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Report

Method for top-down analyses of electrical end-use demand

Weather dependency detection of total load with hourly intervals

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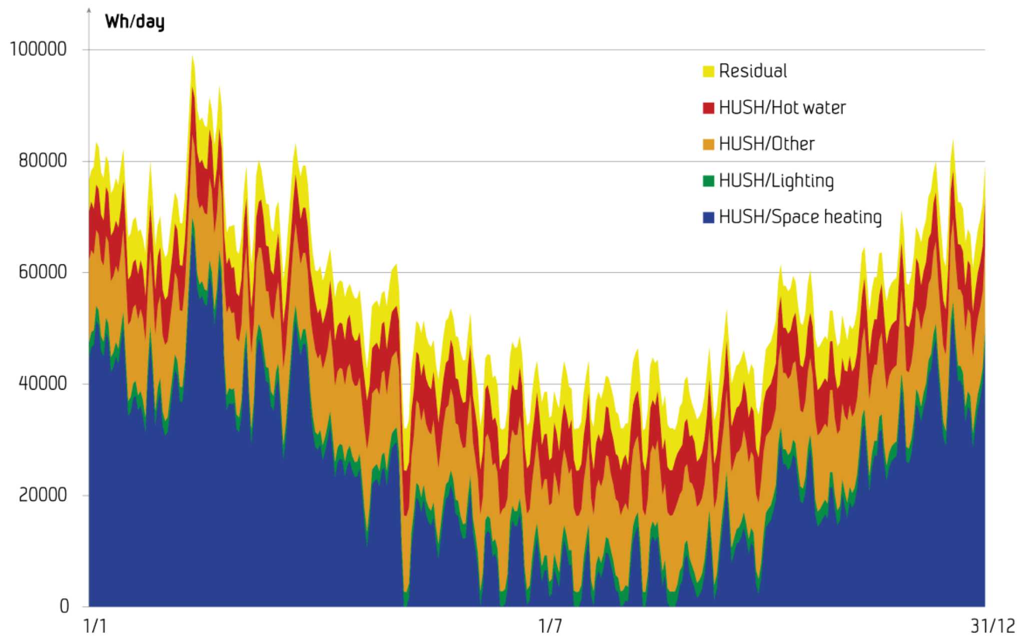

SINTEF Energy Research

Electric Power Systems

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The report describes how weather dependency and segmentation of hourly metered load of the total consumption of smart metered customers can be determined. The method described uses step wise regression on temperature and total load to produce standardized load profiles that applies as a model for a group of similar customers. These load profiles are stored in a database, and are applied when customer data belonging to the equivalent customer group should be segmented into end-uses. An example shows how the electricity demand of typical residential customers can be segmented into end-uses including space heating. The segmented time series will have a resolution of one hour.
The weather dependency method is not based on availability of end-use data and can be used for customer groups where end-use segmentation until now has not been possible due to lack of end-use metering. Applications of the method could offer data information based on analyses of customers' electricity demand that could enable the participation of most customer groups in Demand Response to help balancing the electricity market.
Segmentation of total demand into space heating, air-conditioning and appliances (unidentified demand) will help communities, regional municipalities and national authorities to decide on energy planning to make better decisions on building standards and to decide on use of energy carrier solutions as investing in district heating and use of bio fuels.

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Summary

The present report is a part of the Electricity Demand Knowledge (ElDeK) research project, and documents how weather dependency can be detected based on metered data with hourly resolution and outdoor temperature series with daily values. Wind, sun radiation and other weather elements also have impact on the energy consumption of Norwegian buildings, but the impact from outdoor temperature is the factor that by far is the most important factor regarding the energy consumption of Norwegian buildings. The reason for this is the fact that most Norwegian customers use electricity, directly or by heat pumps, for space heating.

A metering campaign was conducted within the ElDeK project, where the total electricity consumption of a residential customer has been metered with hourly resolution for a period of one year, and the electricity consumption for some selected electrical appliances has been metered with one minute intervals for a period of four weeks.

Residential customers from different parts of Norway have participated in the metering campaign. The availability of data from residential customers has enabled the weather dependency detection method to be checked for this type of customers. The method could also be used for other types of customers.

The ElDeK project was a part of national research program RENERGI and was financed by the Research Council of Norway, Norwegian Water Resources and Energy Directorate (NVE) and Enova SF.

In the report the weather dependency detection method is described and examples of use are shown. Metered total and appliance demand of residential customers plus temperature series are used as basic input data for the presented analysis. The results of the analysis are discussed and are shown to comply with results from earlier research.

The software USELOAD has been used in the analyses (See Appendix).

In the study the customer demand is further divided into demand from groups of end-use appliances, since such data were available. The reason for this is to enable comparison with earlier research, e.g. REMODECE [4] to quality assure the method and results. Even though end-use segmentation is important, the weather dependency segmentation is an interesting tool by itself, and has many applications.

The weather dependent load is considered as the part of the load that is due to electric space heating, and for the case of Norway space heating is known to be a substantial part of the total load for different types of customers. Electric space heating can be substituted by other heat sources as for example wood- or gas fired stove, and due to this, space heating can be used as flexible load for demand response purposes.

All kinds of customers' demand for electricity can be analyzed with the method described in this report, provided that the necessary data is available: Smart metering with at least hourly resolution and daily outdoor temperature data. It is important to understand that metered end-use data is not needed to use the method. By using the method it is possible to detect the space heating more precisely than before for customer groups such as residential commercial, service industry, social buildings and even industry customers. This fact makes the method very powerful.

Applications of the method could offer data information based on analyses of customers' electricity demand that could support many customers to participate in demand response to help balancing the electricity market.

The new approach provide cost efficient and rapid statistical methods for development of detailed load profiles, based essentially on metered data with resolution one hour or higher, collected with use of technology for smart metering. It allows identifying a potential for more goal-oriented energy efficiency actions and later verifying impacts of these. Division of the load between weather-dependent and independent segments indicates potential flexibility in the consumption (Demand Response) and creates basis for load forecasts.

List of Abbreviations

CFL	Compact Fluorecent Lamp
COP	Coefficient of Performance
DNMI	The Norwegian Meteorological Institute
DR	Demand Response
DRR	Demand Response Resource
DSM	Demand Side Management
DSO	Distribution System Operator
ECEEE	European Council for Energy Efficient Economy
EIE	Energy Intelligent Europe
ElDeK	Electricity Demand Knowledge
EPRI	The Electric Power Research Institute
NVE	Norwegian Water Resources and Energy Directorate
SSD	Sum of squared differences
ToU	Time of Use

1 Introduction

The implementation of Smart Metering in Europe creates new opportunities for studies of electricity consumption patterns. Measurement of end-uses on appliance level remains however to be very time consuming and expensive, so the possibility to model segmented end-use demand based on metering of total electricity consumption is important [13].

The present report is a part of the Electricity Demand Knowledge (ElDeK) research project. The project's main objective is to contribute to increased knowledge both concerning the total electricity demand for different customers groups (households and offices) and electricity demand segmented into different end-uses. As only residential customers have participated in the metering campaign of the project, the necessary data for only residential customers are currently available for the methods described in this report.

The project was a part of national research program RENERGI and was financed by the Research Council of Norway, Norwegian Water Resources and Energy Directorate (NVE) and Enova SF.

1.1 Benefits of the project activity

Knowledge of the dependency on weather of the demand can have great interest for production planning, and also for the development of the total energy production system – since space heating can be accomplished by other energy carriers as bio energy, oil/gas, district heating etc. The fact that space heat has a flexibility regarding energy carrier and considerable thermal inertia enables space heating and hot water heating as a potential Demand Response Resource (DRR) and a facilitation of Time of Use (ToU) pricing [12]. This is possible since some of the space heating, particularly floor heating, can be reduced for some hours without affecting the comfort of the user. Particularly interesting is the fact that technology for smart metering in the near future will be required by national authorities (in case of Norway from 01.01.2019), and then time series of the electricity consumption will be available for every residential customer.

1.2 Benefits for the residential customer

It will be possible to use the methods described in this report to systematically divide the user demand into weather dependent load and appliance load, resulting in segmented time series with hourly resolution for each separate customer. The residential customer (under a spot price contract and/or *Time Of Use* transmission contract) will earn information that enables planning of how the use of different appliances during the day could reduce the electricity bill. Examples are to avoid the peak hours with high electricity prices to do household tasks as dishwashing and clothes washing and drying etc. Such conduct would also lead to reduced demand during peak hours which in turn would off-load the distribution grid.

The described methods can also be applied to aggregated sets of customers, as for example all residential customers in a specific region – or all residential customers in the country. The benefit for the Distribution System Operator (DSO) would be e.g. a tool for better forecasting load distribution during the day, or to determine which user appliances are in use at a specific moment – which is helpful for reducing bottleneck situations locally in low voltage – or in general to support Energy efficiency measures.

The report describes how segmentation of hourly metered load of the total consumption from residential and other types of customers can be achieved provided that data are available. The method described uses stepwise regression on temperature and total load to produce load profiles that apply as a model for a group of similar customers. The load profiles are stored in a database, and can be applied when other customer data belonging to the equivalent customer group should be segmented into end-uses.

2 Data

The present study is essentially based on so-called primary data, the data which was collected and verified directly by the project. The secondary data are collected and verified by others.

2.1 Primary data

Metered data for total electricity demand from smart metering technology with hourly resolution, and metered demand for end-use appliances with one minute resolution have been the source for the analyses in the project. During the project metered data have been collected from 98 Norwegian residential customers, and load data from approximately 500 end-use appliances have been sampled from the customers.

The collected primary data used in the work presented in this report includes the following categories:

- **End-use consumption data,** collected by using PowerDetective equipment delivered by S.L. Energiteknikk [2]. The equipment was installed at 98 households belonging to four different Distribution System Operators (DSOs). The equipment was used for metering electricity consumption of different home appliances with resolution of one minute during four weeks periods.
- **Customers' individual metered data**, measured by smart metering technology. The data were collected by the respective DSOs and transferred to SINTEF Energy Research. The data has resolution one hour.
- **Data about individual households**, describing different properties as for example floor space, building year, number of persons living in the household, income, general space heating patterns etc. for each participating household. The data was collected through two different questionnaires distributed among the customers.

2.2 Secondary data

The only secondary data used in the project were outdoor temperature values, collected by the Norwegian Meteorological Institute [3] (DNMI). The temperature data have day intervals as this is easily obtainable. Hourly resolution of outdoor temperature might give increased accuracy of the load analyses, but since most buildings show slow response to changes in the outdoor temperature, the consequences of the use of less temperature resolution is considered to be minor. Furthermore, the project includes experiences from some SINTEF's previous projects and in particular REMODECE[1].

2.3 Limitations of the data

During the ElDeK project it has been observed unstable functioning of the metering equipment (PowerDetective), resulting in loss of registered data from some of the participating households.

[1] REMODECE is an EU EIE/IEE-project where end-use demand was metered at several households in different European countries. SINTEF Energy Research participated in this project and metered end-use demand at 100 households.

3 Method for top-down analyses

3.1 Description of method

Based on metered data of the total customer demand with hourly resolution, demographic data and statistical analyses the two following methodologies have been used within the ElDeK project:

- Methodology for estimation of the demand of groups of end-use (Top-down approach)
- Methodology for estimation of the total electricity demand based on metered end-uses (Bottom-up approach)

Household-level load shapes can be disaggregated into their main components by means of tailored statistical methods. In Norway the weather dependent share of the load is particularly interesting, since this segments account roughly for half of the total energy consumption of the residential sector. This load is weather dependent due to space heating, which is normally controlled by thermostats. Some components of space heating are less dependent on outdoor temperature, as for example electric floor heating cables. Floor heating in bathrooms and secondary rooms as halls and corridors are slow to respond to outdoor temperature, since many home owners have heated floors that are based on concrete and stone constructions. Many heated floors are run with pre-set power level that is manually adjusted during the year, since thermostats are difficult to adjust properly due to slow thermal response. The energy demand for floor heating cables will be less dependent on outdoor temperature since the power demand can be constant during long periods.

The method proposed in the ElDeK project will identify loads that respond to changes of the outdoor temperature – so that the power demand increases with lower temperature, due to the operation of the heating system. Other heating appliances that show little dependency with outdoor temperature presented in this report as floor heating (electric heating cables) will from this reason not be identified by the method. In stead this "independent" part of the space heating will be a part of the *residual* – the portion of the load that cannot be clearly identified as weather dependent load, or as an appliance specific end-use.

The top-down method based on hourly metering of total consumption for residential customers is given in this chapter. It may be possible to develop the method further to enable industrial/ commercial customers to use the methods and share the work of the project.

The structure of the top-down method is illustrated in Figure 3.1 (for explanation of "light as residual" see Section 3.3.6).

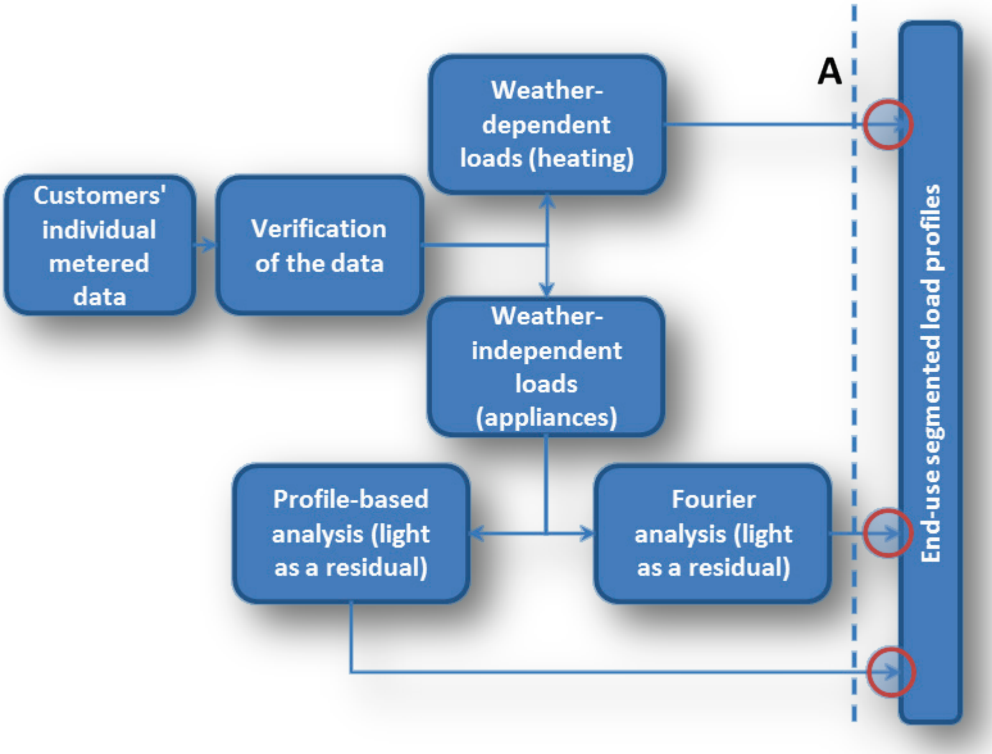

Figure 3.1 Illustration of the structure of the top-down method.

Based on the metered data of a customer's total electricity consumption, the described method can:

1. Verify the data and remove invalid data/wrong data/data from special days
2. Divide the metered data into weather dependent and weather independent[2] loads

Further segmentation can be found for the appliance dependent (weather independent) part:

1. Divide the load into load profiles known from the ElDeK- and REMODECE project [4] – for all electrical appliances at the customer (Profile-based analysis)
2. Divide the load further with use of Fourier analyses (EPRI approach, [1]) on the weather independent part if end-use metered data is not available (other buildings than households).
3. A combination of the methods could also be used if only parts of the end-uses are metered for a customer type to provide load profiles for non metered appliances.

The developed approach was initially inspired by a method described by The Electric Power Research Institute (EPRI) in the report "Residential End-Use Load-Shape Estimation Volume 1" [1]. The development of the present method has however resulted in many changes in the final approach compared to EPRI's original solution:

EPRI used Fourier transforms and spectral analysis of the load to segment the load into end-uses. In a study it was found that the load shapes were periodic, and the load shapes transformed into line spectra superimposed on relatively low level "noise". EPRI decided to use sinusoids as predictors for the weather-independent component of the load.

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[2] The appliance dependent part is also a weather independent part.

In this report Fourier transforms are not applied to find end-use demand from hourly metering of total load, but load profiles from separately metered end-use demand (One minute resolution) are used. Using data from actually metered load rather than using spectral analysis should result in more reliable profiles for the study presented in this report. The EPRI method is a good alternative to use when no end-use metering is available, but the ElDeK project was in the favourable position to have access to end-use metered data.

3.2 USELOAD Software

SINTEF Energy Research has significant experience in statistical methods related to analyses of end-use demand. These methods are also implemented in the USELOAD software [8], used in the ElDeK project for analysing metered data. USELOAD is a software tool designed with the purpose of segmenting metered time series into end-use and/or different customer categories.

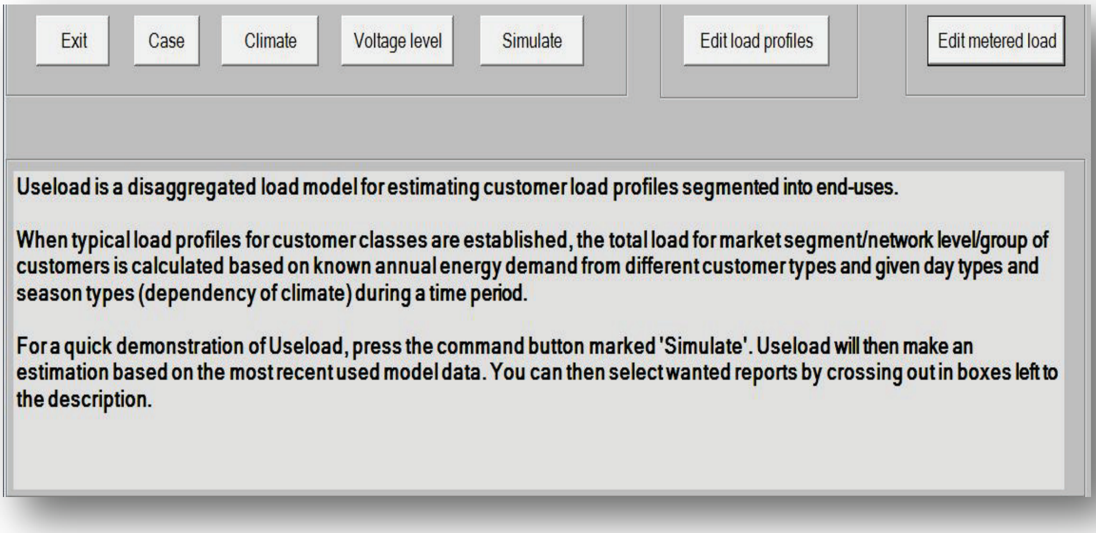

Figure 3.2 USELOAD main form.

The USELOAD software is based on hourly metered data for customers, and minute level metered data for different appliances used by a given customer group. The customer data are collected during participation in several national load research projects. For more detailed description of USELOAD see Appendix.

3.3 Terms and definitions

The method chosen by SINTEF uses separate values for each hour of thermostat settings, saturation and time constants. These are described in the different sub chapters below.

3.3.1 Weather-dependency

The present study uses the term *weather-dependency*, describing relationship between electricity consumption and outdoor temperature. Even though the term "weather" in its common understanding includes several factors such as outdoor temperature, humidity, precipitation, solar radiation and wind, in the scope of the present study the term weather-dependency refers to outdoor temperature only.

3.3.2 Hourly thermostat settings

In Norway many households have installed automated systems that reduce the temperature during night and some also reduces the temperature during work hours – when no one is present in the household. The goal of such systems is to reduce the heating power demand without affecting the comfort of the owner. The automated system will reduce the thermostat during night – and often boost the temperature in the morning so that the users will have comfortable temperature when waking up. The temperature will be lowered again when the inhabitants leave the household for work – if this is wanted. From this description it is clear that the thermostat settings will be variable, and will be low during night and work hours, an hourly thermostat setting is needed to properly describe the energy demand.

3.3.3 Hourly saturation

Many households in Norway have installed heat pumps as well as direct wall mounted electric space heating. The use of heat pumps will reduce the need for heating energy, but the gain from heat pumps will depend on outdoor temperature. At cold temperatures the thermal efficiency (Coefficient of Performance - COP) from heat pumps will be low – so that other heating sources are needed. The fact that different heating systems operate depending on indoor and outdoor temperature, results in a variable saturation temperature of the heating system. Therefore an hourly saturation temperature should be used. Saturation in this context means that the output from the heating or cooling system has reached the maximal limit dependent on the hour of day i.e. the maximum installed capacity.

3.3.4 Hourly time constants

The time constant describes how fast the energy demand of a building responds to changes of the outdoor temperature. Since the thermostat settings of many buildings are altered during the day from automated energy saving systems, the response of the heating system from changes of the outdoor temperature will depend on the hour. In USELOAD the time constant is set to be dependent on the hour of the day.

During night hours the building will cool off, if the thermostat setting is lowered during night, so changes in the outdoor temperature will to a lower degree affect the heating system power resulting in a low time constant.

During evenings the heating system is boosted if the outdoor temperature is low, resulting in a high time constant.

3.3.5 Quiet periods

In the EPRI method quiet periods are removed from the metered data- to enable the Fourier analysis of end-use demand. This is avoided in the ElDeK project method because this would remove important parts of the data material from the model. Quiet periods are important periods since many people often are not home during weekends and vacations. Using the EPRI approach would result in a model that only accounted for the 'active' days of the metered customer behaviour, and the estimated energy demand would then be too high compared to the original. Under the method used in the ElDeK project all data are assigned to some period such as weekend, working day, vacation and holidays. With this method different periods during a given year using the specific calendar of the year can be identified. Special days such as constitution day, Easter vacation, Christmas, and other days categorised by state church ordinance can therefore be identified.

3.3.6 The residual part of the load

When analysing the appliance dependent load, the user has the possibility to treat lighting as the residual (the part of the load that is not allocated to any specific end-use appliance), since lighting consists of several electrical points in a house and it is costly and cumbersome to meter. However, experience from previous projects shows that the magnitude of the residual suggests that lighting cannot be the only source of the residual demand. The heating appliances that show little dependency to outdoor temperature as floor heating (electric heating cables) have also been included into the residual.

In USELOAD the user is free to select any end-use appliance to balance the end-uses to the total load, or the residual can be shown without connection to any end-use. In ElDeK it has been decided to use the last method – to show the residual – and in this way end-uses are not altered to balance the total consumption, but the residual is shown to indicate the portion of the load that is not identified as a specific appliance type. Most of the time the residual is positive, but also negative values are possible - when the total of end-uses exceeds the total demand. This occurs since not all end-uses are metered at all customers.

The end-use metering of ElDeK and previous metering plus analyses of this data, have resulted in several load profiles for different end-use categories for the customer, as for example heating, cooling, cooking, entertainment, lighting etc. Due to specifics of the metering equipment, such as the necessity to plugin the metering device between the socket and the plug of the appliance, it has not been possible to meter appliances that are directly connected. For this reason, floor heating, luminous tubes, fans etc. are not metered. Additionally, some appliances are too infrequent in use or have modest energy demand, as electric toothbrushes, hairdryers, electric clocks, hand tools etc. and from this reason have not been metered. Common for all unmetered appliances is that the demand of these will be assigned to the residual.

3.4 Data validation

Prior to analyzing the data for weather dependency, the data series must be quality assured to avoid bad data as part of the analysis. Bad data are the result of problems like meter errors, recorder failure, data transmission problems and human failure. Such data can be removed by searching for data that are out of predefined limits. Negative values and too high values (so-called outliers) are removed, and also data that are flagged as missing. It is also necessary to remove data that are estimated by the Metering service; as such data can be non-characteristic regarding temperature sensitivity or have other problems.

In EPRI's method "quiet periods" are removed from the time-series. Such data are abnormal in the sense that the data violates the mathematical model that should be constructed. Quiet periods are normally the result of the absence of most of the household members, and vacations and business trips are often the cause. If Fourier analysis (EPRI approach) is used to segment weather independent load it is necessary to remove quiet periods since the basis for the spectral analysis is violated in these periods. Using the ElDeK's approach the removal of quiet periods is not necessary.

3.5 Evaluation and adaption of the method

Although quiet periods are abnormal in the sense that the data violates the mathematical model that should be constructed, it has been decided in the ElDeK project not to remove total consumption data from quiet periods. The reason is that it is normal behavior for households to be on vacations for periods during the year, and to have other absence from home. By letting quiet periods be a part of the analyzed data material, the mathematical model will appreciate and allow for the occasional habits of households to have shorter periods of lower activity. Also, if such periods were not a part of the model, the simulation of household energy demand would need to include quiet periods anyhow – to achieve the normal energy demand for longer periods. The simulation model would then have to mimic the occasional lower activity periods, by somehow including this at stochastic intervals, and one would also have to model the hourly activity during the quiet periods.

4 Estimation of Weather Dependent Load

In this chapter the method for estimation of weather dependent load will be described. The focus is on metered data of total load of households. By using regression analysis on time series of demand and concurrent outdoor temperature – with hourly resolution, it is possible to decide which portion of the demand that is dependent on the weather (i.e. the outdoor temperature). The weather dependent load is assigned as space heating when segmented load is presented.

4.1 Factors that impact on the weather dependent load

The weather dependent load is the electricity used for space heating. The power demand of the weather dependent load (i.e. the heating) is not directly proportionate to the outdoor temperature. An example of this is that two consecutive cold days do not result in the same demand, since the second day will require more power due to aggregation of coldness in the building volume. In the mathematical model for electricity demand the load will be described to be dependent on the temperature of the current day, and also the temperature of the day before. The weight of current and day-before temperature will be determined by using step wise regression to find the best fit showing lowest regression error.

There are numerous other factors that impact on the demand for electric space heating, and some are mentioned below.

4.1.1 Building characteristics

A building made of concrete has a slow temperature response to changes in outdoor temperature, since concrete is a heavy material and needs long time to heat. In comparison, a wooden building will show a quicker response. In effect a concrete building will depend more on yesterday's temperature compared to a building made from wood, due to the *time constant* of the building. In USELOAD the average time constant of the buildings that are metered is found by stepwise regression: a set of time constants is tried in a software loop, and the most suitable value is found that results in the best fit to the regression line.

The *insulation* of the building will also affect the space heating, since low or missing insulation of outdoor walls, ceiling, basement, doors and windows leads to requirement of much heating in periods with low outdoor temperature. Also thermal bridges (non-insulated parts of the building shell) lead to requirement of more space heat.

4.1.2 Thermostat settings and control schemes

Many home owners use day and night temperature reduction schemes so that the room temperatures manually or automatically are reduced when the need for comfort is low, since the inhabitants are asleep, are at work or are not present from other reasons. Of course using such schemes leads to low electricity consumption during night and partly during the day, and increased electricity demand when the inhabitants wake up/get home. In turn using day and night temperature reduction schemes will lower the overall energy demand of the building – since the average indoor temperature is lowered compared to no change in temperature. The power demand of the building will off course move from power reduction intervals to the hour when the inhabitants have the need for comfort temperature.

4.1.3 Heating system and energy carriers

It is commonly known that using an air/air heat pump may reduce the energy consumption for space heating considerably, and a water/water heat pump may reduce this even more - depending on the difference between the indoor and outdoor temperatures. The electricity consumption of the heat pump will be weather dependent.

Many home owners use wood- or petroleum-fired stoves for space heating, and most of these furnaces are operated manually, which means that they are not used when the residents are not present e.g. at work.

Central heating and district heating will of course also reduce the electricity consumption in the household, and these energy carriers can also supply hot tapping water for reducing the electricity consumption further.

Using the weather dependent method, the set of metered buildings are randomly selected and will have a composition of different heating systems that will mirror the composition of the total population. In ElDeK, the buildings heating systems are not treated by using stratification in any sense, and the method in use is dependent on the size of the sample. In a big sample the error in the composition of heating systems will be less. Since the size of the ElDeK sample is 98 buildings the error due to bias of heating systems should be small.

4.1.4 Outdoor heating systems

Some home owners have electric heating systems for their cars (so-called block heaters) that manually or automatically (use of timer) pre-heat the car prior to use. Such systems can add significantly to the energy consumption, so the consumption can easily exceed the demand of most indoor appliances such as washing machines and refrigerators etc. Since the auto heating system depends on the outdoor temperature (only needed during the winter) – the USELOAD model could to some extent identify the load as weather dependent.

Also electric driveway heating cables and snow removal systems will be identified as weather dependent since the use is affected by the outdoor temperatures (only needed during the winter).

4.1.5 Excess heat from appliances

The homeowners' appliances use electricity or other kinds of energy carriers. A significant part of energy, consumed by the appliances will in turn be transferred to the indoor air as heat, and will contribute to the space heating, provided that space heating is needed in the moment of time. Some heat will quickly 'move' to the ceiling by convection of air and stay there, so it will contribute less to the space heating. A home owner that has a lot of appliances in use will reduce the space heating demand substantially, but can also experience a lot of excess heat during hot seasons, that needs to be removed by ventilation or air-conditioning.

4.2 Model of power demand

A mathematical model for the power demand of a building specifies how the electricity load is dependent on outdoor temperature for space heating, cooling and due to electricity consumption of appliances. This is specified in Equation 1. The different factors in the equation need to be detected and stored by the method in order to model the buildings that are metered.

The method presented in this report detects the weather dependency factors such as a_h and a_c of Equation 1, and also how the outdoor temperature should be normalized in order to model thermostat settings and saturation effects. Saturation in this context means that the output from the heating or cooling system has reached the maximal limit. Normalization of temperature will be handled in next paragraph.

The model of power demand is set up for a selected set of metered customers. If wanted, the user can select a set of customers to be assigned to be statistically analyzed dependent on the building type: Detached, row house, apartment, or any other building or user characteristic could be a selection criterion. In USELOAD the use of stratification will be applied so that the result of the analysis of the sample will be changed according to the characteristics of the total population.

Equation 1 is set up for each hour and for each day type (work and weekends/vacations etc.) and season (only one season is used in ElDeK), and models how heating, cooling and appliances are dependent on the outdoor temperature:

Equation 1 $$\boldsymbol{P = a_h \cdot t_{nh} + b + a_c \cdot t_{nc}}$$

Where

P:	Total Power consumption of the building (per hour)
a_h:	Factor for current days temperature corrected for the heating system
t_{nh}:	Temperature corrected for the heating system, weighted (normalized) value of current and yesterdays outdoor temperature
b:	Constant – energy use of end-use appliances (data per hour – season and day type)
a_c:	Factor for current days temperature corrected for the cooling system (i.e. air-conditioning)
t_{nc}:	Temperature corrected for the cooling system, weighted (normalized) value of current and yesterdays outdoor temperature

Equation 1 specifies that the power consumption P is linearly dependent on the *normalized* outdoor temperature for space heating t_{nh}, and similar temperature for air-conditioning t_{nc}. The demand of appliances is governed by a constant (hour, day type and season dependent) b. Appliance load will be further segmented into separate end-uses by use of equation 1, but with separate data for each appliance.

4.2.1 Normalized temperature for heating and air-conditioning

The electricity demand of buildings does not immediately respond to the outdoor temperature, since much heat is stored in the construction. As it was mentioned earlier, when the temperature changes to colder weather, the temperature of the material in the construction is slowly reduced, and after a certain time the indoor temperature is reduced so that the thermostat turns the heating on. The method now incorporated in USELOAD identifies the thermal inertia of the heating system – similarly for cooling system, and composes normalized outdoor temperatures to account for this – as time constants (weight factors) w_h and w_c. Time constants are the topic of later paragraphs in this report.

Space heating is proportionate to the normalized outdoor temperature as illustrated in Figure 4.1. In the example the saturation temperature (t_{sh}) is reached at -20 degrees, so the electricity used for heating will not exceed the power consumption at -20 degrees. This temperature is defined as the saturation set point. At temperatures greater than +15 degrees (t_{th}) the heating systems is turned off. This temperature is representing the thermostat setting.

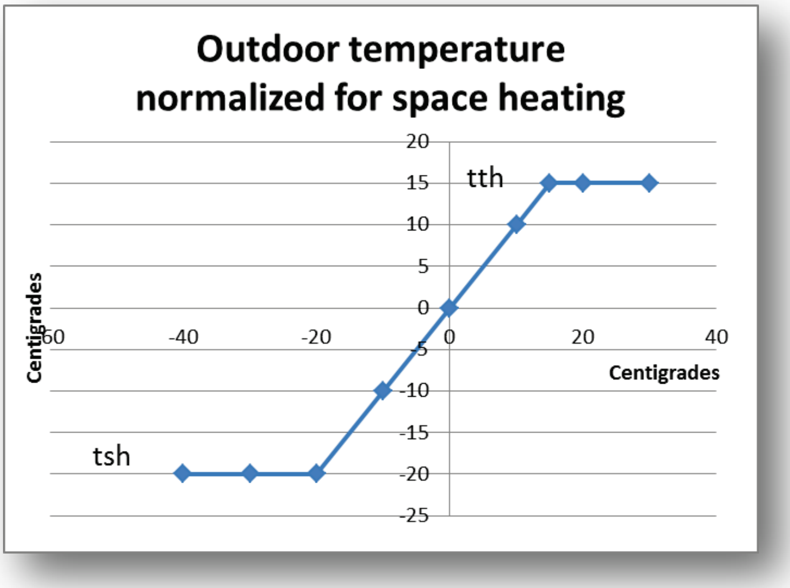

Figure 4.1 Normalized temperature for heating.

The normalized temperature for heating is determined by the saturation set point t_{sh} and the thermostat setting t_{th}. The values of t_{sh} and t_{th} are determined based on the time series of electricity demand and temperature in a stepwise regression analysis, where all "possible" values of t_{sh} and t_{th} are tried in the regression analysis in turn, and where the "best" tries are recorded. To decide on the "best" values the Sum of Squared Differences (SSD) value of the regression is used. The SSD value indicates how well the normalized temperature series apply to the recorded demand. In the paragraph *4.2.2 Weighting current and yesterday's* temperature this process will be explained in more detail.

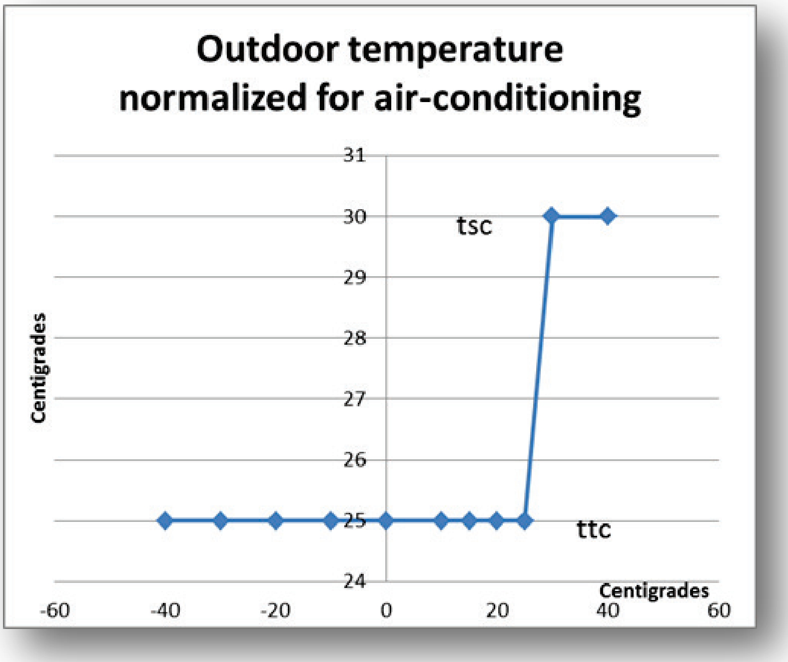

Figure 4.2 Normalized temperatures for air-conditioning.

Figure 4.2 shows the normalized temperatures for cooling/air-conditioning. In the example the saturation temperature (t_{sc}) is reached at 30 degrees, so the air-conditioning electricity consumption will not exceed the power consumed at 30 degrees. At temperatures lower than +25 degrees (t_{tc}) the cooling systems are turned off. The values of t_{sc} and t_{tc} are determined by step wise regression analysis.

4.2.2 Weighting current and yesterday's temperature

A building's electricity demand will have dependencies both on the current day's outdoor temperature, and also on the outdoor temperature of the day before, and this is due to the slow response on temperature change of the building. This behavior is dependent on the material of the building, concrete buildings will e.g. response slower on changes in the outdoor temperature and will have a greater dependency on 'yesterdays' outdoor temperature.

The following equation will be used to estimate the weighted temperature consisting of current and day before current outdoor temperature. The weight factor are modeled different for heating and cooling, and are identified from analyzing the metered demand regressed on the outdoor temperature.

Equation 2 $$t = w \cdot t_c + (1 - w)t_y$$

Where
t: Weighted temperature
t_c: Outdoor temperature of current day
t_y: Outdoor temperature of day before current day
w: Weight factor – 60% to 100%. Different weight factors will exist for cooling and heating.

All factors in equation 2 must be estimated and stored in the database for each hour, day type (work day or weekend) and season.

It is also necessary to estimate the heating saturation temperature t_{sh} and the heating thermostat temperature t_{th} (Figure 4.1). Similarly for air-conditioning: saturation temperature t_{sc} and the cooling thermostat temperature t_{tc} must be estimated (Figure 4.2).

In addition to the factors described, the standard deviation of the hourly power demand must be estimated based on metered load.

4.3 Estimation of optimal factors

For a given type of building the following scheme can be used for estimating the optimal factors that define the model of the building type.

4.3.1 Estimation of factors for the heating system

For a given metered building in the sample of the building type, the optimal heating system factors for an hour, season and day type will be estimated with the following method:

USELOAD identifies different day types that indicate a season e.g. "winter months" and a day during week e.g. work days and weekends. The program also models each hour interval independently.

The outdoor daytime temperatures of the building area must exist for the corresponding days of the metered series. Also the metered load must be quality checked for "bad" observations, out of limits (outliers) etc. Observations for special days (Christmas, vacation, Easter etc.), will normally be considered as weekends since the demand of such days are different from work days.

During estimation of best model the USELOAD software in turn considers each given day type and each hour interval during the day (hour).

The program then circulates through all possible combinations of model settings for t_{sh}, t_{th} and w_h. When a model description is set, the original time series of each building consisting of pairs of hourly demand and temperature (the mean day temperature is used for all hours) are altered according to the settings as follows:

- The w_h setting governs how temperatures for this day and yesterday are weighted to form the temperature to be used. Possible values are from 0 to 100%.
- The temperature is then altered according to the settings of t_{th} so that if the outdoor temperature is higher than t_{th} the temperature is set equal to t_{th}.
- The temperature is then altered according to the settings of t_{sh} so that if the outdoor temperature is lower than t_{sh} the temperature is set equal to t_{sh}.

In this stage we have time series that are altered to suit the current setting of the model. The time series are then analyzed in a regression analyzer to find the least squares regression line for the time series. The regression analysis calculates a regression line that best fits to the time series of points. The regression line is defined by a constant b and "gain" a. The gain describes the dependency of the demand on the outdoor temperature.

The regression analysis also calculates a value "SSD" (sum of squares) that indicates how well the regression line fits to the time series. A low SSD indicates that the regression line is a good model of the time series. If SSD is zero, the regression line goes through all points in the time series of points. A high SSD value shows that the regression line is less related to the model, so there is little connection between the temperature series and the demand. The flow diagram of step wise regression is presented in Figure 4.3.

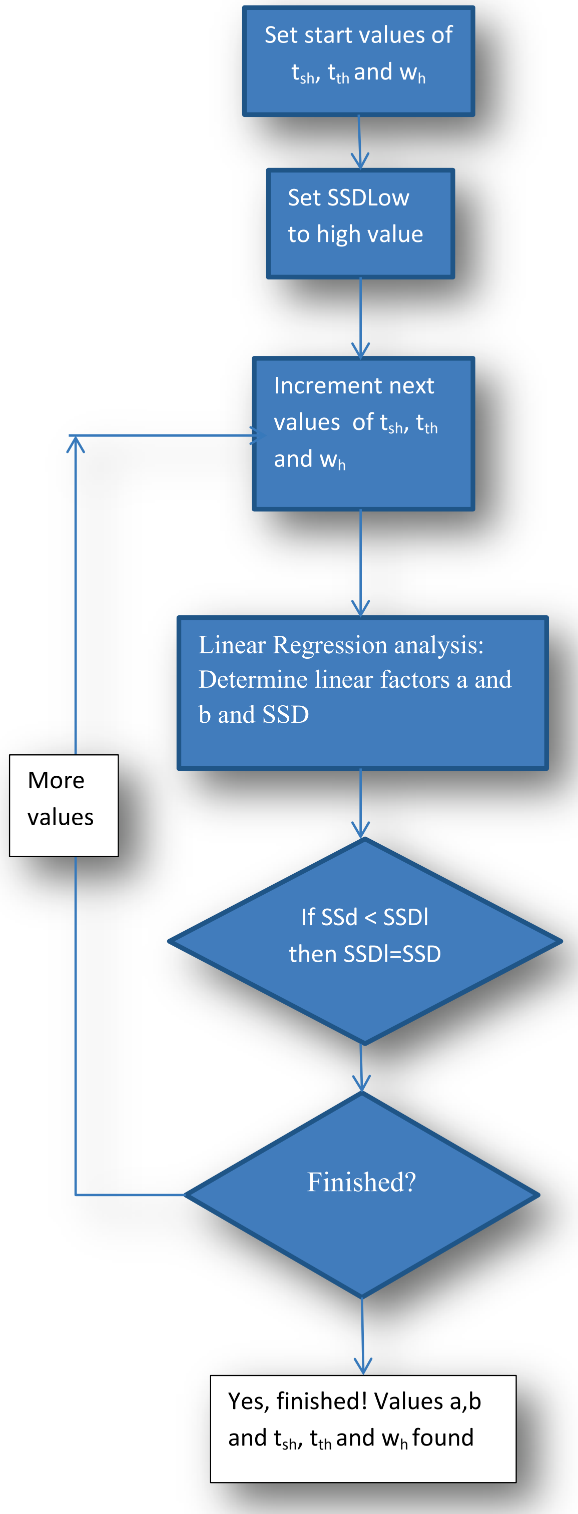

Figure 4.3 Flow diagram of stepwise regression.

The formula in Equation 3 shows how SSD is calculated, the $\hat{y}$ values are the observed values of electricity demand, and the y values are the calculated values from the regression line.

Equation 3 $$SSD = \sum(\hat{y} - y)^2$$

After looping through all possible combinations (limits to each factor can be set by the user) of the model set points, the combinations that leaves the lowest value of SSD is identified, and the best regression line is found.

For air-conditioning a similar method will be used, but the normalization of the outdoor temperature will simulate air-conditioning thermostat settings and saturation levels.

4.4 Expected value

The expected value for a given hour, day type and season of the typical demand for each building of the building sample is determined using equation 4.
The expected demand for a building is found based on metered demand of the buildings time series.

Equation 4 $$\boldsymbol{\mu^2 = \sum y / n}$$

Where
μ: Expected value
y: Quality checked metered values
n: Number of observations of the hour

4.5 Standard deviation

The standard deviation of the typical demand with hourly resolution is needed to be able to determine the coincident (simultaneously) peak demand for a building type. The standard deviation is also needed in order to determine confidence intervals of estimated expected demand.
The standard deviation for a building in the sample of the building type is found based on the time series of the building. The standard deviation (σ) will be calculated using the standard formula in Equation 5:

Equation 5 $$\boldsymbol{\sigma^2 = \left(\sum(y - \mu)^2\right) / (n - 1)}$$

Where
σ: Standard deviation
y: Quality checked metered values
μ: Expected value
n: Number of observations of the hour

4.6 Final calculation

Finally expected demand and standard deviations for each hour, day type and season of the typical building are calculated based on values from each building that are metered in the sample of buildings.
The expected demand of the typical building is found as the average of the expected demand for the metered buildings of the sample using equation 6:

Equation 6 $$\boldsymbol{\mu_t = \frac{1}{n}\sum \mu}$$

Where
μ_t: Expected demand that models the behavior of one typical building
μ: Expected demand of each metered building
n: The number of buildings that are metered.

The total standard deviation of the typical building, is found by adding up the squares of the standard deviations of the metered buildings, using the formula in Equation 7

Equation 7 $$\boldsymbol{\sigma_t = \sqrt{\frac{1}{n}\sum \sigma^2}}$$

Where
σ_t: Standard deviation that models the behavior of one typical building
σ: Standard deviation of each metered building
n: The number of buildings that are metered.

The set of parameters from the analysis now describes the characteristics of the group of buildings that are metered. To enable modeling and simulation of the demand the parameters are stored in the database for later retrieval.

4.7 Values to be stored in the database

The described method has now identified the following factors for space heating.

a_h: Factor for current days temperature
t_{sh}: Saturation temperature set point
t_{th}: Thermostat temperature set point
b: Constant – energy use of end-use appliances (data per hour – season and day type). Separate values for each end-use are used to further splitting up the value of b.
w_h: Weight factor – 60% to 100%.
σ_t: Standard deviation

These values are stored in the database along with an ID that uniquely identifies the *profile* values. Sets of 24 hourly values are stored for each profile, for each day type and season. Individual values will be defined for air-conditioning and space heating.

4.8 Estimation of factors for the air-conditioning system

For a given building, the optimal cooling system factors for an hour, season and day type can be estimated in similar way as shown for the heating system. As air-conditioning of households is less important in Norway due to a cold climate, it is considered that the consequence for the modeling of residential demand of not including air-conditioning is limited. For other customer types as offices the modeling of air-conditioning would be essential also in Norway.

4.9 Estimation of the residual demand of the model

When the weather dependent share of the customer demand is analyzed, we are left with a residual share of the total load that is due to demand from appliances, lighting, air-conditioning and static heating (heating that is not directly connected to outdoor temperature).
In the ElDeK project the residual part of the load is be further segmented into types of end-use or appliances by using load profiles modeled from analyses of direct metering.

5 Estimation of appliance dependent load

5.1 Profile based modelling

When the total load of a household (or a building) is analysed, the result of the analysis is stored in the database as a named 24 hour profile with separate values for different day types and seasons. See chapter 4 for further details.

The profile can later be used to generate a similar demand distribution to the original, in hourly intervals. If the original temperature series are used, for an equivalent time period – the energy demand will be equivalent to the original. The weather dependent part of the load will also be generated from a separate part of the load profile.

5.2 End-use modelling

The remaining part of the demand – the weather independent part - is due to electrical appliances. The total of end-use appliance demand for a customer type is defined by the constant value ***b*** in the load profile for the total demand (ref. Equation 1). Each appliance for a customer type is modelled separately based on metered data.

For results presented in this report the appliance modelling is based on time series metered as part of the ElDeK project. For appliance groups that has been metered a profile is generated, which can be used for modelling the demand of similar appliances.

The modelling of end-use appliances is based on time series of 4 weeks of metered demand from different types of appliances. The metered time series for end-use is analysed by a regression against outdoor temperature, and dependency of temperature are found along with the constant demand and the standard deviation of the demand. Actually the temperature dependency of most appliances is negligible, and in the ElDeK project it is decided to neglect the temperature dependency of end-use appliances. The metered demand has been quality assured, and bad data was removed prior to analysis.

The basis of the analysis of end-uses is time series of one minute intervals for four weeks – the analysis will determine a profile for the appliance with separate values for each hour, for different seasons and day types. The standard deviation of the hourly demand will be transformed from the basis of minute intervals to hourly demand by Equation 8.

From the equation it follows that the standard deviation for minute intervals is greater compared to the similar value for hourly intervals, which can be explained since it is less probable that a big power demand will last for a full hour. The coincident peak demand for minute intervals will then be greater than the coincident peak demand for an hour.

Equation 8

$$\boldsymbol{\sigma_h = \sqrt{\frac{1}{60}\sum \sigma^2}}$$

Where

σ_h: Standard deviation that models the behavior during an hour

σ: Standard deviation of minute intervals during a specific hour

When applying Equation 8 one assumes that there is no significant correlation of the demand from one minute interval to the demand of other intervals. The effect of cross-correlations among minute intervals has however not been studied, and later project activity should definitely explore this topic. By disregarding the effect of correlation the hourly standard deviation will be less than the real value.

Values stored in the database
Each end-use appliance is stored in the database with the following values, along with a unique ID that defines the customer group and the appliance type:

a: Factor for gain dependent on current day's temperature
b: Constant – energy use of end-use appliances (data per hour – season and day type).
σ_h: Standard deviation that models the hourly standard deviation of one appliance from a group of appliances

5.3 End-use segmentation of an average building's demand

USELOAD will generate appliance demand for all available profiled appliance groups, and scale the demand according to the typical number of appliances that is owned and used by a building. If the sum of appliance demand for an hour, including weather dependent demand, is less than the simulated total – the remaining demand is considered to be the result of non metered appliances, i.e. the **residual.** The residual can also be negative – if the sum of appliance and weather dependent load is greater than the total simulated demand.

USELOAD has built-in methods for extracting building profiles and end-use profiles from metered time series of end-use and end-uses. The analysis estimate expected load, temperature sensitivity and standard deviation for each interval (hour) according to defined seasons and day types.

Table 5.1 Number of appliances per household.

End-use	REMODECE	ElDeK
Water heater	0.85	0.85
Light kitchen	3.4	4.0
Light living room	12.7	4.0
Cooker	0.96	0.96
PC laptop	1.42	1.42
Dishwasher	0.88	0.88
Dryer	0.47	0.47
Freezer	0.73	0.73
Fridge	1.18	1.18
Kettle	1	1
TV	1.7	1.7
Washing Machine	0.96	0.96

Table 5.1shows the typical number of appliances in a household. The table compares the number from the REMODECE project [4] to the calibrated values from the ElDeK project. The values from ElDeK are changed for lighting so that the average sum energy demand of appliances and temperature dependent load is less than the average energy demand of the total consumption.

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6 Analytical results

6.1 General

Using the top-down methods described in this report, an analysis of the total hourly demand of all customers that have participated in the ElDeK project has been carried out. The analysis of the customers demonstrates how the new methods apply, and also functions as a quality assurance measure for the project.

The weather dependent part of the demand is identified based on regression analyses of how the total demand and outdoor temperature correspond. The modeling of the buildings includes how thermostat settings and saturation temperature are distributed during a day; the new approach for modeling gives a better understanding of the structure of the customer demand.

Data from 98 customers that have taken part in the ElDeK metering project are analyzed for this report. The total demand with hourly resolution of each household is metered and included in our metering database under the USELOAD software. Also metered are selected end-uses from each household; end-uses are metered for approximately four weeks periods with one minute intervals.

Questionnaires from each household are obtained; the answers in the questionnaires contain data that places the household in one of three strata:

- Stratum 1: Households of young singles or couples without children (1-2 inhabitants)
- Stratum 2: Households with more than 2 inhabitants – families with children
- Stratum 3: Households with retired 1-2 inhabitants

Each stratum group contains different number of customers, but the statistical precision of the analyses of the groups are similar.

6.2 Stratified random sampling

By using stratified random sampling in the sample design, the results of the analyses are altered so that the proportion of each stratum in the total population in Norway is obtained. Example: Since the number of households in stratum 2 is approximately 28% in Norway, the results from the analysis of this group are scaled down from 41% in the analysis material to 28% in the total population.

Table 6.1 Showing shares of strata of households in Norway and in the ElDeK project.

Type of stratum	Norway	ElDeK
One - two persons household	60%	37%
Three or more persons	28%	41%
Share of household for retired persons	12%	21%

The end-uses are also handled in the similar way regarding strata, so the stratum classification of the attached customers is used when analyzing the end-uses.

6.3 End-use segmentation

The average annual electricity demand of the 98 customers (households) that have participated (households) is estimated to be 21.538 kWh, and the maximal power demand (in total) is found to be 6,062 Wh/h, (when simulated for the year 2001 for Oslo climate). This gives a time of use of 3.552 hours - which is quite high, but considered that the estimated peak is the average /coincident demand for a big number of customers – the value is reasonable.

Figure 6.1 and Figure 6.2 show simulated average demand during workday and weekends for customers participating in the ElDeK project that have been analyzed. The demand is segmented into typical end-use demand, such as lighting, space- and water heating. The category "Other" denotes end-use appliances such as refrigerators, TV and PC and other entertainment appliances and different kitchen equipment etc.

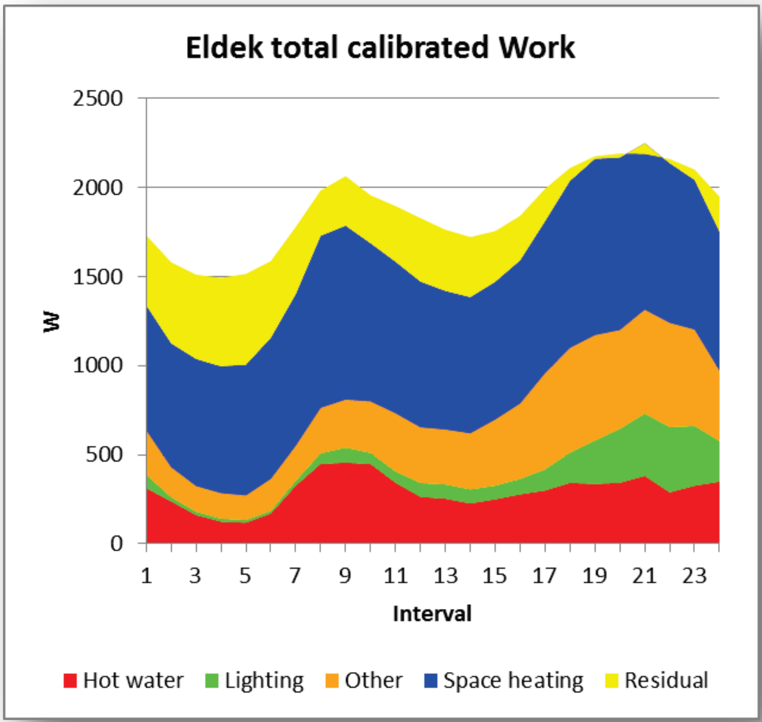


Figure 6.1 Simulated average demand during workdays.

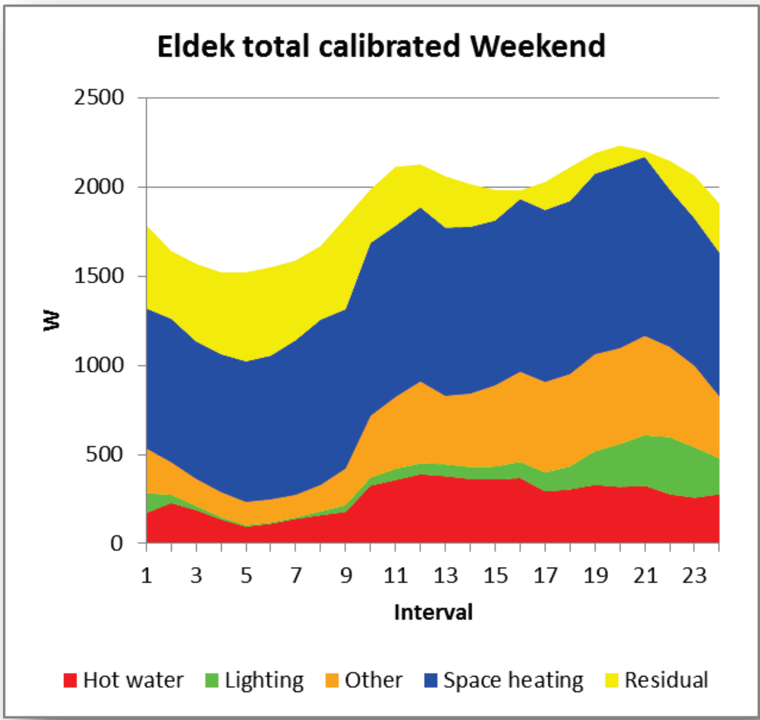


Figure 6.2 Simulated average demand during weekends.

The demand is calibrated to a total yearly demand of 16.500 kWh, which is the average for Norwegian households. As can be seen the residual is greater during night and early hours during day-time. The reason for this is that the metered households in average have larger living space than the average Norwegian household, and the heating demand will accordingly be higher than normal.

In the REMODECE project [4] it was established that load profiles for households that do not use electric space heating shows high demand during evening hours when the inhabitants are present, similar these households have little electricity demand during night and morning. So if a greater part of the metered households of the ElDeK project had smaller living space, the total evening demand would be higher compared to the demand during night. This would result in a residual that is distributed more evenly during the day.

The end-use segmentation shown in Figure 6.1 and Figure 6.2 are based on metered appliances from the customers similar to the customers that have taken part in the ElDeK project. If all types of end-use demand were metered during equivalent time period as the total demand, the residual should be zero. Since this is not the case, the segmentation is not perfect, and some part of the appliance demand is not accounted for.

The main differences between end-uses and total demand regarding metering are:

- The end-uses are metered in shorter period than the total demand, since a limited number of metering devices for metering end-use have been available. The end-uses are metered for four weeks periods at each customer, and the metered demand can be uncharacteristic of the demand for the appliance during a longer period.
- Another limitation of the end-use sample is that only approx. 6-12 appliances are metered at each household, and it must be possible to hook up the metering device on the electricity connection to

the appliance. Many lighting /lamps are permanently connected to the circuit, and from this reason cannot be metered – so the lighting appliance is poorly handled in the sample - leading to a poor simulation of the lighting appliance. Some end-use appliances are not metered at all; examples are hand tools, floor heating systems, and car heating systems during winter etc.

6.4 Distribution of annual energy demand

The buildings' demand show a great consistence with the outdoor temperature, and approx. 45% of the demand is identified as being weather dependent. Figure 6.3 shows the distribution of the annual energy demand of end-use appliances based on the ElDeK analysis. In Figure 6.3 the weather dependent demand is shown as space heating.

45% of the energy demand is due to space heating. The rest of the energy demand is divided into residual 15%, hot water 15%, lighting 6% and other appliances 19%.

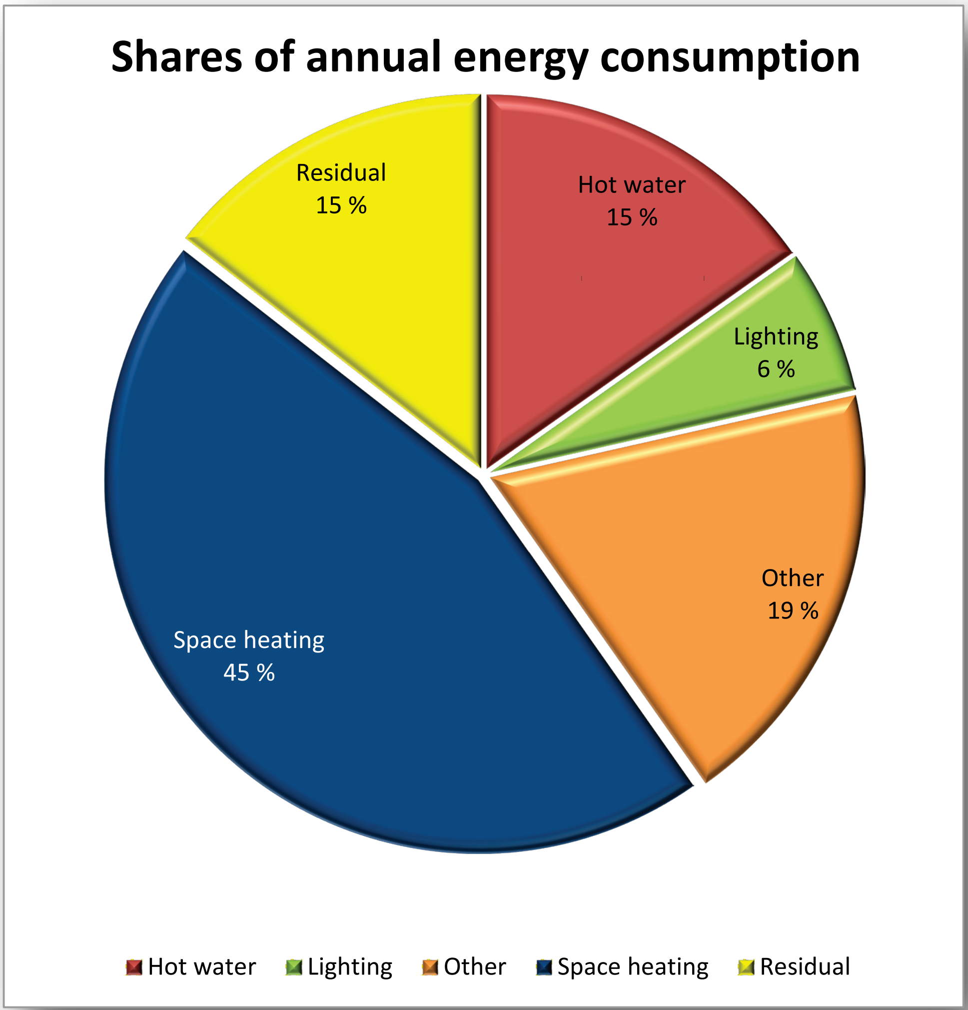


Figure 6.3 End-use shares of annual energy demand.

6.5 Comparison to REMODECE

In [5] (from the REMODECE project) in 2008 it was found that space heating and "miscellaneous appliances" accounted for 62% of the energy demand, a percentage that is higher compared to the results of the ElDeK project with 45% space heat and 15% residual that sums up to 60%. **Error! Reference source not found.**Table 6.2 compares the results of REMODECE to similar results from ElDeK.

Table 6.2 Comparison of results from REMODECE and ElDeK.

Type of appliance	REMODECE	ElDeK
Space heat and miscellaneous	62%	60%
Water heater	14%	15%
Lighting	9%	6%
Appliances	15%	19%

The main difference is a higher share of water heater up from 14% to 15%, and of appliances up from 15% to 19%. The higher share of appliances can be explained by new TV's and PC's with bigger screens and change in patterns of use.

Lighting is down from 9% in REMODECE to 6% in ElDeK. This could be an effect of the change from using traditional incandescent lamps to modern efficient CFL's (Compact Fluorecent Lamps). The later years the government has imposed that the households use CFL's rather than the old technology – to save energy.

Other changes in the share of energy could be the result of uncertainties in the analysis due to factors as:

- Bias of selected metered customers: More than 90% of the customers in ElDeK live in detached houses – this is not the case for the average Norwegian household.
- Number of metered customers: 98 customers have been metered – in general, a greater number of metered customers in smaller apartments could give better analysis results.

7 Discussion of results from analysis of the heating system

In this chapter the results from an analysis of the total hourly demand of all customers that have taken part in the ElDeK project are discussed, with focus on the result of the heating system. The analysis of the customers will demonstrate how the new top-down methods apply, and also functions as a quality assurance measure for the project.

7.1 Estimated values for the heating system

When an analysis of customer data is performed, the USELOAD software produces outputs that show graphical and statistical results from the analysis. As an example the results of an analysis of Norwegian households is discussed to evaluate the value of the analysis, and to consider if the results are meaningful.

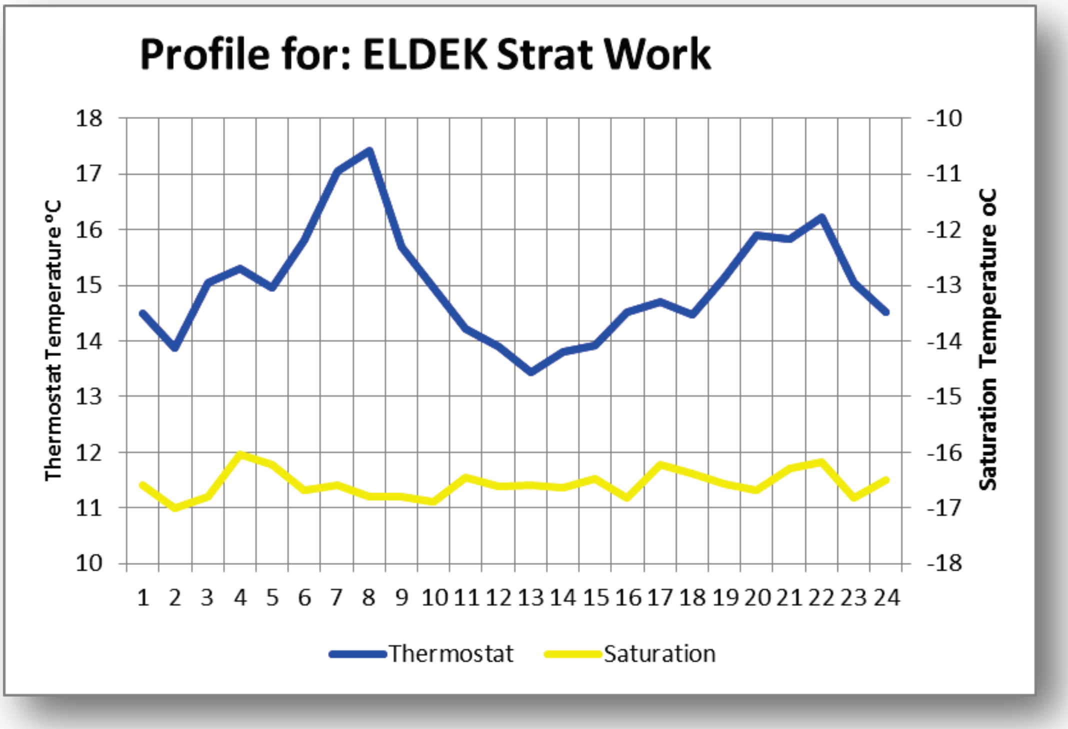


Figure 7.1 Thermostat and saturation settings of workdays.

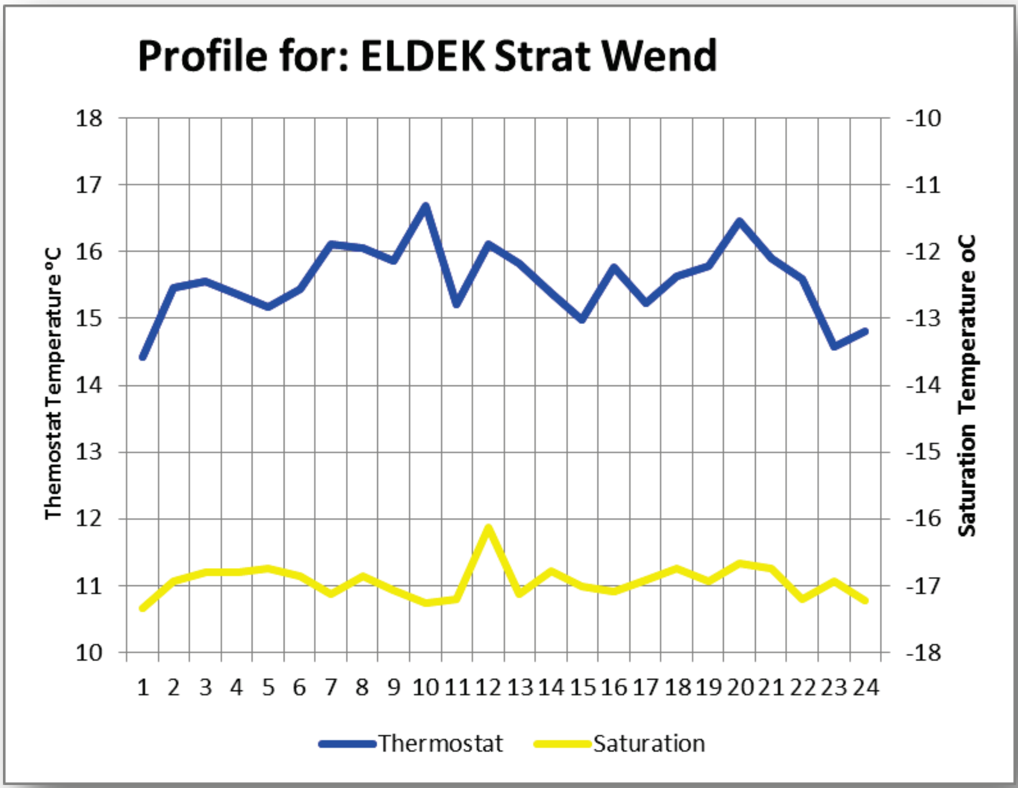


Figure 7.2 Thermostat and saturation settings of weekends.

7.2 Switch-off setting

In Figure 7.1 and Figure 7.2 the average determined settings of the heating system are shown. It is evident from the graphs that the values of the switch off (thermostat) temperature heating power (appliances) and saturation temperature are dependent on the hour of day. Based on the top-down methods and the metered data the thermostat setting is estimated to fluctuate around 14-17 degrees. This would mean that when the outdoor temperature exceeds 15-16 degrees the heating system is switched off. Excess heat from other sources as appliances and from the present inhabitants would provide the extra heat, so that the indoor temperature would be around 22 degrees.

The time of the morning peak demand is estimated to occur between 07:00 and 09:00 for working-days, which agrees with the common 08:00-16:00 working hours of Norway. In the evening there is a similar peak between 20:00-21:00 hours, a time when most people are at home and are doing housework, such as washing dishes and/or clothes, or are taking a shower after training – but of course this is only speculations.

It is interesting to note that the heating system is detected to be switched off when temperatures are higher than circa 16 degrees. This fact agrees very well with the definition of the ***Degree day method***, a method for estimation of the annual energy demand which is in common use. The Degree day method defines the switch off temperature to be 17 degrees. The Degree day method has been in use since the 1960 (at least), but still this definition seems to hold.

7.3 Saturation temperature

The saturation temperature would also depend on which heating system that is in use during the day and dependent on different outdoor temperatures during the period, when the houses are metered. The Figure 7.1 and Figure 7.2 show a quite stable saturation temperature fluctuating around -16 degrees. This could be interpreted so that other energy carriers are started and are contributing with part of the load when the heating demand exceeds the needs for -16 degrees. The result would also indicate e.g. that residents start the wood or petroleum fired stove, when the temperature is extremely low.

Many residents have installed air-air heat pumps that are less efficient at lower temperatures (have lower coefficient of performance (COP)). At around -10 to -20 degrees most of these heat pumps will provide so little heating, that other sources of energy are needed. The heat pump will work at full power at a certain temperature, and the electricity demand will not increase for temperatures below this. Most probable this is part of the explanation for the estimated result of the saturation temperature of the analysis.

7.4 Working-days

It is interesting to see that for workdays in Figure 7.1 the thermostat setting is low during night, and during work hours – from 09:00-17:00. The highest values are between 07:00 and 09:00 in the morning – "the morning peak", and between 20:00 and 22:00 "the evening peak". The workday graph also shows that the power demand has similar distribution as the thermostat setting, and that peaks occur at about the same hours.

7.5 Weekends, holidays and vacations

For weekends and vacations in Figure 7.2 the thermostat setting fluctuates more randomly, but the power consumption is high from 11-12 and from 20-21 hours. The morning peak from 11-12 could be the result of later start of the days activity during weekends. The evening peak is similar to the peak of workdays in magnitude and time during the day.

8 Applications and further work

In this report a method for top-down segmentation of end-use demand has been described. In this chapter it is evaluated what the method can be used for.

8.1 General

The weather dependent load is considered as the part of the load that occurs due to electric space heating, and for the case of Norway space heating is known to be a substantial part of the electric load. Electric space heating can be substituted by other energy carriers, and this suggests that space heating can be used for demand response purposes to help balance the electricity demand with the production. In a future where intermittent renewable energy sources will be a substantial part of the production, the energy system will need mechanisms to balance the production. It is obvious that the use of Demand Response (DR) as a balancing tool should be considered, since this could be the least cost method compared to taking measures at the production side of the power system.

8.2 Use of method for different customer groups

Perhaps the most interesting application of weather dependency determination is that the method can be used for other customer types than residential customers. The method is not based on the availability of end-use profiles, so customer types for which there does not exist end-use profiles, can also be segmented by the method. The few necessities for using the method are to have access to metered demand with hourly resolution, and a temperature series that correspond to the climate of the region where the customers are situated. It might well be that the method could be used even for greater regions containing many different customer types, and that have some differences regarding temperature distribution.

8.2.1 Commercial and industrial customers

For commercial and industrial end-users an application of the weather dependency method could be applied to segment the users' power and energy demand into three segments: Space heating, Air-conditioning and Appliances/other. Further segmentations would be possible in the future provided that branch related end-use demand is metered and analyzed.

For commercial customers the electricity use for space heating and air-conditioning can be substantial, so even the coarse segmentation into only three groups will have importance and interest. Since most commercial customers have power related tariffs, it would be of great interest to address the power consumption of the peak day, which would display and illustrate the distribution on the three segments. Adjustments of operation schedules and routines could easily save money for the user, based on peak day analyses and information.

For investment decisions the annual energy demand segmented into heating, air-conditioning and appliances could be of great interest for the building owner and users. If the heating share of the annual energy demand is big, and greater compared to other buildings in the same area – this signals that investments in better insulation or change of thermostat settings during night should be evaluated.

8.2.2 Residential customers – Apps for presenting consumption information

For residential customers one could imagine to offer Internet based Apps that provide information for the user based on recorded time series from Smart Metering and information about which and how many appliances the customer has installed:

To make things simple the user could choose to use a default set up from a menu of typical home owners:

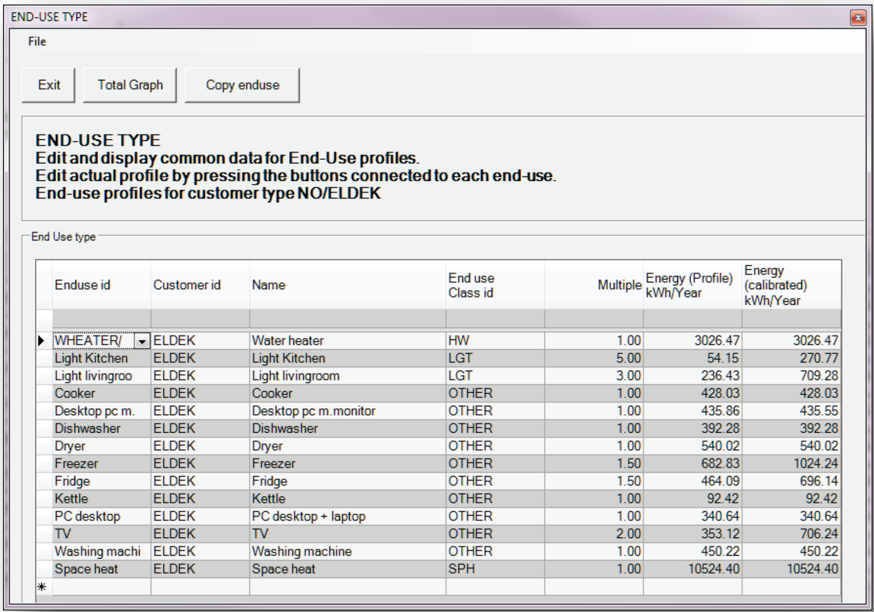
- 1 resident age 15-30
- 2 residents age 15-30
- Small family 1-2 small children
- Big family more than 2 children
- Small family 1-2 youngsters
- 2 residents age 30+

The user could then alter the values to agree with own setup. The values would be stored in the pc or hand held device. The set-up would also define which sociological stratum the user belongs to, which in turn defines if the user typically is home during day, or away on work etc. The size of the home, construction type etc. should also be defined.

By refining the set up the user could get better and more precise answers, but addressing more strata increases the need for metered load so that all strata should reflect a statistical significant data material.

For the analysis in the ElDeK project only 3 strata have been defined – connected to the size of the building. If the use of e.g. heat pumps should define new strata we would need to have 6 strata effectively doubling the size of the sample.

When the user clicks "Total graph", or another possible button (here USELOAD is used as an illustration), an end-use segmented time series is shown for the user.


END-USE TYPE
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END-USE TYPE
Edit and display common data for End-Use profiles.
Edit actual profile by pressing the buttons connected to each end-use.
End-use profiles for customer type NO/ELDEK

End Use type

Enduse id	Customer id	Name	End use Class id	Multiple	Energy (Profile) kWh/Year	Energy (calibrated) kWh/Year
WHEATER/	ELDEK	Water heater	HW	1.00	3026.47	3026.47
Light Kitchen	ELDEK	Light Kitchen	LGT	5.00	54.15	270.77
Light livingroo	ELDEK	Light livingroom	LGT	3.00	236.43	709.28
Cooker	ELDEK	Cooker	OTHER	1.00	428.03	428.03
Desktop pc m.	ELDEK	Desktop pc m.monitor	OTHER	1.00	435.86	435.55
Dishwasher	ELDEK	Dishwasher	OTHER	1.00	392.28	392.28
Dryer	ELDEK	Dryer	OTHER	1.00	540.02	540.02
Freezer	ELDEK	Freezer	OTHER	1.50	682.83	1024.24
Fridge	ELDEK	Fridge	OTHER	1.50	464.09	696.14
Kettle	ELDEK	Kettle	OTHER	1.00	92.42	92.42
PC desktop	ELDEK	PC desktop + laptop	OTHER	1.00	340.64	340.64
TV	ELDEK	TV	OTHER	2.00	353.12	706.24
Washing machi	ELDEK	Washing machine	OTHER	1.00	450.22	450.22
Space heat	ELDEK	Space heat	SPH	1.00	10524.40	10524.40

Figure 8.1 Defining the number of appliances in USELOAD.

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8.2.3 Power saving information

Information on the hourly demand of appliances would have interest in it self, and even more if presented in combination with forecasted hourly electricity prices, that would differ per hour.
The user could, based on the displayed information, plan when to do different tasks during the day, to reduce costs. In this way the user most probably would avoid using power during hours where the price is forecasted to be high.
The user could be presented from a menu with different schedules of appliance uses during the next day – showing the total cost of different approaches. The user then could select an approach that suits her/him, and could be signaled by the calendar application when to start different tasks during the day.

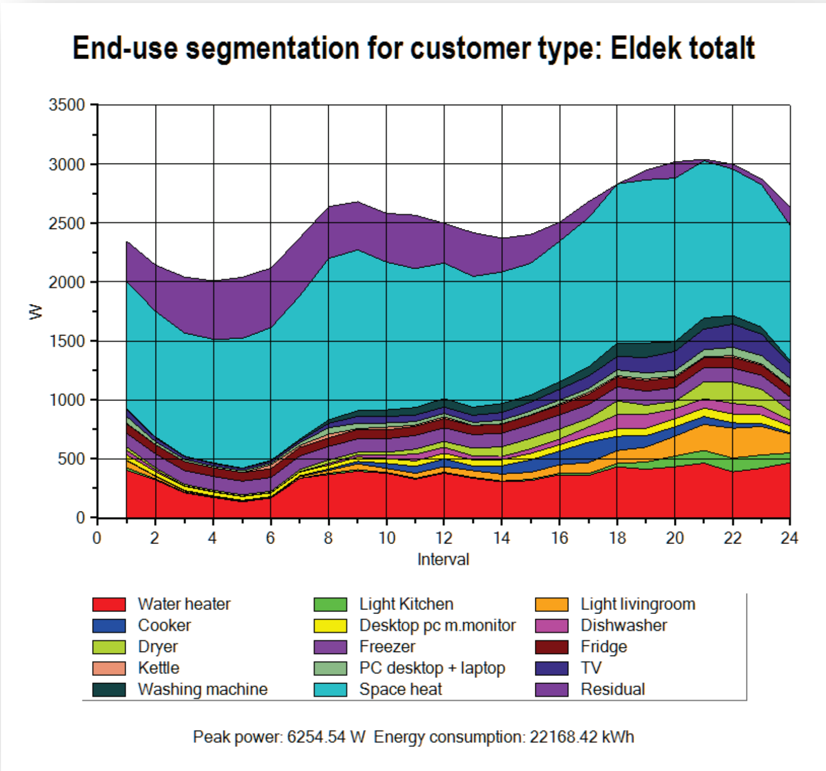

Figure 8.2 Example of presentation of end-use segmented load of a customer (USELOAD)

8.2.4 Energy saving information

To inform the user of possible energy savings potential, a distribution of the yearly energy demand could be useful.

Additionally, the user can for example choose to be presented for a calculation of different investments he could do to the home to reduce cost, e.g. insulation project – complete with cost – down payments, energy savings, and monetary savings total.

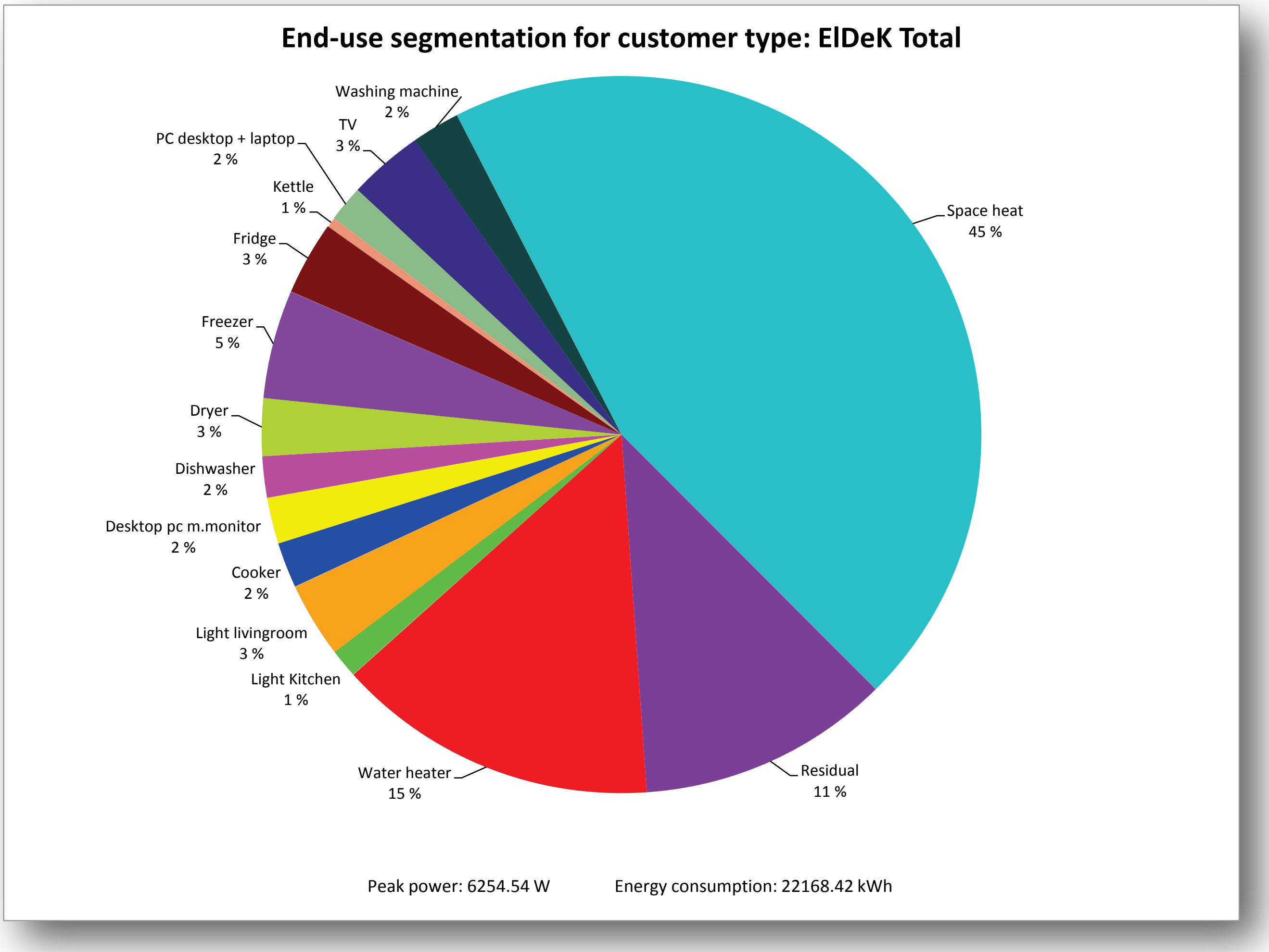

Figure 8.3 Example of pie presentation of total energy consumption during year (USELOAD).

8.3 Further work

The top-down segmentation of the end-use demand from metering of total electricity demand for households are based on the work presented in [1] and on metering data made available through the ElDeK project. The total electricity demand has been metered with hourly resolution for a period of one year and the end-use demand has been metered with one minute intervals for a period of four weeks.

Based on experiences from the ElDeK project, the following further work is suggested:

- In the ElDeK project the metering of the end-use demand has mainly been performed among households living in detached houses. A future project should address more households living in semi detached houses and apartments to address the composition of the Norwegian households – to better describe the end-use segmentation of the country.
- Additionally the metering of the end-use demand has been performed for a shorter period than the total demand, i.e. four weeks versus one year, and not all electrical end-uses have been metered since a limited number of metering devices for metering end-use have been available. The metered demand can be uncharacteristic of the demand for the appliance during a longer period. Further work should focus on a longer period for metering of the end-use demand, or metering the consumption for several periods at the same households and also metering a larger share of the appliances.
- In [1] Fourier transforms and spectral analysis of the load were used to segment the load into end-uses. EPRI used sinusoids as predictors for the weather-independent component of the load. This method was not used in the ElDeK project since meter data of end-use demand was available, but could be a candidate for further work.
- To further evaluate the method described in this report, further work could also focus on comparing this method with similar alternatives.
- For different types of customers one could imagine to include this method in an Internet based App that provide information about energy consumption and costs in total and for different appliances, based on recorded time series from Smart Metering and information about which and how many appliances the customer has installed.

9 References

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APPENDIX : Software tool USELOAD

Through seasonal/day type/hourly regression analysis of metered load in relation to outdoor temperature USELOAD analyses and generates hour based load curves and end-use load curves. Particular customer loads are selected through "signatures" of individual customers, so that strata of customers are the basis for each customer type profiles. Each stratum consists of customers having similar number of inhabitants, equal level of income and/or similar education. Other characteristics can also be used for filtering customers as heating systems, building year, insulation level and energy carriers. The user is free to use any characteristic to filter customers as long as the characteristic can be provided for all customers in the program, and that there is sufficient number of customer in each stratum.

The program can estimate the network losses – proportional to the square of the load. USELOAD is particularly interesting regarding diversification of coincident peak demand, and estimates the load factor dependent on the number of customers under consideration.

The program applies statistical methods, climatic dependencies and the diversification of load among different individual customers. It also estimates coincident peak demand in a network with selected level of significance.

Development of the software was started during end of 1990s by SINTEF Energy Research in cooperation with Electricité de France, Sycon (Sweden), VTT Energy (Finland), Electricity Association (UK) and DEFU (Denmark). SINTEF Energy Research has since the start worked with further development of USELOAD, and the software has been applied in several national and European R&D projects.

Data generated by USELOAD as load profiles for day and temperature sensitivities has for many years been used as the source for load modelling in network information system NetBas, developed by Powel ASA [8] and also for the FASIT software [14]. Since 2006 USELOAD functionality and data have partly been available through the GeoNIS data program marketed from GeoData AS [11], [15]. In 2008 in the REMODECE EU project, USELOAD was used as the tool for analysis of end-use data for 12 European countries - by analysing data from 5-10 end-uses of 100 customers from each country. The analysis resulted in achieving end-use segmentation of typical residential customers from each country. The analysis provided important material to decide on the optimal participation of residential customer groups in demand response and demand side management – to help save energy demand and balance the power production to the demand.

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