSB, 2011). Because of the reduction in average living area the energy consumption decreased similarly. While average energy consumption in detached houses and farm houses together decreased by 7% from 1995 to 2012, the average energy consumption in apartments have reduced by 14% (SSB, 2012a).

Regulatory requirements for energy efficiency

Authorities in Norway frequently define energy efficiency requirements for new building projects. This is in line with strategic planning in the longer horizon. For instance, all new building constructions or major refurbishments must comply with the newest standard (Tek17). This could be meeting limited values for either the total net energy consumption for space heating, cooling, and hot water or for individual building components (byggkvalitet, 2017; IEA, 2017a).

(Bergesen et al., 2012) conclude that standards for energy efficiency in buildings probably have a major impact on the energy demand of a residential area since the main portion of the energy need is used for space heating. The mentioned report has compared the energy demand for differenttechnical standards and therefore conclude that energy efficiency standards and new technical building regulations will provide a significant reduction in demand for space heating in Norwegian houses.

Tek17 is a step forward towards the goal of Zero energy buildings (ZEB) in 2020. The new standard is stricter than Tek 10 on building's total energy losses and allowed energy consumption per square meter. Furthermore, there are another set of legal standards specific for passive and low energy houses (NS3700), which has higher demands than Tek 10 and Tek17. Figure 2-4 (Andresen et al., 2010) shows the annual energy demand (kWh/m^2) for a typical building block, as a function of energy standard. The figure is illustrative for comparing energy demand for each standard code. For example, a low energy house (NS3700) has a total heat demand of roughly 40% of the corresponding heat demand for a

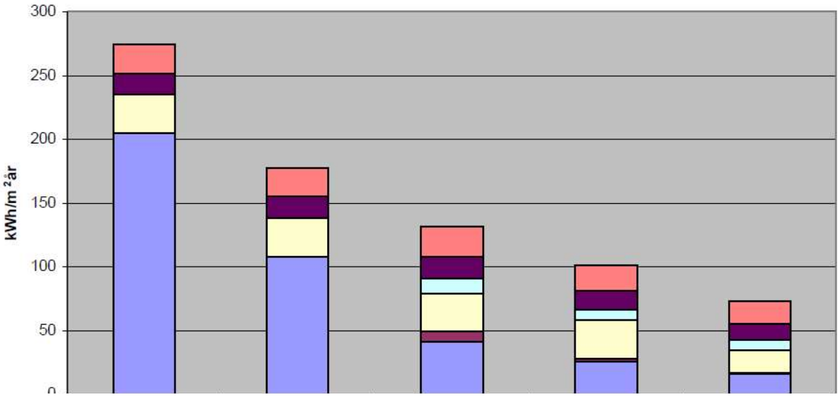

Figure 2-4 Average annual energy demand per m^2 by buildings standards (Andresen et al., 2010)

home built in accordance with the minimum requirements of 1997. The corresponding number for a passive house is equivalent to 25%.

Another requirement which affected the electricity consumption on residential buildings is the "fossil fuel ban". From 2016, new buildings requirements banned the installation of any fossil fuel heating in new buildings. In addition, the parliament also demanded the government to prepare the legislation of similar restriction on existing buildings on 2020 (IEA, 2017a).

The government has set out an ambitious energy efficiency target for reduction of energy intensity (energy consumption per GDP) by 30% and 10TWh energy consumption reduction in existing building by 2030 (IEA, 2017a). Therefore, it would be expected to observe a significant increase in buildings' energy efficiency in near future.

2.2.4 Buildings features

Norwegian residential buildings could be categories into 3 group: Detached houses, semi-detached or terraced houses and apartments. Which have shares of respectively 50%, 25% and 25% of total housing (SSB, 2019).

All new building construction and major renovations have to follow the national regulation. The quality of the buildings and structural factors has the largest impact on energy efficiency of the building (A. Kavousian, Rajagopal, & Fischer, 2015). Since a major part of energy in a household is used for space heating and hot water, the thermal mass of building, isolation on wall and windows can play an important role in energy efficiency of buildings. For example, studies shows that households equipped with double-pane window and efficient lightbulbs can increase the efficiency of buildings by 3.5 and 4 percent (A. Kavousian et al., 2015).

The energy efficency of Norwegian buildings is improving. Projections of the future building stock was carried out by (Lindberg, 2017), and illustrated in figure 2-5. In this projection she used the historic growth of building stock (categorized by technical standards Ch.3.2.3) and population and combining them with the official projections of the population growth from SSB. The figure suggests that not only the high standard buildings (green) will replace the old buildings stock (blue) but also the growth rate for new buildings projects would be higher in future and reach to share of 20% of the building stock on 2030.

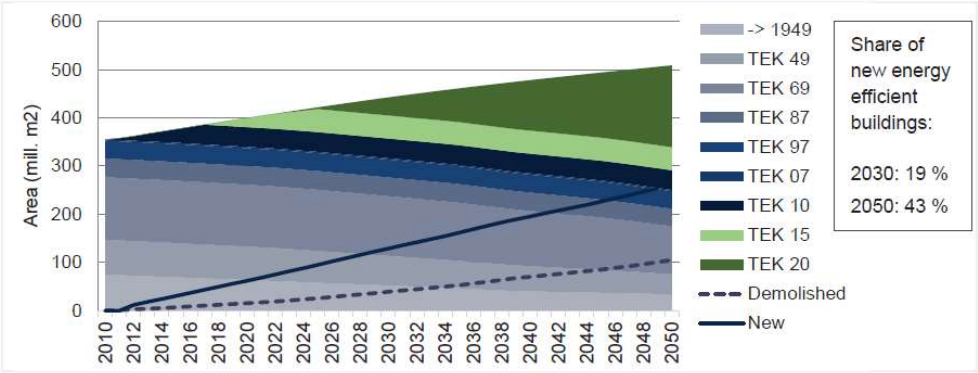

Figure 2-5 Projection of the Norwegian building stock by technical standard (Lindberg, 2017)

2.2.5 Human behavioural factor

Several studies have investigated the effect of consumer behaviour on energy consumption. Although behavioural factors and characteristics of occupants is not the most important factor for energy consumption, it has a significant effect on energy use. A study carried out in Netherland, showed that occupant behaviour and characteristic contribute to 4.2% of the variation in energy use for space heating (Guerra Santin, Itard, & Visscher, 2009). Several studies on consumers statistical power consumption data suggest that there are positive and significant correlations between energy consumption and socio-economic factors (e.g. occupant’s age, household type, education level, employment and ownership of house) (Guerra Santin et al., 2009; Amir Kavousian et al., 2013; A. Kavousian et al., 2015). A study carried out on electricity consumption of 1628 Irish households indicates that households of occupants with higher education are 1.3% more energy efficient (A. Kavousian et al., 2015). The study showed that families with kids are more energy efficient compared to single-person households. This is probably because they have full time job, higher education and spend more time outside compared to families with no kids, unemployment, retired or have care giver during day.

(Guerra Santin et al., 2009) Believe that the actual amount of energy used in buildings is often different from the estimated energy use. They discuss that due to conservation measures, energy savings will be lower than the calculated amount because the impact of consumer behaviour is often neglected in measurements.

Kavousian et al., also discuss that the residents' motivation and interest for making change towards energy-saving lifestyle is directly correlated to energy-saving behaviours. In addition, those who track their power consumption has been 0.4% more efficient compare to others. This shows a direct relation between consumer awareness and the power consumption. Therefore, higher efficiency would be achievable with educational program for consumers.

Despite the importance of price incentive measures for participation of consumers in demand response programs the role of consumer awareness cannot be neglected. A study carried out on low level income participants in Nicaragua, surprisingly shows that improved access to energy information had stronger effect than financial benefit from participation in a demand flexibility project (Ponce de Leon Barido, Suffian, Kammen, & Callaway, 2018).

2.3 Development of household energy demand

Institute for Energy and Technology (IFE) has carried out a projection on energy demand toward 2050 for all sectors (Rosenberg & Espegren, 2014). The report calculates the energy

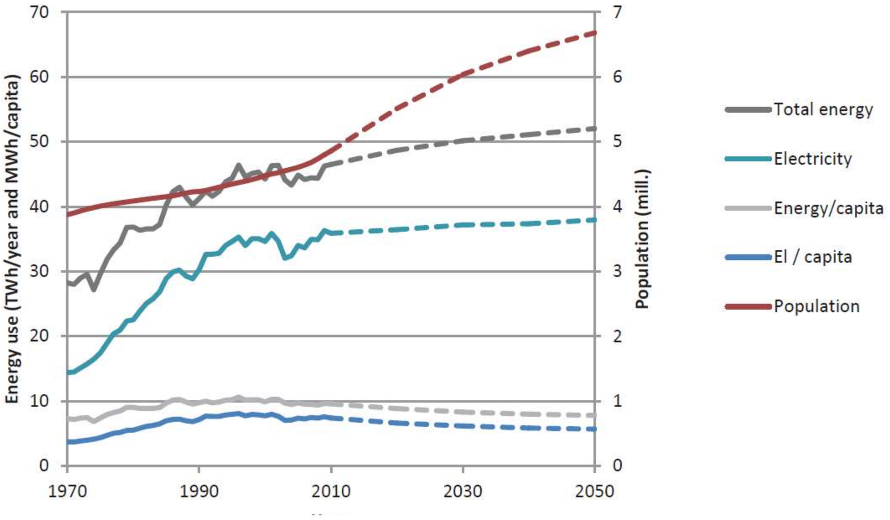

Figure 2-6 Development of residential total energy use and electricity use (TWh/year), energy and electricity use MWh per capita and population (mill.).source: (Rosenberg & Espegren, 2014)

demand for the entire household sector and per dwellings, floor areas and population.
The report estimated a significant decrease in energy demand for space heating for all the above categories. For instance, the energy demand per dwellings is expected to decrease from 12,1 MWh to 8,7MWh. This is probably due to low energy demand in both new and refurbished buildings. The energy demand for water heater and electric specific equipment will not have a significant change to all the studied categories (per dwellings, floor areas and population). While the energy demand for lighting will reduce by almost 50% until 2030 and remain steady afterward.

However, the total energy consumption will increase from 44TWh in 2010 to 52TWh in 2050 which 38TWh of this amount is electricity and 4.5TWh is related to ambient energy absorbed by heat pumps. The research also emphasizes in case of using energy efficiency measures it would be possible to further reduce the estimation by 6TWh. This could be investment in heat pumps for detached buildings, improving isolation, automation at home, energy labelling, etc.

2.4 Energy profile

2.4.1 Equipment and appliances

As discussed in chapter 2.2 the outside temperature and building's standard are critical factors for energy consumption especially during the winter. Electricity is the main energy carrier for space heating in Norwegian households. Space heating in average accounts for 64 -66% of the energy consumption in dwellings (Bergesen et al., 2012; Grinden & Feilberg, 2009) (See table 1). Therefore, due to a large share of electric heating in the total energy consumption, electricity consumption is very temperature dependent and high peak consumption can occur on cold winter days. One of the energy efficient space heating equipment is heat pump which fortunately has increasing trend in recent years. Almost half of the detached houses in Norway are using heat pumps (Kipping, 2016) .

Electric water heaters are the second largest power consumer in Norwegian households. Electric water boilers with large tank are intuitively very suitable for flexibility, as water can be heated during off-peak hours and remain warm as the boiler is switched off during peak hours. This makes the loss of comfort almost imperceptible to consumers (Dromacque et al., 2017). Electric boilers' load can be shifted in time or regulated so it heats up the water to a lower degree in peak hours. Appendix A presents the result of a field survey on the effect of home equipment and other parameters on energy consumption in Irish households.

Table 1 compares the results of 3 different surveys and studies on energy consumption of different energy services in Norwegian households.

Table 1 Annual electric energy demand in Norwegian households

Electrical Appliances	**TIMES Norway**[1]		**REMODECE**[2]		**ElDeK**[3]	
	kWh/dwelling	share	kWh/dwelling	share	kWh/dwelling	share
Space Heating	13352	66%	12947	64%	9103	45%
Water heating	2428	12%	3034	15%	2428	12%
Lighting	1011	5%	1214	6%	1011	5%
Other appliances	3439	17%	3035	15%	3844	19%
Elastic demand	15779	78%	15982	79%	11532	57%
Inelastic demand	4451	22%	4248	21%	4855	24%
Total	20230[4]	100%	20230	100%	16386	81%

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[1] (Rosenberg & Espegren, 2014)

[2] (Grinden & Feilberg, 2009)

[3] (Morch, Sæle, Feilberg, & Lindberg, 2013) Distribution of annual electricity consumption which contain 19% residual heat.

[4] SSB Annual energy consumption per dwelling 2014

2.4.2 Smart meters

Advanced Metering Infrastructure (AMS) and publicly known Smart Meters are a power metering device which can facilitate two-way communication between the consumer and the power utility. The consumption information is registered every hour and sent directly to Distribution System Operator (DSO). Unlike conventional energy meters which have one-way communication and just collect the aggregated historical energy consumption data for end users. While the new energy meters can record and store the real time data for a dynamic control and optimization of power supplied and consumed at home (Wang, Xue, & Yan, 2014). The analysis of historical data collected by AMS can be used to forecast future energy demand of an end-user. In a demand response program, an optimization algorithm could give information on the amount of elastic power demand (i.e. controllable loads and shiftable load) and inelastic demand (i.e. fix and sheddable load). Based on this information the optimization algorithm suggest how and when the residents should adjust their demand to benefit from compensations.

AMS can also function as the controller in a smart grid when on-site power generation (e.g. wind turbine and solar cells) and/or energy storage (e.g. battery, thermal storage and EV) are integrated (Wang et al., 2014).

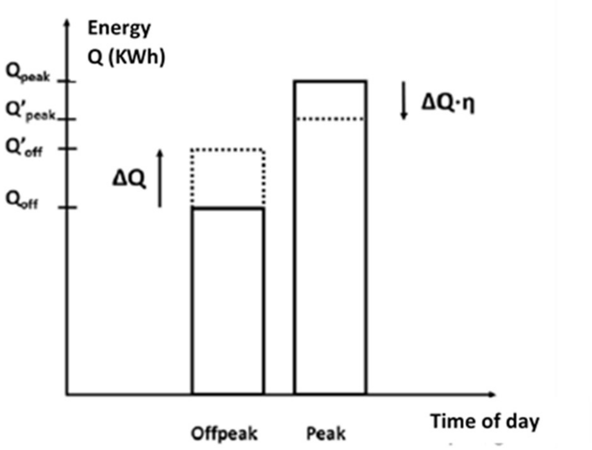
In Norwegian households the conventional power meter data had to be observed and reported by the consumer to the DSO. This was an inefficient metering system since if the consumer neglect to report the consumption he would receive a general fee called “Justert innmatingsprofil (JIP)”. This means that the consumer was billed for an average consumption based on the total network consumption on the neighbourhood. Since the JIP calculation uses the sum of all customers and does not take into account the individual customer's consumption which entail consumption on peak hours and high price electricity.

AMS on the other hand will provide a more accurate and systematic basis for billing towards the end customer. Further, with accurate automatic registering it not only eliminates the possibility to tamper with reported data, but it also would give motivation to consumer for more efficient consumption.

2.4.3 Batteries

Interest in battery technology and storage of electricity has increased significantly in recent years. This is mainly due to the increasing use of intermittent energy sources (e.g. wind, small hydropower and solar), but also a sharp increase in the number of electric vehicles, technology development and falling costs on batteries. Batteries can help load shifting, changing consumption profiles, smoothing of price fluctuations, and the storage of locally produced electricity in buildings. Power storage capacity in batteries give consumers the opportunity to decide when the energy should be used or saved depending on the power prices. On a time-varying power price scheme, battery packages can reduce the household power costs substantially. The extent of this cost saving will depend on energy price variation during the day and night and local energy demand of the household (Henden et al., 2017).

To illustrate how batteries would work in this system we can assume that there are only two periods with different loads, one peak and one off-peak. This would be respectively the largest and lowest prices within 24 hours. The figure 2-7 shows the consumption before and after using batteries.



Q_{off}-Consumption off-peak time without batteries
Q'_{off}-Consumption off-peak time with batteries
Q_{peak}-Consumption off-peak time without batteries
Q'_{peak}-Consumption off-peak time with batteries
ΔQ - Stored amount of energy
η - Efficiency of battery

Figure 2-7 Load shifting by using storage units

In such a system load shifting would be reasonable if the total cost of energy on off-peak period with batteries would be lower than peak hour without battery. By taking the efficiency of the battery into account it could be presented by the following equation:

Total costs without use of battery > total cost with use of battery

$$Q_{off} \cdot P_{off} + Q_{peak} \cdot P_{peak} > (Q_{off} + \Delta Q) \cdot P_{off} + (Q_{peak} - \Delta Q \cdot \eta) \cdot P_{peak}$$

Which can mathematically be simplified into:

$$\eta > \frac{P_{off}}{P_{peak}}$$

Which mean it is reasonable to use the battery if the ratio of power price in off-peak periods and price in peak periods would be less than the efficiency η. The greater the price differences will be in the coming years, the more profitable is the use of the battery. At the same time, expected further improvements in efficiencies of batteries will make them more cost-effective for price variations.

Price variation and efficiency of the battery are not the only determining factors for investment on domestic storage capacity. Investment cost for household application of battery package (including battery, control system and other components) is quite significant today. For example, Tesla Powerwall 2 which advertised recently with an energy capacity of 14 kWh and 10 years operational lifetime costs around 69,000 NOK while the installation costs may vary from 10 to 30 thousand NOK (Tesla, 2018). This is why the Li-ion battery of an electric vehicle not only has larger energy capacity but lower price too (for ex. Battery from Nissan Leaf has 24 kWh and Tesla Model S has 60-85KWh storage capacity). Therefore, it would be interesting to investigate the possibility of utilizing the storage potential of EVs for demand response purposes. This is further discussed in the next subchapter.

From the TSO point of view, batteries in households can contribute to increased flexibility and therefore reliability of the power system. Currently, the power system in Norway use water reservoir for increasing the flexibility. The water reservoirs enable seasonal storage (long-term storage) because they can store a large volume of water which could be released in time of need. Batteries however have a lower storage capacity but could play the same role along with the existing power system on a daily basis. A large number of batteries in the household sector which can be charged at night and tapped during the day can significantly increase the flexibility and reliability of the power system (Henden et al., 2017). The variation of electricity price based on spot price market presented in Figure 2-8. The blue color represent the highest and the orange color represent the lowest weekly/daily prices in these figures. The average price variation for this period on weekly and daily basis are 17.2 EUR/MWh and 6.5 EUR/MWh respectively.

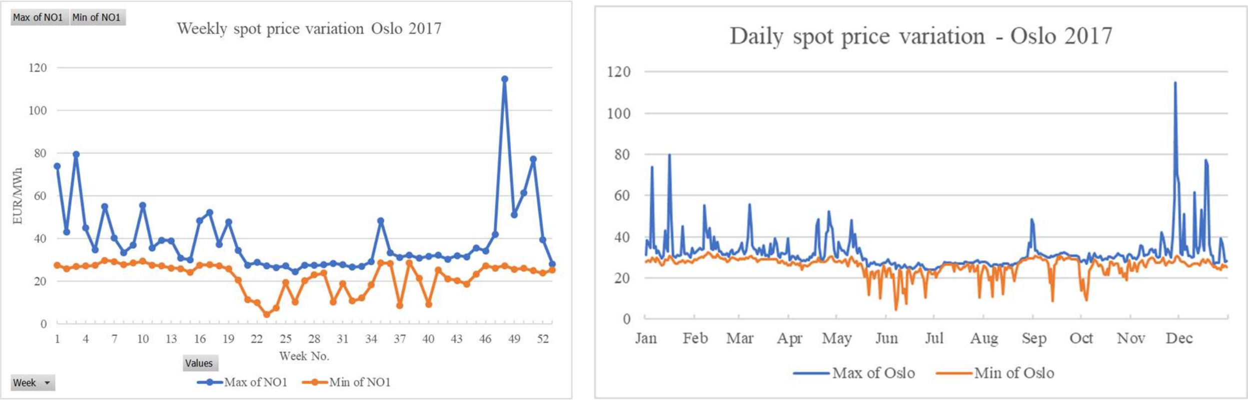


Figure 2-8 Spot price volatility during 2017

Plug-in Electric Vehicles

The market for Electric Vehicle (EV) is booming in Norway. According to Statistic Norway the number of registered Battery Electric Vehicle (BEV) at the start of 2018 was 140,000 with an increase of 43% compared to last year. The registered number for Plug-in Hybrid Vehicles (PHEVs) was 144000 vehicle (SSB, 2018d). This is due to the government incentive program for zero emission vehicles (e.g. Exemptions from purchase taxes and toll road fees, free access to public parking, and funding for infrastructure developments). Just in September 2018 the market share of new EVs reached 48%, which demonstrates the sharp trend (E24, 2018).

Such a sudden increase in electrification of transport could be problematic for the grid. Large number of consumers charging their cars at the same period could also have a sizeable impact on the grid capacity at certain times and locations. In other word it could amplify the peak load or create another peak time. This would consequently result in inadequacy and poor quality of the power supply (IEA, 2017b). The Institute of Transport Economics (TØI) has carried out a survey amount a large group of EV owners. The result of survey shows that 94-95% of BEV and PHEV owners, charge their vehicles at home which is typically at the evening when they come home (Figenbaum & Kolbenstvedt, 2016). Consequently, the peak time for charging the vehicle coincide with the peak power demand from the grid. When people come home from work, start cooking, warming up the rooms, watching TVs etc.

With right instruments, the increasing number of EVs is not only a threat to flexibility and reliability of the grid, but could also be seized as an opportunity. The Norwegian Water Resources and Energy Directorate has by applying the TIMES-Norway model carried out a scenario analysis on how batteries in electric cars can contribute in changing consumption profiles and price variations. The study evaluated three scenarios with different battery availabilities and fuse sizes. The results showed that batteries would change consumption profile by load shifting (lower in high-price periods and higher in low-cost periods). The study estimated the possibility for shifting to approx. 6 - 50% of the peak load within the NO1 price area. This means that resulted effect of load shifting on high scenario can replace the entire power import to NO1 (1,6GW) on peak hours and up to 25% for the low scenario (Henden et al., 2017). As it was indicated earlier the investment cost is a critical factor for use of battery as a storage unit. However, the trend in the market price for Li-ion batteries used in electric cars shows a significant drop during the last few years and it is expected to reduce to around 150 $ per kWh in 2030. (See figure 2-9)

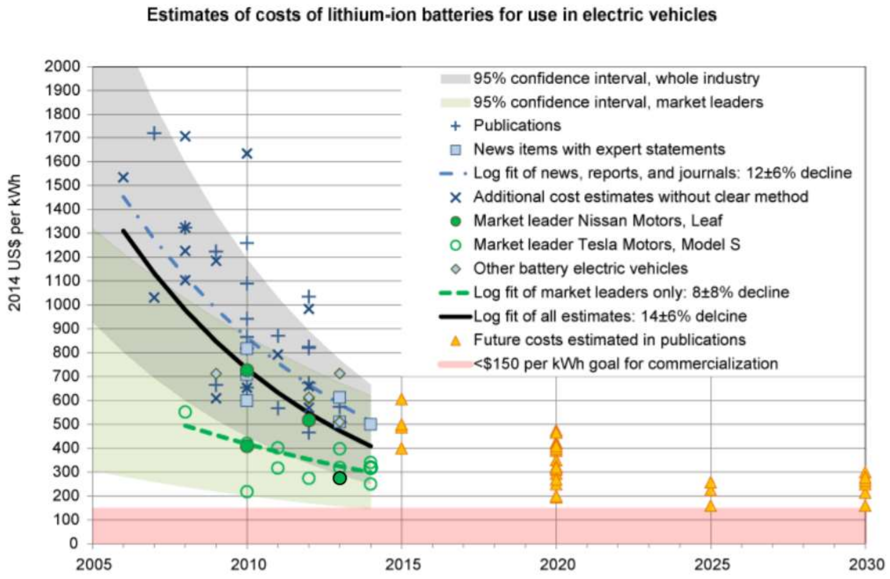


Figure 2-9 Price development of EV batteries

2.4.4 Solar cells coupled with battery

Installing solar sell on the roofs have started to become more popular. In recent years, there has been a significant increase in installed solar power capacity in Norway (from approx. 9 MW in 2010 to 27 MW in 2016) (Henden et al., 2017). By storage of electricity produced by solar cells during the day and consumption of self-produced power during the expensive peak load, the household could save money on electric costs. In addition, reducing the electric specific load in the evening. Figure 2-10 schematically shows how solar energy generated (yellow) could smooth the peak load.

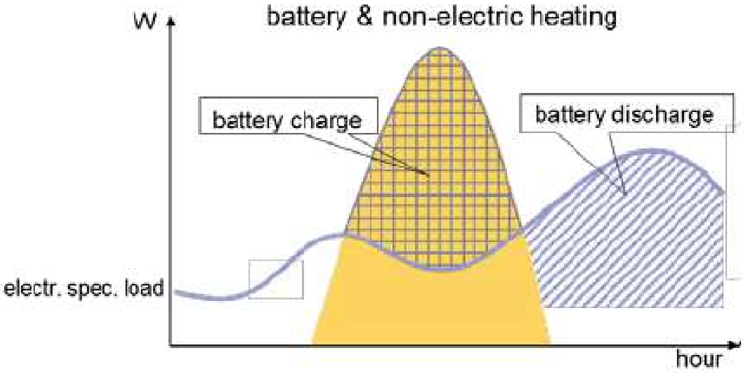


Figure 2-10 Load shifting with PV-battery system

Germany is a pioneer country in this area. The country has done numerus studies on solar energy in the residential sector but also has heavily funded installation of battery storage systems coupled with solar PV panels (EUR 25 million in initial funding) (IRENA, 2015) .

Due to geographical features solar energy production in Norway varies on seasonal basis. The power generation is highest during summer and very low on winter days. Therefore, PV and battery installation has to operate accordingly. This means on winter days when on-site production is very low, all battery capacity can be used for load shifting while during the summer the batteries are mainly used to increase the utilization rate of on-site production.

Figure 2-11 shows the use of PV and battery and the effect of this on power consumption over one year based on TIMES Norway (Henden et al., 2017). In this scenario analysis it was assumed that on winter time, when on-site production is very low, all battery capacity can be utilized for load shifting.

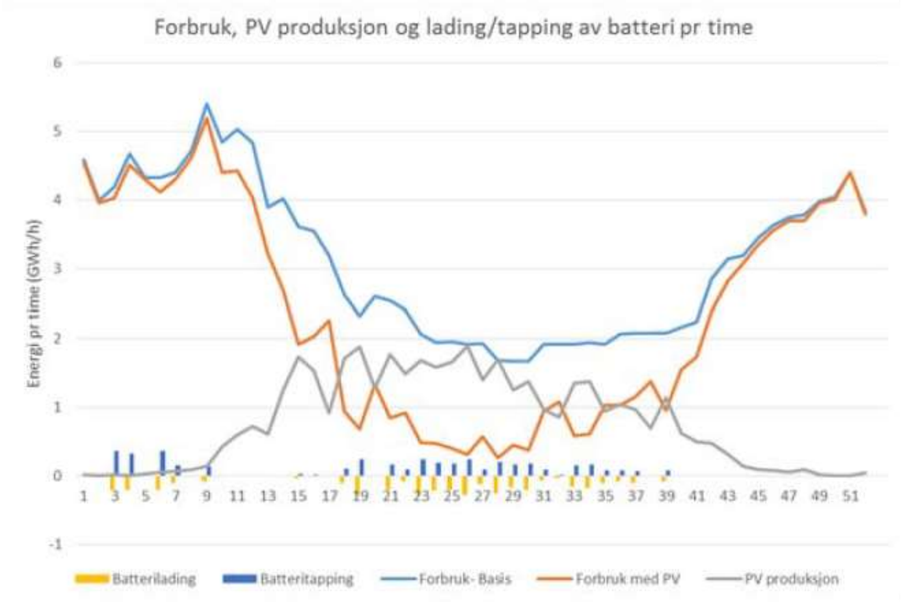
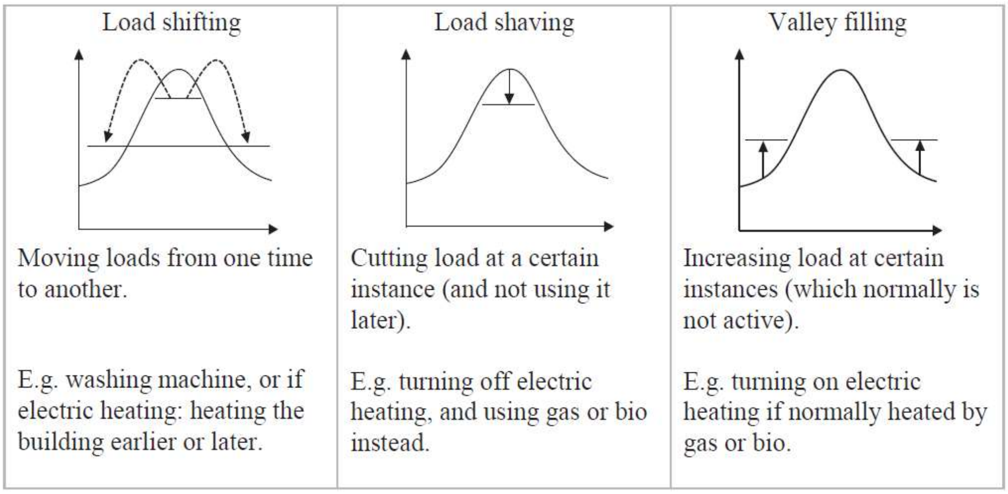


Figure 2-11 Annual power consumption, PV production and tapping of batteries per hour

3. Demand Response

Demand response (DR) or Demand side Response (DSR) are defined as a series of actions which consumers can take to change its demand on power resources at specific peak times in order to reduce the stress on the grid. These actions typically involve either using less electricity at peak times (peak shaving) or shifting electricity use from peak times to off peak times (load shifting) (COWI, 2016). This is often triggered with cost saving rewards which gives incentive to consumer to cooperate. Figure 3-1 illustrate the load shifting and peak shaving and valley filling concepts graphically.



Load shifting	Load shaving	Valley filling
Moving loads from one time to another.	Cutting load at a certain instance (and not using it later).	Increasing load at certain instances (which normally is not active).
E.g. washing machine, or if electric heating: heating the building earlier or later.	E.g. turning off electric heating, and using gas or bio instead.	E.g. turning on electric heating if normally heated by gas or bio.

Figure 3-1 Demand side management mechanism: load shifting, load shaving

The US Federal Energy Regulatory Commission (FERC, 2017) defined demand response as: “Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.”

Losi et.al has presented the economic benefit of demand response in three categories (Losi, Mancarella, & Vicino, 2015):

1- Economic benefit from reducing the peak demands. However, the peak demands do not occur frequently but since the market price for electricity during the peak demand is extremely high due to undersupplied market the total economic impact is significant.

In addition, adding extra capacity to respond the peak demands need high investment on generation, transmission and distribution network. Reducing peak demands can be substitute for these investments.

2- Economic benefit from reducing ancillary services by decreasing the volatility of the demand. In time of high demand TSO need to ramp up the production in order to keep the reliability of the power system. So ancillary services often provided by generating units running in a sub-efficient mode of operation. Example of such are standby gas turbine power plants. Demand response potentially can reduce the need for ancillary service partially or totally. That means reduction of production costs, power price and emission.

3- Economic benefits from saving on transmission and distribution losses. Depend on the loading condition energy losses on the line may vary between 5 to 10 percent. This is due to high distance from power plant to end-users. Demand response can help in relieving heavy load on the grid and subsequently reduce the losses.

There are varieties of methods that can applied for demand response. Examples could be installing an alternative energy service as a back-up for electricity, shifting demand in time due to temperature energy in surrounding area, storage possibilities (battery or heat) or shifting to another time due to elasticity in demand preferences (COWI, 2016).

However, in term of possible service that DR could provide to the power system it could be much larger than Peak shaving and Load shifting. Other possible demand response method are valley filling and load building, but since these methods are not (to my knowledge) applicable in the household sector, they are not covered in this paper.

3.1 Characteristics of DR programs

Demand response programs can be categorized in two main group: Price-based programs and Incentive-based programs where each of them can be divided into different variant. Although both type of these programs aim for a common goal, they have differences in characteristics. Figure 3-2 is illustrative in this regard.

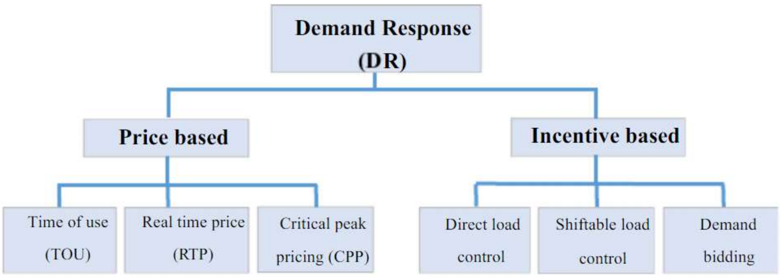


Figure 3-2 Classification of Demand Response (Chen, Xu, Gu, Schmidt, & Li, 2018)

3.1.1 Price-based demand response

Refer the situation that a consumer makes a change in electricity usage in response to price changes. The price-based programs could be either static and dynamic pricing schemes. The Price-based DR could be classified into three groups as bellow:

Time of Use (ToU) is a static pricing scheme. In this sort of pricing, the electricity prices are set in advance and differ depending on the time of day.

(Losi et al., 2015) believes that ToU rates do not reflect the real cost of energy delivery due to their static nature. In addition, in cases that there are more than two rates over a day the consumers, specially the small ones, often have trouble in optimizing their energy use accordingly. Therefore, they may need to have a level of automation (e.g. thermostats with timers) to respond with time varying rates.

Real Time Pricing (RTP) is a dynamic pricing scheme that customers are typically notified of upcoming electricity rates on a day-ahead or hour-ahead basis. Unlike ToU , the RTP reflect the true cost of energy at any given time. RTP requires installation of ICT infrastructure on the consumer side which will facilitate two-way communication with the operator. In the past, only large industrial power consumers have RTP contracts with electricity producers (Kopsakangas Savolainen & Svento, 2012). However recently, due to Advance Metering System (AMS), publicly known as smart meter, this type of pricing is achievable for the household sector.

Critical Peak Pricing (CPP) is a combination of ToU and RTP. In this pricing method Real time prices is applied with exception on certain "peak periods" in which electric prices reflect the costs of wholesale electricity prices. The Consumer receives a warning about the coming peak time with higher rate. Higher prices during peak hours are often triggered by wholesale power prices or reliability-related events in the grid (Losi et al., 2015). In this pricing method it is critical that consumer receive the warning in good time in order to be able reschedule activities accordingly.

3.1.2 Incentive-based demand response

In case of incentive-based DR, costumers allows the operator, utilities or entities who run the DR program to control their load in exchange for receiving monetary incentives (Losi et al., 2015) . Also, this could be done directly by the customer in terms of a formal commitment to reduce the power consumption during the execution of DR program. However, if the customer fail to fulfil his/her consumption reduction commitments, depending on the type of contract, this may results in financial penalties or loss of potential future rewards (Losi et al., 2015). An empirical study done in US showed that incentive based programs accounts for over 90% of demand response load reduction (Cappers, Goldman, & Kathan, 2010).

Incentive based demand response programs can be classified into the following six subcategories:

- Direct Load Control (DLC): In this type of program an utility or aggregator has a direct control on consumer loads. It means that customer's electrical equipment will be remotely shut down, or power consumption will be move to lower demand periods in a short notice. These programs are mainly offered to residential or small commercial customers. Incentive payments typically are in form of a fixed monthly credit on the consumer's invoice and would be granted when load reduction events happen (Losi et al., 2015). In this type of program costumers usually receive options like specifying maximum number and duration of events per year and/or ability to override the program in case of discomfort (Losi et al., 2015).

- Interruptible/Curtailable Service (ICS): In these programs the customers agree to reduce or turn off certain amount of loads for a period of time in exchange for discount rate or bill credit. These contracts often include penalties for contractual response failures. These programs are usually offered to large commercial and industrial customers (Faria & Vale, 2011).
- Demand Bidding/Buyback (DBB)): In this program the customers offer bids to reduce their load based on wholesale electricity market prices or an equivalent. The program mainly target large consumers (Faria & Vale, 2011).
- Emergency Demand Response (EDR) programs that provide incentive payments to customers for load reductions during periods when grids reserve capacity becomes insufficient. Participation of consumer is voluntarily and in case of response to system operator signal they will receive monetary compensation (Losi et al., 2015).
- Capacity Market (CM), "involves load reduction commitments made ahead of time (e.g., months), which the system operator has the option to call when needed. The call option is usually exercised with two or less hours of notice, depending on the specific program design. Customers typically receive day-of notice of events. Incentives usually consist of upfront reservation payments, determined by capacity market prices, and additional energy payments for reductions during events. Capacity programs typically entail significant penalties for customers that do not respond when called" (Energy, 2006).
- Ancillary Services Market (ASM), these programs allow customers to bid on their load reduction in a market as reserves contingency. If their bids are accepted, they are paid the market price for committing to be on standby. If their load reduction would be needed they may receive a payment based on the spot market price(Energy, 2006).

Figure 3-3 shows the integration of different demand response programs in the power system planning process and the time horizon for operation of each program.

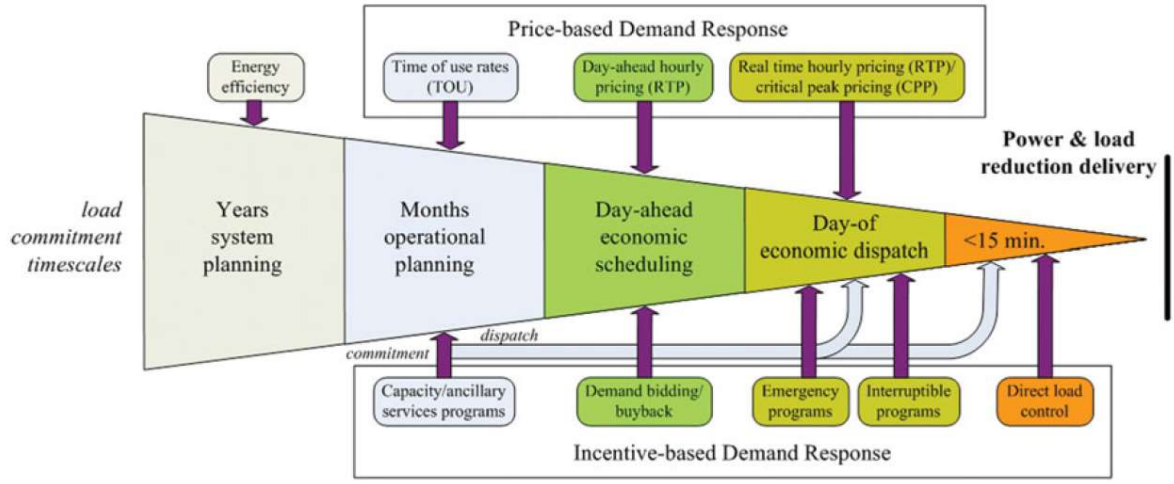


Figure 3-3 Demand Response implementation in different time scale of grid's operation retrieved from: (Faria & Vale, 2011)

3.2 Norwegian power market structure

Norway roughly produce 130TWh annually. Electricity production in Norway is based almost entirely on hydropower resources which account for 96% of electricity generation. While a large share of production capacity is flexible (possibility for 85 TWh hydropower storage), unlike neighbour countries the electricity price does not fluctuate much within a day. However, there is relatively large price variations between seasons (NVE, 2016b).

In Norway hydropower sources are under public ownership as Norwegian Industry Concession Ac, December 1917 has mandated. Therefore, the Norwegian public sector directly or indirectly control the hydropower generation in the country(Navestad & Henriksen, 2017). The Norwegian power market is slightly different from the European model. The Energy Act of 1990 in Norway has liberalised the energy market and established a monopoly for grid management and operation. (Saele & Grande, 2011) has presented the major actors in the Norwegian power system in two groups; first group is Monopoly Actors which are state owned entities which have control on power production, transmission and distribution. The second group are market players consisting of companies in power retail services and Nord Pool as market operator. See fig 3-4

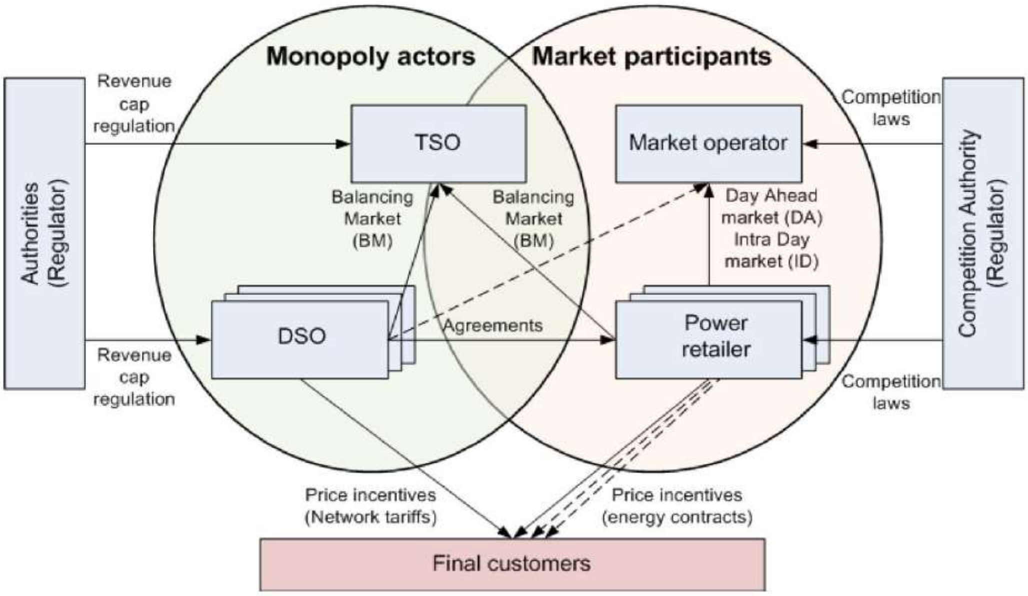


Figure 3-4 Power Market structure in Norway (Saele & Grande, 2011)

Therefore, the Distribution System Operator (DSO) and power retailers are two separate entities. This means that all costumers in Norway have two separate contracts. One contract with the DSO which includes tariffs for use of the grid and another contract with the power retailer for actual used energy (Saele & Grande, 2011). The consumers are free to choose any power retailers and retailers are free to offer various types of contracts as far as it complies with the competition law. For instance, it could be contract with fixed price for a defined period or a spot related price. On the other hand, design of the network tariff established within the framework defined by the Authorities as a part of the monopoly regulations. The Norwegian Water resources and Energy Directorate (NVE) is the responsible body for monopoly activities and overseeing the TSO, DSO and the whole sale market.

Unlike most European countries, transmission of electricity in Norway has three grid levels rather than two: the central grid; the regional grid; and the local distribution grid. To minimize the transmission losses each grid levels operates under different voltage level (respectively 420-300 kV, 132-33 kV and 400-230 V). The central grid, which for most practical purposes is the Norwegian transmission grid, is operated by Statnett as the designated TSO. Statnett owns around 90% of the central grid and operates the remaining based on rental agreements (Navestad & Henriksen, 2017). In addition, Statnett operates real-time balancing and ancillary services markets and maintaining a constant quality of supply throughout the country. Statnett also determines the transmission tariffs once for every four years (IEA, 2017a).

The largest Norwegian electricity producer is Statkraft which is a state-owned enterprise. Statkraft owns approximately 36% of the Norwegian electricity generating capacity. National Association of Securities Dealers Automated Quotations (NASDAQ) is another market operator in Norway which operates a separate financial derivatives market and offers products for long-term financial hedging.

3.2.1 Wholesale power market

Nord Pool is a wholesale power market with 362 market participants. More than 90% of the power trade in Norway takes place at Nord Pool. Norway is one of seven countries that participate in the Nord Pool wholesale spot market. The other members are Sweden, Finland , Denmark, Estonia , Lithuania and Latvia (IEA, 2017a). Nord Pool has facilitated cross-border trading and therefore integration of the Nordic power market into the European market through interconnectors to the adjutant countries.

The Nord Pool offers two types of power markets, the day-ahead market (Elspot) and the continuous intraday market (Elbas).

Day-ahead Market

The day-ahead market or spot market is an auction-based exchange for the electricity to be delivered physically (NordPool, 2018b).Also it could be defined as a collection of regional markets (price zone) while the inter-regional trades are bound by the capacity of the transmission lines. The major part of the power exchange in Nord Pool occurs in this market. The electricity market in Norway is divided into five price areas – NO1, NO2, NO3, NO4 and NO5. Market participants (e.g. producers, local industrial consumers and retailers) submit their hourly demand or supply curves for physical delivery for the next day’s 24-hour period. Nord Pool Spot collect all individual supply and demand bids and clears the market by means of a uniform price for each hour and price zone by considering the transmission constraints (Tangerås & Mauritzen, 2014). See fig 3-5 (a). Therefore, the Day-ahead market could be applied in a ToU program as the bids are placed the day before.

(a) (b) (c)

Figure 3-5 Price formation in Nord Pool spot market (NordPool, 2018b)

But bidding areas are not always in balance, since the areas could have deficit or surplus of electricity too (showed in fig 3-5 (b) and (c). In these cases, electricity will flow from areas with lower price offers towards areas where demand is high, and the price offered is higher. The process would continue until the cross-area lines reach the transmission capacity. If the transmission capacity between bidding areas is not sufficient to reach full price convergence the biding areas will end up with different prices. Figure 3-5 b and c illustrate how the surplus and deficit areas reach equilibrium. Finally, after completion of calculations for all producers and consumers in each area, the trade will reach a homogeneous regional price.

Nord Pool also gives the *system price* for the spot market. The system price is calculated by a cross-market stimulation. Essentially it is the hourly clearing price for the entire market where demand and supply are in equilibrium and transmission constraints (bottlenecks) between regions are not included in calculation. Figure 3-6 shows the hourly spot price and system price variation in a winter day and through the year.

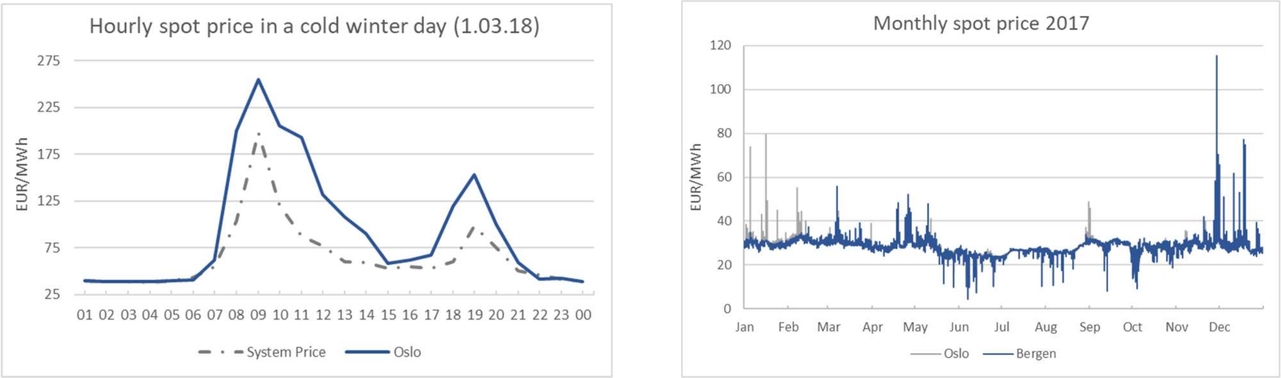


Figure 3-6 Historical spot price on Norwegian power market source:(NordPool, 2018a)

Intraday market

Intraday market or Elbas is another market at Nord Pool which opens two hours after closure of the day-ahead market. The intraday market function as a balancing market which seeks to minimize the mismatch between day-ahead market results and actual power consumption resulted from forecast errors or unpredicted events. The intraday market resembles a regular stock exchange as the trading is continuously and it has pay-as-bid principle. This means that the same product is traded at multiple prices over the course of the trading period as new market information arrives (Tangerås & Mauritzen, 2014). That explains why the intraday market price is very close to the spot price shortly after the market has opened.

Through the intraday market, Nord Pool is responsible for the market balance until one hour before real time or power delivery. After that the market is closed and responsibility for the power system is handed over to the TSO (IEA, 2017a). Therefore, the intraday market could be considered a sort of RTP program, as it is close to real time.

The intraday market at Nord Pool offers three different order types, each designed for specific needs. The available services are Limit orders, Block orders, Iceberg orders. Since these services are typically measures for improving DR flexibility on supplier side and therefore outside of focus of this paper, it won’t be further investigated.

3.2.2 End-user market

Electricity buyers in the end-user market are the ultimate consumers who buy electricity for their own consumption, for instance industry, commercial buildings or households.

As it was highlighted earlier, DSO considering apply of capacity-based tariff for residential end-users. It worth mentioning that although the capacity tariffs may improve the overall economic efficiency by avoiding or delaying the grid investment. But we should be aware that from an economic perspective the increase on power prices does not necessarily reflect the customers willingness to pay for investment or avoiding such investment on the grid. Considering the fact that in some literature grid network defined as public good to end users so pricing for the service may cause underutilization from consumer side. However, cost and benefit analysis grid investment to the end-users is out of scope of this paper and won't be further discussed.

According to Statistic Norway on 2017, around 28 percent of the households had standard variable contracts, 2 percent had fixed price contracts and over 69 percent had spot price based tariffs (SSB, 2018c) . It should be noted that in spot price-based contracts the consumers do not face hourly varying prices. But they would receive the average hourly spot price at the end of each month. Electricity bills in Norway composed of 3 parts; Cost of used electricity, Network fee which is the logistic cots of energy and calculated per KWh and Taxes. Taxes includes 25% value added tax and tax on consumption of electric energy which was 16.6 øre/KWh in 2018. Figure 3.7 shows share of these cost elements on electricity bill.

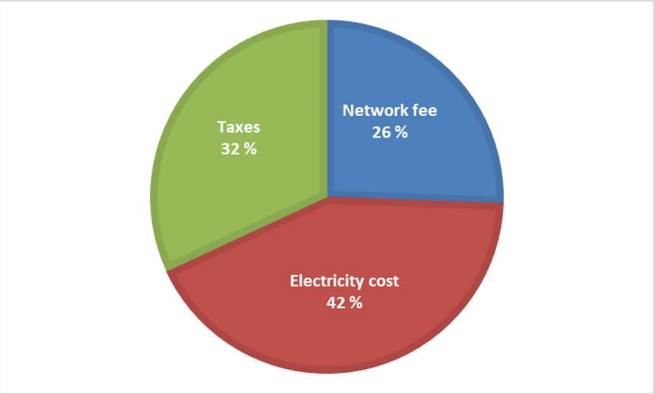


Figure 3-7 Cost elements of electricity bill for residential customers in Norway in first 3 quarter of 2018 Source:(SSB, 2018a)

3.3 Aim of the study

This study aims to investigate how the upcoming grid tariffs would affect the consumers in the residential sector. Also, it seeks for potential cost saving solutions which may help consumers to reduce their electricity costs. In this regard the upcoming tariffs are tested for normal power consumption in 3 different buildings. Furthermore, possibilities for cost saving by implementing load shifting (on water heater, dishwasher, washing machine and dryer) is investigated in the scenario analysis.

4. Methods and Material

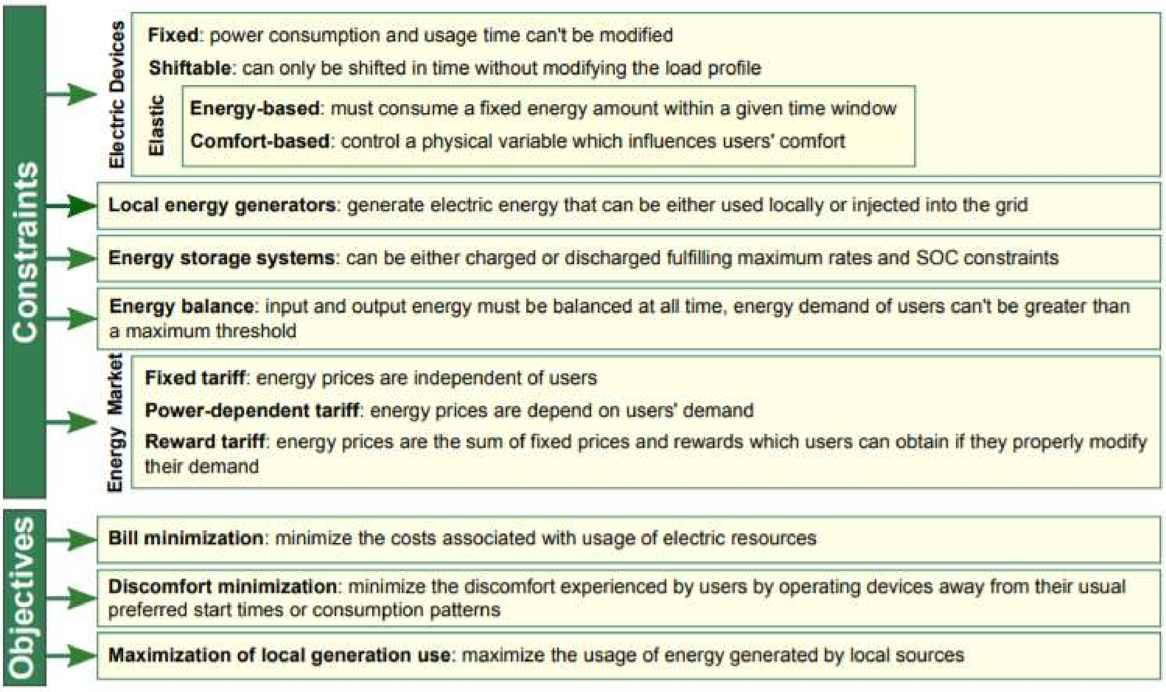
4.1 Methods

Common modelling approaches for evaluation of energy consumption are top-down and bottom up models. The top-down models often apply macroeconomic indicators like population, GDP or employment rate and climate variables like outdoor temperature to model the aggregated energy consumption (Kipping & Trømborg, 2017). While bottom-up models start with mapping the consumption in a more disaggregated way (for instance a single household or electrical units) and then aggregate the total consumption.

There are different estimations and projections of future energy demand in Norway presented by governmental and research organizations. Unfortunately, in many reports most of the basic assumptions and input data are not public. In some cases, information about electricity forecasts is available, but no data on total energy demand, which made it difficult to comprehend the applied approach. For example, in a report from the Ministry of Environment (NVE, 2016a) electricity consumption towards 2050 is estimated to have 50% increase while in another report from the Ministry of Petroleum and Energy, the estimation is lowered to 33% increase (Brubakk et al., 2012). Such inconsistency in evaluations probably relates to the modelling approach. Among governmental entities the top-down methodology and particularly the general equilibrium (demand/supply) model is a common approach for reporting. The weakness of this approach is the technological explicitness, particularly when it's used on technology related studies, like energy demand, it may not present a precise future forecast (Bataille, Jaccard, Nyboer, & Rivers, 2006).

Considering the fact that bottom-up modelling gives a better perspective towards energy technologies and it widely used in energy research institutes (e.g. IEA), it was decided to use a bottom-up modelling approach in this thesis too.

A common approach for DR and demand side management studies is optimization methods. Since the general goal of demand response programs is increasing efficiency across the power system. Optimization methods can help us to explore the boundaries of possibility and target for the highest gain from demand response programs. This method uses mathematical programming to compute the optimal solution(s) or satisfactory solution for the problem. The optimization has two main parts. The first part is the objective function which is an algorithm for the problem. This thesis uses cost minimization as the objective, but other approaches (like social welfare maximization, power exchange minimization, discomfort minimization etc.), are also common for these types of studies. The second part is constraints which determine the boundary of the possible solutions. In pursuance of describing research method, the research question is divided into smaller objective questions/functions bounded by constraints relevant to each scenario. Figure 4-1 gives an illustrative structure of different elements of the optimization problem applied in this paper.



Fixed: power consumption and usage time can't be modified

Shiftable: can only be shifted in time without modifying the load profile

Energy-based: must consume a fixed energy amount within a given time window

Comfort-based: control a physical variable which influences users' comfort

Local energy generators: generate electric energy that can be either used locally or injected into the grid

Energy storage systems: can be either charged or discharged fulfilling maximum rates and SOC constraints

Energy balance: input and output energy must be balanced at all time, energy demand of users can't be greater than a maximum threshold

Fixed tariff: energy prices are independent of users

Power-dependent tariff: energy prices are depend on users' demand

Reward tariff: energy prices are the sum of fixed prices and rewards which users can obtain if they properly modify their demand

Bill minimization: minimize the costs associated with usage of electric resources

Discomfort minimization: minimize the discomfort experienced by users by operating devices away from their usual preferred start times or consumption patterns

Maximization of local generation use: maximize the usage of energy generated by local sources

Figure 4-1 Constraints and objective functions of optimization problem (Barbato & Capone, 2014)

The two usual optimization methods applied on demand response researches are deterministic approach and stochastic approach. In this paper the input data have been either available or assumed, therefore a deterministic approach has been used for calculation of optimal values.

In this research the energy cost minimization method was applied to find the optimal consumption pattern which would reduce the total electricity cost in the household. The optimization functions and related constraints for each case further explained in chapter 5.

Other evaluation methods like cost savings calculation based on annual load duration curve or clustering could be applied for understanding the significance of the demand response problem. Also, it is an easy way of visualizing how consistently the consumers are using the energy they consume. A load duration curve is often used on the supply side of the chain as a tool for power generation and distribution planning. The load duration curve is generated by resorting the annual load curve of consumer(s) on a descending order of the magnitude of the demand and not the time order. In other words, it shows the duration of load demand that start with the highest load down to the lowest load. The figure 4-2 shows the generated duration curve of a detached house.

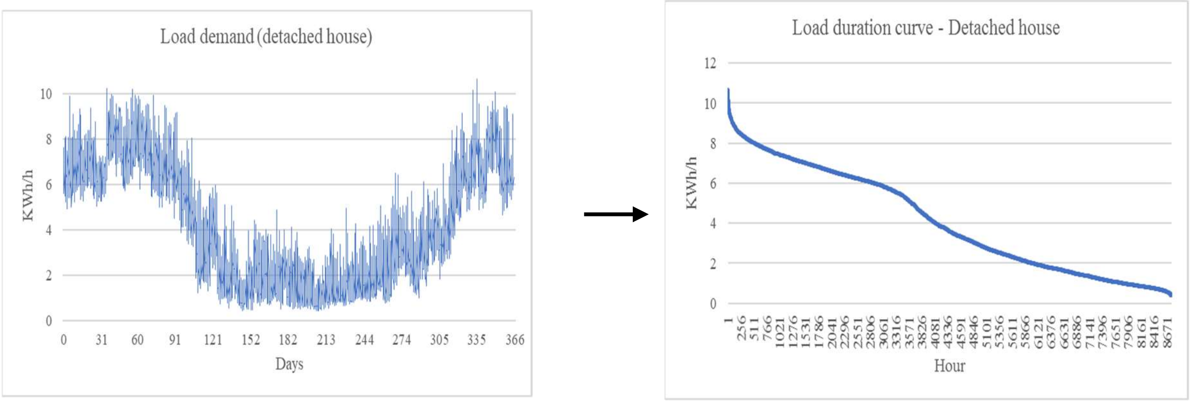


Figure 4-2 Annual power(load) demand and load duration curve for case 1;

It is worth mentioning that during the analysis of data in this thesis, several different optimization tools have been tested for achieving better result (i.e. Python, GAMS and Homer Grid). This was due to computing limitations of the optimization package in Excel. However, this software requires a high level of programming skills and time.

In addition, since this study just interested in shifting of the load for water heating and washing, the load for 6 out of 8 appliances was assumed to be fixed or non-shiftable. Therefore, the disaggregated daily load and load pattern for 6 out of 8 appliance repeated unchanged. So, it was decided to rather do the scenario analysis for smaller samples of a 24 hour period and apply its results on all winter days. The optimization spreadsheets for scenarios 1 to 4 are presented in Appendix C1 to C4.

4.2 Model input

Literature review has been a major help in preparation of this paper, especially in the early stage of the research. Reading the reports and academic work of different researchers not only clarified to me different dimensions of demand response and power consumption in the residential sector but has also assisted me through the writing process as a guideline.

In this thesis annual hourly load profile of three different buildings (Detached house, semi-detached house and apartment)has been usedd in the scenario analysis. The load profiles are related to consumers in the Follo district (Akershus state) in Norway and was provided by Norges Nett As. The mentioned load profiles are the hourly observation of smart meters (AMS) installed in the consumers' buildings. Information about the buildings are presented in table 2.

Table 2 General information on case studies

Dwelling type	Building year	Floor area (m^2)
Detached house	1930	166
Semi-detached	1971	128
Apartment	1970	70

Despite efforts on obtaining more details about the samples, there was no better sample or further details was not provided to this thesis. Therefore, a series of assumption have been taken to reach the research goal. For instance, the number of occupants and number and specification of electrical equipment in the studied cases were assumed based on previous studies on energy consumption in Norwegian households (Enøk; Grinden & Feilberg, 2009; Langseth, Everett, & Ingeberg, 2011). Furthermore, hourly energy consumption of electrical units was organized into 8 categories. So it would be possible to analyze energy demand based on type of demand, magnitude and duration through the whole year.

This means that load disaggregation has been done by subtracting electric specific demand (available on field studies and surveys) from the total load. So the remaining would be space heating and water heating energy demand. Table 3 shows the annual disaggregated load for a detached house. Appendix B1, B2 and B3 presents the disaggregated load for the two other cases (semi-detached and apartment).

Table 3 Annual disaggregated load for a detached house

Electric appliances	Detached house Family with kids (kWh).[5]	Household more than two persons (kWh).[6]	Enøk (kWh) [7]	Average. annual (kWh)
Space heater				26362
Water heater	-	3947	3600	3773.5
Lightning approx.20spot	962	1000	2800	1587
Cooling	825	803	1110	912.67
– *Refrigerator without freezer*		275	470	
– *Freezer*		528	640	
Washing	1 317	1081	1720	1373
– *Washing machine*		401	470	
– *Clothes dryer*		405	520	
– *Dishwasher*		275	730	
Cooking	513	424	810	582
– *El. Cooker/oven*		397		
– *Microwave oven*		27		
Small El	249		370	434
– *Water kettle*		29	270	
– *Hair dryer*		-	40	
– *Toaster*		-	10	
– *Vacuum cleaner*		50	50	
Media	1122	765		943.5
– *PC*	334	240		
– *Laptop*	74	53		
– *Router*	54	54		
– *Wireless AP*	130	65		
– *Printer*	-	26		
– *TV LCD*	444	160	110	
– *Hi-Fi*	69	135	40	
– *DVD player*	17	32		
Annual observed electricity consumption KWh				35961.92

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[5] (Langseth et al., 2011)

[6] (Grinden & Feilberg, 2009)

[7] (Enøk)

After disaggregating the total load into the eight categories, it was needed to distribute the calculated load for each timestep of the model. The electric specific loads (cooling, washing, cooking, media and small electrical equipment) do not change a lot during the year. In other words, they are not affected significantly by seasonal effects. Therefore, they are distributed evenly for both summer and winter. But the demand for the other categories (space heating, water heating and lightning) vary with regards to ambient temperature and seasonal differences. Therefore, the energy demand for these categories are weighted according to the change in observed power consumption in summer and winter. See the table below:

Table 4 Appliances energy demand distribution for a detached house

Electrical appliances	Winter*		Summer**		Total	
	kWh	percent	kWh	percent	kWh	percent
Space heating	20993	76.7 %	5369	62.5 %	26362	73 %
Water heater	3005	11.0 %	768	9.0 %	3773	10 %
Lighting	1264	4.6 %	323	3.8 %	1587	4 %
Cooling	456	1.7 %	456	5.3 %	913	3 %
Washing	687	2.5 %	687	8.0 %	1373	4 %
Cooking	291	1.1 %	291	3.4 %	582	2 %
Small el.	217	0.8 %	217	2.5 %	434	1 %
Media	472	1.7 %	472	5 %	944	3 %

*Winter: Nov, Dec, Jan, Feb, May, April
**Summer: May, June, July, Aug, Sept, Oct

The above information on a detached house' energy consumption for appliances was used to calculate the daily load for each of the 8 categories. The energy demand for space heating, water heating and lighting is four times higher in winter compare to summer time. After calculating the daily power consumption of appliances for the detached house, the hourly load of electric specific appliances were assigned logically based on common consumption patern. So, the difference between hourly observed load and el-specific loads would represent the remining appliances (space heating and water heater). Thus the 8760 hours of consumption pattern of the 8 categories of appliances were plotted and made ready for programming and then optimisation. A similar process was repeated for the two other buildings (semi-detached and apartment) which presented in Appendix B.

The consumption profile of all appliances could be plotted after disaggregation of the daily load. Mapping the energy consumption of electric devices based on category and type of demand allows us to realize which part of the energy demand that possibly could be shifted, delayed or just removed from the profile. As it was discussed in chapter 3, demand response methods cannot be applied to all categories of electric devices. Therefore, it is suggested to sort the devices loads based on their nature for more accurate optimization. So, the load of the electric devices could simply fall into the following 3 groups:

1. Fixed or non-shiftable load
2. Flexible or shiftable load
3. Elastic or deferrable load (Interruptible deferrable load and Uninterruptible deferrable load)

Examples of interruptible deferrable load and uninterruptible deferrable load devices are normal electric space heaters and dishwashers, respectively. Sorting the load type was necessary for this thesis in order to definethe constraints of the optimization problem.

After disaggregating and mapping the consumption load, the optimization model was defined. The focus of this work is minimization of the electricity cost, so a cost minimization equation was defined based on the cost elements of electricity bills (see 3.2.2). Historical spot prices from the Nord pool database have been used as input for electricity costs during 2018 for this work. The network fees are calculated based on a proposal from The Norwegian Water Resources and Energy Directorate (NVE) for possible upcoming network tariffs (Hansen, Jonassen, Løchen, & Mook, 2017). In that report, four different tariff models are proposed as a suggestion for reducing the future capacity shortage in distribution net. These tariff models are used in this thesis as a basis for calculating network fees on the studied cases.

Furthermore, taxes are calculated based on real tax fees on 2018. Table 4 gives an overview over elements in the studied scenarios.

Table 5 Scenario overview

Scenarios	Network tariff	Electricity cost	Taxes	Power storage / Production
Scenario 1	Subscribed power	Spot price	25%VAT+kr/kWh	-
Scenario 2	Energy tariff	Spot price	25%VAT+kr/kWh	-
Scenario 3	Observed power	Spot price	25%VAT+kr/kWh	-
Scenario 4	Time of use	Spot price	25%VAT+kr/kWh	-
Scenario 5	Observed power	Spot price	25%VAT+kr/kWh	Battery+ PV

4.2.1 Energy plot

The hourly power consumption gathered by smart meters (AMS) in 3 buildings were plotted with help of the Homer Grid software and presented in figures 4-3 to 4-5. While the x-axes represent the day of the year, the y-axes of the diagrams show the time of the day. The intensity of the power consumption is presented by colors. The bluish colors show the low consumption and the reddish color indicates the peak times of use. As it is evident the peak consumption hours occurred during morning and evening in winter time.

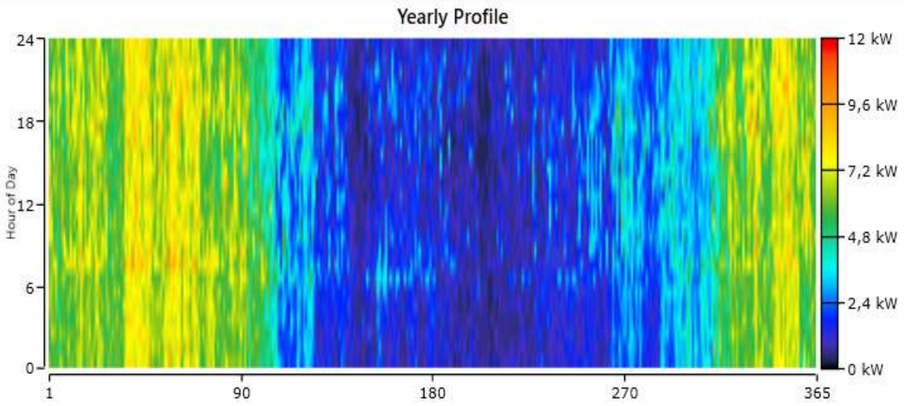

Figure 4-3 Yearly profile detached house -166m2

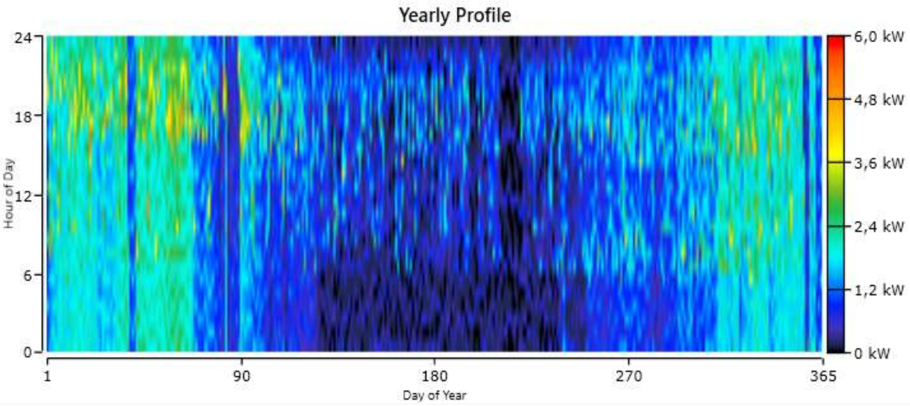

Figure 4-4 Yearly profile of Semi-detached house -128m2

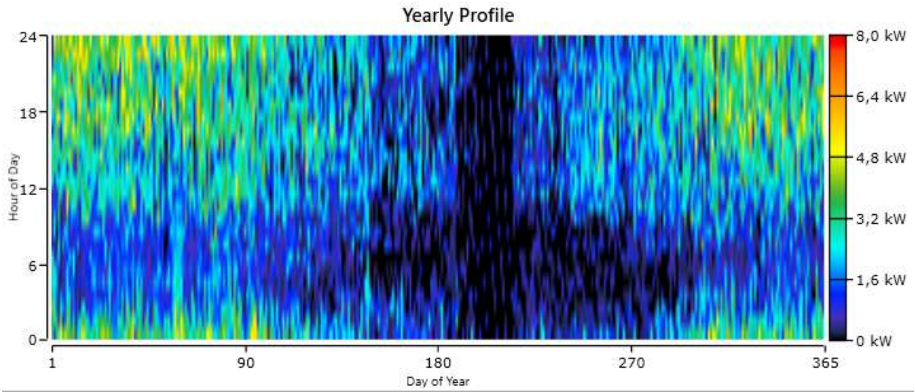

Figure 4-5 Yearly profile apartment - 70m2

In order to define the optimisation model for the selected scenarios, it was necessary to plot the energy consumption of the various devices for each building. This was done by disaggregating the hourly load presented in figures 4-4 to 4-5. The results are presented in figures 5-7, 5-9 and 5-11 showing the energy plot of the various devices in the three buildings.

Detached house:

The "building" has a relatively high power consumption. Considering the fact that it has 166 sqm floor area, 36 MWh annual consumption which is 34.8% higher than average national consumption for that floor area (SSB, 2012b). For this consumer the load exceeds 70% of peak load in 11.5% of the hours. This is two times higher than the frequency for similar case study by (Sæle, Ø, & Nordgård, 2016). Figure 4-2 and the histogram in figure 4-6 gives an illustration the on annual load pattern of this building.

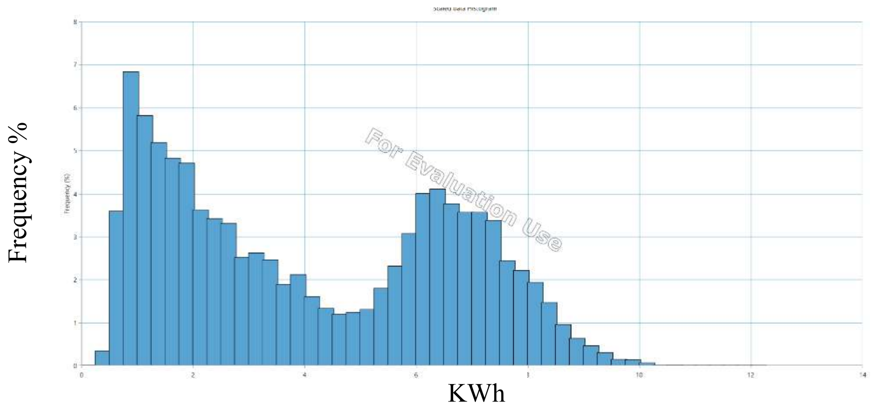

Figure 4-6 Detached house load profile histogram

The building consumption on studied day has a moderate peak load on 7 AM and a high peak load of 10.17 kWh/h at 5PM. This is probably the time that everybody came back home and using the electrical devices. The disaggregated load for this day presented in figure 4-7.

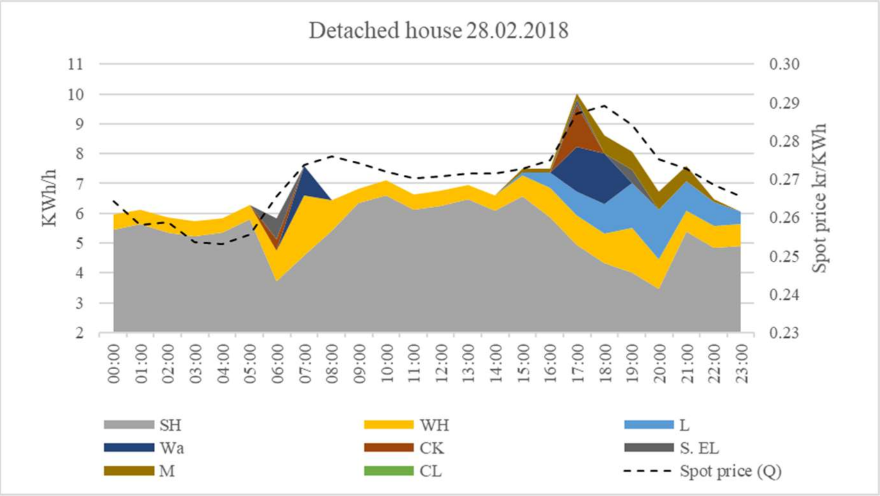

Figure 4-7 Disaggregated hourly load (Detached house)

Semi-detached house:

The building has relatively low and stable power consumption. The building has annual power consumption of 15.7 MWh which is equal to just 62.5% of average national power consumption for 128m^2 floor area. The building also does not have frequent peak load. According to information form load duration curve we can see that the consumer reached to 70% of its highest peak load in just 2% of the hours. See figure 4-8. The disaggregated load for electric appliances of this consumer presented in figure 4-9.

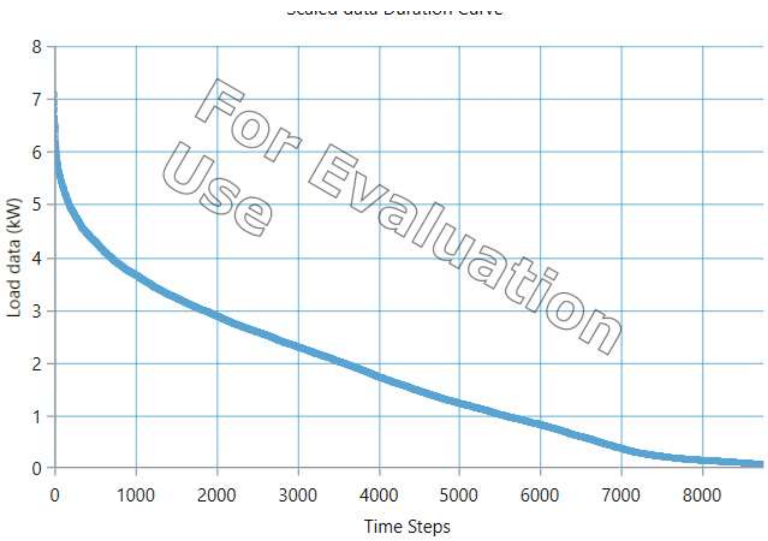

Figure 4-8 Semi-detached house load duration curve

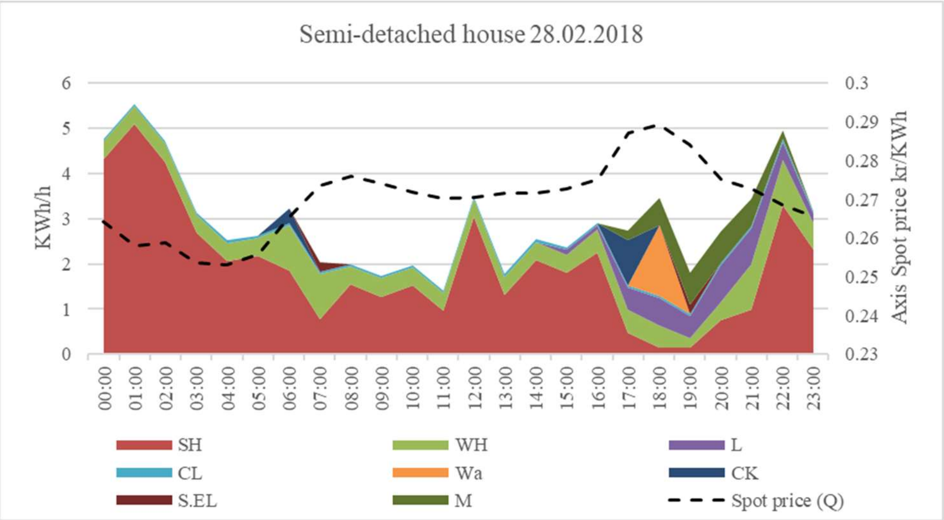

Figure 4-9 Disaggregated hourly load (Semi-detached house)

Apartment:

This building has the lowest floor area among studied cases. The building has a relatively stable power consumption during the year and on examined date. This is evident form the load duration curve for the building in figure 4-10. For this consumer the load exceeds 50% of the peak load on just 5% of the hours. The peak month for this profile is February.

It is common for apartments in Norway to rely on a shared central heating device for space heating needs. The figure 4-11 presents the disaggregated load for the building. This figure may suggest that the building has radiators connected to a central heating device. Since additional information about the building was not available, it was assumed that all buildings have its own heating system.

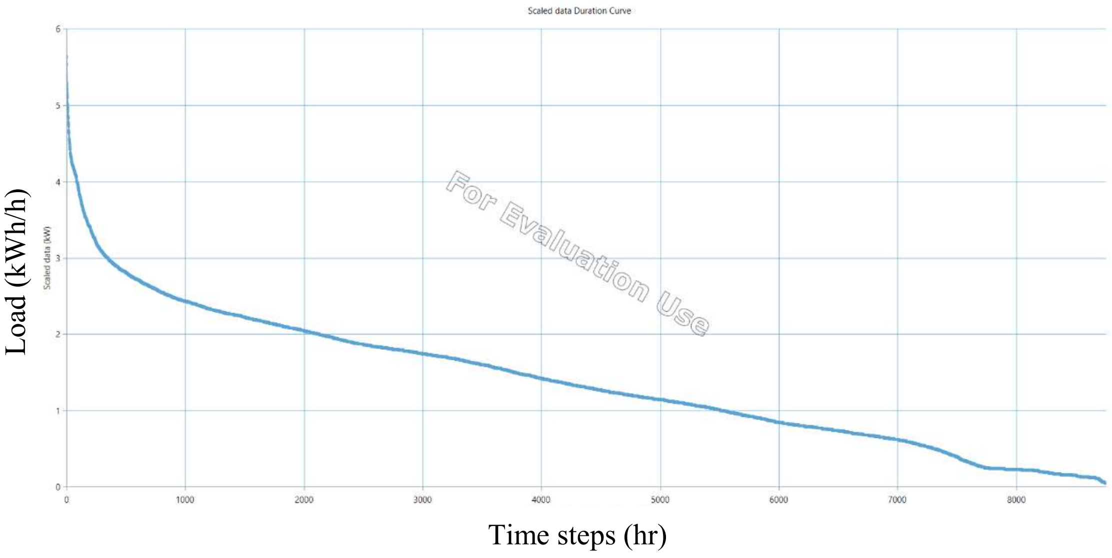

Figure 4-10 Apartment time duration curve

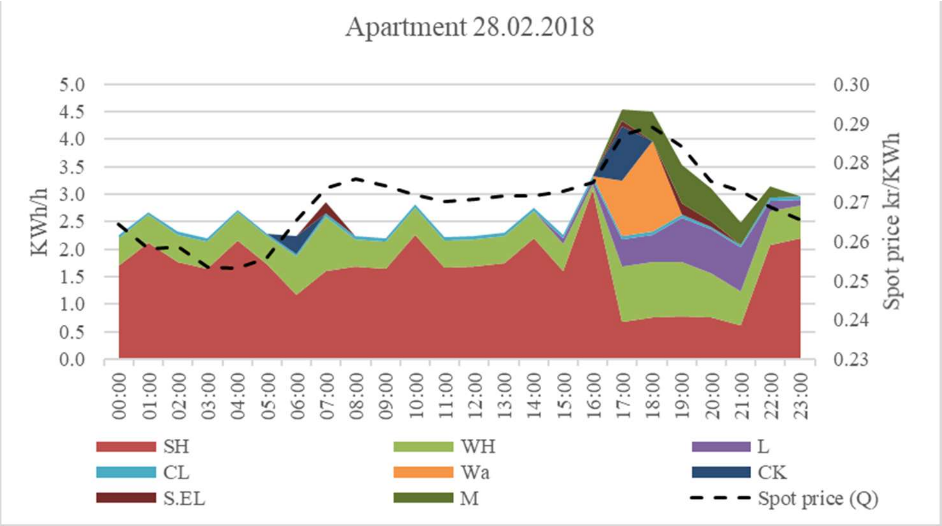

Figure 4-11 Disaggregated hourly load (Apartment)

5. Results and discussion

In this work, load shaving was not included in the calculations and in the optimisation model. Cutting the load of electric devices are directly related to consumer’s comfort, preferences and real needs. So, it was considered that making assumptions on this matter would be inaccurate and add further complexity to the optimisation model and scenario analysis.

However, there are many references suggesting measures for improving the efficiency in operation of electric devices also general energy saving at home (Bergesen et al., 2012; Dokka, hauge, thyholt, klinski, & kirkhus, 2009; Amir Kavousian et al., 2013; A. Kavousian et al., 2015). For instance, load cutting measure like using more energy efficient devices (e.g. heat pumps), turning off the lighting and heating devices after leaving home, changed showering and washing habits, installing water saver showers and others could reduce the consumption significantly. Appendix A has highlighted a few points related to this topic.

As it was indicated in chapter 4, this thesis has studied 6 different scenarios in the calculation of daily power cost in the buildings. For simplicity it was decided to limit the load shifting in the scenario analysis to the Water heater (WH) and Washing (Wa) devices.

Inherently, the load for washing devices are deferrable but also uninterruptible. So, in order to avoid spreading the load for washing to several hours through the day, a binary variable was defined to limit the number of washings per day. Therfore, the stimulation will not change the content of the load, but would change the time of consumption, and therefore change the total cost.

5.1 Scenario analysis

Scenario 1: Subscribed power

In this tariff model, the consumers are granted with a slightly higher degree of freedom by choosing a package that is more suited to their power demand. Compared to other proposed schemes, this tariff model has a more fair cost design to all customers, especially consumers with lower consumption. Since they pay according to the actual amount of power consumption ,they carry less of a burden from high consumers. The net tariff has both a fixed and a variable term. All consumers pay an annual fixed cost of 1060 kr and then choose a subscription with a certain amount of kW per hour. The minimum subscription could be 1kWh and each kWh would cost 689 kr/kWh. For the consumption within the range of the subscribed package, the consumer will pay just 5 øre/kWh. But exceeding the subscription costs 1kr/kWh, which is relatively high term. Therefore, the drawback of this model is that the consumers ought to be careful when choosing the right subscription size. Consumers need to choose the optimal size, otherwise they will either pay the penalty fee or pay for an oversized package. However, with analyses of the historical electricity consumption of the consumer, the subscription size could easily be estimated.

By assuming the β_A (kr/year) as the fixed part of annual grid tariff cost, the γ (kWh/h) standing for size of subscription package and M for variable part of the annaul cost of grid. Also P_{high} (kr/kWh/day) assumed as the penalty rate for over consumption beyond subscription $W_{d,t\ high}$ is the hourly consumption exceed than subscription size, P_{low} as the variable cost of grid tariff and $W_{d,t}$ (kWh) as the total hourly power consumption. The $Q_{d,t}$ is the electricity spot price (kr/kWh) at day *d* and time *t*. Furthermore, the hourly load for the 8 category of equipment defined per (kWh/h) and at hour t and day d. The sign for equipments defined as following: Sh, stand for space heating. Wh stand for water heater. L stand for lighting. Cl stand for cooling. Wa stand for washing. Ck stand for cooking. M stand for media and S.el stand for small electric appliances.

The costs related to energy, grid rent and taxes are written as:

$$[1]\ Net\ tariff = \beta_A + \gamma m + \sum_{d=1}^{365}\sum_{t=1}^{24} P_{low} * W_{d,t} + \sum_{d=1}^{365}\sum_{t=1}^{24} P_{hig} * W_{d,t\ high}$$

$$\forall \ W_{d,t_{high}} = \sum_{d=1}^{365} \sum_{t=1}^{24} (W_{d,t} - \gamma)$$

$$[2]\ Energy\ cost = \sum_{d=1}^{365} \sum_{t=1}^{24} Q_{d,t} * W_{d,t}$$

$$[3] Taxes^{8} = (Net\ tariifs + Energy\ cost\ ) * 32\%$$

The cost minimization equation for subscribed power tariff by use of equation 1, 2 and 3 could be written as follows.

$$[4] Min\ Z = \left(\sum_{d=1}^{365} \sum_{t=1}^{24} P_{low} * W_{d,t} * Q_{d,t} + \sum_{d=1}^{365} \sum_{t=1}^{24} P_{high} * W_{d,t\ high} + \beta_A + \gamma * m \right) * 1.32$$

$Subject\ to$:

$$[5]\ W_{d,t} = \sum_{d=1}^{365} \sum_{t=1}^{24} Sh_{d,t} + Wh_{d,t} + L_{d,t} + Cl_{d,t} + Wa_{d,t} + Ck_{d,t} + M_{d,t} + Sel_{d,t}$$

$$[6]\ W_{d,t_{high}} = \sum_{d=1}^{365} \sum_{t=1}^{24} (W_{d,t} - \gamma)$$

$\beta_A = 1060\ kr/year$
$m = 689\ kr\ per\ kW\ \ subscription$
$P_{low} = 0.05\ kr/kWh$
$P_{high} = 1\ kr/kWh$

$\gamma = Subscription\ package\ size\ kWh/h$

In this scenario, it was assumed that the detached house has a subscription for an energy package of 8 kWh/h. Also, an energy package of 4 kWh/h was considered for both the semi-detached house and the apartment. However, it might be wise to run an optimization on the package size when calculating the total annual cost.The results of above optimization model on studied date presented in table 6.

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[8] VAT + energy consumption taxes on 2018

Date: 28.feb.2018	Detached house	Semi-detached	Apartment
Before optimization	74 NOK	36.5 NOK	32.3 NOK
After optimization	71 NOK	34.5 NOK	31.2 NOK

Table 6 Energy cost based on scenario 1. on studied date. (Excl. taxes)

As seen, the optimisation has reduced the daily power cost for the detached, semi-detached and the apartment respectively by 4%, 5% and 3%. Also in the detached house, as it's evident from the results of the optimization presented in figure 5-1, the stimulation has shifted the load for the water heater and the washing to hours with lower consumption. So the new load profile is more stable around 8 kW, which also coincides with the package limit to avoid the penalty fee for over consumption. The optmisation has shifted 20% of the peak load for detached house, 7% for for the semi-detached and 12% for the apartment. This means that the new load curves are much more flat and stable during the day. If the load shifting is applied to all winter days, the total cost of the grid tariff will be reduced from 8655 kr to 8097 kr. The annual cost of the grid tariff for the apartment and the semi-detached house based on primary load is 4462 kr and 5068 kr respectively.

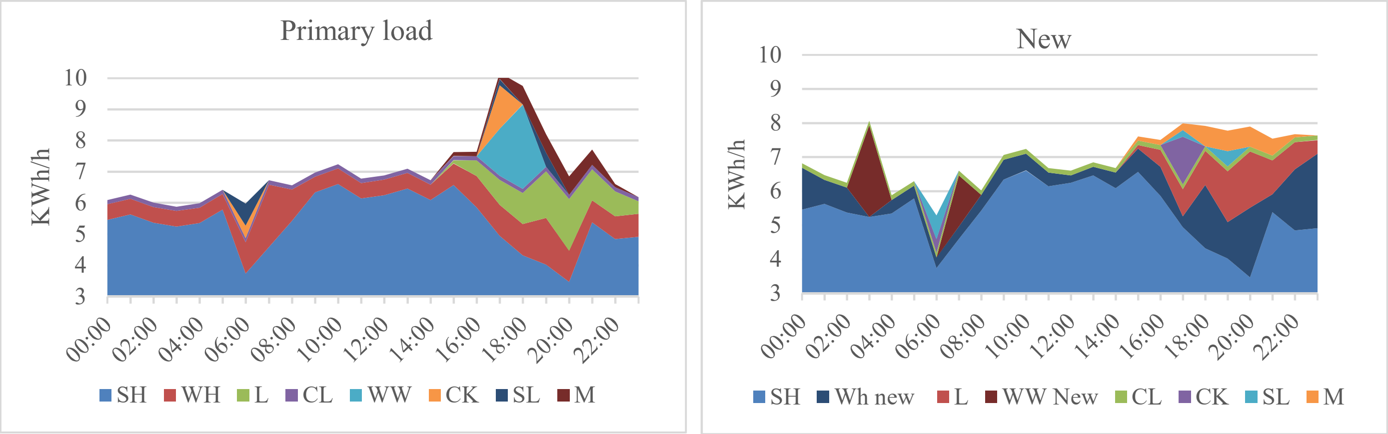

Figure 5-1 Scenario 1. detached house primary load (left) and after load shifting (right)

Scenario 2: Energy tariff

This tariff model is more simple. The consumers pay an annual fixed cost of 1749 kr and pay a variable cost of 19.4 øre/kWh. This model is to some extent close to what is applied today. In this tariff scheme, both high and low consumers pay the same fixed cost and variable rate for their usage. Supposedly, this tariff model due to constant vaiable pricing may not incentivize all consumers to lower their consumption on peak hours. Although it possibly help to reduce the total consumption load as the variable rate is relatively high .

The cost minimization equation for energy tariff could be written as:

$$[7]\, Net\ tariff = \beta + \sum_{d=1}^{365} \sum_{t=1}^{24} P * W_{d,t}$$

$$[8] Energy\ cost = \sum_{d=1}^{365} \sum_{t=1}^{24} Q_{d,t} * W_{d,t}$$

$$[9] Taxes = (Net\ tariifs + Energy\ cost\ ) * 32\%$$

Here, β (kr/year) is the fixed part of annual grid tariff cost, P (kr/kWh)is the rate for the variable net cost and $W_{d,t}$ (kWh) is the total hourly power consumption. Also, the $Q_{d,t}$ is the electricity spot price (kr/kWh) at day *d* and time *t*. Furthermore, the hourly load for the 8 category of equipment defined per (kWh/h) and at hour t and day d. The sign for equipments defined as following: Sh, stand for space heating. Wh stand for water heater. L stand for lighting. Cl stand for cooling. Wa stand for washing. Ck stand for cooking. M stand for media and S.el stand for small electric appliances.

Therefore, the cost minimisation model could written as:

$$[10]\ Min\ Z = \left(\beta + \sum_{d=1}^{365} \sum_{t=1}^{24} P * W_{d,t} * Q_{d,t}\right) * 1.32$$

$$[11]\ W_{d,t} = \sum_{d=1}^{365} \sum_{t=1}^{24} Sh_{d,t} + Wh_{d,t} + L_{d,t} + Cl_{d,t} + Wa_{d,t} + Ck_{d,t} + M_{d,t} + S.el_{d,t}$$

$Subject\ to$:

$\beta = 1749\ kr/year$

$P = 0.194\ kr/kWh$

The result of the optimisation on the selected buildnings are presenteded in table 6.

Table 7 Energy cost(kr) on studied date based on scenario 2. (Excl.taxes)

Date: 28.feb.2018	Detached house	Semi-detached	Apartment
Before optimization	82	37.3	35.2
After optimization	81	37	34.9

In this scenario, the grid tariff is constant during the day. So the difference between the optimized and non-optimized results is related to shifting the consumption to hours with a lower spot price. However, variation of hourly spot price on this day is just a few øre/kWh, therefore the effect on the total cost is very small. The annual cost of the grid tariff based on primary load in this scenario is 8725 kr for the detached house, 4797 kr for the semi-detached and 4121 kr for the apartment. Fiugure 5-2 illustrates how the stimulation changed the consumption pattern of water heater for a very little cost effect. The resulted profile has a 179% higher peak load than original profile, while the total power cost is slightly reduced.

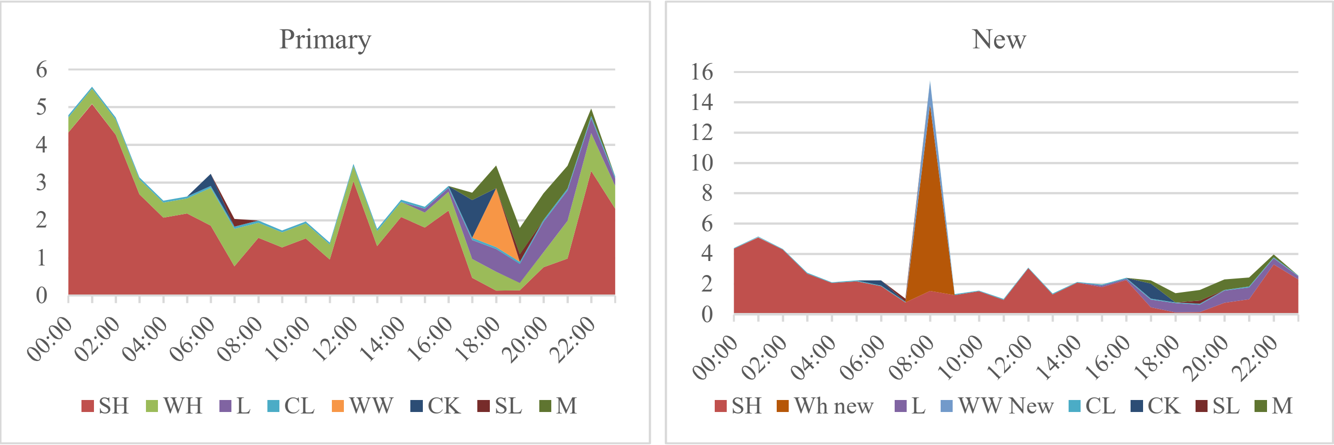

Figure 5-2 Scenario 2. Semi-detached house primary load (left) and after load shifting (right)

Scenario 3: Observed power

This tariff model has a more creative design. The tariff is composed of 3 parts, a fixed annual cost, a variable rate per kWh and a penalty fee for the highest consumption of each day. The fixed cost is 1749 kr per year, the energy cost is 5 øre/kWh and the penalty fee is 1,86 kr/kWh/h. For this tariff scheme, the consumers would be incentivized to lower their daily peak hour consumption in order to pay a lower penalty.

The cost minimization equation for the observed power could be written as:

$$[12]\ Net\ tariff = \beta + \sum_{d=1}^{365}\sum_{t=1}^{24} P_{low} * W_{d,t} + \sum_{d=1}^{365} P_{high} * W_{dn_{max}}$$

$$[13]\ Energy\ cost = \sum_{d=1}^{365}\sum_{t=1}^{24} Q_{d,t} * W_{d,t}$$

$$Taxes = (Net\ tariifs + Energy\ cost\ ) * 32\%$$

Where β (kr/year) is the fix part of annual grid tariff, P (kr/kWh) is the rate for variable net cost ,$W_{d,t}$ (kWh) is the total hourly power consumption and W_{max} (kWh) is the highest hourly consumption per day . The $Q_{d,t}$ (kr/kWh)is the spot price at time *t* and day *d*, and P_{high} (kr/kWh) is the penalty rate for highest consumption of each day. Also, the sign for equipments defined as following: Sh, stand for space heating. Wh stand for water heater. L stand for lighting. Cl stand for cooling. Wa stand for washing. Ck stand for cooking. M stand for media and S.el stand for small electric appliances. Therefore, the cost minimisation problem could be written as:

$$[14] Min\ Z = \left(\beta + \sum_{d=1}^{365}\sum_{t=1}^{24} P_{low} * W_{d,t} * Q_{d,t} + \sum_{d=1}^{365} P_{high} * W_{dn_{max}}\right) * 1.32$$

$Subject\ to$:

$$[15]\ W_{d,t} = \sum_{d=1}^{365}\sum_{t=1}^{24} Sh_{d,t} + Wh_{d,t} + L_{d,t} + Cl_{d,t} + Wa_{d,t} + Ck_{d,t} + M_{d,t} + S.el_{d,t}$$

$\beta = 1749$ (kr/year)

$P_{low} = 0.05$ (kr/kWh)

P_{high} =1.86 (kr/kWh)

The result of the above optimisation function for the selected buildings are presented in table 8.

By optimising the consumption, load shifting resulted in over 6% reduction in power costs for the detached house, 2.4% for the semi-detached and 5.9% for the apartment. Additionally, an associated reduction of 25% in peak load of the day is experienced for the detached house. Assuming 25% peak load reduction for all winter day,s the annual grid payments will be reduced from 7463 kr to 6789 kr (9% reduction). See figure 5-3 for details. The corresponding figures for the semi-detached house and the apartment are 7% and 21.6%, respecitively. The peak load reduction is 2.2% for the semi-detached house and 5.3% reduction for the apartment.

Table 8 Daily energy cost(kr) on studied date based on scenario 3. (Excl. taxes)

28.feb.2018	Detached house	Semi-detached	Apartment
Before optimization	76.7	37.4	34
After optimization	72	36.5	32

Figure 5-3 Scenario 3 detached house primary load (left) and after load shifting (right)

Scenario 4: Time of use

Time of use tariff models are widely used worldwide. In this model the TSO determines a few hours with higher energy prices than other hours. This istypically the peak hours in the grid. The advantage of this tariff model, from the TSO point of view, is that the TSO can set a price target at the hours which typically experience a higher demand. The consumers will reduce the consumption to avoid the high cost and therefore the TSO can handle the capacity challenges on the grid. The proposed tariff from NVE includethree variable elements. The rate of energy consumption during summer season are fixed to 12.2 øre/kWh, which is almost 80% of the consumption on off-peak hours during the winter (15.2 øre/kWh). In this tariff model, the peak hours are defined from 06:00 to 20:00 on winter days and the rate for this time of day is 38øre/kWh ,which is 250% higher than off-peak hours. According to the report, the winter time in this model is defined from the start of November to the end of March. The various equations below define the tariff scheme:

$$[16]\ Net\ tariff = \beta + \sum_{d=1}^{90}\sum_{t=1}^{24} P_\alpha * \alpha_{d,t} * W_{d,t} + \sum_{d=304}^{365}\sum_{t=1}^{24} P_\alpha * \alpha_{d,t} * W_{d,t} + \sum_{d=90}^{304}\sum_{t=1}^{24} P_{summer} * W_{d,t}$$

$$[17]\ Energy\ cost = \sum_{d=1}^{365}\sum_{t=1}^{24} Q_{d,t} * W_{d,t}$$

$$Taxes = (Net\ tariffs + Energy\ cost\ ) * 32\%$$

Where β (kr) is the fix part of annual grid tariff, P (kr/kWh) is the rate for variable net cost which defined at 3 rates , summer time price P_{summer} (kr/kWh), winter peak hour $P_{\alpha=1}$ (kr/kWh) and winter off-peak $P_{\alpha=0}$(kr/kWh) . Also $W_{d,t}$ (kWh) is the total hourly power consumption and the $Q_{d,t}$ (kr/kWh) s the hourly spot price. Also, the sign for equipments defined as following: Sh, stand for space heating. Wh stand for water heater. L stand for lighting. Cl stand for cooling. Wa stand for washing. Ck stand for cooking. M stand for media and S.el stand for small electric appliances.

Therefore, the cost minimisation model could be written as:

$$[18] Min\ Z = \left(\beta + \sum_{d=1}^{90}\sum_{t=1}^{24} P_\alpha * \alpha_{d,t} * W_{d,t} + \sum_{d=304}^{365}\sum_{t=1}^{24} P_\alpha * \alpha_{d,t} * W_{d,t} + \sum_{d=90}^{304}\sum_{t=1}^{24} P_{summer} * W_{d,t} + \sum_{d=1}^{365}\sum_{t=1}^{24} Q_{d,t} * W_{d,t}\right) * 1.32$$

$Subject\ to:$

$$[19]\ W_{d,t} = \sum_{d=1}^{365}\sum_{t=1}^{24} Sh_{d,t} + Wh_{d,t} + L_{d,t} + Cl_{d,t} + Wa_{d,t} + Ck_{d,t} + M_{d,t} + Sel_{d,t}$$

$\beta = 1749\ kr$
$P_{summer} = 0.122\ kr/kWh$
$P_{\alpha=1} = 0.38\ kr/kWh$

$P_{\alpha=0} = 0.152\ kr/kWh$

The annual grid tariff based on the primary load is 10216 kr for the detached house, 5241 kr for the semi-detached and 4535 kr for the apartment. Compared to the other 3 alternatives, this tariff model gives a higher energy cost for the end-user. Calculation of the total yearly savings due to load shifting was not done in this scenario due to due to a much more complicated equation. Althoug the stimulation results are presented on figure 5-4 and appendix C4.

The result of above optimisation equation on studied buildnings presented in tabel below:

Table 9 Energy cost (kr) based on scenario 4. Excl. taxes

28.feb.2018	Detached house	Semi-detached	Apartment
Before optimization	98,7	41,9	41,5
After optimization	96,9	40,9	40,18

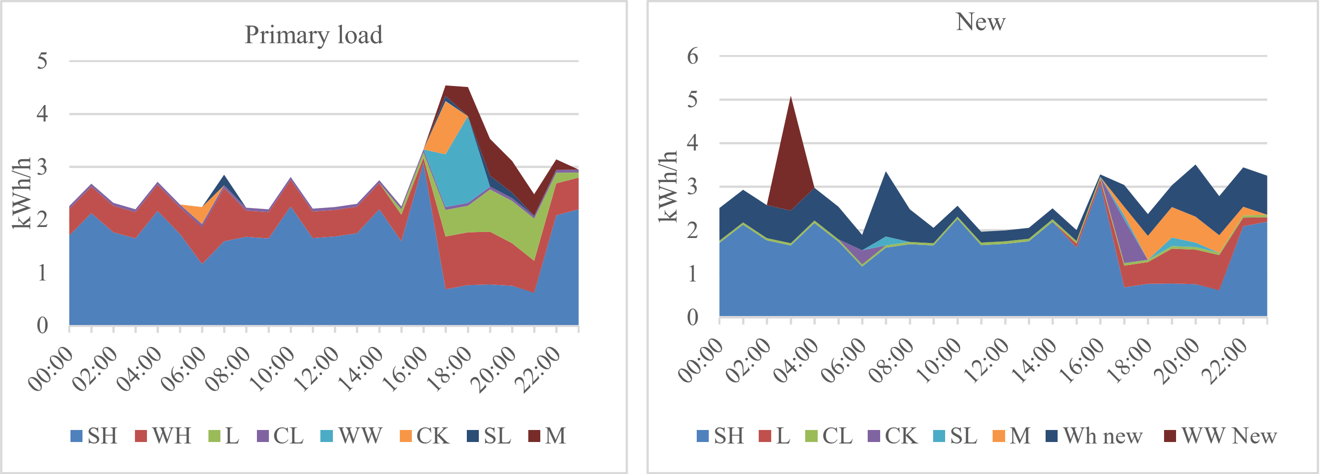

Figure 5-4 Scenario 4. Apartment primary load (left) and after load shifting (right)

Scenario 5: PV-battery system

Energy storage (e.g. batteries) are a flexible technolgy that can relieve capacity shortages in the distribution grid. As it was discussed in chapter 2.4.3, use of storage units can potentially reduce the energy cost in buildings. This scenario is an attempt to search for a meaningful energy cost reduction in a household, by assuming the use of energy storage units together with on-site production.

A series of assumptions were made in the calculations for this scenario. Like the first three scenarios, disaggregated energy consumption profiles were tested in a situation with spot prices for energy costs, with the observed power (målt effekt) as net tariff. So the new tariff would be tested against a situation with solar power production and energy storage units installed in a detached house in this scenario. The cost optimization for this scenario includes non-linear functions, and normal optimization tools was not able to solve the model. Therefore, this study used an energy management software called Homer Grid .

The input information about solar radiation for the Oslo area was obtained from the NASA Surface meteorology and Solar database (SSE) which is the monthly average value over a 22 year period (July 1983-June 2005). The values of available solar energy in the area was applied to calculate the power output of solar panels in the Homer software.

In this scenario, it was assumed that flat PV with an installed capacity of 13.3 kW were placed on the roof of the detached house and paired with a generic 1 kWhli-ion battery. The solar panels for this stimulation produced 13 MWh during the year, where 8.5MWh of this were consumed in the building. Also, due to large production in the summer time 4.6, MWh has been sold back to the grid. Figure 5-6 presents an overview of hourly generated power.

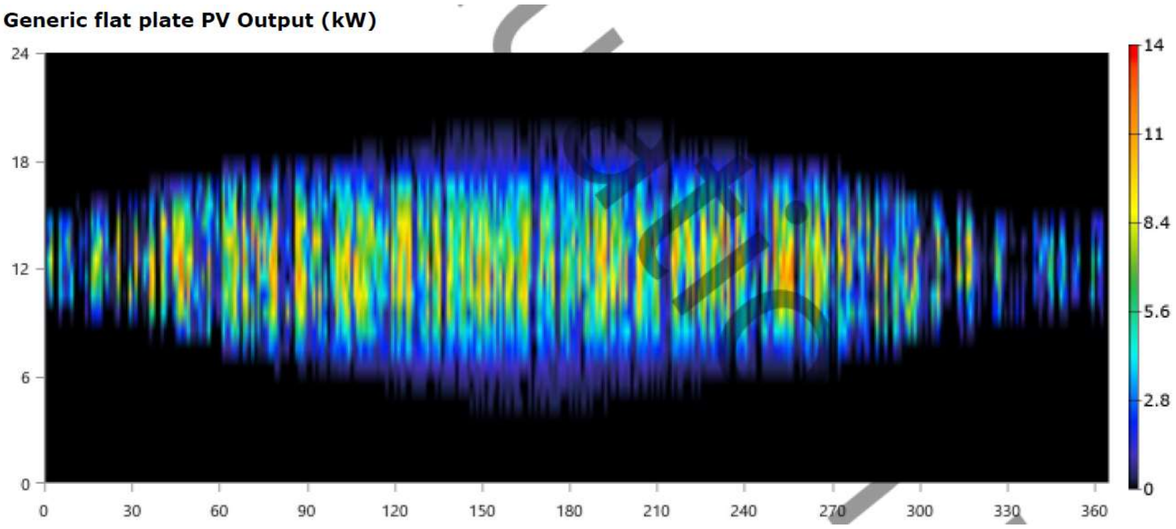

Figure 5-5 PV hourly power generation at detached house

More details about produced and consumed power can be found in Appendix D.

The Levelised Cost of Energy (LCOE) has been calculated for this scenario by summing all the costs incurred during the lifetime of the PV and batteries divided by the kWh of energy produced during the lifetime of the project. Since the solar cells and batteries have different lifetime, the LCOE was calculated separately for each one. The LCOE before taxes for solar cells with 25 years lifetime is 122 øre/kWh and 52,5 øre/kWh for the battery with 15 years of operational life. It is expected that the investment cost for solar cells and batteris further decrease in next 10 years. If these cost reduction happen according to NVE's estimations , it would be expected that LCOE for PV on 2035 would be around 59 øre/kWh. reportbattery storage is still high and therefore made it an expensive investment choice. Furthermore, if the idea of energy independent buildings (Zero Energy Buildings) selling their extra produced power back to the grid become possible in near future there will be more opportunity to exploit.
The calculation for LCOE can be found in appendix E.

Figure 5-6 shows the solar power production on the 28th of February (the brown curve at the bottom). The on-site production is around 3 kWh on this winter day and consumed directly. So, the cost savings from the production is very little for this day. The red line in the figure represents the primary load of the building which is reduced according to the production. It is evident from the graph that the PV production did not affect the peak load of the day. Therefore, the consumer still will meet the same penalty costs of 1.86 kr/kWh for the highest consumption of the day.

Figure 5-7 gives detailed information about the contribution of the storage device in the system along with PV production.

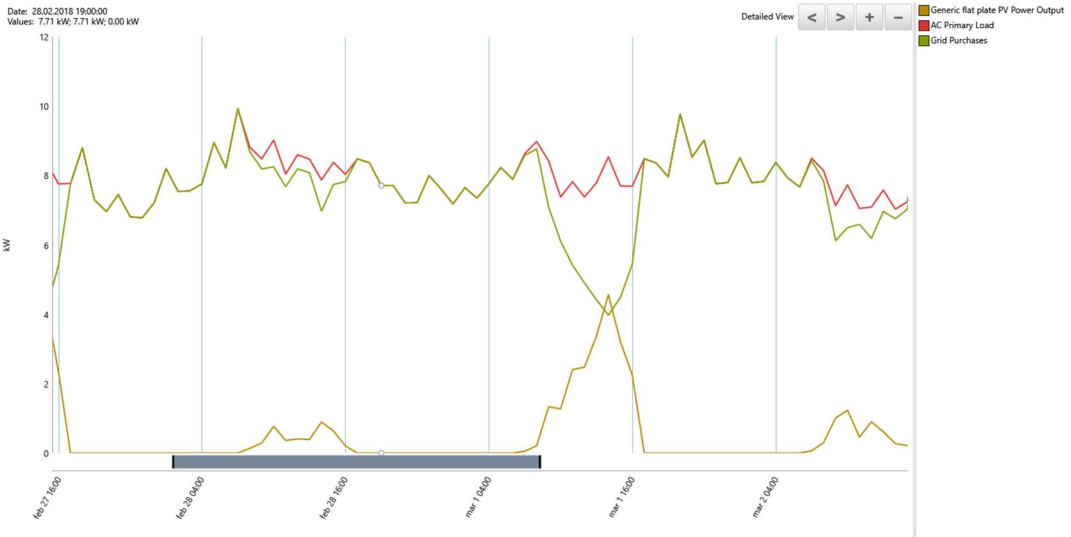

Figure 5-6 Hourly load profile and PV production

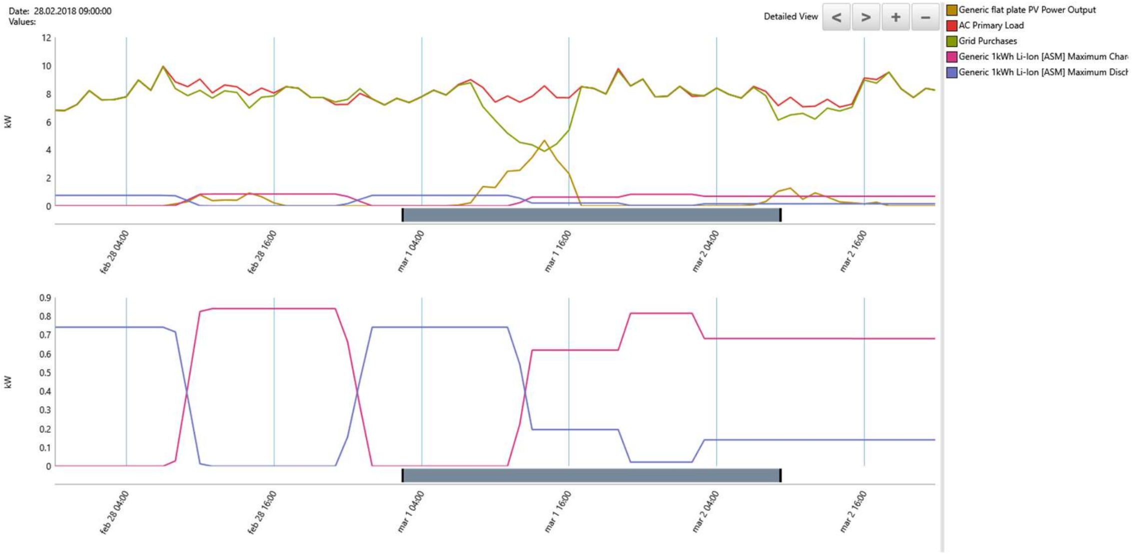

Figure 5-7 Hourly consumption and battery load for detached house

6. Conclusion

Distribution system operators (DSO) planning a transit from an energy based net tariff to a capacity based tariff. This study was aimed at evaluating the financial cost associated with this change to the end-users. The results of the various tariffs showed that subscribed power and observed power respectively gives the lowest costs. It's very likely that there is high potential for demand response in these tariff models.

However, by observing the results of the optimization, we can strongly claim that the observed power (Målt effekt) by far is the best tariff alternative for both the consumer and the operator. Since it gives the lowest total cost and the highest reduction of peak load on the grid. Further, it creates enough incentives for the costumer to change his consumption behavior.

However, considering the fact that the use of batteries and solar cells (studied on scenario 6) could facilitate even higher levels of load shifting. Beside the fact that on-site production not only assists to reduce the demand pressure on the grid, but also selling the power back to the grid can amount to 14% of annual electricity costs. On the other hand, the cost of generating power is reasonable and it is expected that the investment costs for solar panels will further decrease in the future.

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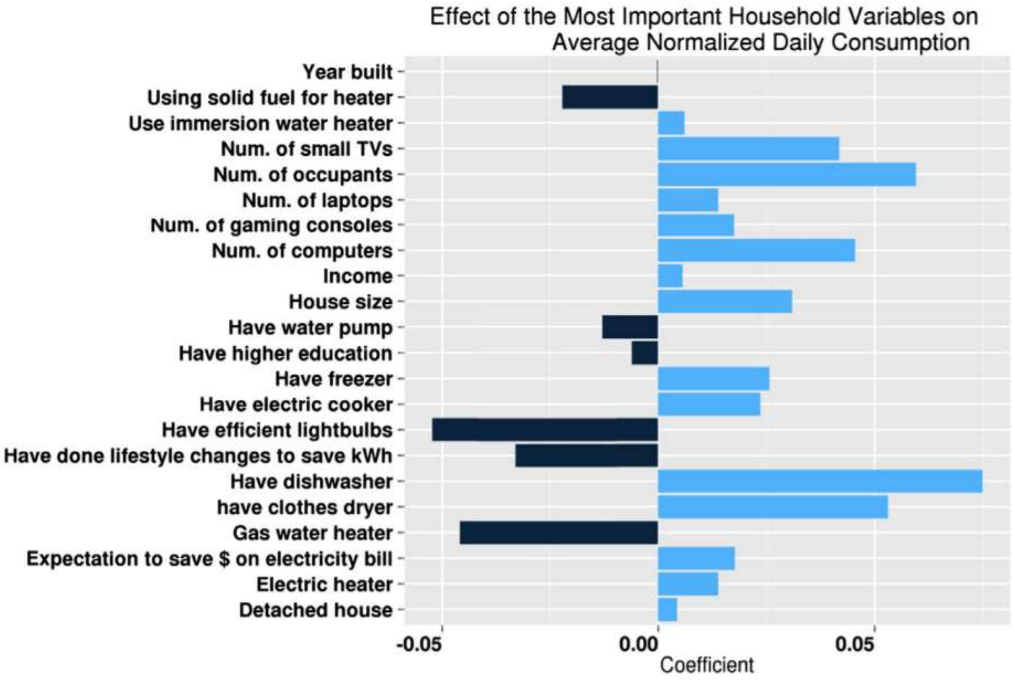
Appendix

Appendix A

The results of a study carried out on Irish household showing the magnitude of correlation between type and number appliances with daily power consumption.(A. Kavousian et al., 2015)



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Appendix B.1

Table 10 Annual disaggregated load for a semi-detached house

Electric appliances	Semi-detached house Family without kids (kWh).[9]	Household more than two persons (kWh).[10]	Average annual (kWh)
Space heater	-	-	9920
Water heater	-	2600	2600
Lightning approx.20spot	706	1000	853
Cooling	461	322	391.5
– *Refrigerator with freezer*		322	
Washing	455	492	474
– *Washing machine*		128	
– *Clothes dryer*		196	
– *Dishwasher*		168	
Cooking	600	262	431
– *El. Cooker/oven*		235	
– *Microwave oven*		27	
Small El	120		120
– *Water kettle*			
– *Hair dryer*			
– *Toaster*			
– *Vacuum cleaner*			
Media	1093	747	920
– *PC*	334	176	
– *Laptop*	74	80	
– *Router*	54	80	
– *Wireless AP*	130	78	
– *Printer*	-	-	
– *TV LCD*	415	220	
– *Hi-Fi*	69	100	
– *DVD player*	17	13	
Semi-detached house nnual observed electricity consumption KWh			15709

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[9] (Langseth et al., 2011)

[10] (Grinden & Feilberg, 2009)

Appendix B.2

Table 11 Appliances energy demand distribution for a semi-detached house

Electrical appliances	Winter*		Summer**		Total	
	kWh	percent	kWh	percent	kWh	percent
Space heating	7134	66 %	2786	57 %	9920	63.1 %
Water heater	1870	17 %	730	15 %	2600	17 %
Lighting	613	6 %	240	5 %	853	5 %
Cooling	196	2 %	196	4 %	391.5	2 %
Washing	237	2 %	237	5 %	474	3%
Cooking	216	2 %	216	4 %	431	3 %
Small el.	60	0.56 %	60	1 %	120	0.76 %
Media	460	4 %	460	9 %	920	5.9 %

*Winter: Nov, Dec, Jan, Feb, May, April
**Summer: May, June, July, Aug, Sept, Oct

Table 12 Appliances energy demand distribution for a apartment

Electrical appliances	Winter*		Summer**		Total	
	kWh	percent	kWh	percent	kWh	percent
Space heating	4861	58 %	1871	48 %	6732	55.1 %
Water heater	1878	22 %	722	19 %	2600	21.0 %
Lighting	522	6 %	201	5 %	723	6.0 %
Cooling	186	2 %	186	5 %	372	3.0 %
Washing	284	3 %	284	7 %	567	5.0 %
Cooking	159	2 %	159	4 %	317	3.0 %
Small el.	83	1 %	83	2 %	165	1.0 %
Media	374	4 %	374	10 %	748	6.0 %

*Winter: Nov, Dec, Jan, Feb, May, April
**Summer: May, June, July, Aug, Sept, Oct

Appendix B.3

Table 13 *Annual disaggregated load for a apartment*

Electric appliances	Flat single husehold (kWh).[11]	Household more than two persons (kWh).[12]	Average annual (kWh)
Space heater			6732
Water heater	-	2600	2600
Lightning	446	1000	723
Cooling	422	322	372
– *Refrigerator with freezer*		322	
Washing	642	492	567
– *Washing machine*		128	
– *Clothes dryer*		196	
– *Dishwasher*		168	
Cooking	396	238	317
– *El. Cooker/oven*		235	
– *Microwave oven*		3	
Small El	165		165
– *Water kettle*			
– *Hair dryer*			
– *Toaster*			
– *Vacuum cleaner*			
Media	749	747	748
– *PC*	334	176	
– *Laptop*	74	80	
– *Router*	54	80	
– *Wireless AP*	130	78	
– *Printer*	-	-	
– *TV LCD*	415	220	
– *Hi-Fi*	69	100	
– *DVD player*	17	13	
Semi-detached house nnual observed electricity consumption KWh			12224

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[11] (Langseth et al., 2011)

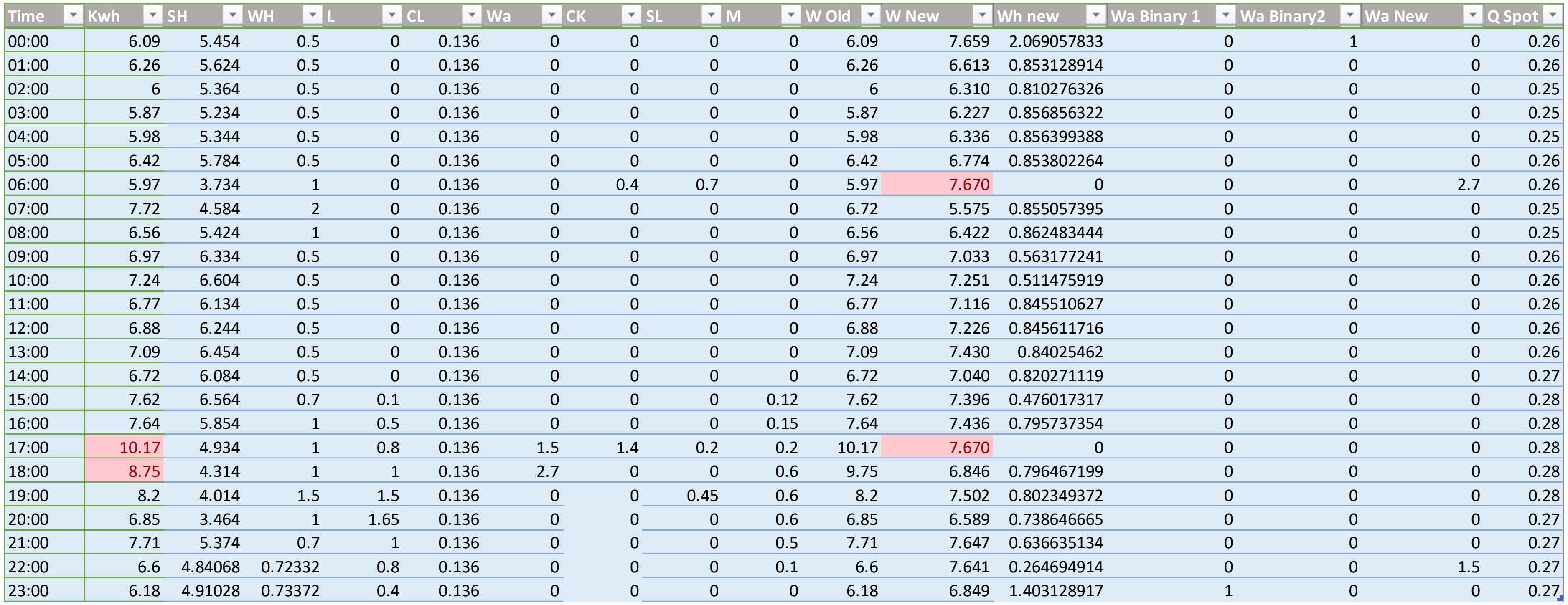
[12] (Grinden & Feilberg, 2009)

Appendix C.

Calculation for energy cost and optimization of energy profile based on the 4 tariff models , for the water heater and washing using Solver.

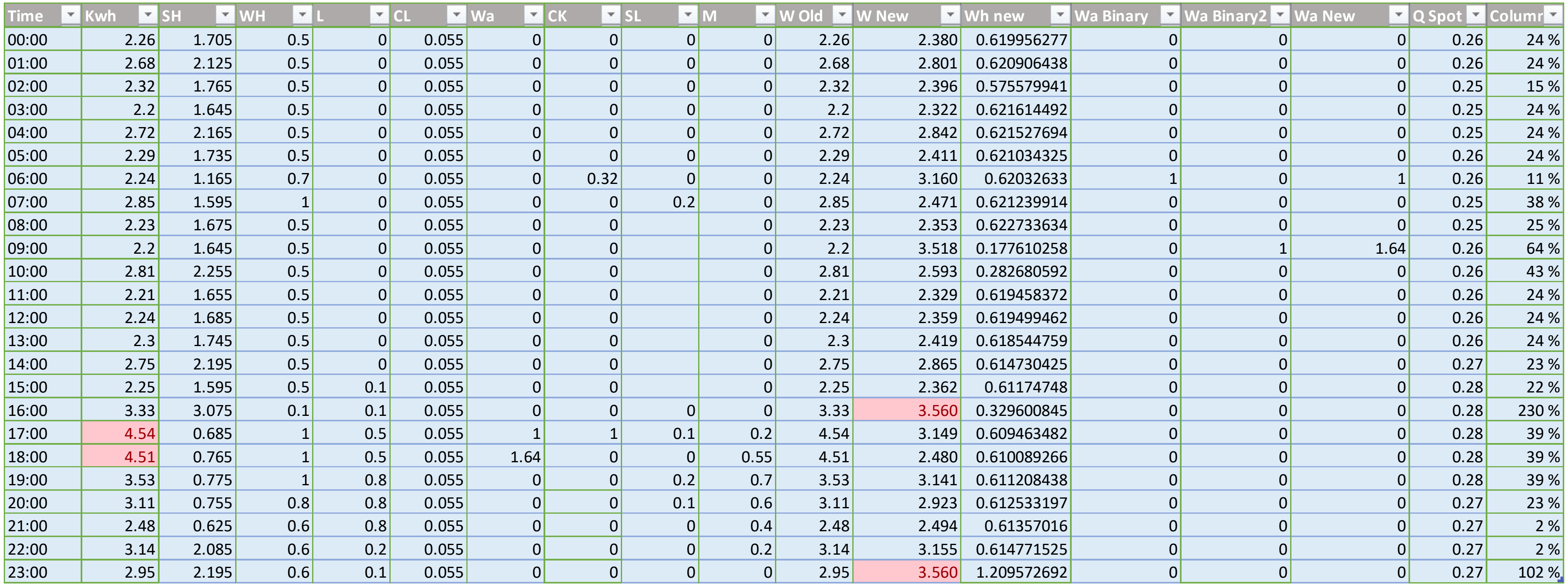
Appendix C.1

- Optimization spreadsheet for the detached house on Observed power tariff 28.feb.2018



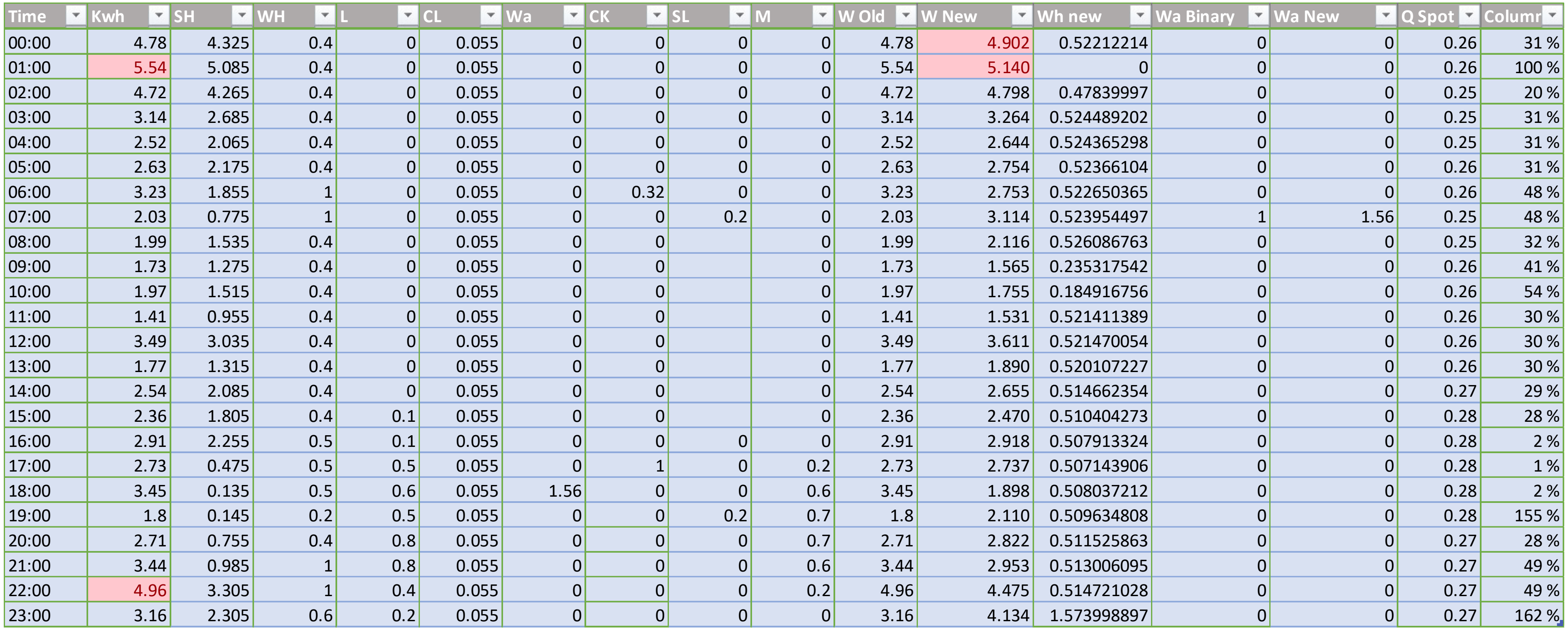
Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa Binary 1	Wa Binary2	Wa New	Q Spot
00:00	6.09	5.454	0.5	0	0.136	0	0	0	0	6.09	7.659	2.069057833	0	1	0	0.26
01:00	6.26	5.624	0.5	0	0.136	0	0	0	0	6.26	6.613	0.853128914	0	0	0	0.26
02:00	6	5.364	0.5	0	0.136	0	0	0	0	6	6.310	0.810276326	0	0	0	0.25
03:00	5.87	5.234	0.5	0	0.136	0	0	0	0	5.87	6.227	0.856856322	0	0	0	0.25
04:00	5.98	5.344	0.5	0	0.136	0	0	0	0	5.98	6.336	0.856399388	0	0	0	0.25
05:00	6.42	5.784	0.5	0	0.136	0	0	0	0	6.42	6.774	0.853802264	0	0	0	0.26
06:00	5.97	3.734	1	0	0.136	0	0.4	0.7	0	5.97	7.670	0	0	0	2.7	0.26
07:00	7.72	4.584	2	0	0.136	0	0	0	0	6.72	5.575	0.855057395	0	0	0	0.25
08:00	6.56	5.424	1	0	0.136	0	0	0	0	6.56	6.422	0.862483444	0	0	0	0.25
09:00	6.97	6.334	0.5	0	0.136	0	0	0	0	6.97	7.033	0.563177241	0	0	0	0.26
10:00	7.24	6.604	0.5	0	0.136	0	0	0	0	7.24	7.251	0.511475919	0	0	0	0.26
11:00	6.77	6.134	0.5	0	0.136	0	0	0	0	6.77	7.116	0.845510627	0	0	0	0.26
12:00	6.88	6.244	0.5	0	0.136	0	0	0	0	6.88	7.226	0.845611716	0	0	0	0.26
13:00	7.09	6.454	0.5	0	0.136	0	0	0	0	7.09	7.430	0.84025462	0	0	0	0.26
14:00	6.72	6.084	0.5	0	0.136	0	0	0	0	6.72	7.040	0.820271119	0	0	0	0.27
15:00	7.62	6.564	0.7	0.1	0.136	0	0	0	0.12	7.62	7.396	0.476017317	0	0	0	0.28
16:00	7.64	5.854	1	0.5	0.136	0	0	0	0.15	7.64	7.436	0.795737354	0	0	0	0.28
17:00	10.17	4.934	1	0.8	0.136	1.5	1.4	0.2	0.2	10.17	7.670	0	0	0	0	0.28
18:00	8.75	4.314	1	1	0.136	2.7	0	0	0.6	9.75	6.846	0.796467199	0	0	0	0.28
19:00	8.2	4.014	1.5	1.5	0.136	0	0	0.45	0.6	8.2	7.502	0.802349372	0	0	0	0.28
20:00	6.85	3.464	1	1.65	0.136	0	0	0	0.6	6.85	6.589	0.738646665	0	0	0	0.27
21:00	7.71	5.374	0.7	1	0.136	0	0	0	0.5	7.71	7.647	0.636635134	0	0	0	0.27
22:00	6.6	4.84068	0.72332	0.8	0.136	0	0	0	0.1	6.6	7.641	0.264694914	0	0	1.5	0.27
23:00	6.18	4.91028	0.73372	0.4	0.136	0	0	0	0	6.18	6.849	1.403128917	1	0	0	0.27

- Optimization spreadsheet for the apartment on Observed power tariff 28.feb.2018



Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa Binary	Wa Binary2	Wa New	Q Spot	Column
00:00	2.26	1.705	0.5	0	0.055	0	0	0	0	2.26	2.380	0.619956277	0	0	0	0.26	24 %
01:00	2.68	2.125	0.5	0	0.055	0	0	0	0	2.68	2.801	0.620906438	0	0	0	0.26	24 %
02:00	2.32	1.765	0.5	0	0.055	0	0	0	0	2.32	2.396	0.575579941	0	0	0	0.25	15 %
03:00	2.2	1.645	0.5	0	0.055	0	0	0	0	2.2	2.322	0.621614492	0	0	0	0.25	24 %
04:00	2.72	2.165	0.5	0	0.055	0	0	0	0	2.72	2.842	0.621527694	0	0	0	0.25	24 %
05:00	2.29	1.735	0.5	0	0.055	0	0	0	0	2.29	2.411	0.621034325	0	0	0	0.26	24 %
06:00	2.24	1.165	0.7	0	0.055	0	0.32	0	0	2.24	3.160	0.62032633	1	0	1	0.26	11 %
07:00	2.85	1.595	1	0	0.055	0	0	0.2	0	2.85	2.471	0.621239914	0	0	0	0.25	38 %
08:00	2.23	1.675	0.5	0	0.055	0	0		0	2.23	2.353	0.622733634	0	0	0	0.25	25 %
09:00	2.2	1.645	0.5	0	0.055	0	0		0	2.2	3.518	0.177610258	0	1	1.64	0.26	64 %
10:00	2.81	2.255	0.5	0	0.055	0	0		0	2.81	2.593	0.282680592	0	0	0	0.26	43 %
11:00	2.21	1.655	0.5	0	0.055	0	0		0	2.21	2.329	0.619458372	0	0	0	0.26	24 %
12:00	2.24	1.685	0.5	0	0.055	0	0		0	2.24	2.359	0.619499462	0	0	0	0.26	24 %
13:00	2.3	1.745	0.5	0	0.055	0	0		0	2.3	2.419	0.618544759	0	0	0	0.26	24 %
14:00	2.75	2.195	0.5	0	0.055	0	0		0	2.75	2.865	0.614730425	0	0	0	0.27	23 %
15:00	2.25	1.595	0.5	0.1	0.055	0	0		0	2.25	2.362	0.61174748	0	0	0	0.28	22 %
16:00	3.33	3.075	0.1	0.1	0.055	0	0	0	0	3.33	3.560	0.329600845	0	0	0	0.28	230 %
17:00	4.54	0.685	1	0.5	0.055	1	1	0.1	0.2	4.54	3.149	0.609463482	0	0	0	0.28	39 %
18:00	4.51	0.765	1	0.5	0.055	1.64	0	0	0.55	4.51	2.480	0.610089266	0	0	0	0.28	39 %
19:00	3.53	0.775	1	0.8	0.055	0	0	0.2	0.7	3.53	3.141	0.611208438	0	0	0	0.28	39 %
20:00	3.11	0.755	0.8	0.8	0.055	0	0	0.1	0.6	3.11	2.923	0.612533197	0	0	0	0.27	23 %
21:00	2.48	0.625	0.6	0.8	0.055	0	0	0	0.4	2.48	2.494	0.61357016	0	0	0	0.27	2 %
22:00	3.14	2.085	0.6	0.2	0.055	0	0	0	0.2	3.14	3.155	0.614771525	0	0	0	0.27	2 %
23:00	2.95	2.195	0.6	0.1	0.055	0	0	0	0	2.95	3.560	1.209572692	0	0	0	0.27	102 %

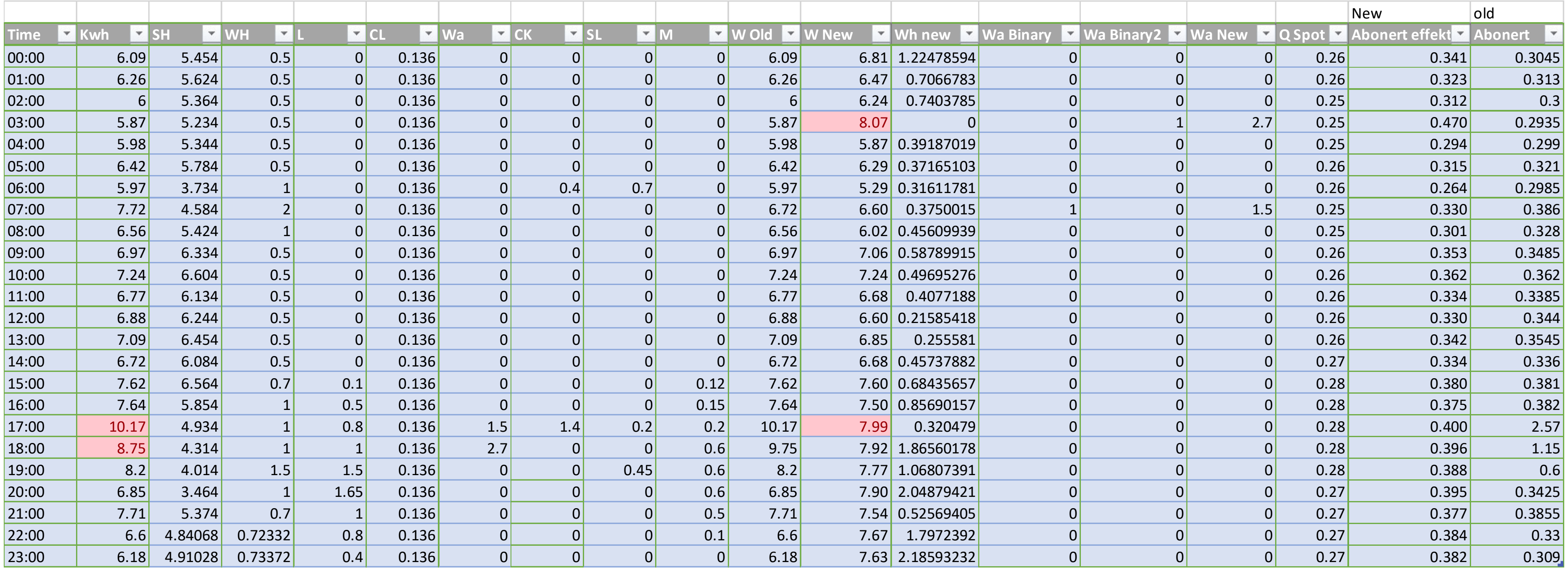
- Optimization spreadsheet for the semi-detached house on Observed power tariff 28.feb.2018



Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa Binary	Wa New	Q Spot	Columr
00:00	4.78	4.325	0.4	0	0.055	0	0	0	0	4.78	4.902	0.52212214	0	0	0.26	31 %
01:00	5.54	5.085	0.4	0	0.055	0	0	0	0	5.54	5.140	0	0	0	0.26	100 %
02:00	4.72	4.265	0.4	0	0.055	0	0	0	0	4.72	4.798	0.47839997	0	0	0.25	20 %
03:00	3.14	2.685	0.4	0	0.055	0	0	0	0	3.14	3.264	0.524489202	0	0	0.25	31 %
04:00	2.52	2.065	0.4	0	0.055	0	0	0	0	2.52	2.644	0.524365298	0	0	0.25	31 %
05:00	2.63	2.175	0.4	0	0.055	0	0	0	0	2.63	2.754	0.52366104	0	0	0.26	31 %
06:00	3.23	1.855	1	0	0.055	0	0.32	0	0	3.23	2.753	0.522650365	0	0	0.26	48 %
07:00	2.03	0.775	1	0	0.055	0	0	0.2	0	2.03	3.114	0.523954497	1	1.56	0.25	48 %
08:00	1.99	1.535	0.4	0	0.055	0	0		0	1.99	2.116	0.526086763	0	0	0.25	32 %
09:00	1.73	1.275	0.4	0	0.055	0	0		0	1.73	1.565	0.235317542	0	0	0.26	41 %
10:00	1.97	1.515	0.4	0	0.055	0	0		0	1.97	1.755	0.184916756	0	0	0.26	54 %
11:00	1.41	0.955	0.4	0	0.055	0	0		0	1.41	1.531	0.521411389	0	0	0.26	30 %
12:00	3.49	3.035	0.4	0	0.055	0	0		0	3.49	3.611	0.521470054	0	0	0.26	30 %
13:00	1.77	1.315	0.4	0	0.055	0	0		0	1.77	1.890	0.520107227	0	0	0.26	30 %
14:00	2.54	2.085	0.4	0	0.055	0	0		0	2.54	2.655	0.514662354	0	0	0.27	29 %
15:00	2.36	1.805	0.4	0.1	0.055	0	0		0	2.36	2.470	0.510404273	0	0	0.28	28 %
16:00	2.91	2.255	0.5	0.1	0.055	0	0	0	0	2.91	2.918	0.507913324	0	0	0.28	2 %
17:00	2.73	0.475	0.5	0.5	0.055	0	1	0	0.2	2.73	2.737	0.507143906	0	0	0.28	1 %
18:00	3.45	0.135	0.5	0.6	0.055	1.56	0	0	0.6	3.45	1.898	0.508037212	0	0	0.28	2 %
19:00	1.8	0.145	0.2	0.5	0.055	0	0	0.2	0.7	1.8	2.110	0.509634808	0	0	0.28	155 %
20:00	2.71	0.755	0.4	0.8	0.055	0	0	0	0.7	2.71	2.822	0.511525863	0	0	0.27	28 %
21:00	3.44	0.985	1	0.8	0.055	0	0	0	0.6	3.44	2.953	0.513006095	0	0	0.27	49 %
22:00	4.96	3.305	1	0.4	0.055	0	0	0	0.2	4.96	4.475	0.514721028	0	0	0.27	49 %
23:00	3.16	2.305	0.6	0.2	0.055	0	0	0	0	3.16	4.134	1.573998897	0	0	0.27	162 %

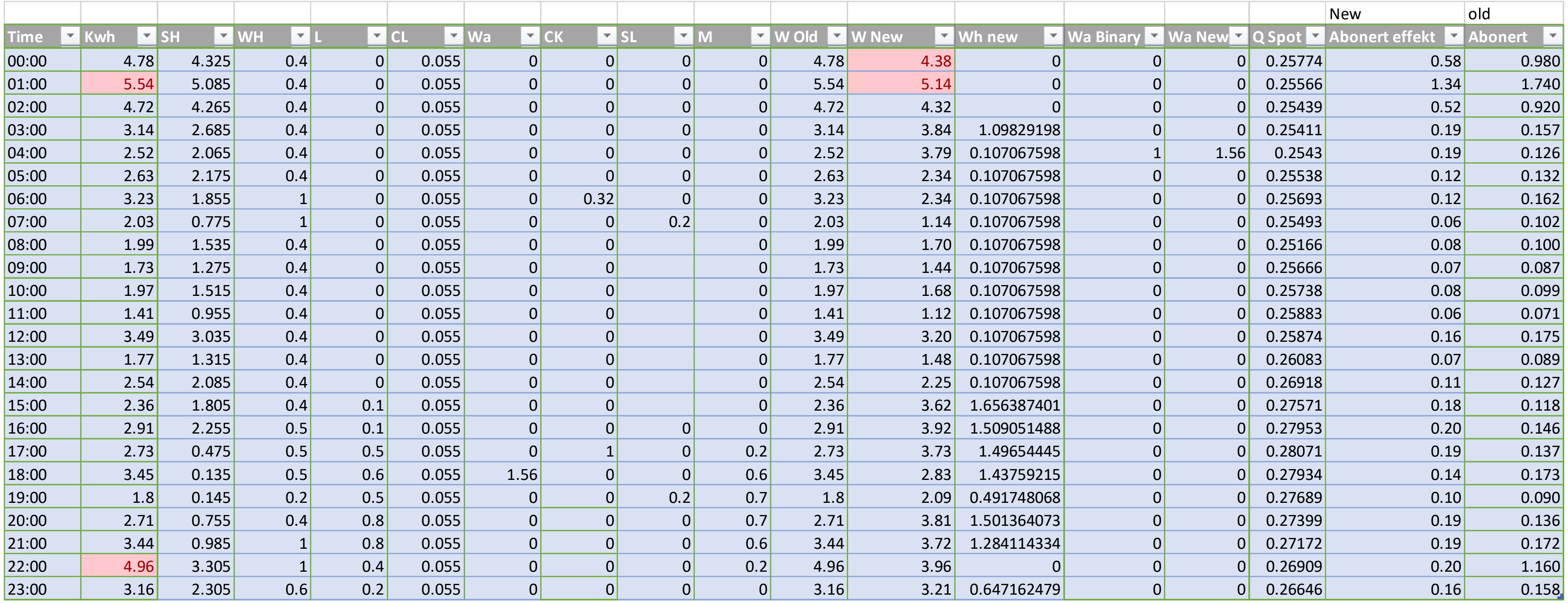
Appendix C.2

- Optimization spreadsheet for the detached house based on subscribed power on 28.feb.2018



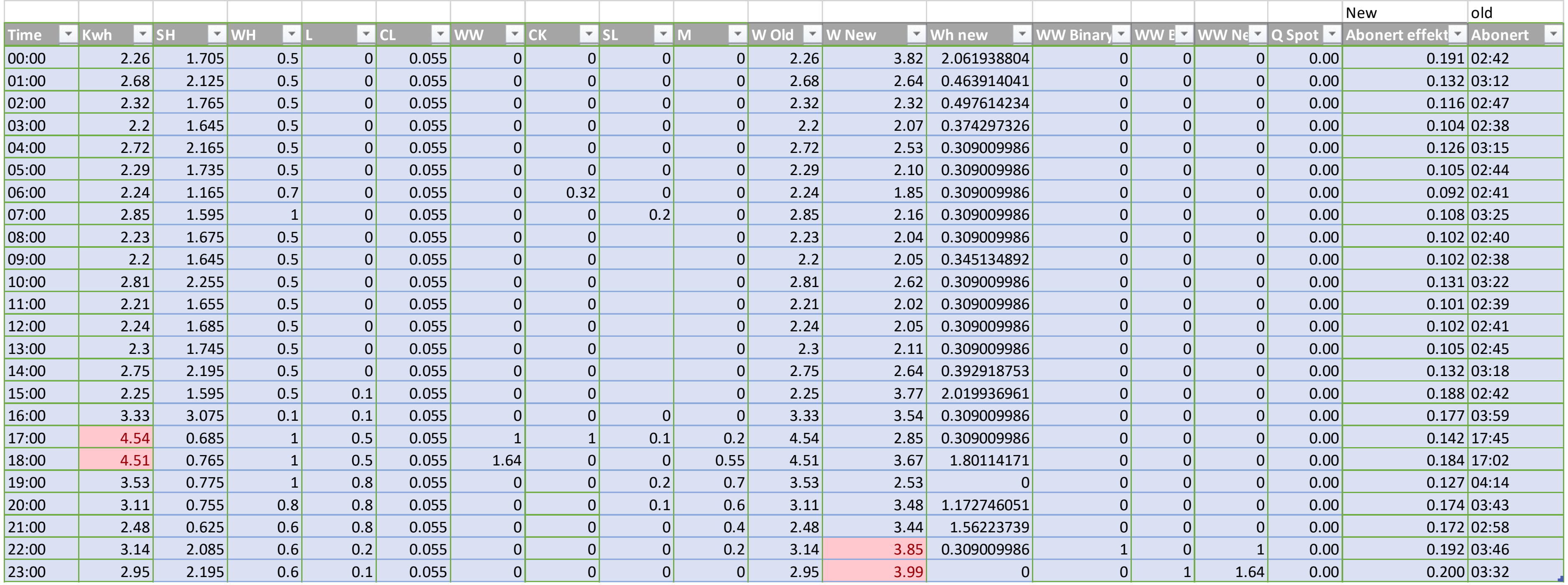
																	New	old
Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa Binary	Wa Binary2	Wa New	Q Spot	Abonert effekt	Abonert
00:00	6.09	5.454	0.5	0	0.136	0	0	0	0	6.09	6.81	1.22478594	0	0	0	0.26	0.341	0.3045
01:00	6.26	5.624	0.5	0	0.136	0	0	0	0	6.26	6.47	0.7066783	0	0	0	0.26	0.323	0.313
02:00	6	5.364	0.5	0	0.136	0	0	0	0	6	6.24	0.7403785	0	0	0	0.25	0.312	0.3
03:00	5.87	5.234	0.5	0	0.136	0	0	0	0	5.87	8.07	0	0	1	2.7	0.25	0.470	0.2935
04:00	5.98	5.344	0.5	0	0.136	0	0	0	0	5.98	5.87	0.39187019	0	0	0	0.25	0.294	0.299
05:00	6.42	5.784	0.5	0	0.136	0	0	0	0	6.42	6.29	0.37165103	0	0	0	0.26	0.315	0.321
06:00	5.97	3.734	1	0	0.136	0	0.4	0.7	0	5.97	5.29	0.31611781	0	0	0	0.26	0.264	0.2985
07:00	7.72	4.584	2	0	0.136	0	0	0	0	6.72	6.60	0.3750015	1	0	1.5	0.25	0.330	0.386
08:00	6.56	5.424	1	0	0.136	0	0	0	0	6.56	6.02	0.45609939	0	0	0	0.25	0.301	0.328
09:00	6.97	6.334	0.5	0	0.136	0	0	0	0	6.97	7.06	0.58789915	0	0	0	0.26	0.353	0.3485
10:00	7.24	6.604	0.5	0	0.136	0	0	0	0	7.24	7.24	0.49695276	0	0	0	0.26	0.362	0.362
11:00	6.77	6.134	0.5	0	0.136	0	0	0	0	6.77	6.68	0.4077188	0	0	0	0.26	0.334	0.3385
12:00	6.88	6.244	0.5	0	0.136	0	0	0	0	6.88	6.60	0.21585418	0	0	0	0.26	0.330	0.344
13:00	7.09	6.454	0.5	0	0.136	0	0	0	0	7.09	6.85	0.255581	0	0	0	0.26	0.342	0.3545
14:00	6.72	6.084	0.5	0	0.136	0	0	0	0	6.72	6.68	0.45737882	0	0	0	0.27	0.334	0.336
15:00	7.62	6.564	0.7	0.1	0.136	0	0	0	0.12	7.62	7.60	0.68435657	0	0	0	0.28	0.380	0.381
16:00	7.64	5.854	1	0.5	0.136	0	0	0	0.15	7.64	7.50	0.85690157	0	0	0	0.28	0.375	0.382
17:00	10.17	4.934	1	0.8	0.136	1.5	1.4	0.2	0.2	10.17	7.99	0.320479	0	0	0	0.28	0.400	2.57
18:00	8.75	4.314	1	1	0.136	2.7	0	0	0.6	9.75	7.92	1.86560178	0	0	0	0.28	0.396	1.15
19:00	8.2	4.014	1.5	1.5	0.136	0	0	0.45	0.6	8.2	7.77	1.06807391	0	0	0	0.28	0.388	0.6
20:00	6.85	3.464	1	1.65	0.136	0	0	0	0.6	6.85	7.90	2.04879421	0	0	0	0.27	0.395	0.3425
21:00	7.71	5.374	0.7	1	0.136	0	0	0	0.5	7.71	7.54	0.52569405	0	0	0	0.27	0.377	0.3855
22:00	6.6	4.84068	0.72332	0.8	0.136	0	0	0	0.1	6.6	7.67	1.7972392	0	0	0	0.27	0.384	0.33
23:00	6.18	4.91028	0.73372	0.4	0.136	0	0	0	0	6.18	7.63	2.18593232	0	0	0	0.27	0.382	0.309

- Optimization spreadsheet for the semi-detached house based on subscribed power on 28.feb.2018



																New	old
Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa Binary	Wa New	Q Spot	Abonert effekt	Abonert
00:00	4.78	4.325	0.4	0	0.055	0	0	0	0	4.78	4.38	0	0	0	0.25774	0.58	0.980
01:00	5.54	5.085	0.4	0	0.055	0	0	0	0	5.54	5.14	0	0	0	0.25566	1.34	1.740
02:00	4.72	4.265	0.4	0	0.055	0	0	0	0	4.72	4.32	0	0	0	0.25439	0.52	0.920
03:00	3.14	2.685	0.4	0	0.055	0	0	0	0	3.14	3.84	1.09829198	0	0	0.25411	0.19	0.157
04:00	2.52	2.065	0.4	0	0.055	0	0	0	0	2.52	3.79	0.107067598	1	1.56	0.2543	0.19	0.126
05:00	2.63	2.175	0.4	0	0.055	0	0	0	0	2.63	2.34	0.107067598	0	0	0.25538	0.12	0.132
06:00	3.23	1.855	1	0	0.055	0	0.32	0	0	3.23	2.34	0.107067598	0	0	0.25693	0.12	0.162
07:00	2.03	0.775	1	0	0.055	0	0	0.2	0	2.03	1.14	0.107067598	0	0	0.25493	0.06	0.102
08:00	1.99	1.535	0.4	0	0.055	0	0		0	1.99	1.70	0.107067598	0	0	0.25166	0.08	0.100
09:00	1.73	1.275	0.4	0	0.055	0	0		0	1.73	1.44	0.107067598	0	0	0.25666	0.07	0.087
10:00	1.97	1.515	0.4	0	0.055	0	0		0	1.97	1.68	0.107067598	0	0	0.25738	0.08	0.099
11:00	1.41	0.955	0.4	0	0.055	0	0		0	1.41	1.12	0.107067598	0	0	0.25883	0.06	0.071
12:00	3.49	3.035	0.4	0	0.055	0	0		0	3.49	3.20	0.107067598	0	0	0.25874	0.16	0.175
13:00	1.77	1.315	0.4	0	0.055	0	0		0	1.77	1.48	0.107067598	0	0	0.26083	0.07	0.089
14:00	2.54	2.085	0.4	0	0.055	0	0		0	2.54	2.25	0.107067598	0	0	0.26918	0.11	0.127
15:00	2.36	1.805	0.4	0.1	0.055	0	0		0	2.36	3.62	1.656387401	0	0	0.27571	0.18	0.118
16:00	2.91	2.255	0.5	0.1	0.055	0	0	0	0	2.91	3.92	1.509051488	0	0	0.27953	0.20	0.146
17:00	2.73	0.475	0.5	0.5	0.055	0	1	0	0.2	2.73	3.73	1.49654445	0	0	0.28071	0.19	0.137
18:00	3.45	0.135	0.5	0.6	0.055	1.56	0	0	0.6	3.45	2.83	1.43759215	0	0	0.27934	0.14	0.173
19:00	1.8	0.145	0.2	0.5	0.055	0	0	0.2	0.7	1.8	2.09	0.491748068	0	0	0.27689	0.10	0.090
20:00	2.71	0.755	0.4	0.8	0.055	0	0	0	0.7	2.71	3.81	1.501364073	0	0	0.27399	0.19	0.136
21:00	3.44	0.985	1	0.8	0.055	0	0	0	0.6	3.44	3.72	1.284114334	0	0	0.27172	0.19	0.172
22:00	4.96	3.305	1	0.4	0.055	0	0	0	0.2	4.96	3.96	0	0	0	0.26909	0.20	1.160
23:00	3.16	2.305	0.6	0.2	0.055	0	0	0	0	3.16	3.21	0.647162479	0	0	0.26646	0.16	0.158

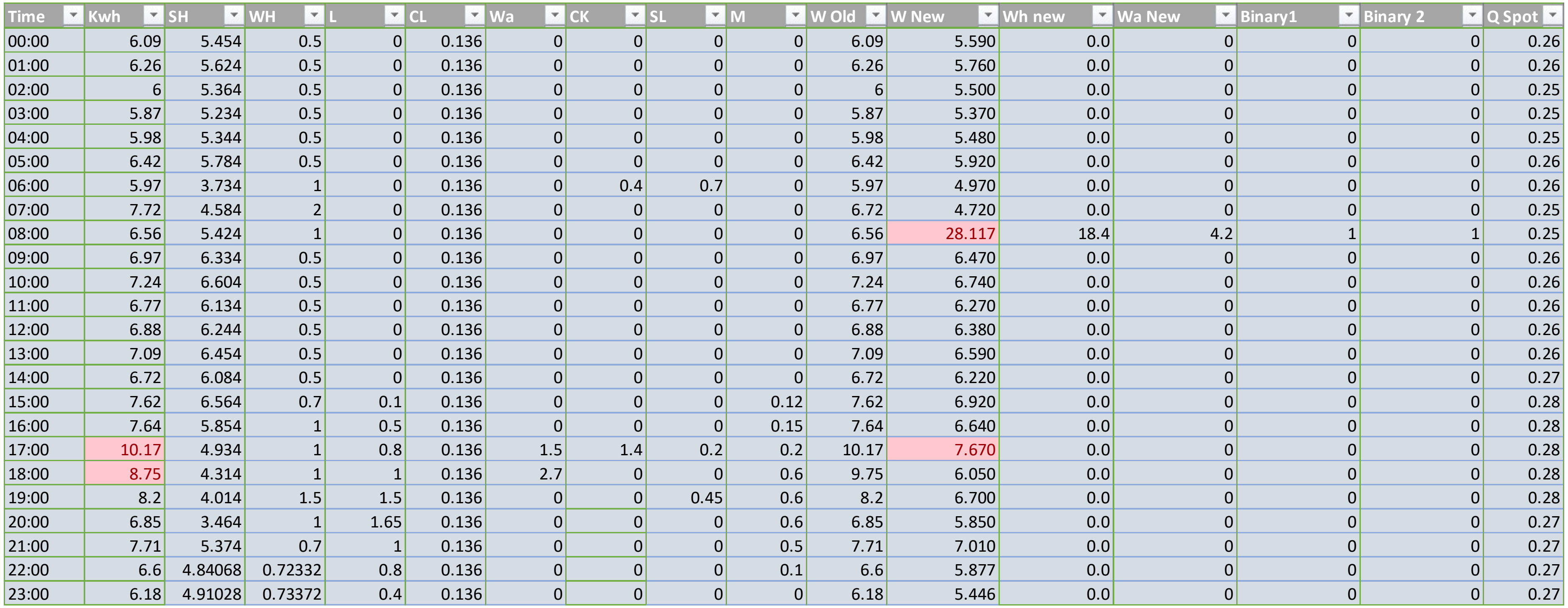
- Optimization spreadsheet for the apartment based on subscribed power on 28.feb.2018



																		New	old
Time	Kwh	SH	WH	L	CL	WW	CK	SL	M	W Old	W New	Wh new	WW Binary	WW E	WW Ne	Q Spot	Abonert effekt	Abonert
00:00	2.26	1.705	0.5	0	0.055	0	0	0	0	2.26	3.82	2.061938804	0	0	0	0.00	0.191	02:42
01:00	2.68	2.125	0.5	0	0.055	0	0	0	0	2.68	2.64	0.463914041	0	0	0	0.00	0.132	03:12
02:00	2.32	1.765	0.5	0	0.055	0	0	0	0	2.32	2.32	0.497614234	0	0	0	0.00	0.116	02:47
03:00	2.2	1.645	0.5	0	0.055	0	0	0	0	2.2	2.07	0.374297326	0	0	0	0.00	0.104	02:38
04:00	2.72	2.165	0.5	0	0.055	0	0	0	0	2.72	2.53	0.309009986	0	0	0	0.00	0.126	03:15
05:00	2.29	1.735	0.5	0	0.055	0	0	0	0	2.29	2.10	0.309009986	0	0	0	0.00	0.105	02:44
06:00	2.24	1.165	0.7	0	0.055	0	0.32	0	0	2.24	1.85	0.309009986	0	0	0	0.00	0.092	02:41
07:00	2.85	1.595	1	0	0.055	0	0	0.2	0	2.85	2.16	0.309009986	0	0	0	0.00	0.108	03:25
08:00	2.23	1.675	0.5	0	0.055	0	0		0	2.23	2.04	0.309009986	0	0	0	0.00	0.102	02:40
09:00	2.2	1.645	0.5	0	0.055	0	0		0	2.2	2.05	0.345134892	0	0	0	0.00	0.102	02:38
10:00	2.81	2.255	0.5	0	0.055	0	0		0	2.81	2.62	0.309009986	0	0	0	0.00	0.131	03:22
11:00	2.21	1.655	0.5	0	0.055	0	0		0	2.21	2.02	0.309009986	0	0	0	0.00	0.101	02:39
12:00	2.24	1.685	0.5	0	0.055	0	0		0	2.24	2.05	0.309009986	0	0	0	0.00	0.102	02:41
13:00	2.3	1.745	0.5	0	0.055	0	0		0	2.3	2.11	0.309009986	0	0	0	0.00	0.105	02:45
14:00	2.75	2.195	0.5	0	0.055	0	0		0	2.75	2.64	0.392918753	0	0	0	0.00	0.132	03:18
15:00	2.25	1.595	0.5	0.1	0.055	0	0		0	2.25	3.77	2.019936961	0	0	0	0.00	0.188	02:42
16:00	3.33	3.075	0.1	0.1	0.055	0	0	0	0	3.33	3.54	0.309009986	0	0	0	0.00	0.177	03:59
17:00	4.54	0.685	1	0.5	0.055	1	1	0.1	0.2	4.54	2.85	0.309009986	0	0	0	0.00	0.142	17:45
18:00	4.51	0.765	1	0.5	0.055	1.64	0	0	0.55	4.51	3.67	1.80114171	0	0	0	0.00	0.184	17:02
19:00	3.53	0.775	1	0.8	0.055	0	0	0.2	0.7	3.53	2.53	0	0	0	0	0.00	0.127	04:14
20:00	3.11	0.755	0.8	0.8	0.055	0	0	0.1	0.6	3.11	3.48	1.172746051	0	0	0	0.00	0.174	03:43
21:00	2.48	0.625	0.6	0.8	0.055	0	0	0	0.4	2.48	3.44	1.56223739	0	0	0	0.00	0.172	02:58
22:00	3.14	2.085	0.6	0.2	0.055	0	0	0	0.2	3.14	3.85	0.309009986	1	0	1	0.00	0.192	03:46
23:00	2.95	2.195	0.6	0.1	0.055	0	0	0	0	2.95	3.99	0	0	1	1.64	0.00	0.200	03:32

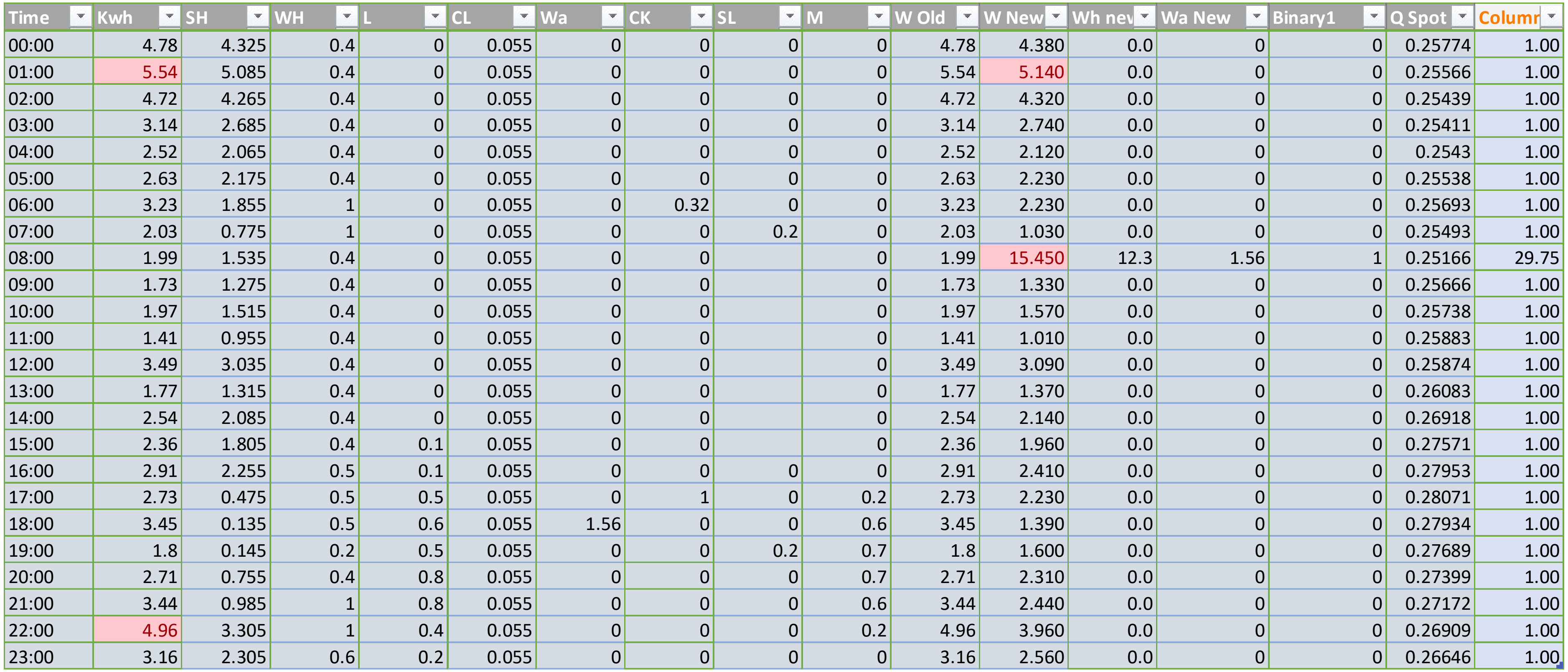
Appendix C.3

- Optimization spreadsheet for the detached house based on Energy tariff on 28.feb.2018



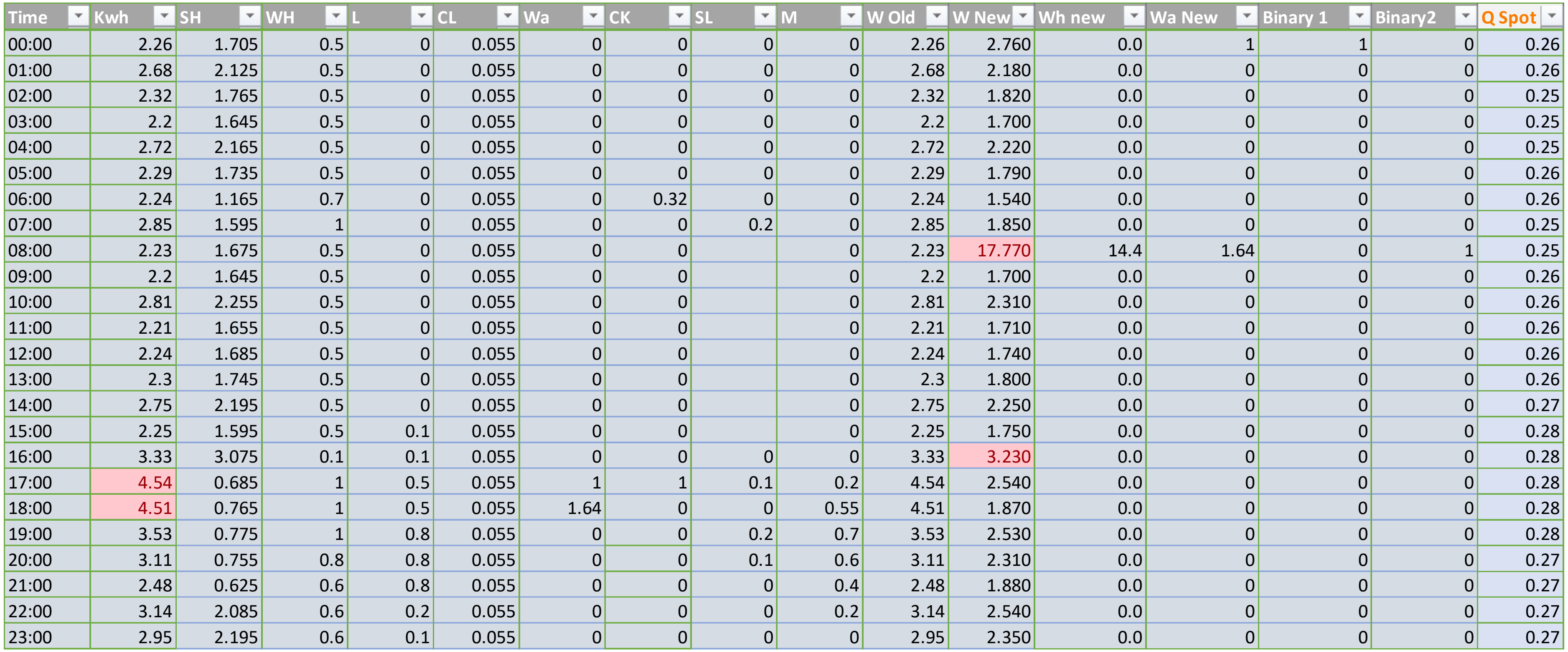
Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa New	Binary1	Binary 2	Q Spot
00:00	6.09	5.454	0.5	0	0.136	0	0	0	0	6.09	5.590	0.0	0	0	0	0.26
01:00	6.26	5.624	0.5	0	0.136	0	0	0	0	6.26	5.760	0.0	0	0	0	0.26
02:00	6	5.364	0.5	0	0.136	0	0	0	0	6	5.500	0.0	0	0	0	0.25
03:00	5.87	5.234	0.5	0	0.136	0	0	0	0	5.87	5.370	0.0	0	0	0	0.25
04:00	5.98	5.344	0.5	0	0.136	0	0	0	0	5.98	5.480	0.0	0	0	0	0.25
05:00	6.42	5.784	0.5	0	0.136	0	0	0	0	6.42	5.920	0.0	0	0	0	0.26
06:00	5.97	3.734	1	0	0.136	0	0.4	0.7	0	5.97	4.970	0.0	0	0	0	0.26
07:00	7.72	4.584	2	0	0.136	0	0	0	0	6.72	4.720	0.0	0	0	0	0.25
08:00	6.56	5.424	1	0	0.136	0	0	0	0	6.56	28.117	18.4	4.2	1	1	0.25
09:00	6.97	6.334	0.5	0	0.136	0	0	0	0	6.97	6.470	0.0	0	0	0	0.26
10:00	7.24	6.604	0.5	0	0.136	0	0	0	0	7.24	6.740	0.0	0	0	0	0.26
11:00	6.77	6.134	0.5	0	0.136	0	0	0	0	6.77	6.270	0.0	0	0	0	0.26
12:00	6.88	6.244	0.5	0	0.136	0	0	0	0	6.88	6.380	0.0	0	0	0	0.26
13:00	7.09	6.454	0.5	0	0.136	0	0	0	0	7.09	6.590	0.0	0	0	0	0.26
14:00	6.72	6.084	0.5	0	0.136	0	0	0	0	6.72	6.220	0.0	0	0	0	0.27
15:00	7.62	6.564	0.7	0.1	0.136	0	0	0	0.12	7.62	6.920	0.0	0	0	0	0.28
16:00	7.64	5.854	1	0.5	0.136	0	0	0	0.15	7.64	6.640	0.0	0	0	0	0.28
17:00	10.17	4.934	1	0.8	0.136	1.5	1.4	0.2	0.2	10.17	7.670	0.0	0	0	0	0.28
18:00	8.75	4.314	1	1	0.136	2.7	0	0	0.6	9.75	6.050	0.0	0	0	0	0.28
19:00	8.2	4.014	1.5	1.5	0.136	0	0	0.45	0.6	8.2	6.700	0.0	0	0	0	0.28
20:00	6.85	3.464	1	1.65	0.136	0	0	0	0.6	6.85	5.850	0.0	0	0	0	0.27
21:00	7.71	5.374	0.7	1	0.136	0	0	0	0.5	7.71	7.010	0.0	0	0	0	0.27
22:00	6.6	4.84068	0.72332	0.8	0.136	0	0	0	0.1	6.6	5.877	0.0	0	0	0	0.27
23:00	6.18	4.91028	0.73372	0.4	0.136	0	0	0	0	6.18	5.446	0.0	0	0	0	0.27

- Optimization spreadsheet for the semi-detached house based on Energy tariff on 28.feb.2018



Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh nev	Wa New	Binary1	Q Spot	Columr
00:00	4.78	4.325	0.4	0	0.055	0	0	0	0	4.78	4.380	0.0	0	0	0.25774	1.00
01:00	5.54	5.085	0.4	0	0.055	0	0	0	0	5.54	5.140	0.0	0	0	0.25566	1.00
02:00	4.72	4.265	0.4	0	0.055	0	0	0	0	4.72	4.320	0.0	0	0	0.25439	1.00
03:00	3.14	2.685	0.4	0	0.055	0	0	0	0	3.14	2.740	0.0	0	0	0.25411	1.00
04:00	2.52	2.065	0.4	0	0.055	0	0	0	0	2.52	2.120	0.0	0	0	0.2543	1.00
05:00	2.63	2.175	0.4	0	0.055	0	0	0	0	2.63	2.230	0.0	0	0	0.25538	1.00
06:00	3.23	1.855	1	0	0.055	0	0.32	0	0	3.23	2.230	0.0	0	0	0.25693	1.00
07:00	2.03	0.775	1	0	0.055	0	0	0.2	0	2.03	1.030	0.0	0	0	0.25493	1.00
08:00	1.99	1.535	0.4	0	0.055	0	0		0	1.99	15.450	12.3	1.56	1	0.25166	29.75
09:00	1.73	1.275	0.4	0	0.055	0	0		0	1.73	1.330	0.0	0	0	0.25666	1.00
10:00	1.97	1.515	0.4	0	0.055	0	0		0	1.97	1.570	0.0	0	0	0.25738	1.00
11:00	1.41	0.955	0.4	0	0.055	0	0		0	1.41	1.010	0.0	0	0	0.25883	1.00
12:00	3.49	3.035	0.4	0	0.055	0	0		0	3.49	3.090	0.0	0	0	0.25874	1.00
13:00	1.77	1.315	0.4	0	0.055	0	0		0	1.77	1.370	0.0	0	0	0.26083	1.00
14:00	2.54	2.085	0.4	0	0.055	0	0		0	2.54	2.140	0.0	0	0	0.26918	1.00
15:00	2.36	1.805	0.4	0.1	0.055	0	0		0	2.36	1.960	0.0	0	0	0.27571	1.00
16:00	2.91	2.255	0.5	0.1	0.055	0	0	0	0	2.91	2.410	0.0	0	0	0.27953	1.00
17:00	2.73	0.475	0.5	0.5	0.055	0	1	0	0.2	2.73	2.230	0.0	0	0	0.28071	1.00
18:00	3.45	0.135	0.5	0.6	0.055	1.56	0	0	0.6	3.45	1.390	0.0	0	0	0.27934	1.00
19:00	1.8	0.145	0.2	0.5	0.055	0	0	0.2	0.7	1.8	1.600	0.0	0	0	0.27689	1.00
20:00	2.71	0.755	0.4	0.8	0.055	0	0	0	0.7	2.71	2.310	0.0	0	0	0.27399	1.00
21:00	3.44	0.985	1	0.8	0.055	0	0	0	0.6	3.44	2.440	0.0	0	0	0.27172	1.00
22:00	4.96	3.305	1	0.4	0.055	0	0	0	0.2	4.96	3.960	0.0	0	0	0.26909	1.00
23:00	3.16	2.305	0.6	0.2	0.055	0	0	0	0	3.16	2.560	0.0	0	0	0.26646	1.00

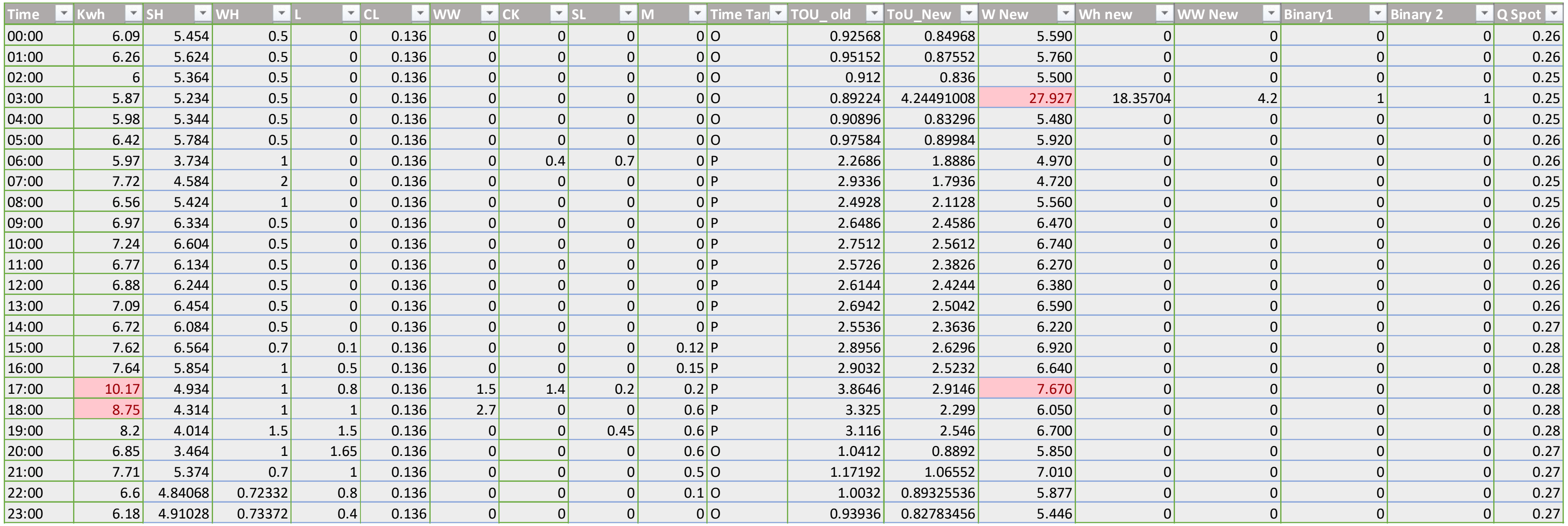
- Optimization spreadsheet for the apartment based on Energy tariff on 28.feb.2018



Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	W Old	W New	Wh new	Wa New	Binary 1	Binary2	Q Spot
00:00	2.26	1.705	0.5	0	0.055	0	0	0	0	2.26	2.760	0.0	1	1	0	0.26
01:00	2.68	2.125	0.5	0	0.055	0	0	0	0	2.68	2.180	0.0	0	0	0	0.26
02:00	2.32	1.765	0.5	0	0.055	0	0	0	0	2.32	1.820	0.0	0	0	0	0.25
03:00	2.2	1.645	0.5	0	0.055	0	0	0	0	2.2	1.700	0.0	0	0	0	0.25
04:00	2.72	2.165	0.5	0	0.055	0	0	0	0	2.72	2.220	0.0	0	0	0	0.25
05:00	2.29	1.735	0.5	0	0.055	0	0	0	0	2.29	1.790	0.0	0	0	0	0.26
06:00	2.24	1.165	0.7	0	0.055	0	0.32	0	0	2.24	1.540	0.0	0	0	0	0.26
07:00	2.85	1.595	1	0	0.055	0	0	0.2	0	2.85	1.850	0.0	0	0	0	0.25
08:00	2.23	1.675	0.5	0	0.055	0	0		0	2.23	17.770	14.4	1.64	0	1	0.25
09:00	2.2	1.645	0.5	0	0.055	0	0		0	2.2	1.700	0.0	0	0	0	0.26
10:00	2.81	2.255	0.5	0	0.055	0	0		0	2.81	2.310	0.0	0	0	0	0.26
11:00	2.21	1.655	0.5	0	0.055	0	0		0	2.21	1.710	0.0	0	0	0	0.26
12:00	2.24	1.685	0.5	0	0.055	0	0		0	2.24	1.740	0.0	0	0	0	0.26
13:00	2.3	1.745	0.5	0	0.055	0	0		0	2.3	1.800	0.0	0	0	0	0.26
14:00	2.75	2.195	0.5	0	0.055	0	0		0	2.75	2.250	0.0	0	0	0	0.27
15:00	2.25	1.595	0.5	0.1	0.055	0	0		0	2.25	1.750	0.0	0	0	0	0.28
16:00	3.33	3.075	0.1	0.1	0.055	0	0	0	0	3.33	3.230	0.0	0	0	0	0.28
17:00	4.54	0.685	1	0.5	0.055	1	1	0.1	0.2	4.54	2.540	0.0	0	0	0	0.28
18:00	4.51	0.765	1	0.5	0.055	1.64	0	0	0.55	4.51	1.870	0.0	0	0	0	0.28
19:00	3.53	0.775	1	0.8	0.055	0	0	0.2	0.7	3.53	2.530	0.0	0	0	0	0.28
20:00	3.11	0.755	0.8	0.8	0.055	0	0	0.1	0.6	3.11	2.310	0.0	0	0	0	0.27
21:00	2.48	0.625	0.6	0.8	0.055	0	0	0	0.4	2.48	1.880	0.0	0	0	0	0.27
22:00	3.14	2.085	0.6	0.2	0.055	0	0	0	0.2	3.14	2.540	0.0	0	0	0	0.27
23:00	2.95	2.195	0.6	0.1	0.055	0	0	0	0	2.95	2.350	0.0	0	0	0	0.27

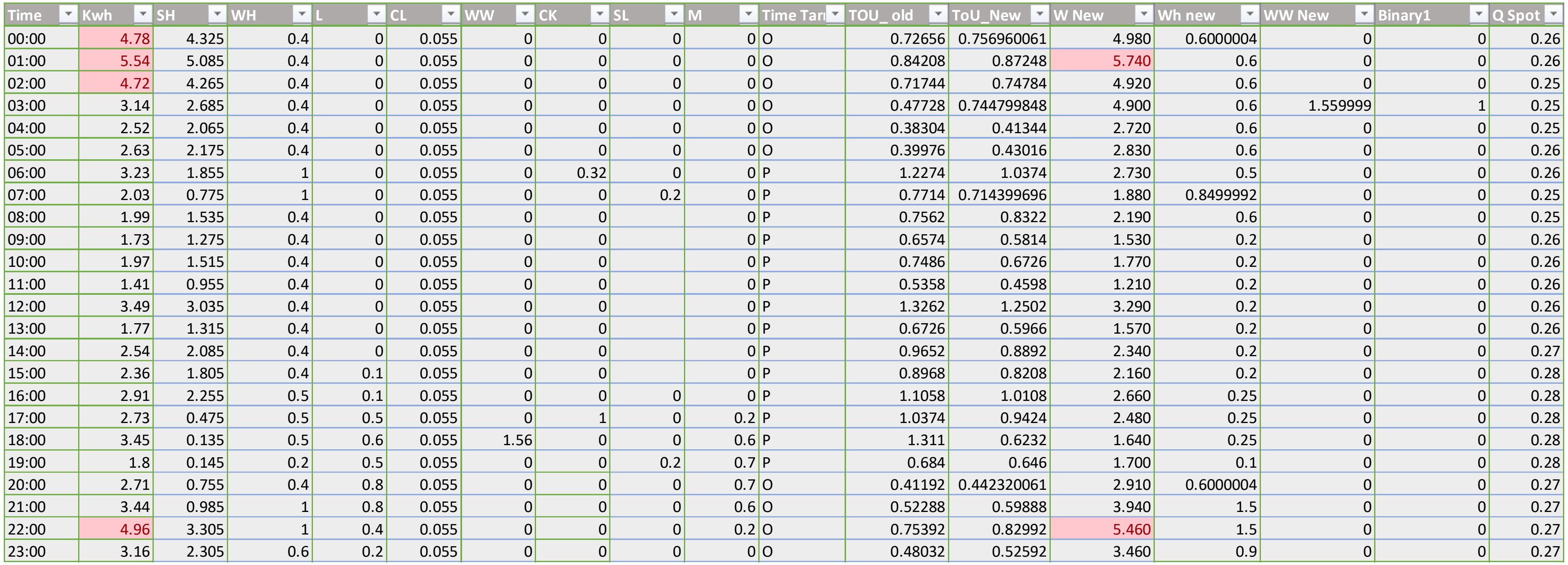
Appendix C.4

- Optimization spreadsheet for the detached house based on Time of Use on 28.feb.2018



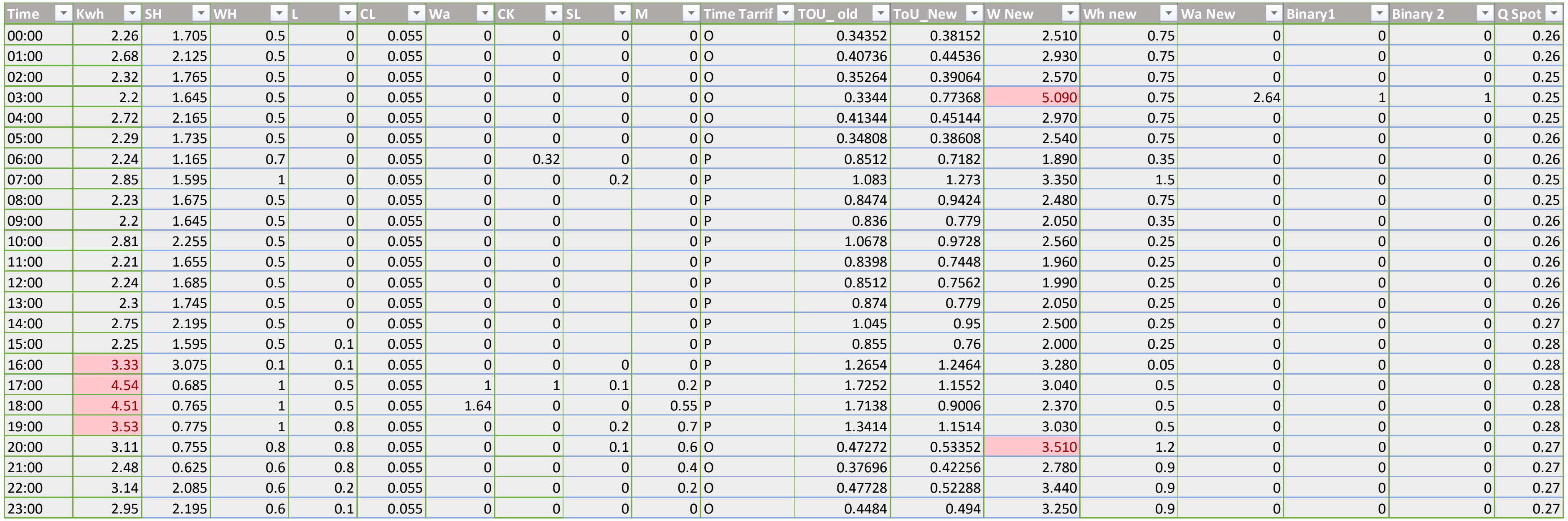
Time	Kwh	SH	WH	L	CL	WW	CK	SL	M	Time Tari	TOU_ old	ToU_New	W New	Wh new	WW New	Binary1	Binary 2	Q Spot
00:00	6.09	5.454	0.5	0	0.136	0	0	0	0	O	0.92568	0.84968	5.590	0	0	0	0	0.26
01:00	6.26	5.624	0.5	0	0.136	0	0	0	0	O	0.95152	0.87552	5.760	0	0	0	0	0.26
02:00	6	5.364	0.5	0	0.136	0	0	0	0	O	0.912	0.836	5.500	0	0	0	0	0.25
03:00	5.87	5.234	0.5	0	0.136	0	0	0	0	O	0.89224	4.24491008	27.927	18.35704	4.2	1	1	0.25
04:00	5.98	5.344	0.5	0	0.136	0	0	0	0	O	0.90896	0.83296	5.480	0	0	0	0	0.25
05:00	6.42	5.784	0.5	0	0.136	0	0	0	0	O	0.97584	0.89984	5.920	0	0	0	0	0.26
06:00	5.97	3.734	1	0	0.136	0	0.4	0.7	0	P	2.2686	1.8886	4.970	0	0	0	0	0.26
07:00	7.72	4.584	2	0	0.136	0	0	0	0	P	2.9336	1.7936	4.720	0	0	0	0	0.25
08:00	6.56	5.424	1	0	0.136	0	0	0	0	P	2.4928	2.1128	5.560	0	0	0	0	0.25
09:00	6.97	6.334	0.5	0	0.136	0	0	0	0	P	2.6486	2.4586	6.470	0	0	0	0	0.26
10:00	7.24	6.604	0.5	0	0.136	0	0	0	0	P	2.7512	2.5612	6.740	0	0	0	0	0.26
11:00	6.77	6.134	0.5	0	0.136	0	0	0	0	P	2.5726	2.3826	6.270	0	0	0	0	0.26
12:00	6.88	6.244	0.5	0	0.136	0	0	0	0	P	2.6144	2.4244	6.380	0	0	0	0	0.26
13:00	7.09	6.454	0.5	0	0.136	0	0	0	0	P	2.6942	2.5042	6.590	0	0	0	0	0.26
14:00	6.72	6.084	0.5	0	0.136	0	0	0	0	P	2.5536	2.3636	6.220	0	0	0	0	0.27
15:00	7.62	6.564	0.7	0.1	0.136	0	0	0	0.12	P	2.8956	2.6296	6.920	0	0	0	0	0.28
16:00	7.64	5.854	1	0.5	0.136	0	0	0	0.15	P	2.9032	2.5232	6.640	0	0	0	0	0.28
17:00	10.17	4.934	1	0.8	0.136	1.5	1.4	0.2	0.2	P	3.8646	2.9146	7.670	0	0	0	0	0.28
18:00	8.75	4.314	1	1	0.136	2.7	0	0	0.6	P	3.325	2.299	6.050	0	0	0	0	0.28
19:00	8.2	4.014	1.5	1.5	0.136	0	0	0.45	0.6	P	3.116	2.546	6.700	0	0	0	0	0.28
20:00	6.85	3.464	1	1.65	0.136	0	0	0	0.6	O	1.0412	0.8892	5.850	0	0	0	0	0.27
21:00	7.71	5.374	0.7	1	0.136	0	0	0	0.5	O	1.17192	1.06552	7.010	0	0	0	0	0.27
22:00	6.6	4.84068	0.72332	0.8	0.136	0	0	0	0.1	O	1.0032	0.89325536	5.877	0	0	0	0	0.27
23:00	6.18	4.91028	0.73372	0.4	0.136	0	0	0	0	O	0.93936	0.82783456	5.446	0	0	0	0	0.27

- Optimization spreadsheet for the semi- detached house based on Time of Use on 28.feb.2018



Time	Kwh	SH	WH	L	CL	WW	CK	SL	M	Time Tari	TOU_ old	ToU_New	W New	Wh new	WW New	Binary1	Q Spot
00:00	4.78	4.325	0.4	0	0.055	0	0	0	0	O	0.72656	0.756960061	4.980	0.6000004	0	0	0.26
01:00	5.54	5.085	0.4	0	0.055	0	0	0	0	O	0.84208	0.87248	5.740	0.6	0	0	0.26
02:00	4.72	4.265	0.4	0	0.055	0	0	0	0	O	0.71744	0.74784	4.920	0.6	0	0	0.25
03:00	3.14	2.685	0.4	0	0.055	0	0	0	0	O	0.47728	0.744799848	4.900	0.6	1.559999	1	0.25
04:00	2.52	2.065	0.4	0	0.055	0	0	0	0	O	0.38304	0.41344	2.720	0.6	0	0	0.25
05:00	2.63	2.175	0.4	0	0.055	0	0	0	0	O	0.39976	0.43016	2.830	0.6	0	0	0.26
06:00	3.23	1.855	1	0	0.055	0	0.32	0	0	P	1.2274	1.0374	2.730	0.5	0	0	0.26
07:00	2.03	0.775	1	0	0.055	0	0	0.2	0	P	0.7714	0.714399696	1.880	0.8499992	0	0	0.25
08:00	1.99	1.535	0.4	0	0.055	0	0		0	P	0.7562	0.8322	2.190	0.6	0	0	0.25
09:00	1.73	1.275	0.4	0	0.055	0	0		0	P	0.6574	0.5814	1.530	0.2	0	0	0.26
10:00	1.97	1.515	0.4	0	0.055	0	0		0	P	0.7486	0.6726	1.770	0.2	0	0	0.26
11:00	1.41	0.955	0.4	0	0.055	0	0		0	P	0.5358	0.4598	1.210	0.2	0	0	0.26
12:00	3.49	3.035	0.4	0	0.055	0	0		0	P	1.3262	1.2502	3.290	0.2	0	0	0.26
13:00	1.77	1.315	0.4	0	0.055	0	0		0	P	0.6726	0.5966	1.570	0.2	0	0	0.26
14:00	2.54	2.085	0.4	0	0.055	0	0		0	P	0.9652	0.8892	2.340	0.2	0	0	0.27
15:00	2.36	1.805	0.4	0.1	0.055	0	0		0	P	0.8968	0.8208	2.160	0.2	0	0	0.28
16:00	2.91	2.255	0.5	0.1	0.055	0	0	0	0	P	1.1058	1.0108	2.660	0.25	0	0	0.28
17:00	2.73	0.475	0.5	0.5	0.055	0	1	0	0.2	P	1.0374	0.9424	2.480	0.25	0	0	0.28
18:00	3.45	0.135	0.5	0.6	0.055	1.56	0	0	0.6	P	1.311	0.6232	1.640	0.25	0	0	0.28
19:00	1.8	0.145	0.2	0.5	0.055	0	0	0.2	0.7	P	0.684	0.646	1.700	0.1	0	0	0.28
20:00	2.71	0.755	0.4	0.8	0.055	0	0	0	0.7	O	0.41192	0.442320061	2.910	0.6000004	0	0	0.27
21:00	3.44	0.985	1	0.8	0.055	0	0	0	0.6	O	0.52288	0.59888	3.940	1.5	0	0	0.27
22:00	4.96	3.305	1	0.4	0.055	0	0	0	0.2	O	0.75392	0.82992	5.460	1.5	0	0	0.27
23:00	3.16	2.305	0.6	0.2	0.055	0	0	0	0	O	0.48032	0.52592	3.460	0.9	0	0	0.27

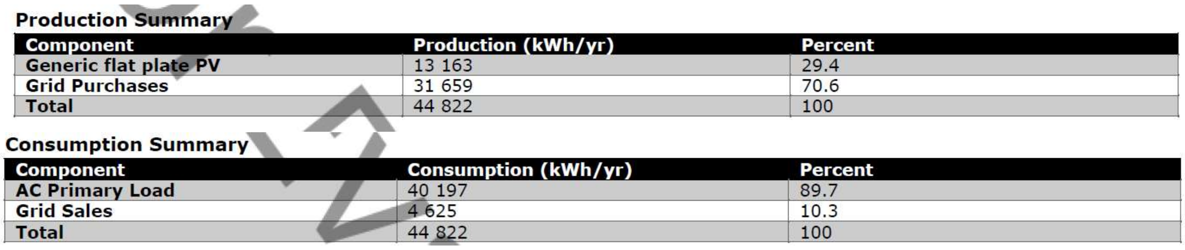
- Optimization spreadsheet for the apartment based on Time of Use on 28.feb.2018



Time	Kwh	SH	WH	L	CL	Wa	CK	SL	M	Time Tarrif	TOU_old	ToU_New	W New	Wh new	Wa New	Binary1	Binary 2	Q Spot
00:00	2.26	1.705	0.5	0	0.055	0	0	0	0	O	0.34352	0.38152	2.510	0.75	0	0	0	0.26
01:00	2.68	2.125	0.5	0	0.055	0	0	0	0	O	0.40736	0.44536	2.930	0.75	0	0	0	0.26
02:00	2.32	1.765	0.5	0	0.055	0	0	0	0	O	0.35264	0.39064	2.570	0.75	0	0	0	0.25
03:00	2.2	1.645	0.5	0	0.055	0	0	0	0	O	0.3344	0.77368	5.090	0.75	2.64	1	1	0.25
04:00	2.72	2.165	0.5	0	0.055	0	0	0	0	O	0.41344	0.45144	2.970	0.75	0	0	0	0.25
05:00	2.29	1.735	0.5	0	0.055	0	0	0	0	O	0.34808	0.38608	2.540	0.75	0	0	0	0.26
06:00	2.24	1.165	0.7	0	0.055	0	0.32	0	0	P	0.8512	0.7182	1.890	0.35	0	0	0	0.26
07:00	2.85	1.595	1	0	0.055	0	0	0.2	0	P	1.083	1.273	3.350	1.5	0	0	0	0.25
08:00	2.23	1.675	0.5	0	0.055	0	0		0	P	0.8474	0.9424	2.480	0.75	0	0	0	0.25
09:00	2.2	1.645	0.5	0	0.055	0	0		0	P	0.836	0.779	2.050	0.35	0	0	0	0.26
10:00	2.81	2.255	0.5	0	0.055	0	0		0	P	1.0678	0.9728	2.560	0.25	0	0	0	0.26
11:00	2.21	1.655	0.5	0	0.055	0	0		0	P	0.8398	0.7448	1.960	0.25	0	0	0	0.26
12:00	2.24	1.685	0.5	0	0.055	0	0		0	P	0.8512	0.7562	1.990	0.25	0	0	0	0.26
13:00	2.3	1.745	0.5	0	0.055	0	0		0	P	0.874	0.779	2.050	0.25	0	0	0	0.26
14:00	2.75	2.195	0.5	0	0.055	0	0		0	P	1.045	0.95	2.500	0.25	0	0	0	0.27
15:00	2.25	1.595	0.5	0.1	0.055	0	0		0	P	0.855	0.76	2.000	0.25	0	0	0	0.28
16:00	3.33	3.075	0.1	0.1	0.055	0	0	0	0	P	1.2654	1.2464	3.280	0.05	0	0	0	0.28
17:00	4.54	0.685	1	0.5	0.055	1	1	0.1	0.2	P	1.7252	1.1552	3.040	0.5	0	0	0	0.28
18:00	4.51	0.765	1	0.5	0.055	1.64	0	0	0.55	P	1.7138	0.9006	2.370	0.5	0	0	0	0.28
19:00	3.53	0.775	1	0.8	0.055	0	0	0.2	0.7	P	1.3414	1.1514	3.030	0.5	0	0	0	0.28
20:00	3.11	0.755	0.8	0.8	0.055	0	0	0.1	0.6	O	0.47272	0.53352	3.510	1.2	0	0	0	0.27
21:00	2.48	0.625	0.6	0.8	0.055	0	0	0	0.4	O	0.37696	0.42256	2.780	0.9	0	0	0	0.27
22:00	3.14	2.085	0.6	0.2	0.055	0	0	0	0.2	O	0.47728	0.52288	3.440	0.9	0	0	0	0.27
23:00	2.95	2.195	0.6	0.1	0.055	0	0	0	0	O	0.4484	0.494	3.250	0.9	0	0	0	0.27

Appendix D.

A summery on important numbers obtained from stimulation by Homer Grid on scenario 5. Below presented the generated power by PV, purchased power from the grid , sold power back to the grid and amonthly report on energy cost.

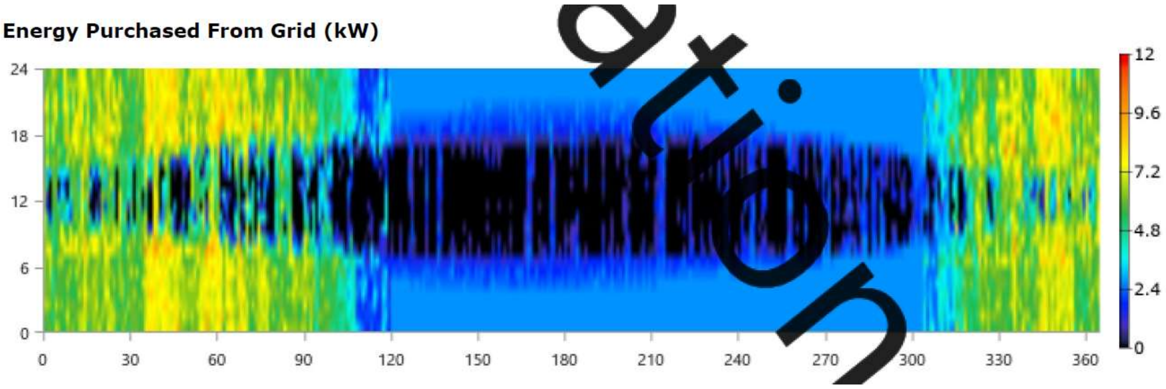


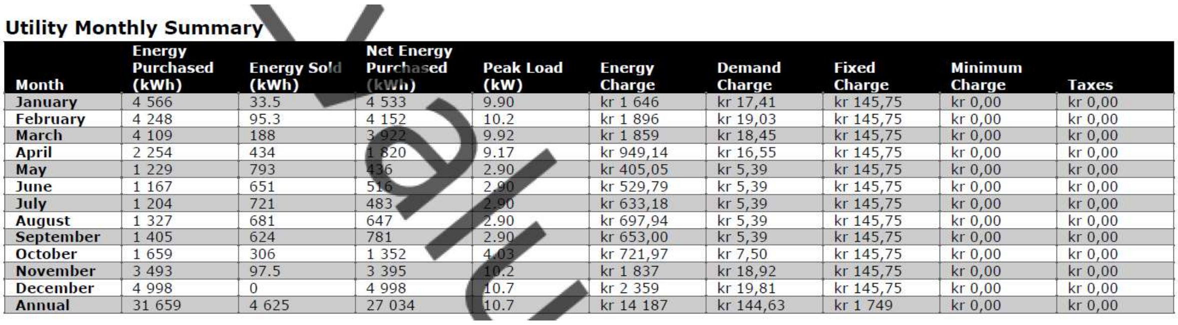
Production Summary

Component	Production (kWh/yr)	Percent
Generic flat plate PV	13 163	29.4
Grid Purchases	31 659	70.6
Total	44 822	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	40 197	89.7
Grid Sales	4 625	10.3
Total	44 822	100





Utility Monthly Summary

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Fixed Charge	Minimum Charge	Taxes
January	4 566	33.5	4 533	9.90	kr 1 646	kr 17,41	kr 145,75	kr 0,00	kr 0,00
February	4 248	95.3	4 152	10.2	kr 1 896	kr 19,03	kr 145,75	kr 0,00	kr 0,00
March	4 109	188	3 922	9.92	kr 1 859	kr 18,45	kr 145,75	kr 0,00	kr 0,00
April	2 254	434	1 820	9.17	kr 949,14	kr 16,55	kr 145,75	kr 0,00	kr 0,00
May	1 229	793	436	2.90	kr 405,05	kr 5,39	kr 145,75	kr 0,00	kr 0,00
June	1 167	651	516	2.90	kr 529,79	kr 5,39	kr 145,75	kr 0,00	kr 0,00
July	1 204	721	483	2.90	kr 633,18	kr 5,39	kr 145,75	kr 0,00	kr 0,00
August	1 327	681	647	2.90	kr 697,94	kr 5,39	kr 145,75	kr 0,00	kr 0,00
September	1 405	624	781	2.90	kr 653,00	kr 5,39	kr 145,75	kr 0,00	kr 0,00
October	1 659	306	1 352	4.03	kr 721,97	kr 7,50	kr 145,75	kr 0,00	kr 0,00
November	3 493	97.5	3 395	10.2	kr 1 837	kr 18,92	kr 145,75	kr 0,00	kr 0,00
December	4 998	0	4 998	10.7	kr 2 359	kr 19,81	kr 145,75	kr 0,00	kr 0,00
Annual	31 659	4 625	27 034	10.7	kr 14 187	kr 144,63	kr 1 749	kr 0,00	kr 0,00

Appendix E.

Calculation of LCOE for PV-Battery system on scenario 5.

Scenario 5. Solar power production LCOE

Capacity factor	Type of measure %	Detached house 13.3 kW 11.3	Detached house 13.3kW incl. VAT	Homer Grid stimulation
Operational hours	hr/yr	4 378	4 378	Homer Grid stimulation
Investment costs				
PV Panels	kr	95 273	119 091	TIMES Norway
Other equipment	kr	78 965	98 706	TIMES Norway
Installation	kr	58 512	73 140	TIMES Norway
Sum CAPEX	kr	232 750	290 938	
Fix operational costs	kr/yr	1 164	1 455	
Electricity production per year	kWh/yr	13 165	13 165	

Present values (PV)			
Investment costs	øre	23 275 000	29 093 750
Fix operational costs	øre	1 818 020	2 272 524
Produced electricity	kWh	205 671	205 671

LCOE 2018	**øre/kWh**	**122.0**	**152.5**	
Technology improvement factor 2016 - 2035		0.48	0.48	TIMES Norway
LCOE 2035	**øre/kWh**	**58.9**	**73.6**	

*Assumptions: Discount rate 4%, lifetime 25 years, VAT 25%

Scenario 5 Battery storage LCOE				
	Measure	Detached house	Detached house incl. VAT	
Operational hours	hr/yr	8 261	8 261	Homer Grid
Investment costs				
Battery 1KW	kr/kWh	-		
Inverter	kr/kWh	-		
Installation	kr/kWh	-		
Sum CAPEX	kr/kWh	10 250	12 813	(Henden et al., 2017)
Fix operational costs	kr/kW/yr	103	128	1% of CAPEX

Energy in	kWh/yr	1 970	Homer Grid stimulation
Energy Out	kWh/yr	1 790	Homer Grid stimulation
Losses	kWh/yr	19	Homer Grid stimulation
Electricity throughput per year	kWh/yr	1 951	Homer Grid stimulation

Present values (PV)			
Investment costs	øre	1 025 000	1 281 250
Fix operational costs	øre	113 963	142 454
Produced electricity	kWh	21 696	21 696

LCOE 2018	**øre/kWh**	**52.5**	**65.6**

*Assumptions: Discount rate 4%, lifetime 15 years, VAT 25%