Demand Side Management of Households in Bergen
- A study of potential peak load reductions

Laststyring av husholdninger i Bergen
- En studie av potensialet for topplastreduksjoner

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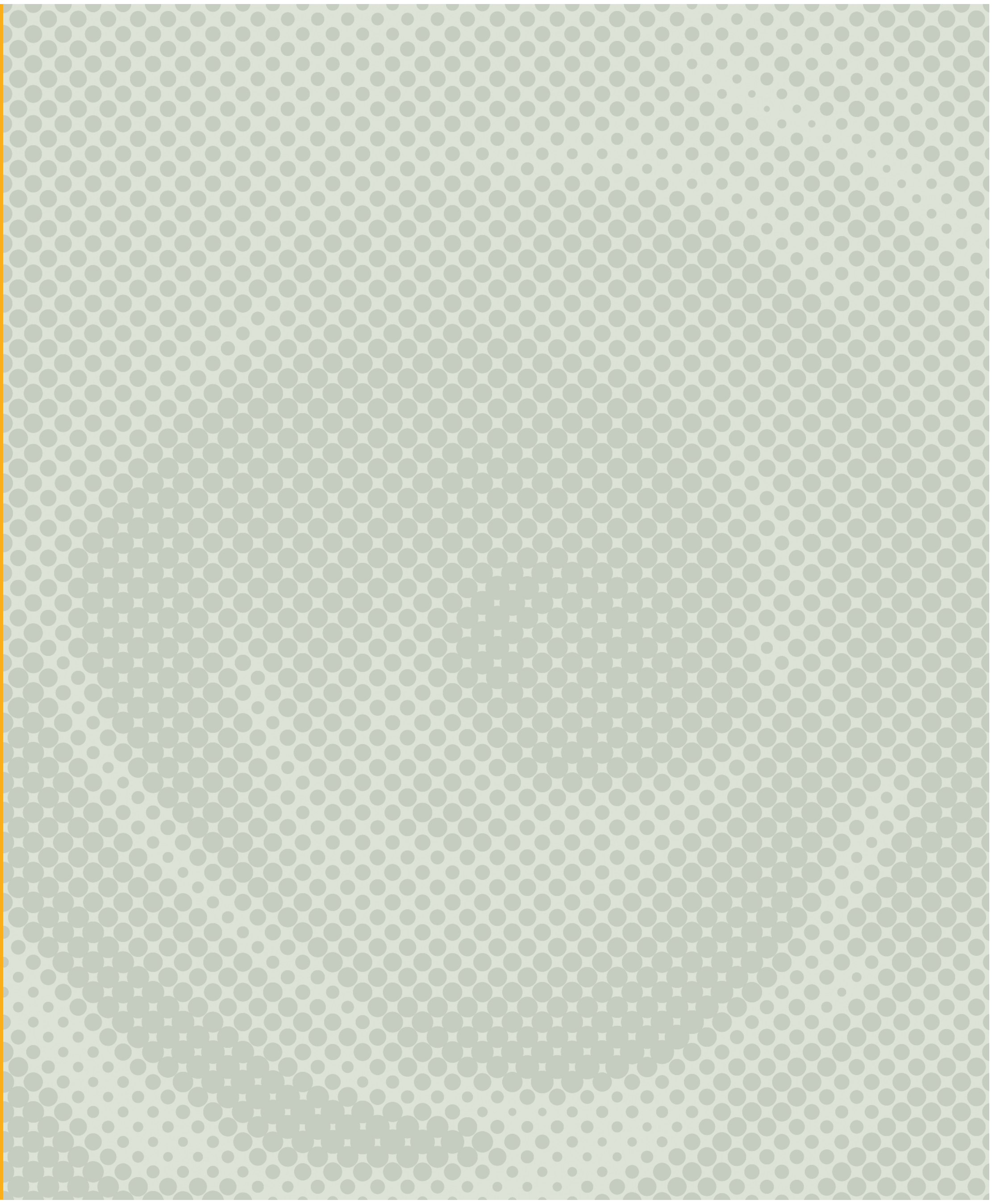

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Any errors in this thesis are my sole responsibility.

Ås, 15th May 2013

Abstract

This thesis explores Demand Side Management of residential power demand in Bergen, Norway. Three distribution transformers supplying have been selected in order to model end-use appliance load curves of households. The modelled appliances are: electric furnaces, water heaters, washing machines, clothes driers, refrigerators and freezers. Appliance load curves are obtained by using the method of diversified demand. The three selected areas Midtbygda, Fyllingsdalen and Helldal constitute 23 % of all households in Bergen, and are statistically representative of the building category distribution. By enrolling 11 % of the households in each area, ripple control of electric furnaces and water heaters may reduce peak loads on the respective distribution transformer by at least 3 % between 07:00 and 08:00. In contrast, the municipal utility Bergen Kommunale Kraftselskap, expects peak demand to increase by 1 % annually. The proposed load control of residential appliances suggests an alternative to load growth, where utilities have many possibilities and benefits from engaging in Demand Side Management.

Sammendrag

Masteroppgaven utforsker styring av topplast i husholdninger i Bergen. Tre transformatorstasjoner som hovedsakelig forsyner husholdninger er valgt ut for å modellere lastkurver. Lastkurver er modellert for følgende apparat: panelovn, varmtvannsbereder, vaskemaskin, tørketrommel, kjøleskap og fryseboks. Lastkurvene er modellert gjennom en metode som tar hensyn til at lastene opptrer på ulik tid og i ulikt omfang. Da de tre valgte områdene er statistisk representativ for boligtypene i Bergen, kan metoden brukes til å modellere og beregne effekten av laststyring. Ved å strategisk koble ut panelovner og varmtvannstanker i 11 % av husholdningene, vil spisslasten kunne reduseres med minst 3 % mellom kl. 07:00 og 08:00. Dette står i kontrast til beregninger gjort av nettselskapet Bergen Kommunale Kraftselskap, hvor topplast forventes å vokse med 1 % årlig. Det foreslåtte laststyringsprogrammet viser at styring kan være et alternativ til økene topplast, og at nettselskaper har mange muligheter for å utforme et effektivt laststyringsprogram.

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1. Definitions

General supply
Energy supplied to the residential and tertiary sector, as well as other industries other than the power-intensive industries (SSB 2013).

Temperature corrected energy consumption
The temperature corrected energy consumption is actual consumption adjusted for the heating degree-days of the municipality.

Utility company
An electric utility company can be a supplier, producer and system operator of power. Norwegian utilities are normally publicly owned at the national or municipal level. This thesis uses the shorthand term utility.

Energy carrier
An energy carrier is a medium that can store and transport energy. This thesis deals mainly with electricity.

Energy services
The services obtained by energy carriers. This thesis deals with services such as comfortable indoor temperatures, hot water, clean and dry clothes, cold and frozen foods.

Short term
In this thesis, short term is defined as less than 24-hours.

Power demand
The demand of an appliance, group or system is the load at the receiving terminal during a specific interval of time, such as daily load on a distribution transformer (Dillard 1959).

Load curve
A load curve for a certain appliance, group or sector shows the hourly variations of power demand.

Load duration curve
A load duration curve is an ascending curve of annual loads, often showing how much load exceeds a certain threshold.

Peak load
Peak load, or peak demand, is the maximum power demand for a defined energy system at a certain time. Peak load can be annual, seasonal daily or hourly. This thesis focuses on annual peak load, and models short-term load curves.

Diversified demand
Diversified demand, or coincident demand, is the sum of contributions from a composite group of related loads.

Maximum diversified demand
Maximum diversified demand refers to the maximum load of a group of residential appliances.

Household type
Refers to the residents of the household; family, single persons etc.

Building category
Refers to the building category of a residential unit; apartment buildings, terraced, detached, or semi-detached houses.

Apartment buildings
Buildings with 2 or more floors and 2 or more residential units.

Terraced houses
Houses that are attached to at least two other buildings.

Detached
Houses that are not attached to other buildings.

Semi-detached
Houses that are attached to another building and contain two residential units.

2. List of translations

English	Norsk
General supply	Alminnelig forsyning
Primary sector	Primærsektor
Secondary sector	Industrisektor
Tertiary sector	Tjenesteytendesektor
Utility company	Nettselskap
Central grid	Sentralnett
Distribution grid	Distribusjonsnett
Distribution transformer	Transformatorstasjon
Peak power demand	Topplast
Coincidence peak	Aggregert topplast
Demand Side Management	Laststyring
Demand Response	Forbrukerfleksibilitet
Apartement building	Boligblokk
Terraced house	Rekkehus
Detached house	Enebolig
Semi-detached house	Tomannsbolig

3. Introduction

In 2005, Norway's national utility proposed controversial transmission grids through Hardangerfjord, to secure electricity supply in Bergen. Dispute climaxed in 2010, as campaigners refused to compromise areas of international value. The Norwegian Society for the Conservation of Nature commissioned a report to address alternatives, concluding that the main issue was insufficient transmission capacity on days of peak demand in Bergen (Brunborg 2011). Although peak demand rarely occurs, its size is crucial for utility companies to determine transmission capacity. The debate highlighted new aspects of national energy planning, in particular peak power supply and its disproportionate environmental impact.

More recently, following a long period of cold weather, Norwegian electricity demand reached new heights on the 22nd of January 2013. The municipal utility, Bergen Kommunale Kraftselskap (BKK), also reported record-high demand at 08:20 in their supply area, as shown in Fig. 1 (Natås, I. M. 2013e) (Langeland Haugen 2013b).

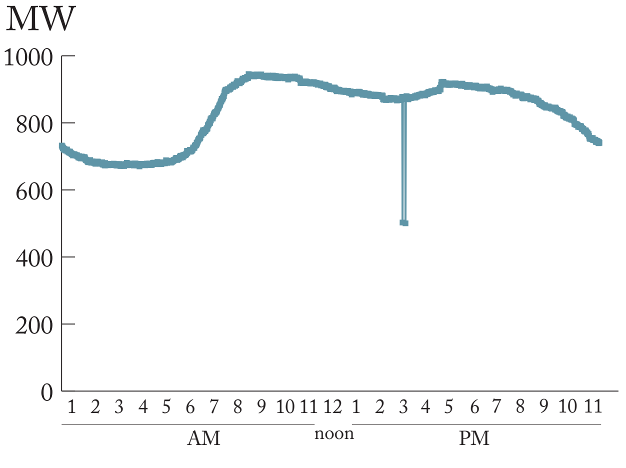

Figure 1 - Peak demand occurred at 08:20 in Bergen, Os, Askøy, Kollsnes, Mongstad, Kvam and Lindås on the 22nd January 2013 (Natås, I. M. 2013e)

BKK expects peak demand to increase, and in return proposes several transmission grids in and around Bergen (BKK 2012). Traditionally, grid-planning must accommodate system dynamics and load growth to ensure sufficient capacity, where peak demand sets the minimum standard. Alternatively, system capacity is achieved by strategically controlling loads, known as Demand Side Management (DSM). By assuming that consumers do not require energy, but the services that energy provides, BKK may control the timing of electricity demand rather than simply adhering to it. In short, DSM allows utilities to strike a balance between demand for energy services and limited transmission capacity (IEA 2008). Examples, presented in the following chapter, show that DSM may reduce grid investments, avoid environmental degradation and improve system efficiency.

Designing and operating a distribution system with DSM requires knowledge of load characteristics, including real-time measurements and the relative load contribution from different sectors and their appliances. In the absence of such data, the method of maximum diversified demand is used to estimate residential loads placed on distribution transformers, outlined in Chapter 5. Twenty-one distribution transformers supply Bergen; this thesis focuses on three. The selected areas Midtbygda, Fyllingsdalen and Helldal encompass almost a quarter of total households in Bergen, and are presented in section 6.1.

This thesis models load curves for the following appliances: electric furnaces, electric water heaters, washing machines, clothes driers, refrigerators and freezers. The appliances contribute to around 30 %

of total load placed on the three transformation stations. The appliance load curves enable a DSM proposal to reduce peak demand on the distribution transformer by at least 1 %. The goal is met by ripple control of electrical furnaces and water heaters, whilst sustaining energy services. Conversely, BKK assumes an annual growth rate of 1 %, equal to the expected population growth in Bergen (BKK 2012). The proposed DSM scheme is outlined in Chapter 7.

The method and results are limited by the fact that there are no real-time measurements of residential end-use in Bergen. The proposed DSM scheme is a starting point for load management, which is discussed further in Chapter 8.

4. Theoretical approach

4.1 Demand Side Management

In this section Demand Side Management is presented through a literature review. Demand Side Management refers to the targeted actions that reduce electricity consumption to avoid system strain (IEA 2008). System strain may be alleviated using several strategies, shown in Fig. 2. The basic assumption is that customers do not require electricity as such, but rather the services it provides. If these services can be maintained to customer-satisfaction whilst reducing peak demand, it can be cost-effective for a utility company to incentivize DSM.

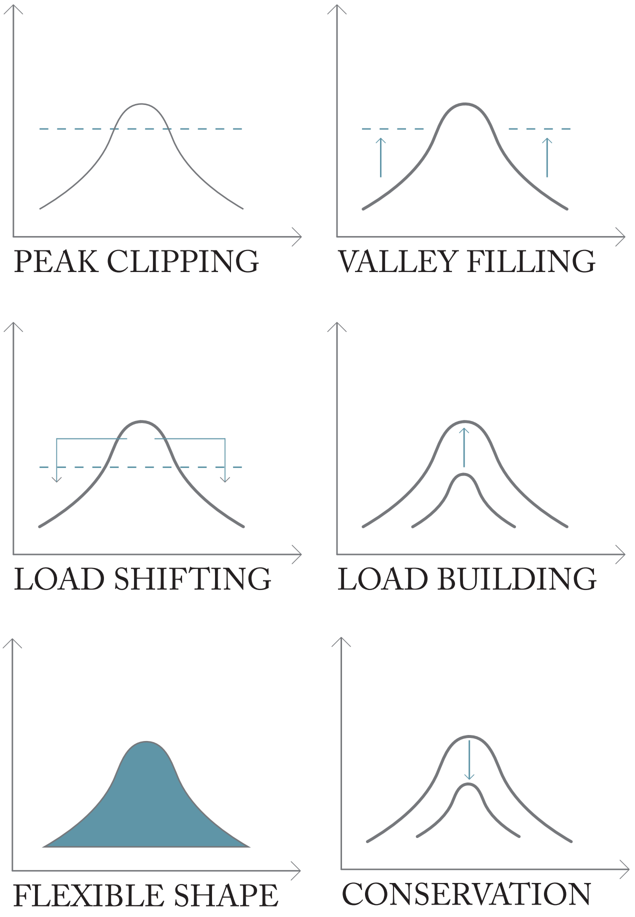

Figure 2 - Strategies for peak load alternations. Adapted from (CEB 2012), (Nilsson 2007) and (Lislebø et al. 2012).

The origins of Demand Side Management can be traced back to the 1970's energy crisis in America, and the term was publicly introduced by the Electric Power Research Institute in 1986 (Balijepalli et al. 2011). The basic ideas remain: peak clipping, valley filling, load shifting, load conservation, strategic load building and flexible load shaping can control peak demand. Peak clipping means reducing peaks at critical peak hours. Valley filling increases load in off-peak hours. Load shifting reduces loads but also replaces them at a later hour. Strategic load building means increasing loads equally during all or most hours of the day. Conversely, conservation is evenly reducing loads. The flexible load shape describes the program a utility may set up to alter customer electricity use during a day.

The ways of achieving DSM are numerous, and range from price incentives to direct control schemes. A distinction can be drawn between who actively modifies demand: the utility, the customer, or both (Table 1). The utility may implement load control for peak

Table 1 - DSM distinctions and their actions. Adapted from (Albadi & El-Saadany 2008) and (IEA 2008).

<table>
<tr><th>Utility</th><th>Customer</th></tr>
<tr><td>Direct Load Control</td><td>Time of Use (TOU) pricing</td></tr>
<tr><td>Distributed Generation</td><td>Critical Peak Pricing (CPP)</td></tr>
<tr><td>Change Energy Carrier</td><td>Real Time Pricing (RTP)</td></tr>
<tr><th colspan="2">Utility & Customer</th></tr>
<tr><td colspan="2">Integrated Demand Side Management</td></tr>
<tr><td colspan="2">Opt-In Programs</td></tr>
<tr><td colspan="2">Energy Efficiency</td></tr>
</table>

clipping, valley filling and load shifting of larger customers. The scheme requires that a direct communication link connects the utility and customer, in which the utility may shut down or cycle certain appliances between customer groups (IEA 2008). Such strategies are known as ripple control. Distributed generation is using energy carriers already present in the supplied system, like stand-by generation or cogeneration facilities. In contrast to distributed generation, changing energy carrier is a long-term strategy, such as planning district heating. The customer-led strategies are all variants of Demand Response (DR), where different price mechanisms are used to simulate off-peak use (Albadi & El-Saadany 2008). DR can be understood as the sum of changes customers make to their electricity use, as a response to high prices and/or problems in the electricity network. The utility will usually notify customers when short-term load reductions are needed.

The schemes requiring dual efforts are Integrated Demand Side Management, Opt-In Programs and Energy Efficiency. Energy efficiency is formally regulated through building standards, but the utility may encourage retrofitting of existing buildings, such as a DSM scheme in France (IEA 2008). As a DSM-action, energy efficiency reduces load levels by decreasing the amount of energy used to obtain energy services.

An opt-in programme describes the agreement between utilities and customers to allow the utility to interrupt certain loads. The customer usually receives a reduced tariff, but may also face fees by choosing to use an override option. The integrative approach assigns strategies to suit the objective of the DSM-scheme. All of the DSM measures are common, and many examples exist worldwide (IEA 2008). In Canada for example, demand peaks due to air-conditioning on hot summer afternoons. The municipal utility in Ontario can directly reduce load by disconnecting 136 600 households enrolled in the Peaksaver program. The estimated total load reduction is 64.5 MW (Newsham et al. 2011). Even though opt-in programmes require up-front investments, utilities find that the benefits outweigh the costs. For example, the New York Independent System Operator has paid 7.2 million USD in incentives to more than 140 000 program participants, which may release 700 MW of peak capacity. On a peak day during the summer of 2003, the load reduction provided benefits of over 50 million USD. In general, benefits exceed the costs by a factor of 7:1 (Albadi & El-Saadany 2008).

A further example is Orion Energy in New Zealand, who aimed at decoupling growth of peak demand, by applying a mix of direct load control and pricing strategies. The utility may control up to 90% of the residential water heaters when the system exceeds a certain threshold (IEA 2008).

Demand Side Management offers benefits for both utilities and customers. Effects may also cascade into the national power system. The national utility in Australia has identified several examples (PC 2012). DSM may:

- Avoid peak demand growth, which can reduce the need for peak specific network investments
- Improve utilisation of supply side capacity
- Improve reliability of supply
- Reduce volatile demand
- Decrease electricity bills in the short term
- Halter growth of electricity prices in the long term

DSM is also used to specifically avoid environmental degradation. The DSM

Eco-programme in France is the largest in the European Union, and has substituted the need for upgrading a large transmission line intended to supply the Provence-Alpes-Côte d'Azur (IEA 2008). Planning started in 1983, and several years of impact assessments, public commissions and protests suspended the project. In 2000, alternative solutions to simply upgrade and replace existing lines and engage the utility in DSM were proposed. The protesters refused to compromise the scenic areas, and planning permission was eventually denied. This left DSM as the only option meet load growth and keep demand within the capacity of the existing transmission line. After quantifying the amount of peak load reductions that would avoid network constraints, the programme reduced load by modifying consumption across all sectors. Using load growth projections, the utility registered when constraints would occur again, and tailored the DSM to be a direct substitute (IEA 2008).

4.2 Reference Energy System and Energy Services

The following section approaches residential energy demand from the end-use perspective by organizing a Reference Energy System (RES). A RES is an overview of a defined energy system at any given moment. Practically, the RES is a network showing all the necessary technologies that can meet demand. Fig. 3 follows energy from production to consumption in Bergen 2010, and energy consumption is temperature corrected (Natås, I. M. 2013b). The different sectors, local generation and residential appliances are coded, summarized in Table 2. The only energy carrier obtained within municipal (henceforth called system) boundaries is waste.

Table 2 - Codes used in the Reference Energy Sytem (RES)

Sector	Code
Primary sector	1-SEC
Secondary sector	2-SEC
Tertiary sector	3-SEC
Residential sector	HOUSE
Recreational buildings	REC
Local generation	Code
Small-scale hydropower	S-EL
Cogeneration - electricity	CO-EL & CO-HE
Residential appliances	Code
Electric furnace	RHE
Heat pump	RHP
Wood stove	RHW
Fossil based furnace	RHF
Light bulbs	RL
El-specific	RS
Water heater	RWH

Petroleum and gas are sourced outside the system boundaries, and transmission grids supply electricity from regional hydropower. In 2010, 98 % of electricity use was imported via transmission grids, and a minimal amount was produced from municipal small-scale hydro (S-EL) and cogeneration (CO-EL). Cogeneration runs on waste, gas, oil and electricity, to mainly produce district heating (Natås, I. M. 2013c).

Consumption, given in GWh, shows that electricity is the main energy carrier for all sectors. In total, the secondary sector (2-SEC) used 633 GWh. The tertiary sector (3-SEC) used 1925 GWh, of which 1467 was electricity. 245 GWh of petroleum products and 52 GWh gas, as well as 161 GWh of district heating is also consumed. The primary sector (1-SEC) used 8 GWh electricity and 4 GWh petroleum products. Recreational dwellings (RECRE) consume only electricity, and in 2010 this was 6 GWh.

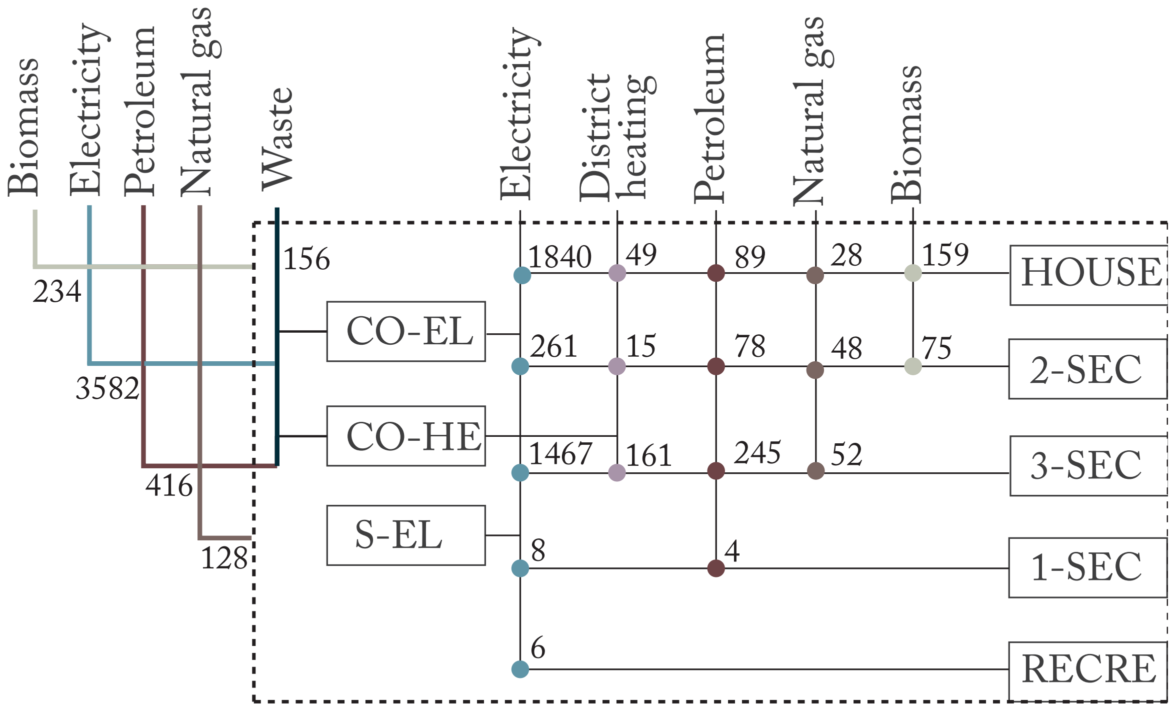

Figure 3 - The Reference Energy System for Bergen 2010 follows energy from production to end-use of all sectors.

Fig. 4 illustrates that the residential sector consumes most energy, totalling 2164 GWh. The largest energy carrier is electricity; 1840 GWh was consumed in 2010. This sector also consumes most biomass.

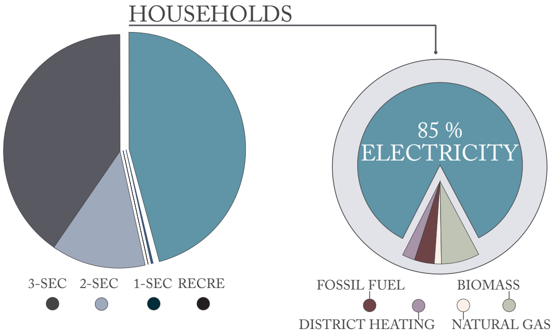

Figure 4 - In 2012, the residential sector consumed most energy, of which 85 % was electricity (Natås, I. M. 2013b).

In this thesis, energy services for the residential sector are: comfortable indoor temperatures, hot water, light, clean and dry clothes, chilled and frozen foods. The services are delivered through the stock of household appliances, such as electric furnaces, water heaters, washing machines, clothes driers, refrigerators and freezers. This is illustrated in Fig. 5 and explained below.

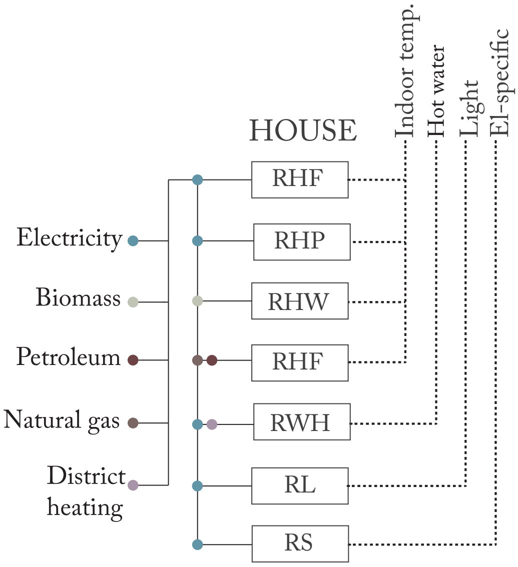

Figure 5 - Energy services appliances and energy carriers used in the residential sector in Bergen 2010.

Comfortable indoor temperatures; are obtained via electric furnaces (RHE), heat pumps (RHP), wood stoves (RHW) and fossil based furnaces (RHF). Wood stoves (RHW) and fossil based furnaces (RHF) are met by direct biomass and direct fossil fuels such as oil, gas or propane, whereas heat pumps make use of heat in the air or ground and consume some electricity. Hot water is stored in a water heater (RWH), and is supplied with electricity (IMP-EL) or district heating from cogeneration (CO-EL). Residential lighting is met by the stock of light bulbs (RL). El-specific demand includes all objects run on electricity, such as computers, washing machines, fridges, freezers etc. Practically, this energy service is delivered through sockets in households (RS).

The following section examines electricity supply in Bergen, and identifies the main issues arising from peak power demand.

4.2 Peak power demand in Bergen

Since the main energy carrier in Norway is electricity, the greatest potential for freeing grid capacity is by targeting consumption in buildings and households (Lislebø et al. 2012). DSM of buildings in Bergen could be a tactical strategy to secure electricity supply on days of peak demand, as total demand can quickly exceed transmission capacity of the two lines supplying the municipality. When demand exceeds capacity the utility is breaching the N-1 criteria; if one fault on one line occurs, power may be cut off. If power is cut off, BKK will face penalties as the responsible utility company, called KILE-costs (BKK 2012). Fig. 6 shows where two transmission grids supply Bergen and where electricity is distributed via 21 distribution transformers. The distribution transformers are shown with peak loads in 2012 in relation to the outer circle, 70 MW (Natås, I. M. 2013d).

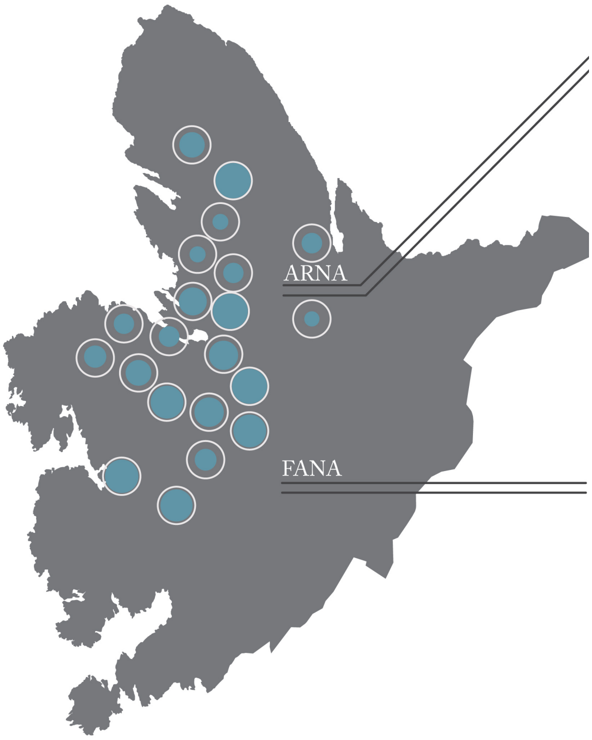

Figure 6 - Supply and distribution of electricity in Bergen from two transmission grids, distributed further via 21 transformers. Peak loads for 2012 are represented; the outer circle is 70 MW (Natås, I. 2013).

To assess the potential of deploying a DSM strategy, peak demand and load curves are a natural starting point. As load curves reflect different activity levels from different sectors in society, the goal of DSM is to even out behaviour and activity. Any successful DSM strategy will therefore require extensive knowledge on the load curves for certain customer groups and their appliances. Residential appliance load curves are obtained in using the method of diversified demand. For the other sectors in Bergen, the varying load curves can be summarized using illustrations placed on BKK's load curve for peak power in 2013. Fig. 7 is a visualisation since conclusions on how different sectors contribute to the peak cannot readily be drawn. However, the observed peaks on the total load curve do indicate that a substantial part of the customer group is engaging in simultaneous activities, increasing power demand These activities are typically office hours, industrial activity or increasing room temperature, and are often influenced by common, external factors such as outdoor temperature and time of day.

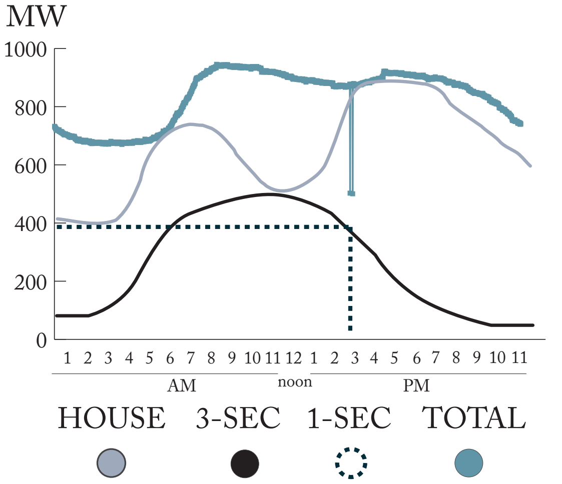

Figure 7 - Total power demand in Bergen on the 22nd of January 2013 (Natås, I. M. 2013e). Illustrations of residential, tertiary and primary sector load curves. Adapted from (Lislebø et al. 2012).

Two distinct peaks occur in the residential sector. The first peak is between 07:00 and 08:00 as people wake up, turn on lights and heating, have a shower and cook breakfast. The peak quickly descends as people go to work, but perhaps heating is left on, and electric appliances on stand-by. The second peak occurs somewhere between 17:00 and 19:00, as people return to their homes and need electricity for their afternoon activities. The tertiary sector does not have two distinct peaks, but elevates from 08:00 to 16:00, corresponding with the length of a day's work. Computers, heating, office lights and other electrical appliances are probably left on stand-by when office hours are over, explaining some of the underlying demand.

Industries are typically energy-intensive in Norway, and could operate as long as people are on shift. But when production is done for the day the effects are rapid. Two dramatic reductions take place at 15:13 and 15:21 respectively; power demand reduces by 375 MW in less than a minute, before returning to normal levels. These points reveal the effect of either heavy industries momentarily halting production, or it could be signs of load control. If the former, one can assume that 375 MW are more or less present in the load curve at all times.

The total load curve will peak when there is coincident high usage across all sectors: residential, secondary, tertiary and industrial. During hours of critical peak demand, high marginal costs are reflected in high electricity prices. When power peaked in the BKK-area between 08:00 and 09:00, so did prices at 63.35 EUR/MWh. This was repeated during the second peak where prices rose to 81.33 EUR/MWh. The lowest price was 37-74 EUR/MWh, making price peaks twice as high (NordPoolSpot 2013). The day of peak demand was also the coldest in the past 12 months (MET 2013). The relationship between coincident electricity use and low temperatures is widely noted in Norway (Ericson & Halvorsen 2008) (Bjørgum 2013).

To summarize, the main peak demand issues in Bergen are:

1) High electricity demand in all sectors, aggravated by low temperatures
2) System bottlenecks driving prices up during hours of peak demand
3) During peak demand, the N - 1 criterion may be breached, risking blackout and generating fees for the utility company.

4. Methodology

The following section outlines the rationale behind the method of diversified demand.

4.1 The Method of Diversified Demand

The method of diversified demand is an appliance end-use model. Even though appliances constitute total load, individual loads cannot be summarized, as they do not occur simultaneously. On the other hand, an aggregate load curve reflects the total, uncorrelated load but cannot readily be broken down into separate appliances. An aggregated load curve for a set of residential appliances can be obtained by using the method of diversified demand, initially developed by Arvidson in 1940. The method estimates the load on distribution transformers when measurements of the actual load are limited. It has successfully estimated loads in Christchurch, New Zealand (Gyamfi & Krumdieck 2012), and in Safri, the Middle East (Al-Alawi & Islam Unknown). Fig. 8 outlines data-input to calculate appliance loads: total number of households (HH_j) appliance frequency (s_i,) maximum diversified demand (MDD_i) and finally hourly load variations (AHVF). AHVF, MDD_i and s_i are appliance specific.

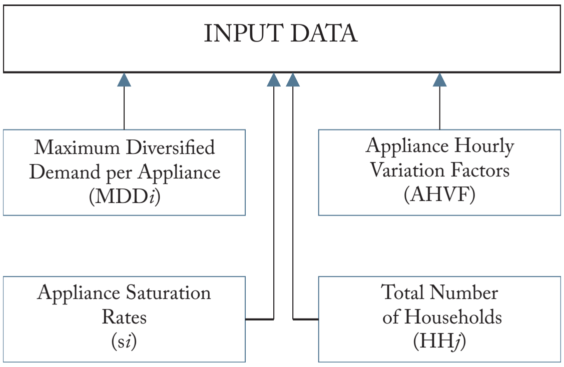

Figure 8 - Required data-input to calculate appliance loads. Adapted from Gyamfi and Krumdieck (2012).

The appliance saturation rate, s_i, is defined as the percentage of households that own at least one of the appliances in question. The model simulates appliance use with Appliance Hourly Variation Factors, a digit between 0 - 1. When AHVF = 1, the appliance draws power equivalent to its MDD_i. The average maximum diversified demand, $MDD_{(av,max)}$ decreases when the number of appliances increases, shown in Fig. 9.

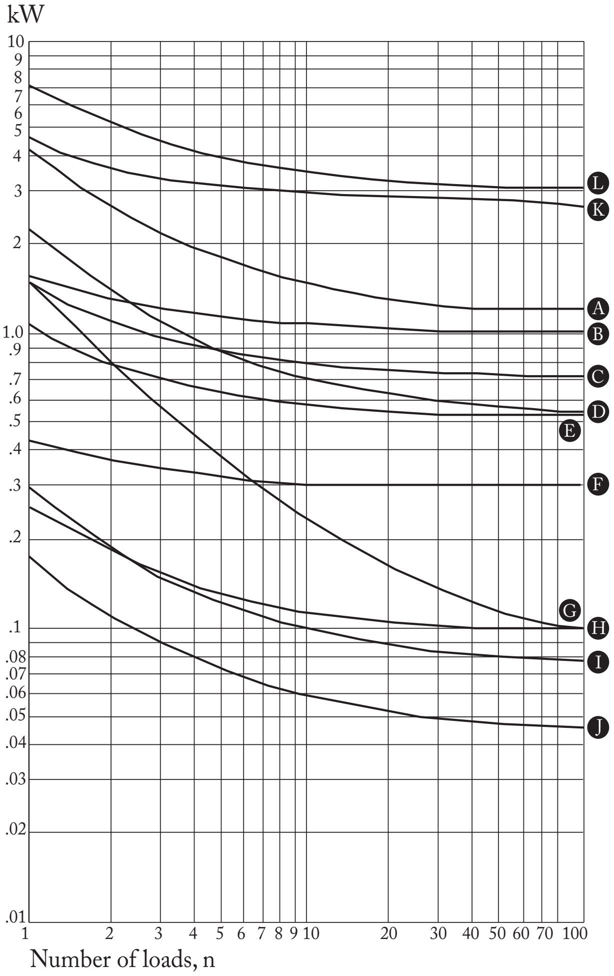

Figure 9 - Maximum diversified 30-min demand characteristics of various residential loads: A = clothes dryer; B = off-peak water heater, "off-peak" load; C = water heater, uncontrolled, interlocked elements; D = range; E = lighting and other miscellaneous appliances; F= 0.5-hp room coolers; G= off-peak water heater, “on-peak” load, upper elements uncontrolled; H = oil burner; I = home freezer; J = refrigerator; K = central air-conditioning, including heat pump cooling, 5-hp heat pump (4-ton air conditioner); L = house heating, including heat-pump-heating-connected load of 15-kW unit type resistance heating or 5-hp heat pump (Gönen 1986).

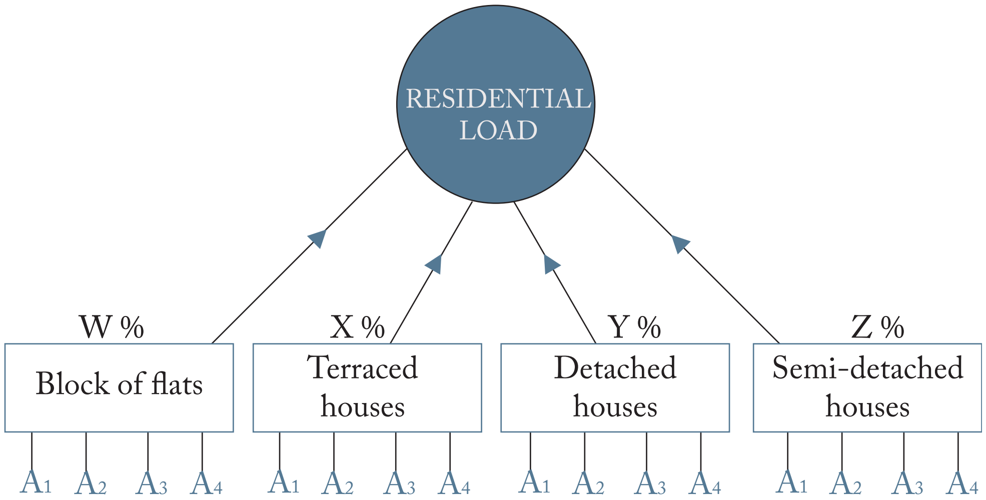

Figure 10 - Total residential load is a weighted sum of appliance loads from different building categories. Adapted from (Gyamfi & Krumdieck 2012)

Fig. 10 outlines the approach to obtain total residential load placed on one distribution transformer. The total residential load is the sum of loads from different building categories; block of flats, terraced, detached and semi-detached houses. Each selected area has a certain building distribution, given by the percentages W, Y, X and Y. Total residential load is weighted accordingly. Each building category has a total number of households that contribute to demand via different appliances, denoted A_i. The maximum load of appliance *i* in building category *j* ($MDD_{i,j}$) is calculated from Eq. (1):

$$MDD_{i,j} = MDD_{(av,\,max)} \times HH_j \times s_{i,j} \qquad (1)$$

$MDD_{(av,max)}$ is the average maximum diversified demand of an appliance per household, and HH_j is the total number of households in building category *j*. $s_{i,j}$ is the percentage of households within building category j that own at least one of appliance *i*.

From Eq. (1), the total number of appliances, n_i, is obtained by the total number of households in building category *j*, HH_j, multiplied by the appliance saturation rate for the building category $s_{i,j}$. When many appliances are modelled for many different households, the more out of synch their use and loads are. The average maximum diversified demand per appliance will therefore decrease, as shown previously in Fig. 9. During a day the maximum diversified demand will also fluctuate, creating the load curve. The model estimates the load curve using Appliance Hourly Variation Factors (AHVFs). The maximum diversified demand of an appliance *i* in a given hour *t*, is calculated from Eq. (2):

$$MDD_{(t.max)\ i} = MDD_{(av,max)} \times HH_j \times s_{i,j} \times f_i(t)$$

The hourly variation factors reflect the behaviour of residents and vary between household types and location. Appropriate AHVFs may be obtained from real-time measurements.

The following steps, summarized in Dillard (1959), explain how to calculate the short-term load curve of appliance *i*,:

1) Multiply the total number of households in each building category by the appliance saturation rate in order to obtain the total number of appliances, n_i.
2) For the number of appliances, n_i, read the average maximum diversified demand, $MDD_{(av,max)i}$, in kW/load from Fig. 9.
3) Multiply the value obtained in 2) with the number of appliances to obtain the maximum demand of that particular appliance load.
4) Multiply the value obtained in 3) by the hourly variation factor, $f_i(t)$ to obtain the contribution of that type of load to the group maximum demand.

The steps are repeated for each appliance, and summarized to obtain the total load curve for the building category. The total residential load is the weighted sum of all building categories.

The model requires appliance specific data-inputs, outlined in the next section.

4.2 Input Data

It is necessary to adjust the initial input data given in Dillard (1959) and Gönen (1986), to obtain results reflecting the selected areas in Bergen. An end-use measurement campaign conducted in Sweden provides the best results on load curves and electricity usage to date (Bennich et al. 2009). The study monitored electricity consumption in 200 houses and 190 apartments between September 2005 and June 2008. Most of the households were monitored for only one month, but 40 households were monitored for one year (Zimmermann 2009). Households were differentiated into three main categories: houses with electric heating, houses without direct electric heating and apartments. The subcategories regarded the household inhabitants and their age, in order to identify the effect on consumption and load. The load curves are given for holidays (Sat- Sun) and workdays (Mon – Fri). Since the peak loads for Bergen occurred on weekdays in 2010, 2012 and 2013, initial simulations are compared with workday load curves shown in Zimmermann (2009).

In the following section the appliance saturation rate, $s_{i,j}$, the average maximum diversified demand per appliance, $MDD_{(av,max)}$ and the hourly variation factors, AHVF for each modelled appliance are defined. The modelled appliances include the electric furnace, water heater, washing machine, clothes dryer, refrigerator and freezer.

Electric furnace

Definition

In Gönen (1986) the house heating appliance is defined as resistance heating (electric furnace) or a heat pump. Both heating appliances use electricity, but the difference lies with the heat pump. A heat-for-heat pump generates more energy services than its energy input, a parameter named coefficient of performance (COP). This makes heat pumps a popular choice, and there are an estimated 24 600 heat-pumps in Bergen BKK (2011). But, as temperatures drop, the heat pump must work harder and the COP is reduced. The heat pump is therefore assumed to be just as efficient as a regular electric furnace on days of peak demand, an assumption also used in Lislebø et al. (2012).

Appliance saturation rate

The appliance saturation rate is determined for buildings built from 1900 to 2001 using national statistics from SSB

(2001). Statistics show that the appliance saturation rate for electric heating differs between the building categories detached, semi-detached, terraced and block of flats. Of the ten heating categories, four are fully or partially based on electricity:

- One system, electric furnaces/heat cables or similar.
- Two or more systems, electric furnaces/heat cables and oven for solid fuels.
- Two or more systems, electric furnaces and oven for liquid fuels.
- Two or more systems, electric furnaces/heat cables and oven for solid and liquid fuels.

The four categories are selected and the average appliance saturation rates calculated, differentiated by building category. The total saturation rate for each area has been weighted according to the percentage of each building category, which varies between Midtbygda, Fyllingsdalen and Helldal. There is no data on appliance saturation rates for the next decade, as statistics are yet to be published. The same appliance saturation rate for 1991 - 2001 has been used for buildings built between 2002 and 2012. These rates are quite large compared with the average, and when updated statistics are published this rate should certainly be reviewed.

Maximum diversified demand

In Gönen (1986), the maximum diversified demand of a single heating appliance is 8 kW/load, and is 3.2 kW/load when the number of loads is 100. This is compared with measurements of 192 houses with direct electric heating in the REMODECE study. One can assume an average maximum diversified demand for electric heating using the average maximum power drawn from these houses and how much heating contributed to total load. This is then weighted by household type, which gives 3,6 kW/load. For the 187 apartments, the number is quite different. Here the weighted average is 0.3 kW/load, and also differed between resident age and family structure. The nuances in the dataset from the REMODECE study are not transferable to the selected areas in Bergen, as no data on household types are obtained. Nevertheless, the age and family structure of the residents impacts power demand, making it important to when tailoring DSM schemes.

Feilberg and Livik (1991) estimate that MDD_i of one house with electric heating in Bergen has a maximum demand of 9,4 kW/load. When the number of households increases to 15, the total maximum diversified demand is 110,4 kW/load, or on average 7,4 kW/load per household. This complies with the theory that as number of appliances increase, the average maximum diversified demand decreases per appliance.

Appliance Hourly Variation Factors

In (Gönen 1986), AHVF = 1 from 08:00 and 09:00, creating the appliance peak. However, the AHVF will simulate a very rapid increase from 07:00 to 08:00, which is not necessarily correct for Bergen. On the day of peak demand in 2013 temperatures were very low, meaning that electric furnaces might be on during the night.

An alternative AHVF has been created using estimates from Feilberg and Livik (1991). A statistical method estimated load curves for households with electric heating in Bergen on a day of -4.3 degrees Celsius. The estimated peak demand occurs at 18:00, and two peaks at 07:00 and 10:00 respectively. The morning peak is not rapid as given in (Gönen 1986), but reflects that demand is already quite high in the night.

The statistical method accounts for climate dependency and the coincidence factor between energy use in different and similar buildings. These factors are unaccounted for in the method of diversified demand. Further, the new AHVF is more likely at low temperatures. From Feilberg and Livik (1991) a new AHVF is created for the electric furnace. The comparison is shown in Fig. 11 and new AHVFs summarised in Table 4.

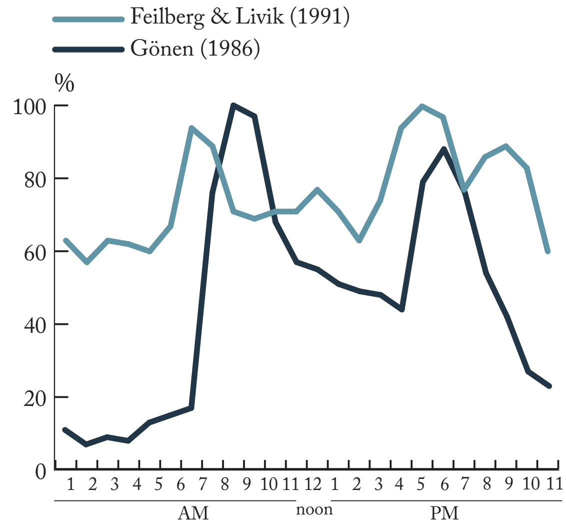

Figure 11 - Comparing Appliance Hourly Variation Factors, given as a percentage of maximum load for the electric furnace (Feilberg & Livik 1991; Gönen 1986).

Table 4 - Appliance Hourly Variation Factors for an electric furnace, as given in Gönen (1986) and adapted from Feilberg and Livik (1991).

Hour	Timeframe	As given in Gönen (1986)	Adapted from Feilberg and Livik (1991)
1	(0-1)	0,11	0,63
2	(1-2)	0,07	0,57
3	(2-3)	0,09	0,63
4	(3-4)	0,08	0,62
5	(4-5)	0,13	0,60
6	(5-6)	0,15	0,67
7	(6-7)	0,17	0,94
8	(7-8)	0,76	0,89
9	(8-9)	1	0,71
10	(9-10)	0,97	0,69
11	(10-11)	0,68	0,71
12	(11-12)	0,57	0,71
13	(12-1)	0,55	0,77
14	(1-2)	0,51	0,71
15	(2-3)	0,49	0,63
16	(3-4)	0,48	0,74
17	(4-5)	0,44	0,94
18	(5-6)	0,79	1,00
19	(6-7)	0,88	0,97
20	(7-8)	0,76	0,77
21	(8-9)	0,54	0,86
22	(9-10)	0,42	0,89
23	(10-11)	0,27	0,83
24	(11-12)	0,23	0,60

Water Heater

Definition

There are three types of water heaters defined in Gönen (1986), with different maximum diversified demands (MDD_i from n= 1 to n = 100);

1. Off-peak water heater, “off peak” load, 1,7 kW ≥ MDD_i ≤ 1,1 kW
2. Water heater, uncontrolled, interlocked elements 1,6 kW ≥ MDD_i ≤ 0,7 kW

3. Off-peak water heater, “on peak” load, upper element uncontrolled 1,6 kW $\geq MDD_i \leq$ 0,1 kW

An off-peak water heater means that the utility company may disconnect power through load control (Fanney & Dougherty 1996). Conversely, an uncontrolled water heater draws power as needed, and is used further in the model.

Appliance Saturation Rate

All houses are assumed to have an individual water heater, and their appliance saturation rate is one. Some apartments in Bergen are supplied with hot water from a central furnace, reducing the appliance saturation rate. In Fyllingsdalen, at least 1350 households in apartment buildings receive hot water from a central furnace run on liquefied natural gas. In Midtbygda, the number is at least 655 (BKK 2011). The application saturation rate has been adjusted accordingly, but is not definitive the two areas. Apartments in Helldal are assigned the appliance saturation rate found in the Norwegian REMODECE study, 0.85 (Sæle et al. 2010).

Maximum Diversified Demand

In Gönen (1986), a single uncontrolled water heater has a maximum diversified demand of 1.6 kW. In other words, this is the capacity of the heating elements. The load decreases to 0,7 kW/load when *n* = 100. By comparison, a recent Norwegian study of 475 households assumes an installed capacity of 2 kW per water tank, where the average tank holds 200 l (Ericson 2009). The maximum diversified demand, referred to as the average potential reduction per household during disconnection, is 0,5 kW/load. The maximum diversified demand found in Ericson (2009) is used. However, the size of the tank may vary, and water usage is a determining factor for the corresponding power demand.

Appliance Hourly Variation Factors

In Gönen (1986), AHVF = 1 at 09:00 and 10:00 as the water tank is simulated to increase power demand after people have used hot water. For the households monitored in the REMODECE study, the morning peak occurs from 07:00 and 09:00 on a workday, although there are variations between building type, residents and family structure. The study also found a second, smaller peak between 07:00 and 08:00, however this was very much dependent on household type. An explanation for the differences could be that newer water tanks increase loads rapidly after hot water usage. The AHVF given in Gönen (1986) may reflect the older water tanks where a certain delay could be expected from the time of water use to the time of increased power drawn to reheat water. The AHVF is moved back, so that it resembles the newer tanks. The comparison between the AHVFs for the water heater is shown in Fig. 12. Table 5 lists the initial and adapted AHVFs for the water heater.

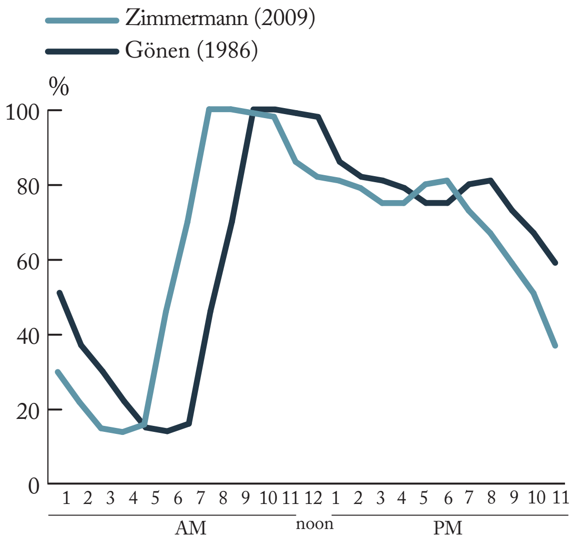

Figure 12 - Comparison of AHVFs for the water heater, in percentage of maximum load, as given in (Gönen 1986) and adapted using (Zimmermann 2009).

Table 5 - Comparison of AHVFs for the water heater as given in (Gönen 1986) and adapted using (Zimmermann 2009).

Hour	Timeframe	As given in Gönen (1986)	Adapted from Zimmermann (2009)
1	(0-1)	0,51	0,3
2	(1-2)	0,37	0,22
3	(2-3)	0,3	0,15
4	(3-4)	0,22	0,14
5	(4-5)	0,15	0,16
6	(5-6)	0,14	0,46
7	(6-7)	0,16	0,7
8	(7-8)	0,46	1
9	(8-9)	0,7	1
10	(9-10)	1	0,99
11	(10-11)	1	0,98
12	(11-12)	0,99	0,86
13	(12-1)	0,98	0,82
14	(1-2)	0,86	0,81
15	(2-3)	0,82	0,79
16	(3-4)	0,81	0,75
17	(4-5)	0,79	0,75
18	(5-6)	0,75	0,8
19	(6-7)	0,75	0,81
20	(7-8)	0,8	0,73
21	(8-9)	0,81	0,67
22	(9-10)	0,73	0,59
23	(10-11)	0,67	0,51
24	(11-12)	0,59	0,37

Refrigerator

The term ”refrigerator” from Gönen (1986) is compared with the term ”fridge” in the REMODECE study.

Appliance Saturation Rate

The average appliance saturation rate for fridges was 0.67 (Zimmermann 2009), and is used further in the model.

Maximum diversified demand

In Gönen (1986), $MDD_{(av,\ max)}$ = 0.8 kW/load when n = 1, and 0,048 kW/load when n = 100. In REMODECE, n = 260 and the average peak load was 0.04 for houses and 0.03 for apartments. In the model, no further modifications are made to the maximum diversified demand of the refrigerator.

Appliance Hourly Variation Factor

Fig. 13 shows that the AHVF for a refrigerator is stable and peaks slightly between 20:00 and 21:00 (Gönen 1986). In REMODECE peaks were measured between 18:00 and 20:00. No further modifications are made to the initial AHVF.

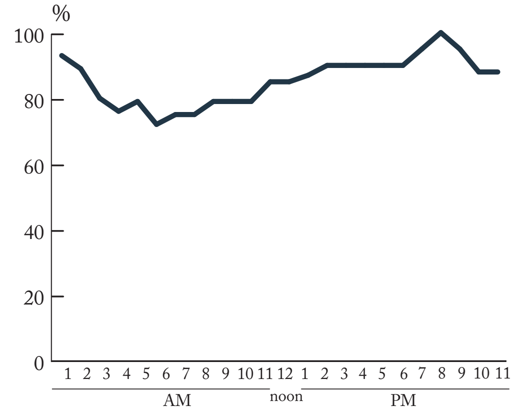

Figure 13 - AHVFs for the refrigerator, in percentage of maximum load, as given in (Gönen 1986).

Freezer

The term ”home freezer” from Gönen (1986) is compared with the term ”vertical freezer” in the REMODECE study.

Appliance Saturation Rate

The appliance saturation rate for separate freezers is 0.9 in Western Norway (Mørk 2010).

Maximum Diversified Demand

In Gönen (1986), the maximum diversified demand is 0.3 kW/load for a single appliance and is reduced to 0.08 kW/load when *n* = 100. In REMODECE, *n* = 357 and the peak average load was 0.06 for houses and apartments. No further modifications were made to $MDD_{(av, max)}$.

Appliance Hourly Variation Factor

Fig. 14 shows that the AHVF given in Gönen (1986) is one from 14:00 to 12:00. The freezer is also stable in REMODECE, and peaks occur between 18:00 PM and 20:00 PM. No further modifications are made to the initial AHVF.

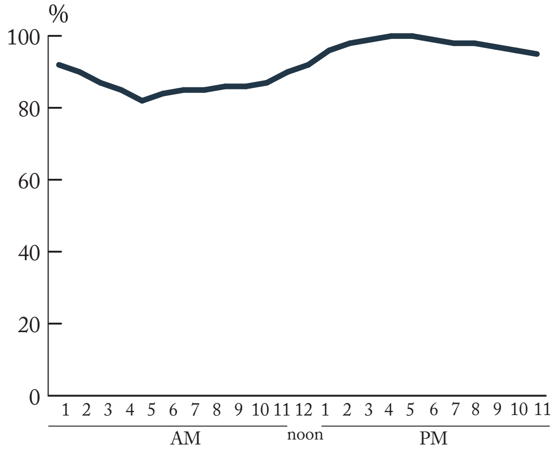

Figure 14 - AHVFs for the freezer, in percentage of maximum load, as given in (Gönen 1986).

Washing Machine

Definition

This appliance is not included in Gönen (1986), but has been added using data from REMODECE (Zimmermann 2009). Zimmermann (2009) defines a washing machine as a clothes washer, and notes that energy consumption is very dependent on the number of residents and wash cycles. The aim of including this appliance is to show how an appliance can be built from scratch to fit the basic calculations in the model.

Appliance Saturation Rate

The appliance saturation rate for washing machines in Western Norway is 0.87 (Mørk 2010), and in REMODECE it is on average 0.92, or 0.52 for apartments and 1 for houses. Using REMODECE-rates gives an average appliance saturation rate of 0.84 for Midtbygda, 0.92 for Helldal and 0.79 for Fyllingsdalen, or an average of 0.85 for the three areas. This compares very well with the appliance saturation rate given in Mørk (2010), in addition to giving a more accurate image of appliance contribution to load by building type.

Maximum Diversified Demand

In the given dataset, a total of 357 appliances are modelled, and the average maximum diversified demand is 0.19 kW. The annual electricity consumption from these appliances is however highly dependent on the number of residents, and houses usually run more cycles than apartments (Zimmermann 2009).

Appliance Hourly Variation Factor

For this particular appliance, the hourly variation factors have been calculated using data from REMODECE (Martinsen 2013). Fig. 15 shows that AHVF is one at 09:00 and 10:00. If load research was conducted in Bergen, similar calculations can be made to create hourly variation factors and use them in the model.

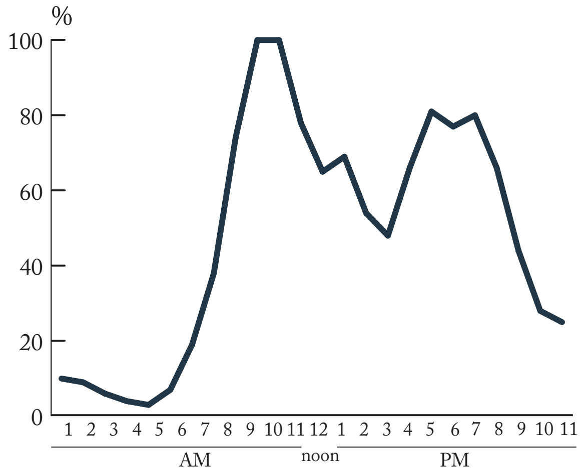

Figure 15 - AHVFs for the washing machne, in percentage of maximum load, as given caclulated from Martinsen (2013).

Clothes Dryer

Definition

The clothes dryer is not explicitly defined in Gönen (1986) and is in Zimmermann (2009) simply called clothes dryer.

Appliance Saturation Rate

The appliance saturation rate for clothes driers in West-Norway is 0.45 (Mørk 2010). In the REMODECE study it is on average 0.36, and is 0.15 for apartments and 0.59 for houses. Using these estimates gives an average appliance saturation rate of 0.43 for Midtbygda, 0.47 for Helldal and 0.36 for Fyllingsdalen, or an average of 0.42 for the three areas. This compares very well with the appliance saturation rate given in Mørk (2010), in addition to giving a more accurate image of appliance contribution to load by building category.

Maximum Diversified Demand

The $\mathrm{MDD}_{(\mathrm{av,\ max})}$ for the clothes dryer is 4,1 kW/load when n = 1 and 1,3 kW/load when n = 100. In REMODECE, n = 144 and ranged between 0.04 and 0.07 kW/load for different household groups. During the weekend, loads increased up to 1.5 kW/load for certain groups, indicating a higher maximum diversified demand.

The maximum diversified demand of clothes driers of a certain household group is undoubtedly a question of residential behaviour. The maximum diversified demand is probably lower since modern appliances are more energy efficient, but the $\mathrm{MDD}_{(\mathrm{av,\ max})}$ given in Gönen (1986) is used.

Appliance Hourly Variation Factor

Clothes dryers peak at 11:00, which requires that enough people be at home to manually shift clothes from the washer to the dryer. This might be the case in the 1940's household, but probably not in modern dwellings as most people have left for work. This particular appliance reflects that the method has been developed in a time when housekeeping was more common, a characteristic also noted by Dillard (1959). The REMODECE study found that the clothes dryer would peak in the evening from 20:00 - 22:00, and some households would have a small peak mid-day.

The load curve should only be taken as an indicator that if customers all intend to dry clothes at the same time, a peak might occur. As Zimmermann (2009) notes, use of the clothes dryer and washing machine is highly correlated with resident behaviour. The AHVF is adjusted to peak between 21:00 and 22:00, Fig. 16 is only meant for illustration purposes. Adjusted AHVFs are listed in Table 6.

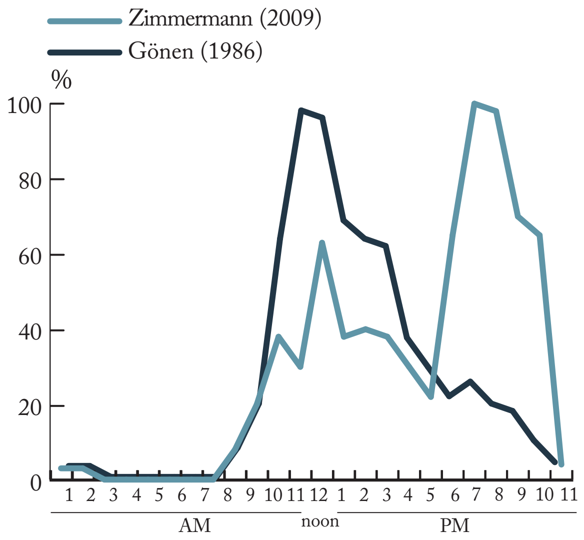

Figure 16 - Comparison of AHVFs for the clothes dryer, in percentage of maximum load, as given in (Gönen 1986) and adapted using (Zimmermann 2009).

Data inputs are summarized in Table 7. The next section presents model application and results of the three selected areas.

Table 6 - Comparison of AHVFs for the clothes dryer as given in (Gönen 1986) and adapted using (Zimmermann 2009).

Hour	Timeframe	As given in Gönen (1986)	Adapted from Zimmermann (2009)
1	(0-1)	0,03	0,03
2	(1-2)	0,03	0,03
3	(2-3)	0	0
4	(3-4)	0	0
5	(4-5)	0	0
6	(5-6)	0	0
7	(6-7)	0	0
8	(7-8)	0	0
9	(8-9)	0,08	0,08
10	(9-10)	0,2	0,2
11	(10-11)	0,65	0,38
12	(11-12)	1	0,3
13	(12-1)	0,98	0,63
14	(1-2)	0,7	0,38
15	(2-3)	0,65	0,4
16	(3-4)	0,63	0,38
17	(4-5)	0,38	0,3
18	(5-6)	0,3	0,22
19	(6-7)	0,22	0,65
20	(7-8)	0,26	1
21	(8-9)	0,2	0,98
22	(9-10)	0,18	0,7
23	(10-11)	0,1	0,65
24	(11-12)	0,04	0,04

Table 7 - Summary of data input used to model three selected residential areas in Bergen.

Appliance	**Average maximum diversified demand**	**Maximum diversified demand for all households (MW)**			**Appliance saturation rate s_i and total number of appliances, n**					
i	MDD $_{(av,max)}$	Midt-bygda	Fylling-sdalen	Hell-dal	Midtbygda		Fyllingsdalen		Helldal	
Electric furnace	3.2	22.8	25.4	16.9	0.7	7111	0.7	7930	0.7	5273
Water heater	0.5	4.7	4.9	3,1	0.94	9474	0.88	9918	0.85	6133
Washing machine	0.19	1.6	1.7	1.3	0.84	8498	0.79	8870	0.92	6673
Clothes dryer	1.2	5.2	4.8	4.1	0.43	4351	0.36	4051	0.47	3414
Refrigerator	0.048	0.3	0.4	0.2	0.67	6786	0.67	7550	0.67	4834
Freezer	0.08	0.7	0.8	0.5	0.9	9116	0.9	10141	0.9	6499

6. Model application

6.1 Selected Areas

The method of diversified demand is applied to three distribution transformers in Bergen. Transformers are nodes of information in the electrical distribution system, and their total capacity reflects power demand in Bergen. Total load can therefore be managed by targeting the demand placed on each transformer. Data on their location and supply area has been combined with a field visit in order to select three areas suitable for DSM. The method for the field visit and household count is described in Appendix A. Data on peak load in 2010 and 2012 has enabled further calculations (Natås, I. M. 2013d).

In order to select the transformer stations that supply residential areas, the areas had to fulfil certain criteria:

1. The supply area was clearly dominated by households.
2. In order to assume that one load management activity can be applied to the whole area, the household areas should be quite unanimous.
3. The transformation stations had to have at least 50 MW max power in 2010 and/or 2012.

The first criteria left out the stations around the city centre, Dokken, Koengen, Strømgaten and Sandviken, as well as Dolvik, and Haukeland who have a dominating tertiary sector. Diverse household areas such as Loddefjord, Simonsvik, Breivik, Solheim and Storetveit were left out after applying the second criteria. After applying the third criteria the remaining stations were Midtbygda, Fyllingsdalen and Helldal.

Regardless of the defined criteria, there is probably load management potential in all areas of Bergen. For a more thorough analysis, areas such as Solheim, Storetveit, Loddefjord, Simonsvik and Breivik, Rå and Salhusvegen could be assessed.

The selected areas constitute 23 % of all households in Bergen and are statistically representative of the municipality. In 2011, the building distribution in Bergen was 28 % detached, 8 % semi detached, 19 % terraced and 45 % block of flats (SSB 2011).

Figure 17 - Selected distribution transformers in Bergen.

In the following section, the building category distribution and building year are summarized, as well as the expected load of each distribution transformer in 2025.

Midtbygda

Midtbygda lies to the north of Bergen, and is dominated by terraced houses with some older detached houses built between 1970 and 1980. Other areas are almost exclusively terraced houses built after 1970, expect for some newer apartments buildings. Detached and semi-detached houses, mainly built between 1951 and 1970, dominate large unanimous areas. Fig. 18. shows the household distribution: 36 % apartment buildings, 29 % terraced houses, 28 % detached houses and 6 % semi-detached houses.

In 2012, the actual peak was 61 MW and the temperature corrected peak 65.8 MW (Natås, I. 2013). With 1 % annual growth, the projected maximum peak for the distribution transformer is 74,9 MW in 2025.

Fyllingsdalen

Fyllingsdalen is located to the west of Bergen town, and is an area with large unanimous residential complexes. In Fyllingsdalen centre there is a mix between apartment buildings built between 1951 and 1971, and terraced houses built between 1970 and 1980. Overall, detached and semi-detached houses were built after 1980. The household distribution is 52 % apartment buildings, 22 % terraced houses, 19 % detached houses and 6 % semi-detached houses.

In 2012, the actual peak was 53 MW and the temperature corrected peak 57,2 MW. The projected maximum peak for the distribution transformer is 65,1 MW in 2025.

Helldal

Helldal lies towards the south of Bergen, and is more rural than the other selected areas. Semi-detached and terraced houses built after 1951 dominate, as well as detached houses built between 1951 and 1980. There are some apartment buildings built between 1951 and 1970, but otherwise many semi-detached houses built after 1980. There are also a lot of newer, detached houses built between 1980 and 2005. The household distribution is 27 % apartment buildings, 18 % terraced houses, 45 % detached houses and 10 % semi-detached houses.

In 2012, the actual peak was 52.4 MW and the temperature corrected peak 56.5 MW.
The projected maximum peak for the distribution transformer is 64.3 MW in 2025.

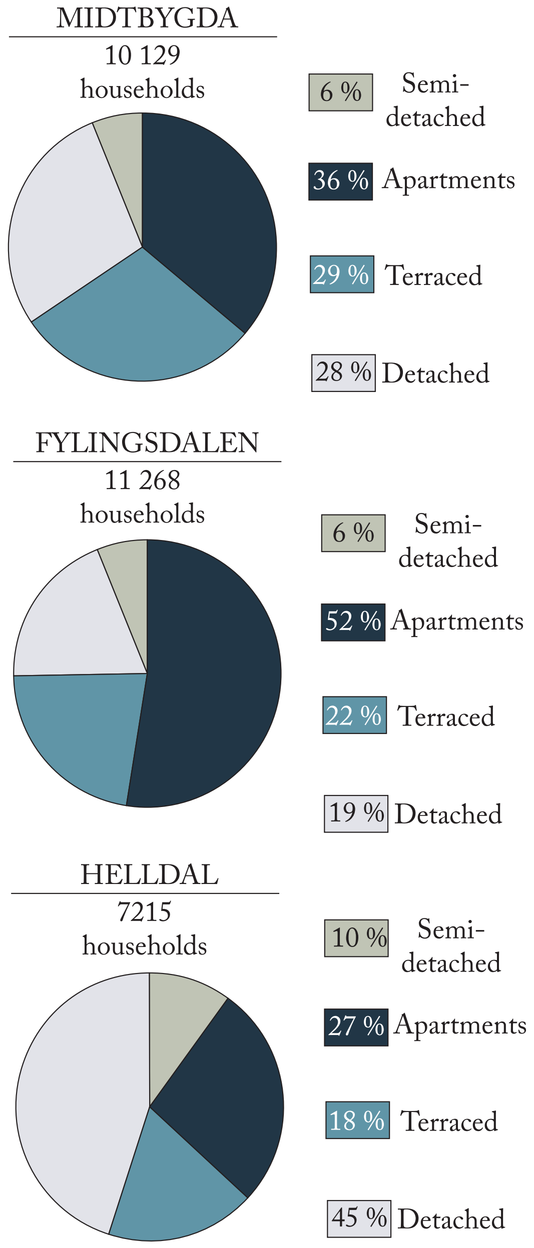

Figure 18 - Building category distribution, in percent, for selected residential areas in Bergen.

6.2 Results

Total load curve
Fig 19. shows the total load curves for Midtbygda, Fyllingsdalen and Helldal. The three areas all have the same peaks and load characteristics. This is due to the variation factors (AHVF) embedded in the model, which essentially define load. The three areas have different load sizes due to varying appliance saturation rates and the number of households. Maximum peak in Bergen 2012 occurred at 09:07, and does not coincide with timing of maximum load estimated for the households. Nevertheless, residential load contributes significantly to total load on their respective distribution transformers, outlined in the following section. Table 8 lists the hourly load and total energy consumption for Midtbygda; full results can be found in Appendix B.

Midtbygda

The total peak load on the distribution transformation station was 65.8 MW at 09:07. The household demand from in hour 10 was 24 MW, contributing to 36 % of peak load.

To reduce total peak load by 1 %, households will have to reduce their peak by 2,8 % or 0.66 MW between 08:00 and 09:00. The household peak is in hour 19 at 31.3 MW.

Fyllingsdalen

The total peak was 57.2 MW, and the household peak was 26 MW. The households accounted for 46 %. To reduce total peak load by 1 %, the household peak must be reduced by at 2.2 % or 0.57 MW between 08:00 and 09:00. The household peak is in hour 19 at 34 MW.

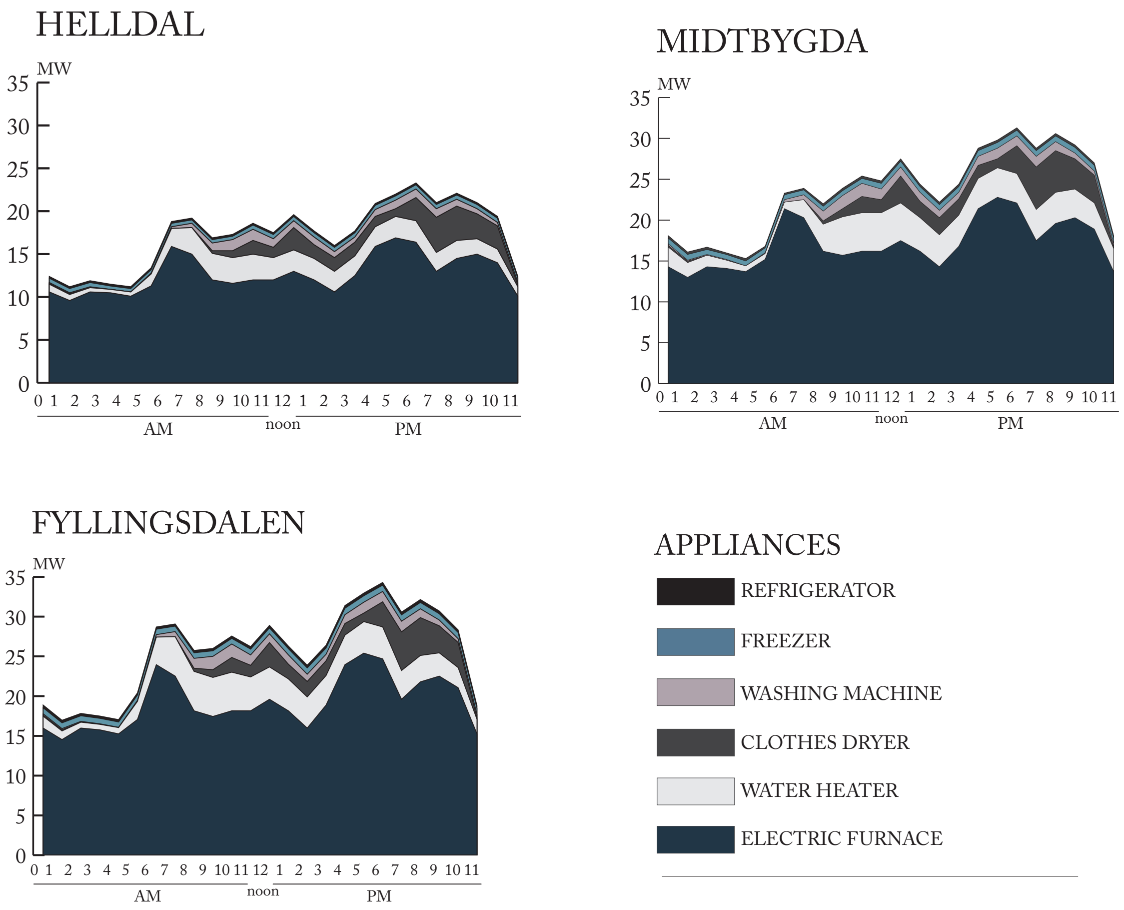

Figure 19 - Total residential load curves for selected areas in Bergen. Residential peaks occur from 20:00 - 21:00.

Table 8 - Hourly residential loads for modeled appliances in Midtbygda.

		Power (MW)						
Hour	Time Frame	Electric furnace	Water heater	Clothes dryer	Clothes washer	Freezer	Refrigerator	Total
1	(0-1)	14,3	1,4	0,2	0,2	0,7	0,3	17,0
2	(1-2)	13,0	1,0	0,2	0,1	0,7	0,3	15,3
3	(2-3)	14,3	0,7	0,0	0,1	0,6	0,3	16,0
4	(3-4)	14,1	0,7	0,0	0,1	0,6	0,2	15,7
5	(4-5)	13,7	0,8	0,0	0,0	0,6	0,3	15,3
6	(5-6)	15,2	2,2	0,0	0,1	0,6	0,2	18,4
7	(6-7)	21,4	3,3	0,0	0,3	0,6	0,2	25,9
8	(7-8)	20,3	4,7	0,0	0,6	0,6	0,2	26,5
9	(8-9)	16,2	4,7	0,4	1,2	0,6	0,3	23,4
10	(9-10)	15,7	4,7	1,0	1,6	0,6	0,3	23,9
11	(10-11)	16,2	4,6	2,0	1,6	0,6	0,3	25,3
12	(11-12)	16,2	4,1	1,6	1,3	0,7	0,3	24,0
13	(12-1)	17,5	3,9	3,3	1,1	0,7	0,3	26,7
14	(1-2)	16,2	3,8	2,0	1,1	0,7	0,3	24,1
15	(2-3)	14,3	3,7	2,1	0,9	0,7	0,3	22,0
16	(3-4)	16,8	3,6	2,0	0,8	0,7	0,3	24,2
17	(4-5)	21,4	3,6	1,6	1,1	0,7	0,3	28,6
18	(5-6)	22,8	3,8	1,1	1,3	0,7	0,3	30,0
19	(6-7)	22,1	3,8	3,4	1,2	0,7	0,3	31,6
20	(7-8)	17,5	3,5	5,2	1,3	0,7	0,3	28,5
21	(8-9)	19,6	3,2	5,1	1,1	0,7	0,3	30,0
22	(9-10)	20,3	2,8	3,7	0,7	0,7	0,3	28,4
23	(10-11)	18,9	2,4	3,4	0,5	0,7	0,3	26,1
24	(11-12)	13,7	1,8	0,2	0,4	0,7	0,3	17,0
Energy use	(MWh)	411,4	72,8	38,4	18,6	16,1	6,7	563,9

Helldal

The total peak load on the distribution station was 56.5 MW. The household peak is 17.4 MW, or 31 % of total peak load. For the total peak load to be reduced by 1 %, the corresponding household peak must be reduced by 3.3 % or 0.57 MW between 08:00 and 09:00. The household peak is in hour 19 at 23 MW.

Based on the results shown in Table 7 and Figure 19 the possibilities for DSM of each modelled appliance is summarized in the next section.

6.3 DSM possibilities

Electric furnace

The electric furnace has DSM possibilities for peak clipping, load shifting, conservation and valley filling. It is a major residential load, and the morning peak occurs from 06:00 - 07:00. The appliance peaks from 17:00 - 18:00. The energy service is indoor temperature, a function of storage capacity of the house. As long as houses can remain warm, electric furnaces can be disconnected. The load of an electrical furnace is volatile during the day and influenced by external factors such as outdoor temperatures (Ericson & Halvorsen 2008). As weather conditions are somewhat predictable, peak loads may be too. At times of peak loads prices also rise, signalling system strain. The system can benefit from peak clipping and load building of the electric furnace, obtained by cycling loads between utility customers.

Water Heater

The morning peak lasts from 07:00 10:00 before ascending. The model simulates the effect of using hot water in the morning, as the water heater must increase the temperature of the colder inlet water. The water heater has a possibility for peak clipping and valley filling. Ericson (2009) notes that the longer the load is disconnected the higher the payback effect. Even though demand could be reduced by 0.5 kW/household, the payback effect was estimated to be 0.28 kW/household.

According to Paull et al. (2010), a DSM scheme for water heaters should classify customers by water usage and not power demand, as water usage is a more accurate measure of behaviour. Paull et al. (2010) argue that domestic electric water heaters cannot be controlled in an aggregate matter, as different households have different occurring peak power demands. Given a top-down load control scheme some users might be adversely affected. In order to properly target households suitable for load control of water heaters, Gomes et al. (1999) suggest that hot water usage patterns are a more accurate starting point for identifying end-user groups. It is also noted that controlling water heaters usually requires cycling between customer groups, specifically targeted when knowledge on their hot water usage is obtained. A schedule for load shedding, of four customer groups should have minimal power interruption to avoid the risk of a high payback effect.

Washing machine & clothes dryer

The washing machine peaks at from 10:00 - 11:00 before ascending, and a second peak occurs from 17:00 - 18:00 PM. The clothes dryer peaks correspondingly from 18:00 - 20:00 PM. The peaks will be influenced by customer behaviour, suggesting that a demand response or opt-in programme could be tailored to target the appliance. Gyamfi and Krumdieck (2011) found that demand response was favourable amongst customers in Christchurch, NZ.

Refrigerator & freezer

With their stable curves, freezers and refrigerators offer a wide time-range for shedding loads. According to Grein and Pehnt (2011), loads are interruptible for a maximum of one hour, and cannot be realized during food delivery periods in the morning and evening. In addition, decentralized fridge systems are usually not technically equipped for load control as the load is relatively small.

Summarized, the electric furnace and water heater are the main residential loads, offer DSM possibilities because of their storage facilities. This is outlined in the next section, where ripple control between household groups is applied.

7. DSM Proposal

Although several appliances are suitable for DSM, the main residential loads will offer the best starting point. During the peak demand placed on the distribution transformers, two-thirds of total residential load are from electric furnaces, and one-fifth from water heaters. In this section, both appliances are exemplified as part of a DSM-proposal utilising ripple control. The goal of the DSM proposal is to allow the municipal utility BKK to reduce and re-schedule main residential loads without compromising the energy services of its customers.

7.1 Electric furnace

The first strategy targets the peaks and valleys of the load curve of electric furnaces, illustrated in Fig. 20. The example assumes a two-way communication device that allows for building and reducing loads. Simply reducing the two peaks may be beneficial for the utility, but inconvenient for customers. To ensure energy services, loads are built prior to load disconnection.

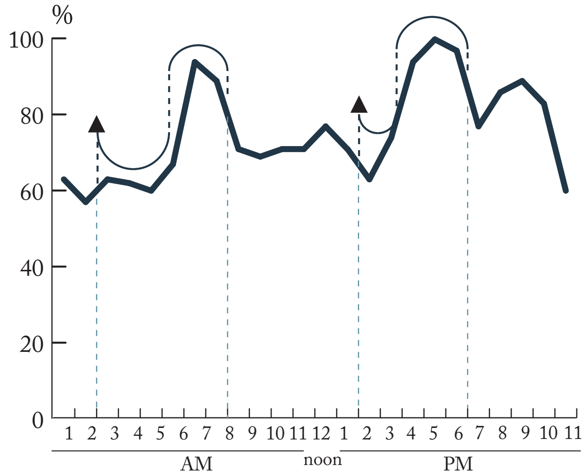

Figure 20 - Strategy for reducing and shifting of electrical furnace loads. Appliance Hourly Variation Factors are given as percentages of maximum diversified demand.

The example assumes that one third of household customers with electric furnaces are enrolled on a voluntary basis. This assumption is based on the response given in Christchurch, New Zealand, where winter peaks occurred between 06:00 to - 10:00 and 17:00 - 20:00, and customers were offered to enrol to a Voluntary Demand Response Scheme (Gyamfi & Krumdieck 2011).

Returning to our example, only the households built from 1900-2001 are included, as the appliance saturation rates for 2002 - 2012 are not entirely accurate. Half of each building type with electric furnaces are enrolled, and modelled separately due to varying appliance saturation rates. The results will also reflect varying percentages of building categories between Midtbygda, Fyllingsdalen and Helldal. For each area, the enrolled households are split into three groups, and the utility may cycle the power use between groups for 1 hour. Known as ripple control, it aims to avoid the simultaneous reconnection of appliances and a new peak.

Ripple control is modelled by adjusting the Appliance Hourly Variation Factors (AHVF). The AHVFs determine the average maximum diversified demand (MDD $_{(av,max)}$ of the modelled appliance. When AHVF = 1 the (MDD $_{(av,max)}$ of appliance *i* is maximum. If one third of the households with electric furnace are enrolled, and they are split into three groups, each group will represent 11 % of total households with the given appliance. When electric furnaces in 11 % of the households are disconnected, their AHVF will drop to 0, simulating that the appliance is not active during the time frame (MDD $_{(av,\ max)}$ = 0 kW/load). When electric furnaces are reconnected, the AHVF is 1; all the households are connected simultaneously and maximum diversified demand is reached. The total AHVF for the entire building type is therefore reduced or increased by the percentage of households that are enrolled in the programme in a given hour. The payback effect is assumed to be half of the maximum diversified demand, so that after each disconnection, MDD $_{\text{(av, max)}}$ increases by 50 %. This is simulated by adding 0.11/2 = 0.06 into the AHVF. Ripple control of the three groups is outlined in Fig. 21.

Here, the payback effect can be seen for instance from 07:00-08:00, when Group 1 reconnects after a power interruption from 06:00-07:00. At the same time, Group 2 will disconnect, reducing its AHVF. The result is an overall reduction of the AHVF where the payback effect is limited. Payback is not entirely avoidable though, as Group 1 reconnects at 10:00-11:00 without another group disconnecting, and Group 3 reconnects at 20:00-21:00 without any other group disconnecting.

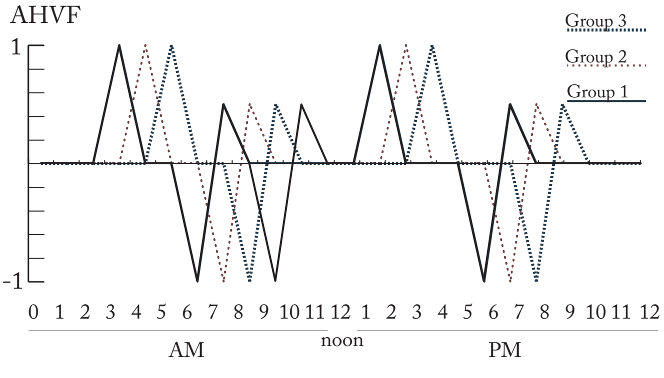

Figure 21 - Ripple control scheme of electrical furnaces for three enrolled customer groups. Load is built when AHVF = 1, load is reduced when AHVF = -1, and the payback effect ocurs when AHVF= 0.5.

Fig. 21 also shows how Group 1 is disconnected once more than the others, from 09:00-10:00. This is when the total system peaks and the payback effect from Group 3 strikes. It defies the point of ripple control to schedule a payback effect when the total system peaks. Therefore, Group 1 is disconnected to limit the payback effect on the total system load.

Fig. 22 reveals the effect on the AHVF of all households and demonstrates ripple control in action: peaks are clipped from 06:00 to 07:00 and 16:00 to 18:00, and load is moved backwards from 03:00 to 06:00 and 13:00 to 15:00. Payback effects occur from 10:00 to 11:00 and 20:00 to 21:00.

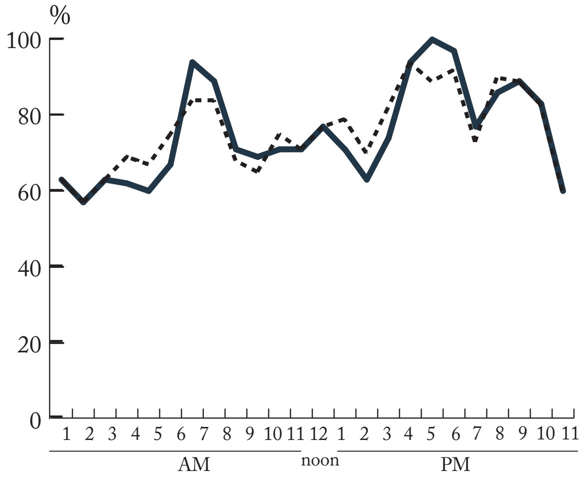

Figure 22 - Comparison of initial (solid line) and the new AHVF after ripple control of three household groups. Appliance Hourly Variation Factors are given in percent of maximum diversified demand

Table 9 shows the simulation of DSM by altering the AHVF for the electric furnace. Figures 23 - 25 show the reductions residential load on each distribution transformer.

Table 9 - Appliance Hourly Variations Facors before and after applying DSM.

Hour	Time frame	Initial AHVF	DSM
1	(0-1)	0,63	0,63
2	(1-2)	0,57	0,57
3	(2-3)	0,63	0,63
4	(3-4)	0,62	0,69
5	(4-5)	0,60	0,67
6	(5-6)	0,67	0,75
7	(6-7)	0,94	0,84
8	(7-8)	0,89	0,84
9	(8-9)	0,71	0,68
10	(9-10)	0,69	0,65
11	(10-11)	0,71	0,75
12	(11-12)	0,71	0,71
13	(12-1)	0,77	0,77
14	(1-2)	0,71	0,79
15	(2-3)	0,63	0,70
16	(3-4)	0,74	0,82
17	(4-5)	0,94	0,94
18	(5-6)	1,00	0,89
19	(6-7)	0,97	0,92
20	(7-8)	0,77	0,73
21	(8-9)	0,86	0,90
22	(9-10)	0,89	0,89
23	(10-11)	0,83	0,83
24	(11-12)	0,60	0,60

HELLDAL

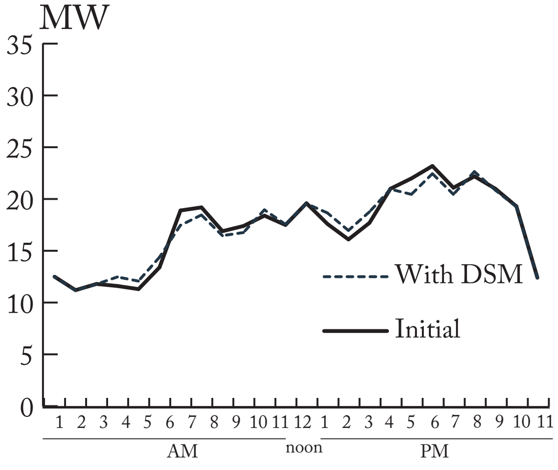

Figure 23 - Total residential load in Helldal before and after DSM. 426 households reduce residential peak from 08:00 - 09:00 by 3.2 %, or 0.6 MW.

MIDTBYGDA

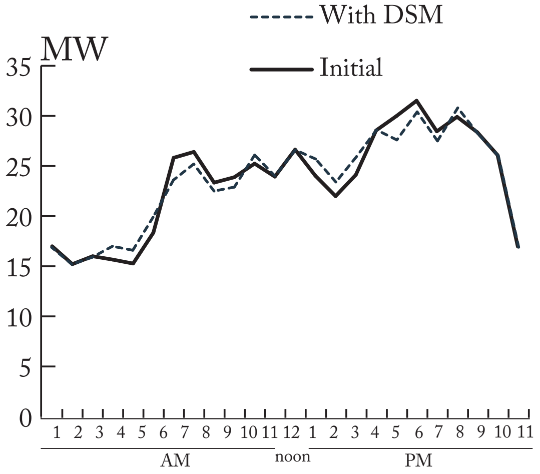

Figure 24 - Total residential load in Midtbygda before and after DSM. 4721 households reduce residential peak from 08:00 - 09:00 by 3.7 %, or 0.9 MW.

FYLLINGSDALEN

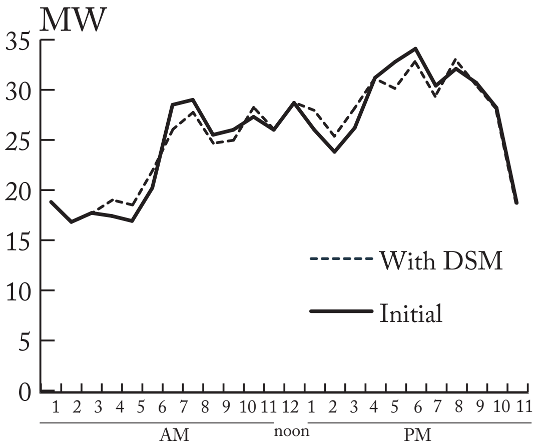

Figure 25 - Total residential load in Fyllingsdalen before and after DSM. 795 households reduce residential peak from 08:00 - 09:00 by 3.8 %, or 1 MW.

In Midtbygda, disconnecting electric furnaces in 721 households reduces total residential load by 3.7 %, or 0.9 MW from 07:00 to 08:00. In Fyllingsdalen, disconnecting electric furnaces in 795 households reduces the residential load by 3.8 %, or 1 MW. In Helldal, 426 households reduce the morning peak by 3.2 %, or 0.6 MW, not fully reaching the target of the DSM strategy.

However, further reductions are achieved during the second ripple control cycle from 6 - 7 PM. The evening residential peaks in Midtbygda and Fyllingsdalen are reduced by 7.8 %, whereas the peak in Helldal is reduced by 6.7 %. This is a substantial decrease, but does not coincide with the peak load on the distribution transformer. In addition, demand becomes sharper when the payback occurs. All in all, peak load is reduced by the required amounts at the required time, apart from in Helldal. The next section outlines a ripple control scheme for the second largest residential load, the water heater.

7.2 Water heater

The possibilities for load shifting the water heater are explored in the following section. A different, uneven cycling scheme is adopted: the scheme differentiates between building category. Still, 11 % of the households with electric water heating are enrolled. The example assumes that block of flats and terraced houses have smaller heating tanks, reducing the length of a disconnection. Detached and semi-detached are assumed to have larger water storage tanks and can withstand a disconnection for up to 3 hours. Fig. 26 shows the ripple control scheme.

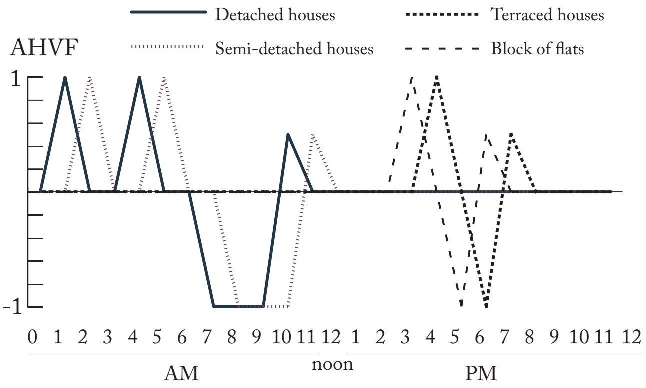

Figure 26 - Ripple control scheme of water heaters for three groups of enrolled households. Load is built when AHVF = 1, load is reduced when AHVF = -1, and the payback effect ocurs when AHVF= 0.5.

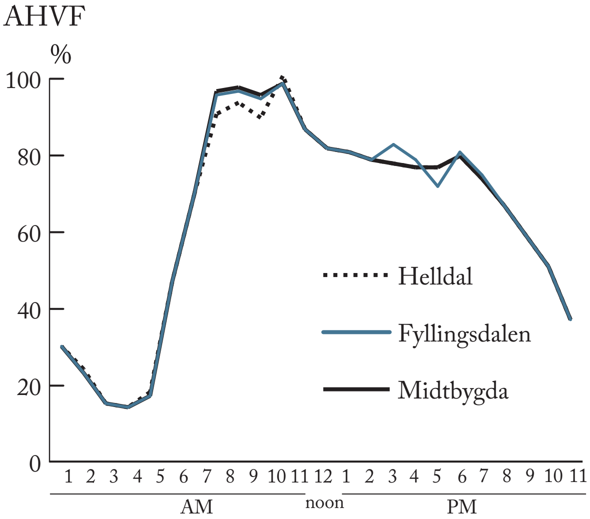

Figure 27 - Differences in AHVF as a result of building type distribution for the selected areas Helldal, Fyllingsdalen and Midtbygda.

The differentiation between building type will ultimately give different load effects, as shown in Fig. 27. The effect of load shifting the water heater is very small for Midtbygda, whereas in Fyllingsdalen it creates a new peak. The peak in Fyllingsdalen is due to many water tanks in apartment buildings reconnected simultaneously. Controlling water heaters in Helldal makes all the difference in the success of the DSM proposal, as the water tanks in detached houses can be disconnected for longer.

Table 10 lists the varying AHVFs of the water heater after applying ripple control. Figures 28 - 30 show the reductions residential load on each distribution transformer after applying ripple control of both the electric furnace and water heater.

Table 10 - Differences in AHVF as a result of building type distribution for the selected areas Helldal, Fyllingsdalen and Midtbygda.

Hour	Time frame	Midtbygda	Fyllingsdalen	Helldal
1	(0-1)	0,30	0,30	0,30
2	(1-2)	0,23	0,23	0,24
3	(2-3)	0,15	0,15	0,15
4	(3-4)	0,14	0,14	0,14
5	(4-5)	0,17	0,17	0,18
6	(5-6)	0,47	0,47	0,47
7	(6-7)	0,70	0,70	0,70
8	(7-8)	0,97	0,96	0,91
9	(8-9)	0,98	0,97	0,94
10	(9-10)	0,96	0,95	0,90
11	(10-11)	0,99	0,99	1,01
12	(11-12)	0,87	0,87	0,87
13	(12-1)	0,82	0,82	0,82
14	(1-2)	0,81	0,81	0,81
15	(2-3)	0,79	0,79	0,79
16	(3-4)	0,78	0,83	0,78
17	(4-5)	0,77	0,79	0,77
18	(5-6)	0,77	0,72	0,77
19	(6-7)	0,80	0,81	0,80
20	(7-8)	0,74	0,75	0,74
21	(8-9)	0,67	0,67	0,67
22	(9-10)	0,59	0,59	0,59
23	(10-11)	0,51	0,51	0,51
24	(11-12)	0,37	0,37	0,37

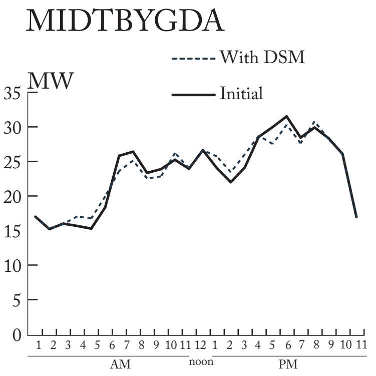

Figure 29 - Total residential load in Midtbygda before and after DSM of electric furnaces and water heaters. An additional 982 households reduce residential peak from 07:00 - 08:00 by 4.3 %, or 1 MW.

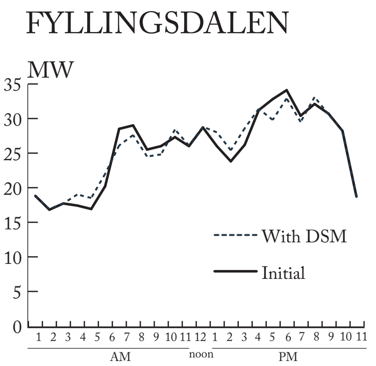

Figure 30 - Total residential load in Midtbygda before and after DSM of electric furnaces and water heaters. An additional 1020 households reduce residential peak from 07:00 - 08:00 by 4.5 %, or 1.2 MW.

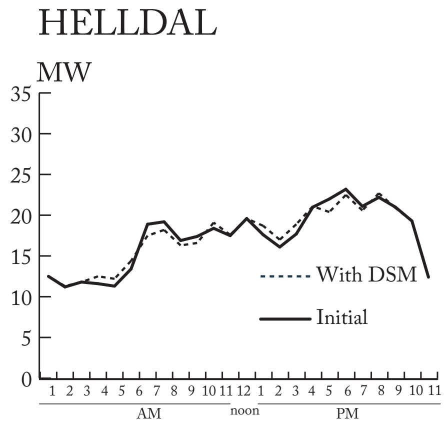

Figure 28 - Total residential load in Helldal before and after DSM of electric furnaces and water heaters. An additional 539 households reduce residential peak from 07:00 - 08:00 by 4.8 %, or 0.8 MW.

In addition to ripple control of electric furnaces, disconnecting water heaters further reduces total residential load placed on the transformer. In Midtbygda, disconnecting electric water heaters in 982 households from 07:00 - 08:00 gives a total load reduction by 4.3 %, or 1 MW. In Fyllingsdalen, the total reduction is 4.5 %, or 1.2 MW from 1020 households. In Helldal, 539 households contribute to reducing total peak load by 4.8 %, or 0.8 MW.

All in all, cycling 11 % of all water heaters did not give a tremendous effect, and other cycling schemes are possible. The cycling scheme reduced peak load by the required amounts, but more water heaters must be controlled to obtain further reductions.

7.3 Evaluation and Further Applications

At the time of development, the average maximum diversified demand of appliances was based on the best data available (Dillard 1959). Although the model is applicable to simulate load reductions, many changes to the original data were necessary to show load curves in Bergen. Changes in appliance designs have caused the original data to be out-dated. However, the general method is of interest as the cost of obtaining short-term load data is high (Gomes et al. 1999).

A further application of the model could be to adapt the method of diversified demand to Norwegian circumstances such as climatic conditions, building construction and technological advancements. If a new set of curves is developed for Norwegian conditions, the method may broaden its reach.

An example of this could be including both current and future building standards in Norway. The maximum power installed per m^2 for three Norwegian building standards, TEK07, low energy and passive houses are shown and exemplified in a 180m^2 detached house (Table 9) (Havskjold 2013). Empirical studies may reveal how much maximum diversified demand sinks per customer.

Table 11 - Maximum power installed for three Norwegian building standards: TEK07, low energy and passive houses, listed in W/m^2 exemplified in a 180 m^2 detached house (kW).

End-uses	TEK07	Low energy	Passive houses
Light			
Power W/m^2	2	2	2
180 m^2 detached house (kW)	0.35	0.35	0.35
Heating ventilated air			
Power W/m^2	4	2	2
180 m^2 detached house (kW)	0.65	0,32	0.32
Space heating			
Power W/m^2	21	17	17
180 m^2 detached house (kW)	3.69	3.03	3.03
Technical appliances			
Power W/m^2	3	3	3
180 m^2 detached house (kW)	0.54	0.54	0,.4
Heating water			
Power W/m^2	5	5	5
180 m^2 detached house (kW)	0.92	0.92	0.92
Pumps and fans			
Power W/m^2	1	1	1
180 m^2 detached house (kW)	0.09	0.13	0.13

8. Discussion

The previous section showed peak load reductions, discussed model limitations and further applications. To complete the theoretical example, some core issues will be discussed in the following section:

1. Energy services and customer satisfaction
2. Technological pre-requisites for load control
3. Programme enrolment

Finally, the role of BKK is discussed before the conclusion.

8.1 Energy services

Ideally, the ripple control scheme should maintain energy services. Even though loss of energy services is not quantified in the example, comparing energy use of the electric furnace between days with and without ripple control can indicate changes. Total energy consumption is the area under the load curve of a given appliance. One electric furnace would use 58 kWh on a day without ripple control, and if the household was enrolled in Group 1, consumption would be reduced to 48 kWh. If the household was enrolled to Group 2 or 3, the electric furnace would use 51 kWh during the day. In other words, energy consumption will decrease due to ripple control, however load building can help to reduce the loss.

Reduced indoor temperatures are only perceived when the residents are at home. A solution to ensure energy services would be to disconnect loads when residents leave for work. In addition, scheduling load building prior to residents returning home will provide a timed energy service at the customer's convenience. If the day of peak demand occurs on a holiday or weekday when people are likely to be home, the disconnect should be communicated and therefore anticipated, to facilitate the use of short term substitutes such as wood stoves. However, on a day of peak demand in Bergen, particle combustion is not an ideal outcome of such a substitute (Langeland Haugen 2013a).

Another way to measure the loss of energy services is by identifying the thermal properties of the buildings. If heat transmits quickly, a 1 hour disconnect will be an inconvenience. One way reduce loss of heat during load disconnects is by enrolling well-isolated buildings, or buildings with smaller surface areas. Examples include apartments buildings and to some degree terraced houses, which are prevalent in both Midtbygda and Fyllingsdalen. Even though newer buildings were excluded from the example due to inaccurate appliance saturation rates, their improved building standards would make them suitable for disconnecting electric furnaces. Furthermore, building legislation is likely to require passive house standard from 2015 (MD 2012). Passive houses are very well insulated, and could be enrolled for longer disconnects. On the other hand they would have a lower appliance saturation rate of electrical furnaces, and a lower maximum diversified demand for heating, as presented in the previous chapter.

8.2 Technological pre-requisites

Two-way communication connects the load placed on distribution transformers and the utility in control, and also enables consumption metering. In order to disconnect the load of a specific appliance, the utility must also install devices in the fuse-box of every enrolled customer (Grande & Graabak 2004).

Grande and Graabak (2004) recommend a pilot project to test suitable communication devices between the utility and customer. The equipment should be tested on all levels for 100 - 500 installations. When the pilot project is conducted, experience harvested and results achieved, one can include more households. Grande and Graabak (2004) also suggested two-way communication in the entire grid system, which is expected to be installed within 2017 (Venjum et al. 2011).

8.3 Programme design

The true potential of an opt-in ripple control scheme is determined by customer motivation. How can a utility enrol customers with the purpose of controlling their loads? What motivates customers to conserve energy? To find out, utilities may map customer motivation through a survey. Gyamfi and Krumdieck (2011) explored customer-motivation to enrol in a voluntary demand response scheme in Halswell, NZ by addressing external factors: cost, environment and security. Residents would be required to shift loads themselves according to three signals during peak demand: increased price, increased CO_2 emissions in percentage and low, medium or high risk of blackout. Respondents were found to be price sensitive, favoured renewable energy and were overall intolerant to blackouts. In general, environmental signals did not alter customer behaviour as much as security and price signals.

By comparison, 1586 participants of an opt-in programme "Flex Your Power" in California considered use of energy resources and protecting the environmental as important motivations for energy conservation. Following the 2001 energy crisis several motivations were expressed and summarized in Table 12 (Lutzenhiser et al. 2002).

Table 12 - Customer motivatin to conserve energy in Caifornia (Lutzenhiser et al. 2002)

Motivations for reducing demand	Respondents (%)
To stop energy suppliers from overcharging	79
Using energy resources wisely	78
To avoid blackouts	77
To reduce electricity bills	77
To protect the environment	70
To qualify for a utility rebate	33

A DSM-strategy in Bergen should consider that Norwegian society is built on the pre-requisite and expectation of adequate, stable electricity supply (OED 2012). However, the controversial Hardanger grids are a potent example of the environmental effects of accommodating peak demand. In the heat of the debate, all types interest groups, stakeholders, economists and politicians were outraged by the environmental sacrifices (Hetland 2010).

To further strengthen electricity supply to the north of Bergen, BKK has applied for a grid connection from Modalen, via Kollsnes and to Mongstad (BKK 2012). In total, there are over 30 plans for new transmission grids of varying voltages by 2025 (BKK 2012), which will secure supply of electricity for years to come. A natural first approach for utilities wanting to adopt DSM principles is to broaden their understanding of secure electricity supply. Today, cutting off certain end-use loads due to critical peak demand is seen as a last resort, described as a temporary solution until the necessary grid facilities have been built (BKK 2012). This is partly due to KILE-costs, which effectively hinder utilities from seeing load disconnection as beneficial: it is a fine for every hour of system failure.

Another underlying driver of increased transmission capacity is exponential load growth calculations used by utilities in system reports (BKK 2012). If load grows 1 % every year, peak demand in Bergen will have increased by more than 100 MW within 2025. If the DSM scheme can reduce peak loads by 1 % annually in Bergen, this is arguably the avoided increase in transmission capacity.

A different DSM approach entirely would be to increase the grid tariffs during hours of peak demand. In doing so, the success and responsibility of peak load reductions is placed in the hands of the consumer. It requires a smart grid or load control switch and a communication device for fluctuating prices. The prices must also fluctuate in a manner that reflects the capacity issues for the utility. Most households in Norway do not receive Time of Use (ToU) pricing, but are billed using a flat rate and linear taxes, summarized in Eq. 3:

Nord Pools monthly spot price + additional fees (2 øre /kWh + green certificate cost) + energy dependent segment including fees + power segment

Communicating price fluctuations is therefore challenging as it includes both the market price and grid-tariffs. When exposed to ToU pricing and Critical Peak Pricing, households in Buskerud and Skagerrak reduced their peaks by from 12-27 % in the morning, and 21 - 23 % in the evening (Grande & Graabak 2004). Although ToU and CPP may be effective, Gyamfi and Krumdieck (2011) argue that pricing incentives should be pursued with care, as low-income families tend to make lifestyle cutbacks when faced with increased prices. The effect of CPP, if not targeted correctly, could breach with policy principles of promoting social equality (Gyamfi & Krumdieck 2012).

According to (Nilsson 2007), end-users cannot be expected to understand all social, economical and environmental aspects of reducing peak power demand, leaving some responsibility with the utility to tailor a DSM scheme to achieve certain goals.

DSM promotes systems flexibility by enabling utilities to dynamically control loads and equips customers to respond to peak pricing. The vision in this thesis has been to allow for a compromise between direct load control and customer satisfaction. It is, after all, a combined effort to solve a dual problem: strained grid capacity, risk of system failure, KILE-costs, high electricity prices and negative environmental impact.

Energy efficiency, smart meters and DSM have synergistic effects (Gyamfi & Krumdieck 2011). Energy efficiency is enforced through improved legislation and smart meters are on the horizon, which suggesting that DSM is the missing piece in the puzzle. Given that the utility can enroll enough participants, the power system will advance towards increased flexibility.

Summarized, Norwegian utilities such as BKK could engage in the following:

1. Calculate DSM benefits, as a function of:
    a. Reduced risk of KILE-costs
    b. Reduced or avoided investments in grid facilities
2. Establish and communicate a goal for the DSM scheme to households
3. Design and distribute a customer survey to establish a beneficial customer scheme
4. Enrol a pilot group of customers

9. Conclusion

The limit of this thesis is also an effective barrier for targeted DSM: incomplete knowledge and measurements of short-term load curves. The method of diversified demand can estimate loads, but necessary improvements such as adjusting data and conducting are evident. The model has considered the current conditions for residential areas, and may be adapted to include future building standards and overall Norwegian conditions. As a step towards increasing knowledge on short-term load curves, peak demand and capacity issues, utilities could be encouraged to consider such topics in the biennial report they are required to produce.

The purpose of an electrical distribution system is to distribute power to customers and provide energy services. The most favourable system may be considered to be the one that most economically provides the established quality of a service. This thesis has considered the residential load on three distribution transformers, and obtained load characteristics to propose DSM strategies. The results of the analysis indicate that a DSM-scheme is within reach for Bergen, offering an alternative way to secure electricity supply.

10. Reference list

Al-Alawi, A. & Islam, S. (Unknown). *Estimation of electricity demand for remote area power supply systems including water desalination and demand side management models*: Centre for Renewable Energy and Sustainable Technologies Australia. Unpublished manuscript.

Albadi, M. H. & El-Saadany, E. F. (2008). A summary of demand response in electricity markets. *Electric Power Systems Research*, 78 (11): 1989-1996.

Balijepalli, V. S. K. M., Pradhan, V., Khaparde, S. A. & Shereef, R. M. (2011, 1-3 Dec. 2011). *Review of demand response under smart grid paradigm*. Innovative Smart Grid Technologies - India (ISGT India), 2011 IEEE PES. 236-243 pp.

Bennich, P., Lopes, C., Öfverholm, E. & Kadic, Z. (2009). *How can increased energy efficiency lead to increased energy consumption – answer from in-depth metering of the electricity demand in 400 Swedish households*. Act! Innovate! Deliver! Reducing energy demand sustainably, Côte d' Azur, France.

Bjørgum, H. T., Bent. (2013). *Vi satte ny strømrekord igjen*. Available at: http://www.nrk.no/nyheter/norge/1.10884179 (accessed: 24.1).

BKK. (2011). Energiutredning Bergen kommune 2011. Bergen: Bergenhalvøens Kommunale Kraftselskap.

BKK. (2012). Regional Kraftsystemutredning for BKK-området og indre Hardanger 2012 - 2025.

Brunborg, S. R. (2011). Innovasjon, miljø og utvikling - et alternativ til kabel og luftspenn. Oslo: Bevar Hardanger.

CEB. (2012). *Demand Side Management*. Sri Lanka: Ceylon Electricity Board. Available at: http://www.ceb.lk/sub/knowledge/demandside.html (accessed: 1.05).

Dillard, J. K. (1959). *Electric Utility Engineering Reference Book*. Distribution Systems, vol. 3. Pennsylvania.

Ericson, T. & Halvorsen, B. (2008). Hvordan varierer timeforbruket av strøm i ulike sektorer? *Økonomiske analyser*, 6.

Ericson, T. (2009). Direct load control of residential water heaters. *Energy Policy*, 37 (9): 3502-3512.

Fanney, A. H. & Dougherty, B. P. (1996). The Thermal Performance of Residential Electric Water Heaters Subjected to Various Off-Peak Schedules. *Journal of Solar Energy Engineering*, 118: 73 -80.

Feilberg, N. & Livik, K. (1991). Sammenlagring av effekt. Beskrivelse av statistisk metode. Trondheim: Energiforsyningens Forskningsinstitutt A/S.

Gomes, A., Martins, A. G. & Figueiredo, R. (1999). Simulation-based assessment of electric load management programs. *International Journal of Energy Research*, 23 (2): 169-181.

Grande, O. S. & Graabak, I. (2004). Forbrukerfleksibilitet ved effektiv bruk av IKT : analyseresultater. Trondheim: Sintef Energiforskning AS.

Grein, A. & Pehnt, M. (2011). Load management for refrigeration systems: Potentials and barriers. *Energy Policy*, 39 (9): 5598-5608.

Gyamfi, S. & Krumdieck, S. (2011). Price, environment and security: Exploring multi-modal motivation in voluntary residential peak demand response. *Energy Policy*, 39 (5): 2993-3004.

Gyamfi, S. & Krumdieck, S. (2012). Scenario analysis of residential demand response at network peak periods. *Electric Power Systems Research*, 93 (0): 32-38.

Gönen, T. (1986). Electric Power Distribution System Engineering. In, pp. 62 - 66. USA: McGraw-Hill Book Company.

Havskjold, M. (2013). *Energi- og effektdata*. Oslo: Rambøll (11.04.2013).

Hetland, T. (2010). Monsteret som skremde Jens. *Stavanger Aftenblad*.

IEA. (2008). Worldwide Survey of Network-driven Demand-side Management Projects. Australia: The International Energy Agency Demand Side Management Programme.

Langeland Haugen, E. (2013a, 22.1). Nå er luften helseskadelig. *Bergens Tidene*.

Langeland Haugen, E. (2013b). *Skyhøyt strømforbruk i Bergen*. Bergens Tidene. Bergen. Available at: http://www.bt.no/nyheter/okonomi/Skyhoyt-stromforbruk-i-Bergen-2831612.html.

Lislebø, O., Naper, L. R., Havskjold, M. & Bakken, E. (2012). Nettplan Stor-Oslo: Alternativer til nettutbygging. En potensialstudie for Oslo og Akershus: Xrgia AS & EC-group AS.

Lutzenhiser, L., Gossard, M. H. & Bender, S. (2002). *Crisis in Paradise: Understanding the Household Conservation Response to California's 2001 Energy Crisis*. ACEEE Summer Study on Energy Efficiency in Buildings.

Martinsen, T. (2013). *Load Curve Washing Machine* (25.04.2013).

MD. (2012). *Meld. St. 21 - Norsk klimapolitikk*. Miljøverndepartementet. Oslo.

MET. (2013). *Været som var, Bergen (Hordaland)*: yr.no. Available at: http://www.yr.no/sted/Norge/Hordaland/Bergen/Bergen/statistikk.html (accessed: 14.04.2013).

Mørk, E. (2010). *Tabell: 05068: Husholdninger med utvalgte varige forbruksvarer, etter landsdel (prosent)*. Oslo: SSB.

Møster, G. (2013). *Datainnhenting matrikkelen* (19.04.2013).

Natås, I. (2013). *Prognose forbruk 2012 - 2030*. Bergen: BKK.

Natås, I. M. (2013a). Bergen: BKK (2.04.2013).

Natås, I. M. (2013b). *Energibruk - næring og kilde*. Bergen: BKK (29.01.2013).

Natås, I. M. (2013c). *Energimiks alle år + prognose prod*. Bergen: BKK (6.03.2013).

Natås, I. M. (2013d). *Prognose forbruk*. Bergen: BKK (14.03.2013).

Natås, I. M. (2013e). *Sumkurven innen kommunegrensen Bergen maksdag 2013*. Bergen: BKK (22.03.2013).

Newsham, G. R., Birt, B. J. & Rowlands, I. H. (2011). A comparison of four methods to evaluate the effect of a utility residential air-conditioner load control program on peak electricity use. *Energy Policy*, 39 (10): 6376-6389.

Nilsson, H. (2007). Demand Side Management (DSM) - A renewed tool for sustainable development in the 21st century. Sweden: IEA DSM-Programme.

NordPoolSpot. (2013). *Elspot prices*. Oslo.

NVE. (2013). *NVE Atlas*. Oslo.

OED. (2012). *NOU 2012: 9 Energiutredningen - verdiskaping, forsyningssikkerhet og miljø*. energidepartementet, O.-o. Oslo.

Paull, L., Li, H. & Chang, L. (2010). A novel domestic electric water heater model for a multi-objective demand side management program. *Electric Power Systems Research*, 80 (12): 1446-1451.

PC. (2012). Productivity Commision Draft Report. *Electricity Network Regulatory Framworks*. Melbourne: Australian Government.

SSB. (2001). *Tabell 03112: Boliger, etter bygningstype, byggeår og systemer for oppvarming*. SSB (ed.). Oslo: Statistikkbanken.

SSB. (2011). *Boliger - 1. januar 2011*. SSB (ed.), 2013, 18.03. Oslo: Stastikkbanken.

SSB. (2013). *Variabeldefinisjon - Forbruk i alminnelig forsyning*. Available at: http://www.ssb.no/a/metadata/conceptvariable/vardok/2651/nb (accessed: 10.03).

Sæle, H., Rosenberg, E. & Feilberg, N. (2010). State-of-the-art Projects for estimating the electricity end-use demand. Trondheim: Sintef Energy Research.

Venjum, A., Rllinggard, K., Grammeltvedt, T. E., Borgli, E., Mellison, H. & Skapalen, F. (2011). Avanserte måle- og styringssystem (AMS). In Grammeltvedt, T. E. (ed.). Oslo: Norges vassdrags- og energidirektorat.

Zimmermann, J. P. (2009). End-use metering campaign in 400 households in Sweden. In Zimmermann, J. P. (ed.). Eksiltuna.

Appendix A - Data Collection

1. Method for field visit to distribution transformers stations in Bergen

Prior to departure, 11 – 16th March 2013

Prior to departure, the transmission grids were mapped to identify the location of each station, and general information on which transmission grids supply the distribution transformers (NVE 2013). Based on the mapping, the locations of the transformers are split into five general areas: North, City Centre, East, West and South:

1. North includes stations: Salhusvegen, Midtbygda, Eidsvåg, Hellen
2. City Centre includes stations: Sandviken, Koengen, Dokken, Strømgaten, Simonsvik, Solheim, Haukeland
3. East includes stations: Arnavågen, Tangeland
4. West includes stations: Loddefjord, Fyllingsdalen, Breivik
5. South includes stations: Skjold, Dolvik, Rå, Helldal, Storetveit.
6. A dummy Word document was created including: name and address of station, and nearby street addresses. The following text was also included for building category registration:
   i. Most dominating
   ii. Somewhat dominating
   iii. Spread around
   iv. Few or none (if applicable)

On the day of the field visit 29th March 2013

1. Drive to the step-down transformation station.
2. Document with photos
3. Drive to the street names; take photos and notes
   a. Which sectors are prominent? If residential, what kind of building categories? Any prevailing building year? What kind of newly built households are there?
4. Summarize area into text. Leave blank if general impression is vague.
5. Drive to next station, repeat steps.

All stations expect Arnavågen and Tangeland were visited during the field visit. After the field visit, results were summarized and areas unvisited assessed using Google Maps and finn.no. Three stations were then selected according to three criteria explained in the model application section.

Following the field visit, a map showing the exact supply area was received by BKK[1] (Natås, I. M. 2013a) for validation. The field visit enabled a general description of the type of buildings and building year, whereas the municipal records are used to determine the exact amount of household types.

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[1] The map, courtesy of BKK, contains sensitive information on societal infrastructures and cannot be included in this thesis.

2. Method for systemizing total number of households per building category

The records for Bergen include data on building type, building year, and number of floors, area and state of use. However, the records were not explicit, and several registrations for did not include the building year. Indirectly, the building is from before the 1980's (Møster 2013). Each building has a state of use, and several indicate that there are residents present. This is not an absolute measure of where people live, as the municipal records are not completely updated at all times. In addition, a house may have several households that have occurred at different stages of the buildings life (Møster 2013). The municipal records are therefore trimmed down to only include relevant observations:

1. Any buildings that are not households were removed, such as office buildings, buildings for social care, and various other categories such as garage buildings, sport halls, municipal buildings, boathouses and recreational buildings.
2. Residential buildings were then split into separate categories: block of flats, terraced, detached, semi-detached. The categories were defines using the following Norwegian definitions:
    a. **Apartment buildings:** Buildings with 3 or more floors, and buildings with 2 or more floors with 2 or more household units in them. These are "stort frittliggende boligbygg på 3, 4, 5 etg el mer", "stort frittliggende boligbygg på 2 etg", "terrassehus" and "store sammenbygde boligbygg på 3 og 4 etg".
    b. **Terraced houses:** Houses that are attached to at least two other buildings. These are "rekkehus" and "kjede/atriumhus"
    c. **Detached houses:** Houses that are not attached to other buildings. These are "eneboliger", "våningshus", "eneboliger m/ hybel/sokkeleilighet", and "andre småhus m/3 boliger el fl".
    d. **Semi-detached houses:** Houses attached to another building and that contain two household units. These are "tomannsbolig, horisontaldelt", "tomannsbolig, vertikaldelt" & "store sammenbygde boligbygg på 2 etg".
3. All households with status burnt or demolished are removed.
    a. All households not currently in use are removed. The following Norwegian statuses indicate that there are residents: "midlertidig brukstillatelse", "tatt i bruk" and "ferdigattest". The following statuses have been removed from the dataset: "rammetillatelse" and "igangsettingstillatelse".

Appendix B - Appliance Loads

FYLLINGSDALEN

		Power (MW)						
Hour	Time Frame	Electric furnace	Water heater	Clothes dryer	Clothes washer	Freezer	Refrigerator	Total
1	(0-1)	16,0	1,5	0,1	0,2	0,7	0,3	19,9
2	(1-2)	14,5	1,1	0,1	0,1	0,7	0,3	17,7
3	(2-3)	16,0	0,7	0,0	0,1	0,7	0,3	18,5
4	(3-4)	15,7	0,7	0,0	0,1	0,7	0,3	17,9
5	(4-5)	15,2	0,8	0,0	0,0	0,7	0,3	17,0
6	(5-6)	17,0	2,3	0,0	0,1	0,7	0,3	18,8
7	(6-7)	23,9	3,5	0,0	0,3	0,7	0,3	26,0
8	(7-8)	22,5	5,0	0,0	0,6	0,7	0,3	26,4
9	(8-9)	18,1	5,0	0,4	1,2	0,7	0,3	24,2
10	(9-10)	17,4	4,9	1,0	1,7	0,7	0,3	26,0
11	(10-11)	18,1	4,9	1,8	1,7	0,7	0,3	27,6
12	(11-12)	18,1	4,3	1,5	1,3	0,7	0,3	26,8
13	(12-1)	19,6	4,1	3,1	1,1	0,7	0,3	29,6
14	(1-2)	18,1	4,0	1,8	1,2	0,8	0,3	26,5
15	(2-3)	16,0	3,9	1,9	0,9	0,8	0,3	24,0
16	(3-4)	18,8	3,7	1,8	0,8	0,8	0,3	26,7
17	(4-5)	23,9	3,7	1,5	1,1	0,8	0,3	31,5
18	(5-6)	25,4	4,0	1,1	1,4	0,8	0,3	32,7
19	(6-7)	24,6	4,0	3,2	1,3	0,8	0,3	34,0
20	(7-8)	19,6	3,6	4,9	1,3	0,8	0,3	30,9
21	(8-9)	21,8	3,3	4,8	1,1	0,8	0,4	32,8
22	(9-10)	22,5	2,9	3,4	0,7	0,8	0,3	31,4
23	(10-11)	21,0	2,5	3,2	0,5	0,8	0,3	29,1
24	(11-12)	15,2	1,8	0,2	0,4	0,8	0,3	19,9
Energy use	(MW)	459,0	76,2	35,7	19,4	17,9	7,4	615,7

		Power (MW)						
Hour	Time Frame	Electric furnace	Water heater	Clothes dryer	Clothes washer	Freezer	Refridgerator	Total
1	(0-1)	10,6	0,9	0,1	0,1	0,5	0,2	13,1
2	(1-2)	9,6	0,7	0,1	0,1	0,5	0,2	11,7
3	(2-3)	10,6	0,5	0,0	0,1	0,5	0,2	12,3
4	(3-4)	10,5	0,4	0,0	0,0	0,4	0,2	11,8
5	(4-5)	10,1	0,5	0,0	0,0	0,4	0,2	11,2
6	(5-6)	11,3	1,4	0,0	0,1	0,4	0,2	12,4
7	(6-7)	15,9	2,1	0,0	0,2	0,4	0,2	17,2
8	(7-8)	15,0	3,1	0,0	0,5	0,4	0,2	17,5
9	(8-9)	12,0	3,1	0,3	0,9	0,4	0,2	16,0
10	(9-10)	11,6	3,0	0,8	1,3	0,4	0,2	17,4
11	(10-11)	12,0	3,0	1,6	1,3	0,5	0,2	18,5
12	(11-12)	12,0	2,6	1,2	1,0	0,5	0,2	17,9
13	(12-1)	13,0	2,5	2,6	0,8	0,5	0,2	20,1
14	(1-2)	12,0	2,5	1,6	0,9	0,5	0,2	17,8
15	(2-3)	10,6	2,4	1,6	0,7	0,5	0,2	16,2
16	(3-4)	12,5	2,3	1,6	0,6	0,5	0,2	17,9
17	(4-5)	15,9	2,3	1,2	0,8	0,5	0,2	21,1
18	(5-6)	16,9	2,5	0,9	1,0	0,5	0,2	21,8
19	(6-7)	16,4	2,5	2,7	1,0	0,5	0,2	23,0
20	(7-8)	13,0	2,2	4,1	1,0	0,5	0,2	21,3
21	(8-9)	14,5	2,1	4,0	0,8	0,5	0,2	22,6
22	(9-10)	15,0	1,8	2,9	0,6	0,5	0,2	21,4
23	(10-11)	14,0	1,6	2,7	0,4	0,5	0,2	19,8
24	(11-12)	10,1	1,1	0,2	0,3	0,5	0,2	13,1
Energy	use (MWh)	305,1	47,1	30,1	14,6	11,5	4,8	413,1